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Causal-Comparative Analysis of Factors Affecting Psychological Capital of Knowledge-Based Companies: The Mediating Role of Entrepreneurial Orientation and Social Capital

Suzan Zandazar[1], Kurosh Rezaei-Moghaddam[1]*, and Mahsa Fatemi[1]

ABSTRACT

Nowadays, entrepreneurship and knowledge-based companies are highly considered. This study aimed to investigate the factors affecting Psychological Capital (PsyCap) in two groups of agricultural and non-agricultural knowledge-based companies from Science and Technology Park (STP) of Fars Province, Iran. The population included the companies located in the STP incubators in Fars Province. The data were collected by a questionnaire from 238 participants (100 from agricultural companies and 138 from other companies). The difference between agricultural and non-agricultural companies was remarkable in the effect of services provided by the incubators on the other variables. For the agricultural companies, the services provided by the park had no significant effect on entrepreneurial orientation, social capital, and product development process, indicating a direct significant effect on PsyCap. Regarding the non-agricultural companies, the services provided by the park had a significant effect on entrepreneurial orientation, social capital, and product development process, but had no direct effect on PsyCap. Due to the objectives of incubators` establishment as well as the cost and investment in this regard, the lack of appropriate efficiency was completely obvious in these centers, especially about agricultural companies that could be effective in providing food security using new technologies. Regarding the effect of services and facilities provided by STPs on the performance of companies at incubators, it is suggested that such services and facilities become more specialized and reinforced. In addition, it is emphasized to consider the necessity of educational and operational strategies in order to strengthen the entrepreneurial orientation, social capital, and PsyCap among the members.

Keywords: Entrepreneurial orientation, Fars Province, Product development process, Resilience.

INTRODUCTION

In recent years, governments are trying to resolve economic issues such as job development, reducing unemployment, economic growth, increasing competition and improvement of the country's income by supporting Small and Medium-sized Enterprises (SMEs). Incubators can be a facilitator and sponsor as a government support tool for these SMEs, especially in the start-up of these businesses. Actually, small companies play an essential role in employment as well as the economy improvement. However, their survival as new-born companies is often difficult and full of challenges, thus, many new companies are unfortunately unable to survive in their first years, which can be referred to as critical years, for various reasons. One can mention not having enough capital and experience and not being able to compete with other newly established or old companies. What should be done for these

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companies? An obvious solution is to create a supportive environment for young enterprises (Bollingtoft, 2012). Creating and development of incubators would be considered as one of these supportive programs.

Today, entrepreneurial ecosystems are highly regarded and numerous studies are available on this subject (Torun *et al.,* 2018; Covin *et al.,* 2020). Governments are invested for the growth and development of the STPs and incubators (Rezaei-Moghaddam *et al.,* 2023). The National Business Incubator Association (NBIA) defines business incubators as "nurtures the start-up companies and helps them survive during the start-up period when they are vulnerable." Such centers provide appropriate business support services and resources for new companies. The most significant objectives of incubators are creating jobs, strengthening the entrepreneurial atmosphere, maintaining jobs in society, creating growth in local industry, and diversifying local economies" (Kemp, 2013). Incubators are considered as a part of entrepreneurial ecosystems. The activity of incubators has different generations. Accordingly, the services and facilities provided to companies are different. The first generation is related to the years before 1980 and focused mainly on providing an administrative atmosphere and some common facilities. The second generation is related to 1980-1990 which expanded into consulting services, network access, and sometimes investment. The main focus is on start-ups in the information technology sector and advanced technologies with the onset of the third generation in the late 1990s and mostly after 2000 (Torun *et al.,* 2018). Therefore, the main purpose of the current research was to study the effects of different services and facilitates of science parks through incubators creation for innovative young SMEs in their first years of establishment. The other research questions were to understand that placing SMEs at incubators could be helpful for improving the individual characteristics of company members such as entrepreneurial orientation (creativity, innovation, risk-taking and competition spirits) as well as other sociological factors like social capital (better networking and team working) and psychological capital (optimistic and hopeful entrepreneurs with resilient businesses) or not?

The services and facilities provided by STPs would be effective on the psychological capital of companies` members. Therefore, it would be important to study the effects of these services on entrepreneurs` PsyCap working in the knowledge-based companies settled at the park`s incubators. PsyCap is highly critical for the success of entrepreneurs since entrepreneurs always encounter a lack of financial, human, and social capital. As a result, entrepreneurs should trust themselves in this regard (Elsafty *et al.,* 2020). The services provided to companies in incubators potentially increase the synergy of psychological factors and PsyCap of companies, affecting the performance of entrepreneurs in business incubators, which can increase the PsyCap of innovators and entrepreneurs and enhance the self-confidence and optimism of innovators. The individuals working in incubators continue entrepreneurship by improving self-efficacy, which has a positive effect on the innovation performance of the technology start-up companies (Wang *et al.,* 2020).

Entrepreneurial Orientation (EO) is considered as another psychological factor that was affected by the services and facilities of parks. In other words, providing and facilitating various services with higher quality for start-up companies at park`s incubators would be effective on the entrepreneurs` incentives and improve their personal characteristics as well. Entrepreneurial orientation is regarded to cope with environmental challenges stimulating entrepreneurial behavior and creating flexibility and adaptability for businesses. The significance of EO is hidden in its potential to help the senior management in the company to define the organizational goal, maintain the company vision, and develop a strategy to achieve a competitive advantage over competitors (Covin *et al.,* 2020). It is considered as the orientation of senior managers or company owners to entrepreneurial efforts. Some studies indicated a positive relationship between EO and overall company performance (Rezaei and Ortt, 2018). Working at incubators can promote innovation, risk-taking, and entrepreneurial spirit.

Social Capital (SC) can be significant in the entrepreneurship of companies located in incubators. It considers the consequences of human socialization and their relationships with individual and social structures as well as the resources that are available to individuals and groups through membership in social networks (Carrillo Álvarez and Riera Romaní, 2017). SC refers to the characteristics of social organizations such as networks, norms, and trust, which facilitate action and cooperation for mutual benefit and improves, creates significant value, and increases performance when the companies in the incubator create strong network interactions (Hughes *et al.,* 2007). In a trustworthy environment, the companies located in the incubator tend to help each other because of the low risk of opportunistic behavior. Establishing a relationship with customers and friends enables the entrepreneur to have access to key strategic business information. Thus, facilitating the profitability of businesses and supporting networks result in improving growth and survival for new companies (Elsafty *et al.,* 2020).

Product Development Process (PDP) is one of the essential processes for the success, survival, and renewal of organizations, particularly for the companies in fast or competitive markets. Product development is considered as a set of activities that starts by identifying and understanding the opportunities on the market and ends by producing, selling, and delivering a product (Theodorakopoulos *et al.,* 2014). The PD process is critical for producing the products that satisfy customer needs and differentiate the company from competitors. An incubator facilitates the development and commercialization of new products and new business models by improving some opportunities to access resources.

The early models and theories of behavior analysis emphasized on the important variables of attitude, intention and subjective and social norms as explanations of behavior (Ajzen, 1991). The evolution trend of these models in Theory of Planned Behavior (TPB) model showed that other important elements, especially the perceived control of behavior, also play an undeniable role in the occurrence of the considered behavior. Inspired by these models, the conceptual framework was designed for the analysis of PsyCap of knowledge-based companies (Figure 1), so that SFSTP represents the perceived control of behavior and EO expresses the tendency and intention for

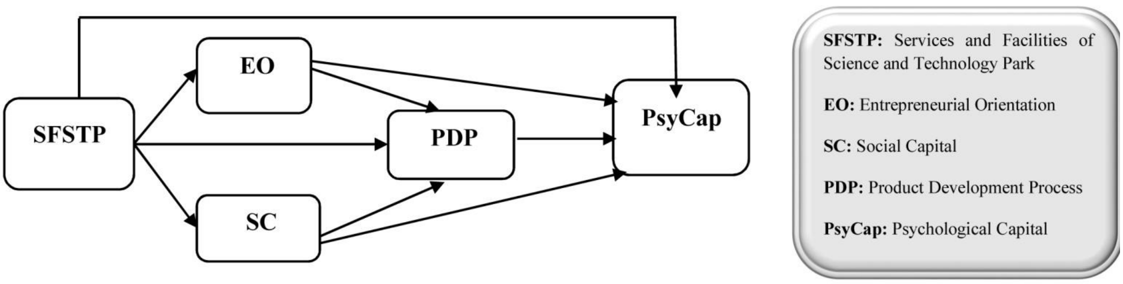

Figure 1. Theoretical framework of study.

entrepreneurial activities in the companies' members. Considering that entrepreneurs in companies are engaged in PDP, both individually or in the form of collective activities of the company, the social capital variable was clearly included in the model as an explanation of reference groups' viewpoints (subjective and social norms) affecting entrepreneurs. Therefore, all these variables were analyzed on the dependent variable of PsyCap in theoretical model. On the other hand, Entrepreneurial Event Model (EEM) (Shapero and Sokol, 1982), similar to TPB, offers three affecting factors to predict entrepreneurial behavior that consists of perceived desirability, perceived feasibility and propensity to act that refers to Services and Facilities of STPs (SFSTP). Based on these two models, TPB and EEM, it can be seen that the influencing factors of entrepreneurial behavior comprise three components of attitude, social, and psychological dimensions that are equivalent to entrepreneurial orientation, social capital, and psychological capital, respectively. Previous studies highlighted the role of these three factors (EO, SC and PsyCap) as strong predictor of successful entrepreneurship (Linan and Santos, 2007; Do and Dadvari, 2017; Jin, 2017). These indicate, theoretically and empirically, that PsyCap is positively associated with increased performance (SFSTP) and positive attitudes (EO). PsyCap is also part of the study of motivation theory, which assess optimistic variables, hope, self-efficacy and resilience. Referring to the two theories of TPB and EEM, it appears that attitude (EO) and Social and Psychological dimensions (SC and PsyCap) are vital in order to improve entrepreneurship behavior. Therefore, it makes sense that EO and social capital are considered to be the mediate effect SFSTP to PsyCap and entrepreneurial behavior (Esfandabadi *et al.,* 2018; Mahfud *et al.,* 2020). This study evaluates the effect of each service variable provided in the park, social capital, EO, and PDP on the PsyCap of companies located in STP Incubators in two areas of agricultural and non-agricultural knowledge-based companies (Figure 1).

MATERIALS AND METHODS

This study was conducted using survey. The study population included the members of knowledge-based companies located in STP Incubators in Fars Province, Iran. According to the statistics of the STP Deputy Office, there were 2,502 members from 331 companies. The sample was selected through multi-stage stratified random sampling method based on the sampling formula (Fowler, 2009). First, 79 companies (Equation 1) were randomly selected, then, 238 members (Equation 2) of the managers and members of the companies were estimated as the samples. Third, these 238 members were selected from both types of companies active in agricultural field (100 members) and companies active in non-agricultural fields (138 members). They were randomly selected and studied according to the size of each class.

$$n = \frac{N\delta^2}{(N-1)D + \delta^2}$$

$$n = \frac{(331)(25.6)}{(330) + (25.6)} = 79$$

$$D = \frac{B^2}{4} = 0.25$$

N= Total companies of Fars STP

n= Sample size

δ^2= Sample variance (Based on pilot study)

B= Probable error (Assumed 1 in this study)

$$n = \frac{N\delta^2}{(N-1)D + \delta^2}$$

$$n = \frac{(2502)(65.9)}{(2501) + (65.9)} = 238$$

N= Total employees of the companies of Fars STP

Data collection was conducted through a questionnaire from the members of the companies located in STP incubators in

2022. The face validity was confirmed by a group of professors at the School of Agriculture in Shiraz University, Iran. For testing the reliability of the questionnaire, the pilot study was carried out by collecting 30 questionnaires out of the main sample (companies located in the STP in Kerman Province). Cronbach's Alpha for all variables was higher than 0.9 and the measurement tool had high reliability. After confirming the questionnaire, the data were collected and analysed by SPSS16 and SmartPLS2. Descriptive statistics and Structural Equation Model (SEM) were used for data analysis. Here are the conceptual and operational definitions of the variables as well as the research hypotheses:

Psychological Capital

PsyCap is defined as a multi-dimensional factor that refers to the positive psychological state of a person's growth and is known for optimism, resilience, self-efficacy and hope (Nkeshimana, 2018). In other words, PsyCap is characterized by the followings:

Self-confidence *(self-efficacy)* to conduct the required activities to succeed in challenging tasks,

Positive reference *(optimism)* about success in the present and future,

Perseverance in reaching goals and changes in paths towards goals *(hope)* for success,

Sustainability when the company faces problems and adversities,

Backwardness and even beyond that *(resilience)* to achieve success (Ramsden, 2019).

This variable was measured as a set of the following 18 questions:

(a) Self-efficacy with Four Items of

"(1) Carrying out duties in collective activities,

(2) Participating and commenting in critical debates,

(3) Determining life goals,

(4) Facing people to discuss around issues and problems";

(b) Optimism with Four Questions about

(1) Try to show better performance in difficulties,

(2) Look at positive aspects,

(3) Optimistic to the future work,

(4) Achieving what is expected and desirable.

(c) Hope through Five Items of

(1) Pursuing the business goals,

(2) Several ways for every problem,

(3) Be the most successful person at work,

(4) Finding many ways to achieve work goals,

(5) Coping with the work goals.

(d) Resilience with Five Questions Including

(1) Having the ability to solve the work`s problems and obstacles and continue,

(2) Managing various problems,

(3) Having the ability to do all activities alone at special circumstances,

(4) Overcoming work`s problems due to previous experiences,

(5) Reduce the vulnerability by diversifying duties and responsibilities (Baluku *et al.,* 2016; Luthans and Youssef-Morgan, 2017).

The questions were designed with a Likert scale including never (0), rarely (1), relatively (2), somewhat (3), and completely (4).

Hypotheses

Hypothesis 1 (H_1)

The members of agricultural and non-agricultural knowledge-based companies are different in terms of the total amount of PsyCap and its four dimensions.

(a) Social Capital

It refers to the characteristics of collective action enabling people to cooperate and act more effectively with each other to achieve common goals. Various aspects of social capital with an organizational approach are considered in three dimensions.

(b) Structural

The general pattern of contacts between individuals, including network relationships between individuals, network configuration, and appropriate organization;

(c) Communication

The type of personal relationships that individuals have with each other based on their interactions, the most significant aspects of which are trust, commitment and mutual understanding;

(d) Cognitive

The sources which provide interpretations and common meaning systems among groups. Cooperation and common values are the most critical aspects of the cognitive dimension (Hughes *et al.,* 2007; Fandiño *et al.,* 2015). Social capital was measured with 27 questions ranged from completely disagree (1), disagree (2), not agree nor disagree (3), agree (4), and completely agree (5).

Hypothesis 2 (H_2)

The members of agricultural and non-agricultural knowledge-based companies are different due to the social capital.

Hypothesis 3 (H_3)

Social capital has a positive and direct effect on PsyCap of agricultural and non-agricultural knowledge-based companies.

Entrepreneurial Orientation

This variable is defined by five dimensions of:

(a) Innovation: The desire to introduce new and emerging things through experimentation and creative processes for developing new products, services, and new processes.

(b) Pioneering: As one of the characteristics of a market leader who has the foresight ability for using opportunities in predicting future market demands.

(c) Aggressive Competition: Means numerous efforts to surpass industrial competitors, which is characterized by an aggressive situation or reaction to improve a position or overcome a threat in a competitive market.

(d) Risk-Taking: Means making decisions and taking action without awareness on the possible results.

(e) ***Independence:*** Independent action by an individual or team to present a business concept or vision until the work is completed (Satar and Natasha, 2019; Covin *et al.,* 2020). This variable was measured with a set of 33 questions (nine items for innovation, five questions for pioneering, seven items for aggressive competition, eight ones for risk-taking, and four items for independence) ranged from completely disagree (1), disagree (2), not agree neither disagree (3), agree (4), and completely agree (5).

Hypothesis 4 (H_4)

The members of agricultural and non-agricultural knowledge-based companies are different due to their entrepreneurial orientation.

Hypothesis 5 (H_5)

Entrepreneurial orientation has a positive and direct effect on PsyCap of agricultural and non-agricultural knowledge-based companies.

Services and Facilities of STP

All of the services and facilities provided by STP to the companies located in the park incubators. Such services include physical services (office and laboratory spaces, etc.), financial facilities (loan payment, assistance in access to loan from banks, investors, etc.), communication (relationship with internal and external customer networks, relationship with academic centres, creating network activities between companies inside and outside the incubator), information (training programs such as business training, insurance, tax, trade and marketing), human (introducing the workforce, identifying the management team and advisory boards and trainers), legal (familiarity with laws and regulations, consulting legal issues and intellectual property), and organizational (helping international trade, technology commercialization, etc.) (Pauwels *et al.,* 2016). This variable was measured with 36 questions in the form of a Likert scale as follows: Never (0), rarely (1), sometimes (2), often (3), and always (4).

Hypothesis 6 (H_6)

The members of agricultural and non-agricultural knowledge-based companies are different in terms of the services and facilities that have been benefitted from STP.

Hypothesis 7 (H_7)

Services and facilities provided by STP has a positive and direct effect on PsyCap of agricultural and non-agricultural knowledge-based companies.

Product Development Process

It normally follows a process in which a company pictures a new product idea and then studies, plans, designs, prototypes, and tests it before introducing to the market. The PD process is required for creating the products, which meet customer needs and differentiate the company from competitors (Kazimierska and Grębosz-Krawczyk, 2017; Sharma, 2019). This variable was measured with 12 questions ranged from never (0), rarely (1), sometimes (2), often (3), and always (4).

Hypothesis 8 (H_8)

The members of agricultural and non-agricultural knowledge-based companies are different due to the process of product development.

Hypothesis 9 (H_9)

Product development process has a positive and direct effect on PsyCap of agricultural and non-agricultural knowledge-based companies.

RESULTS AND DISCUSSION

Agricultural and non-agricultural companies had no significant differences in terms of STPs, EO, social capital and PD process (Table 1). Thus, due to the t-tests results, H_2, H_4, H_6 and H_8 of study were rejected.

Although no significant difference was found between agricultural and non-agricultural companies in overall PsyCap (Table 1), two sub-components—optimism (Sig. = 0.022) and self-efficacy (Sig. = 0.041)—did show significant differences between the two types of companies.Since the mean of agricultural companies in both dimensions was more than non-agricultural companies, agricultural companies located in STPs had more self-confidence in making efforts to succeed in challenging activities (self-efficacy). In addition, these companies had a more positive attitude towards success in the present and future (optimism). Thus, H_1 of study was rejected, which means the agricultural and non-agricultural companies were not different in term of total PsyCap, but these companies showed differences due to the self-efficacy and optimism dimensions (Table 1).

First Group: Agricultural Knowledge-Based Companies

In this group, 100 individuals were interviewed from the managers and personnel of agricultural knowledge-based companies, of which 61% were men and 39% were women. The mean of respondents` age of agriculture group were 35 years and their educational level`s mean were 18.66 years. Their mean of working background was 84.14 months (around 7 years) and the mean of their settling in the incubators of STP was 35.42 months (about 3 years). First, the conceptual model was examined for agricultural companies (Figure 2).

Factor Loadings

To evaluate the model reliability, the factor loadings of the items related to each variable were studied. If the value was equal to or more than 0.4, the reliability was acceptable. As shown in Figure 2, the factor loadings of all the items were higher than 0.4 (Davari and Rezazadeh, 2017), indicating one of the reasons for the reliability of the measurement model. The range of factor loadings of the variables were computed as below:

SFSTP: 0.44 to 0.89
PDP: 0.66 to 0.85
EO: 0.53 to 0.86
PsyCap: 0.64 to 0.82
SC: 0.56 to 0.88

Cronbach's Alpha and Composite Reliability

All Cronbach's Alphas were higher than 0.7, which was a good value, indicating the item reliability of the measurement model.

Table 1. T-test results of variables among agricultural and non-agricultural companies.[a]

Variable	Agricultural companies		Non-agricultural companies		T value	Sig.
	Mean	SD	Mean	SD		
SFSTP	66.78	28.56	62.35	28.45	1.18	0.238
EO	127.94	18.55	127.36	1.14	0.247	0.805
SC	108.89	16.88	110.17	15.34	-0.61	0.543
PDP	31.99	6.54	31.22	7.08	0.776	0.439
PsyCap	55.62	9.45	53.84	9.02	1.47	0.143
Self-efficacy	13.27	2.18	12.62	2.58	2.055	0.041
Hope	15.12	3.36	14.8	3.08	0.744	0.457
Resilience	14.79	3.09	14.74	2.98	0.131	0.896
Optimism	12.43	2.52	11.67	2.49	2.302	0.022

[a] **Scale:** (SFSTP: 0-144); (EO: 1-165); (SC: 1-135); (PDP: 0-48); (PsyCap: 0-72); (Self-efficacy: 0-16); (Hope: 0-20); (Resilience: 0-20); (Optimism: 0-16).

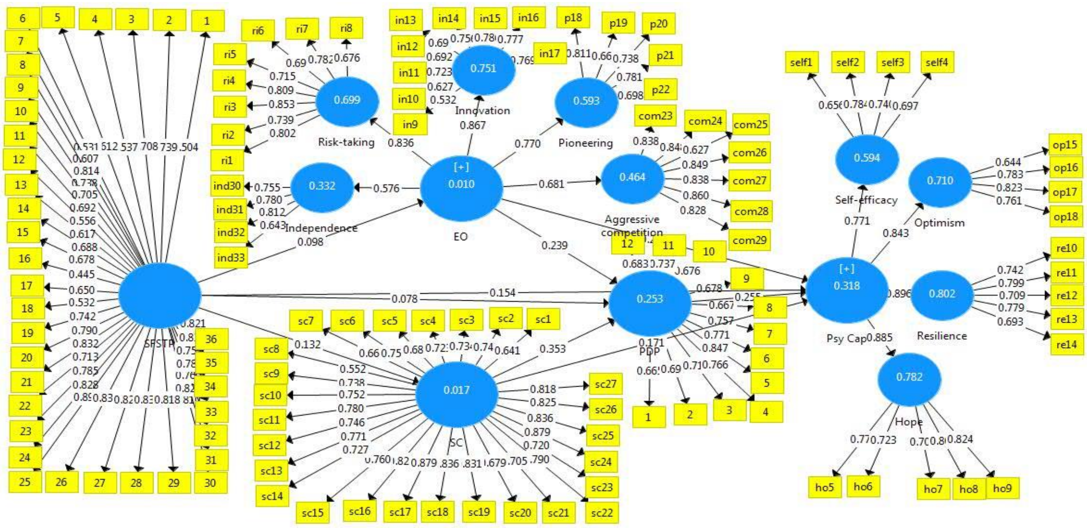

Figure 2. Agricultural knowledge-based companies' model.

The value of the composite reliability coefficients was more than 0.7, showing good composite reliability (Table 2).

Convergent Validity

According to Table 2, the Average Variance Extracted (AVE) value for all variables is more than or equal to 0.5, indicating the convergent validity of the model and the fit of the measurement model.

Divergent Validity

Fornell and Larcker matrix method is used to evaluate the divergent validity (Rönkkö and Cho, 2022). In this method, the correlation of a factor with its indicators is compared with the correlation of that factor with other variables. Table 3 shows that the AVE root value of all the first-order variables is more than the correlation value between them, indicating the appropriate divergent validity and the optimal fit of the measurement model.

Structural Equation Model

To fit the structural model, the significance coefficients, R^2, and Q^2 were used. The second criterion for evaluating the fit of the structural model is the R^2 coefficients related to the latent endogenous variables of the model, showing the effect of an exogenous variable on an endogenous variable. Values of 0.19, 0.33 and 0.67 have been assumed for R^2 as weak, moderate and strong, respectively (Davari and Rezazadeh, 2017). Table 2 presents the R^2 value of all endogenous variables from the first order to the second order. Furthermore, Q^2 shows the predictability of the model regarding endogenous factors. Q^2 should be higher than zero. As for the intensity of the predictive power of the model regarding the endogenous variables, three values were determined i.e. 0.02, 0.15, and 0.35 (Davari and Rezazadeh, 2017).

Significant coefficients are among the items that are studied for fitting the structural model (Table 3). If "t" is more than 1.96, it is significant at the 5% level, but if t is more than 2.58, it is significant at the 1% level. Table 4 shows the t value, the effects of park services on entrepreneurial orientation (0.95), social capital (1.42) and product development process (1) are less than 1.96 and are not significant. In other words, the services provided by the incubators and STP have no direct effect on EO, social capital, and PDP. Further, the effect of social capital on PsyCap (1.66) is lower than 1.96 and insignificant. Thus, the social capital of companies have no direct effect on the PsyCap of agricultural companies.

Table 2. Results of some indices of agricultural companies.

Variable	Cronbach`s Alpha	Composite reliability	AVE	R^2	Q^2	Communality
PsyCap	0.91	0.91	0.57	0.32	0.12	0.41
Self-efficacy	0.69	0.81	0.52	0.59	0.25	0.52
Hope	0.82	0.87	0.58	0.78	0.45	0.58
Resilience	0.79	0.86	0.55	0.80	0.37	0.56
Optimism	0.74	0.84	0.57	0.71	0.40	0.57
EO	0.94	0.87	0.52	0.01	0.003	0.34
Independence	0.74	0.84	0.56	0.33	0.18	0.56
Innovation	0.87	0.90	0.50	0.75	0.37	0.50
Risk-taking	0.89	0.92	0.58	0.69	0.40	0.58
Aggressive Competition	0.91	0.93	0.66	0.46	0.30	0.66
Pioneering	0.79	0.86	0.54	0.59	0.32	0.55
SC	0.97	0.97	0.58	0.017	0.008	0.57
SFSTP	0.97	0.97	0.53	-	-	0.53
PDP	0.92	0.93	0.52	0.25	0.12	0.52

Table 3. Divergent validity matrix of the variables for agricultural companies.

Variables	Independence	PDP	SFSTP	Self-efficacy	Optimism	Innovation	Hope	Pioneering	Aggressive competition	Risk-taking	SC	Resilience
Independence	0.75											
PDP	0.32	0.72										
SFSTP	0.19	0.15	0.73									
Self-efficacy	0.25	0.29	0.15	0.72								
Optimism	0.27	0.39	0.21	0.53	0.75							
Innovation	0.35	0.30	-0.01	0.23	0.32	0.71						
Hope	0.30	0.40	0.21	0.58	0.67	0.35	0.76					
Pioneering	0.40	0.24	0.30	0.17	0.27	0.69	0.28	0.73				
Aggressive Competition	0.40	0.20	0.21	0.05	0.19	0.37	0.25	0.43	0.81			
Risk-taking	0.40	0.31	0.03	0.16	0.34	0.69	0.25	0.48	0.41	0.76		
SC	0.04	0.44	0.13	0.36	0.38	0.26	0.27	0.16	0.26	0.35	0.76	
Resilience	0.41	0.40	0.23	0.63	0.68	0.32	0.69	0.27	0.29	0.27	0.31	0.74

Table 4. Internal relationship in causal model of agricultural companies.

Internal relationship	Standard Error	T-Value	P-Value
PsyCap ⟶ Resilience	0.018	48.05	0.0001
PsyCap ⟶ Hope	0.028	32.98	0.0001
EO⟶ Innovation	0.024	35.28	0.0001
PsyCap⟶ Optimism	0.037	22.75	0.0001
EO⟶ Risk-taking	0.029	28.6	0.0001
PsyCap ⟶ Self-efficacy	0.04	17.58	0.0001
EO⟶ Pioneering	0.047	16.35	0.0001
EO⟶ Aggressive competition	0.064	10.65	0.0001
EO ⟶ Independence	0.086	6.66	0.0001
SC⟶ PDP	0.08	4.08	0.0001
PDP⟶ PsyCap	0.108	2.34	0.021
EO ⟶ PsyCap	0.081	3.08	0.003
EO⟶ PDP	0.086	2.79	0.006
SC⟶ PsyCap	0.102	1.66	0.132
SFSTP⟶ PsyCap	0.07	2.06	0.030
SFSTP⟶ PDP	0.078	1.00	0.505
SFSTP ⟶ EO	0.103	0.95	0.547
SFSTP ⟶ SC	0.092	1.42	0.293

Table 5. The effects of variables on PsyCap of agricultural companies.

Variable	Direct effect	Indirect effect	Total effect	Sig.
SFSTP	0.154	0.050	0.204	0.030
SC	0.171	0.092	0.263	0.132
EO	0.250	0.06	0.310	0.003
PDP	0.255	-	0.255	0.021

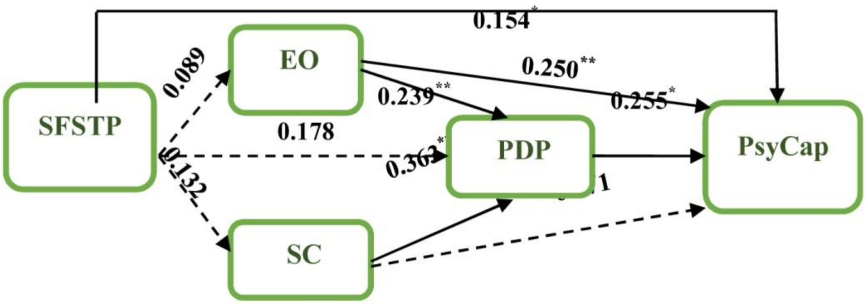

Figure 3. Causal model of factors affecting PsyCap of agricultural companies.

Table 5 and Figure 3 show the direct and indirect effects of independent and mediating variables on PsyCap in agricultural companies. The services provided by the park have a direct and significant effect (0.154) on PsyCap. (***H***$_7$ was approved). The more the number of services and facilities of the STP, the more improved are the four dimensions of PsyCap of the active members in the companies such as optimism, self-efficacy, hope and resilience. Providing facilities to companies strengthens their spirit and hope for the continuity of their business activities. Moreover, the support from the park is considered as confidence for the entrepreneurs of the incubator to be resilient in crises. EO had a direct and significant effect (0.25) on PsyCap. (***H₅*** was approved). In other words, the more the EO of company members, the stronger their PsyCap. The EO had a significant indirect effect on PsyCap through affecting the PDP. When the entrepreneurs active in incubators have higher dimensions of EO such as the innovativeness, pioneering, independence, and competitiveness, they can produce better products and technologies, leading to the improvement of the PsyCap dimensions such as hope, optimism, and resilience of the members towards the continuity of their business activities in the future. The effective role of EO dimensions in entrepreneurial activities was emphasized by Kashef Ganjdaredar *et al.* (2022).

SC had a significant indirect effect on PsyCap by affecting the PDP. Therefore, ***H₃*** was rejected, because SC did not have direct effect on PsyCap, but had some effects indirectly through PDP. Enhancing entrepreneurs' interactions and team contributions leads to improvements in the quality of product development processes, the services provided by companies, and the psychological capital (PsyCap) of team members. The PDP has a direct and significant effect (0.255) on PsyCap. (***H₈*** was approved). In other words, the four dimensions of PsyCap for the members will be increased when the companies become more successful in presenting their products.

According to the model fit of causal model of agricultural companies, the fit measures were computed as SRMR= 0.80, D-G= 0.487, NFI= 0.94, All the measures met the recommended thresholds, indicating that they are within acceptable ranges and suitable for analysis. The GoF criterion is used for fitting the overall model. The fitting of the overall model can be controlled using this criterion after studying the fitting of the measurement and structural analysis of the model. This index is measured as the squared product of the mean coefficient of determination of the endogenous (latent) variables by the average shared values of the variables. Based on the values of 0.1, 0.25, and 0.36, which are considered weak, average, and strong values for GoF, the number 0.51 shows the overall strong fit of the model.

SRMR stands for Standardized Root Mean Square Residual, which measures the difference between observed and predicted correlations in the model.

D-G stands for Dillon–Goldstein's rho,

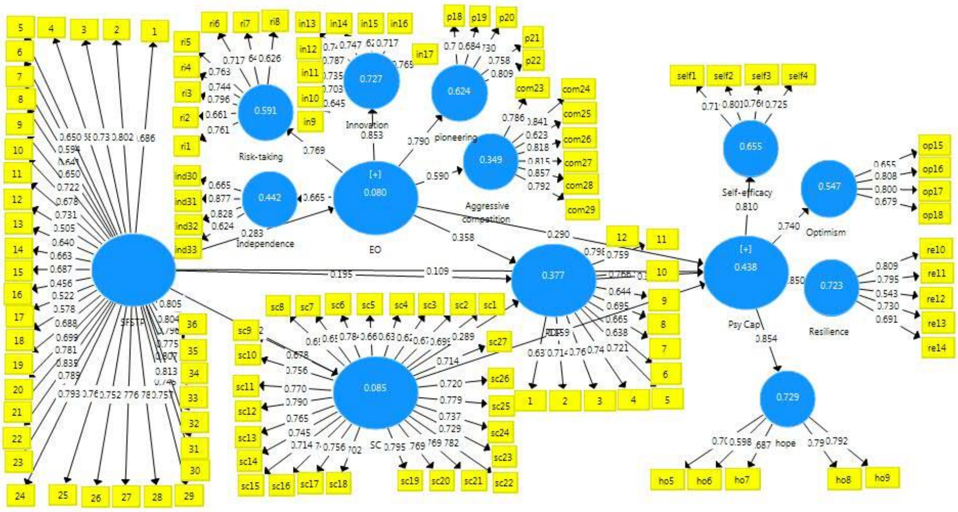

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Figure 4. Non-agricultural knowledge-based companies' model.

also known as Composite Reliability (CR), which assesses the internal consistency of a construct.

NFI stands for Normed Fit Index, which evaluates the goodness-of-fit of the model

$$\text{GoF}=\sqrt{\overline{\text{communalities}} \times \overline{R^2}} = 0.51$$

$$\overline{R^2} = 0.48$$

$$\overline{\text{communalities}} = 0.558$$

Second Group: Non-Agricultural Knowledge-Based Companies

As for the description of the second group, 138 individuals were studied from the managers and other members of non-agricultural knowledge-based companies, of whom 96 individuals (69.6%) were men and 42 (30.4%) were women. The mean of their age was 33.12 years and their educational level`s mean were 17.28 years. The mean of non-agricultural group`s working background was 79.45 months (around 6.5 years) and the mean of their settling in the incubators of STP was 36.87 months (about 3 years).

Factor Loadings

As shown in Figure 4, the factor loadings of all variables are higher than 0.4, which is considered as one of the reasons for reliability. The range of factor loadings of the variables were computed as below:

SFSTP: 0.45 to 0.83
PDP: 0.64 to 0.80
EO: 0.62 to 0.88
PsyCap: 0.54 to 0.81
SC: 0.62 to 0.79

Cronbach's Alpha and Composite Reliability

All Cronbach's Alphas are more than 0.7, which is a good value and shows the appropriate fit of the measurement models. The value of the composite reliability coefficients is more than 0.7, showing the favourable composite reliability (Table 6).

Fitting the Structural Equation Model

After evaluating the measurement models for fitting the structural model, R^2 and Q^2 were studied, the values of which are presented in Table 8, indicates a good fit of the structural model.

Divergent Validity

The AVE root value of all first-order variables is higher than the correlation value between them, indicating the appropriate divergent validity and the optimal fit of the measurement model (Table 7). Table 8 indicates internal relationship in causal model of non-agricultural companies.

Table 9 and Figure 5 present the path coefficients of the causal model variables related to the non-agricultural companies. The services provided by the park had no direct effect on PsyCap (H_7 was rejected), but had an indirect effect on PsyCap through affecting the mediating variables of EO and PDP. In other words, a variety of facilities and services provided by the park has made the entrepreneurs of incubators to produce better technological products with their innovation, competitiveness and higher risk. Finally, such an effect leads to companies with better PsyCap such as self-efficacy, higher optimism and hope, and resilience in difficult situations. The members of non-agricultural companies have succeeded in developing a higher quality product by having the facilities of the park and establishing stronger social networks with specialized consultants and other business owners in the market, leading to the strengthening of the four dimensions of PsyCap. EO has a direct and significant effect (0.290) on PsyCap. Thus, H_5 was approved. In this regard, PsyCap improves when the dimensions of EO such as innovation, pioneering, independence and competition are strengthened more among the members. EO has an indirect effect on PsyCap through the PDP. Innovative entrepreneurs with a higher spirit of competition, produce more technological and innovative products and the prosperity of their business result in the self-efficacy of members and improve their optimism, hope and resilience while facing challenges.

As observed in Figure 5, SC has no significant effect on PsyCap directly (***H_3*** was rejected), but has an indirect effect on this variable through the moderating variable of the PDP. Improving the dimensions of SC such as social cohesion, social trust, and social participation of active entrepreneurs in incubators results in strengthening the development process for their products and improving their PsyCap level. Eventually, the PDP has a direct, significant and relatively strong effect (0.320) on PsyCap (***H_8*** was approved). This result is also confirmed in the study of Kashef Ganjdaredar *et al.* (2022). Companies with a stronger R&D would have more purposeful and detailed plans for their product development. Thus, they will have members with high self-efficacy and are more optimistic about the continuity of their future business activities and have more resistance while facing professional ups and downs.

Due to the model fit of causal model, the fit measures were computed as below: SRMR was 0.78, D-G was 0.567, NFI was 0.97, and all of the measures were acceptable compared with the suggested amounts. Then, the GoF criterion was calculated to fit the general model in case of non-agricultural companies. The obtained number of 0.51 indicates the strong fit of the model.

$$GoF = \sqrt{\overline{communalities} \times \overline{R^2}} = 0.51$$

$$\overline{R^2} = 0.489$$

$$\overline{communalities} = 0.54$$

CONCLUSIONS

Evaluating knowledge-based companies in agricultural and non-agricultural sectors in STP incubators revealed differences in how services impact entrepreneurial outcomes. For agricultural companies, services had no significant effect on entrepreneurial orientation, product development, or social capital, while only directly affecting PsyCap. In contrast, services for non-agricultural companies positively influenced entrepreneurial orientation, product development, social capital, and indirectly enhanced PsyCap. These findings suggest that current incubator services are more aligned with non-agricultural activities and need to be tailored for agricultural

Table 6. Results of some indices of non- agricultural companies.

Variable	Cronbach`s Alpha	Composite reliability	AVE	R^2	Q^2	Communality
PsyCap	0.89	0.89	0.81	0.44	0.15	0.35
Self-efficacy	0.74	0.84	0.51	0.65	0.30	0.57
Hope	0.76	0.84	0.51	0.73	0.37	0.51
Resilience	0.76	0.84	0.52	0.72	0.30	0.52
Optimism	0.72	0.83	0.54	0.55	0.31	0.54
EO	0.93	0.85	0.54	0.08	0.02	0.30
Independence	0.74	0.84	0.57	0.44	0.25	0.57
Innovation	0.88	0.90	0.52	0.73	0.37	0.52
Risk-Taking	0.86	0.89	0.51	0.59	0.30	0.51
Aggressive competition	0.90	0.92	0.63	0.35	0.21	0.63
Pioneering	0.80	0.86	0.56	0.62	0.36	0.56
SC	0.96	0.97	0.53	0.08	0.04	0.53
SFSTP	0.97	0.97	0.51	-	-	0.51
PDP	0.91	0.92	0.51	0.38	0.18	0.51

companies, which require larger spaces, specific management support, and customized services to address sector-specific challenges such as weather, pests, and resource management. Strengthening social capital, family and organizational support, and networking opportunities can enhance entrepreneurial orientation, product development, and PsyCap, fostering hope, resilience, self-efficacy, and optimism among entrepreneurs. Overall, targeted interventions, including appropriate infrastructure, skill development, and networking facilitation, are essential to promote the success and sustainability of rural knowledge-based companies, particularly in agriculture, with implications for economic development, food security, and stakeholder well-being.

The main limitation of this study was that data collection coincided with the COVID-19 pandemic, which restricted access to company personnel due to office closures and reduced full-time attendance. Additionally, visiting companies located in incubators across different counties of Fars Province was time-consuming and costly. Finally, measuring certain indices, such as PsyCap, social capital, and entrepreneurial orientation, was challenging due to the interdisciplinary nature of the research, requiring adaptation and localization of standard scales to fit the cultural context of the study.

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تحلیل علی-مقایسه ای عوامل مؤثر بر سرمایه روانشناختی شرکت های دانش بنیان: نقش میانجی گرایش کارآفرینانه و سرمایه اجتماعی

سوزان زندآذر، کوروش رضایی مقدم، و مهسا فاطمی

چکیده

امروزه توجه ویژه ای به کارآفرینی و شرکت‌های دانش‌بنیان می‌شود. در این پژوهش به شناسايي عوامل مؤثر بر سرمایه روان‌شناختی در بین دو گروه شرکت‌های دانش‌بنیان کشاورزی و غیرکشاورزی از پارک علم و فناوری فارس در ایران، پرداخته شد. جامعه آماری، شرکت‌های مستقر در مراکز رشد و مؤسسات پارک علم و فناوری استان فارس بود که داده‌ها از طریق پرسشنامه از 238 نفر (100 نفر از شرکت‌های کشاورزی و 138 نفر از شرکت‌های غیرکشاورزی) به عنوان نمونه آماری اخذ گردید. طبق یافته‌ها، اختلاف بین دو گروه شرکت‌های کشاورزی و غیرکشاورزی در تأثیری که خدمات ارائه‌شده توسط مراکز بر سایر متغیرهای پژوهش می‌گذارند، محسوس بود. خدمات ارائه‌شده در پارک، تأثیر معنی‌داری بر گرایش کارآفرینانه، سرمایه اجتماعی و فرآیند توسعه محصول در شرکت‌هاي کشاورزي نداشت، اما بر سرمایه روان‌شناختی به صورت مستقیم، تأثیر معنی‌داری را نشان داد. در مورد شرکت‌های فعال در حوزه غیرکشاورزی، خدمات ارائه‌شده در پارک اثر مثبت و معنی‌داری بر گرایش کارآفرینانه، سرمایه روان‌شناختی و فرآیند توسعه محصول داشت، اما تأثیر مستقیمی بر سرمایه روان‌شناختی نشان داده نشد. با توجه به اهداف تأسیس مراکز رشد و هزینه و سرمایه‌گذاری که در این خصوص صورت گرفته است، عدم بهره‌وری کامل از این مراکز، خصوصاً در رابطه با شرکت‌های کشاورزی که می‌توانند با بکارگیری فناوری‌های نوین در تأمین امنیت غذایی مثمثر واقع شوند، کاملاً محسوس است. با توجه به تأثیرگذاری خدمات و امکانات ارائه‌شده از سوی پارک‌های علم و فناوری بر کارکرد شرکت‌های مستقر در مراکز رشد، پیشنهاد می‌شود تا این نوع خدمات و امکانات، تخصصی‌تر شده و تقویت گردد. همچنین، لزوم اقدامات آموزشی و عملیاتی برای تقویت گرایش کارآفرینانه، سرمایه اجتماعی و سرمایه روان‌شناختی اعضا نیز مورد تأکید است

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Designing a Model of Planned Management Behavior for Consequences of Climate Change in Iran's Agriculture

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ABSTRACT

The purpose of this research was to design a Model of Planned Management Behavior (MPMB) for consequences of climate change in Iran's agriculture. A mixed method was used in this research. The study sample of qualitative phase included 25 key experts and, in quantitative section, there were 100 experts. Based on the qualitative results, the consequences of climate change were identified. In the quantitative phase, it was determined that 69.3% of the attitude towards the consequences of climate changes were explained by the concerns about social, economic, and environmental consequences, feeling the need for risk management, and perceived value. Also, 71.2% of changes in planned management intention to control the consequences are affected by the attitude towards the consequences, tendency to control behavior, personal and mental norms. Finally, 69.8% of changes in PMB to control the consequences of climate changes are caused by the use of planned management intention to control the consequences, action planning, and coping planning. The results of this research could contribute to planned management to control the consequences of climate change in agricultural sector and pave the way for future research in this field.

Keywords: Attitude, Climate changes and social concerns, Khuzestan Province, Model of Planned Management Behavior.

INTRODUCTION

Climate change is a phenomenon that is happening in most parts of the world, including Iran (Karimi *et al*., 2018). This phenomenon has very wide consequences. As one of the biggest global challenges, climate change has wide-ranging effects on different parts of human life (Ghalibaf *et al*., 2023). Among the sectors that are directly affected by these changes are agriculture and food security (Rajabalinejad *et al*., 2024).

Considering the importance of these issues, investigating the effects of climate change on agriculture and food security is of particular importance. The increase of greenhouse gases, mainly carbon dioxide gas, increase in temperature and decrease in precipitation are among the components of climate change that have had destructive effects on the agricultural sector (Karimi *et al*., 2018). This alarming phenomenon will change the performance of crops and overall production in the agricultural sector in the future (Vaseghi and Esmaeili, 2008). Knowing the social, economic and environmental consequences of this sinister phenomenon is very important. Based on the results of the study by Malkoutikhah and Farajzadeh (2019), it was found that fluctuations or differences from the average of temperature and rainfall variables have a

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significant effect on the production in the agricultural sector. Also, the results of the research of Vathaghi and Ismaili (2008) showed that, due to the increase in greenhouse gas emissions, the increase in temperature and decrease in rainfall until the next 100 years will cause 41% decrease in the yield of wheat cultivation in Iran. The effect of climate change on the agricultural sector is more than all other sectors (Karimi *et al*., 2018). Therefore, the necessity of increasing food security along with reducing the risks of climate change requires a transition to a system of agricultural production that has higher productivity, more efficiency per unit of input consumption, higher flexibility to long-term changes and stability against risks and turbulences (Hertel and Lobell, 2014). More productive and sustainable agriculture seeks to make changes in the use of land, water, nutrients, soil and genetic resources in order to improve the productivity of these resources (Mansouri Daneshvar *et al*., 2019). Obviously, achieving such a system will require significant changes in national and local policies and mechanisms (Thornton, 2014).

Several models are used regarding technology acceptance and behavior prediction in different fields. In this research, the theoretical framework of the research is based on the Theory of Planned Behavior (TPB) and Belief and Concern Theory (Bamberg, 2003; Ajzen, 2005). TPB assumes that a person's behavioral intention is predicted by three key components: attitude toward the behavior, mental norms, and perceived behavioral control. These three predictors significantly cooperate to explain behavioral intention in a range of behavioral domains. Bamberg (2003) also points to belief and concerns. Based on them, the theoretical framework of the research is shown in Figure 1. The novelty of this research is that no research has been conducted in the study area on planned management behavior in the field of managing the consequences of climate change in the agricultural sector. Therefore, conducting this research will greatly contribute to completing the body of knowledge in this field. The phenomenon of climate change it have resulted in a 20 to 30 percent decrease in the quantity and quality of agricultural products. According to a report by the Ministry of Agricultural Jihad, climate change has caused 200 trillion tomans, equivalent to 2 billion and 757 million dollars ($1 in 2024= 70 thousand tomans) within a year, to damage the agricultural sector of Iran (Mehr News Agency, 2024). In previous research, no researcher had addressed the identification of the consequences of climate change on the agricultural sector through a qualitative method. In addition, none of them had paid any attention to designing a planned management behavior model to control the consequences of climate change.

The research objectives were to identify the followings:

Consequences of climate change in agriculture sector.

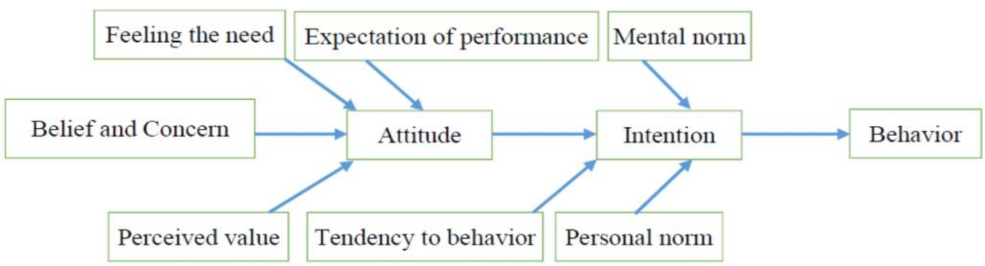

Figure 1. Theoretical model of the research.

Factors affected on attitude towards social, economic and environmental consequences of climate change.

Which factors affected planned management intention of controlling consequences of climate change?

Which factors affected the behavior of planned management of consequences that control climate change?

MATERIALS AND METHODS

This research is an applied and non-experimental type of research, and two qualitative and quantitative paradigms have been used. The purpose of this research was to identify the consequences of climate change and design a model that controls the consequences through planned behavioral management. The research plan consisted of two parts. In the first stage, the qualitative paradigm was used (n_1=25), and in the second stage, the quantitative paradigm (n_2= 100). In the qualitative research paradigm, interviews with experts and brainstorming were used, and in the quantitative paradigm, the descriptive research method and the structural equation model. Face-to-face interviews and brainstorming methods were used to extract concepts, subcategories and categories in the qualitative part. The study sample of this research in the qualitative phase included key experts who had knowledge of the consequences of climate change in Khuzestan Province, and included 10 university faculty members and 15 agricultural managers. Qualitative data collection continued until theoretical saturation was reached. The analysis steps in the qualitative section included three types of coding i.e. open coding, axial coding and selective coding. The statistical population in the quantitative part included the experts of Agricultural Jihad of Khuzestan Province. The number of statistical samples was considered to be 100 people according to Krejcie and Morgan's (1970) table. In order to validate the presented model, confirmatory factor analysis was used in the framework of the structural equation model. Smart PLS3 software was used for quantitative statistical analysis. Based on the theoretical framework of the research (Bamberg, 2003; Ajzen, 2005) and based on the opinion of the experts, the conceptual framework of the research was designed and presented in Figure 2.

Based on the conceptual model of the research, the hypotheses of the research were as follows:

H1: Understanding the social consequences has a significant effect on the attitude towards the consequences.

H2: Understanding the economic consequences has a significant effect on the attitude towards the consequences.

H3: Understanding the environmental consequences has a significant effect on the attitude towards the consequences.

H4: Feeling the need for risk management has a significant effect on the attitude towards social, economic and environmental consequences.

H5: The perceived value has a significant effect on the attitude towards social, economic and environmental consequences.

H6: Expectation of performance has a

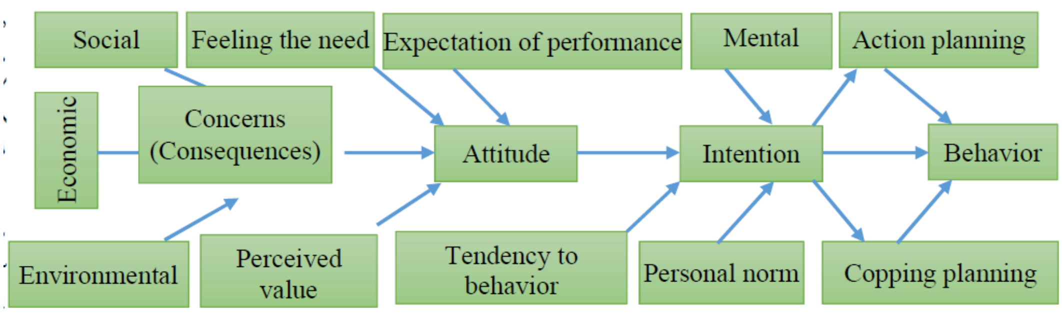

Figure 2. Conceptual model of the research.

significant effect on attitude towards social, economic and environmental consequences.

H7: The attitude towards social, economic and environmental consequences has a significant effect on the planned management intention to control the consequences.

H8: The tendency to control behavior has a significant effect on the planned management intention to control the consequences.

H9: Personal norm has a significant effect on planned management intention to control consequences.

H10: Mental norm has a significant effect on planned management intention of controlling consequences.

H11: The intention of planned management for control of consequences has a significant effect on the behavior of planned management for control of consequences.

H12: The intention of planned management for control of consequences has a significant effect on the action planning of applying the planned management of consequences control of climate change.

H13: The intention of planned management for control of consequences has a significant effect on the coping planning of planned management for control of consequences of climate change.

H14: The action planning of applying the planned management for control of consequences has a significant effect on the behavior of the planned management for control of consequences.

H15: The copping planning of planned management for control of consequences has a significant effect on the behavior of planned management for control of consequences.

RESULTS

Identifying the social, economic and environmental consequences of climate change

In order to design a Model of Planned Management Behavior (MPMB), identifying the social, economic and environmental consequences of climate change through semi structured and face-to-face interview methods and a brainstorming with a grounded theory approach was considered. The study sample of this research in the qualitative phase included key experts who had knowledge of the consequences of climate change in Khuzestan Province. They included: 10 university faculty members and 15 agricultural managers. For this purpose, Strauss and Corbin coding method was used to achieve specific goals (Strauss and Corbin, 1998). The current research included 25 in-depth interviews and brainstorming with experts. The duration of the interviews was from 25 to 50 minutes and the brainstorming time was 200 minutes in two sessions. A total of 890 minutes of interviews were conducted. As a result, 71 concepts (initial codes) were expressed, and a total of 17 subcategories were extracted.

Identifying Social Consequences of Climate Change

A systematic process of coding was used to conduct a qualitative study, which was conducted in the form of 3 stages of open coding, axial coding, and selective coding using MAXQDA12 software.

Open Coding

In the open coding phase, experts' statements about social consequences of climate change were analyzed and concepts were extracted from them. The results of the interview and the brainstorming session were identified and extracted in the form of 41 concepts. First, the main sentences under the title of concepts were extracted from direct quotes that had at least 5 repetitions. Then similar concepts were combined. Finally, 29 final concepts were identified and coded. Each of the codes was indicated by an S symbol. The results of open coding are shown in Table 1.

Each of the codes was indicated by an S symbol. The results of open coding are shown in Table 1.

Axial Coding

In this step, the number of repetitions of concepts was determined and subcategories were extracted. Based on the results of the axial coding of social consequences, 8 subcategories were determined in the form of 29 concepts with 296 repetitions (Table 2).

Selective Coding

In selective coding, the intensity of the relationship between sub-categories and categories was determined based on the repetition of concepts in the form of a diagram. First, the main sentences under the title of concepts were extracted from direct quotes that had at least 5 repetitions. Then similar concepts were combined. Finally, 29 final concepts were identified and coded. Each of the codes was indicated by an S symbol. The results of open coding are shown in Table 1.

Table 1. Conceptualization of the data obtained from experts' answers for social consequences of climate change (Open coding).

Concepts (Initial codes)	Code
The fields of agricultural employment have disappeared.	S1
The population working in the agricultural sector has decreased.	S2
Youth unemployment has increased.	S3
Immigration has increased and marginalization has grown.	S4
Life expectancy has decreased.	S5
Security problems have increased.	S6
Poverty has spread.	S7
Social welfare has decreased.	S8
Crime and theft have increased.	S9
Mental and psychological tensions, anger and frustration have appeared.	S10
Rural society has lost its freshness.	S11
Conflicts and ethnic and religious conflicts have increased.	S12
Self-confidence and productive motivations have decreased.	S13
The trading process has been disrupted.	S14
The desire for non-productive businesses and mediation has increased.	S15
Agriculture-related industries have been damaged.	S16
Public and collaborative works in villages have decreased.	S17
Local institutions and organizations have weakened.	S18
Ecotourism areas in the village have been destroyed.	S19
The income from tourism has decreased.	S20
Diseases and malnutrition have increased.	S21
The general health of the society has decreased.	S22
Self-reliance, independence and human dignity have disappeared.	S23
The style of dressing, food and rural techniques have disappeared.	S24
Increasing dissatisfaction and pessimism towards government support policies.	S25
The social values of the traditional beliefs and opinions have changed.	S26
The cohesion of rural and nomadic households has been broken.	S27
Family visits have decreased.	S28
Food security has decreased.	S29

Table 2. Subcategories extracted from the concepts of social consequences.

Category	Subcategories	Concepts code	Repetitions
Social consequences	Increase in unemployment and immigration	S1, S2, S3, S4	11, 15, 10, 9
	Reduction of welfare and social security	S6, S7, S8, S9	10, 8, 11, 13
	Increasing frustration, dissatisfaction and psychological tensions	S5, S10, S11, S13, S23, S25	8, 7, 11, 10, 9, 7
	Creating problems for agricultural related industries and increasing intermediation and brokering	S14, S15, S16	8, 9, 11
	Increasing social conflicts	S12, S17, S18	10, 11, 9
	Change in social beliefs and values	S24, S26, S27, S28	9, 11, 10, 8
	Reduced public and social health	S21, S22, S29	12, 15, 8
	Ecotourism problems	S19, S20	10, 9, 7

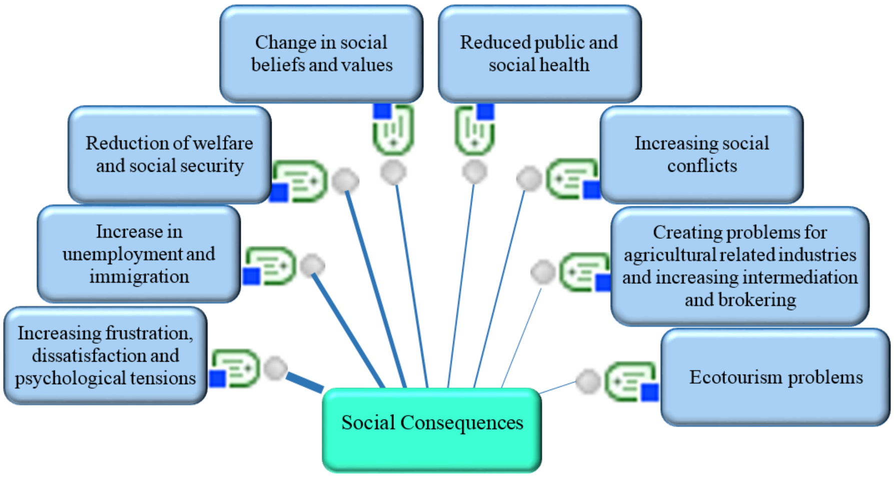

Figure 3. Social consequences of climate change.

Identifying Economic Consequences of Climate Change

Open Coding

The results of the interview and the brainstorming session were identified and extracted in the form of 36 concepts. First, the main sentences under the title of concepts were extracted from direct quotes that had at least 5 repetitions. Then, by combining similar concepts, 24 final concepts were identified and coded with the number of repetitions. Each of the codes was indicated by an E symbol. The results of open coding are shown in Table 3.

Axial Coding

In this step, the number of repetitions of concepts was determined and subcategories were extracted. Based on the results of the axial coding of economic consequences, 5 subcategories were determined in the form of 24 concepts and with 301 repetitions (Table 4).

Table 3. Conceptualization of data obtained from experts' answers for economic consequences of climate change (Open coding).

Concepts (Initial codes)	Code
Decrease in income	E1
Decrease in purchasing power	E2
Increase in the price of agricultural products	E3
Reducing the amount of investment in product production	E4
Decrease in financial ability to repay loans	E5
Reducing the ability to guarantee loans	E6
Increase in production costs	E7
Reducing the production of products	E8
Fodder becoming more expensive in region	E9
Changing the occupation of farmers	E10
Reducing the number of livestock	E11
Reducing the financial ability of farmers in providing the necessities of life	E12
Increasing migration of villagers due to economic problems	E13
Reduction of productivity	E14
Reducing the performance of products	E15
Increasing seasonal and permanent unemployment of farmers	E16
Reduction of production efficiency	E17
Increase in the price of agricultural tools	E18
Reducing the productivity of agricultural land	E19
Reduction of production capacity	E20
Failure to cultivate various crops in the year	E21
Reduction of livestock production	E22
Reduction of water resources	E23
Reduction of financial support facilities	E24

Selective Coding

Figure 4 shows that, reduction of product performance, efficiency, productivity and production capacity, and reducing the financial power and income of farmers are, based on priority, the most important economic consequences of climate change.

Identifying Environmental Consequences of Climate Change

Open Coding

The results of the interview and the brainstorming session were identified and extracted in the form of 28 concepts. First, the main sentences under the title of concepts were extracted from direct quotes that had at least 5 repetitions. Then, by combining similar concepts, 18 final concepts were identified and coded with the number of repetitions. Each of the codes was indicated by an N symbol. The results of open coding are shown in Table 5.

Axial Coding

In this step, the number of repetitions of concepts was determined and subcategories were extracted. Based on the results of the axial coding of economic consequences, 4 subcategories were determined in the form of 18 concepts with 216 repetitions (Table 6).

Selective Coding

Based on priority, Figure 5 shows that air and water pollution and reduction of water resources, soil pollution and erosion, the spread of pests and diseases and the extinction of species, destruction of pastures and forests and desertification are the most important environmental consequences of climate change.

Table 4. Subcategories extracted from the concepts of economic consequences.

Category	Subcategories	Concepts code	Repetitions
Economic consequences	Reducing the financial power and income of farmers	E1, E2, E5, E6, E12	11, 9, 13, 15, 14
	Increase in production costs	E7, E9, E18	14, 8,15
	Reduction of product performance, efficiency, productivity and production capacity	E8, E11, E14, E15, E17, E19, E20, E21, E22, E23	9, 12, 11, 14, 12, 11, 10, 15, 8, 10
	Reduction of support facilities, investment, increase in product prices and reduction of people's purchasing power	E3, E4, E24	14, 12, 18
	Increase in immigration and unemployment	E10, E13, E16	12, 15, 19

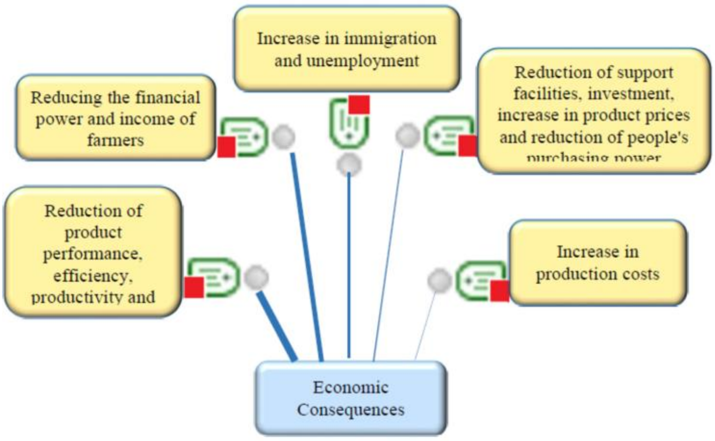

Figure 4. Economic consequences of climate change.

Table 5. Conceptualization of data obtained from experts' answers for environmental consequences of climate change (Open coding).

Concepts (Initial codes)	Code
Lowering of underground water, wells and aqueducts	N1
Drying of surface water such as springs	N2
The spread of pests and diseases to garden and agricultural products	N3
Reduction of farmers' rights	N4
Increase in dust and air pollution	N5
Soil erosion and destruction	N6
Reduction of vegetation and loss of pastures	N7
Conversion of agricultural and pasture lands to barren lands	N8
Saltiness and bitterness of water	N9
Increase in the attack of beasts on the village environment	N10
Pollution of underground water sources	N11
soil pollution	N12
Destruction of soil microorganisms	N13
Destruction of forests	N14
Extinction of some animal species	N15
Extinction of some plant species	N16
Reliance on chemical inputs	N17
Pollution of rivers	N18

Table 6. Subcategories extracted from the concepts of environmental consequences.

Category	Subcategories	Concepts code	Repetitions
Environmental Consequences	Air and water pollution and reduction of water resources	N1, N2, N4, N5, N9, N11, N18	14, 11, 12, 15, 13, 8, 11
	Soil pollution and erosion	N6, N12, N13, N17	12, 15, 12, 8
	Destruction of pastures and forests and desertification	N7, N8, N14,	10, 15, 14
	The spread of pests and diseases and the extinction of species	N3, N10, N15, N16	10, 9, 13, 14

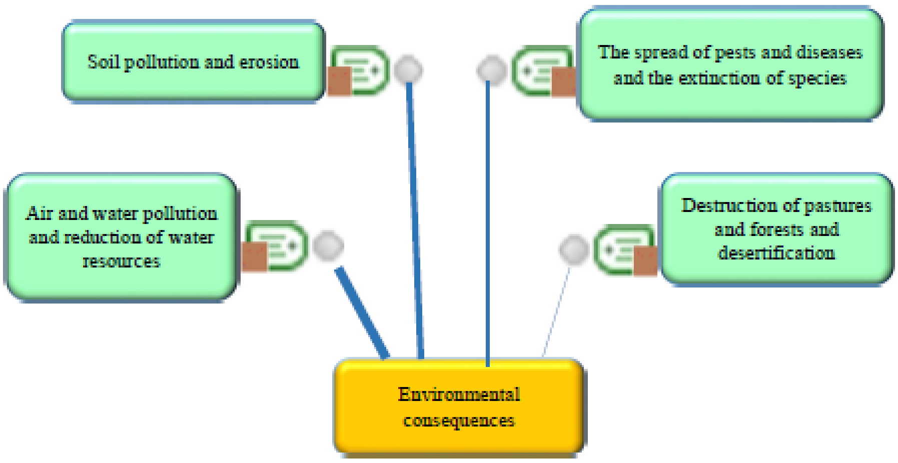

Figure 5. Environmental consequences of climate change.

Table 7. R^2, Q^2 and GOF amount for fitting the outcomes model.

Construct	R^2	Q^2	GOF
PMB	0.837	0.721	0.731

Research Model Test (PMB Model for Climate Change Management)

To test the research model and hypotheses, the Structural equation modeling (SEM) was applied using Smart PLS_3 software. The fit of the structural model was also evaluated using R^2, Q^2 and GOF criteria. According to the results of Table 7, the fit criteria had acceptable amount.

Next, the research hypotheses were tested. The way to decide to reject or confirm the hypotheses is to compare the t-value with the numbers +1.96 and -1.96. If the calculated values are between these two values, the desired hypothesis is rejected, and if it is not, the hypothesis is confirmed. The results of the hypothesis test are presented in Table 8 and the final research model is presented in Figures 6 and 7.

The results of table 8 showed that understanding the social consequences (β= 0.61), economic consequences (β= 0.72), environmental consequences (β= 0.58), feeling the need for risk management (β= 0.62), perceived value (β= 0.61) and expectation of performance (β= 0.67) had a positive and significant effect on attitude towards the consequences of climate changes. Also attitude towards the consequences of climate changes (β= 0.58), tendency to control behavior (β= 0.74), personal norm (β= 0.49) and mental norm (β= 0.69) had a positive and significant effect on planned management intention to control the consequences of climate changes. In addition, intention of planned management (β= 0.73), action planning (β= 0.64), and copping planning (β= 0.61) had a positive and significant effect on PMB.

Table 8. The results of the research hypotheses test

Hypotheses	Independent	Dependent	Path coefficient	t-Value	R^2	Test results
H1	Understanding the social consequences	Attitude	0.61	3.82	0.39	Confirmed
H2	Understanding the economic consequences	Attitude	0.72	4.51	0.53	Confirmed
H3	Understanding the environmental consequences	Attitude	0.58	5.27	0.31	Confirmed
H4	Feeling the need for risk management	Attitude	0.62	3.54	0.38	Confirmed
H5	Perceived value	Attitude	0.61	3.45	0.35	Confirmed
H6	Expectation of performance	Attitude	0.67	3.12	0.45	Confirmed
H7	Attitude	Planned management intention	0.58	3.09	0.31	Confirmed
H8	Tendency to control behavior	Planned management intention	0.74	3.29	0.55	Confirmed
H9	Personal norm	Planned management intention	0.49	3.99	0.28	Confirmed
H10	Mental norm	Planned management intention	0.69	3.87	0.47	Confirmed
H11	Planned management intention	Action planning	0.72	3.44	0.53	Confirmed
H12	Planned management intention	Copping planning	0.45	3.29	0.25	Confirmed
H13	Intention of planned management	PMB	0.73	3.48	0.54	Confirmed
H14	Action planning	PMB	0.64	3.88	0.39	Confirmed
H15	Copping planning	PMB	0.61	3.71	0.35	Confirmed

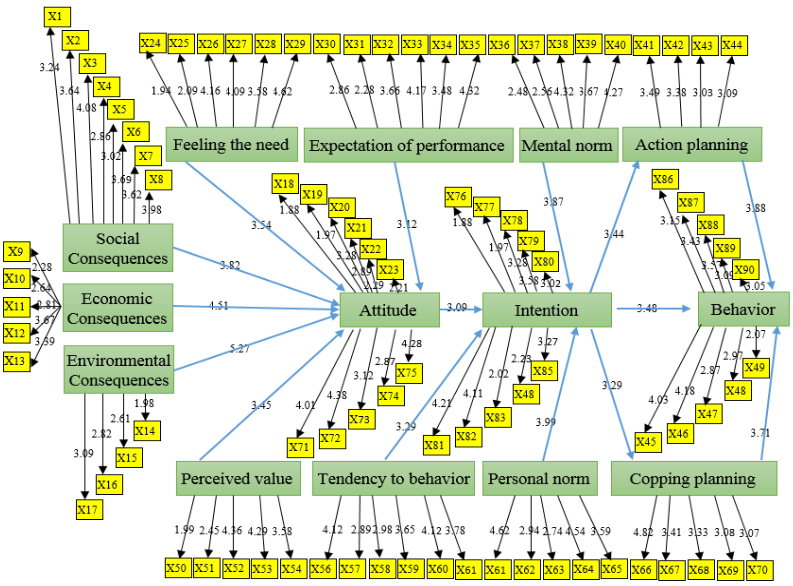

Figure 6. t-Values for the relationships between factors and variables of PMB causal model.

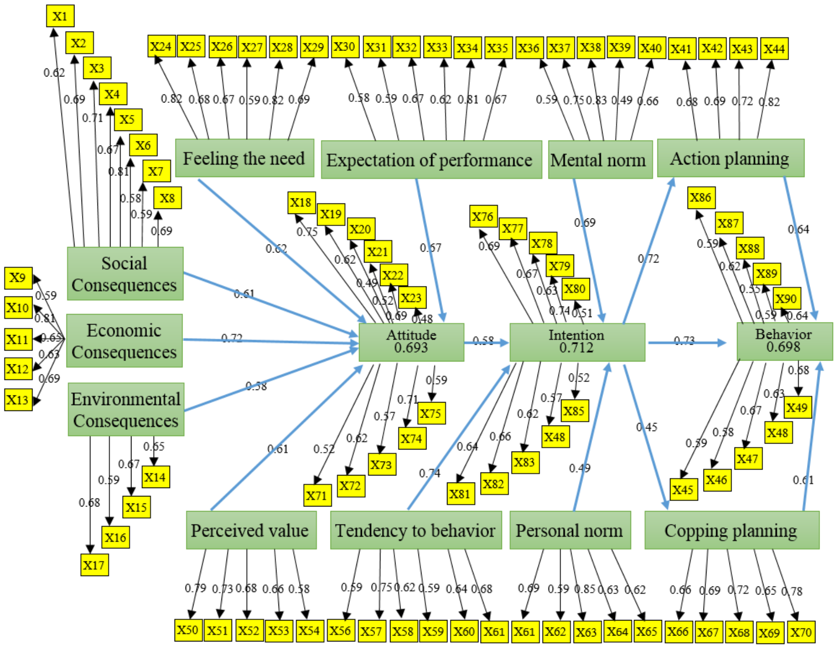

Figure 7. The values of the standardized loadings for each of the factors and variables of the PMB causal model.

Based on the results of Figure 6, which is the output of Smart PLS3 software, it can be stated that 69.3% of the attitude towards the consequences of climate changes are explained by the independent variables of social, economic and environmental consequences, feeling the need for risk management, and perceived value. Also, 71.2% of the changes in planned management intention to control the consequences of climate changes are affected by the attitude towards the consequences, tendency to control behavior, personal and mental norms. Finally, 69.8% of changes in PMB of controlling the consequences of climate changes are caused by the use of planned management intention to control the consequences, action planning, and copping planning.

DISCUSSION

According to the results of the research, the first hypothesis i.e. "understanding the social, economic and environmental consequences have a significant effect on the attitude towards the consequences" is confirmed. This finding is consistent with the results of Chaudhary and Bisai (2018) and Felicilda-Reynaldo *et al*., (2018). In fact, as people's understanding of the consequences increases, their attitude will change. Improving knowledge and information is very effective in improving people's understanding.

The results also show that the second hypothesis i.e. "feeling the need for risk management has a significant effect on the attitude towards social, economic and environmental consequences", was confirmed. This finding is consistent with the results of Hillson and Murray-Webster (2006) and Wang and Yuan (2011). The consequences of climate change are important risks that affect the agricultural sector. Sensing the need for risk management will lead to improved perceptions and a favorable attitude towards adopting management strategies to control the consequences of climate change.

According to the results, the third hypothesis i.e. "the perceived value has a significant effect on the attitude towards social, economic and environmental consequences” was also confirmed. This finding is consistent with the results of Hassan *et al*. (2022). Understanding the economic, social and environmental value of controlling the consequences of climate change in the agricultural sector is effective in creating the necessary grounds for optimizing individuals' attitudes in carrying out planned management actions.

Furthermore, the fourth hypothesis i.e. “the expectation of performance has a significant effect on attitude towards social, economic and environmental consequences." was also confirmed. This finding is consistent with the results of Collado and Evans (2019). Similarly, the fifth hypothesis i.e. “the attitude towards social, economic and environmental consequences has a significant effect on the planned management intention to control the consequences." was also confirmed. This finding is consistent with the results of Kwistianus *et al*. (2020) and Moon (2021). The research results also confirmed the sixth hypothesis i.e. “the tendency to control behavior has a significant effect on the planned management intention to control the consequences.". This finding is consistent with the results of Ahmed *et al*. (2021) and Close *et al*. (2018).

According to the results, the seventh hypothesis i.e. “the personal norm has a significant effect on planned management intention to control consequences." was also confirmed. This finding is consistent with those of Roos and Hahn (2019). Besides, the eighth hypothesis i.e. “the mental norm has a significant effect on planned management intention of controlling consequences." was confirmed, too. This finding is consistent with the results of Ateş (2020).

The results also confirmed the ninth hypothesis “the intention of planned management of consequences control has a significant effect on the behavior of planned management of consequences control". This finding is consistent with the results of Trivedi *et al*. (2018) and Sun *et al*. (2018). Also, the tenth hypothesis i.e. “the intention of planned management of consequences control has a significant effect on the action planning of applying the planned management of consequences control of climate change." was confirmed. This finding is consistent with the results of Brown *et al*. (2018).

For the eleventh hypothesis i.e. “the intention of planned management of consequences control has a significant effect on the copping planning of planned management of consequences control of climate change" the results were confirmed. This finding is consistent with those of Strong *et al*. (2018). The twelfth hypothesis i.e. “the action planning of applying the planned management of consequences control has a significant effect on the behavior of the planned management of consequences control." was also confirmed. This was consistent with the results of Brown *et al*. (2018) and Strong *et al*. (2018).

Results of the thirteenth hypothesis i.e. “the copping planning of planned management of consequences control has a significant effect on the behavior of planned management of controlling the consequences." were confirmed as well. This finding is consistent with the results of Brown *et al*. (2018) and Strong *et al*. (2018).

Policymakers need to benefit from the participation of users to achieve the desired results. Therefore, policymakers can use the results of this research to control the consequences of climate change on the agricultural sector. According to the objectives of this research and the identified results, it is possible to identify the consequences of climate change in the agricultural sector. Also, factors affecting the attitude towards social, economic and environmental consequences of climate change can be understood. Next, factors effect on planned management intention of controlling consequences of climate change were analyzed. In addition, factors affected on the behavior of planned management of consequences control of climate change and in this way, necessary policymaking was planned to manage the consequences of climate change.

CONCLUSIONS

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Based on the results, it was found that feeling the need for risk management has a significant effect on the attitude towards social, economic and environmental consequences. Therefore, it is recommended to increase the awareness of the audience regarding risk management mechanisms. The findings showed that the perceived value of strategies to control the effects of climate change has a significant impact on the attitude towards social, economic and environmental consequences, therefore, it is recommended to take the necessary measures to increase the understanding of the value of strategies to control climate change. Expectation of performance has a significant effect on attitude towards social, economic, and environmental consequences; therefore, it is recommended to take the necessary measures to increase the expectations of the users of their performance by holding training and extension classes. Also, the attitude towards consequences has a significant effect on the planned management intention to control the consequences. Therefore, it is recommended to take the necessary measures to optimize the attitude of farmers in the field of strategies to control the effects of climate change. Further, the tendency to control behavior has a significant effect on the planned management intention to control the consequences. Therefore, it is recommended to improve the tendency of farmers to control behavior by holding motivational and participatory courses. Also, the personal norm has a significant effect on planned management intention to control consequences. Therefore, it is recommended to distribute brochures, tracts and announcements warning about the effects of climate change among farmers. Based on the findings, the mental norm has a significant effect on planned management intention of controlling consequences. The research results showed that the intention of planned management of consequences control has a significant effect on the behavior of planned management of consequences control. It is suggested that the necessary incentives by the government for farmers to use strategies to control the consequences of climate change. This research provides valuable assistance to planners, policy makers and farmers in completing the existing gap for PMB development. In this research, to identify the consequences of climate change, the status of the users' attitude and the factors affecting it in this regard, planned management intention and the factors affecting it and, finally, planned management behavior, and the effects of attitude on intention and the effects of intention on the occurrence of behavior were identified. The application of these results on the emergence of planned behavior to control the consequences of climate change will be very important and vital.

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طراحی الگوی رفتار مدیریت برنامه ریزی شده برای پیامدهای تغییر اقلیم در کشاورزی ایران

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چکیده

تغییر اقلیم ایران در سال های اخیر باعث کاهش بارندگی و افزایش دما و خشکسالی های مداوم شده است. تولیدات کشاورزی در ایران تحت تأثیر تغییرات اقلیمی قرار گرفته و با کاهش تولید محصولات مختلف مواجه شده است. بنابراین استفاده از راهکارهایی برای مدیریت پیامدهای تغییرات اقلیمی ضروری است. هدف از این تحقیق طراحی مدل رفتار مدیریت برنامه ریزی شده (MPMB)برای پیامدهای تغییر اقلیم در کشاورزی ایران بود. در این تحقیق از روش ترکیبی استفاده شد. نمونه پژوهش مرحله کیفی شامل 25 خبره کلیدی و در بخش کمی 100 کارشناس بود. بر اساس نتایج کیفی، پیامدهای تغییر اقلیم شناسایی شد. در مرحله کمی مشخص شد که 69.3 درصد نگرش نسبت به پیامدهای تغییرات اقلیمی با نگرانی در مورد پیامدهای اجتماعی، اقتصادی و زیست محیطی، احساس نیاز به مدیریت ریسک و ارزش درک شده تبیین می شود. همچنین 71.2 درصد از تغییرات در قصد مدیریت برنامه¬ریزی شده برای کنترل پیامدها متأثر از نگرش به پیامدها، تمایل به کنترل رفتار، هنجارهای شخصی و ذهنی است. در نهایت، 69.8 درصد از تغییرات رفتار مدیریت برنامه ریزی شده (PMB) برای کنترل پیامدهای تغییرات اقلیمی ناشی از استفاده از قصد مدیریت برنامه ریزی شده برای کنترل پیامدها، برنامه¬ریزی اقدام و برنامه ریزی مقابله است. نتایج این تحقیق کمک قابل توجهی به مدیریت برنامه ریزی شده برای کنترل پیامدهای تغییر اقلیم در بخش کشاورزی خواهد کرد و راه را برای تحقیقات آینده در زمینه کنترل پیامدهای تغییرات اقلیمی هموار می کند.

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Exploring Factors Affecting the Pastoralists Resilience against Climate Change

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ABSTRACT

Climate Change (CC) is one of the major challenges of our time that impacts rangelands regionally and globally. The rising vulnerability among pastoralists highlights the need to prioritize resilience thinking. Pastoralists' resilience refers to the ability of rangeland businesses to endure, adapt to, and remain flexible in the face of threats or challenges. This research was conducted with the primary goal of analyzing the factors that influence resilience from the perspective of pastoralists in Tehran Province under CC conditions. The research was both goal-oriented and exploratory in methodology. The study sample consisted of 317 pastoralists selected through stratified random sampling. The data collection tool was a researcher-made questionnaire. Software SmartPLS was used for data analysis. The validity of the questionnaire was assessed using the average variance extracted, while its reliability was established by calculating composite reliability and Cronbach's Alpha. Data were analyzed using the structural equation modeling technique with Smart PLS software. The structural equation modeling indicated that economic, institutional, ecological, physical, social, educational, extensional, and individual factors had the greatest impact on Pastoralists' Resilience under Climate Change (PRCC) conditions and explained 75.5% of the conditions.

Keywords: Pastoralism, Rangeland businesses, Structural Equation Modeling, Zagros Mountains.

INTRODUCTION

Pastoralism in the Zagros Mountains began approximately 9,000 years ago and is globally significant for its contributions to food production, ecosystem services, livelihoods, culture and civilization. Pastoralists care for, maintain, and use livestock in rangeland areas under unpredictable weather conditions (Dong *et al*., 2016). Today, rangeland degradation is a global issue that not only threatens the existing plants and animal populations, but also human communities (Husein, 2021). CC is one of the factors contributing to rangeland degradation in many parts of the world (Angerer *et al*., 2023).

CC causes alternations in temperature and precipitation in a region (Brêda *et al*., 2020). In semi-arid areas, vulnerability and food security pose significant challenges (Raj and Sharma, 2023). Iran is located in one of the driest regions of the world and has been affected by CC in recent years, particularly by drought (Bahrami *et al*., 2021).

In Iran, rangelands cover is approximately 55% (Sadeghi and Hazbavi, 2022). Pastoralists identified three factors of reduced forage quality, increased barren land, and reduced livestock production as the most important impacts of drought on rangelands (Behmanesh *et al*., 2021).

The rangelands of the province of Tehran, being in a critical state of destruction (Yousefi *et al*., 2021), has not been spared from meteorological station data (2001-2021), which indicates the phenomena of CC and

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drought (Javadi *et al*., 2024). These issues have led to reduced forage production in rangelands, making it more difficult for pastoralists. Consequently, pastoralists have been compelled to overgraze beyond livestock capacity of the rangelands. This has also led to degradation of these areas (Yousefi *et al*., 2021).

There is an agreement among experts that problems cannot be solved solely through technical innovations, policy reforms, or economic development: new researches and monitoring programs need to be designed for pastoralists that might address ecological, social, and economic interdependencies within resilience frameworks (Dong *et al*., 2016).

There is no consensus among experts on the concept of resilience. Resilience has been defined differently in various disciplines over time. Holling (1973) first introduced this term as an ecological concept. In the recent decades, this concept has emerged in the literature on socio-ecological systems and rangeland management (Dong *et al*., 2016; Kapruwan *et al*., 2024). The adaptive cycle illustrates how this system maintains its activities or quickly regains its previous state when faced with external shocks such as drought. However, these shocks and stresses may lead to new approaches or cause a socio-ecological system to be disrupted or abandoned (Meuwissen *et al*., 2019). If the pastoral system is not resilient, it is likely to disappear because it cannot guide itself through the adaptive cycle. When faced with challenges such as drought, resilient pastoralists attempt to steer the current situation toward improvement and positive outcomes by adopting logical and effective solutions.

Given the challenges and problems raised by CC, the most important issue is finding solutions that can improve the lives of pastoralists. This is because pastoralists are major food producers who are highly vulnerable and possess low recovery capacity due to their dependence on the environment, particularly under CC and drought conditions. Therefore, it is necessary to take significant steps by developing effective strategies in the CC management process such as adopting a resilience approach. Various dimensions, indicators and variables related to resilience can be discussed, and some of the most important of which are discussed here.

Meuwissen *et al*. (2019) proposed that distinguishing three resilience capacities can help evaluate a wide range of resilience strategies. Adzawla *et al*. (2020) argued that factors such as education, income, etc. are effective in promoting resilience. Ahmad and Afzal (2021) asserted that access to services is one of the key factors influencing resilience. Melketo *et al*. (2021) found that savings, livestock diversity, and similar resources contribute to improved resilience. Le Goff *et al*. (2022) also believed that farmers maintain their resilience through mutual community interactions and institutional support under various conditions. Finally, Kapruwan *et al*. (2024) carried out a research in India and found that promoting and strengthening organizational structures enhances community resilience to CC.

Programs and strategies for rangeland climate are more effective when they are tailored to local conditions. Opinions of local rangeland advisers are crucial for the development of these resources (Dinan *et al*., 2021). Localization was achieved through a systematic review. (Darvish *et al*., 2023).

According to the various studies done, several factors influence the PRCC. Proper management of these factors improves resilience, which is the capacity of pastoralists to cope with CC. It has been measured through indicators of robustness, adaptability, and transformability.

By studying previous research, the following hypotheses can be considered in the current study:

1. Individual factors significantly influence the resilience of pastoralists in Tehran Province under CC conditions. The individual factor includes a sense of self, that the pastoralist has, and guides itself in the right direction when faced with CC. This factor is measured in terms of psychological indicators (Connor-Davidson Resilience Scale), health and family.

2. Educational and extension factors significantly influence the resilience of pastoralists in Tehran Province under CC conditions. The educational and promotional factors encompass educational and technical support provided by the extension sector, which enhances the attitude, insight, knowledge and skills of pastoralists with response to CC conditions. This factor is measured by two indicators of education and extension.

3. Social factors play a significant role in the resilience of pastoralists in Tehran Province under CC conditions. These social factors include the feelings that pastoralists gain from their society, such as their perception of other pastoralists, their sense of responsibility toward one another, the trust they have in each other, and their understanding of the social structure that guides them in effectively facing CC. This factor is comprising indicators of social security, participation, trust, and social coherence.

4. Economic factors significantly influence the resilience of pastoralists in Tehran Province under CC conditions, under which the economic factor pertains to the assets of pastoralists and their access to the resources needed to engage in resilience activities. This factor is measured in terms of job and income indicators, financial support, and economic capability.

5. Physical factors play a significant role in influencing the resilience of pastoralists in Tehran Province under CC conditions. The physical factor refers to pastoralists' access to communication infrastructure necessary for their activities, etc. This factor has two indicators: access to infrastructure and machinery.

6. Ecological factors significantly influence the resilience of pastoralists in Tehran Province under CC conditions. The ecological factor refers to pastoralists' access to natural resources and their enhancement to sustain pastoral activities. Indicators of this factor include ecological assets and protection of natural resources.

7. Institutional factors are crucial in shaping of the resilience of pastoralists in Tehran Province under CC conditions. The institutional factor pertains to government governance, which plays a fundamental role in improving the conditions for PRCC conditions. Government laws and regulations, government support, and the relationship between the government sector and pastoralists are effective in increasing PRCC (Pastoralists' Resilience to Climate Change). This factor comprises indicators related to institutional context, institutional relations and institutional coherence.

Based on prior research, including studies by Meuwissen *et al*. (2019) and Darvish *et al*. (2023), the conceptual model for the present study was developed. It features seven variables and 21 components, as illustrated in Figure 1. The seven factors - individual, educational-extensional, social, economic, physical, ecological and institutional – will collectively influence the resilience of pastoralists. Robustness, adaptability, and transformability are outcomes of the resilience that arise from the conditions related to PRCC.

MATERIALS AND METHODS

Study Area

Tehran Province is located in the northern half of Iran (Figure 2). It has three elevation zones and an annual rainfall ranging from 230 to 500 mm. The largest area, accounting for 40.51%, is designated for rangeland use. Additionally, the majority of the province, at 49.56% percent, is classified as having a semi-arid climate (Javadi *et al*., 2024).

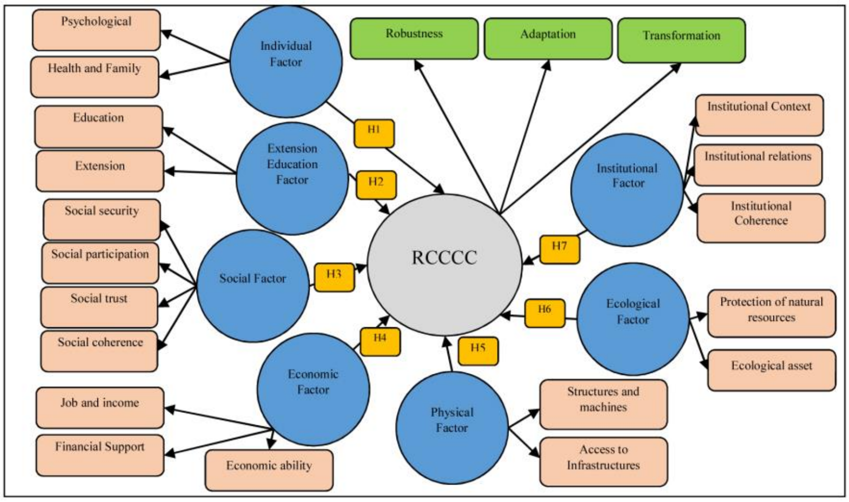

Figure 1. Conceptual model of the research (authors).

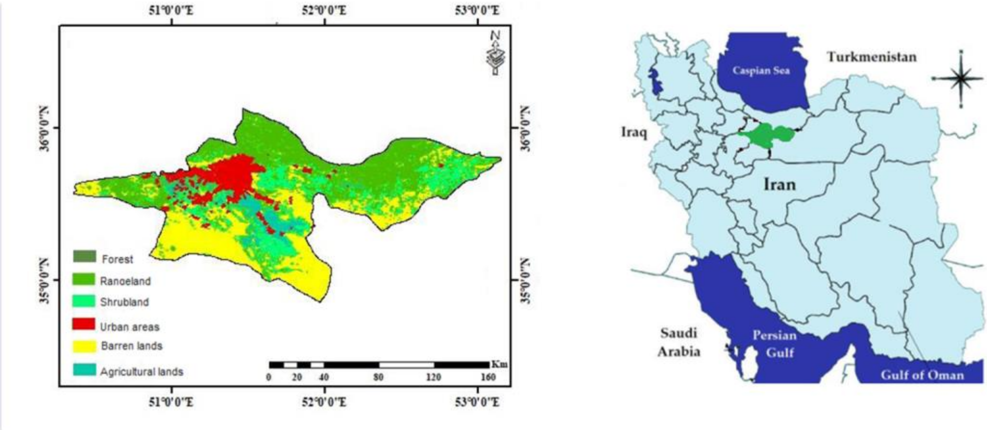

Figure 2. Study area (Javadi *et al*., 2024).

Research Methodology

The present study employed a survey method to analyze the factors affecting resilience of pastoralists in Tehran Province under CC conditions. The statistical population of this study consists of the 5,584 pastoralists as of 2024, according to the available statistics. To estimate the sample size from this population we utilized the Cochran formula, selecting a total of 318 individuals through stratified random sampling, taking into account the existing counties. To measure the factors affecting PRCC conditions, we developed a questionnaire with response options based on the Likert scale. D_{tat} analysis was conducted using SMART PLS and SPSS software. To ensure the validity of the research instrument, the questionnaire was reviewed by experts and specialists in natural resources. Their feedback was incorporated, leading to the necessary revisions and confirming the validity of the questionnaire. To determine the reliability of the research tool, Cronbach's Alpha coefficient was calculated for each section of the questionnaire, indicating the appropriate internal consistency of the items and its stability.

To validate the measurement model (Table 1), we found that the Composite Reliability (CR) and Average Variance Extracted (AVE) were both above 0.7, suggesting solid internal consistency among the model's variables. The AVE value exceeded 0.5 for

Table 1. Reliability and convergent validity in the measurement model.

Constructs	Cronbach Alpha	Convergent validity	Composite Reliability (CR)	Average variance extracted
Individual factor	0.782	0.792	0.873	0.697
Educational and extensional factor	0.777	0.888	0.840	0.534
Social factor	0.860	0.909	0.897	0.527
Economic factor	0.870	0.912	0.903	0.626
Physical factor	0.831	0.870	0.874	0.564
Ecological factor	0.737	0.774	0.787	0.525
Institutional Factor	0.820	0.894	0.868	0.652
Robustness	0.823	0.826	0.883	0.654
Adaptability	0.777	0.779	0.857	0.599
Transformability	0.812	0.815	0.877	0.642

the variables, indicating acceptable convergent validity.

To examine the discriminant validity of the measurement model, the Fornell and Larcker criterion was employed. According to Tables 2 and 3, the square root of AVE for each construct in the present study is greater than the correlations among them. Therefore, it can be concluded that the model constructs had stronger association with their own indicators than with the indicators of other constructs. In other words, the discriminant validity of the model is considered to be at an acceptable level.

RESULTS

The age range of the sample studied was 26 to 70 years. The mean age was 46.23 years, and the standard deviation was 9.88. The median age was 47 years, and the mode was 45 years. In terms of gender, 1.3% of the respondents with a frequency of 4 were women, while 98.7% with a frequency of 314 were men. In terms of education level, the most frequent level of education was high school diploma. The median work experience among the participants was 20 years. The order of the most common types of livestock owned by of the pastoralists were sheep, goats, cows, and camels.

Measurement Model

To examine the causal relationships between the observed and latent variables, a confirmatory factor analysis was used. Figure 3 illustrates the measurement model of PRCC conditions based on factor loadings and t-values. If t-values exceeded

Table 2. Fornell-Larcker criterion.

Constructs	1	2	3
1. Robustness	0.808		
2. Adaptability	0.609	0.774	
3. Transformability	0.618	0.719	0.801

Table 3. Fornell-Larcker criterion.

Constructs	1	2	3	4	5	6	7
1. Individual factor	0.834						
2. Educational and extensional factor	0.727	0.730					
3. Social factor	0.721	0.716	0.725				
4. Economic factor	0.765	0.705	0.670	0.791			
5. Physical factor	0.679	0.671	0.681	0.719	0.750		
6. Ecological factor	0.642	0.614	0.633	0.692	0.670	0.724	
7. Institutional factor	0.686	0.658	0.692	0.768	0.685	0.680	0.807

1.96, it indicated the significance of the corresponding variable (Vinzi *et al*., 2010).

As can be seen in Table 4, factor load values of indicators are more than 0.4; that is, the variance of indicators with their related construct was acceptable, indicating the suitability of indicators for measuring the latent variables of PRCC conditions. Also, the significance of all indicators is greater than 1.96, indicating a meaningful correlation between indicators and latent variables of PRCC conditions (Vinzi *et al*., 2010).

In this study, in the first stage, the indicators psy10, psy5, psy3, edu1, ext5, par2 and abi3 were removed from the model due to having a factor load of less than 0.4 and a t-statistic of less than 1.96. Then, the measurement model was re-examined and it was found that factor load values of other indicators were more than 0.4, indicating the suitability of the indicators for measuring the latent variables of the factors affecting PRCC conditions. Also, the significance of all indicators was greater than 1.96, indicating a meaningful correlation between indicators and latent variables of factors affecting PRCC conditions (Table 5).

Structural Model Fit

Figure 4 presents the research structural model based on the t-values. Since the t-values for all paths exceed 1.96, this indicates that all paths are significant, confirming the research hypotheses at the 95% confidence level.

The R^2 value for the construct of PRCC was calculated as 0.755. Considering the benchmark values, this confirms the fitness of the structural model. The effective size criterion (f^2) for all constructs is greater than 0.02, indicating an average effect of the independent variables in the study. Additionally, the stone-geisser criterion or Q^2 for endogenous variables exceeds the threshold of 0.35, demonstrating strong predictive power for the model and confirming the appropriate fit of the structural model. According to the software output, the redundancy criterion for PRCC conditions is 0.568. The indicator of communalities, derived from the average factor loadings of each latent endogenous factor, is positive. This reflects the quality of the measurement model of the latent variables. The overall fit of the model was evaluated using a single criterion known as the Goodness of Fit (GOF). In this study, the GOF was found to be 0.559, indicating a strong overall fit for the model.

The results of testing the research hypotheses with reference to Figure 3 are presented in Table 6. The results show that individual, educational and extensional, social, economic, physical, ecological, and institutional factors have a significant and positive effect on PRCC, and improving them will lead to enhancing PRCC conditions.

DISCUSSION

Given the critical conditions arising from climate changes and recent droughts, natural resources policymakers are concerned that no appropriate program and actions have been taken to reduce vulnerability and enhance the resilience of pastoralists. This is the gap that has always existed. Furthermore, the actions taken to improve resilience have often resulted in the misallocation of significant resources. Therefore, analyzing the factors influencing resilience was a primary objective of this study, which aimed to enhance pastoralists' resilience.

Based on this, the present study aimed to analyze the factors affecting resilience from the perspective of Tehran Province pastoralists under climate change conditions. Consequently, seven factors, educational and extensional, social, economic, physical, ecological and institutional were investigated. According to the literature review, the individual factor included psychological indicators, health and family dynamics. The educational and extension factor encompassed indicators related to education and extension services. The social factor was defined by indicators of social security, participation, trust, and coherence. The economic factor involved measures of employment and income, financial support, and economic capacity. The physical factor included indicators related to access to infrastructure, structures and machinery. The ecological factor focused on ecological assets and the protection of natural resources. Lastly, the institutional factor comprised indicators of institutional context, institutional relations, and institutional coherence. Robustness, adaptation, and transformability were identified as outcomes of resilience and were investigated.

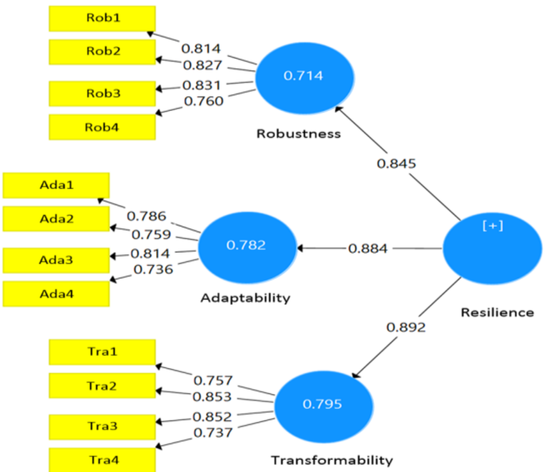

Figure 3. Measurement model.

Table 4. Specifications of the indicators in the measurement model.

Indicator	Factor loads	t
Robustness	0.845	43.484
After something challenging has happened, it is easy for my rangeland to bounce back to its current profitability	0.814	34.865
As a pastoralist, it is hard to manage my rangeland in such a way that it recovers quickly from shocks	0.827	34.873
Personally, I find it easy to get back to normal after a setback	0.831	34.683
A big shock will not heavily affect me, as I have enough options to deal with this shock on my rangeland	0.760	22.968
Adaptability	0.884	62.395
If needed, my rangeland can adopt new activities, varieties, or technologies in response to challenging situations	0.786	27.518
As a pastoralist, I can easily adapt myself to challenging situations	0.759	26.949
In times of change, I am good at adapting myself and facing up to rangeland challenges	0.814	39.277
My rangeland is not flexible and cannot easily be adjusted to deal with a changing environment	0.736	22.801
Transformability	0.892	66.771
For me, it is easy to make decisions that result in a transformation	0.757	26.955
I am in trouble if external circumstances were to drastically change, as it is hard to reorganize my rangeland	0.853	46.104
After facing a challenging period on my rangeland, I still have the ability to radically reorganize my rangeland	0.852	55.130
If needed, I can easily make major changes that would transform my rangeland	0.737	25.889

Table 5. Specifications of indicators in the measurement model.

Indicator	Standard factor loads	t	Indicator	Standard factor loads	t
Individual factor	0.882	58.620	Abi2	0.819	42.338
Psychological	0.953	107.663	Abi4	0.795	36.846
Psy1	0.559	17.353	Abi5	0.804	34.593
Psy2	0.823	39.542	Financial support	0.876	57.622
Psy4	0.751	27.812	Fin1	0.812	33.090
Psy6	0.743	23.749	Fin2	0.763	28.915
Psy7	0.789	35.944	Fin3	0.866	58.064
Psy8	0.750	27.480	Fin4	0.829	48.990
Psy9	0.648	23.924	Fin5	0.730	22.872
Health and family	0.897	48.938	Physical factor	0.875	58.114
Heal1	0.722	48.238	Structures and machines	0.878	42.696
Heal2	0.837	48.674	Str1	0.801	39.126
Heal3	0.888	61.264	Str2	0.853	40.310
Heal4	0.776	28.748	Str3	0.850	46.347
Educational and extensional factor	0.865	46.635	Access to Infrastructure	0.943	103.092
Education	0.947	110.189	Inf1	0.793	36.824
Edu2	0.787	31.155	Inf2	0.764	28.060
Edu3	0.858	51.091	Inf3	0.820	40.669
Edu4	0.813	37.027	Inf4	0.687	20.627
Edu5	0.818	39.536	Inf5	0.732	23.381
Extension	0.911	72.089	Inf6	0.693	22.846
Ext1	0.745	31.497	Ecological factor	0.831	40.794
Ext2	0.790	36.012	Ecological asset	0.929	66.954
Ext3	0.837	47.193	Eco1	0.713	20.818
Ext4	0.861	61.256	Eco2	0.766	23.128
Social factor	0.885	68.724	Eco3	0.844	48.766
Social Security	0.705	24.036	Eco4	0.709	19.434
Sec1	0.901	81.267	Eco5	0.814	38.213
Sec2	0.800	22.896	Protection of Natural resources	0.833	43.141
Social Participation	0.868	55.075	Nat1	0.868	56.800
Par1	0.988	243.104	Nat2	0.744	21.362
Par3	0.989	288.606	Nat3	0.738	18.634
Social Trust	0.921	118.508	Institutional factor	0.869	49.629
Tru1	0.913	103.230	Institutional Solidarity	0.915	74.681
Tru2	0.913	104.959	Sol1	0.901	82.467
Social Coherence	0.858	49.396	Sol2	0.745	22.894
Coh1	0.890	79.972	Sol3	0.589	12.537
Coh2	0.872	51.790	Sol4	0.907	81.336
Economic factor	0.934	114.668	Institutional Relations	0.919	95.074
Job and income	0.882	54.359	Rel1	0.752	23.351
Job1	0.751	25.569	Rel2	0.858	56.401

Table 5 Continued…

Continued of Table 5.

Indicator	Standard factor loads	t	Indicator	Standard factor loads	t
Job2	0.811	41.156	Rel3	0.809	37.898
Job3	0.784	28.403	Institutional Platform	0.836	45.896
Job4	0.758	31.332	Pla1	0.868	68.685
Job5	0.765	28.676	Pla2	0.763	37.415
Economic Ability	0.882	55.360	Pla3	0.724	35.138
Abi1	0.744	25.145	Pla4	0.847	43.181

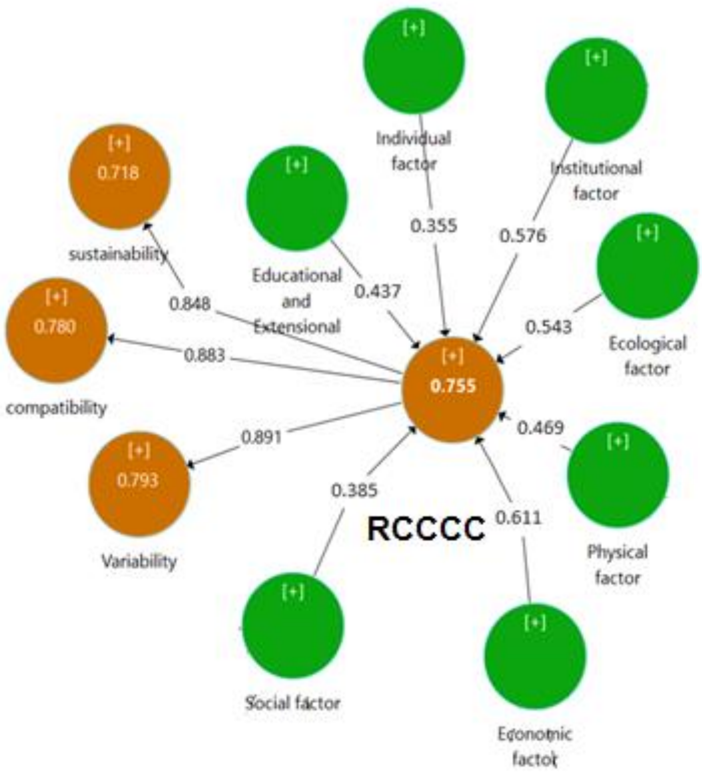

Figure 4. Research structural model based on t values.

Table 6. The results of hypotheses testing.

	Hypothesis			Standardized Path Coefficients	t-Value	F2	Result
H1	Individual factor	□	RCCCC	0.355	5.849	0.023	Confirmed
H2	Educational and extensional factor	□	RCCCC	0.437	8.516	0.025	Confirmed
H3	Social factor	□	RCCCC	0.385	6.273	0.041	Confirmed
H4	Economic factor	□	RCCCC	0.611	13.643	0.039	Confirmed
H5	Physical factor	□	RCCCC	0.469	8.928	0.022	Confirmed
H6	Ecological factor	□	RCCCC	0.543	10.137	0.098	Confirmed
H7	Institutional factor	□	RCCCC	0.576	11.422	0.068	Confirmed

In this study, seven hypotheses were formulated and tested using structural equation modeling with Smart PLS software. The impact analysis revealed path coefficients and significance values for the individual (0.355, 5.849), educational and extension (0.437, 8.516), social (0.385, 6.273), economic (0.611, 13.643), physical (0.469, 8.928), ecological (0.543, 10.137) and institutional (0.576, 11.422) factors. This indicates that the seven aforementioned factors have a positive and significant effect on PRCC conditions with 95% confidence. This finding is consistent with some studies (Adzawla *et al*., 2020; Melketo *et al*., 2021; Ahmad and Afzal *et al*., 2021; Le Goff *et al*., 2022; Kapruwan *et al*., 2024).

The R^2 value for the construct of PRCC was calculated as 0.755, considering the benchmark values, confirming the fitness of the structural model. The GoF (0.559) criterion value indicated that the overall quality of the model was strong and the overall model of the study was an appropriate model. Therefore, the need to pay more attention to the model is felt.

The second part of the model was dedicated to ranking the factors affecting PRCC conditions. The findings showed that the economic factor with a value of 0.611, the institutional factor with 0.576, the ecological factor with 0.543, the physical factor with 0.469, the educational and extension factor with 0.437, the social factor with 0.385, and the individual factor with a value of 0.355 had significant and positive effects on PRCC conditions, respectively. They directly explain 75.5% of the changes related to the variable of PRCC conditions.

Considering the results of the second dimension, there is an increasing need to pay more attention to economic, ecological, and institutional factors. Attention to economic factor has been noted in some studies (Adzawla *et al*., 2020; Melketo *et al*., 2021; Ahmad and Afzal *et al*., 2021; Le Goff *et al*., 2022; Kapruwan *et al*., 2024). However, Le Goff *et al*. (2022) and Kapruwan *et al*. (2024) stated other priorities for strengthening the resilience of communities to CC.

CONCLUSIONS

This research was carried out in one of the key regions of Iran to explore the factors influencing pastoralists' resilience to CC. Identifying appropriate measures to enhance pastoralists' resilience to CC can improve their adaptability to crises, thereby preventing rangeland degradation and migration of pastoralists. Accordingly, this study attempted to identify resilience measures and analyze them in the form of seven hypotheses and models. In this study, a new and comprehensive interpretation of the factors is considered via combination of the previous findings. They have been added to the existing body of knowledge in this field. The findings of this study indicated the significant effect of these factors on improving the resilience of the studied pastoralists. Economic, institutional and ecological factors are the most important ones affecting them. Drought affects vegetation and makes it difficult for pastoralists to meet basic needs. Government financial and technical support can protect livelihoods during times of crisis and increase resilience.

Government managers and planners must pay special attention to the economic institutional and ecological factor in order to enhance resilience and support pastoralists.

In this study, variations in rangeland cover, climate, and livestock types indicates that pastoralists in this region do not form a homogeneous group and represents a limitation of the research.

Finally results of this study should be generalized with caution to other regions that are less similar to this area.

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تحلیل عوامل موثر بر تاب‌آوری مرتع‌داران در شرایط تغییر اقلیم

امیرکیوان درویش، مریم امیدی نجف آبادی، سیدمهدی میردامادی، و سیدجمال فرج‌اله حسینی

چکیده

پدیده تغییر اقلیم یکی از بزرگترین چالش‌های عصر حاضر است که مراتع را در مقیاس جهانی و منطقه‌ای تحت تاثیر قرار داده است. افزایش آسیب‌پذیری در میان مرتع‌داران، اهمیت تمرکز بر تفکر تاب‌آوری را نشان می‌دهد. تاب‌آوری مرتع‌داران به ظرفیت کسب و کارهای مرتع‌داری در مواجهه با تهدیدها یا چالش‌ها، بصورت مقاومت، سازگاری و تغییرپذیری است. این پژوهش با هدف کلی تحلیل عوامل موثر بر تاب‌آوری از دیدگاه مرتع‌داران استان تهران در شرایط تغییر اقلیم انجام شد. این پژوهش از نظر هدف کاربردی و روش شناسی اکتشافی بود. نمونه مورد مطالعه شامل 317 مرتع‌دار بود که به روش نمونه‌گیری تصادفی طبقه‌ای انتخاب شدند. برای گردآوری داده‌ها، از پرسشنامه "محقق ساخته" استفاده شد. روایی پرسشنامه با استفاده از میانگین واریانس استخراج شده و پایایی آن از طریق محاسبه پایایی ترکیبی و آلفای کرونباخ تعیین شد. داده‌ها با استفاده از تکنیک مدل سازی معادلات ساختاری با نرم افزار Smart PLS مورد تجزیه و تحلیل قرار گرفت. نتایج نشان داد که عوامل فردی، آموزشی و ترویجی، اجتماعی، اقتصادی، فیزیکی، اکولوژیکی و نهادی بر تاب‌آوری مرتع‌داران در شرایط تغییر اقلیم رابطه معنادار دارند. این عوامل 75.5% تاب‌آوری مرتع‌داران را در شرایط تغییر اقلیم تبیین کرد.

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Exploring the Disparities in Agricultural Information Networks: Insights from Tribal and Coastal Farm Women of Odisha in India

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ABSTRACT

This study seeks to examine and assess the differences between the social networks of respondents living in tribal areas and in coastal areas. 240 respondents from Ganjam and Rayagada, and Odisha were sampled using multiple steps. To map farmers' communication pattern, Social Network Analysis (SNA) was used. Respondents from both areas consider the most educated person in family and village and Self-Help Group (SHG) as their primary source of information, but respondents from coastal area were much smart in networking with other information sources as well, like using TV, training, demonstration, field days, other farmers, agriculture department, input dealers etc. Women farmers were less likely to receive information when betweenness centrality was used in targeting, suggesting there were important gender differences: In tribal area, men are likely to talk to the cosmopolite information sources and respondents are generally engaged in the farm activities more, whereas in coastal area, respondents are actively involved in both farm activities as well as gathering information from different sources.

Keywords: Centrality measures, Information network, Self-help group, Social network analysis.

INTRODUCTION

Information aims to improve user comprehension and reduce uncertainty and confusion. Information must be accurate, timely, and relevant to be effective. A "source of information" might be anything seen or experienced (Bates, 2012). Additionally, information sources help meet the needs of various user groups. Many sources of information exist. Men have more access to mobile phones, radios, and other media than women. Thus, they seek farming advice from men (Msofi Mgalamadzi *et al*. (2024). Farm women rarely benefit from financial services (Taylor and Boubakri, 2013). Timely, relevant information that enhances output, revenue, and sustainability is vital to India's rural economies and farm communities. Farm women in rural and underdeveloped areas benefit from information networks. Fram women avoid these services due to cultural, economic, legal, and educational hurdles (FAO, 2019). Although their content, size, and structure vary, social networks are universally recognised as a source of social capital (Magnan *et al*., 2015). Farmers share and discuss knowledge in their social networks as a resource for production and social engagement. However, information transit within networks depends on both people. Informing aims to reduce confusion and improves comprehension. Effective communication requires accuracy, timeliness, and relevance. Sight or experience can be a "source of information". Information sources benefit different user groups. Many information sources exist. Mobile phones, radios, and other media are more accessible to men. They consult males for farming guidance

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(Msofi Mgalamadzi *et al*. (2024). Rural women rarely benefit from financial services (Taylor & Boubakri, 2013). Rural India relies on agriculture and farm communities need timely, relevant information to enhance output, revenue, and sustainability. Information networks assist rural and marginalized farm women improve their lives. Farmers debate knowledge in their social networks for production and socialization. Information transmission in networks depends on social interactions and network structure (Kolleck *et al.*, 2013). Tribal and coastal issues and potential are studied. Tribal and coastal Odisha farmers use different methods and resources. These two regions are appropriate for comparative research because their geography, socioeconomics, and cultures affect farm women's agricultural knowledge utilization. Information networks educate and aid tribal and coastal communities. SHG and agricultural cooperative knowledge, financial inclusion, skill development, and social solidarity benefit women. Policymakers can create region-specific outreach programs that build on strengths and minimize weaknesses by understanding information networks. Agricultural information network research among tribal and coastal respondents in Odisha fills a gap in understanding regional issues and potential for rural women in agriculture. Feminine and male farmer network systems have been hardly studied. No research compares tribal and coastal farming women. Tribal and coastal respondents' information sources, networking habits, and community institutions are examined to inspire future efforts to establish inclusive, effective, and sustainable information systems that empower women to lead rural India's agricultural revolutions.

A social network negotiates and creates possibilities to meet needs and interests. They promote knowledge transfer, eliminate information asymmetries, and fund agricultural innovations (Kassie *et al*., 2013). Technology spread depends on network size, composition, and structure (Taylor, S. and Boubakri, N., 2013). Unique social structure patterns show how humans learn from different sources (Thuo *et al*., 2013). Communication and information systems are studied using social network theories and mapping (Nyambo and Ligate, 2013). According to De Nooy *et al.* (2011), Social Network Analysis (SNA) should focus on interactions, not persons. Centrality measures in SNA help study social connections' features for a particular element (Gava *et al*., 2017). Complex stakeholder interactions reveal interconnectedness, networking, and social exchanges while using sophisticated agriculture technologies (Weyori *et al*., 2018). This phenomenon was explained using social constructivism and social learning theory. In cognition, social constructivism stresses social relationships. Research shows farmers prefer learning from peers and exchanging experiences (Franz *et al*., 2010). Communication of knowledge, ideas, and information affects technology adoption. Social media users share information. More network members and information flow boost social learning. In person-level networks differ in their innovation information access and exchange (Reed and Hickey, 2016). By visualising and assessing relationships between people, groups, and institutions. SNA can understand complex systems.

Tabular summary of social networks and agricultural information transmission findings from sources are given in Table 1.

MATERIALS AND METHODS

To determine how tribal and coastal respondents in Odisha receive and use agricultural information, this study explored their agricultural information networks. The research area comprised tribal and coastal areas. Through structured interviews, focus group discussions, and participant observations, respondents from both regions provided data. The research helps create targeted strategies to promote knowledge distribution among Odisha women farmers.

Table 1. Summary of literature use in the study.

Year	Title	Author	Publication	Findings	Knowledge Gap
2020	Climate Change and Women Farmers: A Comparative Analysis	S. Panda	Environmental Studies Journal	Coastal women more vulnerable due to their reliance on climate-sensitive livelihoods.	Limited data on how climate-sensitive vulnerabilities impact the information needs and access methods of tribal versus coastal women.
2021	Mobile Technology for Agricultural Extension in Odisha	T. Kumar	Journal of Mobile Technology	Significant benefits but also challenges in technology adoption.	Few studies on specific barriers to mobile technology adoption among women farmers in diverse rural settings.
2023	The Role of Self-Help Groups in Women's Agricultural Development	P. Pritiprada	Development Studies Review	Showing they can enhance access to information and resources, leading to improved agricultural practices.	Lack of analysis on the comparative effectiveness of SHGs in providing agricultural information in tribal vs. coastal regions.
2024	Digital Literacy and Agricultural Information Access	B. Nanda	Journal of Digital Literacy	Finding that increased digital literacy significantly improves information access and agricultural outcomes.	Insufficient focus on how varying levels of digital literacy impact access and quality of agricultural information among tribal and coastal women.

Study Area and Sampling

In Odisha, the research focused on the tribal Rayagada District and the Coastal Ganjam District, which have different agricultural settings. Rayagada women farm traditionally with limited access to modern agricultural technologies and resources. In contrast, greater infrastructure and agricultural extension services in Ganjam enable women to participate in varied agricultural enterprises.

The study employed a random sampling method approach to select districts i.e. Rayagada and Ganjam. A total of 240 respondents were selected, and the research design employed was ex-post facto research design.

Social networks and graph theory were applied to analyze social structures and mapping respondents' information networks. The topology was surveyed based on research questions. UCINET, an open-source software, visualized networks and calculated Degree, Betweeness, Closeness centrality, and Density (Borgatti *et al.*, 2009), while Netdraw displayed UCINET's binary network (Kolleck, 2013). Data were organized into an n×m matrix, with rows and columns representing persons and sources. Thuo *et al.* (2013) emphasized that affiliation networks should capture multiple information sources for farm women.

Social Network Analysis (SNA)

SNA, using graph theory and networks, studies the flow of information, resources, and influence among people, groups, and organizations. It highlights influential actors and nodes within a network. SNA visualizes complex social networks, such as farm women's information exchange. UCINET and Netdraw are used to compute and display network metrics, including degree (connections), betweenness (information flow control), and closeness centrality (node proximity). Figures 3 and 4 show SNA flowcharts and Odisha's agriculture information network. Sample sizes for SNA vary from 10-50 for small groups to 50-200 for larger community networks, with over 200 people providing structural insights.

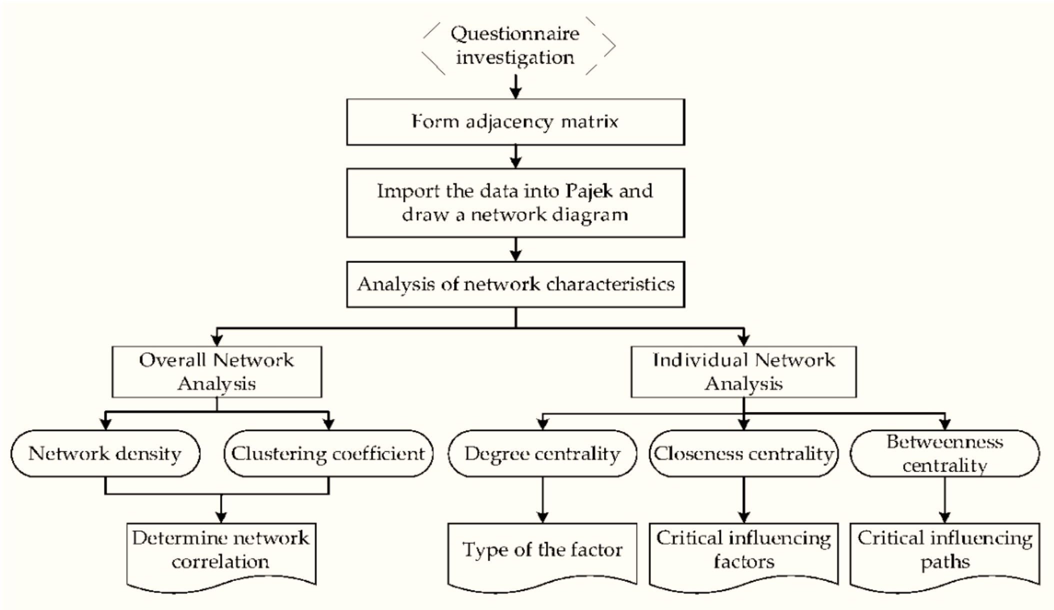

Figure 3. Flowchart for SNA using UCINET 6.

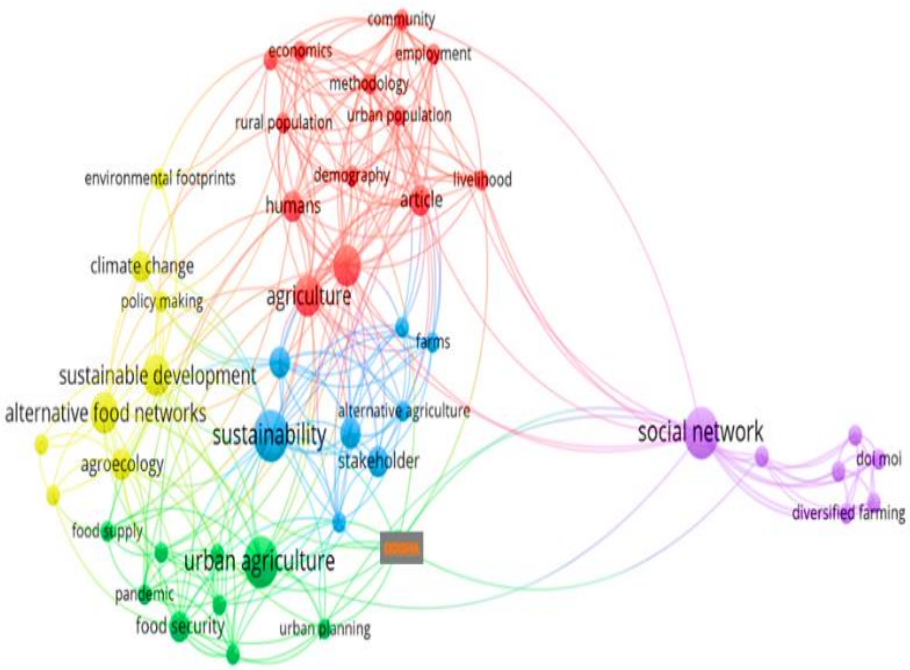

Figure 4. Agriculture network visualization.

RESULTS

Social Network Structures among the Respondents

SNA reveals two-mode affiliation networks between farm women and information sources, highlighting the most important, trusted, and valuable sources. Some respondents rely on only one source, while others use multiple (De Nooy *et. al.*, 2011). Actors with many networks' connections influence others' behaviour. The information networking diagrams for both districts are based on their betweenness centrality values (Nasiri *et al.*, 2022). Gatekeepers, or information sources with high betweenness centrality, play a key role. The networking diagram contains 137 nodes, categorized by information source use, importance, closeness, and value to respondents (Table 2).

Table 2 shows that most tribal respondents rely primarily on their family's most educated member for information, their second most-used source (Bankapur and Bhavanishankar, 2018). They attend training, demonstrations, and field days for up-to-date knowledge (Oktarina *et al.*, 2020). The government supports these efforts to enhance food security and livelihoods. Respondents prefer SHGs, which align well with commodity groups, and consult other farmers over publications due to limited formal education. Newspapers are the least used. Key knowledge sources include the family's educated member, SHGs, village contacts, friends, neighbours, and the agricultural department, consistent with Das *et al*. (2020).

Table 3 shows that coastal respondents trust SHGs over the most educated family member. SHG memberships foster essential partnerships. The agriculture department supports those with primary education, using

Table 2. Information exchange and actors of Tribal District respondents (n_1= 120).

S. No	Information source	Extent of use		Importance		Closeness		Value	
		Mean score	Rank	Mean score	Rank	Mean Score	Rank	Mean score	Rank
1	Most educated person in family	1.60	2	1.68	1	1.68	1	1.65	2
2	Most educated person in village	1.44	4	1.55	4	1.55	3	1.45	3
3	Neighbors or friends	1.20	6	1.14	6	1.42	4	1.18	5
4	Other farmers (Progressive, relative)	1.30	5	1.33	5	1.30	6	1.20	4
5	Input dealers	0.24	11	0.57	3	0.22	14	0.23	17
6	Agriculture department	0.50	7	1.08	7	0.60	9	1.03	6
7	Farmers call center	0	14	0.30	15	0	16	0.35	15
8	Radio	0	15	0.77	12	0.35	11	0.93	9
9	TV	0.27	9	0.94	8	0.37	10	1.00	8
10	News paper	0	17	0.23	17	0	17	0.50	13
11	Training, demonstration and field days	1.63	1	0.91	9	1.37	5	1.02	7
12	Cooperatives society	0	16	0.81	10	0.81	7	0.65	12
13	SHG	1.52	3	1.59	2	1.59	2	1.87	1
14	NGO	0.41	8	0.75	13	0.75	8	0.88	11
15	Leaflets, Folder	0.12	13	0.32	14	0.32	12	0.42	14
16	Internet	0.26	10	0.80	11	0.26	13	0.93	10
17	Others (Micro finance organization, bank)	0.16	12	0.24	16	0.10	15	0.30	16

Table 3. Information exchange and actors of Coastal District respondents (n_2= 120).

S. No	Information source	Extent of use	
		Mean score	Rank
1	Most educated person in family	1.43	3
2	Most educated person in village	1.30	4
3	Neighbors or friends	1.29	5
4	Other farmers (Progressive, relative)	1.15	6
5	Input dealers	1.17	7
6	Agriculture department	1.10	9
7	Farmers call center	0.55	16
8	Radio	0.28	17
9	TV	1.58	2
10	News paper	0.71	13
11	Training, demonstration and field days	1.09	10
12	Cooperatives society	0.99	11
13	SHG	1.60	1
14	NGO	0.80	12
15	Leaflets, Folder	0.64	14
16	Internet	1.16	8
17	Others (Micro finance organization, bank)	0.56	15

booklets, training, and online resources. TV, rather than radio, is now the main information and entertainment source. Key information sources include the most educated family member, SHGs, village contacts, neighbours, other farmers, and the agriculture department.

Centrality Measures of Various Information Sources

Centrality measurements for information sources in different networks are used to evaluate their influence. Centrality measures a network node's importance. Degree centrality-network node significance. It depends on node connections. Closeness Centrality—for assessing each network node's importance. Betweenness Centrality measures the shortest pathways between nodes and which gets frequented most.

Information Source and Its Extent of Use by the Respondents

Information usage patterns show that tribal respondents prefer trusted sources within their community. Figure 5 illustrates that their network is less dense, with highest reliance on other farmers (progressive or relatives), followed by the village's most educated person, family’s most educated member, training events, SHGs, and neighbours (Table 3).

The main dependable information sources for respondents include the agricultural department, TV, input dealers, and the Internet, with NGOs having lower centrality due to limited infrastructure and materials. Leaflets are least used due to literacy limitations (Mago, 2012).

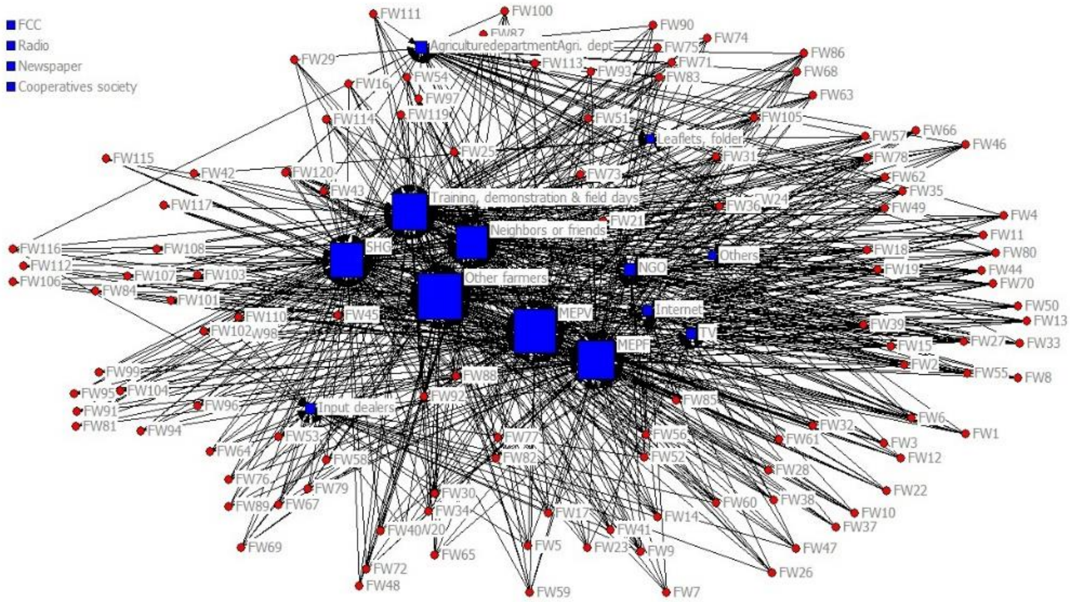

Figure 5. Information network of information source and its extent of use by the TRIBAL respondents

The FCC, radio, newspaper, and cooperative society are disconnected from respondents. With 120 connections, progressive and relative farmers are the most central sources, while only 12 rural women used leaflets due to their high closeness centrality. In Figure 6, the Coastal District shows a dense network, with TV as a reliable and timely source, followed by SHG, friends, the agriculture department, the most educated family member, training events, input dealers, cooperative society, farmers, and the Internet (Table 4). NGO has lower betweenness centrality than newspapers, leaflets, FCC, and financial sources. The most educated villager had 117 connections, while radio, with high closeness centrality, was used by only 30 women.

Importance of Information Sources as Perceived by the Respondents

The value of information sources depends on their role in agricultural decision-making. Figure 7 indicates that tribal respondents' networks were less dense, with central connections primarily to the most educated family member, SHG, village, friends, progressive farmers, agriculture department, training events, and TV.

Farmer's call centers are less central than NGOs, radio, the Internet, input dealers, leaflets, FCC, and other financial sources, while newspapers are the least-used source (Table 5). The family's most educated person has 117 edges; thus 117 respondents get information from them. Newspapers' closeness centrality discourages respondents (20) from using them for agri-allied information.

In Figure 8, Coastal District respondents' network is mainly through leaflets, folders, SHGs, training events, educated family members, progressive farmers, TV, friends, neighbours, cooperative societies, village's most educated, and the agriculture department. FCC has lower "Betweenness centrality" than NGOs, the Internet, and newspapers, with radio being used the least. Leaflets and folders have the highest centrality with 120 connections, while only 61 respondents use newspapers for agri-related information due to its high centrality.

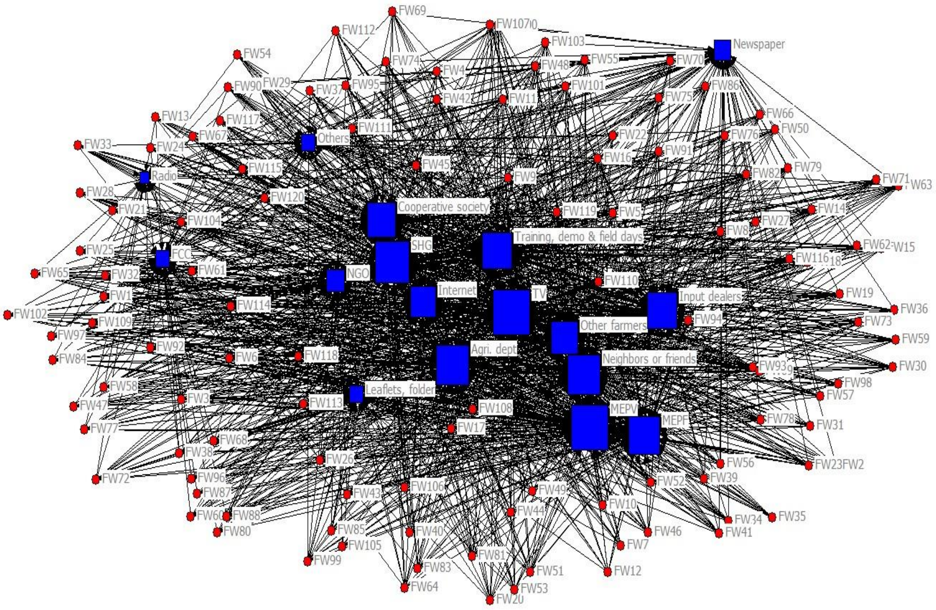

Figure 6. Information network of information source and its extent of use by the COASTAL respondents.

Table 4. A comparative table of centrality measures of information source and its extent of use by the respondents (n= 240).

S. No	Information source	Tribal			Coastal		
		Degree	Betweenness	Closeness	Degree	Betweenness	Closeness
1	Most educated person in family	108	1201.558	716.000	108	616.027	176.000
2	Most educated person in village	118	1458.864	696.000	117	741.141	158.000
3	Neighbors or friends	100	972.899	732.000	111	658.683	170.000
4	Other farmers (Progressive, relative)	120	1523.575	692.000	96	481.869	200.000
5	Input dealers	23	43.933	890.000	104	570.300	184.000
6	Agriculture department	43	152.875	846.000	108	623.888	176.000
7	Farmers call center	-	-	-	56	152.928	280.000
8	Radio	-	-	-	30	41.747	332.000
9	TV	26	55.755	880.000	118	754.120	156.000
10	News paper	-	-	-	66	213.843	260.000
11	Training, demonstration and field days	108	1174.793	716.000	105	583.758	182.000
12	Cooperatives society	-	-	-	101	534.098	190.000
13	SHG	102	1053.938	728.000	112	674.278	168.000
14	NGO	42	155.190	848.000	73	266.380	246.000
15	Leaflets, Folder	12	10.751	910.000	55	153.540	282.000
16	Internet	22	41.231	888.000	93	450.758	206.000
17	Others (Micro finance organization, bank)	15	17.636	904.000	57	152.641	278.000

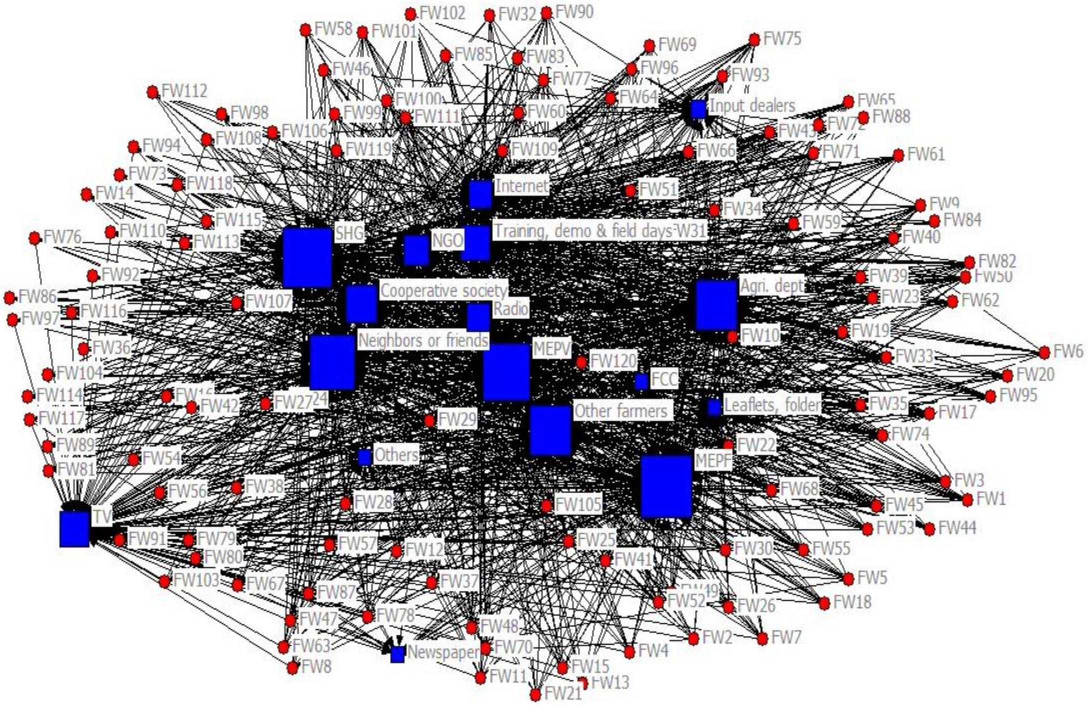

Figure 7. Information network of importance of information sources perceived by the TRIBAL respondents.

Table 5. A comparative table of centrality measures of importance of information sources perceived by the respondents (n= 240).

S. No	Information source	Tribal			Coastal		
		Degree	Betweenness	Closeness	Degree	Betweenness	Closeness
1	Most educated person in family	117	1014.094	158.000	112	592.986	168.000
2	Most educated person in village	113	921.292	166.000	94	391.687	204.000
3	Neighbors or friends	108	842.484	176.000	106	515.753	180.000
4	Other farmers (Progressive, relative)	105	776.194	182.000	112	580.551	168.000
5	Input dealers	42	112.903	308.000	93	380.564	206.000
6	Agriculture department	103	757.499	186.000	92	387.836	208.000
7	Farmers call center	28	46.031	336.000	70	219.510	252.000
8	Radio	70	323.299	252.000	62	164.788	268.000
9	TV	79	435.363	234.000	109	573.963	174.000
10	News paper	20	26.341	352.000	61	165.552	270.000
11	Training, demonstration and field days	84	466.559	224.000	114	630.652	164.000
12	Cooperatives society	85	503.657	222.000	100	478.923	192.000
13	SHG	113	943.894	166.000	117	665.101	158.000
14	NGO	74	347.941	244.000	70	212.043	252.000
15	Leaflets, Folder	32	59.069	328.000	120	700.723	152.000
16	Internet	70	305.986	252.000	66	200.646	260.000
17	Others (Micro finance organization, bank)	22	32.396	348.000	120	700.723	152.000

Information Sources and Its Closeness in Relation to the Respondent

Information closeness familiarity and belonging from several knowledge sources is examined in this study. "Closeness to the respondent" usually means emotional or psychological intimacy in a relationship or contact. It can include trust, empathy, understanding, and affection.

As shown in Figure 9, tribal respondents information networks are less dense and closely connected to the most educated person in the family or village, Self-Help Groups (SHGs), progressive and relative farmers, training and demonstration events, friends, and cooperative societies (Table 6; Jeeva *et al*., 2020). Centrality is low for NGOs, agriculture departments, TV, radio, leaflets, input dealers, and the Internet. Microfinance organizations and banks are the least-used information sources.

The Farmer Call Canter (FCC) and newspapers are isolated nodes, indicating no connection with respondents. The most educated family member is the most central information source, with 117 connections. The FCC, newspapers, and other financial sources have high closeness centrality due to their lack of engagement with respondents for agri-allied information.

Coastal respondents have close access to various information sources (Figure 10), forming a complex farm knowledge communication network. The closest sources include SHGs and TV, followed by neighbours or friends, the most educated individuals in their village or family, cooperative societies, and training events (Table 6). Input merchants are less central compared to agriculture departments, NGOs, and other sources. Folders, leaflets, and Farmer Communication Centers (FCC) rank below newspapers in betweenness centrality, while radio is used the least. SHG and TV are the most central sources, each connecting 120

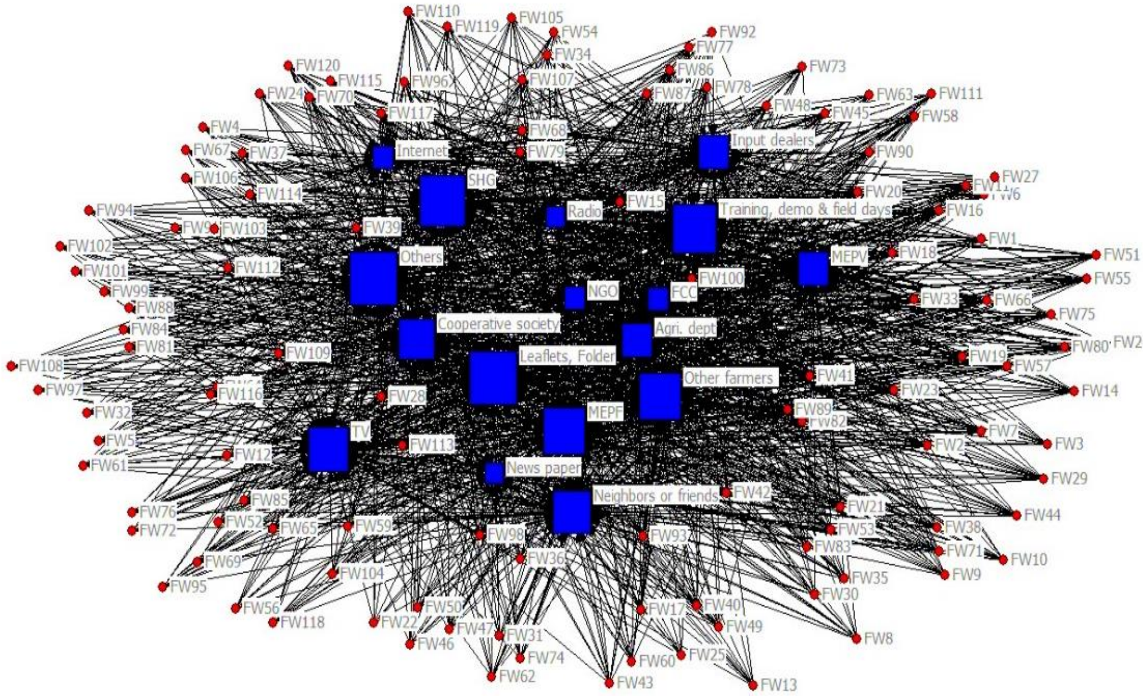

Figure 8. Information network of Importance of information sources perceived by the COASTAL respondents. Symbols as in previous Figures.

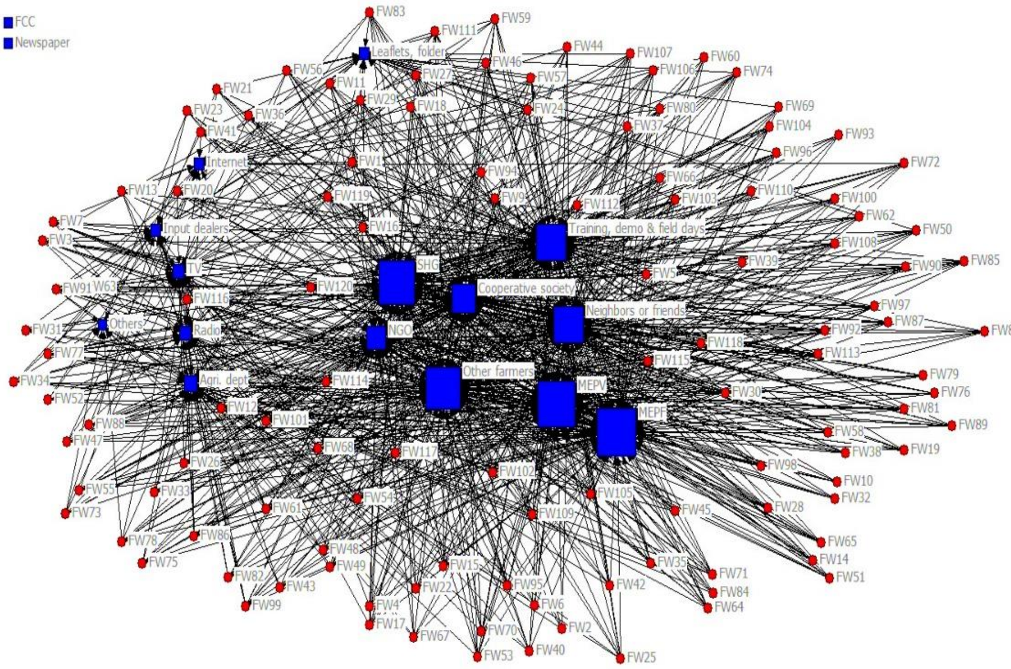

Figure 9. Information network of Information sources and its closeness in relation to the TRIBAL respondents. Symbols as in previous Figures.

respondents, while fewer than 18 women rely on radio for agri-allied information (Kekulandala *et al*., 2023).

Information Sources and Its Value as Perceived by the Respondent

The information value is based on the respondent's judgment of its potential benefit in uncertain times. As shown in Figure 11, tribal respondents' information networks are less dense and more prominent within SHGs, followed by other farmers, educated family members, friends, educated villagers, NGOs, the agriculture department, and training or demonstration events (Table 7). TV is less central than the Internet, radio, cooperative societies, printed materials, newspapers, and financing organizations (Das and Chowdhury, 2024). Input dealers are the least-used information source. SHGs have the highest centrality as information sources (Mahato, 2023), connecting 120 respondents, while only 20 women access agri-allied information through input dealers due to their high closeness centrality.

As shown in Table 7, respondents in the Coastal District networked the importance of information sources most densely in the case of the most educational person in the family, followed by SHG, Training, demonstration and field days, Internet, and TV. (Basak and Chowdhury, 2024). Agriculture department, most educated villager, neighbours or friends, input dealers, other farmers (progressive/relative), other information sources, newspaper, cooperative society,

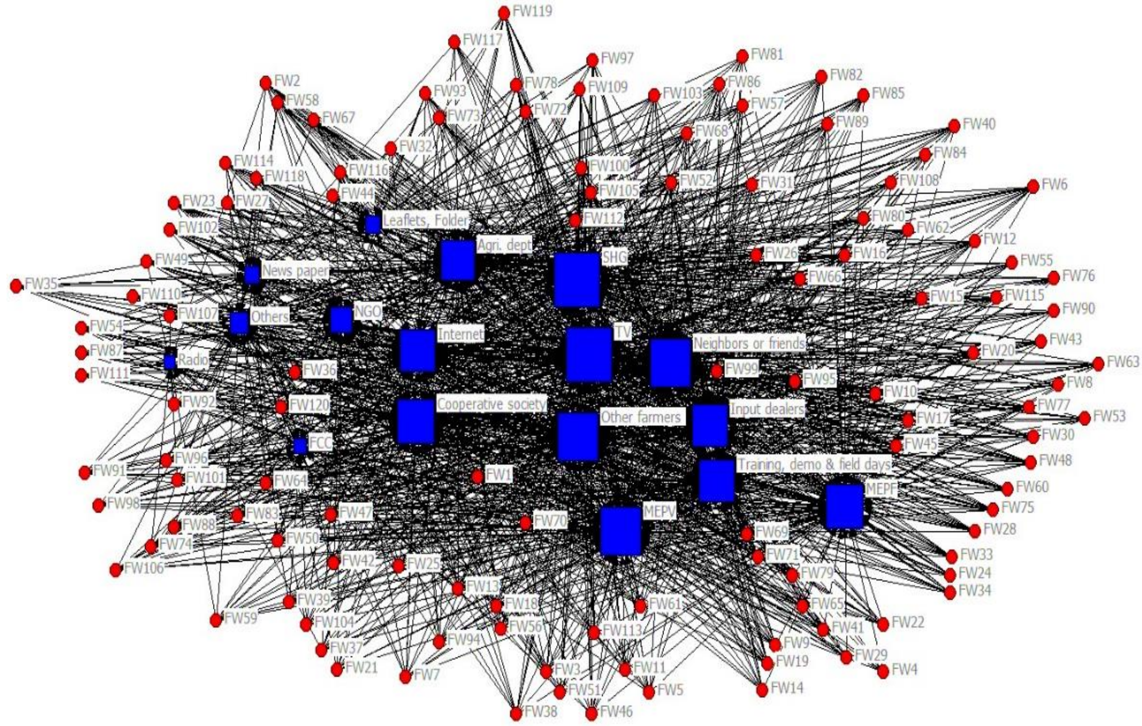

Figure 10. Information network of "Information sources" and its closeness in relation to the COASTAL respondents. Symbols as in previous Figures.

Table 6. A comparative table of centrality measures of Information sources and its closeness in relation to the respondent (n= 240).

S. No	Information source	Tribal			Coastal		
		Degree	Betweenness	Closeness	Degree	Betweenness	Closeness
1	Most educated person in family	117	1244.782	428.000	105	619.682	182.000
2	Most educated person in village	113	1156.704	436.000	111	672.502	170.000
3	Neighbors or friends	99	840.245	464.000	111	680.058	170.000
4	Other farmers (Progressive, relative)	108	1048.649	446.000	112	702.494	168.000
5	Input dealers	24	43.676	614.000	103	556.272	186.000
6	Agriculture department	48	174.587	566.000	102	543.915	188.000
7	Farmers call center	-	-	-	27	36.441	338.000
8	Radio	36	96.754	590.000	18	15.098	356.000
9	TV	36	98.850	590.000	120	813.493	152.000
10	News paper	-	-	-	42	89.988	308.000
11	Training, demonstration and field days	101	901.239	460.000	103	577.439	186.000
12	Cooperatives society	85	612.409	492.000	104	595.203	184.000
13	SHG	113	1146.634	436.000	120	813.493	152.000
14	NGO	74	431.311	514.000	67	225.730	258.000
15	Leaflets, Folder	31	73.775	600.000	39	78.944	314.000
16	Internet	22	39.331	618.000	102	568.116	188.000
17	Others (Micro finance organization, bank)	12	12.055	638.000	55	150.133	282.000

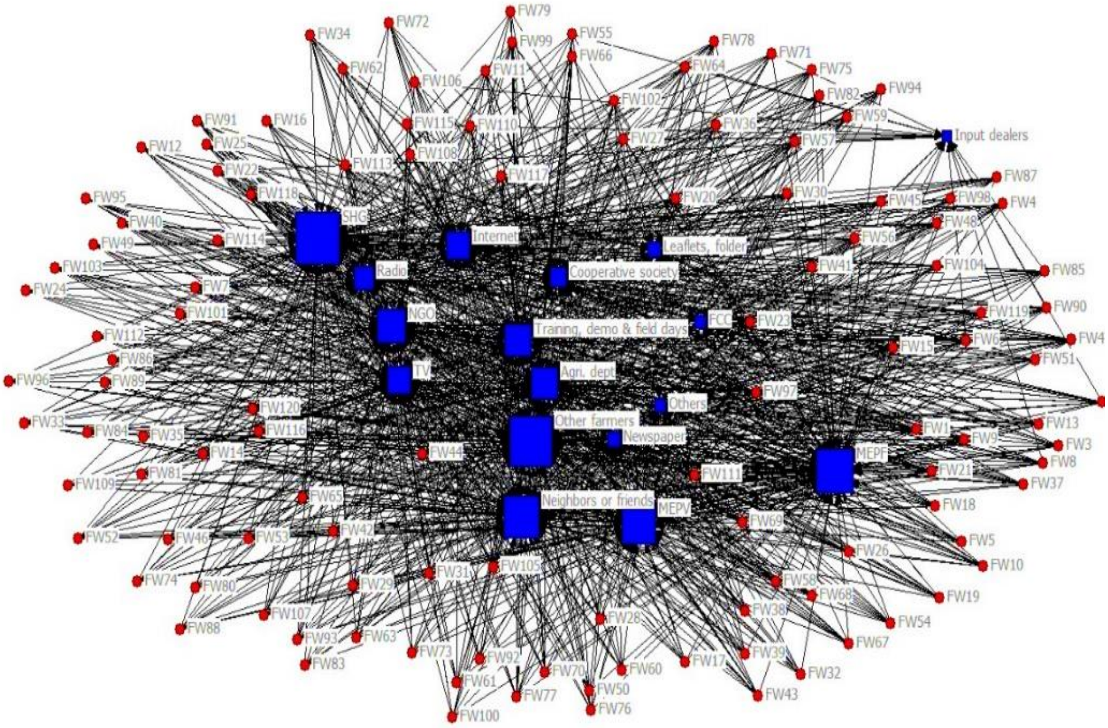

Figure 11. Information network of Information sources and its value in relation to the TRIBAL respondents. Symbols as in previous Figures.

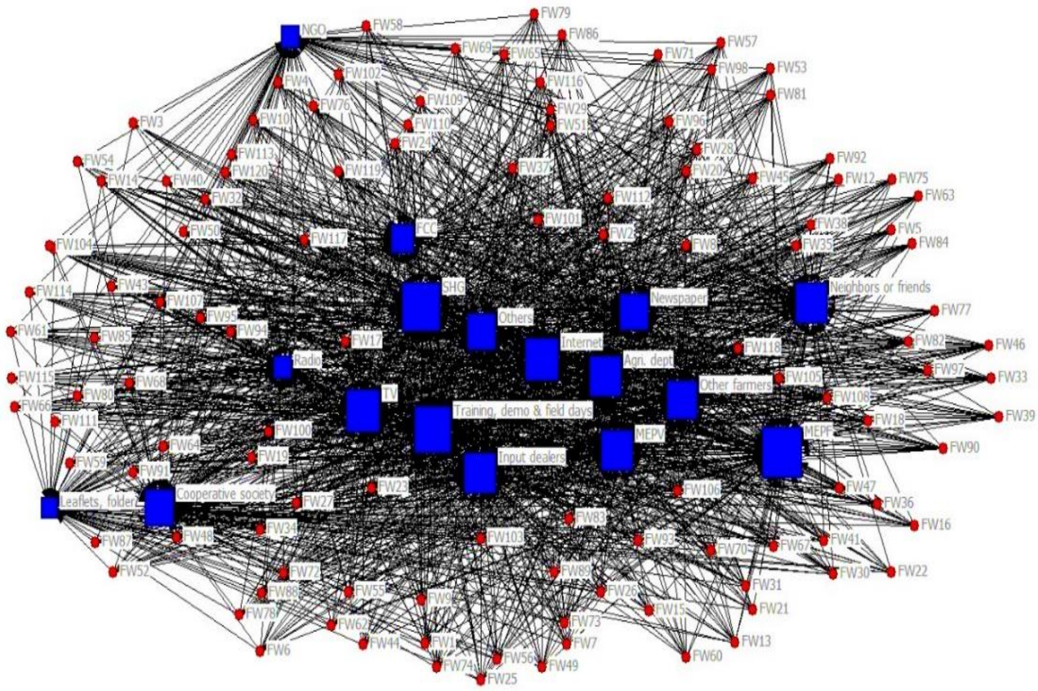

Figure 12. Information network of Information sources and its value in relation to the COASTAL respondents. Symbols as in previous Figures.

Table 7. A comparative table of centrality measures of Information sources and its value in relation to the respondents (n= 240).

S. No	Information source	Tribal			Coastal		
		Degree	Betweenness	Closeness	Degree	Betweenness	Closeness
1	Most educated person in family	110	868.261	172.000	120	655.280	152.000
2	Most educated person in village	101	730.284	190.000	105	492.690	182.000
3	Neighbors or friends	106	806.080	180.000	106	485.250	180.000
4	Other farmers (Progressive, relative)	117	1017.181	158.000	105	474.439	182.000
5	Input dealers	20	26.879	352.000	104	482.689	184.000
6	Agriculture department	87	536.987	218.000	106	499.325	180.000
7	Farmers call center	28	53.309	336.000	82	288.100	228.000
8	Radio	69	319.433	254.000	66	186.751	260.000
9	TV	80	454.580	232.000	110	532.674	172.000
10	News paper	42	110.266	308.000	101	442.246	190.000
11	Training, demonstration and field days	86	525.064	220.000	114	585.606	164.000
12	Cooperatives society	56	208.727	280.000	100	430.886	192.000
13	SHG	120	1076.639	152.000	117	615.946	158.000
14	NGO	91	577.909	210.000	65	184.600	262.000
15	Leaflets, Folder	42	117.108	308.000	63	167.232	266.000
16	Internet	80	447.764	232.000	110	539.873	172.000
17	Others (Micro finance organization, bank)	26	42.528	340.000	100	442.411	192.000

FCC, radio, and NGO have relatively low betweenness centrality.

Respondents utilize leaflets and folders the least. The most educated member in the family is the most central information source, with 120 edges, meaning 120 respondents obtain knowledge from it. Leaflets and folder have the highest closest centrality, thus only 63% of respondents use it for agri-allied information.

DISCUSSION

Drawing on the information and social network literature, the findings of this study align strongly with prior evidence that information diffusion in agriculture is fundamentally shaped by network structure, central actors, and social positioning (Bates, 2012; Borgatti *et al.,* 2009; Scott, 2017). Consistent with Borgatti and Halgin (2011) and De Nooy *et al*. (2011), the Social Network Analysis reveals marked structural differences between tribal and coastal farm women's information networks in Odisha. Quantitatively, coastal farm women exhibit higher degree centrality across a wider range of information sources, indicating more diverse and frequent connections compared to their tribal counterparts, who remain concentrated around a few core nodes such as family, village elites, and SHGs. This pattern corroborates findings by Spielman *et al.* (2011) and Ramirez (2013), who emphasize that dense and diversified networks enhance access to timely and actionable agricultural knowledge. While SHGs and educated family members emerge as key hubs in both contexts, their relative dominance is more pronounced in tribal areas, suggesting a dependency on bonding social capital rather than bridging ties, as also observed by Hartwich *et al.* (2008) and Young (2009). Numerically, the sharp contrast in degree and betweenness values for formal and cosmopolite sources such as input dealers, agriculture departments, training programs, and financial institutions demonstrates that coastal women occupy more strategically advantageous positions for information brokerage, echoing evidence from Liverpool-Tasie and Winter-Nelson (2012) and Magnan *et al.* (2015). In tribal networks, lower betweenness centrality for women indicates limited control over information flows, reinforcing gendered constraints noted by Krishnan (2012) and FAO (2019), where men often act as intermediaries with external agencies. Higher closeness scores for peripheral sources in tribal areas further suggest longer information pathways, implying delays and potential distortions in knowledge transmission, consistent with Franz *et al.* (2010) and Nyambo and Ligate (2013). In contrast, coastal women's relatively balanced centrality across mass media, institutional, and interpersonal sources reflects stronger learning loops and adaptive capacity, as highlighted by Kassie et al. (2013) and Weyori *et al.* (2017). Overall, the numerical comparison underscores that targeting only high-betweenness or elite nodes risks excluding women in structurally weaker networks, supporting arguments by Kolleck (2013) and Reed and Hickey (2016) for inclusive, gender-sensitive network interventions that deliberately strengthen bridging ties for tribal farm women.

Numerically, the comparison highlights substantial gaps between tribal and coastal networks. Coastal farm women show consistently higher degree values for formal and mass-based sources, with input dealers, cooperatives, training programmes, internet and financial institutions recording degrees above 100, whereas the same sources in tribal areas remain below 60 in most cases, indicating restricted outreach. Betweenness centrality is also more evenly distributed in coastal networks, suggesting multiple information brokers, while in tribal areas it is concentrated around SHGs and educated family members, increasing vulnerability to information bottlenecks. These results are consistent with Borgatti *et al.* (2009) and Spielman *et al.* (2011), who report that diversified brokerage structures accelerate innovation diffusion. Similar to findings by Kassie *et al.* (2013) and Ramirez *et al.* (2013), higher centrality scores in coastal settings correspond with greater exposure to sustainable practices and institutional support.

CONCLUSIONS

In Odisha, India, coastal and tribal agricultural women share information through their social networks. The study uses Social Network Analysis (SNA) to map networks and identify key sources. A trustworthy and efficient respondents information system can be created using the findings. Results suggest that coastal respondents use Self-Help Group (SHG) and tribal respondents consult the most educated family member. The study also reveals how social networks affect respondents' knowledge transfer. Using SHGs for collective participation, improving women's information networks, minimizing mobile phone-use to reach women farmers owing to ownership and phone literacy concerns, and developing community information canters can bridge the gender gap in information transmission (Mahato, 2023). SNA enhances agricultural extension, gender equity, and rural sustainable development.

This study's focus on Odisha may limit its applicability to other cultural, socioeconomic, and agricultural situations. The study also uses SNA to understand network structure and key participants, however, it may not fully capture the qualitative components of information exchange, such as knowledge depth or source credibility.

Similar research and activities in other countries can use SHGs, improve women's information networks, reduce mobile phone use, and create community information centers. This research affects countries and areas confronting similar issues in agricultural information transmission, gender equality, comparative analysis in different cultural contexts, policy formation and extension services, and gender equality.

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بررسی تفاوت‌ها در شبکه‌های اطلاعات کشاورزی: بینش‌هایی از زنان کشاورز قبیله‌ای و ساحلی اودیشا در هند

شیلپا باهوبالندرا، و بیشنوپریا میشرا

چکیده

این پژوهش برای بررسی و ارزیابی تفاوت‌های بین شبکه‌های اجتماعی پاسخ‌دهندگان ساکن در مناطق قبیله‌ای و مناطق ساحلی است. پروژه با 240 پاسخ‌دهنده از گنجام (Ganjam) و رایاگادا (Rayagada) و اودیشا (Odisha) با استفاده از چندین مرحله نمونه‌گیری انجام شد. برای ترسیم الگوی ارتباطی کشاورزان، از تحلیل شبکه اجتماعی (SNA) استفاده شد. پاسخ‌دهندگان از هر دو منطقه، تحصیل‌کرده‌ترین فرد در خانواده و روستا و گروه‌های خودیاری (SHG) را منبع اصلی اطلاعات خود می‌دانند، اما پاسخ‌دهندگان از منطقه ساحلی در ایجاد شبکه با سایر منابع اطلاعاتی نیز بسیار هوشمندانه عمل کردند، مانند استفاده از تلویزیون، آموزش حضوری، نمایش، روزهای مزرعه، سایر کشاورزان، اداره کشاورزی، فروشندگان نهاده‌ها و غیره. احتمال دریافت اطلاعات توسط زنان کشاورز در وقتی که از مرکزیت بینابینی (Betweenness Centrality) در هدف‌گیری استفاده می‌شد کمتر بود، و این نشان از تفاوت‌های جنسیتی مهمی داشت: در مناطق قبیله‌ای، مردان احتمالاً با منابع اطلاعاتی جهان‌شهری (Cosmopolite Information Sources) صحبت می‌کنند و پاسخ‌دهندگان عموماً بیشتر درگیر فعالیت‌های کشاورزی هستند، در حالی که در مناطق ساحلی، پاسخ‌دهندگان به طور فعال در فعالیت‌های کشاورزی و همچنین جمع‌آوری اطلاعات از منابع مختلف مشارکت دارند.

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Identifying Priority Strategies for Entrepreneurial Development in the Poultry Industry: Evidence from Mashhad, Iran

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ABSTRACT

The increasing demand for food, especially poultry products, highlights critical challenges to food security. In this context, agricultural entrepreneurship in the poultry sub-sector plays a vital role in addressing these challenges by enhancing food supply and contributing to economic growth and development. This study specifically focuses on fostering entrepreneurship within the poultry industry in Mashhad County, emphasizing its pivotal role in Iran's economy and its contribution to food security. Using an exploratory research method along with SWOT and Ordinal Priority Approach (OPA) analysis, 18 factors influencing entrepreneurship in the poultry industry were identified and weighted, leading to the development and ranking of 14 strategies. The results indicate that strategies such as transferring the tasks related to the poultry industry from the government to the private sector and using the capacities of knowledge-based companies for innovation in the supply of poultry input have the highest scores. In contrast, strategies such as organizing workshops and training courses and hiring skilled labore (have lower scores. The findings suggest practical concepts for poultry entrepreneurs, including branding, technology adoption, establishing international animal welfare standards, collaborating with knowledge-based companies, and privatization under government supervision. These strategies can foster regional development by promoting entrepreneurship, which in turn can increase employment, economic growth, and productivity, ensuring a balanced distribution of the opportunities and resources.

Keywords: Entrepreneurship, Ordinal priority approach, Regional development, Strategic analysis, SWOT.

INTRODUCTION

The dynamic prospects of economic development, increasing population growth, global food demand, and rising income levels have intensified the need for sustainable solutions in the agricultural sector (Tilman *et al.*, 2011). This growth in population and income not only heightens food consumption but also presents challenges to food security and sustainable development processes (Molotoks *et al.*, 2021; Erdaw and Beyene, 2022). Thus, balancing the rising demand for food with long-term sustainable development is essential (Bijl *et al.*, 2017). As the agricultural sector serves as the cornerstone of any nation’s economy (World Bank, 2016), it plays a crucial role in ensuring food security and sustainable development (Pawlak and Kołodziejczak, 2020). A self-sufficient agricultural sector allows resources to be directed toward infrastructure and other areas critical to economic growth, while dependence on food imports can delay the process of sustainable development (Ali *et al.*, 2021, Mohammadi

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and Saghaian., 2022). In Iran, agriculture is a major economic sector, accounting for approximately 10% of GDP and 15% of total employment (Statistical Centre of Iran, 2021). It not only supplies food, raw materials, and investment for sustainable economic growth (Kleyn and Ciacciariello, 2021), but also serves as the foundation for rural development, supporting income generation, employment, and industrial activities. (Zecca and Bataineh, 2016). Among the vital sub-sectors in Iran's agriculture is the poultry industry, which has transformed from traditional farming practices to a significant player in agricultural production and employment, largely due to substantial capital investment (Zaghari, 2018). The poultry industry contributes to food security, employment, poverty reduction, and economic growth(Shoofiyani *et al.*, 2022), providing around 60% of the per capita animal protein intake through chicken meat and eggs in Iran (Zaghari, 2018).

Despite the substantial role of the poultry industry in food security and economic stability, it faces significant challenges in Iran (Rahimi, 2013). One of the primary issues is the high cost of poultry feed combined with government price controls on poultry meat, aimed at consumer price support (Zamani *et al.*, 2019). While these price controls benefit consumers, they reduce the profitability and incentives for poultry producers, ultimately impacting production levels (Mohammadi *et al.*, 2023). This gap between the current constraints in the industry (high costs and limited incentives) and the desired state of a thriving, self-sustaining poultry sector that fosters growth and innovation represents a critical problem (Mottet and Tempio, 2017). Addressing this gap requires strategic interventions that enhance producer incentives and foster an environment conducive to entrepreneurial activities (Simonov and Girfanova, 2023). Entrepreneurship is crucial in overcoming these challenges and exploiting potential opportunities within the poultry industry (Lin *et al.*, 2021). Agricultural entrepreneurship, defined as the strategic pursuit of market opportunities to initiate and expand business activities (Jafari-Sadeghi *et al.*, 2021), is particularly important in modernizing the poultry sector.

One of the most important goals of entrepreneurship development in agriculture is to modernize agricultural structures and create a new agricultural environment for job creation (Gholamrezai *et al.*, 2021). In general, Agricultural entrepreneurship, accompanied by the risks of the agricultural sector, creates avenues for employment, increase income, enhance quality of life, and greater individual participation in the economy. (Mohammadi *et al.*, 2017). An entrepreneurial farmer interprets challenges and environmental changes as opportunities and uses the existing resources to produce new products or services (Aliabadi *et al.*, 2016).

Given the critical role of opportunity recognition in the entrepreneurial process and its potential to advance and strengthen entrepreneurship (Rosca *et al.*, 2020), it is essential to identify and implement effective strategies for entrepreneurial development in agricultural sub-sectors, including the poultry sector, to achieve an optimal level and position in entrepreneurship. In this context, the present study explores the landscape of entrepreneurship in agriculture, with a specific focus on the poultry industry. By examining the challenges and opportunities within this sector, it aims to provide insights for the development of effective entrepreneurial strategies. Agricultural entrepreneurship has been investigated in numerous studies.

Existing research (Table 1) has examined the general factors influencing agriculture entrepreneurship, exploring its dimensions and obstacles through various quantitative and qualitative methods, including decision-making approaches (Regmi and Naharki, 2020), economic analysis (Khoshmaram *et al.*, 2019), qualitative analysis (Choudhury and Easwaran, 2019; Khosravipour and Shoeibi, 2022), correlation analysis, and

Table 1. Literature on agricultural entrepreneurship.

Author	Area of study	Goal of the study	Methodology	Results
Pindado and Sánchez (2017)	Europe	Analysing entrepreneurial behaviour in new and existing investments in European agriculture.	Random effects logit models	Newcomers in agriculture tend to lean more towards entrepreneurship compared to individuals with more prior agricultural experience.
Choudhury and Easwaran (2019)	Brahmaputra Valley, Assam (India)	Examining the factors influencing agricultural entrepreneurship in the Brahmaputra Valley, Assam.	Qualitative analysis and mean decomposition analysis	Human resources with limited knowledge and awareness, market facilities, and most importantly, supply and demand, serve as constraints in agricultural entrepreneurship development.
Martinho (2020)	European Union	Exploring Entrepreneurship Dimensions in European Union Agriculture Towards a More Sustainable Sector.	Descriptive data analysis and Cobb-Douglas Model-based regressions.	Policy tools play a significant role in entrepreneurship, so it is essential to enhance the mutual relationship between agricultural policies and entrepreneurship. Moreover, in agricultural entrepreneurship, economic aspects are pivotal.
Regmi and Naharki (2020)	Nepal	Evaluating the factors influencing agricultural trade entrepreneurship.	SWOT	Increasing awareness about agricultural entrepreneurship, human resource development, infrastructure, government support, and establishing special export zones can contribute to harnessing the potential of agricultural trade entrepreneurship in Nepal.
Gholamrezai *et al.* (2021)	Iran	Designing a model for sustainable entrepreneurship among domestic producers of agricultural inputs	Structural Equation Model	Sustainable entrepreneurship is influenced by external factors such as mindset, contextual conditions like education and community understanding, and intervention factors such as government support and the development of technical infrastructure

structural equation modelling (Gholamrezai *et al.*, 2021).

However, there is a gap in studies where previous research does not specifically focus on entrepreneurship in a sub-sector of agriculture and, generally, examines the agricultural sector as a whole. This study addresses this gap by focusing on entrepreneurship in the poultry industry and providing strategies for its promotion based on a comprehensive analysis of Strengths, Weaknesses, Opportunities, and Threats (SWOT). In other words, the development of entrepreneurship in the poultry industry requires a multi-level approach that considers the macro (industry), meso (sectoral), and micro (firm) levels, as the optimal implementation of many macro-level strategies necessitates their execution at both the meso and firm levels.

On the other hand, it is necessary to formulate entrepreneurship development strategies suitable to each region based on its unique economic, cultural, political, and climatic conditions is essential. Moreover, the integration of SWOT analysis and OPA (Ordinal Priority Approach) in this study represent a new approach that reveals hidden judgments, contradictions and uncertainties of decision makers, which have often been neglected in previous studies. The SWOT analysis is used as a valuable tool for strategic planning, enabling decision-makers to assess internal and external factors crucial for effective program formulation (Vashishtha and Dhawan, 2023). Simultaneously, the OPA, an advancement in Multi-Criteria Decision Making (MCDM), addresses the limitations of traditional methods like WASPAS and BWM. By independently estimating weights of experts, criteria, and options, OPA minimizes pairwise comparisons, enhancing compatibility (Sadeghi *et al.*, 2022).

This study contributes to the existing literature through several innovations. First, by focusing on the poultry industry as a specific agricultural sub-sector, it addresses a research gap in entrepreneurship in small and medium enterprises within this industry. Secondly, the use of an integrated SWOT-OPA approach, as a novel method in Multi-Criteria Decision-Making (MCDM) enables a more comprehensive and precise identification of factors influencing entrepreneurial development. Thirdly, all factors affecting entrepreneurship development have been identified in terms of strengths, weaknesses, opportunities, and threats, providing a better understanding of the internal and external environments of the poultry industry. Fourthly, examining this topic in a new geographical area aids in understanding regional conditions and their impact on entrepreneurship.

The structure of this study is organized as follows: first, the introduction and the research necessity are presented. This is followed by a review and explanation of the theoretical foundations. Next, the research methodology is described, and subsequently, the results and discussion are provided. Finally, the study concludes with recommendations and key insights for fostering entrepreneurship in the poultry sector.

Theoretical Foundations

Entrepreneurial development strategies refer to a set of planned actions and policies aimed at fostering an entrepreneurial culture, identifying and leveraging innovative opportunities, and building entrepreneurial capacities within organizations or industries. These strategies may include support for innovation, empowerment of human resources, encouragement of risk-taking, and the establishment of supportive infrastructures, all contributing to economic growth and societal value creation. Such approaches are crafted at both macro and micro levels with the goal of enhancing competitiveness and entrepreneurial capabilities (Morris *et al.*, 2009).

In the field of entrepreneurial development strategies, various theories have been proposed, each addressing specific aspects of entrepreneurship and offering insights for enhancing organizational and industrial performance in this domain. Schumpeter's Theory of Creative Destruction (1934) regards entrepreneurship as a force of creative destruction that drives innovation and economic development (Croitoru, 2012). According to this theory, entrepreneurs introduce new products, technologies, and processes, reshaping market structures and creating new opportunities that contribute to economic growth. Kirzner (1973) emphasizes in his "Theory of Entrepreneurial Discovery" the importance of identifying untapped market opportunities, proposing that entrepreneurs can enhance the economy by addressing and leveraging market imbalances. The Resource-Based View (RBV) by Barney (1991) posits that an organization's unique resources and capabilities can lead to sustainable competitive advantage and entrepreneurial development. Additionally, Innovation Systems Theory of Freeman (1987) highlights that innovation and entrepreneurship depend on supportive environments, policies, institutions, and networks, suggesting that entrepreneurial development requires appropriate infrastructure, governmental support, and policies to strengthen innovation and industrial growth. The Cognitive Theory of Entrepreneurship by Mitchell *et al.* (2002) focuses on the cognitive and psychological processes of entrepreneurs, examining the mental and psychological factors involved in identifying and acting upon opportunities. The Theory of Planned Behavior of Ajzen (1991) posits that individuals' intentions for entrepreneurial behavior are influenced by three main factors: attitudes toward the behavior, subjective norms, and perceived behavioral control, which help entrepreneurs better understand the determinants of their decision-making processes. Finally, the Entrepreneurial Ecosystem Theory of Isenberg explores the factors that shape the entrepreneurial environment and are essential for entrepreneurial development, such as human capital, venture capital, infrastructure, government policies, and an entrepreneurial culture (Aryal, 2021). Collectively, these theories provide robust theoretical frameworks for fostering entrepreneurial development and assist organizations and policymakers in identifying strengths and opportunities to create environments conducive to entrepreneurial growth and innovation.

In this regard, entrepreneurial development strategies can be classified at three levels: macro (industry), meso (sectoral), and micro (firm). At the macro level, these strategies focus on establishing infrastructure, supportive policies, and an environment conducive to entrepreneurial growth across the entire industry. Examples include creative destruction strategies, based on Schumpeter's theory, which emphasize fostering innovation and new technologies to reshape market structures and create new opportunities; opportunity discovery strategies, grounded in Kirzner's theory, which focus on identifying and capitalizing on new opportunities and addressing market imbalances at the industry level; entrepreneurial ecosystem strategies, which aim to strengthen ecosystem factors like human capital, venture capital, infrastructure, and government policies to support entrepreneurship; and innovation enhancement strategies, derived from Innovation Systems Theory, which build a supportive environment at the industry level through infrastructure, institutions, and policies that encourage sustained innovation.

Meso-level entrepreneurial development strategies, acting as a bridge between macro policies and micro-level actions, focus on strengthening key factors for fostering entrepreneurship within a specific sector. These strategies include creating and enhancing value networks and supply chains, supporting sector-specific innovation and technology, establishing industry associations and cooperatives, and providing training and skill development at the sectoral level. Drawing on the theories of Creative Destruction, Innovation Systems, and Entrepreneurial Ecosystems, these initiatives provide the necessary infrastructure and connections, enabling entrepreneurs to capitalize on new opportunities while enhancing collaboration and human resources. Additionally, these strategies encourage risk-taking and cultivate an entrepreneurial culture within the industry, creating a foundation for sustainable innovation and growth.

Finally, at the micro level, entrepreneurial development strategies are directed toward identifying, leveraging, and enhancing internal capacities within organizations to foster sustainable innovation and competitiveness. These include resource and capability-based strategies, based on the Resource-Based View (RBV), which strengthen unique organizational resources and capabilities to achieve sustainable competitive advantage. Additionally, cognitive entrepreneurship strategies, grounded in Cognitive Theory, develop entrepreneurs' cognitive processes for identifying and utilizing internal opportunities. Planned behavior-based strategies, based on the Theory of Planned Behavior, reinforce factors such as attitudes, subjective norms, and perceived control that influence entrepreneurial intent within the organization. Furthermore, internal innovation enhancement strategies focus on supporting in-house innovation and empowering human resources to develop new ideas and products.

Together, these strategies at macro, meso, and micro levels assist industries and organizations in leveraging resources to create environments conducive to entrepreneurial growth and innovation across the poultry industry.

MATERIALS AND METHODS

Study Area

The county of Mashhad, located in the north-eastern region of Iran, was selected as the study area due to its critical role in agricultural and poultry industries of the country. The county's agricultural potential and its significance in the poultry sector make it an ideal region for investigating entrepreneurial opportunities in agriculture. Mashhad serves as the capital of Khorasan Razavi Province (Figure 1), and accounts for 3.9% of Iran's total livestock production, with an annual output of 1,575,727 tons. The province ranks second in egg production with a 13% share and is the third-largest producer of poultry meat in Iran, with an annual production of approximately 120,000 tons (Ministry of Agriculture-Jahad, 2021). The share of Mashhad in the agricultural production of Khorasan Razavi Province is 13%, holding the first rank among the counties in the province. In terms of the number of livestock units, it also ranks second in the province, accounting for a 10% share (Ministry of Agriculture-Jihad 2021). Currently, there are 210 poultry farming units in the county of Mashhad, employing 20,414 workers (Ministry of Agriculture-Jihad, 2021). Therefore, the poultry industry in Mashhad is one of the most significant economic sectors, offering substantial potential for job creation and production growth. Thus, considering the potential of the county of Mashhad in the production of poultry-related products and the role of agricultural entrepreneurship in the economy, this county was chosen as the study area to ultimately provide solutions for the development of entrepreneurship in this region.

Population

In this study, the sampling method used was a form of purposive sampling, i.e. "Sampling to Achieve Representativeness or Comparability". Purposive sampling, also known as qualitative sampling, involves intentionally selecting participants to gain specific insights or knowledge. Unlike methods that aim to establish generalizable findings or fixed rules, purposive sampling focuses on deepening understanding within a

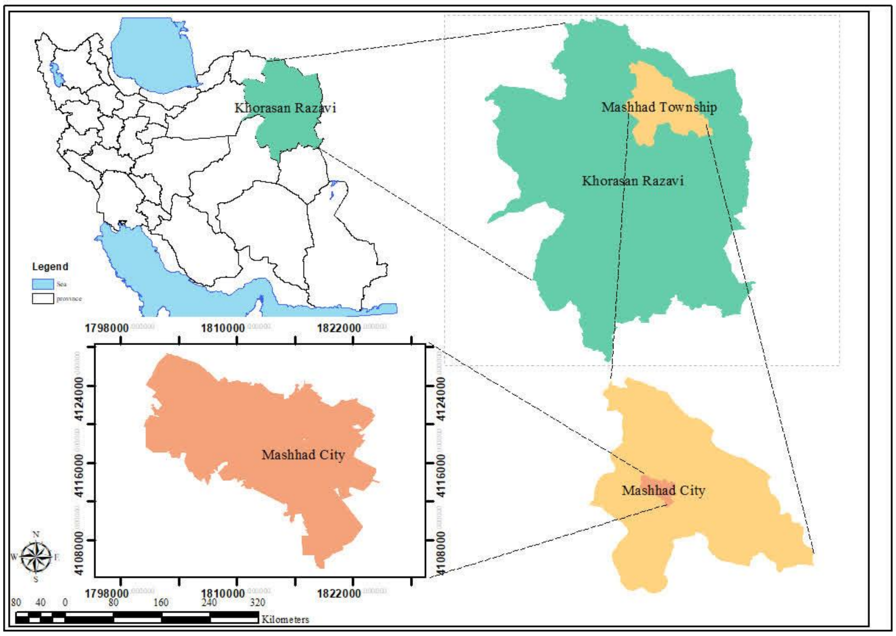

Figure 1. Geographical location of the study area in Khorasan Razavi Province, Iran (Bahraseman *et al.*, 2024).

specialized context. In this approach, researchers determine sample size based on mental processes, seeking participants who will provide the most comprehensive information about the phenomenon under investigation. Accordingly, twenty interviews were conducted with stakeholder groups in September 2023 to examine the challenges related to enhancing and developing entrepreneurship in small and medium-sized enterprises within the poultry industry.

This study utilized field research, literature review, interviews, and surveys to identify strategies for enhancing entrepreneurship in the poultry industry. Accordingly, twenty interviews were conducted with stakeholder groups in September 2023 to examine the challenges related to enhancing and developing entrepreneurship in small and medium-sized enterprises within the poultry industry. Table 2 displays the frequency of individuals' participation in the interviews related to the research.

Methodology

This study adopts a pragmatic paradigm with a quantitative and exploratory approach to identify and prioritize strategies for entrepreneurial development in the poultry industry. Utilizing SWOT analysis integrated with the Ordinal Priority Approach (OPA), the research employs a systematic and quantitative method for evaluating and ranking strategic factors. The OPA model was applied using specialized web-based software for multi-criteria decision analysis. Ataei *et al*. (2020) and Mahmoudi et al. (2023) were the developers of this software.

Figure 2, shows the incorporation of the SWOT-OPA methodology used in this study to identify the factors influencing entrepreneurship development in the poultry industry. The primary aim of this approach was to outline and prioritize alternative strategies for the progression of entrepreneurship within the poultry sector. The process of identifying factors influencing entrepreneurship in the poultry industry included conducting a SWOT analysis. Following this, the OPA approach was implemented to assess the weight of each SWOT sub-factor, and the OPA method was employed to prioritize alternative strategies. The next section presents a brief overview of the methodologies applied in this study.

SWOT

The SWOT (Strengths, Weaknesses, Opportunities, and Threats) analysis is a strategic planning tool used to evaluate internal and external factors that affect an organization's success (Taherdoost and Madanchian, 2021). Strengths and weaknesses are internal factors, while opportunities and threats are external. Strategies derived from SWOT analysis include (Figure 3): Aggressive strategies (SO), leveraging strengths to capitalize on opportunities; conservative strategies (WO), mitigating weaknesses by exploiting opportunities; competitive strategies (ST), utilizing strengths to mitigate the impact of threats; and defensive strategies (WT), employed when external threats align with internal weaknesses. In this scenario, the defensive strategy aims to prevent negative internal weaknesses from being highly vulnerable to external threats (Raddad, 2022). This analysis is widely applied in business, marketing, and decision-making to formulate strategies based on a thorough

Table 2. The rate of engagement of stakeholders in interview sessions.

Participants	Number of participants
Government organization managers	7
Academic individuals	5
Poultry farmers	8
Total	20

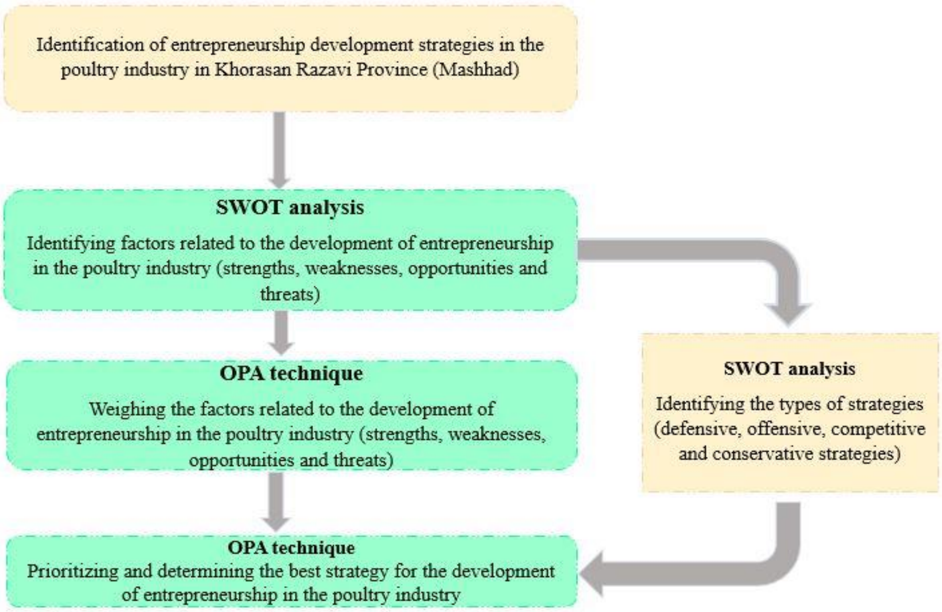

Figure 2. The framework of SWOT-OPA in the study.

Figure 3. The configuration of the SWOT matrix.

Internal / External	Strengths	Weaknesses
Opportunities	SO strategy (Offensive)	WO strategy (Conservative)
Threats	ST strategy (Competitive)	WT strategy (Defensive)

understanding of influencing factors (Stefan *et al.*, 2021). This study employed SWOT analysis to propose strategies for enhancing entrepreneurship in Mashhad's Poultry Industry.

Ordinal Priority Approach (OPA)

The OPA is a significant advancement within the field of Multiple Criteria Decision Making (MCDM) theory through a linear mathematical model. This approach was suggested by Ataei *et al.* (2020). The OPA method supports both individual and group decision-making by simultaneously considering experts, criteria, and alternatives. It excels in calculating rankings, expert weights, and criteria weights without the need for conventional normalization, and can handle incomplete data. This means that when experts lack sufficient knowledge or relevant experience in the judgment process, they can skip certain options related to a specific criterion, thereby enhancing decision-making accuracy and efficiency (Sadeghi *et al.*, 2022).

OPA, unlike similar decision-making techniques, calculates alternatives rankings, expert weights, and criteria weights simultaneously. OPA does not require aggregation methods for gathering expert judgments in group decision-making. Furthermore, OPA does not utilize pairwise comparison matrices for alternatives and criteria (Mahmoudi *et al.*, 2021). Instead, it requires ordinal data for criteria and alternatives. In order to explain the steps of OPA, it is essential to have a clear understanding of the variables, indexes, and sets as outlined in Table 3.

The computational process of OPA encompasses the following stages:

Table 3. Sets, indexes, and variables used in the OPA.

Sets	
I	Set of experts $\forall I \in$ I
J	Set of criteria $\forall j \in$ J
K	Set of alternatives $\forall k \in$ K
Indexes	
i	Index of the experts $(1, \ldots, p)$
j	Index of preference of the criteria $(1, \ldots, n)$
k	Index of the alternatives $(1, \ldots, m)$
Variables	
Z	The objective function
$W_{ijk}{}^{r}$	Weight (importance) of k^{th} alternative based on j^{th} criterion by i^{th} expert at r^{th} rank
Parameters	
i	The rank of expert i
j	The rank of criterion j
r	The rank of alternative k

Step 1 involves the process of identifying the criteria and sub-criteria for alternatives selection.

Step 2 entails determining the ordinal preferences for criteria and sub-criteria.

Step 3 involves constructing the linear model (Equation 1) using the information collected from steps 1 and 2. Subsequently, it can use appropriate software such as LINGO, MATLAB, Python, or similar tools to solve the model.

$$Max\ Z$$

s.t.

$$Z \leq i\,(j\,(r\,(W_{ijk}{}^{r} - W_{ijk}{}^{r+1}))) \quad \forall\ i,\ j,\ k \text{ and } r$$

$$Z \leq ijmWijkm \qquad \forall\ i, j \text{ and } k$$

$$\sum_{i=1}^{p}\sum_{j=1}^{n}\sum_{k=1}^{m} Wijk = 1 \tag{1}$$

$Wijk \geq 0 \quad \forall\ i,\ j$ and k where Z: Unrestricted in sign

After successfully solving the model, Equation (2) is employed to determine the alternatives weights.

$$Wk = \sum_{i=1}^{p}\sum_{j=1}^{n} Wijk \qquad \forall\ k \tag{2}$$

In order to determine the criteria weights, Equation (3) is applied.

$$Wj = \sum_{i=1}^{p}\sum_{k=1}^{m} Wijk \qquad \forall\ j \tag{3}$$

For the computation of expert weights, Equation (4) is utilized.

$$Wi = \sum_{j=1}^{n}\sum_{k=1}^{m} Wijk \qquad \forall\ i \tag{4}$$

Subsequently, these weights can be utilized for decision-making and the ranking of criteria, experts, and alternatives.

RESULTS AND DISCUSSION

Effective factors influencing entrepreneurship development in the poultry subsector in Mashhad have been identified based on library research, expert interviews, field studies, and relevant literature (Column 3 (SWOT sub-factors) Table 4). The results of the evaluation matrix of internal and external factors for entrepreneurial development in the poultry subsector, using the OPA approach, are reported in Table 4. Among the four strengths ranked by the expert community,

Table 4. Matrix of internal and external factors evaluation for entrepreneurial development in the poultry subsector.

SWOT factors	Symbol	SWOT sub-factors	Weight	Rank[1]	Overall rank
Strengths (S)	S1	High market share	0.9027	2	12
	S2	Presence of significant technical knowledge and specialized human resources in the poultry sub-sector	0.7750	4	14
	S3	The conditions and capacities of the province in the field of poultry-related productions	0.8431	3	13
	S4	Existence of poultry farmers' unions and associations	0.9222	1	9
Weakness (W)	W1	Insurance coverage shortages and weaknesses in support programs during crisis conditions	0.9789	2	3
	W2	Lack or insufficiency of poultry product processing and storage industries	0.9552	4	6
	W3	Low diversity of processed products	0.9444	5	7
	W4	Low competitiveness	0.9279	6	8
	W5	Lack of attention to branding	0.9554	3	5
	W6	Low capacity for the production of inputs in the country and a shortage of poultry inputs	0.9813	1	2
Opportunities (O)	O1	Proximity to the border for exports	0.9662	1	4
	O2	Market growth and increased demand for poultry products	0.9131	2	11
	O3	Existence of private sector capital	0.1751	4	18
	O4	One of the priority sub-sectors in agriculture for the government	0.2045	3	16
Threats (T)	T1	Sanctions on the country and difficulties in obtaining equipment such as drugs, vaccines, and technology transfer	0.6808	3	15
	T2	Fluctuations in raw material prices	0.9853	1	1
	T3	Market imbalance and inefficiency of supportive policies for production	0.9196	2	10
	T4	Existence of contagious avian diseases	0.1863	4	17

Source: Research findings.

factor S4, which is the presence of poultry farmers' unions and associations, secured the highest ranking with a score of 0.0922.

Experts in this research find that poultry farmers' unions and associations in Mashhad are crucial for poultry entrepreneurship due to their role in information exchange, resource procurement, and understanding market challenges. These organizations help reduce production costs, improve access to quality resources, and foster an entrepreneurial culture. This supports findings by Karami and Agahi (2018), who noted that cooperatives and supplier associations positively impact the capabilities and motivation of poultry business owners.

Among the identified six weaknesses, the low capacity of input production and the shortage of poultry inputs in the country (W6) have been assigned the highest ranking with a score of 0.0981. Experts identify the scarcity of poultry inputs and reliance on imports as a major weakness, leading to higher production costs and reduced competitiveness. This shortage hampers export performance, limits new business development, and poses challenges for entrepreneurs in the poultry industry. It may even lead entrepreneurs to fear a lack of input, discouraging them from initiating new businesses. In this regard, reference can be made to Zaghari (2018), which identifies poultry nutrition and the shortage of production inputs as one of the main challenges in poultry farming in Iran.

Source: research findings.

According to the results of the OPA approach for evaluating the matrix of external factors, as per the experts' opinions, it is evident that the highest priority among the four identified opportunities for entrepreneurial development in the poultry subsector is attributed to the proximity to borders for exports (O1). This criterion has been assigned the highest ranking with a score of 0.9662. Proximity to borders creates new export opportunities and encourages producers to optimize production by adhering to international standards, which enhances product quality and competitiveness. Additionally, export activities driven by production growth provide a platform for entrepreneurial development and increased employment. In support of this conclusion, reference can be made to the study conducted by Doan (2022), which has found that changes in international trade market dynamics in Vietnam and access to export markets significantly impact the activities of entrepreneurial enterprises. Furthermore, Khanal (2018) considers access to distant Western markets as a motivator for entrepreneurial farmers in Nepal.

The analysis of identified threats has shown that changes in raw material prices (T2) have obtained the highest score of 0.985. Fluctuations in raw material prices increase production costs, reducing profitability and raising final product prices, which negatively impacts marketability and competitiveness. This is particularly challenging for new entrepreneurs and small businesses in the poultry industry. As a result, these price changes can dampen investment decisions, entrepreneurial enthusiasm, and business development strategies. In this regard, the findings of the study by Shoofiyani *et al.* (2022) also demonstrated that price fluctuations in commodities (such as chicken feed or vaccines/boosters) have resulted in increased costs and impact the activities of the supply chain.

As illustrated in Figure 4, a comprehensive comparison was conducted for all sub-factors of the SWOT analysis pertaining to entrepreneurship in the poultry industry The foremost factors, in descending order of significance, include fluctuations in raw material prices (T2) with a weight of 0.985, low capacity for the production of inputs in the country and a shortage of poultry inputs (W6) with a weight of 0.981, and Insurance coverage shortages and weaknesses in support programs during crisis conditions (W1) with a weight of 0.979.

After identifying the internal and external factors related to entrepreneurial

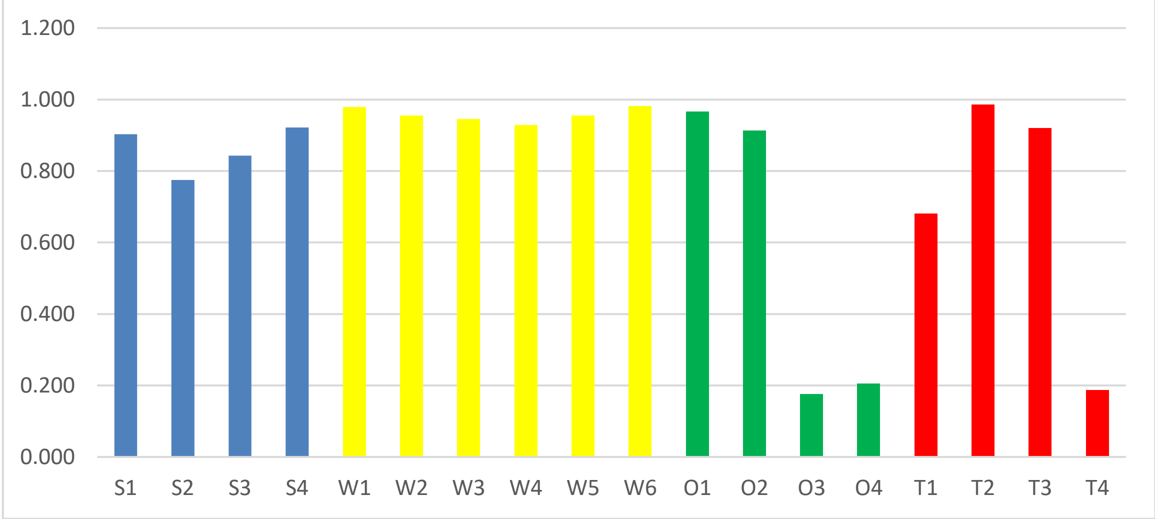

Figure 4. Overall ranking of criteria (sub-factors within the SWOT analysis).

Table 5. Entrepreneurship development strategies ranking in the poultry subsector using the OPA technique.

Symbol	**Strategies**	**Weight**	**Rank**
ST1	Establishing a strong network (strengthening collaboration)	0.0722	8
WO1	Investing in Infrastructure	0.0833	6
WO2	Transferring responsibilities related to the poultry industry from the government to the private sector	0.1119	1
SO1	Improving Animal Welfare	0.0260	14
WT1	Utilizing the capacities of knowledge-based companies for the provision of new inputs	0.0968	2
WT2	Branding and marketing	0.0931	3
WO3	Diversifying income streams	0.0728	7
ST2	Implementing biosecurity measures	0.0463	12
WT3	Expanding insurance coverage	0.0921	4
ST3	Market Research	0.0615	10
WO4	Utilizing Innovative Technologies in Production Units	0.0666	9
SO2	Conducting workshops and training courses for entrepreneurs in this field	0.0359	13
SO3	Developing an entrepreneurial culture in the poultry industry (to enhance risk-taking)	0.0507	11
WT4	Financial provision	0.0907	5

Source: Research findings.

development in the poultry subsector and scoring them using the OPA method, practical strategies for entrepreneurship development in this area were extracted (Table 5). Subsequently, the prioritization of these strategies was performed using the OPA technique. Columns 3 and 4 of Table 5, respectively, indicate the final weights and rankings of the strategies.

As depicted in Table (5), this study suggests four defensive strategies, three offensive strategies, three competitive strategies, and four conservative strategies.

As shown in Figure 5, all strategies related to entrepreneurship development in the poultry industry were compared. Transferring responsibilities related to the poultry industry from the government to the

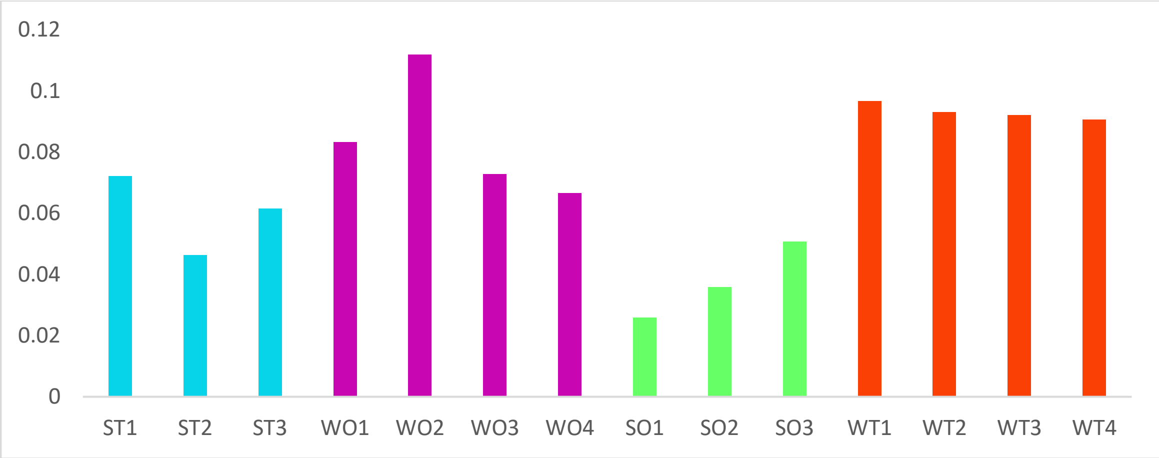

Figure 5. Overall ranking of strategies.

private sector (WO2), utilizing the capacities of knowledge-based companies for the provision of new inputs (WT1), and branding and marketing (WT2) have been recognized as the important strategies, each assigned weights of 0.112, 0.097, and 0.093, correspondingly. According to the results of Table 5 and Figure 5, the most important entrepreneurship development strategies in the poultry subsector include:

Rank 1: Transferring Responsibilities Related to the Poultry Industry from the Government to the Private Sector (WO2)

The institutional structure of Iran's poultry industry is characterized by a significant level of government intervention, which, while aimed at stabilizing prices and ensuring food security, often leads to inefficiencies. Government-supervised privatization, as a context-specific strategy, seeks to leverage the capabilities of the private sector to mitigate bureaucratic delays and foster innovation. This approach aligns with the successful implementation of similar strategies in other sectors, where gradual privatization under regulatory oversight has improved operational flexibility and market responsiveness (Barcho, 2019). In the context of Iran, the role of cohesive cooperatives and associations within the poultry sector can be expanded to take on responsibilities traditionally held by the government, such as input procurement and market coordination. This shift reduces bureaucratic barriers, enhances entrepreneurs' autonomy, and creates a competitive environment conducive to new business ventures. Additionally, the transfer of tasks must be complemented by robust institutional support, including clear regulatory frameworks and incentives, to ensure a smooth transition and sustained growth in entrepreneurial activities. This finding is consistent with the research by Ilham (2015), which highlights that privatization, combined with government oversight, can enhance the performance of poultry industry businesses. This approach strengthens production structures, reduces economic vulnerabilities, and improves efficiency.

Rank 2: Utilizing the Capacities of Knowledge-Based Companies for the Provision of New Inputs (WT1)

Knowledge-based companies lead innovation in nutrition, health, and technology within the poultry industry, creating new opportunities for entrepreneurs in breeding and processing. Their close connections with the market help entrepreneurs effectively understand and respond to market needs (Bayo and

Emmanuel, 2020). By offering solutions to optimize input production and supply high-quality inputs, these companies reduce risks and enhance production management. Leveraging their expertise is crucial for improving processes and fostering entrepreneurial growth in the poultry sector.

Rank 3: Branding and Marketing (WT2)

Branding creates a unique business identity and, when paired with effective marketing, protects against market fluctuations, ensuring stability. In the poultry industry, where price volatility is frequent, developing and reinforcing product brands is crucial for long-term success (Doan, 2022). In this regard, Shoofiyani *et al.* (2022) also emphasized that new entrants in the poultry industry, particularly entrepreneurs, must enhance consumer awareness of their brand. One effective approach to enhance product awareness is the implementation of a comprehensive marketing strategy. Additionally, Subagja *et al.* (2022) consider continuous improvement in the quality of poultry slaughterhouse products and a strong brand as essential elements for competing with similar businesses.

Rank 4: Expanding Insurance Coverage (WT3)

Insurance coverage can support producers against economic losses resulting from various factors such as natural disasters, diseases, or market fluctuations (Alam *et al.*, 2020). Insurance provides compensation to poultry farmers in Iran if the entire farm stock (flock) is lost, which can diminish the motivation of entrepreneurs in the poultry sub-sector. In general, increasing insurance coverage in the poultry industry (i.e. payment of indemnity in case of losses and damage to a percentage of the flock) can create a more secure environment for entrepreneurs, encouraging them to take risks and expand their businesses.

Rank 5: Financial Provision (WT4)

Access to financial resources is crucial for establishing, expanding, and managing poultry businesses, as it allows for easier procurement of production inputs and mitigates risks from price fluctuations (Daemane and Muroyiwa, 2022). Favorable financial conditions also encourage innovation in production, marketing, and management, improving efficiency and fostering entrepreneurial growth in the poultry industry. In this regard, Aqajani *et al.* (2008) have identified financial provision through low-interest loans as a primary need for entrepreneurs, which is considered one of the main responsibilities of the government. Additionally, De Clercq *et al.* (2009) identified lack of capital and financial resources as obstacles to entrepreneurship.

Rank 6: Investing in Infrastructure (WO1)

Investment in infrastructure, including poultry farms, transportation, and processing facilities, enhances efficiency and stimulates local economies, contributing to business competitiveness (Subagja *et al.*, 2022). Such investments create a favorable environment for entrepreneurship in the poultry industry. Regmi and Naharki (2020) emphasize that supporting agriculture entrepreneurship requires investment in essential infrastructures like (Regmi and Naharki (2020)) systems, transportation, marketing, and storage facilities. These investments are crucial for promoting and sustaining entrepreneurship in the sector.

Rank 7: Diversifying Income Streams (WO3)

Diversifying income streams in the poultry industry through multiple sources, like meat and egg sales or innovative technologies, reduces risks and increases business resilience. This strategy enhances competitiveness, attracts new customers, and strengthens market position, enabling entrepreneurs to capitalize on various opportunities while minimizing risks.

Rank 8: Establishing a Strong Network (Strengthening Collaboration) (ST1)

Being part of a network allows entrepreneurs to stay informed about market trends, consumer preferences, and industry innovations. Networking and access to exhibitions and conferences can strengthen the entrepreneurial culture and relationships among entrepreneurs, while also helping them better manage challenges and risks. (Ribeiro *et al.*, 2021). Networking can reduce the lack of entrepreneurial culture, leading to the identification and creation of diverse job opportunities (Regmi and Naharki, 2020). Aqajani *et al.* (2008) emphasized in their study that implementing entrepreneurial ideas requires an understanding of prerequisites, which can be achieved through organizing exhibitions and conferences.

Rank 9: Utilizing Innovative Technologies in Production Units (WO4)

The adoption of innovative technologies, such as the Internet of Things (IoT), in poultry production enhances safety, product quality, and access to international markets, leading to increased productivity and profitability (Kraus *et al.*, 2021). These efficiency gains motivate entrepreneurs in the poultry sector. Developing organizational data strategies and attracting specialized IoT talent are crucial for leveraging these technologies to boost revenue and drive entrepreneurial motivation (Shoofiyani *et al.*, 2022).

Rank 10: Market Research (ST3)

When entrepreneurs have a clear understanding of the market needs and opportunities through market research, they can tailor their poultry-related ventures to meet those demands more effectively, enhancing the entrepreneurship landscape in the sector. Identifying innovative opportunities and assessing market demand ensures successful product supply, supporting the growth and sustainability of poultry businesses (Khoshmaram *et al.*, 2019). (Sarihan) 2024) proposed that increasing consumer awareness of the benefits of export products could lead to higher demand and strengthen exports to target markets. Additionally, Hosseinzadeh *et al.* (2022) emphasized that focusing on the development of new products, understanding global markets, and engaging with the broader community leads to growth and improvement in agricultural entrepreneurship activities. Moreover, Regmi and Naharki (2020) concluded that lack of agricultural research is a significant barrier to the overall development of the agricultural sector in Nepal.

Rank 11: Developing an Entrepreneurial Culture in the Poultry Industry (To Enhance Risk-Taking) (SO3)

Developing an entrepreneurial culture fosters innovation and encourages individuals to embrace new ideas, increasing their willingness to take risks. This, in turn, supports entrepreneurial development and the establishment of innovative businesses in the poultry industry. In this context, one can refer to the findings of the study by Fritsch and Wyrwich (2018), who stated that the prevalence of entrepreneurial culture has had a significant impact on the emergence of new businesses in Germany.

Rank 12: Implementing Biosecurity Measures (ST2)

Poultry production generates by-products such as waste from droppings, hatcheries, and feed, raising environmental and health concerns (Ka and Benson, 2014). Environmental pollution, widespread diseases, etc. impact entrepreneurship development and societal progress (Doan, 2022). Biosecurity measures in the poultry industry reduce the risk of disease transmission and potential economic losses and mortality. These measures also help meet regulatory standards and consumer expectations, ensuring the quality and safety of poultry products.

Rank 13: Conducting Workshops and Training Courses for Entrepreneurs in This Field (SO2)

Workshops provide entrepreneurs with market insights and specialized knowledge, enhance their confidence and decision-making abilities, and offer motivation for successful business investments (Galvão *et al.*, 2020). So, empowering individuals through enhancing their knowledge and skills levels in performing activities leads to development (Abdollahi Kalourazi *et al.*, 2020). Furthermore, Karami and Agahi (2018) stated that if creativity and innovation in agriculture are combined with individuals' skills and managerial capabilities, agricultural entrepreneurship will experience significant growth.

Rank 14: Improving Animal Welfare (SO1)

Improving animal welfare by providing proper spaces, nutrition, and natural conditions reduces stress and disease, enhances product quality (Buller *et al.*, 2020). High-quality products are more readily accepted in the market and can command better prices. Additionally, improving animal welfare can align businesses with local and international regulations and standards, aiding in the recognition and validation of businesses while promoting ethical and social standards associated with animal husbandry (FAO, 2023). Enhancing animal welfare in the poultry industry fosters entrepreneurial opportunities in equipment production, welfare-focused management, and consulting services. This not only creates new business prospects but also supports the long-term sustainability of poultry farming.

By amalgamating these approaches, one can improve the advancement of entrepreneurship in the poultry sector, consequently, fostering the generation of economic prospects and augmenting the sustainability and adaptability of the food system.

Ultimately, the results of this study recommend:

1. Transfer of Responsibilities to the Private Sector: The study results indicate that the primary strategy for fostering entrepreneurship in the poultry industry is the transfer of responsibilities related to the poultry industry from the government to the private sector and associations. Delegating responsibilities to the private sector can enhance flexibility, competition, and private investment, as the private sector can more swiftly address market needs without bureaucratic delays. Given the existence of cohesive cooperatives and associations, it is recommended that tasks related to the poultry industry be transferred from the government to the private sector, with the government overseeing the execution of these responsibilities.
2. Utilization of Knowledge-Based Companies for Innovation: The second priority is to leverage the capabilities of knowledge-based companies to drive innovation in poultry input production. Given the constraints on input production in

Iran and the challenges faced by poultry producers, utilizing these companies for developing new inputs is crucial. Therefore, it is recommended to create platforms for communication between knowledge-based companies and poultry producers to facilitate technology transfer. Additionally, monitoring and evaluating the impact of these innovations is essential. In this regard, allocating experimental farms for this purpose can ensure the enhancement of production processes through the capabilities of knowledge-based companies.

3. Establishment of International Animal Health Standards and Financial Incentives for Export: At the international level, it is recommended that governments establish and advance international animal health standards and provide financial incentives to entrepreneurs for entering global markets and boosting exports, thereby increasing competition in the poultry industry. Additionally, governments should leverage successful practices from leading countries to enhance this sector's contribution to global food security.

4. Organizing Workshops and Training Courses for Entrepreneurs: The findings of this study can have practical implications for producers in the poultry sub-sector, such as organizing workshops and training courses. These initiatives can boost the confidence and motivation of entrepreneurs, encouraging them to initiate and succeed in business ventures. 5. Improving Access to Financial Resources and Expanding Insurance Coverage. Other implications include improving government support programs to facilitate access to financial resources for entrepreneurs. Additionally, creating employment policies in the poultry industry and expanding insurance coverage to support producers in managing production risks are highlighted as potential outcomes of these results.

This study, while comprehensive, has certain limitations that should be acknowledged. Addressing these limitations in future research could enhance the reliability and applicability of findings related to entrepreneurial development in the poultry industry. Regional Limitation: This research is focused specifically on Mashhad County, which may limit the generalizability of its findings to other regions. To address this, future research should replicate similar studies across different regions with distinct cultural, economic, and regulatory conditions. This comparative approach would allow for region-specific strategies that better suit local needs. Timeframe Constraints: The data collection was conducted over a limited period, capturing a snapshot of the industry at a particular time. Given the dynamic nature of markets, technologies, and government policies, future studies should consider a longitudinal design. This would provide a more comprehensive view of how changes over time affect the entrepreneurship landscape, allowing for adaptive strategies that remain relevant as conditions evolve. Sector-Specific Scope: This research is confined to the poultry industry, potentially limiting its applicability to other agricultural sub-sectors. Future studies could expand the scope to include similar agribusiness sectors, such as livestock or aquaculture. This broader approach would yield comparative insights, highlighting unique challenges and opportunities across agricultural industries. Addressing these limitations can guide future research toward more robust, versatile, and contextually relevant findings that better inform strategies for fostering entrepreneurship in agriculture.

CONCLUSIONS

This study aimed at enhancing entrepreneurship in the poultry industry of Mashhad. Through SWOT analysis and the Ordinal Priority Approach (OPA), 14 strategies for entrepreneurial development were identified and prioritized. The results indicated that transferring responsibilities from the government to the private sector, utilizing the capacities of knowledge-based companies for innovation, and focusing on branding and marketing are among the key strategies for fostering entrepreneurship in this sector. Additionally, challenges such as the shortage of input production and fluctuations in raw material prices were identified as major barriers to growth. These strategies, when implemented together, can contribute to sustainable development and increased productivity in Mashhad's poultry industry.

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شناسایی راهبردهای اولویت‌دار برای توسعه کارآفرینی در صنعت طیور: شواهدی از مشهد، ایران

مریم دهقانی دشتابی، حسین محمدی، علیرضا کرباسی، و ساسان اسفندیاری بهراسمان

چکیده

افزایش تقاضا برای مواد غذایی، به ویژه محصولات طیور، چالش‌های مهمی را برای امنیت غذایی برجسته می‌کند. در این زمینه، کارآفرینی کشاورزی در زیربخش طیور با افزایش عرضه مواد غذایی و کمک به رشد و توسعه اقتصادی، نقش حیاتی در رفع این چالش‌ها ایفا می‌کند. این مطالعه به طور خاص بر تقویت کارآفرینی در صنعت طیور در شهرستان مشهد تمرکز دارد و بر نقش محوری آن در اقتصاد ایران و سهم آن در امنیت غذایی تأکید می‌کند. با استفاده از روش تحقیق اکتشافی به همراه تحلیل SWOT و رویکرد اولویت ترتیبی(OPA) ، 18عامل مؤثر بر کارآفرینی در صنعت طیور شناسایی و وزن‌دهی شدند که منجر به تدوین و رتبه‌بندی 14 استراتژی شد. نتایج نشان می‌دهد که استراتژی‌هایی مانند انتقال وظایف مربوط به صنعت طیور از دولت به بخش خصوصی (SO) و استفاده از ظرفیت‌های شرکت‌های دانش‌بنیان برای نوآوری در تأمین نهاده‌های طیور (WT) بالاترین امتیاز را دارند. در مقابل، استراتژی‌هایی مانند برگزاری کارگاه‌ها و دوره‌های آموزشی (WO) و استخدام نیروی کار ماهر (ST) امتیاز کمتری دارند. یافته‌ها، مفاهیم کاربردی برای کارآفرینان طیور، از جمله برندسازی، پذیرش فناوری، ایجاد استانداردهای بین‌المللی رفاه حیوانات، همکاری با شرکت‌های دانش‌بنیان و خصوصی‌سازی تحت نظارت دولت را پیشنهاد می‌کنند. این استراتژی‌ها می‌توانند با ترویج کارآفرینی، توسعه منطقه‌ای را تقویت کنند که به نوبه خود می‌تواند اشتغال، رشد اقتصادی و بهره‌وری را افزایش دهد و توزیع متعادل فرصت‌ها و منابع را تضمین کند.

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Personal and Institutional Determinants of an Effective Entrepreneurial Intervention

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ABSTRACT

This study employed linear regression analysis and principal component analysis to examine the determinants of entrepreneurial success and identify factors contributing to effective interventions across three distinct entrepreneurial categories: farm-based, off-farm based, and service/tech entrepreneurs. Data was gathered through structured interviews involving two hundred agri-entrepreneurs in Rajasthan and Telangana states. The regression analysis revealed that diverse psycho-personal and socioeconomic variables like marital status, income levels, and achievement motivation were of significant influence. The principal component analysis provided valuable insights into the institutional factors underpinning effective entrepreneurship promotion interventions. Technical factors like tailored project support, financial enablers including government funding and tax incentives, and robust implementation mechanisms involving stakeholder collaboration were highlighted. Operational elements such as training institute-industry-market-entrepreneur linkages, administrative commitments, and policy consistency, collectively shaped intervention effectiveness across the entrepreneurial ecosystems. This comprehensive examination of individual and institutional determinants offered a holistic perspective on fostering successful agri-enterprises, emphasizing the need for contextualized approaches that align personal attributes with tailored institutional interventions.

Keywords: Agri-preneurship, Effective interventions, Incubation, Principal Component analysis, Rajasthan and Telangana States.

INTRODUCTION

India's agricultural landscape has undergone a remarkable transformation, evolving from a nation grappling with food scarcity to becoming a global leader in food grain production. This journey underscores the resilience of its farming community. However, despite achieving self-sufficiency and recording unprecedented agricultural output, the economic vulnerability of farmers persists (Economic Survey, 2023). While productivity has surged, farmers' income growth significantly lags behind other professions, highlighting the challenges in translating increased yields into higher economic returns (Sharma, 2017; Press Information Bureau (PIB), 2023). The prevailing production-centric approach has constrained the ability of farmers to harness

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their entrepreneurial potential and realize profits through value addition, marketing, and processing of their produce. This necessitates a shift towards a market-oriented strategy that empowers farmers to adopt an entrepreneurial mind-set and view their farms as viable enterprises as implied by the Doubling Farmers' Income Committee (Dalwai, 2018). Agri-entrepreneurship emerges as a pivotal catalyst for enhancing production, profitability, and the overall sustainability of the agricultural sector. Its importance is particularly pronounced in India, where a significant proportion of farmers are classified as small and marginal, confronting escalating unemployment and poverty in rural areas (Kademani *et al.*, 2020; NSSO, 2022). While often viewed as an exciting opportunity, agri-entrepreneurship is a critical need for boosting production and profitability within agriculture and its allied sectors. In line with recommendations from various committees, many organizations are actively engaged in promoting agri-preneurship in the country, collectively forming an entrepreneurship ecosystem. The factors related to policy and institutional support is crucial for entrepreneurship development (Andreoni and Chang, 2014).

The literature reveals a comprehensive framework of factors and interventions that influence entrepreneurial success, particularly in agricultural ventures. Demographic, cognitive, and social capital serve as determinants of agricultural entrepreneurship (Arafat *et al.*, 2018), while various interventional mechanisms significantly enhance entrepreneurial outcomes. Educational and training interventions have emerged as crucial success factors, as reported in a meta-analysis study by Martin *et al.* (2013) demonstrating a significant positive correlation ($r=0.217$) between entrepreneurship education and entrepreneurial outcomes. Institutional support mechanisms play a vital role, as evidenced by Mian *et al.* (2016), who highlight the value creation through resource pooling and knowledge sharing in business incubators. Amezcua *et al.* (2020) noted that such support is most effective when complementing existing institutional frameworks rather than substituting them. Kerr and Nanda (2011), in an analysis of financing constraints, and Howell (2017), in a demonstration of how early-stage grants, facilitate follow-on funding, emphasised the importance of financial support and access as critical enablers. The psychological dimension, as explored by Baum and Locke (2004) and Frese and Gielnik (2014), reveals that personal factors such as goals, self-efficacy, and communicated vision directly impact venture growth. These findings collectively suggest that successful entrepreneurial development requires a holistic approach combining institutional support, educational interventions, financial access, and psychological development, all underpinned by robust monitoring and feedback mechanisms to ensure sustained impact and adaptability.

Research Gap: Despite extensive research on entrepreneurial success factors in agriculture, existing studies often address financial, educational, or psychological components in isolation, lacking a holistic perspective that integrates psycho-personal, socio-economic, and institutional determinants. Furthermore, limited insight exists on how these factors vary across entrepreneurial categories—farm-based, off-farm, and service/tech enterprises—particularly in India's diverse agricultural ecosystems. To address this gap, the current study aims to identify the key psycho-personal and socio-economic factors influencing entrepreneurial success, analyse institutional determinants driving effective interventions, and examine their variations across entrepreneurial categories. This integrated approach offers actionable insights to design tailored strategies for promoting sustainable agri-entrepreneurship, which formulated the research objectives of the study, as follows:

To identify the key psycho-personal and socio-economic factors influencing the success of agri-entrepreneurs across three categories.

To analyse the institutional determinants that contribute to effective entrepreneurial interventions across three categories.

The above objectives aimed to bridge the research gap and provide actionable insights for designing tailored strategies to promote sustainable and effective agri-entrepreneurship interventions in India.

MATERIALS AND METHODS

An exploratory research design was employed, involving two hundred agri-entrepreneurs supported by entrepreneurship promoting institutes. These entrepreneurs were essentially from a pool of trainees among the selected promoting organizations within the two states of Rajasthan and Telangana.This research was conducted in the states of Rajasthan and Telangana due to their notable achievements in promoting agri-entrepreneurship. Telangana was chosen for its abundance of institutions dedicated to fostering agri-entrepreneurship, while Rajasthan, despite its relatively low Human Development Index (HDI), was selected for its remarkable performance in the Agricultural Marketing and Farmer-Friendly Reforms Index (Chand and Singh, 2016). Subsequently, districts within each state were purposively selected based on the presence of supporting institutions and the number of assisted agri-entrepreneurs, facilitating a comparative analysis with distinct contrasts. Two districts each within the states were selected purposively, namely, Kota and Jaipur from Rajasthan, Hyderabad and Rangareddy from Telangana, based on the number of promoting institutions available in the district. It was based on a rationale that the higher the number of institutions, in turn, gives a higher probability of required number of respondents for sampling, hence, data is more amenable to generalization. A total of fifty agri-entrepreneurs were selected from each district that included 20 farm-based entrepreneurs, 20 off-farm entrepreneurs, and 10 service/tech entrepreneurs using stratified random sampling.

To collect the relevant data, a questionnaire was prepared consisting of data points for enumerating psycho-personal and socio-economic factors (24 Nos.) and institutional factors (40 Nos.). The entrepreneurs were asked to respond, based on factual data and psychometric scales for psycho-personal and socio-economic factors, whereas the institutional factors were measured on a continuum of 1-5, with 1 being lowest and 5 being highest weightage, respectively. Certain psychometric scales used in the study includes Risk taking behaviour (Techno Net Asia, 1981); Achievement motivation (McClelland, 1954); Locus of Control (Rotter, 1966); Innovativeness (Techno Net Asia, 1981); Scientific Orientation (Supe, 1969); Level of Aspiration (Mutthaya, 1971); Self-determination (Deci and Ryan, 1985); Proactiveness (Greenglass, 1999); Hope of Success (Techno Net Asia, 1981); and Self-efficacy (Ralf Schwarzer and Jerusalem, 1995). For the present study, agri-entrepreneur is operationalized as, a person involved in either of the enterprises viz. (i) Farm based entrepreneurs (Exotic Fruits/Vegetables cultivation, Organic farming, Floriculture, Aquaculture, Protected cultivation etc.), (ii) Off-farm entrepreneurs (poultry, exporter, animal husbandry and dairying, honey production, mushroom, food processing, cottage industry, vermicomposting etc.), and (iii) Service/Tech entrepreneurs (cold storage, agri-tourism, agri clinics and agri-business centers, custom hiring centers, drone tech, mobile app based, incubatees of ABI's etc.).

The entrepreneurs were assessed for support provided by the institutes, through an "Index of Perceived Effect of Institutional Support for Agripreneurs (I-PEISA)" developed for the study, as a comprehensive tool to evaluate the perceived impact of institutional support on agri-entrepreneurs. A total of 46 indicators spanning five key dimensions—natural, physical, financial, human, and social capital—were identified through extensive literature reviews, expert consultations, and inputs from stakeholders. To ensure relevance and precision, the indicators underwent a relevancy test conducted by 27 experts, who rated each indicator on a five point continuum scale, with only those scoring above a threshold of 3.5 were retained. The validity of the index was further affirmed through a Content Validity Index (CVI), achieving a robust average score of 0.92. Normalization techniques were employed to standardize the data, and weights were assigned to dimensions using methods such as the Equal Weightage Method (EWM), Budget Allocation Process (BAP), and Shannon's Entropy Method (SEM) Schwarzer and Jerusalem 1995. Sensitivity and uncertainty analyses further validated the reliability of the index, allowing it to reflect variations across entrepreneurial categories, ensuring a nuanced assessment of the perceived effect of institutional support. Utilizing the derived index score, i.e. "perceived effectiveness" score as a dependent variable, psycho-personal and socio-economic factors were regressed to find out the determinants. Principal Component Analysis (PCA) was employed to pinpoint institutional factors crucial for successful interventions.

Linear Multiple Regression

A linear multiple regression analysis was performed to discern the factors influencing the effectiveness of interventions, for which dependent variable was "Index Score" derived through I-PEISA. Utilizing a set of independent variables, the relationship was systematically analyzed. The statistical software R was employed to execute the analysis. The regression results furnished coefficients for each independent variable, elucidating their individual contributions to the variation observed in the Index score. Similar methodology was applied to determine the factors influencing successful enterprise among the three categories of entrepreneurs viz. Farm based, Off farm, and Service/Tech entrepreneurs.

In the context of linear multiple regression, the relationship between the dependent variable (Index score) and multiple independent variables (Age, Gender, Marital Status, etc.) can be expressed through the following equation:

$$\text{Index Score } (Y) = \beta 0 + \beta 1.\ \text{Age} + \beta 2.\ \text{Gender} + \ldots + \beta 22.\ \text{Self-Efficacy} + \varepsilon \qquad (1)$$

Here:

- β_0 is the intercept term,
- $\beta_1, \beta_2, \ldots, \beta_{22}$ are the coefficients representing the impact of each independent variable,
- Age, Gender,.. Self-efficacy etc. are the respective independent variables, and
- ε is the error term, accounting for unobserved factors.

The coefficients were interpreted to understand the strength and direction of the relationships. Additionally, the overall model significance and the individual significance of each independent variable were assessed. This analysis aimed to discern which factors, among age, gender, marital status, and others, significantly affected the success of agri-enterprises based on the provided Index score.

Principal Component Analysis

To identify institutional factors influencing an effective intervention, the method of factor analysis, specifically Principal Component Analysis (PCA), was used. The factors were selected based on the stage wise methodology as follows:

Stage-I: Curating the List of Factors Influencing Success of Enterprise

The factors were categorized into technical, financial, implementation, operational, and administrative dimensions. Through a thorough review of literature and discussion with domain experts, a list of factors was curated.

Stage-II: Weightage Assignment for Factors

The curated list of factors was administered to the respondents and asked to assign weightage to each factor based on their perceived importance, on a five-point continuum. The factors that were perceived to influence an effective intervention were assigned higher weightage and vice-versa.

Stage-III: Selection of Principal Components Explaining Highest Variance

The principal component explaining the highest variance (based on eigenvalues) was considered for identifying the determinant of effectiveness. Given that, various factors impact different types of entrepreneurs, namely, farm-based, off-farm, and service/tech, each entrepreneurial category was surveyed separately to assess their agreement with these factors.

Stage-IV: Factor-Wise Contribution

Based on rotated component matrix, those items that occupied more than 0.5 communality score were considered as the determinants of an effective intervention. For all three categories of entrepreneurs, the same method was followed to elucidate the determinants.

RESULTS AND DISCUSSIONS

The results of linear regression analysis between effective interventions and the social, psycho-personal traits of farm-based, off-farm, and service/tech agricultural entrepreneurs are presented in Table 1 (further detailed in Supplementary Table I).

Table 1. Regression table for personal variables of entrepreneurs.

Model Coefficient – Index score			
Predictor	Estimate		
	Farm based	Off farm	Service/Tech
Intercept	2.02531**	2.09651*	2.88532**
Age	-1.86e−4	-0.00114	-0.00194
Gender	0.00742	0.00835	0.00584
Marital Status	0.04172*	0.07733*	-0.00492
Family size	0.00219	1.99e-4	-0.00131
Family type	-0.00468	0.00919	0.04052
Formal Education	-0.01062*	0.01554	-0.00439
Training received	0.00517	0.05500	0.01031
Training duration	-7.79e−4	0.00492	0.00989
Entrepreneurial experience	8.75e-4	0.00437	0.00973
Landholding	-0.00340	-0.00271	-0.01121*
Annual income	0.00476*	0.00119	0.00528*
Social participation	-0.01353	0.06666*	-0.05320*
Cosmopoliteness	-0.08517*	-0.08739	0.04322
Risk taking behaviour	0.03246	0.58055**	-0.03134
Achievement motivation	0.24745**	-0.81748*	0.05242
Locus of control	0.01997	-0.00205	0.18168
Innovativeness	-8.94e−4	-0.38868*	0.06448
Scientific orientation	0.01573	0.78884	0.25754*
Level of aspiration	-0.00382	-0.02156	0.00297
Self determination	0.01684	0.04430	0.05431
Proactiveness	0.04270	-0.04311	-0.25155
Hope of success	0.01576*	0.03201	-0.21001
Self-efficacy	0.06967	0.02146	0.08222

*Significant at 5% level; **Significant at 10% level.

Psycho-Personal and Socio-Economic Determinants

Among the entrepreneurs, personal factors viz. age, gender, family size and family type, did not significantly influence the effectiveness of intervention. Whereas marital status was significantly influencing among farm based and off-farm entrepreneurs. A positive influence observed was supported by studies like Nabi *et al*. (2017) and Singh *et al*. (2020), which highlight spousal support and shared responsibilities as drivers of entrepreneurial success. Education and experience including formal education, training received, training duration and entrepreneurial experience had shown a varied influence on the success of enterprise. Among farm-based entrepreneurs, formal education appeared to have a notably negative impact, in contrast to previous findings by Mustapha *et al.* (2020) and Krueger (2020). This discrepancy might have stemmed from the fact that surveyed respondents with lower education levels have been directly involved in their businesses for an extended period after completing their education. Conversely, respondents with post-graduate and doctoral degrees might have less experience, potentially limiting their entrepreneurial success.

Among the socio-economic characteristics, as depicted in Table 1, landholding, annual income, social participation, cosmo-politeness were significantly influencing the entrepreneurial success. Farm based entrepreneurs depicted a positive influence on entrepreneurial success in relation to cosmopoliteness and annual income whereas off-farm entrepreneurs depicted influence due to social participation. The service/tech entrepreneurs depicted significant influence due to landholding, annual income and social participation. The reasons could be that the information access and resource availability are the enablers of a successful enterprise. Entrepreneurs benefit from larger landholdings for scale and diversification, while higher income offers financial flexibility, reducing stress, and enhancing resilience against economic changes. Those with a cosmopolitan mind set are more open to new opportunities and diverse markets, while active participation in social networks provides access to resources, knowledge, and support, fostering success through valuable connections, mentorship, and collaboration. Similar results were reported by Aldrich and Zimmer (1986), Fairlie and Robb (2007), Jayne *et al.* (2010), Singh and Pandey (2011), Warburton and McKinlay (2017), and Kademani *et al*. (2020).

The psycho-personal factors, depicted in Table 1, such as risk-taking behaviour, achievement motivation, locus of control, innovativeness, scientific orientation, level of aspiration, and self-determination, few have been found to significantly influence the success of entrepreneurship. These factors contribute to shaping an individual's mind set, attitude, and approach towards entrepreneurial endeavours, impacting their ability to identify opportunities, overcome challenges, and achieve their goals in the business world. The success of farm-based entrepreneurs was significantly influenced by achievement motivation and hope of success, whereas off farm entrepreneurs were influenced by risk-taking behaviour, achievement motivation, innovativeness and scientific orientation.

Among the service/tech entrepreneurs scientific orientation and pro-activeness are found to be significantly influencing the entrepreneurial success. Chen *et al*. (2018) found that achievement motivation is positively associated with entrepreneurial success, as individuals with high achievement motivation are more likely to set challenging goals, persist in the face of obstacles, and strive for success. This aligns with the finding that achievement of motivation influences the success of both farm-based and off-farm entrepreneurs, who may face unique challenges, but share the common goal of achieving success in their ventures. Furthermore, risk-taking behaviour has been identified as a key determinant of entrepreneurial success (Torres *et al.*, 2016). Off-farm entrepreneurs, who typically operate in more dynamic and competitive environments, may need to exhibit higher levels of risk-taking behaviour to seize opportunities and adapt to changing market conditions. Similarly, innovativeness and scientific orientation are crucial for off-farm entrepreneurs, who often rely on technology and innovation to differentiate their offerings and stay competitive in the market (Hassan *et al.*, 2020). In the case of service/tech entrepreneurs, scientific orientation and pro-activeness play a significant role in driving entrepreneurial success. Research by Linan *et al.* (2011) suggests that individuals with a scientific orientation tend to approach problems analytically, leveraging research and data-driven insights to inform their business decisions. Pro-activeness, on the other hand, enables entrepreneurs to anticipate market trends, identify emerging opportunities, and take proactive measures to capitalize on them. The influence of psycho-personal factors on entrepreneurial success varies across different types of entrepreneurs due to the unique challenges and opportunities inherent in each. While achievement motivation is a common driver across all sectors, factors such as risk-taking behaviour, innovativeness, scientific orientation, and pro-activeness may exert varying degrees of influence depending on the nature of the entrepreneurial endeavour. The results comply with Hajong (2014), Kobba *et al.* (2021), Afroz *et al*. (2022), and Gupta *et al.* (2023).

Institutional Factors Determining an Effective Intervention

Principal Component Analysis was employed to identify diverse factors, with the factors within the principal component explaining the highest variance considered a determinant of effectiveness. The results indicate that various technical, financial, implementation, operational, and administrative factors significantly contributed to the effectiveness of interventions. The variance explained by the first component of PCA was 43.6% for farm-based entrepreneurs, 55.7% for off-farm entrepreneurs and 64.0% for service/tech entrepreneurs (Ref.: Supplementary Table II). Thus, these components were selected for further analysis. All factors contributing more than 0.5 communality score were tick marked (✓) in Table 2, that presents a comprehensive analysis of various factors influencing the effectiveness of entrepreneurship promotion interventions.

Technical Factors

Considering the results from the Table 2 regarding the technical factors, it could be concluded that support during project formulation and preparation was significantly important to all the categories of entrepreneurs, whereas vocation-oriented syllabi for entrepreneurs in training and hands-on training exposure were marked important by farm and off farm entrepreneurs. Conforming to dynamic quality and standards of the current market is an important consideration for both off farm and service/tech entrepreneurs. Tailor made interventions for each agri-enterprise was a determinant for off farm entrepreneurs. Additionally, availability of labs and facilities for prototype experimentation and also availability of relevant and reliable data on target population is considered crucial for service/tech entrepreneurs, which is justified considering their business orientation. Factors like conducting need assessment surveys, a bottom-up approach for the preparation of Entrepreneurship Development Programs (EDP), and the involvement of delivering professionals in the development of interventions were not uniformly agreed upon across the different entrepreneurial categories, suggesting variations in their perceived significance. Factors such as support during project formulation and preparation and vocation-

Table 2. Assessment of factors determining an effective intervention.

Sl. No.	Factors	Farm based	Off farm	Service/ tech
	Technical factors			
T1	Support during project formulation and preparation to entrepreneurs	✓	✓	✓
T2	Conducting need assessment surveys			
T3	Availability of labs and facilities for prototype experimentation			✓
T4	Vocation oriented syllabi for entrepreneurs in training	✓	✓	
T5	Hands-on-training exposure	✓	✓	
T6	Tailor made interventions for each agri enterprise		✓	
T7	Bottom-up approach for preparation of EDP			
T8	Conforming to dynamic quality and standards of current market		✓	✓
T9	Involvement of delivering professionals in development of the intervention			
T10	Availability of relevant and reliable data on the target population			✓
	Financial factors			
F1	Adequate funding support from the government	✓	✓	
F2	Priority lending in reduced rate of interest to entrepreneurs	✓		✓
F3	Incentives for production to agri-entrepreneurs		✓	✓
F4	Tax benefits and insurance for initial years of enterprise		✓	✓
F5	Clearly defined funding pattern for a period of time			✓
F6	Monetary support for creation of Minimum Viable Product		✓	✓
	Implementation factors			
I1	Monitoring, evaluation and impact assessment of the intervention.			✓
I2	External accountability of the interventions	✓		
I3	Co-designing implementation plan with all stakeholders	✓	✓	
I4	Long term, strategic involvement of institutions	✓	✓	✓
I5	Creating awareness regarding the intervention through adequate mass media engagement			
I6	Continuous follow-up support and troubleshooting		✓	✓
I7	Identifying and establishing appropriate relationships and agreements with other collaborators and key stakeholders necessary for implementing and supporting the intervention	✓	✓	✓
I8	Established timelines or schedules to guide the implementation of the intervention over time	✓		
I9	Appropriate combination of interventions for best results			
	Operational factors			
O1	Training institute-Industry-Market-Entrepreneur (T-I-M-E) connect	✓	✓	✓
O2	Procurement of raw materials for utilization of agri-entrepreneurs to prepare a minimum viable product		✓	✓
O3	Providing market intelligence to agri entrepreneurs		✓	
O4	Adequate man-power for specific intervention			
O5	Dedicated and qualified staff for handling specific interventions			✓
O6	Focus on sustainability of the intervention	✓		
O7	Decentralized mode of delivery	✓		
	Administrative factors			
A1	Simplified procedure for application to avail benefits			✓
A2	Explicitly defined procedures for utilization of funds and for choosing beneficiaries		✓	✓
A3	Organizational commitment in terms of funds and manpower to fulfill the mission of the intervention	✓	✓	✓
A4	Consistent policies as against volatile changes in policy formulations due to changing political scenario			✓
A5	Degree of prescriptiveness of policies and ability to tailor them to local context			
A6	Ability of the institution to provide extra staff in case of need/early stages of implementation			
A7	Consistent political support for interventions at local, regional, and national levels		✓	✓
A8	Formal reinforcement to adopt the intervention (Guidelines, quality indicators, certificates, inspection)	✓	✓	✓

oriented syllabi, are crucial as they provide entrepreneurs with the necessary knowledge and skills to develop and execute their projects effectively. Comprehensive business planning significantly increases venture survival rates as reported by Delmar and Shane (2003). It can be inferred that practical training and industry-aligned curriculum leads to higher entrepreneurial self-efficacy (Venkataraman *et al.*, 2007; Manolova *et al.*, 2019).

Financial Factors

Among the financial factors, adequate funding support from the government was considered a determinant of effective intervention for both farm-based and off-farm entrepreneurs. Priority lending in reduced interest rates to entrepreneurs was marked as determinant for off-farm and service/tech entrepreneurs, emphasizing their significance in these categories. Incentives for production, tax concessions and insurance coverage during the initial years, along with financial support for developing a Minimum Viable Product (MVP), are considered critical for nurturing off-farm and service/technology-based entrepreneurs. A clearly defined funding patterns for a period of time is marked important for service/tech entrepreneurs. This differential marking suggests that the perceived importance of financial factors varies across different types of entrepreneurs, reflecting the distinct needs and challenges associated with each category. Financial factors, including incentives for production and priority lending, play a pivotal role in enabling entrepreneurs to access the resources needed to start and grow their ventures (Beck *et al.*, 2007). Performance based rewards increases firm productivity and innovation as reported by Lerner and Tirole (2004) and Gómez-Meijide *et al.* (2011). The access to credit positively impacts new venture creation and survival as reported by Brown *et al.* (2014).

Implementation Factors

Table 2 highlights key implementation factors influencing the effectiveness of entrepreneurship interventions for three categories of entrepreneurs. A long-term strategic involvement of institutions, identifying and establishing appropriate relationships and agreements with other collaborators and key stakeholders necessary for implementing and supporting the interventions were both crucial factors agreed upon by all the categories of entrepreneurs. Co-designing implementation plan with all stakeholders was an important consideration by both farm and off farm entrepreneurs. Continuous follow-up and troubleshooting were an important factor for off farm and service/tech entrepreneurs. Monitoring, evaluation, and impact assessment of the interventions was solitarily felt important by service/tech entrepreneurs. External accountability and established timelines or schedules to guide the implementation of the intervention over time were marked important by farm-based entrepreneurs only. However, factors like creating awareness regarding the intervention through adequate mass media engagement and appropriate combination of interventions for best results could not gather agreement among any of the entrepreneurial categories. This suggests that implementation factors play a critical role in shaping the success of entrepreneurship promotion interventions, with variations based on the entrepreneurial category and associated characteristics. Implementation factors, such as long-term strategic involvement of organizations and continuous follow-up support, were essential for ensuring that interventions are implemented effectively and sustained over time. Continued support and mentor engagement from incubators are crucial for boosting firm survival rates and enhancing performance (Aerts *et al.*, 2007; Clarysse *et al.*, 2011). Establishing appropriate relationships and agreements with other collaborators and stakeholders also enhances the success of interventions by fostering collaboration and resource sharing. Strong network connections lead to resource sharing further leading to opportunities of innovation and growth (Uzzi and Gillespie, 2002; Zahra and George, 2002).

Operational Factors

As depicted in Table 2, operational factors influencing the effectiveness of interventions across different entrepreneurial types, amongst which the Training Institute-Industry-Market-Entrepreneur (T-I-M-E) connect, was most emphasized by all three categories of entrepreneurs. Procurement of raw materials for creating a Minimum Viable Product (MVP) was marked important by off farm and service/tech entrepreneurs. Market intelligence is emphasized by off farm entrepreneurs. Dedicated and qualified staff for specific interventions was of importance for service/tech entrepreneurs, which is justified based on the diversity of such entrepreneurs. Focusing on sustainability and a decentralized mode of delivery is considered important by farm-based entrepreneurs. The requirement of manpower for specific interventions was not a major consideration for any category of entrepreneurs. This reveals the significance of operational factors, such as connectivity, resource procurement, market intelligence, staffing, sustainability focus, and decentralized delivery in shaping the success of entrepreneurship promotion interventions, with variations based on the entrepreneurial category and associated characteristics. Factors like T-I-M-E connect and procurement of raw materials for MVP, are critical for bridging the gap between training and market access, thereby increasing the likelihood of entrepreneurial success. From the earlier studies like Bruin *et al.* (2012) and Phan *et al*. (2015) it is depicted that university-industry linkages and market orientation positively impacted venture performance. Procurement of raw materials for MVP for enabling rapid prototyping and testing is crucial for early feedback and validation as emphasized by Ries (2011) for building and learning in start-up ventures.

Administrative Factors

Reflecting on the factors related to administration, it is revealed that organizational commitment in terms of funds and manpower along with formal reinforcement to adopt the intervention with specific guidelines, quality indicators, certificates and inspection were the crucial and most emphasized factors collectively agreed by all categories of entrepreneurs. Explicitly defined procedures for fund utilization and choice of beneficiaries along with consistent political support for interventions at local, regional, and national levels were marked to be determinants of an effective intervention by off-farm and service/tech entrepreneurs. The service/tech entrepreneurs also advocated for simplified procedures of application and consistent policies sans volatile changes implicated by political scenario. Various other factors like degree of prescriptiveness of policies and ability to tailor them to local context, the ability of the institution to provide extra staff in case of need/early stages of implementation could not gather overall agreement among the entrepreneurial categories. Organizational commitment in terms of funds and manpower, as well as formal reinforcement through guidelines, quality indicators, and certificates are necessary for ensuring that interventions are properly supported and regulated. Results depict that long-term funding and dedicated staffing in incubators lead to better firm survival (Clarysse *et al.*, 2011; Bosma *et al*., 2018). Similar results were reported regarding clear mentoring guidelines to enhance the effectiveness of support programs by Aerts *et al.* (2007). Overall, these results are supported by previous findings that emphasize the importance of various factors in promoting entrepreneurship and fostering entrepreneurial success. For instance, studies by Kademani *et al*. (2024); Shane and Venkataraman (2000) and Audretsch and Keilbach (2004) highlight the significance of access to finance, training, and supportive institutional environments in facilitating entrepreneurship. Research by Baumol (1990) and North (1990) underscores the role of institutions in shaping entrepreneurial behaviour and outcomes.

CONCLUSIONS

This comprehensive study reveals that agri-entrepreneurial success is shaped by a complex interplay of individual characteristics and institutional support mechanisms. The findings demonstrate that different categories of entrepreneurs, i.e. farm-based, off-farm, and service/tech are influenced by distinct combinations of psycho-personal traits and institutional factors. Achievement motivation emerged as a significant factor for farm-based and off-farm entrepreneurs, while scientific orientation and pro-activeness were crucial for service/tech entrepreneurs. Institutional support mechanisms, including technical assistance, financial aid, and administrative frameworks proved essential across all categories but with varying degrees of importance. Based on these insights, the study recommends designing category-specific training programmes aligned with market needs and supported by practical exposure. It also emphasizes the need for differentiated financial support mechanisms, including sector-specific lending and targeted incentive schemes. Further, strengthening institutional support through improved T-I-M-E (Training Institute–Industry–Market–Entrepreneur) linkages and simplifying administrative processes is considered essential for effective entrepreneurial development.” The study emphasizes the need for a holistic approach that combines psychological development with robust institutional support, tailored to each entrepreneurial category's unique needs.

The study's geographical constraint to two states limits its generalizability across diverse agricultural contexts, while its cross-sectional nature may not fully capture the evolutionary dynamics of entrepreneurial development. The time constraints of doctoral research framework also restricted the scope of investigation into regional variations of institutional frameworks. To address these limitations, future research should expand geographical coverage to understand regional variations in entrepreneurial ecosystems, conduct longitudinal studies to track development stages and success factors over time, and examine urban-rural distinctions in agri-entrepreneurship. Additionally, investigating the role of digitalization and technological advancement could provide insights into scaling support systems effectively. Comparative studies between different agricultural zones and socio-economic contexts could reveal unique challenges and opportunities, leading to more nuanced intervention strategies. Research focusing on the impact of policy changes and institutional reforms on entrepreneurial outcomes would also contribute valuable insights for policy makers and supporting institutions.

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عوامل تعیین‌کننده شخصی و نهادی یک مداخله مؤثر در کارآفرینی

سوجی کادمانی، مانجیت سینگ ناین، راشمی سینگ، شیو کومار، راجندر پارساد، دینش کومار شارما، و سورجیا کانتا روی

چکیده

این پژوهش از تحلیل رگرسیون خطی و تحلیل مؤلفه‌های اصلی برای بررسی عوامل تعیین‌کننده موفقیت کارآفرینی و شناسایی عوامل مؤثر در مداخلات مؤثر در سه دسته کارآفرینی متمایز استفاده کرد: کارآفرینان مزرعه‌دار، کارآفرینان خارج از مزرعه و کارآفرینان خدمات/فناوری. داده‌ها از طریق مصاحبه‌های ساختاریافته با دویست کارآفرین کشاورزی در ایالت‌های راجستان و تلانگانا جمع‌آوری شد. تحلیل رگرسیون نشان داد که متغیرهای متنوع روانی-شخصی و اجتماعی-اقتصادی مانند وضعیت تأهل، سطح درآمد و انگیزه پیشرفت تأثیر معناداری دارند. تحلیل مؤلفه‌های اصلی(principal component analysis) ، بینش‌های ارزشمندی در مورد عوامل نهادی زیربنایی مداخلات مؤثر در ارتقای کارآفرینی ارائه داد. عوامل فنی مانند پشتیبانی متناسب از پروژه، عوامل مالی شامل بودجه دولتی و مشوق‌های مالیاتی و سازوکارهای اجرایی قوی شامل همکاری ذینفعان برجسته شدند. عناصر عملیاتی مانند پیوندهای موسسه آموزشی-صنعت-بازار-کارآفرین، تعهدات اداری و ثبات سیاست‌ها، در مجموع اثربخشی مداخله را در سراسر اکوسیستم‌های کارآفرینی شکل دادند. این بررسی جامع از عوامل تعیین‌کننده فردی و نهادی، دیدگاهی جامع در مورد گسترش شرکت‌های کشاورزی (agri-enterprises) موفق ارائه داد و بر نیاز به رویکردهای زمینه‌ای (contextualized approaches) ه ویژگی‌های شخصی را با مداخلات نهادی متناسب (tailored institutional interventions) همسو می‌کنند، تأکید کرد.

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Risk Managing of Wheat Sustainable Production in Iran: A Portfolio Theory

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ABSTRACT

The challenge of water scarcity poses a significant environmental challenge for the agricultural sector, jeopardizing the sustainable production of vital crops like wheat. Iranian provinces that produce wheat have varying water resources and climatic conditions. These differences have resulted in distinct economic benefits and environmental risks in wheat production among the provinces. In this study, the water footprint of wheat in each province was calculated from 2000 to 2020, and its environmental costs were deducted from the gross margin. Consequently, the social benefit was considered as the return of the wheat production portfolio in each province to manage the risk of sustainable production. Subsequently, the portfolio theory was employed through quadratic mathematical programming to minimize the social benefit-risk and determine the proportion of wheat cultivation in each province for optimal portfolio and sustainable production. The results showed that the provinces of Khuzestan (21.6%), Fars (17.1%), Hamedan (16.1%), Kurdestan (13.2%), Khorasan Razavi (11.4%), Golestan (11.3%), Qazvin (5%), and Kermanshah (4.3%) are in the optimal portfolio. In the optimal portfolio, a significant share of wheat production was related to the provinces with low risk in production (Khuzestan and Fars). The findings suggest that it is necessary to consider economic risks along with environmental risks to achieve sustainable production in the long run. As a result, the eastern and central provinces (Sistan and Baluchestan, South Khorasan, Semnan, Isfahan, Yazd) with the highest water footprint were removed from the optimal portfolio, and the western provinces with higher gross margin and lower water footprint were replaced with a larger share (Kermanshah, Hamedan, and Kurdistan provinces).

Keywords: Portfolio theory, Risk, Social benefit, Sustainable wheat.

INTRODUCTION

About 60% of the world harvested area is devoted to grains. In 2020, global grain production reached 2.79 billion tons, with 649.759 million tons related to wheat. Iran produced 23.81 million tons, 70% of which was wheat, accounting for 50% of arable land cultivation, highlighting its significant agricultural role (FAO, 2021). Agricultural production, especially grains, plays a vital role in food security and Gross Domestic Product (GDP) in Iran.

Iran is located in an arid and semi-arid region with a climate range of hot to humid Caspian Coasts, temperate central plateau, hot and dry southern areas, and cold mountainous regions (Najafi and Alizadeh, 2023). Over two million hectares of irrigated and four million non-irrigated lands are used for wheat production (MAJ 2020). There are two main types: dryland and irrigated. The largest dryland wheat areas are in Kurdistan, East Azerbaijan, Hamedan, Kermanshah, and Zanjan, while the largest irrigated areas are in Khuzestan, Fars, Khorasan Razavi, and Golestan provinces (MAJ 2020). Figure 1 shows the harvested wheat area and

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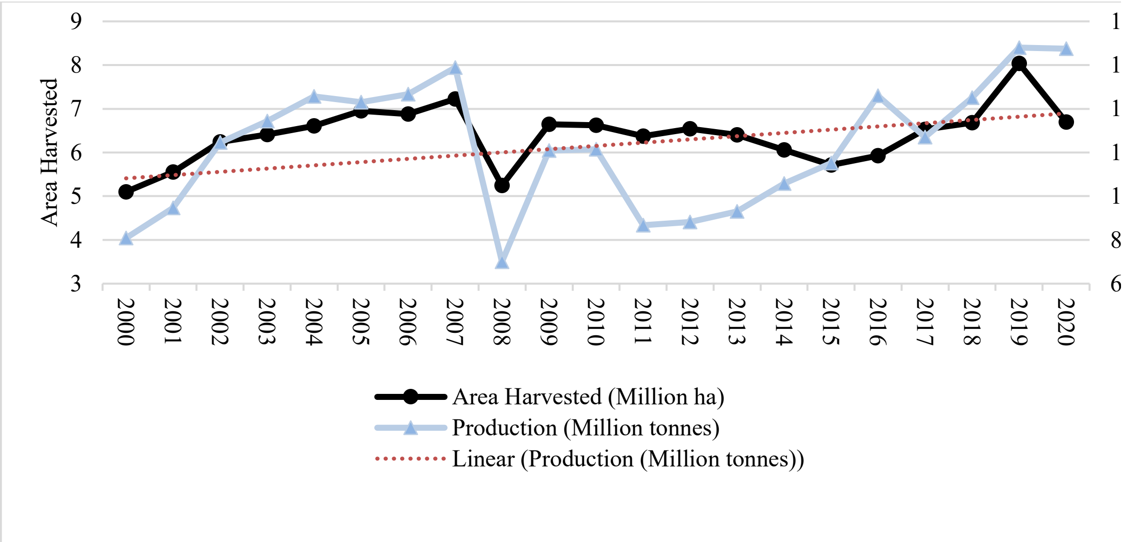


Figure 1. Area harvested and production of wheat in Iran (FAO, 2020).

production trend during the period 2000-2020. Over this period, wheat production has followed an upward trend, largely because attaining self-sufficiency in wheat production has been a major economic priority for Iran in recent years (MAJ, 2020). To meet the needs of the country, which is annually about 12 million tons, the government purchases this product at a guaranteed price to ensure the producer's income and reduce dependency on agricultural production imports (MAJ, 2020). Although a guaranteed price could lead to a higher level of wheat production, there is no guarantee that it also leads to sustainable production in the long run.

Water scarcity is considered one of the long-term issues in agricultural production in Iran (Zhang *et al*., 2016). Demand for water consumption has significantly increased in recent years due to the expanding agricultural activities and the improper use of water. Additionally, there has been a decrease in average annual rainfall over the last few decades as a result of climate change, leading to a reduction in water resources and unreliable access (Chouchane *et al*., 2018; Fathi *et al*., 2020). Thus, the concept of water footprint has been introduced to measure the extent of unsustainable and precarious access to water. The water footprint takes into account the quantity and quality of water (Hoekstra and Chapagain, 2007, 2008; Mekonnen and Hoekstra, 2011; Hoekstra and Mekonnen, 2012). Water footprint refers to the amount of freshwater used to produce the products (Yang *et al*., 2006), which is a multidimensional indicator including the quantity of water (amount of water consumed, known as blue and green water), and the quality of water (amount of contaminated water, known as grey water) (Hoeksta and Chapagain, 2007, 2008; Mekonnen and Hoekstra, 2011; Hoekstra and Mekonnen, 2012; Tom *et al*., 2016; D'Ambrosio *et al*., 2018). Water footprint is influenced by climatic variables like temperature, wind speed, precipitation, humidity, solar radiation, and chemical fertilizer application, posing risks and uncertainties for crop yield and sustainable production (Monjardino *et al*., 2013; Herold *et al*., 2018; Fathi *et al*., 2020). Climate change may cause a decrease in Iran's non-irrigation land and irrigated grain yield over the next 50 years. Risks in sustainable production are influenced by price and market factors (Fathi *et al*., 2020; Sewando, 2022). To reduce risks and have sustainable production, a combination of economic and environmental criteria is needed, considering the environmental side effects of agricultural activities. Therefore, gross margin and water footprint can be suitable criteria for economic evaluation and environmental costs, respectively.

Agricultural risk management has been a focus in various studies (Marko *et al*., 2016; Sewando, 2022; Nguyen-Huy *et al*., 2018; Fathi *et al*., 2020), with a particular emphasis on capital risk management (Kim, 2021; Kim and Choi, 2019; Paquin *et al*., 2016; Atmaca, 2022). Portfolio theory, which aims to determine a set of assets that can achieve minimum risk with the highest return, has been used to maximize profits and minimize risk in agriculture (Markowitz, 1991; Viganò and Castellani, 2020; Bai *et al*., 2021; Atmaca, 2022; Ziakas, 2021). Studies have shown that implementing a crop portfolio can increase yields, reduce financial effects, and enhance profitability (Barkley *et al*., 2010; Goodwin and Hungerford, 2015; Marko *et al*., 2016; Nguyen-Huy *et al*., 2018; Paut *et al*., 2019; Sewando, 2022). Geographical diversity has also been explored as a potential tool for farmer compliance and decision support. Paut *et al*. (2019) found that selecting appropriate varieties can reduce expected yield fluctuations by over 77%. Sewando (2022) evaluated the effectiveness of risk reduction strategies in portfolio diversity among agro-pastoralists, finding that integrated portfolios with good returns and moderate risk could be created through strategic choices between high-return, high-risk or low-return, low-risk crop, and livestock activities. The relationship between the agricultural sector and natural resources, as well as the environment, is significant. As a result, effective management of natural assets is vital for this sector. Nevertheless, there is a scarcity of research focusing on the risk management associated with this form of capital (Alvarez *et al*., 2017).

Water is a critical natural resource whose conservation is essential for enhancing social welfare. In light of this perspective, the current research seeks to address the challenges associated with managing sustainable production risks. This study distinguishes itself from others by focusing on sustainable production while simultaneously minimizing the risks to social benefits across various provinces. Such an approach can provide insights into the optimal integration of diverse wheat-producing regions within the country. Therefore, the outcomes of this study could inform the government in crafting targeted policies to support wheat production in these areas. To achieve this objective, portfolio theory was employed. The optimal portfolio identifies the contribution of each province to wheat production in Iran, taking into account social, economic, and environmental benefits. The criterion for social benefit was defined in terms of returns, ensuring that sustainable wheat production is maintained by minimizing long-term risks, thereby guiding the government in making informed decisions regarding this agricultural product.

The present paper is organized as follows: Initially, the water footprint of wheat production in different provinces of Iran was calculated for the period 2000-2020, and the results were analyzed during this period. Then, by calculating the cost of water footprint (environmental costs) and subtracting it from the gross margin, the social benefit of wheat production was calculated for different provinces during 2000-2020. Finally, using portfolio theory, the optimal efficient frontier and, consequently, the optimal portfolio were determined for wheat-producing provinces in Iran and compared with the current conditions of the country.

MATERIALS AND METHODS

As the basis of modern portfolio theory (Moss, 2010), Harry Markowitz's mean-variance portfolio model was used to determine the optimal portfolio to minimize the risk of social benefit subject to the given level of social benefit. In this model, the minimum variance $(risk\ of\ social\ benefit, \delta_p^2)$ is determined for a certain level of Return (R*) in the portfolio. The quadratic mathematical programming model (Equation 1) was used for this purpose.

$$\text{Min } Z=\delta_p^2$$
$$St: \overline{Y}_p = \sum_{i=1}^{n} W_i\overline{Y}_i = R^* \quad i = 1,\ldots,30$$
$$\sum_{i=1}^{n} W_i=1$$
$$W_i \geq 0 \qquad (1)$$

In Equation (1), $\overline{Y}_i$ represents the average social benefit derived from wheat in the i[th] province. This average social benefit is determined for the period 2000-2020. In next section, a method is provided for calculating social benefits, W_i is the decision variable and represents the share of each province in the total area under cultivation for wheat in the country. In the optimal portfolio, the average expected return of the portfolio ($\overline{Y}_p$) is equal to the Return (R*). The calculation of portfolio return variance, as outlined by Prol and Kim (2022), is presented in Equation (2). Here, σ_i^2 represents the variance associated with the social benefit of the i[th] province.

$$\delta_p^2 = \sum_{i=1}^{n} W_i^2\, \sigma_i^2 + \sum_{i=1}^{n}\sum_{j\neq i}^{n} W_i\ W_j.Cov(\overline{Y}_i\,.\overline{Y}_j) \qquad (2)$$

Social Benefit

Social benefits were used as portfolio returns to determine sustainable wheat production (Equation 3).

$$\boldsymbol{\gamma_{it}} = P_{it}Y_{it} - TVC_{it} - P_{wit}WF_{it} \qquad (3)$$
$$\forall i = Proviance: 1.2 \ldots .30$$
$$\forall t = 2000. \ldots .2020$$

Where, P_{it} is the real Price (Real price is the nominal price divided by the consumer price index (CPI)) (of wheat (10^4 Rials per hectare), Y_{it} represents yield (t ha^{-1}), TVC_{it} is total variable cost (10^4 Rials/ha), P_{wit} is the real Price of water, and WF_{it} represents the Water Footprint of wheat in province i in time t.

It should be noted that after calculating the water footprint of wheat (including blue, green, and grey water), it was multiplied by the price per cubic meter of water to estimate the environmental costs of wheat production, it was multiplied by the price per cubic meter of water to obtain the environmental costs ($P_{wit}WF_{it}$) of wheat production. This value was then subtracted from the gross margin to obtain the social benefit (γ_{it}).

Water Footprint (WF) Calculation

WF is used as an environmental criterion in this research. The total WF during the crop growth season is derived from the total components of blue, green, and grey water (Hoekstra and Chapagain, 2007, 2008; Hoekstra *et al*., 2011):

$$WF: WF_{it} = WF_{it.green} + WF_{it.blue} + WF_{it.grey}. \qquad (4)$$
$$\forall i = Proviance: 1.2 \ldots .30\ ,$$
t=2000, ….,2020

Where, i and t represent different provinces (1, 2, .., 30) and time (1 to 21), respectively. $WF_{it.green}$ is green, $WF_{it.blue}$ is blue and $WF_{it.grey}$ is grey WF for the i[th] province and t[th] year in terms of (m^3 ton^{-1}). To calculate the green WF, effective rainfall was calculated by the US Department of Agriculture method (USDA, 1993). Therefore, effective rainfall during the crop growing season is calculated according to Equation (5), and the green WF is calculated by Equation (6).

$$If: P < 250\ mm.\ P_{eff} = \left(P/_{125}\right) \times (125 - 0 \cdot 2P) \qquad (5)$$
$$If: P > 250\ mm.\ P_{eff} = 125 + 0 \cdot 1P$$

$$WF_{it.green} = \frac{P_{eff} \times 10}{Y_{it}} \qquad (6)$$

Where, P_{eff} represents the effective Precipitation during the growing season (mm), P indicates Precipitation during the growing season (mm), Y_{it} is regarded as the Yield of wheat in province i during the period t (ton ha^{-1}), and 10 shows the conversion factor of mm into m^3 ha^{-1}. Green WF is related to the proportion of water obtained from effective rainfall.

The calculation of Blue WF is conducted using Equations (7) and (8).

$$CWU_{it.blue} = 10 \times \sum_{d=1}^{n} ET_{it,blue} \quad (7)$$

$$WF_{it.blue} = \frac{CWU_{it.blue}}{Y_{it}} \quad (8)$$

Where, CWU represents Crop Water Use in m^3 ha^{-1}, which is calculated by summing up the daily crop Evapotranspiration (ET) during the growing season in mm (Equation 7) (Hoekstra and Chapagain, 2007, 2008; Hoekstra, *et al*., 2011). In this equation, $ET_{it.blue}$ represents ET of blue water (mm) pertaining to province i in time period t. 10 serves as the conversion factor from mm unit to m^3 ha^{-1}.

Crop Evapotranspiration (ET) was determined as follows (Allen *et al*., 1998):

$$ET = K_c \times ET_0 \quad (9)$$

Where, K_c is the crop coefficient (between 0.4 -1.3 during the growth period) and ET_0 is the reference Evapotranspiration (mm d^{-1}). The ET_0 was calculated by the Penman-Monteith equation (Allen *et al*., 1998), which was calibrated by Razzaghi and Sepaskhah (2012) for semi-arid environments in the study area as follows:

$$ET_0 = \frac{\Delta \times (R_n - G) + K_{time} \times \rho_a \times C_p \times \left(\frac{(e_s - e_a)}{r_a} \right)}{\left(\Delta + \gamma \left(1 + \frac{r_c}{r_a} \right) \right) \times \lambda} \quad (10)$$

Where, ET_0 is the reference evapotranspiration (mm d^{-1}), R_n is the net radiation (MJ m^{-2} d^{-1}), G is the soil heat flux (MJ m^{-2} d^{-1}), Δ is the slope of the saturation vapor pressure-temperature relationship (kPa $^{o}C^{-1}$), γ is the psychrometric constant (kPa $^{o}C^{-1}$), λ is the latent heat (MJ kg^{-1}), C_p is the specific heat of the air (kJ kg^{-1} $^{o}C^{-1}$), ρ_a is the mean air density at constant pressure (kg m^{-3}), r_a is the aerodynamic resistance (s m^{-1}), r_c is the canopy resistance (s m^{-1}), e_s is the saturated vapor pressure (kPa), e_a is the actual vapor pressure (kPa) and K_{time} is a time determination conversion coefficient. K_{time} is 86400 (s d^{-1}) if ET_0 is determined in mm d^{-1} (e.g., see Razzaghi and Sepaskhah (2012) and Allen *et al*., (1998) for more details).

The Grey WF component is calculated using Equation (11):

$$WF_{it.grey} = \frac{(\alpha \times ar_{it})/(c_{max} - c_{nat})}{Y_{it}} \quad (11)$$

Where, ar_{it} represents the application rate of fertilizer in the province i at period t (kg ha^{-1}), α indicates the percentage of leached nitrogen (%), which is regarded as the maximum acceptable concentration (kg m^{-3}), and describes the natural concentration for the pollutant examined (kg m^{-3}) (Hoekstra and Chapagain, 2007, 2008; Hoekstra, *et al*., 2011).

WF components are a function of random variables of climatic conditions (i.e., minimum and maximum air temperatures, wind speed, precipitation, relative humidity, solar radiation) in ET estimation. Therefore, the WF of wheat production is a random variable and is affected by climate parameters and water availability.

This study aimed to answer the question of which wheat-producing provinces in Iran have had lower social benefit risk over time. It will examine the hypothesis that provinces leading in wheat production experience lower social benefit risk. In Figure 2, the flow chart of the methodology is shown. Almost all provinces in Iran are wheat producers, and there is a variety of climates and water footprints for wheat production. Therefore, all provinces were chosen for the study. Subsequently, an optimal portfolio for wheat production provinces with minimal risk in social benefit was selected. In the present study, the necessary data used to determine WF were collected from the meteorological stations in the wheat-producing provinces by the Meteorological Services of Iran (2020). Additionally, in order to calculate the economic criterion, the necessary data (price, cost, and yield) were obtained from the Ministry of Agriculture-Jihad (MAJ) (2020) from 2000 to 2020.

RESULTS AND DISCUSSION

The analysis of the water footprint associated with wheat production across 30 Iranian provinces from 2000 to 2020 showed significant differences. The highest WF was found in Guilan, Southern Khorasan, Semnan, and Sistan and Baluchestan, while the lowest was in Ardabil, Tehran, Khuzestan, and Mazandaran. Northeastern, eastern, and southeastern provinces had the highest water footprint in 2000, 2005, 2010, and 2020. The results of this study corroborate earlier research. Specifically, they are in agreement with the findings reported by Ababaei and Etedali (2017) as well as Aliqliania *et al*. (2017). By calculating the components of wheat WF for the whole country, it is observed that the average WF of blue, green, and grey during the study period is equal to 2625.76, 428.10, and 594.13 m^3 ton^{-1}, respectively (Appendix 1). In contrast, the global average for these components in wheat production are significantly lower, at 1279, 343, and 208 m^3 ton^{-1} (Mekonnen and Hoekstra, 2010). This comparison indicates that the average blue and grey water footprints in Iran exceed the global averages by more than a factor of two. Furthermore, Figure 3 shows the wheat water footprint over 5-year time horizons on a map of Iran. The distribution of each component within the total water footprint is characterized by contributions of 72% from blue WF, 12% from green WF, and 16% from grey WF. Therefore, the blue water footprint has the largest share in the total water footprint of wheat, which is due to the country's semi-arid climatic situation. This situation leads to the high-water requirement of a certain plant. On average, the highest amount of green water footprint was related to ‘Kohgiluyeh and Boyer Ahmad’ and ‘Guilan’ Provinces during the study period with 762 and 687 m^3 ton^{-1}, respectively, and the lowest was related to Yazd province with 119 m^3 ton^{-1} (Figure 3). Guilan province has the highest annual precipitation rate and the highest blue water footprint (4184.5 m^3 ton^{-1}), while Khuzestan has the lowest (1,480.7 m^3 ton^{-1}). The high blue water footprint is due to high humidity and wheat yield, consistent with Aliqliania *et al.* (2017) findings. The study shows low precipitation and stable arid and semi-arid climates in most provinces of Azerbaijan, leading to increased use of chemical fertilizers to boost crop yield and mitigate climate effects. The grey water footprint is highest in southern provinces due to the use of chemical fertilizers. The numbers related to the water

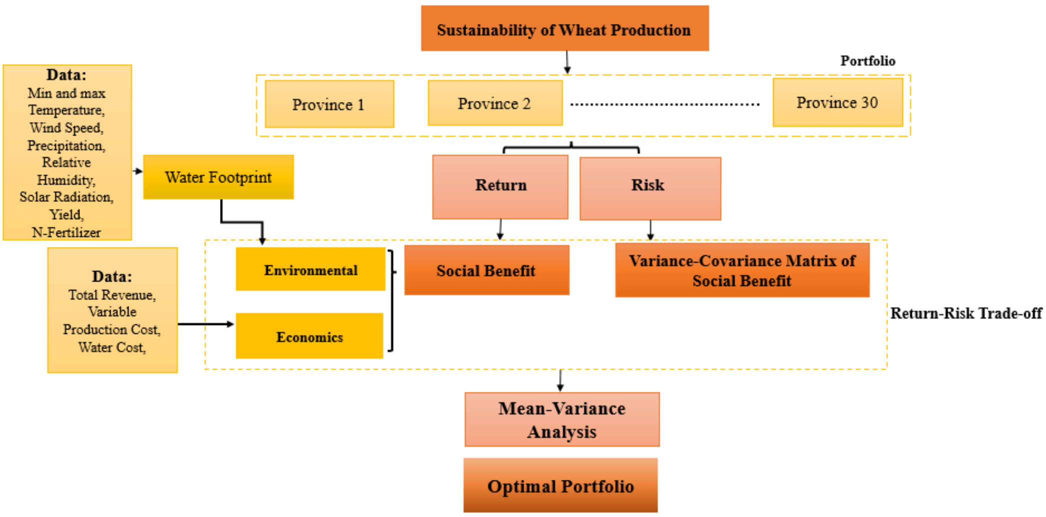


Figure 2. Flow chart of methodology.

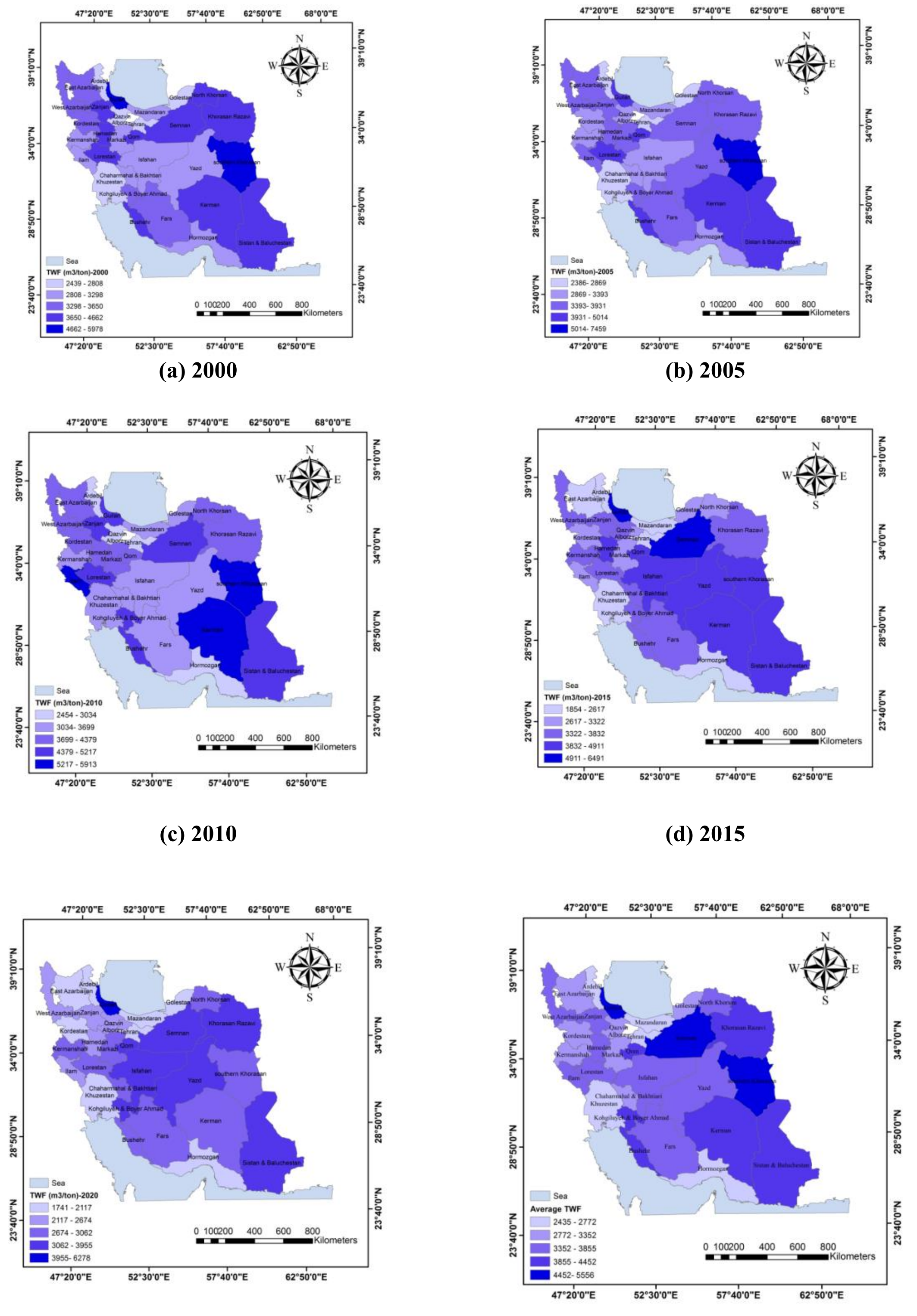
footprint associated with each province are also provided in the Appendix 1.

Figure 4 shows the wheat harvested area (million ha) and the calculated total water footprint of wheat (billion cubic meters). The annual total water footprint of wheat production in the country was calculated using the weighted average. For this purpose, the share of each province in the total wheat harvested area was taken as the weight. The highest and lowest harvested areas are 2.47 (in 2007) and 1.88 (in 2019) Million hectares (Mha), respectively. Moreover, the annual average water footprint of wheat production is 26.2 billion cubic meters during the study period. However, in 2019, due to the reduction of wheat cultivation, the total water footprint decreased to about 19.4 Billion cubic Meters (BM^3). In 2000, with an area of 2.67 Mha, the total water footprint was at its maximum and equivalent to 31.1 BM^3. Therefore, the total wheat harvested area and its distribution among different provinces play a significant role in the overall wheat water footprint. During the period under review, the harvested area of wheat decreased due to climate change in the country. Climate change has led to decreased harvested areas, increased yield risks, and reduced farmers' incomes in Iran. The government has implemented a guaranteed price protection policy to prevent production reduction. Water footprint calculations reveal an increase in environmental damage, highlighting the need for risk management in order to achieve sustainable production.

Figure 5 shows the share of different provinces in the total wheat harvested area during the period 2000-2020 using the column chart. Also, the risk of social benefits due to wheat production during the studied years is shown using a line chart. The risk is quantified as the deviations from the social benefit criterion.

The share of different provinces in the total cultivated area is expressed as a percentage. The last column of the chart shows the share of provinces in the optimal portfolio and the resulting risk. According to the results, Khuzestan (21.6%), Fars (17.1%), Hamedan (16.1%), Kordestan (13.2%), Khorasan Razavi (11.4%), Golestan (11.3%), Qazvin (5%) and Kermanshah (4.3%) are in the optimal portfolio. Despite having a low cultivation share in the provinces of Kurdistan, Golestan, and Hamedan during the study, these provinces have a significant share in the optimal portfolio. This can be attributed to the prevailing climate of these provinces, which are located in the west of the country (Figure 3). Low evapotranspiration in Kurdistan, Golestan, and Hamedan Provinces can reduce water footprint, environmental cost, yield risk, and social benefit-risk in wheat production. Fars and Khuzestan provinces are crucial centers of wheat production in Iran, aligning with the country's annual pattern. According to Figure 5, between 2004 and 2006, the share of these two provinces decreased significantly, which led to an increase in the standard deviation of social benefits of wheat harvested area compared to the other years in this period. This confirms the major role of these provinces in the optimal portfolio in reducing the risk of social benefits of wheat production throughout the country.

The trend line of risk in Figure 5 shows that the social benefit-risk decreases over time, except in 2008, and from 2011 to 2013. From 2014 onwards, this downward trend continued due to the relative stability of the share of major wheat-producing



(a) 2000 **(b) 2005**

(c) 2010 **(d) 2015**

(e) 2020 (f) Average of total WF (2000-2020)

Figure 3. Total Water Footprint (TWF) and average TWF of wheat (m^3 tone).

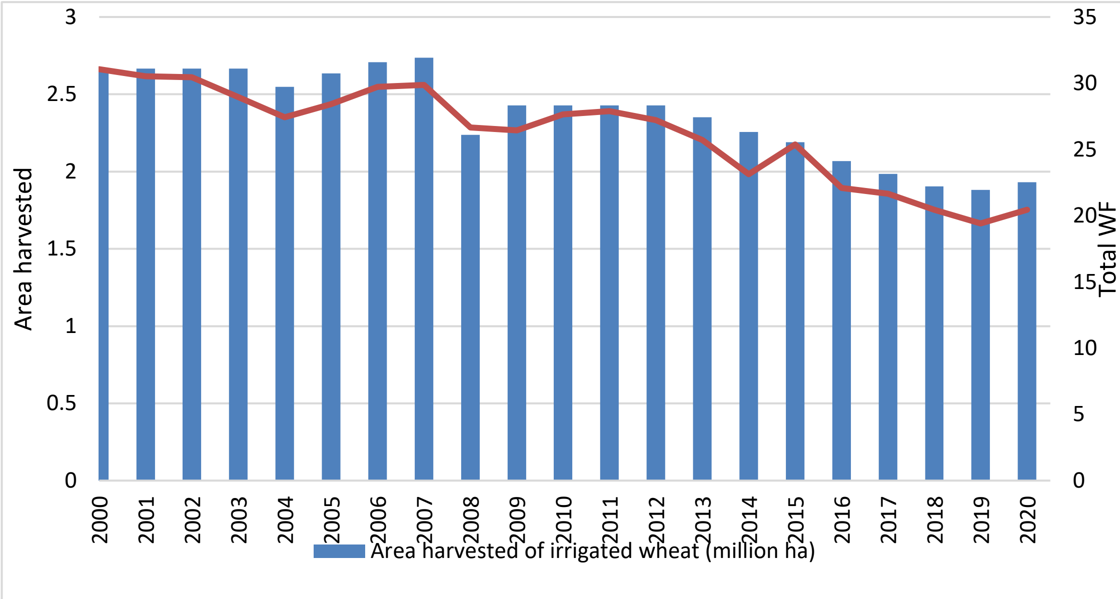


Figure 4. Area harvested and total water footprint of irrigated wheat [MAJ (2020) and research findings].

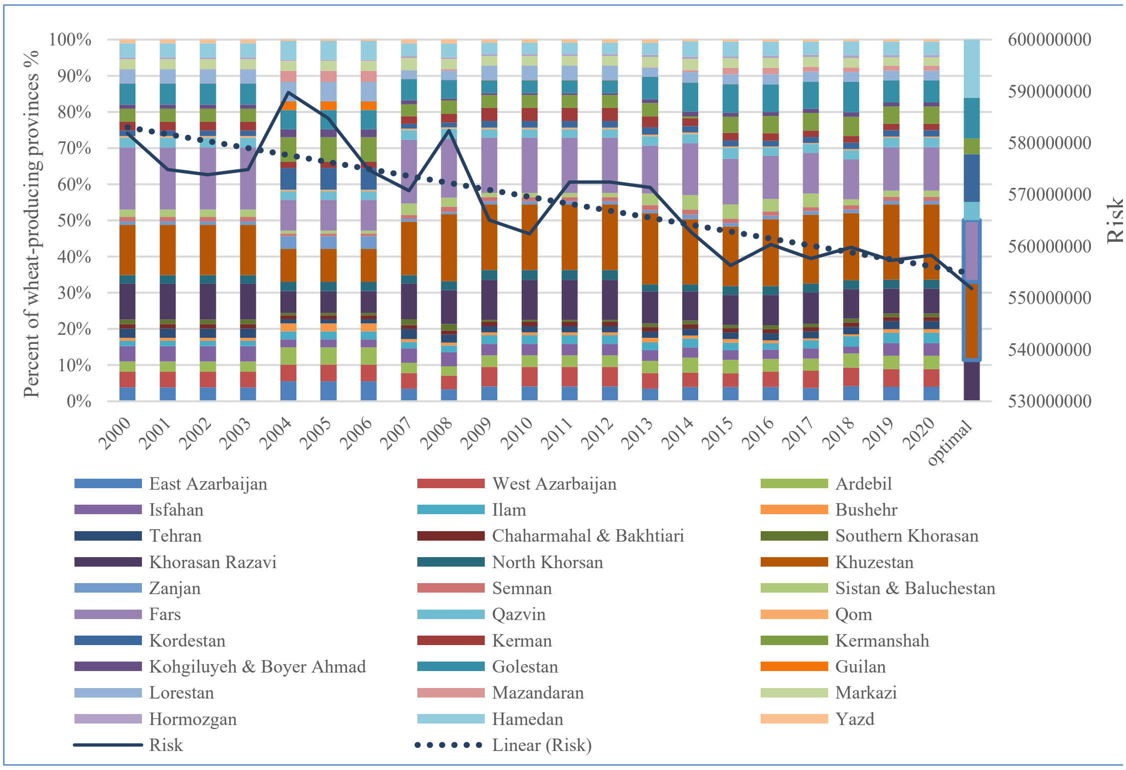


Figure 5. Comparison of the share of cultivated area and social benefit-risk of wheat-producing provinces with optimal basket during the period 2000-2020.

provinces in the total harvested area. The increased risk in 2008 can be explained by the significant decrease in the harvested area compared to other years (Figure 1). The country's precipitation reduction of 143.3 mm that year led to a decrease in harvested area and fluctuating social benefits. Despite high cultivation area, wheat production decreased due to reduced yield per hectare.

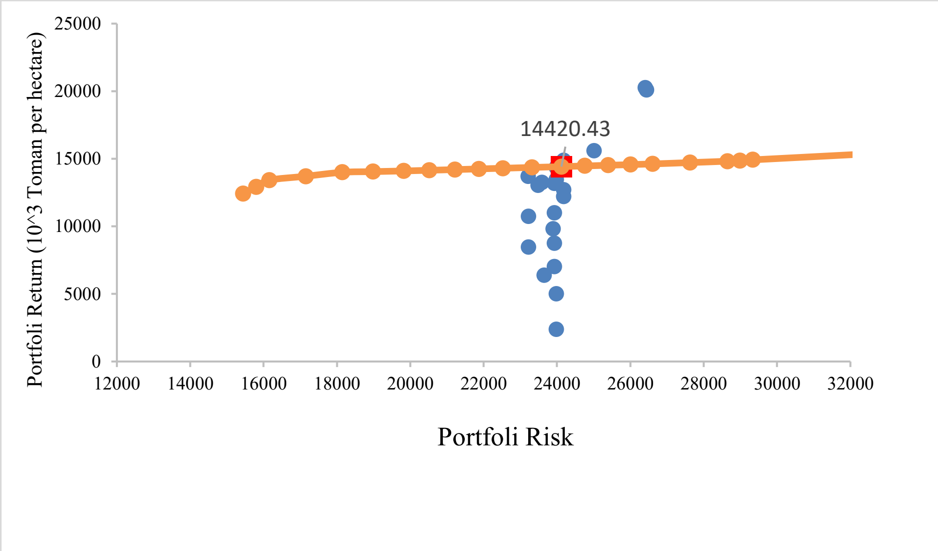


Figure 6. Efficient Frontier of Iran Wheat Production Basket 2000–2020. Note: Efficient frontier is the set of feasible portfolios where the portfolio risk as different target returns is minimized. Portfolio risk and portfolio return are defined as standard deviation and social benefit, respectively. Blue dots in the figure are defined as actual portfolio performance plots of wheat for each year between 2000 and 2020. The red dot in the figure is the optimal portfolio.

The return and risk associated with the wheat cultivation portfolio across various provinces in Iran from 2000 to 2020 are illustrated by blue points in Figure 6. The optimal points of this portfolio delineate an efficient frontier curve, represented in light red on the graph. This frontier signifies the optimal combinations that yield the highest return for a given level of risk, or conversely, the lowest risk for achieving a specified return. The optimal portfolio, characterized by returns of 14,420.3 (10^4 Rials per hectare) and a risk level of 24,120.5, is situated at the midpoint of this curve. Moving along the efficient frontier curve, we should take on higher risks to achieve greater social benefits. In order to attain a specific social benefit, we must be willing to accept a higher level of risk. However, embracing the risk for social benefits results in increased fluctuations in environmental costs (water footprint) or economic benefits (gross margin). Therefore, to achieve higher social benefits, and thus accept more risk, we have to accept the risk of provinces entering the optimal portfolio that have more environmental cost fluctuations in wheat production or create fewer gross margin due to low yields. However, due to the Iranian water resources conditions, it is impossible to include provinces with higher social benefit fluctuations in the optimal portfolio. Therefore, selecting the optimal portfolio (red dot) for a certain social benefit creates a lower risk.

CONCLUSIONS

The conclusions of this study, indicated that taking into account the environmental costs along with the gross margin will lead to sustainable production in the long run while conserving more water resources. Furthermore, the results showed that the provinces with a lower risk during the period 2000 to 2020, such as Fars and Khuzestan, are in the optimal portfolio. It is recommended that the current conditions of wheat cultivation be maintained and improved over time in the mentioned provinces. On the other hand, some provinces were removed from the optimal portfolio due to high fluctuations in water footprint or gross margin. These provinces include those in the east and center of the country, namely, Sistan and Baluchestan, South Khorasan, Semnan, Isfahan, and Yazd. These provinces exhibit high fluctuations in both water footprint and gross margin and, therefore, they should be carefully managed. To mitigate the risks in these provinces and make them more sustainable for wheat cultivation, it is suggested to introduce more resilient agricultural practices, improve water management technologies, and encourage diversification in crop production. Study, like He *et al*. (2021), emphasizes that regional adaptation strategies, such as introducing more resilient crops, modifying irrigation techniques, or adjusting planting times, are often required in areas with higher environmental costs or lower economic returns. But at the same time, the provinces included in the optimal portfolio of the country have fewer water footprints during the study period, which is due to the prevailing climate in these provinces (Kermanshah, Hamedan, and Kurdistan provinces). With lower environmental costs, these provinces could have sustainable wheat production in the country in the long run. These provinces should be encouraged as part of the long-term strategy for sustainable wheat production. Sustainable farming practices, such as conservation tillage and water-efficient irrigation systems, could be promoted to maintain or improve these provinces' positive performance in terms of both economic and environmental aspects. Therefore, it is suggested to increase the share of these provinces in the current production of the country and encourage farmers to develop the harvested area in these provinces. For this, the government should pursue supportive policies other than the guaranteed price policy set throughout the country. The government can support farmers by subsidizing insurance based on the climate index of agricultural products to reduce income risk for farmers in these provinces and create an economic advantage for them to plant wheat. Moreover, the provinces with high environmental costs, including the eastern and central ones, should be removed from the Iranian wheat cultivation portfolio over time, and alternative crops should be offered according to the prevailing climatic conditions in these provinces. Studies by González *et al*. (2019) argue that in regions where environmental conditions, like water availability, are less predictable, risk management strategies need to be considered carefully. Accepting more risk might make sense if the social benefits are crucial for economic development or food security. According to the results and their interpretation, the distribution of wheat among 8 provinces in Iran can create a lower risk with an inevitable expected return. Most of the previous studies conducted under the portfolio analysis framework in production, such as Nguyen-Huy *et al*. (2018), Holly Wang and Zhang (2003), and Barkley *et al*. (2010) found that optimal geographical diversity can be an agricultural risk management approach to achieving optimal expected returns. Similar to the previous studies, the results of this study also show that optimal geographical diversity in the long run is necessary to achieve sustainable production. Although the results of this study have beneficial implications for Iran, this approach applies to other agricultural areas and crops outside the country. This is because the model developed in this study can analyze the risk of social benefits and may help governments and policymakers as part of an optimal geographical distribution strategy to achieve sustainable production. In future studies, different crops in the country's agricultural portfolio and the links between various provinces can be considered to maximize social benefits.

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Appendix 1. A summary of the statistical results of the Water Footprint (WF) (m^3 ton^{-1}) Iranian province calculation (Average of wheat water footprint between 2000-2020).

Water footprint (m^3 ton)				
Province	Blue WF	Green WF	Grey WF	Total WF
East Azarbaijan	2227.41	483.50	400.57	3111.47
West Azarbaijan	2581.95	519.43	368.23	3469.61
Ardebil	1594.46	389.49	451.67	2435.62
Isfahan	2625.69	269.58	662.45	3557.72
Ilam	2640.69	496.25	678.88	3815.83
Bushehr	2891.79	579.52	551.15	4022.45
Tehran	1625.34	338.25	481.00	2444.59
Chaharmahal & Bakhtiari	2171.25	519.96	529.16	3220.37
Southern Khorasan	3841.99	397.77	814.31	5054.08
Khorasan Razavi	3157.54	449.11	683.38	4290.04
North Khorsan	2472.87	496.99	672.58	3642.43
Khuzestan	1480.75	463.47	739.87	2684.09
Zanjan	2654.61	458.11	409.57	3522.29
Semnan	3888.68	233.60	624.92	4747.20
Sistan & Baluchestan	3625.81	188.26	637.30	4451.38
Fars	3598.41	509.25	952.04	5059.70
Qazvin	1938.32	387.81	575.82	2901.95
Qom	3097.32	257.86	754.74	4109.92
Kordestan	2210.72	450.05	395.69	3056.46
Kerman	3317.53	307.25	795.04	4419.82
Kermanshah	2412.59	390.55	457.28	3260.42
Kohgiluyeh & Boyer Ahmad	2696.84	762.00	587.24	4046.08
Golestan	1923.70	481.85	539.10	2944.65
Guilan	4184.54	687.41	704.28	5576.23
Lorestan	2859.72	550.31	445.29	3855.32
Mazandaran	1693.40	620.92	468.28	2782.60
Markazi	2432.53	420.97	498.22	3351.73
Hormozgan	1680.01	262.91	742.79	2685.71
Hamedan	2710.24	420.07	486.88	3617.20
Yazd	2617.68	119.06	780.74	3517.48
Mean	2625.76	428.10	594.13	3647.12
Min	1480.75	119.06	368.23	2435.62
Max	4184.54	762.00	952.04	5576.23

مدیریت ریسک تولید پایدار گندم در ایران: نظریه پورتفولیو

آذر شیخ زین الدین، فاطمه فتحی، و سید عباس سید صالحی

چکیده

چالش کمبود آب یک چالش زیست محیطی مهم برای بخش کشاورزی است و تولید پایدار محصولات حیاتی مانند گندم را به خطر می اندازد. استان های ایران که گندم تولید می کنند، منابع آبی و شرایط آب و هوایی متفاوتی دارند. این تفاوت ها منجر به منافع اقتصادی متمایز و خطرات زیست محیطی در تولید گندم در بین استان ها شده است. در این تحقیق ردپای آب گندم در هر استان از سال 2000 تا 2020 محاسبه شد و هزینه های زیست محیطی آن از حاشیه ناخالص کسر شد. در نتیجه، منفعت اجتماعی به عنوان بازگشت سبد تولید گندم در هر استان برای مدیریت ریسک تولید پایدار در نظر گرفته شد. پس از آن، تئوری پورتفولیو از طریق برنامه ریزی ریاضی درجه دوم برای به حداقل رساندن سود اجتماعی و تعیین نسبت کشت گندم در هر استان برای سبد بهینه و تولید پایدار استفاده شد. نتایج نشان داد که استان های خوزستان (21.6%)، فارس (17.1%)، همدان (16.1%)، کردستان (13.2%)، خراسان رضوی (11.4%)، گلستان (11.3%)، قزوین (5%)، و کرمانشاه (4/3 درصد) در پرتفوی بهینه قرار دارند. در پرتفوی بهینه سهم قابل توجهی از تولید گندم مربوط به استان های کم ریسک در تولید (خوزستان و فارس) بود. یافته‌ها حاکی از آن است که برای دستیابی به تولید پایدار در بلندمدت، لازم است ریسک‌های اقتصادی در کنار ریسک‌های زیست‌محیطی در نظر گرفته شود. در نتیجه استان‌های شرقی و مرکزی (سیستان و بلوچستان، خراسان جنوبی، سمنان، اصفهان، یزد) با بیشترین میزان ردپای آب از سبد بهینه حذف شدند و استان‌های غربی (کرمانشاه، همدان و کردستان) با حاشیه ناخالص بالاتر و ردپای آب کمتر با سهم بیشتر جایگزین شدند.

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Understanding Farmers' Adaptation Behavior against Drought: Application of the Health Belief Model

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ABSTRACT

As climate change intensifies the frequency and severity of droughts, adaptive behavior becomes increasingly crucial. Farmers' capacity to modify their practices in response to evolving climate conditions is vital for ensuring long-term agricultural sustainability and food security. Therefore, this study aimed to investigate the psychological factors influencing farmers' adaptation behaviors in response to drought using the Health Belief Model. The sample comprised 380 farmers from Kuhdashat Township, Lorestan Province, Iran, selected via a three-stage cluster sampling method. Data were collected using a researcher-designed questionnaire, whose validity and reliability were confirmed. Structural Equation Modeling (SEM) results indicated that self-efficacy, perceived benefits, perceived vulnerability, and perceived barriers explained about 49% of the variance in farmers' adaptation behavior. Perceived benefits emerged as the strongest predictor of adaptation, while cues to action and perceived severity were insignificant. These findings support the health belief model's practicality and effectiveness in examining water conservation behavior among Iranian farmers.

Keywords: Climate change, Conservation behavior, Mitigation strategies, Self-efficacy.

INTRODUCTION

The 21st century's climatic changes, including global warming, represent significant global shifts requiring intergovernmental cooperation to address their impacts on ecological, environmental, socio-political, and socio-economic systems (Abbass *et al.,* 2022). Climate change, considered the greatest threat to sustainable development, triggers systemic shocks such as droughts, famines, and biodiversity loss, with drought being the most severe and complex due to its varying characteristics worldwide (Nguyen *et al.,* 2023). Drought, defined as prolonged water shortages, affects over 40% of the global population, with water scarcity projected to worsen, impacting 5 billion people annually by 2050 (Silva, 2024). Water demand is expected to exceed supply by 40% by 2030 (Mulwa *et al.,* 2021). Iran, located in an arid region, faces critical water shortages, with only 117 billion cubic meters of water available annually due to high evaporation rates (Rahimi-Feyzabad *et al.,* 2020). Severe droughts, affecting 72% of Iran's area and population, have occurred frequently over the past decades, with ongoing droughts since 1998 being the worst in nine centuries (Delfiyan *et al.,* 2020; Meteorological Organization, 2020). Iran's agricultural sector consumes 92.8% of its renewable water, exacerbating the crisis (Tajeri Moghadam *et al.,* 2018). Without proper management, Iran faces a significant environmental crisis, with water availability projected to halve by 2050 (Delfiyan *et al.,* 2020).

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Addressing drought involves two main approaches to climate change: mitigation by reducing greenhouse gas emissions and adaptation to new conditions (Wang *et al*., 2024). While mitigation is a long-term solution with challenges like uneven responsibilities and the free rider effect, adaptation is essential for reducing vulnerability and minimizing costs (Wang and Zhang, 2018). Adaptation, as defined by the IPCC, involves adjusting to the impacts of climate change, particularly in agriculture, where uncertainty presents significant risks (Sharifi, 2020). Farmers in drought-prone areas must modify farming practices to be resilient and implement drought risk management strategies (Tesfahunegn *et al.,* 2016). Adaptation is crucial for mitigating drought's adverse effects, particularly in developing countries, where farmers are key to effective management (Shabanali Femi *et al.,* 2020). Recent research highlights various factors influencing farmers' adaptive behaviors and strategies. For example, Hernández-López *et al*. (2024) analyzed farmers' adaptation to drought in Colombia, finding that socio-economic vulnerability and drought perception were key predictors of adaptive behavior. Similarly, Wens *et al*. (2021) studied smallholder farmers in Kenya, revealing that risk assessment, social norms, self-efficacy, and response efficiency significantly affect adaptive behavior. They also emphasized the role of extension services, early warning systems, and financial assistance in fostering adaptation. In Ethiopia, Gebrehiwot and van der Veen (2020) used the Protection Motivation Theory (PMT) model to show that perceived vulnerability and self-efficacy positively influence the implementation of drought risk reduction measures. In Bangladesh, Anik *et al.* (2021) found that education, income from livestock, participation in organizations, and access to ICT in agriculture significantly affected farmers' adaptation strategies. Similarly, Muthelo *et al*. (2019) studied South African farmers, highlighting the influence of age, gender, and marital status on vulnerability and coping strategies like water restrictions during droughts. Studies in India by Patnaik *et al*. (2019) revealed that livelihood interventions, technical training, and agricultural extension services increase the likelihood of adaptation. Collectively, these studies underscore the multifaceted nature of farmers' adaptive behaviors, shaped by socio-economic, institutional, and behavioral factors.

Economic incentives can encourage short-term adaptation, but Iranian policymakers prefer sustainable, voluntary measures (Piñeiro *et al*., 2020). Understanding farmers' behaviors requires integrating insights from behavioral models. This study uses the Health Belief Model (HBM), a preventive health behavior theory that emphasize fear and risk perception (Barattucci *et al*., 2022). The HBM highlights key dimensions, including perceived susceptibility, perceived severity, perceived benefits, perceived barriers, self-efficacy, and cues to action (Subedi *et al.,* 2023). These factors collectively influence decision-making, particularly in drought, where farmers' perceptions of risk and capacity to act are critical. Farmers are more likely to adopt adaptive practices if they perceive themselves as vulnerable to drought and recognize its severe consequences for their livelihoods. In contrast, models like TPB focus on subjective norms and intentions, which may not adequately address the urgency of risk perception in drought-related decisions (Ajzen, 2020). The HBM's incorporation of perceived barriers and benefits provides a balanced view of motivational and practical considerations, unlike the Social Cognitive Theory (SCT), which focuses more on social learning (Hasan *et al*., 2024). Additionally, the HBM considers external cues to action, such as government warnings or observing neighbors' experiences, which are critical for farmers' adaptation. Other models, like the Stages of Change Model, prioritize internal readiness but may overlook external influences (Cardona *et al*., 2023). Self-efficacy, or the belief in one's ability to take action, is another crucial aspect of the HBM. For farmers, having confidence in adopting complex strategies such as implementing new irrigation techniques, is essential. While the HBM was initially developed for health behaviors, its principles are transferable to environmental risks like drought, as both contexts involve similar psychological processes underlying risk perception and decision-making (Raheli *et al*., 2020).

This study pioneers the integration of the HBM into agricultural research to analyze farmers' behavioral adaptations to drought, a pressing challenge exacerbated by climate change. Unlike conventional studies focusing solely on economic or environmental factors, this research examines farmers' perceptions of drought susceptibility, severity, benefits of adaptation, and barriers to action. The study identifies regional variations in adaptive behavior by applying the HBM across diverse geographic and socio-economic contexts, offering policymakers targeted strategies to enhance resilience. The study investigates how the HBM's variables influence farmers' adaptive behaviors in Kohdasht, Iran. The objectives are: (1) To apply the HBM in exploring farmers' adaptation behaviors, (2) To identify variables affecting these behaviors, and (3) To evaluate the HBM's explanatory power in this context. By integrating the HBM into the study of drought adaptation, this research provides a comprehensive understanding of the psychological and practical factors influencing farmers' behaviors, contributing to more effective policy and intervention design. The findings are crucial for addressing water scarcity risks and promoting sustainable agricultural practices in the face of climate change. Based on the HBM framework, the study hypothesizes the followings:

1. Perceived vulnerability significantly affects farmers' adaptation behaviors.
2. Perceived severity significantly affects adaptation behaviors.
3. Perceived benefits significantly affect adaptation behaviors.
4. Perceived barriers significantly affect adaptation behaviors.
5. Self-efficacy significantly affects adaptation behaviors.
6. Cues to action significantly affect adaptation behaviors.

MATERIALS AND METHODS

This quantitative cross-sectional study was conducted in Kohdasht Township, west of Iran, with a population of 25,554 farmers. Using the Krejcie & Morgan (1970) sampling table, the sample size was 380, but 390 questionnaires were completed for greater certainty. A multi-stage cluster sampling method was used due to the large, dispersed population. First, the population was divided into natural clusters based on administrative divisions: central, Tarhan, Kohnani, and Derb Gonbad. These sections were purposively selected for their distinct characteristics. Next, specific districts (Southern Kohdasht, Golgol, West Tarhan, Kohnani, and Derb Gonbad) were chosen to represent diverse farming practices and drought vulnerabilities. A 10% sample of villages in each district was randomly selected, ensuring geographical representation. Finally, a proportional number of farmers from each village was chosen using simple random sampling, maintaining the sample's representativeness. This study followed ethical research principles outlined by Vanclay, Baines, and Taylor (2013). Participants were informed of the study's purpose, risks, and benefits, provided voluntary consent, and were assured confidentiality. Data were anonymized, and participant privacy, dignity, and autonomy were prioritized throughout the research.

The data collection instrument was a researcher-developed questionnaire based on the Health Belief Model (HBM) and related studies. A 5-point Likert scale (1= Strongly

Disagree to 5= Strongly Agree) was used. Experts validated the questionnaire, and a pilot test with 30 farmers in Khorramabad confirmed its reliability, with Cronbach's alpha coefficients ranging from 0.77 to 0.95, indicating acceptable internal consistency (Hair *et al.,* 2010). Table 3 presents all items of the questionnaire. Data were analyzed using Structural Equation Modeling (SEM) with SPSS25 to assess direct and indirect causal relationships, evaluate the model's goodness of fit, and validate latent constructs. SEM is particularly suited for analyzing multiple variables and testing complex theoretical models (Lowry and Gaskin, 2014).

RESULTS

Socio-demographic Characteristics

The descriptive analysis revealed that most farmers (98.2%) were male, while 1.8% were female. The average age of the respondents was 49 years (SD= 12.33, ranging from 18 to 82 years). The majority of farmers (21.8%) had a diploma. The range of changes in farmers' agricultural experience was between 2 and 70 years, and their average work experience was 33.6 years. For most farmers (55.1%), rainfall served as the primary source of irrigation water, while 32.3% of farmers use wells, 7.9% from rivers, and 4.6% of studied farmers used spring water to irrigate their lands. Most farmers (65.7%) irrigated their land using traditional irrigation methods, while 27.4% used rain irrigation systems and 6.9% drip irrigation.

Descriptive Analysis of HBM Constructs

The descriptive results for the HBM constructs showed that cues to action among farmers had the highest average score (Mean= 3.62, SD= 0.73). Following, these were perceived benefits (Mean= 3.29, SD= 1.08), perceived obstacles (Mean= 3.27, SD= 1.06), perceived intensity (Mean= 3.27, SD= 1.11), self-efficacy (Mean = 3.15, SD= 1.02) and perceived vulnerability (Mean= 3.12, SD= 1.06), all of which showed relatively high scores among the samples. Subsequently, we examined the relationships between the seven constructs using Spearman's correlation coefficient. According to Table 1, there was a significant relationship between drought adaptation behavior and other constructs of the HBM.

Structural Model Results

SEM was utilized to explore the relationships between study variables and adaptive behaviors. Six indices were used to assess model fit, and the results indicated that the hypothesized model fit the data well: $\chi2/df$ = 0.941, CMIN/df= 1.43, (P-value = .09, $P > 0.05$), NFI (Δ1)= 0.962, RFI (ρ1) = 0.988, GFI= 0.979, TLI (ρ2)= 1.000, CFI= 1.000, RMSEA= 0.000 (see Table 2). The model is depicted in Figure 1, and detailed path coefficients are presented in Table 4.

Table 1. The results of the variables correlation matrix.

Constructs	1	2	3	4	5	6	7
PS (1)	1						
PSV (2)	0.662**	1					
PB (3)	0.598**	0.606**	1				
PBR (4)	0.616**	0.598**	0.961**	1			
SE (5)	0.658**	0.575**	0.584**	0.595**	1		
CA (6)	0.260**	0.186**	0.197**	0.203**	0.157**	1	
Behavior (7)	0.632**	0.542**	0.581**	0.572**	0.635**	1.69**	1

*P< 0.05. **P< 0.01.

The final model derived from SEM analysis revealed that four HBM constructs could predict 49% of the variance in drought adaptation behavior (Figure 2). This value indicates that the proposed models had moderate explanatory power. Hair *et al.* (2017) suggested that a model that only accesses R2 values is untrustworthy. Therefore, to evaluate the predictive relevance of the structural model, Stone (1974) introduced Q2. Latent exogenous constructs in the structural model have predictive relevance if the value of Q2 is more significant than zero (Chin, 2009). Q2 value of 0.56 was higher than zero, which means that endogenous constructs had enough predictive relevance.

Moreover, the result revealed that the most critical predictor of adaptive behavior was perceived benefits associated with implementing adaptation measures ($\beta = 0.50$, $p < 0.000$). Afterward, perceived barriers ($\beta = 0.35$, $p < 0.001$), self-efficacy ($\beta = 0.34$, $p < 0.000$), and perceived

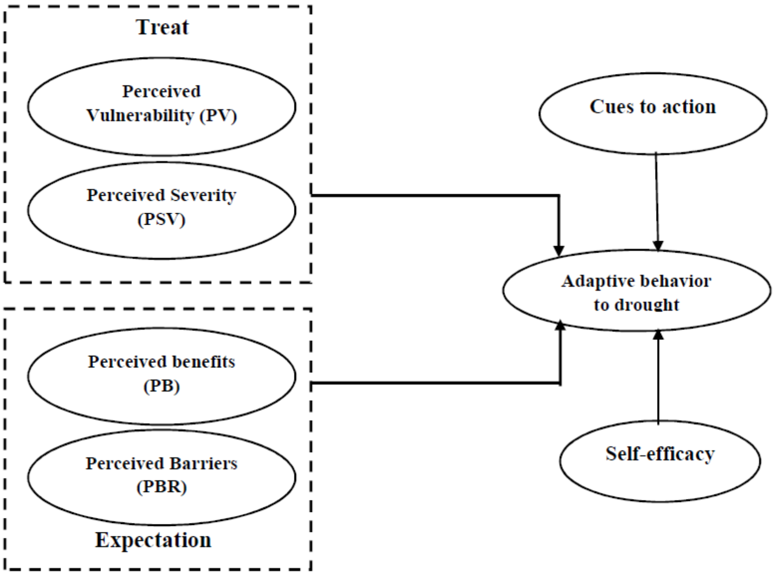

Figure 1. The extended Health Belief Model (HBM) framework (Rosenstock *et al.,* 1998).

Table 2. The indices of goodness of fit test.

Indices of the goodness of fits[a]	Evaluation criteria of acceptable values of indices
χ 2 /df= 0.941	Nonsignificant≥ 0.05 (Jöreskog and Sörbom, 1993)
CMIN/df= 1.43	< 2 (Hair *et al*., 1998)
NFI (Δ1)= 0.962	≥ 0.95 good
	, 0.90 to 0.95 acceptable (Bentler, 1990)
RFI (ρ1)= 0.988	> 0.90 (Bentler, 1992)
TLI (ρ2)= 1.000	≥ 0.95 Or ≥0.90 (Hu and Bentler, 1999; Weston and Gore, 2006)
CFI= 0.979	≥ 0.90 (Hu and Bentler, 1999; Weston and Gore, 2006)
RMSEA= 0.000	≤ 0.5: Very good fit (Browne and Cudeck, 1993; Kline, 2005)

[a] CMIN: Chi-Square Minimum Discrepancy, NFI: Normed Fit Index, CFI: Comparative Fit Index, RFI: Relative Fit Index, TLI: Tucker–Lewis Index, RMSEA: Root Mean Square Error of Approximation.

Table 3. Reliability and validity assessment of Health Belief Model constructs.

Constructs	Factor Loading	R-square value	SMC	CR	AVE
PV (α= 0.85) (β= 0.0.20**)					
1. I believe that my relatives and I are vulnerable to the adverse effects of drought.	0.84	0.70	0.781	0.845	0.578
2. I believe that drought can reduce my agricultural production.	0.79	0.62	0.744		
3. I believe that drought can reduce my income.	0.79	0.62	0.712		
4. I believe the weather conditions (rainfall and temperature) have changed compared to the past.	0.70	0.49	0.824		
5. I believe that the availability of water for agriculture and even drinking has decreased.	0.79	0.62	0.767		
PS (α= 0.84) (β= 0.0.10)					
1. Drought has severely affected the water resources of our village.	0.75	0.56	0.818	0.766	0.537
2. Drought has severely affected the environment and vegetation of our region.	0.76	0.57	0.767		
3. Drought causes irreparable damage to agricultural production and income.	0.77	0.59	0.798		
4. Drought causes irreparable damage to the quality of my agricultural products.	0.81	0.65	0.845		
5. Drought causes irreparable damage to my property.	0.76	0.57	0.756		
PB (α = 0.83) (β = 0.0.50**)				0.712	0.580
1. Adopting strategies to adapt to drought prevents water loss and the depletion of water resources.	0.73	0.53	0.713		
2. Adopting drought adaptation strategies will prevent the reduction of my crop production and income.	0.75	0.56	0.744		
3. Adopting strategies to adapt to drought will prevent migration and evacuation of villages.	0.76	0.57	0.860		
4. Adopting strategies to adapt to drought will preserve agricultural production and food security.	0.82	0.67	0.798		
5. Adopting strategies to adapt to drought will preserve agricultural production and food security.	0.78	0.60	0.744		
PBR (α = 0.82) (β = 0.0.35**)				0.824	0.651
1. I do not have sufficient financial resources to implement strategies for adapting to drought.	0.82	0.67	0.713		
2. I do not have the necessary knowledge and skills to implement drought adaptation strategies	0.72	0.51	0.706		
3. I do not have adequate infrastructure to implement drought adaptation strategies.	0.79	0.62	0.768		
4. Appropriate and affordable tools and technology to implement drought adaptation solutions are unavailable.	0.75	0.56	0.722		
5. There is no necessary cooperation and participation among villagers to adapt to drought	0.72	0.51	0.703		

Table 3 Continued…

Continued of Table 3.

Constructs	Factor Loading	R-square value	SMC	CR	AVE
SE (α= 0.81) (β= 0.0.34**)					
1. In the face of drought, I have enough awareness and knowledge to implement adaptation strategies.	0.80	0.64	0.801		
2. In the face of drought, I possess the necessary experience and expertise to implement adaptation strategies.	0.74	0.54	0.764		
3. In the face of drought, I can implement drought adaptation strategies.	0.82	0.67	0.730	0.760	0.542
4. In the face of drought, I have enough motivation and energy to implement drought adaptation strategies	0.68	0.46	0.721		
5. In the face of drought, I have adequate financial resources to implement adaptation strategies.	0.72	0.51	0.733		
CA (α= 0.71) (β= 0.0.06)					
1. I have heard from my farmer family and friends about the risk of drought and strategies to adapt to it.	0.72	0.51	0.765		
2. I have received information from agricultural experts about the risks of drought and the relevant adaptation strategies.	0.56	0.31	0.721	0.751	0.578
3. I have heard about the risks of drought and adaptation strategies through local and national radio and television.	0.87	0.75	0.735		
4. I have heard about the risk of drought and drought adaptation solutions from cyberspace.	0.85	0.72	0.787		
Behavior (α = 0.90) (R^2 = 0.0.49**)					
1. Planting seeds and modified cultivars with high yield and drought resistance (less water requirement)	0.61	0.37	0.836		
2. Planting seeds deeper to absorb more moisture	0.74	0.54	0.750		
3. Changing the planting and harvesting dates according to weather conditions (planting earlier or later)	0.74	0.54	0.735		
4. Use crop rotation (wheat, barley, peas, alfalfa and other legumes).	0.80	0.64	0.768		
5. Insuring agricultural and livestock products	0.74	0.54	0.780		
6. Modifying the way to guide and transport water (turning earthen streams into concrete streams, using metal or polyethylene pipes to transport water)	0.71	0.50	0.812	0.812	0.545
7. Construction of pools and ponds to collect water	0.72	0.51	0.761		
8. Watering during the cool hours of the day (dusk, night, or early morning) for optimal results.	0.69	0.47	0.735		
9. Using new irrigation methods (drip, rain, and underground irrigation).	0.76	0.57	0.756		
10. Timely service and maintenance of equipment such as pump, filtration station, and other equipment installed in the farm	0.77	0.59	0.801		

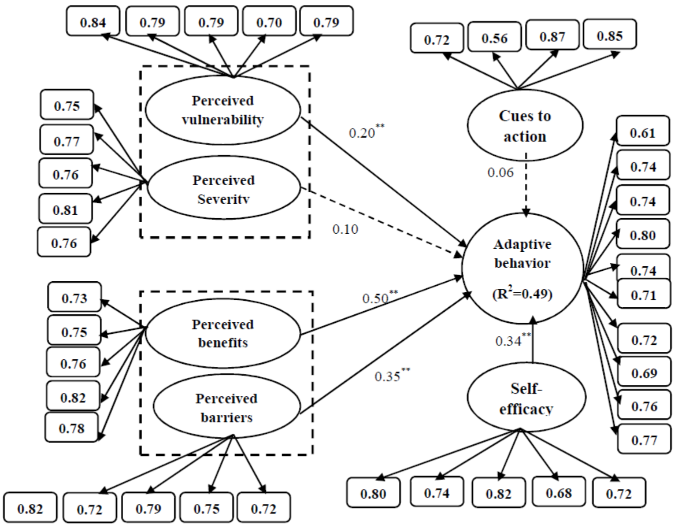

Figure 2. Structural path model. (-------------► Non-significant, * P< 0.05, ** P< 0.01).

vulnerability (β = 0.20, p <0.000). However, certain constructs, such as "cues to action" and "perceived severity," were not significant predictors of behavior (Figure 2). Table 3 provides the standardized factor loadings, R-square values, standardized beta coefficients, SMC, CR, and AVE.

DISCUSSION

This study aimed to identify factors predicting drought adaptation behavior among farmers in Kohdasht Township, western Iran, using the Health Belief Model (HBM). To date, this is one of the first farmers water conservation behaviors. The findings revealed that 49% of the variance in farmers' adaptive behavior could be explained, confirming the model's predictive utility, as supported by previous studies (Tajeri Moghadam *et al*., 2020; Zobeidi *et al*., 2021; Yazdanpanah *et al*., 2022).

The results showed that perceived benefits had the most direct impact on adaptive behavior. Farmers were motivated by the belief that adaptation measures could conserve water, reduce crop losses, secure livelihoods, ensure community food security, and protect the environment. This aligns with studies in China, Sub-Saharan Africa, and Vietnam, where emphasizing economic and environmental benefits encouraged adaptation (Wong *et al*., 2021; Bagagnan *et al*., 2019b; Luu *et al*., 2019). Governments and agricultural agencies should highlight these benefits through targeted campaigns to enhance adoption rates.

This study also found that perceived barriers significantly hindered drought adaptation behavior. These barriers include obstacles that may prevent a farmer from implementing adaptation measures, such as insufficient financial resources, limited knowledge, and skills to implement adaptation strategies, lack of necessary infrastructure, inappropriate tools and technology, and lack of cooperation and participation among farmers. This finding aligns with similar studies in Ethiopia (Gebrehiwot and van der Veen, 2020) and Nigeria (Von Abubakari *et al.,* 2024), where lack of resources and infrastructure were reported as key barriers. However, our results diverge from findings in high-income countries, such as Australia (McIlwain *et al.,* 2022), where institutional support mitigated the impact of perceived barriers. Implementing appropriate support policies and empowering farmers economically and through education can reduce these barriers and promote adaptive behaviors.

Self-efficacy is another significant predictor of farmers' adaptive behavior. Consistent with findings from Ethiopia (Gebrehiwot and van der Veen, 2020) and India (Mitter *et al.,* 2024), self-efficacy positively influences farmers' ability to adapt to drought by enhancing confidence in their skills and resources. However, this contrasts with results from Iran (Delfiyan *et al.,* 2020), where self-efficacy showed a weaker impact. Therefore, enhancing farmers' self-efficacy by improving access to information, advancing technical skills, and increasing financial support through targeted subsidies and low-interest loans should be a priority for agricultural sector planners in this area.

Perceived vulnerability also significantly influenced behavior. Echoing findings from Vietnam and Sub-Saharan Africa, heightened awareness of risks motivated adaptive actions. In Kohdasht, drought and reduced rainfall have caused water shortages, decreased yields, unemployment, and migration. Raising awareness of these risks can encourage farmers to adopt adaptive measures (Luu *et al*., 2019; Bagagnan *et al*., 2019a). In conclusion, enhancing understanding of adaptation benefits, reducing barriers, building self-efficacy, and addressing vulnerability is essential for promoting drought adaptation behavior. These findings provide valuable insights for policymakers aiming to support sustainable farming in drought-prone regions.

The results revealed that perceived severity and cues to action did not significantly influence farmers' adaptation behavior to drought. This could stem from farmers not fully perceiving drought as a severe threat, especially if they have previously coped with droughts. Over time, they may view droughts as a natural part of farming or assume conditions will improve without intervention. External cues, such as weather forecasts or government warnings, may not reach farmers effectively or be distrusted. If advice seems irrelevant to local conditions, farmers may ignore it. Additionally, lack of knowledge about drought-resistant practices or water management strategies can leave farmers uncertain how to adapt. Economic barriers, such as the high cost of adaptation measures like water conservation technologies or irrigation systems, further complicate the situation, especially for farmers with limited resources. Overcoming these challenges requires integrating approaches to address economic, psychological, social, and informational barriers. The study found that perceived benefits had the most significant impact on adaptation behavior. Agricultural extension services should emphasize the long-term benefits of adaptation, such as water conservation, crop resilience, and environmental sustainability. Outreach campaigns and workshops can raise awareness of these advantages. Policies must address financial barriers through subsidies, low-interest loans, or grants for adopting drought-resistant technologies. Improving farmers' confidence through tailored training, demonstrations, and mentorship can encourage adaptive behavior.

CONCLUSIONS

This research highlights the critical factors influencing drought adaptation behavior among farmers in western Iran, focusing on the Health Belief Model (HBM). The study found that HBM effectively predicts farmers' drought adaptation behaviors, explaining 49% of the variance in adaptive behavior. Perceived benefits emerged as the most significant predictor, indicating that when farmers recognize the individual and collective advantages of adaptation measures, such as protecting water resources, maintaining livelihoods, and ensuring food security they are more likely to adopt these behaviors. However, perceived barriers, including financial constraints, limited knowledge, inadequate infrastructure, and lack of cooperation, significantly hinder adaptation efforts. The study underscores the importance of supportive policies and educational programs to empower farmers economically and enhance their technical skills, thereby reducing barriers and increasing adaptive behaviors. Additionally, the positive impact of perceived vulnerability on adaptation behavior suggests that raising awareness of drought-related damages can further motivate farmers to implement adaptive strategies. Overall, the findings emphasize the need for targeted interventions that address the perceived benefits and barriers to foster widespread adoption of drought adaptation behaviors among farmers.

This study has several limitations that need future consideration:

First, reliance on self-reported data may introduce subjectivity; mixed-method approaches combining surveys with objective measures like drought data are recommended.

Secondly, the HBM overlooks social norms and cultural values; incorporating constructs from Social Cognitive Theory or ethnographic studies could address this gap

Thirdly, the HBM focuses on short-term decisions, necessitating longitudinal studies to explore sustainable adaptation behaviors.

Fourthly, factors like institutional trust and technical knowledge access should be integrated into the model.

Lastly, context-specific findings require comparative studies across diverse regions to enhance generalizability.

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درک رفتار سازگاری کشاورزان در برابر خشکسالی: کاربرد مدل اعتقاد بهداشتی

مصطفی مریدی، رضوان قنبری موحد، مهدی رحیمیان، و سعید غلامرضایی

چکیده

همانطور که تغییرات آب و هوایی فراوانی و شدت خشکسالی ها را تشدید می کند، رفتار انطباقی به طور فزاینده ای حیاتی می شود. ظرفیت کشاورزان برای اصلاح شیوه های خود در پاسخ به شرایط آب و هوایی در حال تحول برای تضمین پایداری کشاورزی بلندمدت و امنیت غذایی حیاتی است. لذا این مطالعه با هدف بررسی عوامل روانشناختی مؤثر بر رفتارهای سازگاری کشاورزان در پاسخ به خشکسالی با استفاده از مدل اعتقاد بهداشتی انجام شد. نمونه شامل 380 کشاورز از شهرستان کوهدشت استان لرستان و غرب ایران بود که به روش نمونه گیری خوشه ای سه مرحله ای انتخاب شدند. داده ها با استفاده از پرسشنامه محقق ساخته جمع آوری شد که روایی و پایایی آن تایید شد. نتایج مدل‌سازی معادلات ساختاری (SEM) نشان داد که خودکارآمدی، مزایای درک‌شده، آسیب‌پذیری درک‌شده و موانع درک‌شده حدود 49 درصد از واریانس رفتار سازگاری کشاورزان را توضیح می‌دهند. مزایای درک شده به عنوان قوی ترین پیش بینی کننده سازگاری ظاهر شد، در حالی که نشانه های عمل و شدت درک شده ناچیز بود. این یافته ها از کاربردی بودن و کارایی مدل اعتقاد بهداشتی در بررسی رفتار صرفه جویی در مصرف آب در بین کشاورزان ایرانی حمایت می کند.

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Development and Evaluation of a Combined Two-Level Subsoiler for Strip-Tilling Sugarcane Fields

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ABSTRACT

In Khuzestan Province of Iran, the number of traffic passes made by heavy farm machinery in sugarcane land preparation varies depending upon field conditions, ranging from a minimum of 10 to a maximum of 16 passes annually. To reduce the energy, time and cost, it is imperative to use conservation tillage as well as controlled traffic systems. The objectives of this research were to develop and evaluate a combined strip deep tillage machine equipped with a two-level deep tillage implement including a dual sideway-share and a winged subsoiler, cum with a set of discs. To optimize the dual-sideway-share subsoiler, the effects of share rake angle (7.5° and 15°) and length (150 and 200 mm) on the implement field performance were examined. Also, to optimize the winged subsoiler, it was tested with its wing having different lengths (0, 200, 250, and 300 mm). Finally, the performance of the developed combined strip deep tillage machine was compared with a conventional subsoiler used for deep tillage in the fields. The results showed that the optimized combined strip deep tillage machine should be equipped with the dual sideway-share subsoiler having a share with a 7.5° rake angle and 150 mm length, and the winged subsoiler with 250 mm length of wing. The results showed that the specific resistance of the developed machine decreased by 34% as compared to the conventional subsoiler. Therefore, the machine has higher efficiency and is an environmentally friendly implement for sustainable sugarcane production in southwest Iran.

Keywords: Conservation tillage, Controlled-traffic, Draft, Ripper, Specific resistance.

INTRODUCTION

Sugarcane (*Saccharum officinarum*) is a giant tropical grass, whose stalk has the particular capacity to store a crystallizable sugar, sucrose. Sugarcane cultivation in the irrigated fields of agricultural and industrial companies in Khuzestan, a province in the southwest of Iran, is fully mechanized. In general, the mechanized operations in sugarcane production can be categorized into four primary stages, which included: (1) Soil preparation, (2) Planting, (3) Growing (comprising irrigation, fertilization, pesticide application, and ratooning), and (4) Harvesting (involving cutting, loading, transportation to the factory, and unloading) (Monjazi *et al*., 2017). These operations are characterized by substantial traffic of heavy machinery across various production operations, particularly during cultivation and harvesting, and often practiced under unfavorable moisture conditions. This could result in soil compaction. However, it is well known that soil compaction can reduce crop yields (Shaheb *et al*., 2021). Therefore, it is necessary to develop an effective cultivation system with minimum soil compaction.

The nature of soil tillage operations for sugarcane land preparation is energy-intensive, time-consuming, and expensive. To reduce energy and time it is necessary to use conservation tillage as well as controlled-traffic systems. In conservation

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sugarcane farming system, zonal or strip tillage is when only the row area is cultivated in preparation for planting the sugarcane sett and the inter-row area remains undisturbed and used as traffic zone. Therefore, strip tillage represents a farming method that combines the advantages of reduced tillage for crop rows, with the benefits of no-till in the inter-row spaces (Voorhees, 1991; Licht and Al-Kaisi, 2005; Laufer and Koch, 2017). Sugarcane harvesting involves the use of sugarcane harvesters and transport baskets, and the machinery traffic affects approximately 50% of the total field area. Consequently, the implementation of traffic control principles becomes crucial. This approach entails segregating the area required for crop growth from the region impacted by machinery traffic (Mouazen and Palmqvist, 2015; McHugh et al., 2009 and Mcphee *et al*., 2020).

The adoption of traffic control methods can result in a remarkable reduction in energy consumption, up to 23%, during crop production stages when compared to conventional Random-Traffic Farming (RTF) (Chen *et al*., 2008, 2010).

In today's agricultural practices, there is growing interest in integrated tillage methods. Integrated tillage approaches have gained prominence due to their ability to reduce operating time, fuel consumption, and energy requirements (Prem *et al*., 2016). Essentially, integrated tillage combines various operations to prepare the soil with desirable characteristics, intending to reduce costs and operating times (Manian and Kathirvel, 2001). Integrated machinery tends to be more complex compared to single-purpose machines, but offers numerous advantages and greater efficiency within a similar timeframe (Sahu and Raheman, 2006).

Considering the heavy texture of the soils of north Khuzestan due to their high clay content and the traffic of heavy machinery in unfavorable soil moisture conditions at the time of harvesting, conventional sub-breakers is used to reduce dense layers of soil.

Generally, four common types of subsoilers are used for deep tillage: the bulldozer ripper, the conventional/winged subsoiler, the Para plow, and the bent leg subsoiler (Harrison and Licsko, 1989b; Harrison, 1990; Raper, 2005). In addition to the quantity and quality of the disturbed soil volume, the choice of subsoiler for deep tillage depends on its critical depth, and the required draft force; therefore, an ideal subsoiler has a greater critical depth and requires less draft force (Godwin and Spoor, 1977).

The critical depth is the depth below which soil loosening does not occur and only soil smearing and compaction is observed. In other words, the critical depth is the depth at which the soil no longer creates a crescent failure radiating from just above the tine point, but whose failure zone has its base part way up the tine shank and the soil at the tine base starts to flow forward and sideways rather than lifting upwards (Godwin and Spoor, 1977; Godwin and O'Dogherty, 2007).

The tine implements, such as chisel or subsoiler, are used for shallow and deep soil tillage and are equipped with forward-sloping shares **(**Hoseinian *et al.***,** 2022**).** Recently, a new tine implement with sideway shares has been introduced for shallow subsurface tillage. It was field-tested by Salar *et al*. (2013) and the effect of geometrical variables such as rake angle, tilt angle, and share size on tool resistance forces and the soil disturbance areas were analyzed using Discrete Element Method (DEM) by Hoseinian *et al*. (2022).

In this research, the concept of the "sideway shares" was used for developing a new deep tine implement (subsoiler) as part of a combined strip deep tillage machine for sugarcane fields. Thus, the primary objective of the current study was to develop and evaluate a combined tillage machine equipped with a two-level deep tillage implements comprising the dual sideway-share subsoiler and the winged subsoiler cum with a set of discs for strip deep tillage in sugarcane fields. This research aimed to compare the performance of this machine with that of a conventional subsoiler in sugarcane land preparation operation, considering performance factors such as draft force, area of the disturbed soil, and specific resistance.

MATERIALS AND METHODS

Farm Characteristics

The experimental tests were conducted in the fields of Imam Khomeini Sugarcane Agro-industry (31° 39´- 31° 55´ N and 48° 39´- 48° 48´ E). The agro-industry Co. is situated in the Shoaibiye region, located approximately 30 km south of Shushtar City in Khuzestan Province, Iran. To have soils with different physical and mechanical characteristics, two fields, namely SC13-32 and B1-131, were selected.

Selected Soil Physical Properties

The physical properties of the soil, including soil texture and bulk density, were measured at three layers: 0-20, 20-45, and 45-70 cm. To account for the influence of soil texture on bulk density, Relative Bulk Density (RBD) was employed (Equation 1).

$$RBD = \frac{BD}{BD_{REF}} \quad (1)$$

Where**,** BD represents the Bulk Density of the soil and BD_{REF} signifies the Reference Bulk Density. Given the substantial clay content in the study fields, the Jones equation (Equation 2) was utilized to determine the reference bulk density (Jones, 1983).

$$BD_{REF} = 1.985 - 0.00857clay\% \quad (2)$$

Specifications of the Subsoiler Used in Conventional Deep Tillage

In the sugarcane agro-industry Co. of Khuzestan, a conventional subsoiler with a curved (C-shaped) shank having a rectangular share with a rake angle of 18 degrees, and without any wing, is used for deep tillage.

Specifications of Combined Two-Level Tilling Machine for Strip Deep Tillage

The combined two-level tillage machine for strip deep tilling for the sugarcane fields (Figure 1) includes two implements: 1) Two dual sideway share subsoiler in front, and (2) Winged subsoiler at the back on the machine frame. Additionally, a gang of discs is mounted at the end of the frame to crush sugarcane residues.

For developing the dual sideway-share and winged subsoiler, several parameters were taken into consideration. These parameters account for the physical and mechanical properties of the soil, dimensions, rake angle, and the tilt angle of the shares and

Figure 1. Combined two-level deep tillage machine cum with a conical-type disc gang.

wings. Moreover, since the intended tractor is a track-type bulldozer with an output power of 280 hp, it is crucial for the subsoiler not only to withstand compressive and tensile stresses but also be resistant to the bending forces (resulting from sudden twists of the bulldozer). To meet these requirements, ST52 alloy steel was used to make the shares and wings.

Specifications of Dual Sideway-Share Subsoiler

To determine the suitable geometry of the dual sideway-share subsoiler for achieving adequate penetration into soil and having low specific resistance, the results of the Discrete Element Method (DEM) simulations of Hosienian *et al*. (2022) were considered. Their results stated that the draft force increases with the increase of the rake angle, and they considered the rake angle less than 15 degrees to be appropriate. Also, their results stated that different tilt angle do not have much effect on draft force, but in the range of 20 to 30 degrees, the specific resistance reached its minimum. Two rake angles, i.e. 7.5 and 15 degrees, were selected. In addition, considering the required tilled width of the soil bed (800 mm) for planting two rows of plants on each bed, the shares with widths of 150 and 200 mm were tested. The angle of attachment of the shares to the shank (tilt angle) was set at 30°.

Specifications of the Winged Subsoiler

To achieve sub-soiling to a depth of 700 mm, a winged subsoiler having a share with an 18° rake angle was employed (Figure 2). To provide the necessary disturbed soil volume in depth of the root growth, three different wings with the lengths of 200, 250, and 300 mm were evaluated. The rake angle of the wings matched the sub-soiler's share rake angle, which was 18°, and their tilt angle was set at 30°.

Specification of Disc Gang

To break down the remaining clods and plant residues after sub-soiling, four 710-mm (28-in) conical discs, manufactured from boron steel by OFAS Italy, equipped with 230-mm spools, were used. The shaft of the disc gang was positioned at distances of 800 and 450 mm from the ground surface and the winged subsoiler, respectively (Figure 1).

Field Evaluation of the Combined Deep Tillage Machine

Field evaluation of different parts of the combined two-level deep tillage machine was based on specific resistance, which is obtained from the ratio of the draft force to the cross-sectional area of the disturbed soil. To measure the draft, two-tractor test (RNAM method) was employed. For this purpose, a load cell (S-shaped; H3-C3-20t-6B-D55 model) manufactured by Zemic Co, Germany, was utilized. Data from the load cell were recorded using a data logger with a sampling rate of 1.0 second. The recorded data were stored on a 2-gigabyte memory card.

To measure the cross-sectional area of the disturbed soil, a profile meter with a width of 1000 mm and a height of 800 mm was used. The calculation of the cross-sectional area of the disturbed soil was based on Equation (3).

$$A = \left(\left(\sum_{i=1}^{n} d_i\right) - (d_1 - d_n)\right) \times L \qquad (3)$$

Where, A is the Area of disturbed soil in mm^2, di is readings taken from the profile meter rods in mm, d_1 and d_n are readings obtained from the first and last profile meter rods in mm, and L is the Longitudinal distance between the first and last profile meter rods (mm).

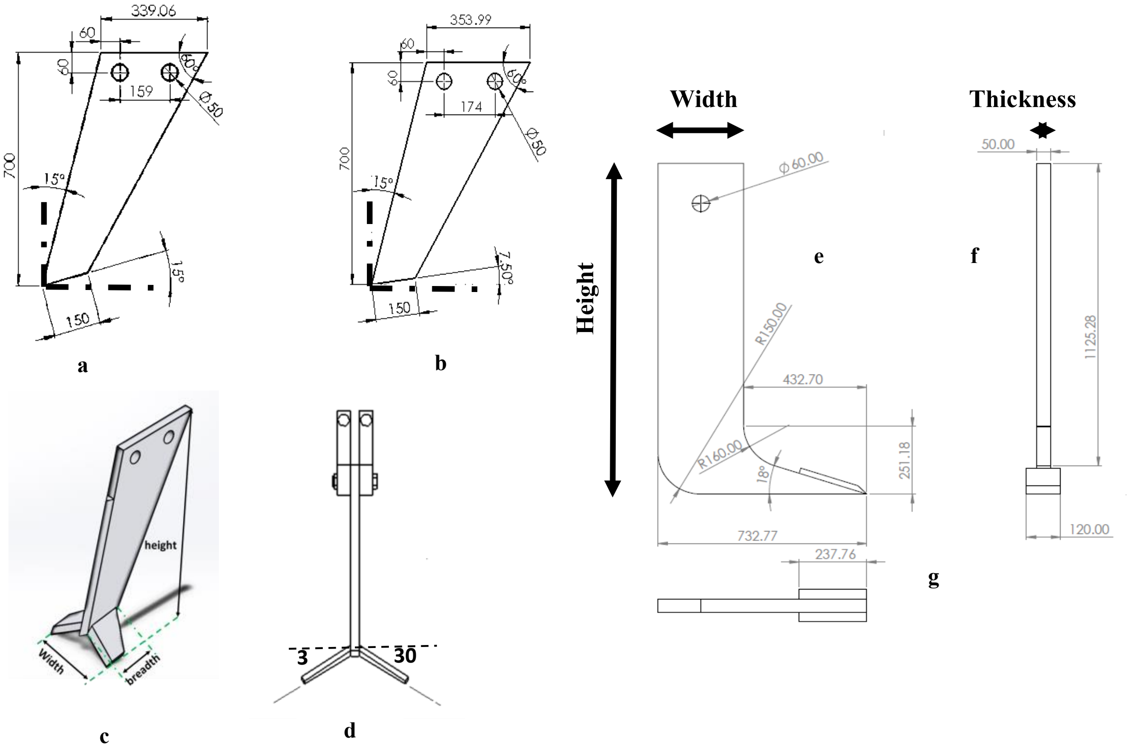

Figure 2. Dimensional characteristics of the dual sideway-share subsoiler: (a) 7.5° rake angle, (b) 15°rake angle, (c) Direction of subsoiler movement (dimensions in mm), and (d) 30° tilt angle. The views of the winged subsoiler having a share with an 18° rake angle from: (e) Front, (f) Right, and (g) Top.

Statistical Analysis

Bulk density and relative bulk density at three layers of 0 to 200, 200 to 450, and 450 to 700 mm of soil, as well as draft force, area of disturbed soil, and specific resistance of the subsoiler were assessed. This assessment was performed for the dual sideway-share subsoiler working to a depth of 450 mm, and for the winged subsoiler tilling to a depth of 700 mm. the rake angle and lengths of the shares were consider for dual sideway-share subsoiler. Also, the length of the wings were considered for winged subsoiler. In each experiment, a randomized completely block design with three replications was used for the field experiments. After checking the normality of the data by Kolmogorov-Smirnov methods (Lilliefors, 1967) and the uniformity of variances, an analysis of variance was conducted, and the means of the data were compared using the Duncan statistic in SAS software (Version 9.4) at 5% probability level.

RESULTS AND DISCUSSION

Soil Texture and Bulk Density

The texture, bulk density, and relative bulk density values at three soil layers in both fields are presented in Table 1. Both fields have the same soil texture, namely, silty clay. The results indicate that despite having similar soil texture, the two fields exhibit different bulk densities. Soil structure and texture largely determine bulk density. Therefore, the two fields differed and did not have similar soil structures. Relative bulk density shows the

Table 1. Soil texture, bulk density, and relative bulk density in different soil layers in SC13-32 and B1-131 fields.[a]

Field	Depth (mm)	Soil particle percentage Clay	Silt	Sand	Texture	Bulk density (g cm^{-3})	Relative bulk density
	0-200	47	43	10		1.63b*	1.03b*
SC13-32	200-450	47	43	10		1.62b	1.04bc
	450-700	49	43	8		167b	1.07c
					Silty clay		
	0-200	41	41	18		1.52a	0.93a
B1-131	200-450	47	45	8		1.53a	0.97a
	450-700	47	45	8		1.61b	1.02b

[a] Mean value followed by the same letter in each column are not significantly different according to Duncan's new multiple range test at the 5% level of probability.

Table 2. Draft force (kN) and specific resistance (kN m^{-2}) of the dual-sideway-share subsoiler in different soils.[a]

SL (mm)	α (deg.)	Draft force (kN) SC13-32	Draft force (kN) B1-131	Specific resistance (kN m^{-2}) SC13-32	Specific resistance (kN m^{-2}) B1-131
150	7.5	19.51a	16.56a	96.70a	64.60a
200	7.5	22.34b	20.83b	101.30a	76.20b
150	15	30.90c	22.80b	138.50b	86.40b
200	15	37.57d	25.99c	149.40b	82.0b

[a] Mean value followed by the same letter in each column are not significantly different according to Duncan's new multiple range test at the 5% level of probability. SL: shear length, α: rake angle, SC13-32 and B1-131: fields with deferent density

compactness of the soil. The 0-450 mm and 450-700 mm layers of the soil have different relative bulk densities. The average bulk density and relative bulk density across the 0-700 mm soil depth were 1.67 g cm^{-3} and 1.05 in the SC13-32 field, while in the B1-131 field, they were 1.55 g cm^{-3} and 0.97, respectively. It is reported that the ideal soil bulk density for silt loams and silty clay loams should be less than 1.40 g cm^{-3}, whereas the value of bulk density more than 1.65 g cm^{-3} restricts root growth (Anonymous, 2023). Therefore, bulk density values in all soil layers for both fields indicate that the soils were over-compacted. However, the SC13-32 field was more compacted than the B1-131.

Field performance of Dual Sideway-Share Subsoiler

The cross-sectional areas of the disturbed soil for the subsoiler having two different share rake angles and lengths tilling 450 mm deep in both fields show that the implement was working above its critical depth (Figure 3, and Table 2). This is due to the large width of the shares (with an aspect ratio greater than one and less than six, Godwin and Spoor, 1977), and, therefore, the dual sideway-share subsoiler was functioning as a narrow tillage tool and operating above its critical depth.

To determine the efficiency of soil loosening, the data of the measured draft force (Table 2) and the area of disturbed soil were analyzed and used to calculate specific resistance.

The field experiments indicated that an increase in the angle or length of the share resulted in a higher draft force requirement. The DEM simulation results given by Hosienian *et al*. (2022) also showed that the increase of the share rake angle or its cutting width linearly increased the draft force of a single sideway share subsurface tillage implement. Notably, the force value in the B1-131 field was significantly lower than in the SC13-32 field. Therefore, the SC13-32 field was more compacted than the B1-131, as shown by measuring the soil bulk density (Table 1).

In the B1-131 field, which had lower soil bulk density compared to the SC13-32 field, there was a greater amount of disturbed soil and soil upheaval (height of the accumulated soil on the surface). The smallest disturbed soil area was associated with the subsoiler having a share with a 7.5° rake angle and 150-mm length, while the largest disturbed soil area was related to the subsoiler featuring a share with a 15° rake angle and 200-mm length (refer to Figure 3). Increasing the rake angle from 7.5° to 15° did not significantly increase the width of the disturbed soil.

The lowest specific resistance was achieved with the dual sideway-share subsoiler equipped with a 7.5° rake angle and a 150-mm share length. Additionally, its value in the B1-131 field was significantly lower than in the SC13-32. Conversely, the highest specific resistance was observed in the soil of the SC13-32 field when using a 15° rake angle and a shared length of 200 mm (Figure 3). These results agree with the findings of Salar *et al*. (2013).

Selection of the optimal share dimensions was determined by comparing the specific draft (resistance) of the subsoiler equipped with different share sizes. The minimum specific draft was associated with the subsoiler having a share with a 7.5° rake angle and 150 mm length tilling soil in the B1-131 field. On the other hand, the maximum specific force was related to soil tillage using the subsoiler equipped with a share having 15° rake angle and 200 mm length in the SC13-32 field (Table 2). In growing two rows of sugarcane plants on a bed, for growth and development of the plant roots, a disturbed soil volume with a width of 110 cm and 45 cm depth is required (Sugarcane and By-Products Development Company, 2012). Therefore, to determine the optimal distance between the two units (shanks) of the dual sideway-share subsoiler, the disturbed surface of the soil in depth and the possibility of passing sugarcane clods and stumps with a diameter between 30 and 40 cm were also taken into consideration. Therefore, the center-to-center distance of 50 cm was considered between the two shanks of the subsoiler (Figure 4). The winged subsoiler with a vertical shank, with working depth of 700 mm was mounted in the middle of the two shanks at the back of the machine frame.

The specific resistance values for conventional and the dual sideway-share subsoiling at the depth of 450 mm are presented in Table 3. The results indicate that in the sugarcane fields of Khuzestan, the specific resistance of the dual sideway-share subsoiler is at least 20% and, in some cases, up to 30% lower than the conventional subsoiler working at 450 mm depth. Because of using the dual sideway-share, the increase in soil rupture exceeded the increase in tensile force.

Field Performance of Winged Subsoiler and Its Optimum Wing Size

To evaluate the performance of the winged subsoiler, measurements were taken for the draft force, area of disturbed soil and, subsequently, computing its specific resistance. This assessment involved wings with lengths of 0, 200, 250, and 300 mm. To create similar soil conditions as those achieved by the combined two-level deep machine, first, the two units of the dual-sided bent share subsoiler were used to till the soil to a depth of 450 mm.

The results of the disturbed soil area measurements using the winged subsoiler are presented in Figure 5. These results reveal that the critical depth for the wingless subsoiler is was about 500 mm. Below this depth, soil loosening (upheaving) does not occur, however, a channel with smeared walls of the same width as the shank in the soil is created. Moreover, increasing the length of the wing leads to increased soil disturbance volume. The area of soil disturbance and soil upheaval due to varying

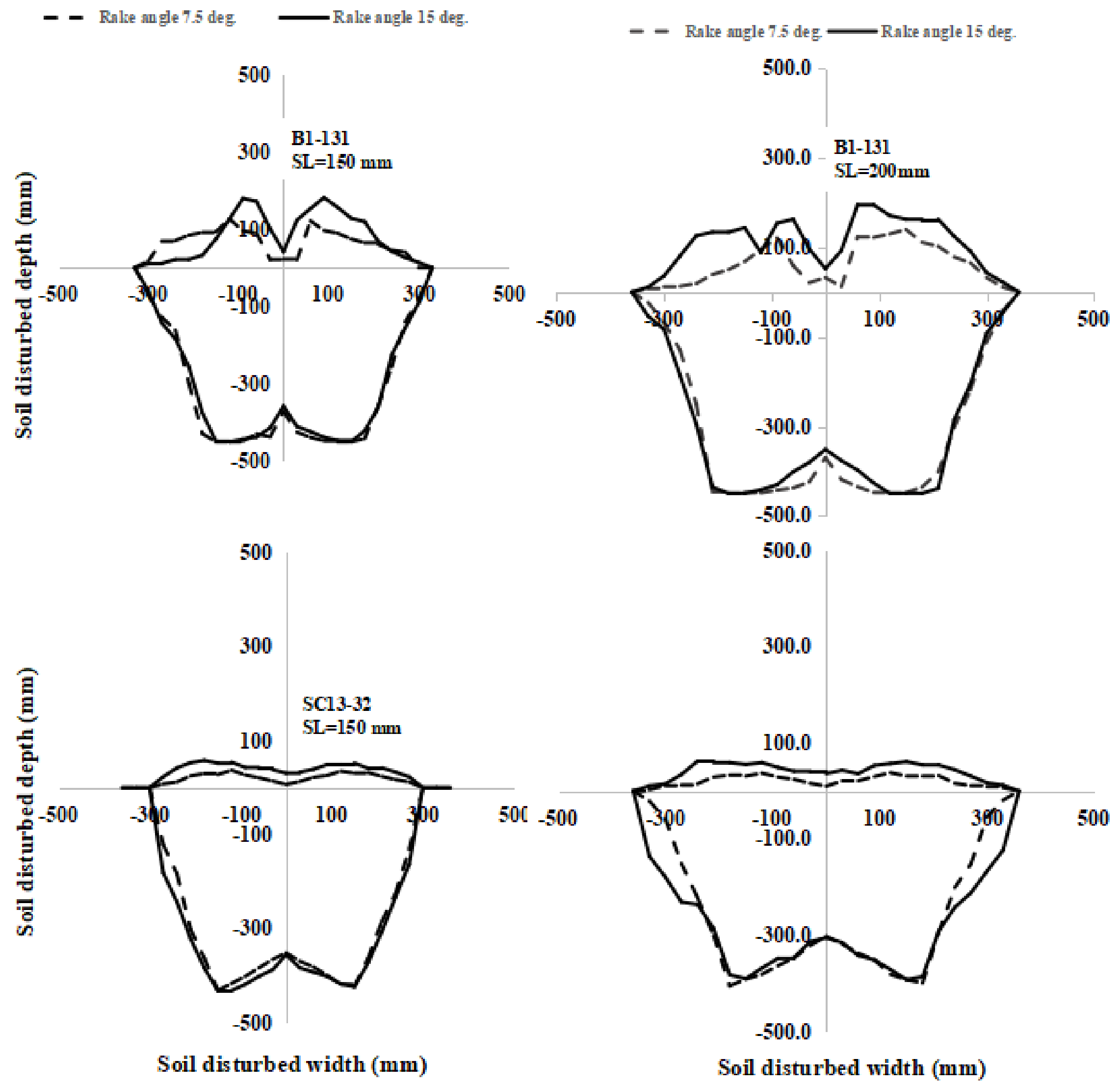

Figure 3. The soil disturbed area (mm^2) using the dual sideway-share subsoiler with different rake angles (α) and share lengths (SL) in both fields.

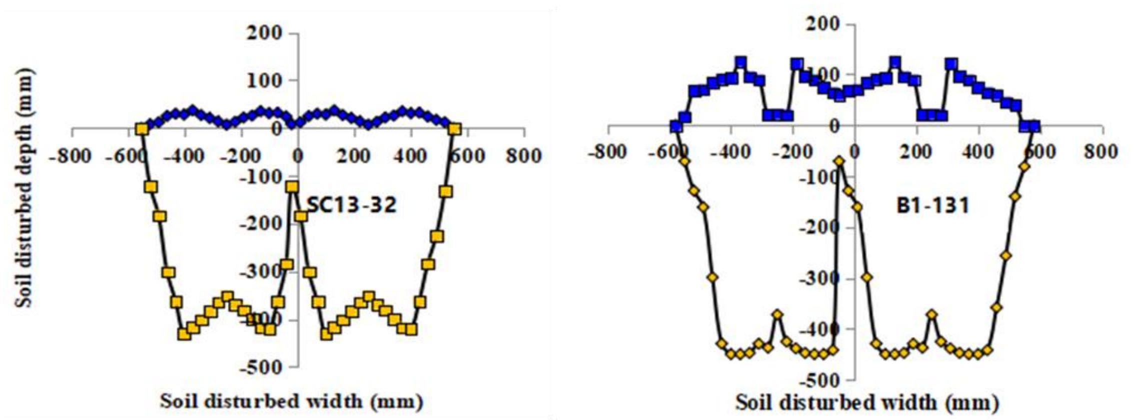

Figure 4. The cross-sectional area of the disturbed soil and soil upheaval during deep tillage with two shanks of the dual sideway-share subsoiler.

Table 3. Specific resistance (kN m^{-2}) of the dual-sideway-share subsoiler as compared to the conventional subsoiler.

Fields	Dual-sided bent share	Conventional	Percentage of reduction
SC13-32	96.7	123.1	21.1
B1-131	66.7	96.1	30.20

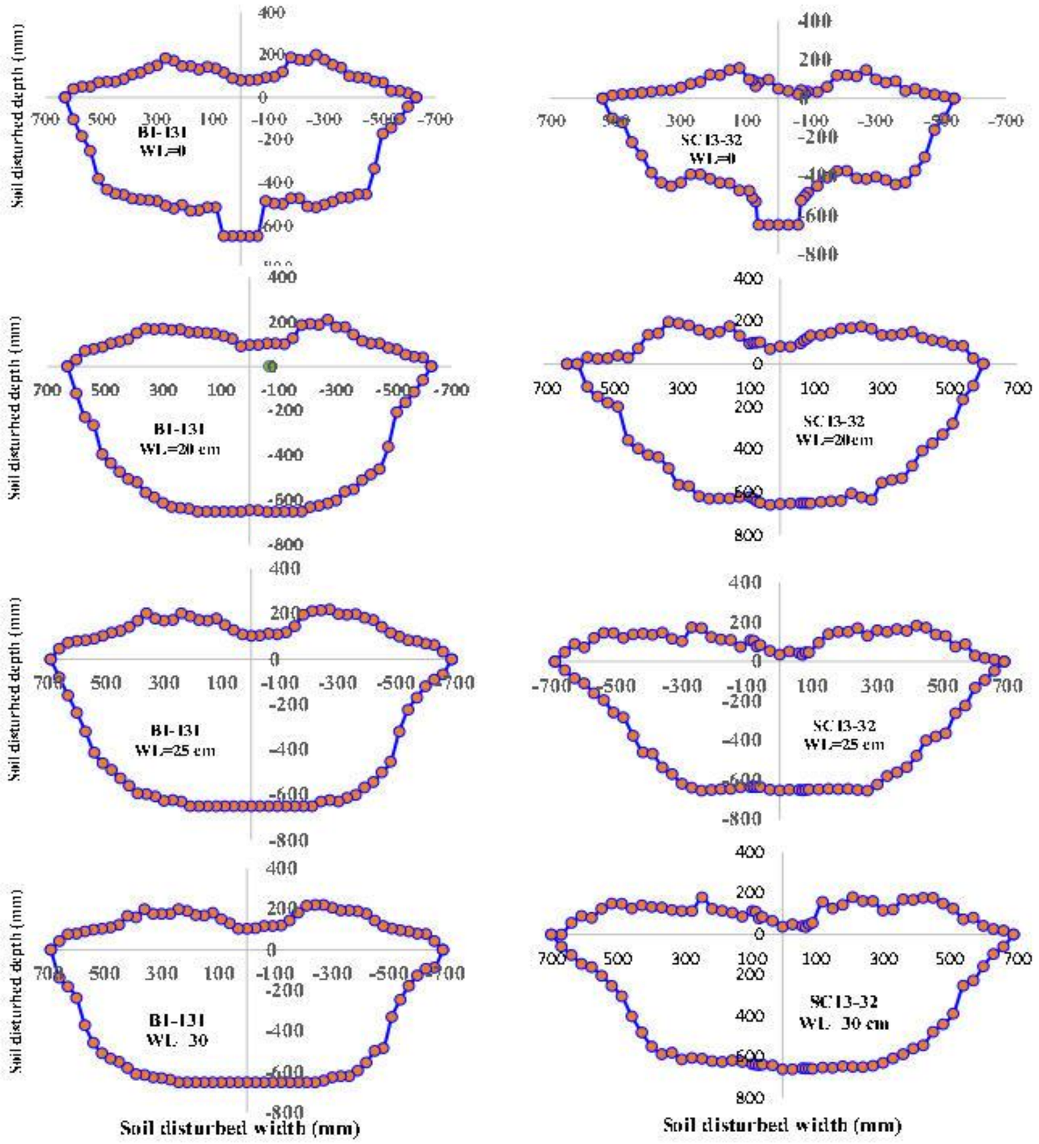

Figure 5. Soil disturbance and upheaving in deep tillage using winged subsoil with different wing lengths.

wing length are summarized in Figure 5. The data shows that, as the wing length increases, both soil upheaval and the area of soil disturbance increase.

The results of the draft force and specific resistance for the winged subsoiler are presented in Table 4. According to these findings, there is an upward trend in draft force as the length of the wing increases. However, there were no significant differences in specific resistance between the wingless and winged subsoiler. In other words, while increasing the wing length led proportionately to a larger area of soil disturbance, it did not significantly affect the specific resistance. Field observations revealed that, in these clay-rich and compacted soils, no horizontal cracks in the direction of the share (point) tip were observed, as reported in other studies (Godwin and O'Dogherty, 2007). Therefore, each wing probably mimicked the behavior of the share (point) in undisturbed soil, and the draft force as well as the volume of the disturbed soil increased proportional to wing length. Consequently, adding wings did not reduce the subsoiler-specific resistance.

In the sugarcane agro-industry company of Khuzestan Province, two rows of sugarcane billets are planted on each ridge (bed) with a horizontal spacing of 450 mm. Additionally, each sugarcane shoot requires a growing space with a radius of 250 mm to develop without competition. Since 70% of the sugarcane billet roots grow within the range of 0 to 450 mm deep in soil (Blackburn, 1984), it is recommended that strip tillage machine provides a bed with a width of 500 mm and a depth of, at least, 450 mm for each sugarcane shoot. Therefore, based on the findings presented in Table 4, it is advisable to use wings with a length of 250 mm. Furthermore, for both fields with different bulk densities, for strip tillage in sugarcane, using wingless subsoiler cultivation is not recommended.

Optimum Positioning of the Winged Subsoiler on the Combined Machine Frame

The efficiency of the subsoiler can be maximized while the longitudinal distance between the two is such that it allows the soil failure by the front subsoiler to stabilize before the rear subsoiler reaches it. Therefore, in determining the longitudinal spacing between the winged and the dual sideway-share subsoiler for developing a combined two-level deep tillage machine, it was necessary to find out the forward "rupture distance" of the winged subsoiler. This ensured that the longitudinal rupture generated by the winged subsoiler intersected under the soil disturbance caused by the front subsoiler, while avoiding interactions between the soil disturbances of both subsoiler (Figure 6). The findings indicate that the deep-working winged subsoiler disrupts the soil in front of itself, covering a distance of up to 740 mm (referred to as the rupture distance) from its share tip. Consequently, to enable independent soil tillage by both implements, there should be a minimum spacing of 740 mm between the shanks of the dual sideway-share subsoiler and the share tip of the winged subsoiler. This ensures that each tool can effectively perform its soil disturbance functions without interfering with the other.

Conventional Sub-soiling versus Strip Sub-soiling Using the Combined Machine

The results of comparing the performance parameters of conventional sub-soiling with the combined machine are presented in Table 5. The findings indicated that, while the draft force required for the combined strip tillage tool in sugarcane cultivation is 29% higher than that of the conventional subsoiler, the amount of soil loosened in the strip tillage method is 90.54% higher compared to the conventional method. Therefore, the specific resistance of the combined deep strip tillage machine is 33.7% lower than that of the conventional deep tillage. Consequently, it is recommended to use the combined two-level strip deep tillage machine in sugarcane cultivation.

The obtained results are in line with the findings reported by Godwin and Spoor (1977). They observed that the addition of wings and surface-working tools in front of the deep-working tools led to an increasing trend in draft force and the disturbed soil area. However, the specific resistance decreased compared to using a single deep-working tool. Moreover, the results obtained from this study are consistent with the findings reported by Gazor and Loghavi (2006). Therefore, strip tillage, which can create an optimal environment for sugarcane plant growth without transferring the compaction effect zone to the crop area, holds significant importance (Mcphee *et al.*, 2020).

The results of the present study showed that the minimum draft force occurred at a rake angle of 7.5° for both shallow and deep dual sideway-share implements. These findings are consistent with those reported by Hoseinian et al. (2022). Askari *et al.* (2019) studied a new tiller, the bent-winged tines, and they found a 10-degree inclination angle to be appropriate compared to a 20-degree angle at 400 mm depth.

CONCLUSIONS

The combined strip tillage machine equipped with two-level deep tillage implements comprising a dual sideway-share subsoiler and a winged subsoiler, cum with a set of discs is a novel and effective approach to deep tillage in sugarcane fields.

Table 4. Draft force (KN) and specific resistance (kN m^{-2}) of winged subsoiler in different soil.[a]

WL (mm)	Rake angle (deg.)	Draft force (KN)		Specific resistance (KN m^{-2})	
		SC13-32	B1-131	SC13-32	B1-131
0	20	18.93a	17.49a	32.27a	25.72a
200		22.23b	20.16b	30.83a	25.81a
250		26.65c	22.38c	33.73a	25.64a
300		28.41d	24.37d	35.51a	27.32a

[a] Mean values followed by the same letter in each column are not significantly different according to Duncan's new multiple range test at the 5% level of probability.

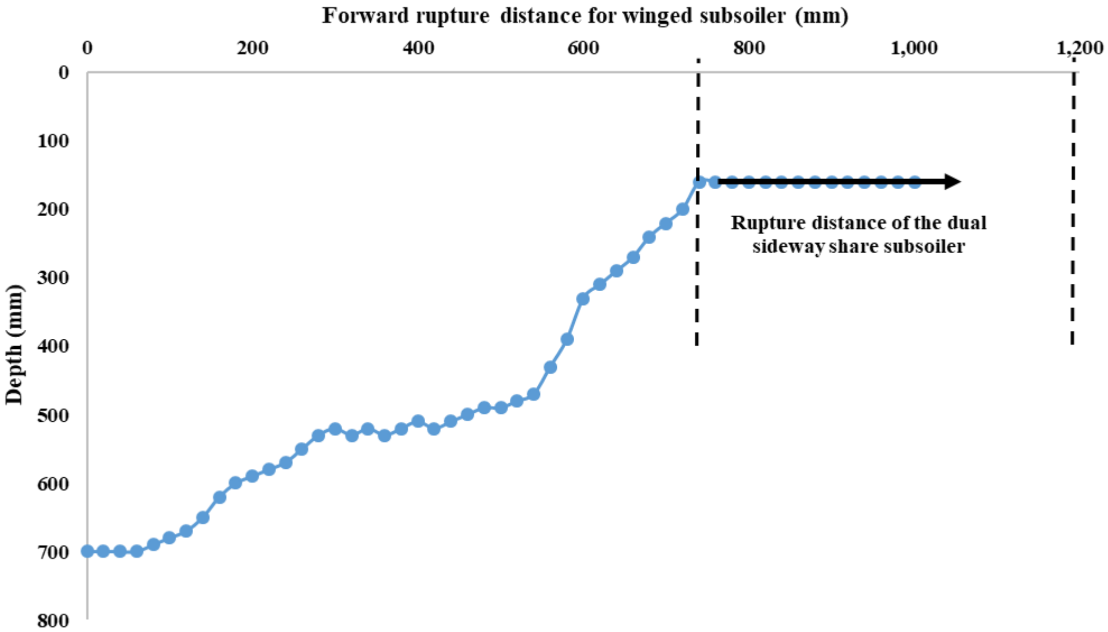

Figure 6. Forward soil disturbed by the winged subsoiler with a 250-mm wing.

Using this new tillage machine, in addition to decreasing the production costs, reduces the soil structural damages. Based on the results from the field experiments, the following conclusions were drawn:

The dual sideway-share subsoiler, with a 7.5° rake angle and 150-mm share length, can reduce specific resistance by more than 20% compared to the conventional sugarcane deep tillage. For strip tillage in sugarcane, the minimum distance between the two adjacent dual sideway-share subsoiler's shanks should be 550 mm.

Deep tillage with a wingless subsoiler beyond its critical depth can promote soil compactness, rather than removing compaction due to plastic failure of the soil around the share and lower shank. Winged subsoiler can provide high levels of tillage efficiency and eliminate critical depth issues, providing the wingspan is sufficient. The best wing for deep sub-soiling in the fields with a high clay content is 250 mm in length.

To use two-level subsoiler for deep strip tillage, the first-level subsoiler should operate at a depth of 450 mm, and the second-level deep subsoiler can operate at a depth of 700 mm.

Using the developed combined strip deep tillage machine compared to the conventional subsoiler demands more draft force, but significantly increases soil disturbance, resulting in a reduction of at least 33% in specific resistance.

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ساخت و ارزیابی زیرشکن دوسطح کار نواری در مزارع نیشکر

سینا لطیف التجار، و عباس همت

چکیده

در استان خوزستان تعداد تردد ماشین‌آلات سنگین کشاورزی برای آماده‌سازی زمین نیشکر بسته به شرایط مزرعه متفاوت و از حداقل 10 تا حداکثر 16 تردد در سال متغیر است .برای کاهش انرژی، زمان و هزینه‌ها، استفاده از خاکـورزی حفاظتی و همچنین سامانه‌های ترافیکی کنترل شده ضروری است. اهداف این تحقیق توسعه، و ارزیابی یک ماشین خاکـورزی عمیق نواری ترکیبی مجهز به یک ابزار خاکـورز عمیق دو سطح‌کار، شامل یک زیرشکن کج تیغه دوطرفه، یک زیرشکن باله‌دار به همراه مجموعه‌ای از دیسک‌ها بود. برای بهینه سازی زیرشکن کج تیغه دوطرفه ، تاثیر زاویه حمله (7.5 و 15 درجه) و طول تیغه (150 و 200 میلی متر) بر عملکرد ابزار مورد بررسی قرار گرفت. همچنین برای بهینه سازی زیرشکن باله‌دار، بال آن با طول های مختلف (0، 200، 250 و 300 میلی متر) مورد آزمایش قرار گرفت .در نهایت، عملکرد دستگاه خاکـورز عمیق نواری توسعه‌یافته با یک زیرشکن معمولی مورد استفاده برای خاکـورزی عمیق در مزارع نیشکر مقایسه شد. نتایج نشان داد که ماشین خاکـورز عمیق نواری ترکیبی بهینه‌شده باید به زیرشکن کج تیغه دوطرفه با زاویه حمله 7.5 درجه و طول 150 میلی‌متر و زیرشکن باله‌دار به طول 250 میلی‌متر مجهز شود. نتایج نشان داد که مقاومت ویژه ماشین توسعه یافته نسبت به زیرشکن معمولی 34 درصد کاهش یافت. بنابراین، این دستگاه دارای راندمان بالاتری است و ابزاری سازگار با محیط زیست برای تولید پایدار نیشکر در جنوب غربی ایران می‌باشد.

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Assessing Genetic Diversity of Soybean Based on Smartphone Image-Derived Canopy Parameter

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ABSTRACT

Convenient and accurate characterization of field-grown crops is essential for effective use of germplasm resources and breeding programs. In this study, we evaluated genetic relationships among 18 soybean accessions at the early growth stage using a smartphone image-derived canopy parameter, the Canopy Cover Rate (CCR). Field experiments were conducted over two consecutive years (2021 and 2022). CCR was estimated from top-view images using image analysis software, providing a non-destructive and efficient indicator of plant morphology. CCR showed significant variation among accessions and was strongly correlated with traditional morphological/biomass traits (Correlation coefficients> 0.8). Multivariate analyses, including Principal Component Analysis (PCA), Hierarchical Cluster Analysis (HCA), and Discriminant Analysis (DA), revealed that CCR could effectively classify accessions, with DA achieving an average correct classification rate of 88.9%. The results suggest that CCR is a reliable index for assessing genetic diversity in field-grown soybean genotypes. This study introduces an innovative, simple, and accurate method for evaluating soybean genetic resources using image-derived parameter.

Keywords: Canopy Cover Rate, *Glycine max* L., Image analysis software, Phenotyping, Soybean genetic resources.

INTROIDUCTION

Soybean (*Glycine max* L.) is a globally important crop, valued for its protein and oil content as well as its role in sustainable agriculture through biological nitrogen fixation research (McDonald *et al*., 2023). Therefore, effective conservation and utilization of soybean genetic resources are essential for breeding programs aimed at improving yield and resilience. Traditionally, genetic diversity has been assessed using morphological traits, which are often labor-intensive, subjective, and influenced by environmental factors (Khadivi, 2018; Shahid *et al*., 2021). Recent advances in digital phenotyping (Liang *et al*., 2018; Zhang *et al*., 2018; Zhou *et al*., 2018; Jong *et al*., 2021), particularly the use of smartphone-based imaging (Barman *et al*., 2020; Adhikari *et al*., 2020), offer promising alternatives for rapid, non-destructive, and objective crop characterization.

A good characterization of the plant materials is necessary for the effective use of germplasm resources and further for crop improvement (Zanklan *et al*., 2018). Because most of morphological and biomass traits may be affected by the genotype × environment interaction, it is essential to comprehensively and accurately evaluate the different phenotypes using image-derived phenotyping approach at growing stage. Wang *et al*. (2020) proposed a multiscale sliding chord matching method for characterizing and recognizing soybean cultivars from leaf images. Here, a chord was defined to slide along the leaf contour for measuring synchronized exterior shape

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features and interior appearance patterns of the soybean leaf image. However, the application of smartphone image-derived canopy parameters for genetic diversity assessment at the early growth stage in field-grown soybean remains unexplored. Because most of morphological / biomass traits may be affected by the genotype×environment interactions, it is essential to comprehensively and accurately evaluate the different phenotypes using image-derived phenotyping approach at the growth stage. Therefore, we hypothesized that the Canopy Cover Rate (CCR), extracted from smartphone images, could serve as a reliable index for evaluating genetic diversity among soybean accessions.

The objectives of this study were to: (i) Evaluate the feasibility of extracting canopy parameters using image analysis software from smartphone images at the early growth stage, and (ii) Assess genetic diversity among soybean accessions based on image-derived canopy parameters. This approach has the potential to enhance the efficiency and accessibility of genetic diversity evaluation in soybean breeding programs.

MATERIALS AND METHODS

Plant Material

Seeds of eighteen soybean accessions were obtained from the Industrial Crops Institute, Academy of Agricultural Sciences, DPR Korea (Figure 1 and Table S1). All accessions were grown under field conditions.

Experiment Site

Field experiments were conducted in experimental station (lat 39° 01′ 10 " N, long 125° 44′ 44" E, alt 30 m asl) of life science faculty of Kim Il Sung University for two consecutive years (2021 and 2022). The soil was classified as gray alluvial clay loam with a pH of 6.2. Maize was grown in the previous cropping system.

Weather Conditions in Experimental Site

Weather data were recorded daily at a nearby meteorological station (2 km distance) and summarized in Table S2.

Experimental Design

A Randomized Complete Block Design (RCBD) was used with three replicates per accession. Each plot measured 2 m² and consisted of two rows (2 m length, 60 cm between rows, and 30 cm between plants). The number of plants per plot was 12, and total number of replicates was three. The border plants were excluded from analysis.

2.5. Management Practices

Standard agronomic practices were followed, including pre-sowing fertilization (15-15-15 N-P_2O_5-K_2O at 200 kg ha^{-1}), manual weeding, and pest control with registered insecticides.

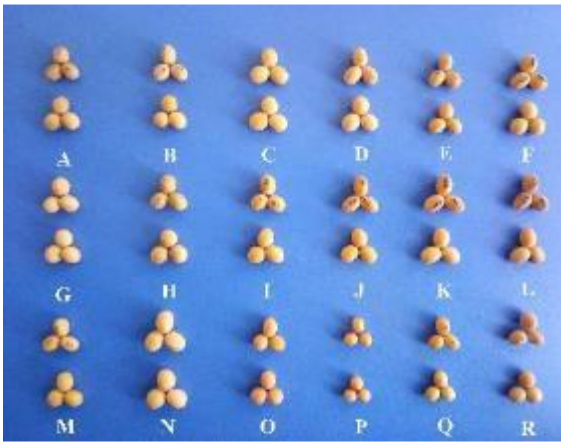


Figure 1. Soybean seeds in various accessions (online color). (A) Kong25-1, (B) Kong26-1, (C) Kong27-1, (D) Kong28-1, (E) Kong29-1, (F) Kangwon1-1, (G) Kangwon30-1, (H) KuNul5-1, (I) Duiguru13-1, (J) Duiguru14-1, (K) Duiguru17-1, (L) Duiguru19-1, (M) Duiguru20-1, (N) Duiguru21-1, (O) Haqjak40, (P) Dongnong50, (Q) Gansokji1-1, and (R) KuNul3-1.

Plant Measurements

Ten plants of twenty-day-old (2021) and 27-day-old (2022) plants were sampled for each accession, excluding border plants. Plant Height (PH, cm) and Root Length (RL, cm) were measured with a ruler. For each root sampling, a block of soil (25×20×30 cm; length, width, and depth) around each individual hill was dug up using a sampling core. The roots of plant in each block of soil were carefully rinsed with a hydro-pneumatic elutriation device (Gillison 's Variety Fabrications, Benzonia, MI, USA). Root samples were used for the measurement of Root Length (RL, cm). Plants were oven-dried at 70°C for 48 hours to determine Plant Dry Mass) (PDM, g), Aboveground Dry Mass (ADM, g), and Leaf Dry Mass (LDM, g).

Image Acquisition and Processing

Canopy cover (top-view) images were captured using a smartphone (Type 2428, Pyongyang, DPR Korea, 48 MP Camera) mounted on a selfie stick at 50 cm above each plant, between 11:30 and 12:30 h under natural light (Figure 2). Altogether, there were three digital images of ten plants for each accessions. Digital images were stored in JPG file format. The cost of Red–Green–Blue (RGB) image acquisition with smartphone camera is much lower than that with other optical instruments. Images were processed using IA software (Golden Field 2.0), developed using Fuzzy C-Means clustering algorithm (FCM) (Figures 3, 4, and 5). As one of the most widely used clustering methods, FCM introduces the fuzziness for the belongingness of each image pixel and can retain more information from the original image than the hard c-means clustering algorithm (Zhao *et al.*, 2013). It is a pixel's clustering process of dividing pixels into clusters so that pixels in the same cluster are as similar as possible, and those in different clusters are as dissimilar as possible (Tan and Isa, 2010). FCM clustering algorithm tries to partition image pixels $\{x_k\}_{k=1}^{N}$ into c clusters. The standard FCM objective function was as follows.

$$J_m(U,v)=\sum_{i=1}^{n}\sum_{k=1}^{c}\mu_{ik}^{m}\left\|x_i-v_k\right\|^2 \quad (1)$$

Where, the fuzzy membership degree of a k th image pixel x_i to a specific cluster v_k was given by the membership value u_{ik} of the data point to that cluster. The membership value was calculated by minimization of a FCM function, which searches for the belongingness that gives the least error.

$$u_{ik}=\frac{1/d_{ik}^{2/(m-1)}}{\sum_{j=1}^{c}1/d_{ij}^{2/(m-1)}} \quad (2)$$

Where, m is a parameter that controls the fuzziness of the clustering process. The

Figure 2. Acquiring canopy image using a smartphone camera fixed with the selfie stick under natural light in field (online color).

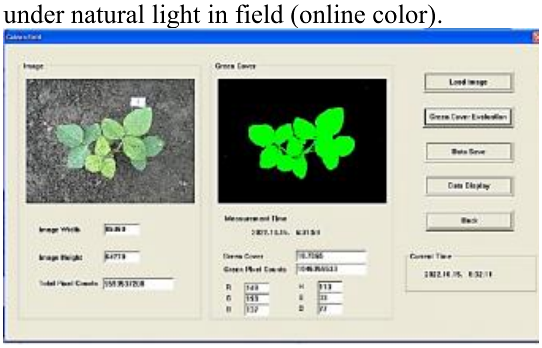


Figure 3. Canopy image processing using FCM algorithm (online color).

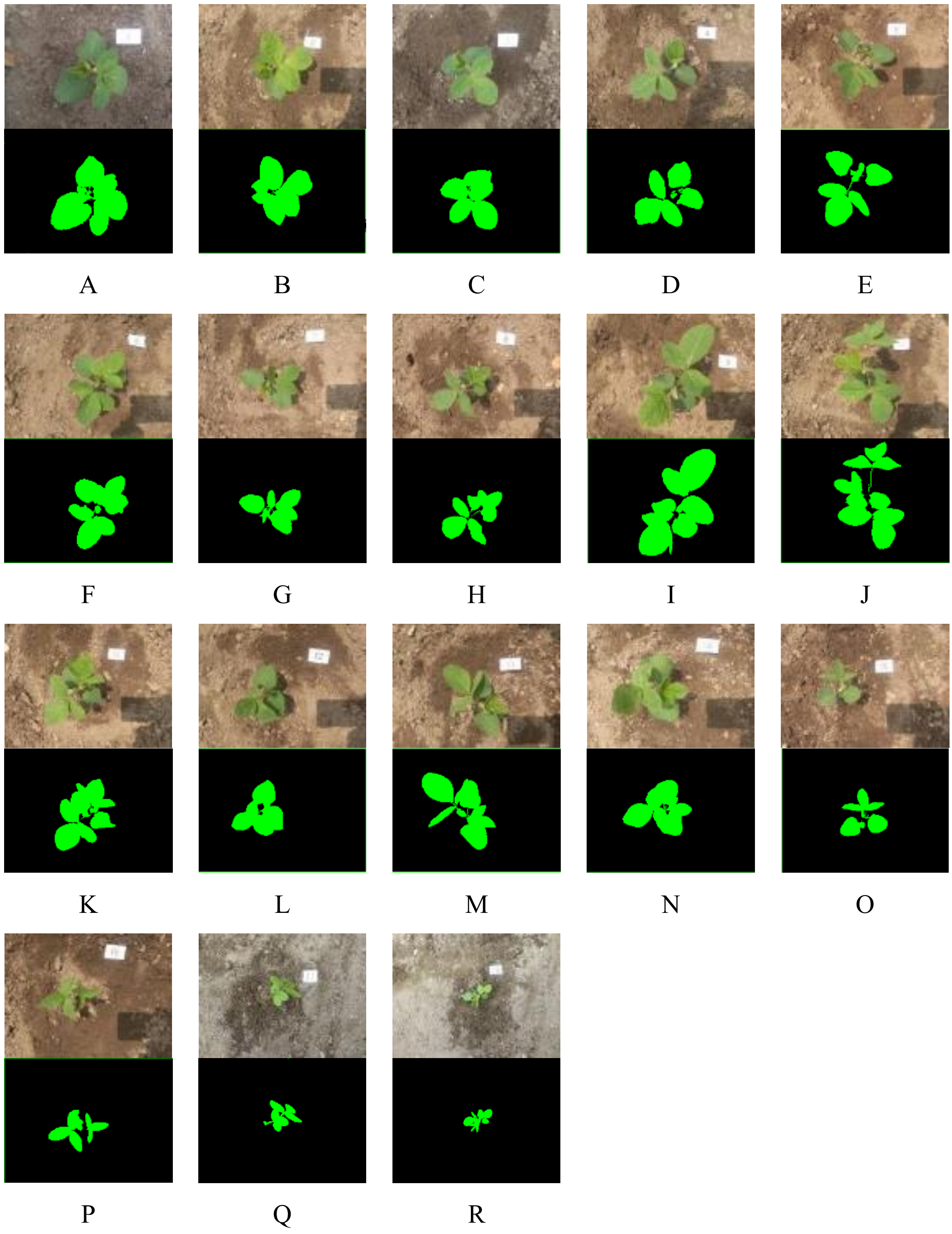


Figure 4. Original canopy image datasets taken from a plant grown during 20 days after sowing in 18 accessions (left) and the corresponding canopy RGB images of processed with IA software (right) in 2021 (online color). (A) Kong25-1, (B) Kong26-1, (C) Kong27-1, D) Kong28-1, (E) Kong29-1, (F) Kangwon11-1, (G) Kangwon30-1, (H) KuNul5-1, (I) Duiguru13-1, (J) Duiguru14-1, (K) Duiguru17-1, (L) Duiguru19-1, (M) Duiguru20-1, (N) Duiguru21-1, (O) Haqjak40, (P) Dongnong50, (Q) Gansokji1-1, and (R) KuNul3-1.

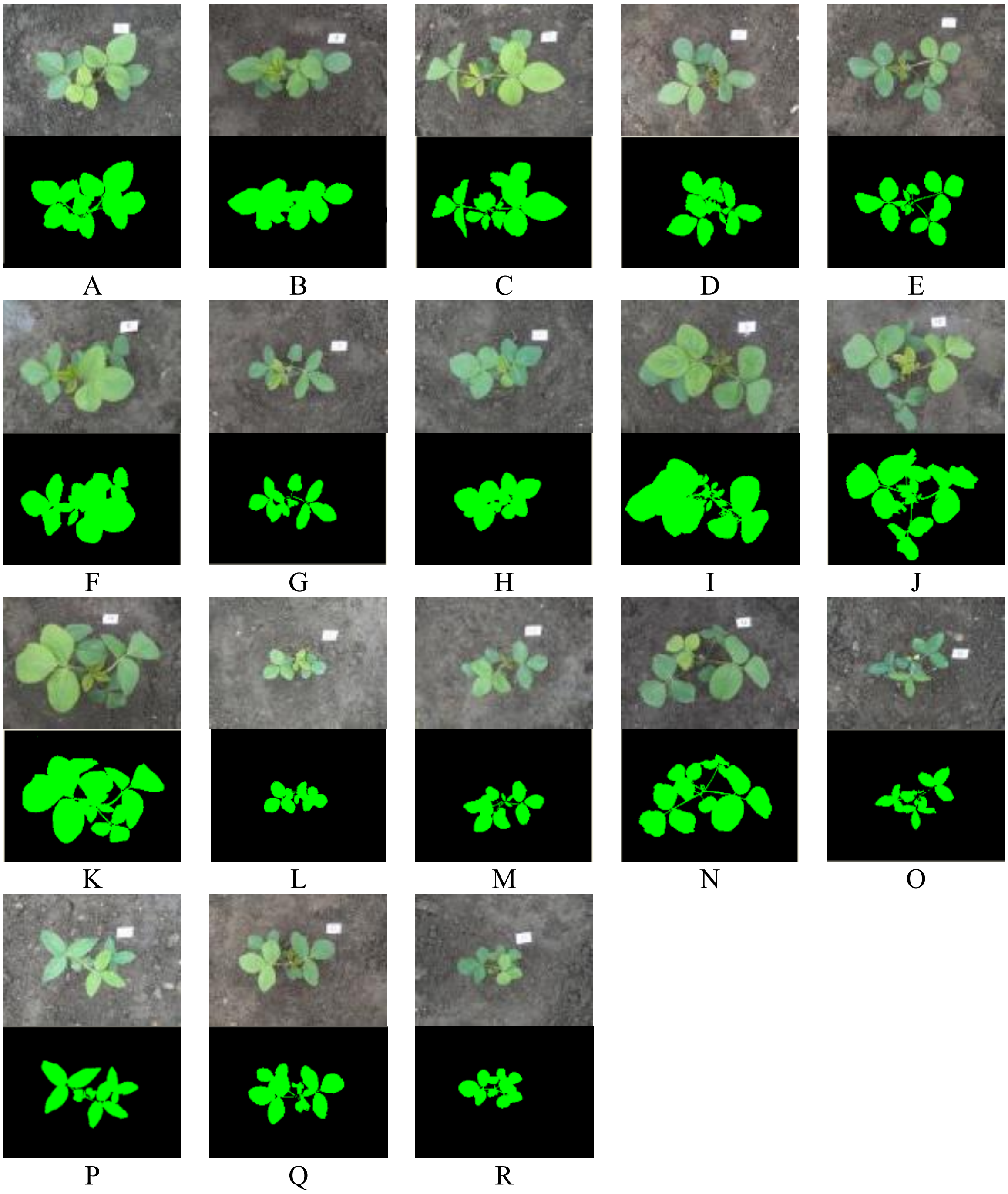


Figure 5. Original canopy image datasets taken from a plant grown during 27 days after sowing in 18 accessions (left) and the corresponding canopy RGB images of processed with IA software (right) in 2022 (online color). (A) Kong25-1, (B) Kong26-1, (C) Kong27-1, D) Kong28-1, (E) Kong29-1, (F) Kangwon11-1, (G) Kangwon30-1, (H) KuNul5-1, (I) Duiguru13-1, (J) Duiguru14-1, (K) Duiguru17-1, (L) Duiguru19-1, (M) Duiguru20-1, (N) Duiguru21-1, (O) Haqjak40, (P) Dongnong50, (Q) Gansokji1-1, and (R) KuNul3-1.

function needs approximate cluster centers v_i, as well as a metric for membership evaluation as input, e.g., the Euclidean distance:

$$d_{ik} = \| x_k - v_i \| \quad (3)$$

The minimization is an iterative process where new cluster centers are computed as weighted averages of all data points, where the membership values are the weights. After the obtained R (Red), G (Green) and B (Blue) values of each pixel from RGB images, these values were transformed into H (Hue), S (Saturation), V (Brightness) color system. HSV values of each pixel were used to distinguish green canopy cover pixels from background pixels using FCM clustering algorithm. Here, the number of the cluster c was 3, green pixels cluster count was 1, background pixels cluster count was 2. Canopy Cover Rate (CCR) was calculated as the ratio of green canopy cover pixels to input image pixel gross.

CCR%= (Canopy cover pixel gross/Input image pixel gross)×100 (4)

Statistical Analyses

Data were analyzed using IBM SPSS Statistics v21. Means, variances, coefficients of variation, and Pearson correlations were calculated. One-way ANOVA was performed for each trait. Multivariate analyses [Principal Component Analysis (PCA), Hierarchical Cluster Analysis (HCA) and Discriminant Analysis (DA)] were

Table 1. Statistical parameters for morphological/biomass traits utilized at the early growth stage in 18 accessions.

Traits	2021					2022				
	Min	Max	Mean	SD[a]	CV[a] (%)	Min	Max	Mean	SD	CV (%)
Plant Height (PH)	9.8	14.0	11.48	1.46	12.7	12.4	22.3	16.4	3.16	19.3
Root Length (RL)	10.9	13.4	12.01	0.82	6.8	21.5	23.1	22.3	0.44	2.0
Plant Dry Mass (PDM)	0.34	1.22	0.72	0.24	33.3	0.64	2.82	1.55	0.64	41.3
Aboveground plant Dry Mass (ADM)	0.27	0.90	0.56	0.19	33.9	0.51	2.30	1.22	0.52	42.6
Leaf Dry Mass per plant (LDM)	0.16	0.71	0.40	0.16	40.0	0.32	1.45	0.78	0.32	41.0

[a] SD: Standard Deviation, CV: Coefficient of Variation.

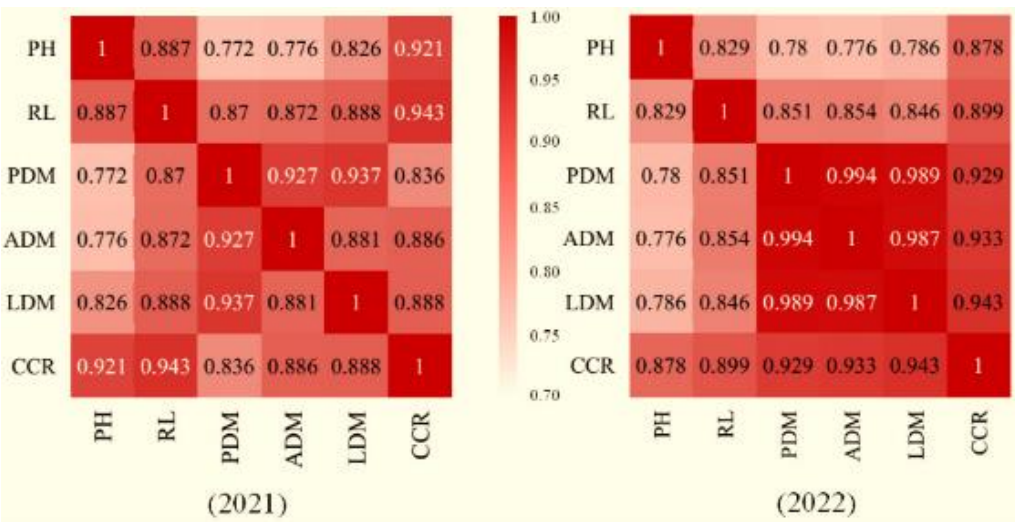


Figure 6. Heatmap of Pearson correlation coefficients between CCR and morphological/ biomass traits in 18 accessions.

conducted to assess genetic diversity and group accessions. Significance was determined at P< 0.05. To determinate the comprehensive trait among the 6 traits investigated, arithmetic mean of sum of coefficients of determination ($\overline{R^2}$) was calculated using the following Equation (5):

$\overline{R^2} = \frac{\sum r^2}{\mathrm{m}-1}$ (m= 6; Number of the traits investigated) (5)

RESULTS

Phenotypic Variation

Statistical analysis revealed significant phenotypic variation among the 18 soybean accessions at the early growth stage (Table 1). PH and biomass traits including PDM, ADM and LDM exhibited highly significant differences (P< 0.01), with Coefficients of Variation (CV) ranging from 12.7% to 40.0% in 2021 and from 19.3% to 42.6% in 2022. In contrast, RL showed much lower variability (CV= 6.8% in 2021, 2.0% in 2022). No significant differences were observed in RL among accessions in both years.

Evaluation of CCR

CCR was estimated from top-view images using image analysis software, providing a non-destructive and efficient indicator of plant morphology. It varied significantly among accessions (Table 2). Duiguru17-1 had the highest CCR (14.01% in 2021, 29.89% in 2022), while Duiguru19-1 had the lowest (3.49% in 2021, 4.60% in 2022). CCR exhibited the highest CV among all traits (42.4% in 2021, 50.5% in 2022), indicating strong discriminatory power (Table 3).

Correlation between CCR and Morphological/Biomass Traits

CCR showed strong and significant positive correlations (P< 0.01) with all measured morphological / biomass traits (Figure 6). In 2021, correlation coefficients ranged from 0.836 (PDM) to 0.943 (RL), while in 2022, they ranged from 0.878 (PH) to 0.943 (LDM).

Because $\overline{R^2}$ of CCR has the highest value (0.8023 in 2021, and 0.8403 in 2022) among $\overline{R^2}$ of 6 traits, CCR seems to be the comprehensive trait among all the investigated traits (Table 4).

Multivariate Analyses (PCA, HCA, DA)

Data on soybean plant descriptors including PH, RL and biomass traits were checked for KMO (Kaiser-Meyer-Olkin Measure) and homogeneity of variance (Bartlett's test). The KMO value (0.808 in 2021 and 0.870 in 2022) showed that it was good, while Bartlett’s test of Sphericity with an associated p value of < 0.001 suggests that we could proceed with PCA.

Table 2. Canopy Cover Rates (CCRs) at the early growth stage in 18 accessions.[a]

Accessions	CCRs (%)	
	2021	2022
Kong 25-1	8.80±0.13[g,*]	19.32±0.65[f,*]
Kong 26-1	10.11±0.09[d,*]	18.20±0.47[g,*]
Kong 27-1	7.02±0.09[i,*]	15.54±0.38[h,*]
Kong 28-1	7.61±0.10[h,*]	12.60±0.31[i,*]
Kong 29-1	6.52±0.02[j,*]	12.79±0.37[i,*]
Kangwon11-1	9.42±0.11[f,*]	20.04±0.52[e,*]
Kangwon 30-1	4.51±0.10[m,*]	8.51±0.21[l,*]
KuNul 5-1	6.11±0.02[k,*]	11.49±0.26[j,*]
Duiguru13-1	11.82±0.15[c,*]	26.71±0.71[b,*]
Duiguru14-1	12.2±0.11[b,*]	23.67±0.65[c,*]
Duiguru17-1	14.01±0.79[a,*]	29.89±0.79[a,*]
Duiguru19-1	3.49±0.10[n,*]	4.60±0.12[p,*]
Duiguru20-1	4.10±0.10[n,*]	7.70±0.19[m,*]
Duiguru21-1	9.61±0.10[e,*]	21.14±0.34[d,*]
Haqjak40	3.72±0.02[p,*]	6.31±0.14[n,*]
Dongnong50	6.60±0.16[j,*]	10.19±0.17[k,*]
Gansokji1-1	5.78±0.08[l,*]	11.43±0.15[j,*]
KuNul3-1	3.61±0.11[o,*]	5.97±0.14[o,*]

[a] Values are means±standard errors with results of statistical analysis, Total pixel counts= 84500 (n= 20).

*Means in column followed by the same letters are not significantly different at P< 0.05 level by the Fisher’s LSD test.

Table 3. Descriptive statistics for CCR among 18 accessions.

Trait	2021					2022				
	Min	Max	Mean	SD	CV (%)	Min	Max	Mean	SD	CV (%)
CCR	3.49	14.01	7.50	3.18	42.40	4.60	29.89	14.78	7.46	50.47

PCA confirmed that two principal components explained over 95% of total variance in both years (Table 5). Table 6 showed the significant correlations were detected between PC1 and PC2 with CCR (0.608 and 0.749 in 2021, and 0.715 and 0.655 in 2022, respectively). Therefore, PC1 and PC2 could explain the characteristics of 18 soybean accessions, instead of morphological / biomass traits.

The individual component values in both years were calculated using the values from the component score coefficient matrix and the following equations, respectively:

PC1= (-0.741) PH+(-0.148) RL+(0.680) PDM+(0.611) ADM+(0.361) LDM (in 2021) (6)

PC2= (1.194) PH+(0.509) RL+(-0.475) PDM+(-0.397) ADM+(-0.094) LDM (in 2021) (7)

PC1= (-0.652) PH + (-0.207) RL+(0.529) PDM+(0.533) ADM+(0.514) LDM (in 2022) (8)

PC2= (1.115) PH +(0.583) RL+(-0.306) PDM+(-0.312) ADM+(-0.289) LDM (in 2022) (9)

The factor loadings that resulted from Varimax rotation were generated with PCs and morphological/biomass traits (Table 7). PC1 was strongly associated with biomass traits, while PC2 was linked to plant height and root length (Table 7). Moreover, PC1 had a strong positive correlation to biomass traits (PDM, ADM and LDM) which characterize the "*biomass*" of the plants, while PC2 showed the close relationships with quantitative traits such as PH and RL describing "*length*". Four main groups of accessions were identified based on PCA scatter plots (Figure 7). The two axes, namely, PC1 and PC2 accounted for 95.0 % (in 2021), and 96.5% (in 2022) of the variability in morphological / biomass traits.

According to scatter plots of PCA for morphological / biomass traits, four categories were identified among 18 accessions in both years. In detail, first category was the largest, consisting of 6

Table 4. The arithmetic mean of R^2 between the investigated traits.

Traits	$\overline{R^2}$ in 2021	$\overline{R^2}$ in 2022
PH	0.7029	0.6574
RL	0.7964	0.7330
PDM	0.7577	0.8322
ADM	0.7566	0.8326
LDM	0.7829	0.8347
CCR	0.8023	0.8403

Table 5. Percentage of variance and cumulative variance, and eigenvalues for two principal components

	2021			2022		
	Eigenvalues	Percentage of variance (%)	Percentage of cumulative variance (%)	Eigenvalues	Percentage of variance (%)	Percentage of cumulative variance (%)
PC1	4.457	89.134	89.134	4.484	89.683	89.683
PC2	0.295	5.898	95.032	0.341	6.822	96.505

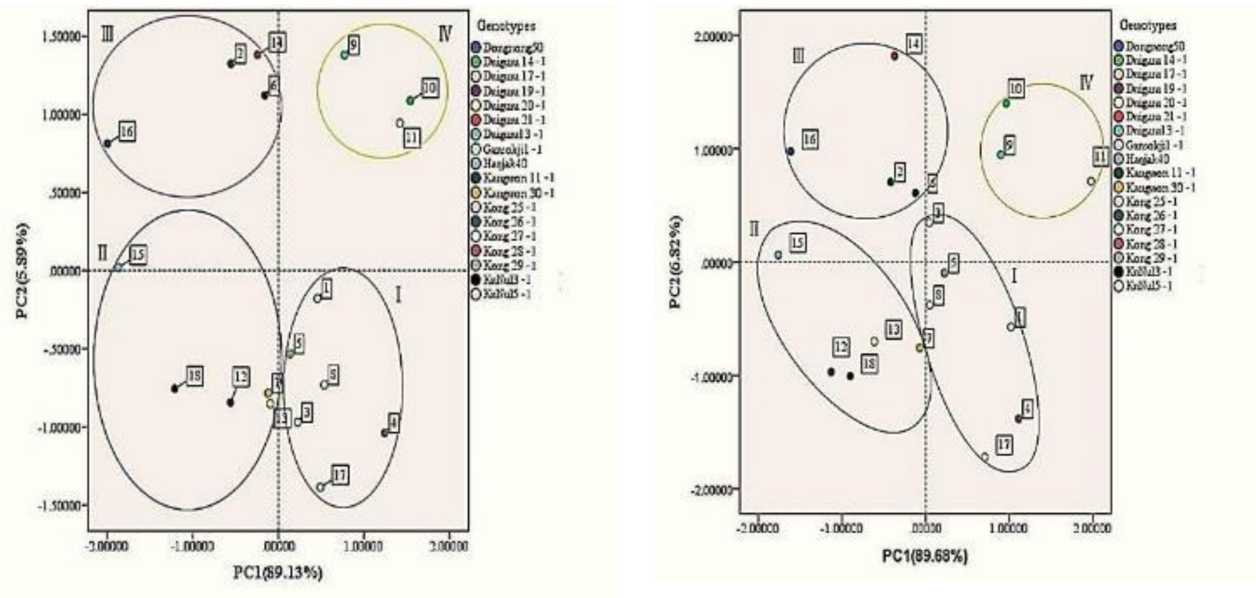
Table 6. Correlation coefficients between PC1 and PC2 with CCR.

		2021		2022	
		Component 1	Component 2	Component 1	Component 2
CCR	Pearson Correlation	0.608**	0.749**	0.715**	0.655**
	Sig.(2-tailed)	0.007	0.000	0.001	0.003
	N	18	18	18	18

Results marked with **are significant at the 0.01 probability levels.

Table 7. Rotated component matrix with Varimax.

	2021		2022	
	Component 1	Component 2	Component 1	Component 2
PH	0.425	0.894	0.407	0.890
RL	0.640	0.726	0.593	0.736
PDM	0.883	0.435	0.882	0.464
ADM	0.855	0.451	0.883	0.462
LDM	0.793	0.550	0.876	0.469



(2021) (2022)

Figure 7. Scatter plots by PCA based on morphological/biomass traits (online color).

accessions, namely, Kong25-1, Kong27-1, Kong28-1, Kong29-1, KuNul5-1 and Gansokji1-1. Second category comprised Duiguru19-1, Duiguru20-1, Kangwon30-1, Haqjak40 and KuNul3-1. Third category was composed of Kong26-1, Kangwon11-1, Duiguru21-1 and Dongnong50, and fourth category contained Duiguru13-1, Duiguru14-1 and Duiguru17-1 (Figure 7).

In PCA, PC1 was positively correlated to biomass traits, respectively (0.883, 0.855 and 0.793 in 2021, and 0.882, 0.883 and 0.876 in 2022), while PC2 was positively correlated to morphological traits, respectively (0.894 and 0.726 in 2021, and 0.890 and 0.736 in 2022) (Table 7).

R-mode HCA was performed using between-groups linkage based on Pearson correlation coefficients to find out the relationships among the investigated traits. It showed that biomass traits had a high correlation coefficient with one another, while CCR had a close similarity to biomass traits (Table 8).

Soybean accessions with the similar morphological / biomass traits were clustered together in Figure 8. When using the relative distance of 5.0 and 10.0 as a threshold, 18 accessions were clustered into three main categories and seven sub-categories. First category was the largest, consisting of 12 accessions, namely, Kangwon30-1, Duiguru20-1, Kong27-1, Gansokji1-1, Duiguru19-1, Haqjak40, KuNul3-1, Kong29-1, KuNul5-1, Dongnong50, Kong25-1 and Kong28-1 in 2021, and 8 accessions, namely, Duiguru19-1, Duiguru20-1, KuNul3-1, KuNul5-1, Kong28-1, Kangwon30-1, Haqjak40 and Gansokji1-1 in 2022. Second category composed of 3 accessions including Duiguru13-1, Duiguru14-1 and Duiguru17-1 in 2021, and 6 accessions including Kong25-1, Kong26-1, Kong27-1, Kong29-1, Kangwon11-1 and Dongnong50 in 2022. Third category consisted of 3 accessions, namely, Kangwon11-1, Duiguru 21-1 and Kong 26-1 in 2021, and 4 accessions, namely, Duiguru13-1, Duiguru14-1, Duiguru17-1 and Duiguru21-1 in 2022.

When 18 accessions were grouped based on CCR, the dendrograms obtained by HCA were shown in Figure 9. Four major categories could be detected using the relative distance of 5.0 and 10.0 as a threshold. First category was the largest, consisting of 6 accessions, namely, Kong27-1, Kong28-1, Kong29-1, KuNul5-1, Dongnong50 and Gansokji1-1 in 2021 and 2022. Second category consisted of 5 accessions, namely, Kangwon30-1, Duiguru19-1, Duiguru20-1, Haqjak40 and KuNul3-1 in 2021 and 2022. Third category comprised of Kong25-1, Kong26-1, Kangwon11-1 and Duiguru21-1 in 2021 and 2022. Fourth category included Duiguru13-1, Duiguru14-1 and Duiguru17-1 in 2021 and in 2022.

Because it was able to classify four major categories, results of HCA based on CCR were more similar to the ones suggested by the PCA than clustering based on morphological / biomass traits.

The group centroid of categories (the first, second, third, fourth category were -0.478, -3.276, 1.295, 4.690 in 2021 and -0.282, -2.502, 0.799, 3.668 in 2022, respectively) was calculated according to the following equations using unstandardized coefficients.

D = (0.907) CCR-6.796 (in 2021) (10)

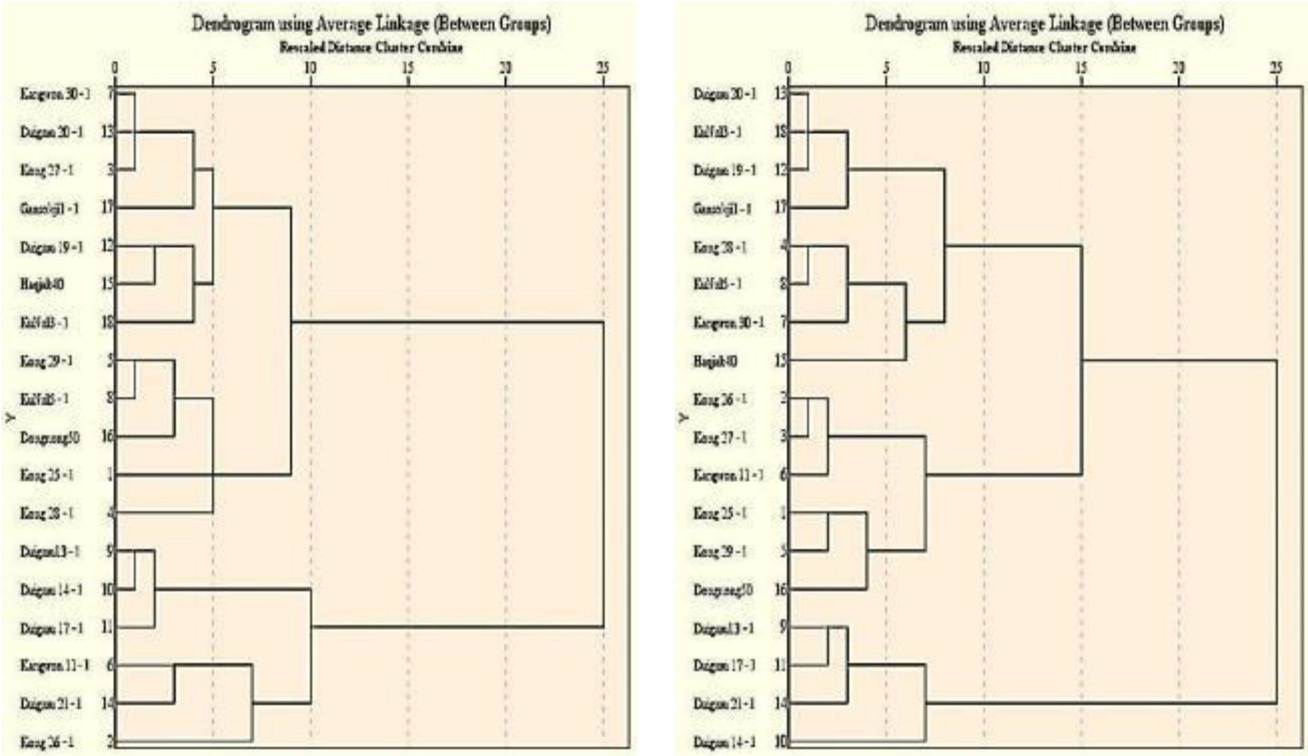
D = (0.306) CCR-4.529 (in 2022) (11)

As results of DA for CCR, Kong25-1 of the first category was classified into the third category and Dongnong50 of the third category was classified into the first category in 2021. However, Kong25-1 was classified into the third category and Dongnong50 was classified into the second category in 2022. The percentage of correctly classified on the basis of CCR was 88.9% of grouped cases by PCA. For the first category 83.3% of the cases were classified correctly, and 75.0% of the cases

Table 8. The agglomeration schedule between morphological/biomass traits and CCR.[a]

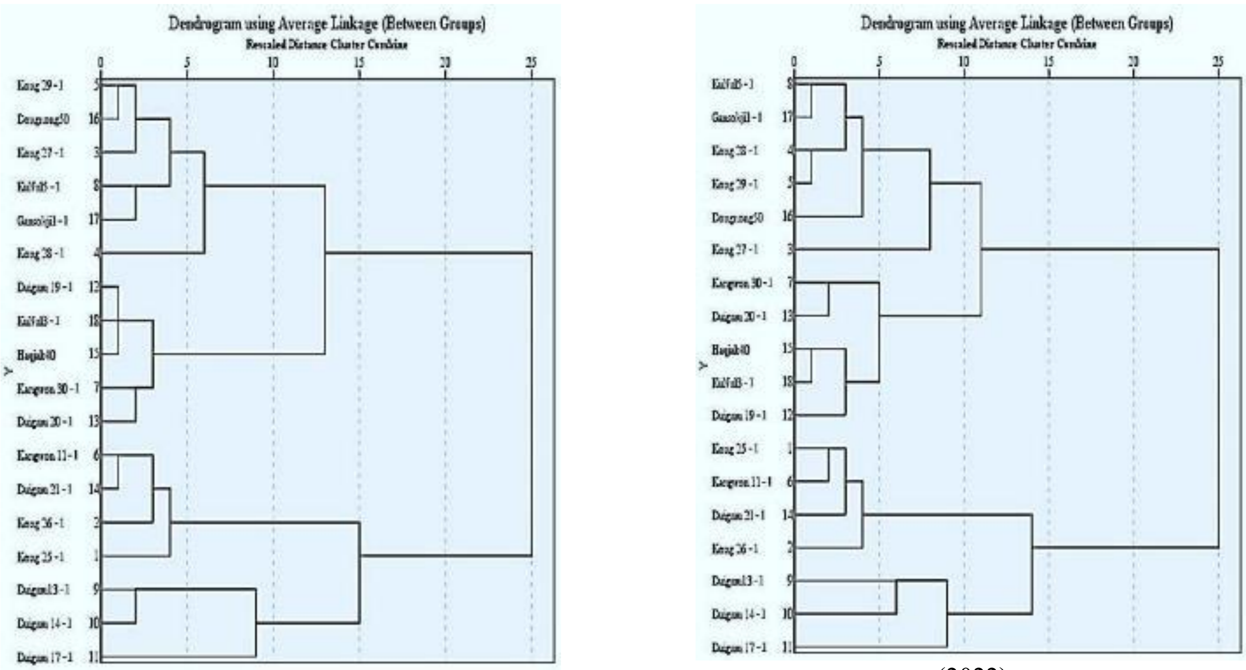
Stage	2021						2022					
	Cluster combined		Coef.	Stage cluster first appears		Next Stage	Cluster combined		Coef.	Stage cluster first appears		Next Stage
	C1	C2		C1	C2		C1	C2		C1	C2	
1	RL	CCR	0.943	0	0	4	PDM	ADM	0.994	0	0	2
2	PDM	LDM	0.937	0	0	3	PDM	LDM	0.988	1	0	3
3	PDM	ADM	0.904	2	0	5	PDM	CCR	0.935	2	0	4
4	RH	RL	0.902	0	1	5	RL	PDM	0.862	0	3	5
5	PH	PDM	0.849	4	3	0	PH	RL	0.810	0	4	0

[a] C1- Cluster 1, C2- Cluster 2, Coef.- Coefficient.



(2021) (2022)

Figure 8. Average linkage, rescaled distance cluster combine dendrograms obtained by HCA of the 18 accessions based on five morphological / biomass traits (online color).



(2021) (2022)

Figure 9. Average linkage, rescaled distance cluster combine dendro-grams obtained by HCA of the 18 accessions based on CCR (online color).

were classified correctly for the third category. Especially, the classification rate of the second category and fourth category was 100% (Table 9).

DISCUSSION

To our knowledge, although image-derived phenotyping has been explored in various crops, its application for genetic diversity assessment at the early growth stage in soybean remains largely unaddressed. In this study, we demonstrated that CCR derived from smartphone images is a robust and efficient index for evaluating genetic diversity among field-grown soybean accessions at the early growth stage. The high correlations observed between CCR and traditional morphological/biomass traits confirm the reliability of this image-derived parameter as an indirect measure of plant growth and architecture. These findings are consistent with recent reports on the utility of digital phenotyping in crop improvement (Zhou *et al*., 2018; Zhang *et al*., 2018), but to our knowledge, this is the first study to apply such an approach for genetic diversity assessment in soybean at early developmental stages.

Traditionally, several quantitative traits have been used to determine the genetic diversity and classify germplasm resources in many plants (Gadissa *et al*., 2020; Shahid *et al*., 2021). However, measuring quantitative traits such as plant height and biomass is the labor-intensive and time-consuming in large breeding populations and field environments (Jiang *et al*., 2016). Furthermore, conventional measuring on biomass traits has been obtained using the destructive method such as the drying in an oven (Wen *et al*. 2017).

In this study, CCR was estimated using IA software from RGB image without any significant alteration of plant morphology at the early growth stage. Moreover, estimation of CCR using IA software from canopy images taken by the smartphone camera seems to be suitable for young plants grown in field environment.

HCA produced similar groupings, especially when based on CCR. DA achieved an average correct classification rate of 88.9%, supporting the utility of CCR for distinguishing genetic diversity among accessions.

A multiscale sliding chord matching method was proposed to characterize and recognize soybean cultivars using joint leaf image patterns (Wang *et al*., 2020). Here, to obtain soybean cultivar leaf image database researchers used the destructive method to take the individual leaf image from the lower, middle and upper parts of the plants of one soybean cultivar, respectively. However, we employed the non-destructive

Table 9. Percentage of 18 accessions classified in each category by DA.[a]

Category			2021					2022				
			Predicted category Membership				Total	Predicted category Membership				**Total**
			1	2	3	4		1	2	3	4	
Original	Count	1	5	0	1	0	6	5	0	1	0	6
		2	0	5	0	0	5	0	5	0	0	5
		3	1	0	3	0	4	0	1	3	0	4
		4	0	0	0	3	3	0	0	0	3	3
	%	1	83.3	0.0	16.7	0.0	100.0	83.3	0.0	16.7	0.0	100.0
		2	0.0	100.0	0.0	0.0	100.0	0.0	100.0	0.0	0.0	100.0
		3	25.0	0.0	75.0	0.0	100.0	0.0	25.0	75.0	0.0	100.0
		4	0.0	0.0	0.0	100.0	100.0	0.0	0.0	0.0	100.0	100.0

[a] 88.9% of original grouped cases was correctly classified.

method to take canopy image using a smartphone camera from individual soybean plant in field environment.

The results above provided the support for the hypothesis that that smartphone image-derived CCR could serve as a simple, accurate, and non-destructive index for evaluating genetic diversity among field-grown soybean accessions at the early growth stage.

Because the present approach using CCR as a genetic diversity index uses a smartphone camera for capturing digital images in the field environment, it is far simpler and lower-cost than the complex and expensive system using LiDAR-based Canopy Height Model, also known as a normalized Digital Surface Model (An *et al*., 2016) and Normalized Difference Vegetation Index using remote sensing (Rees *et al*., 2020) and Leaf Area Index (LAI) estimated by Terrestrial Laser Scanning (Chen *et al*., 2018).

The present approach is adequate for the early growth stage of crops, but is inadequate to the maturing period of high crops such as maize, sugarcane and sorghum, because capturing the top-view canopy image for high plants is difficult with smartphone camera.

Overall, our findings supported the use of smartphone image-derived CCR as a practical and effective tool for genetic diversity assessment in soybean, paving the way for more efficient phenotyping and breeding strategies.

Further validation in larger and more diverse populations, as well as at later growth stages, is recommended to confirm the generalizability of these findings.

CONCLUSIONS

In summary, this study demonstrated that CCR, extracted from smartphone images, is a robust and efficient index for evaluating genetic diversity among field-grown soybean accessions at the early growth stage. The strong correlation between CCR and traditional morphological / biomass traits, together with high classification accuracy in multivariate analyses, highlights the practical value of this approach. By leveraging accessible and low-cost smartphone technology, this method offers a rapid, non-destructive alternative to conventional phenotyping, making it particularly suitable for breeding programs and genetic resource management in resource-limited environments. While further validation across broader germplasm collections and developmental stages is warranted, our findings support the integration of image-derived canopy parameters into modern crop improvement pipelines.

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Table S1. Soybean accessions used in this study.

№	Accession name	Origin	№	Accession name	Origin
1	Kong25-1	DPR Korea	10	Duiguru14-1	DPR Korea
2	Kong26-1	DPR Korea	11	Duiguru17-1	DPR Korea
3	Kong27-1	DPR Korea	12	Duiguru19-1	DPR Korea
4	Kong28-1	DPR Korea	13	Duiguru20-1	DPR Korea
5	Kong29-1	DPR Korea	14	Duiguru21-1	DPR Korea
6	Kangwon11-1	DPR Korea	15	Haqjak40	China
7	Kangwon30-1	DPR Korea	16	Dongnong50	China
8	KuNul5-1	DPR Korea	17	Gansokji1-1	DPR Korea
9	Duiguru13-1	DPR Korea	18	KuNul3-1	DPR Korea

Table S2. Weather conditions in experimental site during crop-growing period in 2021 and 2022.

Year	Air temperatures (℃)			Total rainfall (mm)	Sunshine percentage (%)
	Maximum	Minimum	Mean		
2021 (1 June–20 June)	30.4	14.1	21.8	107.4	40.1
2022 (30 May–June 27)	32.1	11.7	21.9	116.0	32.1

ارزیابی تنوع ژنتیکی سویا بر اساس پارامتر سایبان (Canopy) گرفته شده از تصویر تلفن هوشمند (Smartphone)

مایونگ-کوانگ ری، کوانگ-او جونگ، و یه-کوانگ سین

چکیده

برای استفاده مؤثر از منابع ژرم‌پلاسم و برنامه‌های اصلاحی، توصیف آسان و دقیق محصولات زراعی کشت‌شده در مزرعه ضروری است. در این پژوهش، ما روابط ژنتیکی بین 18 نمونه سویا را در مرحله اولیه رشد با استفاده از پارامتر تاج پوشش گیاهی گرفته‌شده از تصویر تلفن هوشمند، یعنی نرخ پوشش تاجی (Canopy Cover Rate= CCR)، ارزیابی کردیم. آزمایش‌های میدانی طی دو سال متوالی (2021 و 2022) انجام شد. نرخ پوشش تاجی (CCR) با استفاده از نرم‌افزار تحلیل تصویر (Image Analysis) و از روی تصاویر نمای بالا تخمین زده شد که یک شاخص غیرمخرب و کارآمد از مورفولوژی گیاه ارائه می‌دهد. نرخ پوشش تاجی تنوع معنی‌داری را در بین نمونه‌های جمع‌آوری‌شده نشان داد و همبستگی قوی با صفات مورفولوژیکی/زیست‌توده سنتی داشت (ضرایب همبستگی > 0.8). تحلیل‌های چند متغیره، شامل تحلیل مؤلفه‌های اصلی (PCA)، تحلیل خوشه‌ای سلسله مراتبی (HCA) و تحلیل تشخیصی (DA)، نشان داد که CCR می‌تواند به طور مؤثر نمونه‌های جمع‌آوری‌شده را طبقه‌بندی کند، و DA به طور متوسط نرخ طبقه‌بندی صحیح 88.9٪ را به دست آورد. نتایج نشان می‌دهد که CCR یک شاخص قابل اعتماد برای ارزیابی تنوع ژنتیکی در ژنوتیپ‌های سویای کشت‌شده در مزرعه است. این مطالعه روشی نوآورانه، ساده و دقیق برای ارزیابی منابع ژنتیکی سویا با استفاده از پارامتر گرفته‌شده از تصویر معرفی می‌کند.

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Braconid Wasps (Hymenoptera) in Two Iranian Hotspots: Conservation Implications

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ABSTRACT

Biodiversity hotspots are key for identifying priority areas for species conservation. The Alborz Mountains, with two hotspots (the Caucasus on the northern slope and the Irano-Anatolian on the southern slope) provide an ideal landscape for assessing the impacts of vegetation, slope and elevation on species diversity. We examined the alpha and beta diversity of Braconidae across different slopes (northern/southern), elevations (upper/lower positions) and provinces (Guilan and Mazandaran in northern Iran, Qazvin, Tehran, Alborz). Using 31 Malaise traps, we collected 276 species and 5,950 individuals from 20 subfamilies. Shannon-Wiener and Brillouin's indices showed higher diversity on the northern slope. Species diversity peaked at mid-elevation (800–1,200 m). Alpha diversity was highest in Guilan and Alborz-Tehran. Beta diversity analysis indicated that slope, elevation, and province influenced species composition. Similar compositions were found in Mazandaran-Guilan (northern slope), and Alborz-Tehran and Qazvin (southern slope) in vegetation zones with similar environmental conditions. Additionally, the highest species composition similarity was observed between the southern and northern slope positions and upper positions of both slopes. These findings have important implications towards the maintenance of the diversity of braconids, a major beneficial species group, by prioritizing their hotspots.

Keywords: Alpha diversity, Beta diversity, Conservation, Dominant species, Species richness.

INTRODUCTION

The geographical and evolutionary histories of mountainous regions have led to the emergence of biodiversity hotspots (Perrigo *et al.*, 2020). The biodiversity of northern Iran lies within two main hotspots: The Irano-Anatolian (southern slope of the Alborz Mountains) and the Caucasus (northern slope of the Alborz Mountains) hotspots (Noroozi *et al.*, 2019). Iran encompasses 54% of the Irano-Anatolian hotspot and nearly 10% of the Caucasus hotspot (Noroozi *et al.*, 2019). The Alborz Mountains in northern Iran form a natural barrier to the flow of humid air masses from higher latitudes, and prevent the flow of dry central Iranian air masses to the northern slope. As a result, the northern and southern slopes experience distinct climate conditions (Kiani *et al.*, 2017; Noroozi and Körner, 2018). The northern slope is characterized by a semi-humid to humid climate, with an average annual precipitation ranging from

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500 to 1800 mm, low solar radiation, and predominantly forest vegetation that covers the southeastern part of the Caucasus biodiversity hotspot (Williams *et al*., 2006). It contains one of the greatest biological diversity of temperate forest regions across the world, including more than 6,500 species of vascular plants. Interestingly, 25% of the plant species are endemic. This area has more than twice the plant and animal diversity if compared with the adjacent regions of Europe and Asia (Zazanashvili and Mallon, 2009). The southern slope (Irano-Anatolian hotspot) has an arid/semi-arid climate with average annual rainfall, i.e., less than 200 mm to over 500 mm, and sparse herbaceous vegetation (Heydari *et al*., 2020). Climates, elevation, and vegetation could be among the most important key factors that lead to species diversity in different geographical slopes (Ghaladze, 2012; Song *et al*., 2023).

Species diversity is an important feature of the biological community, describing the ecosystems' health (Dudgeon *et al*., 2006). An accurate understanding of species diversity patterns is a prerequisite step to provide an extensive reference for protecting zonal diversity (Socolar *et al*., 2016) and determining the strategies for species conservation in the target areas (Whittaker, 1972).

Species diversity has two basic components including species richness and evenness. Species richness refers to the number of species observed in a certain ecosystem and evenness measures the relative importance of each species. Indeed, when there are large disparities in the number of individuals within each species, the ecosystem has low species evenness. In contrast, high species evenness occurs when the number of individuals within a species is constant (Nwoko *et al*., 2022). It is important to consider species richness and diversity since increasing species diversity can influence the stability of ecosystems. A range of factors have been hypothesized to influence spatial patterns of species richness such as climate, topography, landscape composition and configuration, or natural and human disturbances (Karp *et al*., 2018; Li *et al*., 2021). The display of the spectrum of different vegetation zones, slopes and elevation gradients, makes the Alborz Mountains an ideal landscape for studying the spatial patterns of species diversity and assessing the effects of factors linked with the spatial changes in the richness of wildlife species. Although many studies have investigated the effects of environmental or anthropogenic factors on the alpha diversity of Braconidae (Gadelha *et al*., 2012; Falcó-Garí *et al*., 2014), no comprehensive survey has been conducted on the mechanisms that drive alpha and beta diversity in Braconidae.

Braconids are the most important group of parasitoids attacking all developmental stages of their hosts, especially the larval stage (Chen and van Achterberg, 2019). The host range of Braconidae fall within Lepidoptera, Coleoptera and Diptera. Family Braconidae includes 43 subfamilies and comprises over 21,000 described species (Chen and van Achterberg 2019; Yu *et al*., 2016; Gadallah *et al*., 2022). Braconids are found in all geographic regions of the world (Yu *et al*., 2016). The braconid wasps extensively have been reported from Iran (e.g., Rakhshani *et al*., 2007, 2008; Ameri *et al*., 2015; Farahani *et al*., 2012, 2014a, b, c, 2015, 2016; Ghotbi Ravandi *et al*., 2017; Talebi *et al*., 2018; Zargar *et al*., 2019a, b; Dolati *et al*., 2021; Gadallah *et al*., 2022; Pourhaji *et al*., 2022; Abdoli *et al*., 2019a, b, c, 2021, 2022, 2023a, b). These faunistic researches have led to an increase in the number of Iranian braconid species to 1,363 species in 203 genera and 30 subfamilies (Gadallah *et al*., 2022).

It is hypothesized that the distribution of Braconidae shows strong variation patterns among slopes and elevation gradients. Previous studies on the diversity of other parasitoid wasps in Iran (Lotfalizadeh *et al*., 2014, 2015; Safahani *et al*., 2018; Piruznia *et al*., 2022) have highlighted their ecological importance and distribution patterns. However, there remains a lack of comprehensive research on braconid wasps, which this study aimed to address.

Displaying a spectrum of different vegetation zones, slopes and elevation gradients makes the Alborz Mountains an ideal landscape to study the spatial patterns of species diversity of Braconidae. We, therefore, set out to examine the roles of slope aspects, elevations and provinces on species diversity, including species richness, evenness, community compositions, and alpha and beta diversity indices in two neighboring biodiversity hotspots of the Alborz Mountains.

MATERIALS AND METHODS

Study Area

Alborz is a mountain range in northern Iran, located south of the Caspian Sea, representing the highest mountain system of the region, rising sharply from the Caspian Sea level at -26 m to the highest summit of 5,671 m asl at Damavand peak (Akhani, 1998). North-central Iran includes the northern and southern slopes of the Alborz Mountains. The northern slope (Caucasus biodiversity hotspot) comprises the provinces Mazandaran and Guilan, while the southern slope (Irano-Anatolian biodiversity hotspot) comprises the provinces Alborz-Tehran and Qazvin (Myers *et al*., 2000).

Sampling

The Malaise trap is a well-known device to collect flying insects (Ssymank *et al*., 2018; Skvarla *et al*., 2021) and has been extensively used in several insect diversity projects worldwide (Karlsson *et al*., 2020; Hausmann *et al*., 2020). Thirty-one Malaise traps were placed in a range of different habitats including forests, rangelands and orchards in northern Iran (i.e., Alborz, Guilan, Mazandaran, Qazvin and Tehran Provinces) (Supplementary Data 1). The trapped specimens were collected and identified during 2010 and 2011 (Figure 1). The traps operated continuously over the season, with a two-week collection interval. The slopes of the Alborz Mountains were separated into the upper and lower positions to survey how species richness varies along the elevation gradient (Figure 1). We tried to keep the sampling regions with mid-elevation peak (800–1,200 m) on a position of each slope to examine the effect of these range on species diversity. Therefore, the mid-elevation peak included the upper position of the northern slope and the lower position of the southern slope. The collected braconid wasps were placed in 95% alcohol. The specimens were

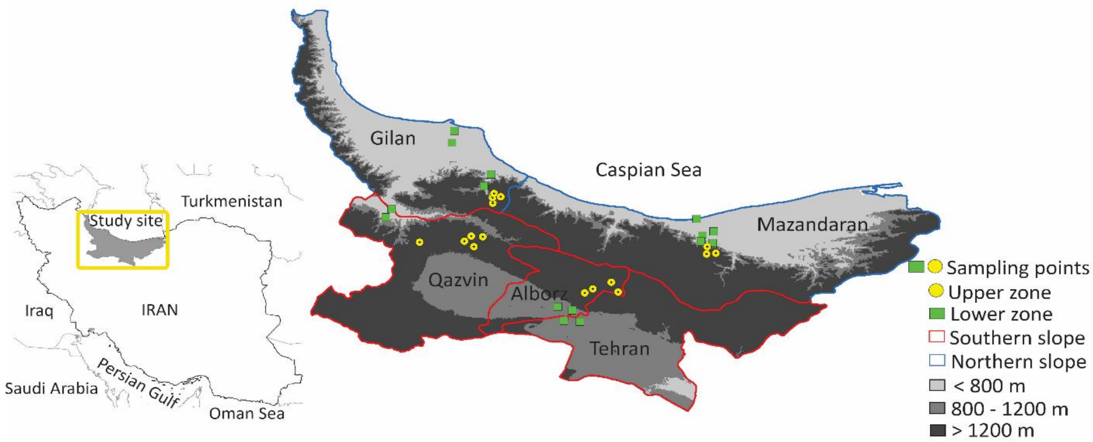

Figure 1. Alborz, Qazvin, Tehran, Guilan and Mazandaran Provinces, where specimens have been collected.

identified by taxonomic experts (see acknowledgements) at the species level by using appropriate identification keys (Telenga, 1955; Nixon, 1965; Mason, 1981; Tobias, 1986; van Achterberg, 1993, 1997) over the past 10 years. The specimens are deposited in the TMUC (Insect Collection of the Department of Entomology, Tarbiat Modares University, Tehran, Iran).

Statistical Analysis

The SDR4 software was used to measure the indices related to species diversity (Seaby and Henderson, 2006). Species richness and alpha diversity of Braconidae were assessed using rarefaction and the Shannon–Wiener/ Brillourin indices. Pielou and Heip indices were also used to evaluate species evenness. Finally, the beta diversity index was calculated by Whittaker's formula to estimate habitat diversity across the studied sites (Whittaker, 1972; Legendre *et al*., 2005).

Structure of Species Composition

The identified species were classified using the Weigmann's classification method (Weigmann, 1973) based on their abundance into four dominance classes: eudominant (> 30%), dominant (10 to 30%), subdominant (5 to 10%), rare (1 to 5%) and sub rare (< 1%).

$D=b/a\times100$

Where, *D*: Dominance; *a*: The total number of collected specimens; *b*: The number of individuals of a specific species.

Species Richness

Species Richness (SR), is the simple and most frequently used measure of biological diversity, representing the number of species per unit area (Brown *et al*., 2007). Rarefaction analysis estimates species richness and provides an expected number of species (Hurlbert, 1971). The number of Species (Sn), that can be expected from a random sample of n individuals, drawn without replacement from *N* individuals distributed among *S* species, is given by:

$$SR = \sum_{i-1}^{S}\left(1-\left[\frac{\binom{N-N_i}{n}}{\binom{N}{n}}\right]\right)$$

Where, *S*: The total number of Species in the collection; *Ni*: The Number of individuals of species *i*.

Alpha Diversity Indices

The Shannon-Wiener index is one of the most commonly used measures of species diversity: For ecological data, it typically ranges between 1.5 and 3.5, though it can occasionally reach up to 4.5. Higher values indicate greater diversity (Southwood and Henderson, 2000). The formula is as follows:

$$H = \sum_{i-1}^{S} P_i \log_g p$$

Where, *Pi*: The relative abundance of each species meaning the individuals of each species to the whole community ratio, *S*: The number of Species or species richness.

Pielou (1975) recommended the Brillouin index, which is similar to the Shannon index but is particularly sensitive to the abundance of rare species in the community. For ecological data, it also ranges between 1.5 and 3.5. Higher values indicate greater diversity (4.5). The Brillouin index is calculated as follows:

$$HB=\frac{\ln N!-\sum_{i=1}^{S}\ln n_i^!}{N}$$

Where, *N* is the total Number of individuals in the sample, n_i is the number of individuals belonging to the i_{th} species, and *S* is the total number of Species.

Evenness Indices

Evenness indices reflect the relative abundance of species, representing the degree of uniformity in species abundance within a community. Communities with higher evenness (value closer to 1) are more balanced, while those dominated by a single species (value closer to 0) are less diverse (Clark *et al*., 1994).

The Pielou J evenness index (Pielou, 1975) is given by the following:

$$J= H/\log S$$

Where, H is the Shannon-Wiener diversity, S is the total number of Species.

The Heip evenness index E (Heip, 1974) is calculated as follows:

$$E= \frac{(e^H-1)}{(S-1)}$$

Where, H is the Shannon-Wiener diversity index and S is the total number of Species.

Beta Diversity Index

The beta diversity index, as described by Wilson and Schmida (1984), measures the variation in species composition among habitats. Whittaker's formula is used as foloows:

Whittaker's $\beta w= (S/\alpha)^{-1}$

Where, S is the total number of Species and α is the average species richness across all samples. Note that all samples must have the same size or sampling effort.

RESULTS

Structure of Subfamily Composition of Braconidae

The abundance and species composition of Braconidae sub-families were studied across different altitudes, slope aspects, and provinces in the Alborz Mountains (Figure 2). A total of 5950 specimens, representing 276 species from 20 subfamilies, were collected across various sampling sites in north-central Iran. Aphidinae was the most abundant subfamily (n= 1,814), while Cardiochilinae, Ichneutinae, Microtypinae, Pambolinae and Rhyssalinae were the least abundant (*n* <10). Some subfamilies, such as Rhyssalinae and Miracinae, were found exclusively on the northern slope, while Cardiochilinae and Ichneutinae were restricted to the southern slope. Among the five provinces, Guilan, Alborz, Tehran, Mazandarn and Qazvin ranked from the highest to lowest in terms of Braconidae abundance. On the northern slope, Macrocentrinae and Aphidinae dominated the lower positions, while Aphidinae showed the highest abundance across both the lower and upper parts of the southern slope.

Species Composition's Structure and Species Relative Abundance

The structure of species composition and relative abundance of Braconidae in five provinces is presented in Supplementary Data 2. In Guilan Province, 163 species were recorded, the highest abundance values were for *Macrocentrus cingulum* Brischke (9.43%), *Lysiphlebus fabarum* (Marshall) (5.18%), *Aphidius smithi* Sharma and Subba Rao (6.45%), *Aleiodes* (*Aleiodes*) *bicolor* (Spinola) (5.67%), and *Microplitis tuberculifer* (Wesmael) (5.47%) classified as subdominant species. In Mazandaran, 129 species were identified, the highest value was for *M. cingulum* (30.59%) as the dominant species, followed by *Orgilus meyeri* Telenga (5.28%) and *Aphidius urticae* Haliday (5.00%) as subdominant species. In Qazvin, 74 species we recorded, *L. fabarum* (28.3) was the dominant species, while *Aphidius matricariae* Haliday, *Diaeretiella rapae* (McIntosh), *Praon volucre* (Haliday) and *Homolobus (Apatia) truncator* (Say) were subdominant with abundances ranging from 6.6%to 8.6%. In Alborz-Tehran, 122 species were noted. *A. matricariae* (5.88%), *D. rapae* (6.72%), *P. volucre* (6.07%), *Chelonus elongatus* Szepligeti (7.65%) and *A. bicolor* (8.25%) were characterized subdominant and the most abundant species when compared to all other species.

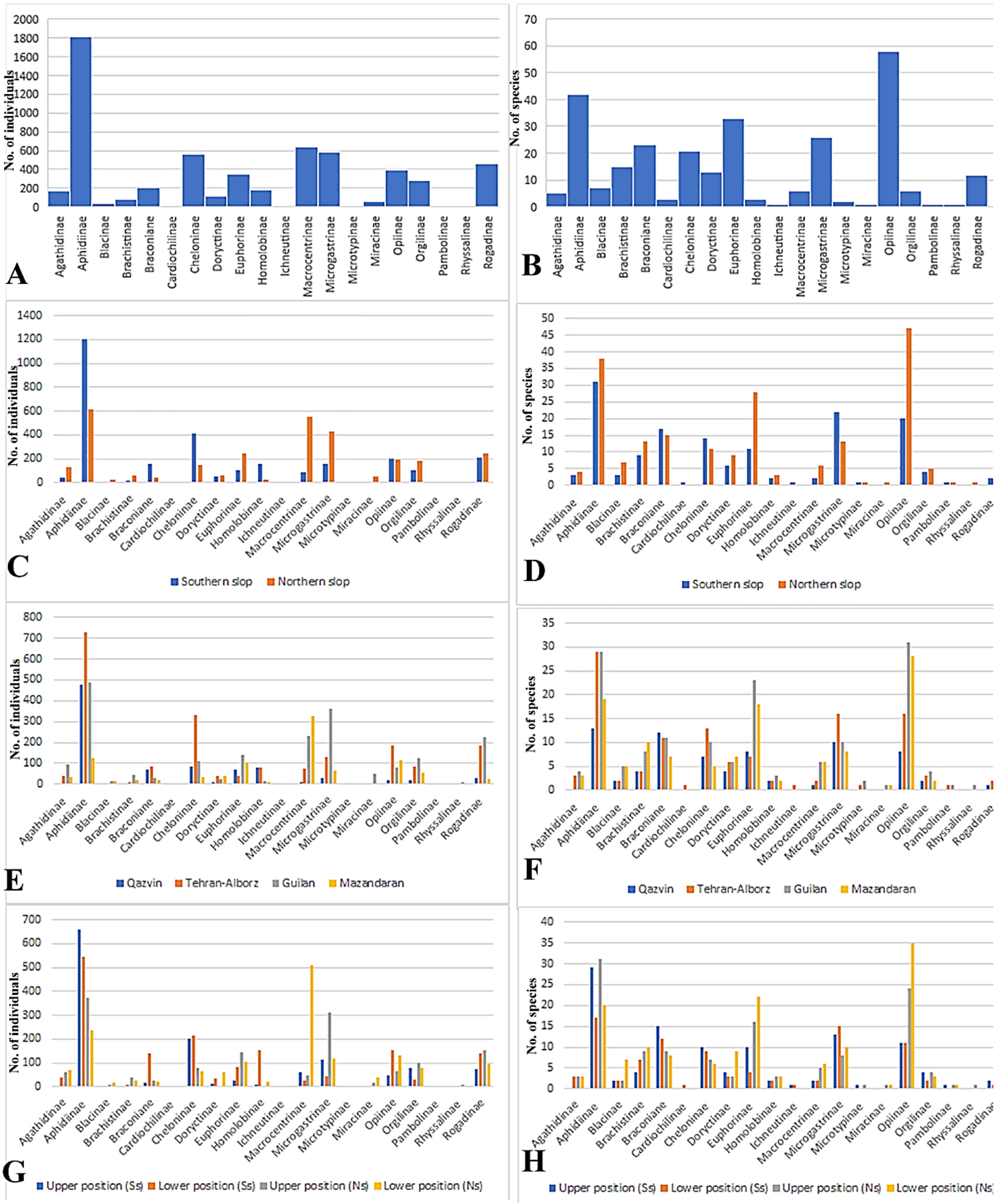

Figure 2. Community structure of the subfamilies of Braconidae collected and identified during the years 2010–2011 in different habitats. (A–B) North central Iran, (C–D) Different slopes of Alborz Mountains, (E–F) Five provinces of north central Iran, and (G–H) Elevations (upper and lower positions) of Alborz Mountains (Ss. Southern slope, and Ns. Northern slope).

The species composition and relative abundance of Braconidae alongthe slopes of the Alborz Mountains are presented in Supplementary data 2. On the northern slopes, where 214 species were identified, *M. cingulum* (16.3%) was the dominant species, followed by *Microplitis spectabilis* (Haliday) (6.86%) as the subdominant species. Conversely, on the southern slopes, which hosted 150 species, *L. fabarum* (11.17%) was the dominant species. subdominant species on the southern slopes included *A. matricariae* (6.17%), *D. rapae* (7.06%), *P. volucre* (6.24%), *C. elongatus* (5.31%), *H. truncator* (5.21%) and *A. bicolor* (6.78%).

The species composition and relative abundance of Braconidae along different positions on the northern slope are presented in Supplementary data 2. In the lower positions of the northern slopes, *M. cingulum* (20.95%) as the dominant species, while *Ascogaster varipes* Wesmael (5.29%) was classified as the subdominant species. In the upper position of the northern slopes, the dominant species were *M. cingulum* (13.32%) and *M. spectabilis* (16.01%), subdominant species included *A. smithi* (5.06%) and *A. bicolor* (7.44%).

The species composition and relative abundance of Braconidae along the different positions of southern slopes are shown in Supplementary data 2. In the lower positions of the southern slopes, *Praon abjectum* dominated with an abundance (17.2%). Subdominant species included *Aphidius persicus* (6.15%), *Homolobus (Apatia) truncator* (9.19%) and *Aleiodes bicolor* (8.63%). In the upper positions of the southern slope, *L. fabarum* had the highest abundance (15.26%) as the dominant species, followed by the subdominant species *A. smithi* (7.71%), *A. matricariae* (6.17%), *C. elongatus* (7.52%), *D. rapae* (8.28%) and *P. volucre* (8.55%).

Species Richness, Evenness, and Diversity in Different Areas

The results of alpha diversity indices in the provinces revealed Shannon–Wiener values ranging from 2.995 to 3.847 for and Brillouin values from 2.869 to 3.722 (Table 1). Guilan showed the highest alpha diversity, followed by Alborz-Tehran, Mazandaran and Qazvin, with significant differences. Species evenness indices (Pielou J and Heip) were highest in Alborz-Tehran, followed by Guilan, Qazvin and Mazandaran (Table 1).

The beta diversity analysis using the Whittaker's dissimilarity index indicated the highest similarity between Mazandaran and Guilan (βw= 0.47), while the greatest dissimilarity was observed between Qazvin and Mazandaran (βw= 0.72), also Mazandaran and Alborz-Tehran (βw= 0.68) (Table 2). The rarefaction analysis of provinces revealed that species richness ranged from the highest in Guilan (163 species) to progressively lower values in Mazandaran (129 species), Alborz-Tehran (122 species) and Qazvin (74 species), respectively (Figure 3).

Regarding the alpha biodiversity indices cross slopes, no significant differences were observed between Shannon-Wiener and Brillouin methods. Both indices indicated that the northern slope exhibited greater diversity compared to the southern slope. However, the species evenness indices, including Pielou J and Heip methods, revealed that the southern slope displayed higher evenness than the northern slope (Table 1). The rarefaction analysis of slopes confirmed higher species richness on the northern slope (214 species) compared to the southern slope (150 species) (Figure 3). A detailed examination of alpha diversity and species evenness indices across different slop positions of the Alborz Mountains showed that the lower positions of the southern slope were more diverse than the upper positions. Conversely, on the northern slope, the upper positions were more diverse than the lower positions. Rarefaction analysis of the slope

Table 1. Alpha diversity and species evenness indices of Braconidae in the north-central Iran.

Diversity indices		Provinces				Slopes		Southern slope		Northern slope	
		Alborz-Tehran	Qazvin	Guilan	Mazandaran	Southern	Northern	Lower zone	Upper zone	Lower zone	Upper zone
SDI[a]	Shannon Wiener	3.757	2.995	3.847	3.462	3.756	3.966	3.589	3.471	3.501	3.643
	Brillourin	3.653	2.869	3.722	3.274	3.667	3.852	3.448	3.372	3.355	3.503
SEI[a]	Pielou J	0.782	0.695	0.755	0.712	0.749	0.739	0.793	0.737	0.695	0.744
	Heip	0.345	0.260	0.283	0.241	0.280	0.243	0.386	0.283	0.210	0.281

[a] SDI= Species Diversity Index, SEI= Species Evenness Index.

Table 2. Values Braconidae Beta diversity index (Whittaker) for dissimilarity amongst different sites.

Collection sites		Provinces				Southern slope		Northern slope
		Alborz-Tehran	Qazvin	Guilan	Mazandaran	Lower position	Upper position	Lower position
Provinces	Alborz-Tehran	1	0.5306	0.5298	0.6813			
	Qazvin		1	0.6273	0.7241			
	Guilan			1	0.4726			
	Mazandaran				1			
Southern slope	Lower position					1	0.4778	
Northern slope	Upper position					0.6444	0.5050	0.4983
	Lower position					0.6992	0.6377	1

positions revealed species richness increasing in the following order: upper positions of the southern slope (111 species), lower positions of the southern slope (92 species), upper positions of the northern slope (133 species) and lower positions of the northern slope (154 species), respectively (Figure 3). The Whittaker's beta diversity index, which measures community dissimilarity, showed the lowest values (indicating the highest similarity) for positions on the southern slope (βw= 0.47), followed by positions on the northern slope (βw= 0.49), and the upper positions of both slopes (βw= 0.50).

DISCUSSION

The highest species richness and alpha diversity across the different slopes of the Alborz Mountains were recorded for the northern slope, revealing that it was more diverse than the southern slope. However, evenness indices presented different results. While species richness was significantly influenced by the presence of rare species, species evenness was high when all species had a relatively similar distribution. These differences may partially stem from the fact that the Alborz region lies within two global biodiversity hotspots (Irano-Anatolian and

Caucasian), which have distinct climatic conditions and vegetation types that influence species abundance. Species richness typically increases with factors like

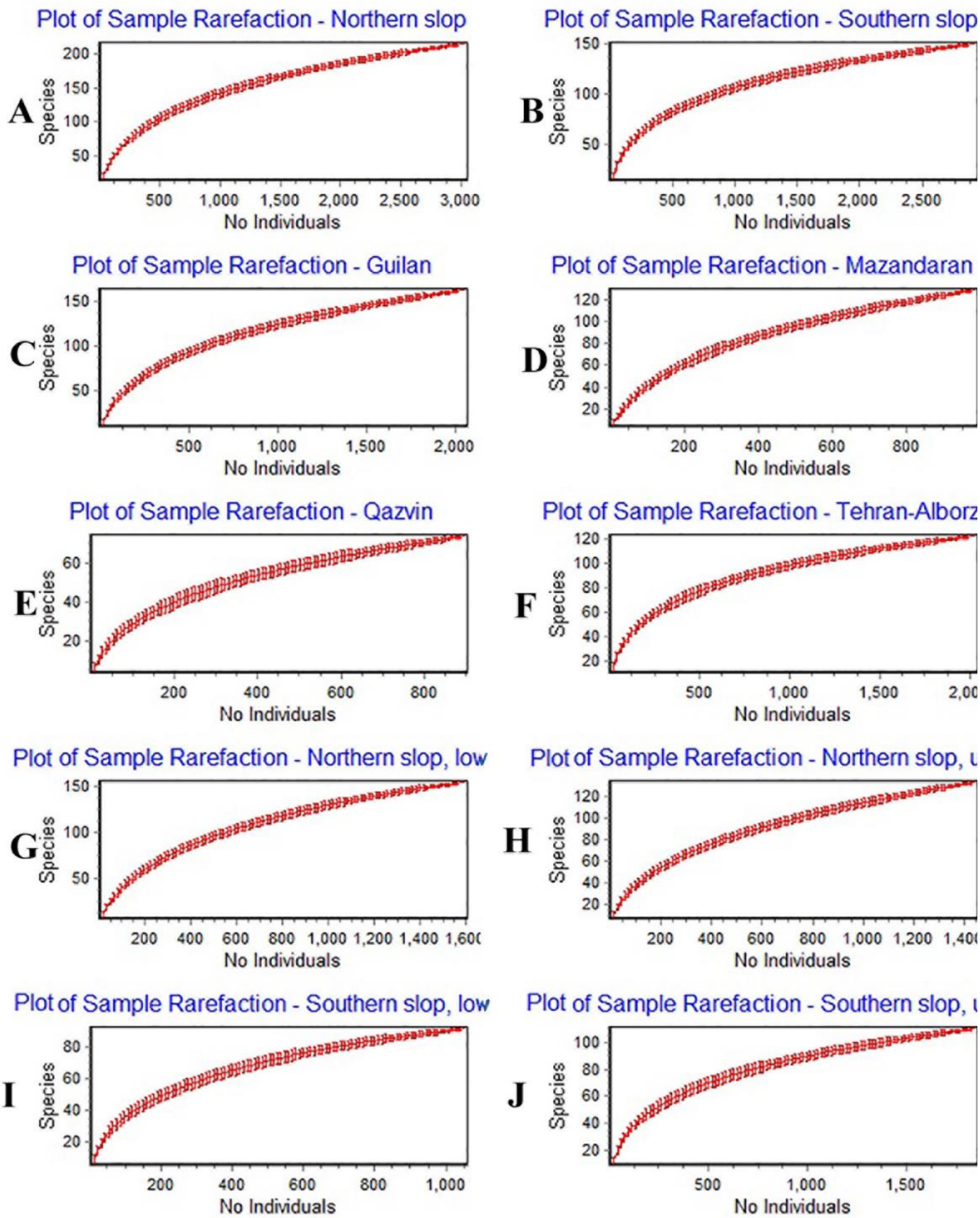

Figure 3. Observed rarefaction curves for Braconidae: (A) Northern slope, (B) Southern slope, (C) Guilan (D) Mazandaran, (E) Qazvin, (F) Tehran, (G) Lower position of northern slope, (H) Upper position of northern slope, (I) Lower position of southern slope, and (J) Upper position of southern slope.

climatic stability and productivity, while it decreases with low temperatures (Mittelbach and Mcgill, 2019). The Alborz Mountain exhibits climatic and vegetative gradients, shifting from humid warm climates with diverse vegetation on the northern slope to a semi-arid continental climate with sparse vegetation on the southern slope (Noroozi and Körner, 2018). The warm and vegetatively diverse conditions in the sampling localities of the northern slope (Caucasian hotspot) compared to the southern slope (Irano-Anatolian hotspot), likely contribute to the higher species richness and biodiversity in the northern slope. Conversely, the southern slope, characterized by greater temperature fluctuations and less diverse vegetation, showed higher species evenness.

The alpha diversity and species evenness indices for provinces followed a similar trend. Guilan and Alborz-Tehran were more diverse than Mazandaran and Qazvin. It is important to note that despite the almost close numbers of species in Mazandaran and Alborz-Tehran, Mazandaran exhibited lower diversity due to non-uniform species abundance and the dominance of a single species. Dominant species play an important role in shaping the distribution of other species within ecosystems. The presence of dominant species can limit species diversity by hindering the establishment of new species (Crutsinger *et al*., 2010).

All indices related to the findings of the current study indicated positions that are close to mid-elevation peak (800–1,200 m) or regions with higher sampling in this elevation range, reaching maximum diversity. For instance, the upper position of the southern slope, above 1,500 m, and the lower position of the northern slope, below 800 m (further from the mid-elevation), exhibited the minimum species diversity on both slopes. The decline in species diversity at the upper position of the southern slope was expected, due to temperature reduction. Conversely, species diversity on the northern slope decreases at lower elevations due to higher temperatures and relative humidity. These findings suggest that braconid diversity is correlated with temperature and altitude. A similar correlation between elevation and biodiversity was also observed by Ghaladze (2012). By studying the climate-based model of spatial pattern of ant species richness in Georgia, the authors found that diversity peaks between 800–1200 m a.s.l. and declines at both lower and upper altitudes. Additionally, previous studies have shown that maximum species richness and relative abundances occur at mid-elevations while declining strongly with the increase of elevation above 1,500 m (Sabu *et al*., 2008).

Recent studies on the diversity of other hymenopterous insects in Iran have reported similar patterns. For instance, Hajian *et al*. (2024) investigated ant diversity along an elevational gradient in the arid regions of Central Iran, highlighting the impact of altitude on species richness. Similarly, Mohammadi-Khoramabadi (2023) studied the diversity of Campopleginae in the Darab damask rose rain-fed plain and reported comparable effects of vegetation and climate on species diversity. Additionally, Piruznia *et al*. (2022) analyzed chalcidoid wasp diversity in the Lake Urmia basin, demonstrating the role of environmental conditions in shaping species composition.

In the present study, the analysis of beta diversity (using the Whittaker index) across slopes, elevations and provinces revealed that similar braconid compositions were found in areas with the same vegetation and comparable environmental conditions. Previous studies have also demonstrated the type and abundance of vegetation, along with factors such as sun exposure, temperature, and humidity play crucial roles in determining species distribution patterns and diversity (Almeida *et al*., 2009; Li and Reynolds, 2009).

The structure of species compositions and relative abundance revealed that *M. cingulum* had the highest distribution and abundance as the dominant species on the northern slope, especially in the lower elevations of Mazandaran Province, where rice is primarily produced. *Macrocentrus cingulum* is a parasitoid of *Ostrinia nubilalis* (Hubner) (Lepidoptera: Crambidae) (van Achterberg, 1993; White and Andow, 2005), a major pest in rice fields in the humid areas of northern Iran (Esmaili *et al*., 1996). The presence of *O. nubilalis* may have contributed to the increase in the *M. cingulum* population. Previous studies have also shown that, as host abundance increases, so does the population of its parasitoids (Hochberg and Ives, 2000).

Lysiphlebus fabarum exhibited the highest distribution and abundance as the dominant species on the southern slope, particularly at the upper position and Qazvin Province. It is an oligophagous parasitoid and ubiquitous in agricultural or natural agroecosystems, issues that make it a valuable biological control agent of aphids (Baghery-Matin *et al*., 2005; Alikhani *et al*., 2010; Tomanović *et al*., 2018). Most distribution of *L. fabarum* on the southern slope is related to sampling regions with elevation above 1,500 m, where winter fruit trees serve as plant hosts, suggesting that it is adaptable to higher elevation and colder climates (Mahi *et al*., 2014).

Praon abjectum was the most widely distributed and abundant species in the lower position of the southern slope. In Europe, several *Aphis* species have been documented as hosts for this parasitoid (Kavallieratos *et al*., 2005). However, other records indicate that it is specifically a parasitoid of *Aphis* species (Starý and Kaddou, 1971).

The occurrence of the Irano-Anatolian and Caucasus hotspots is important from the conservation point of view in terms of biodiversity and endemic species. This study clearly shows that the northern slope that is placed in the Caucasus hotspot has a high value in terms of faunistic biodiversity and scientific importance in the Alborz Mountains. The northern slope of the Alborz Mountains is mostly covered by Hyrcanian forests, but it is endangered due to increasing anthropogenic impacts (e.g., livestock grazing, road construction, logging, and housing developments). Braconidae can be used as bioindicators of anthropogenic effects on ecosystems and can be used to estimate the species richness in the target region (Whitfield and Lewis, 1999; Gonzales and Ruiz, 2000). Furthermore, long-term monitoring surveys are necessary to accurately assess changes in natural densities, distributions, and species composition of beneficial insects in response to anthropogenic impacts and climate change.

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زنبورهای براکونید (Hymenoptera) در دو نقطه داغ بوم‌شناختی ایران: دلالت‌ها برای حفاظت

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چکیده

نقاط داغ تنوع زیستی برای شناسایی مناطق اولویت دار برای حفاظت از گونه‌ها، کلیدی هستند. رشته کوه‌های البرز با دو نقطه داغ (قفقاز در شیب شمالی و ایران-آناتولی در شیب جنوبی) چشم انداز ایده آلی را برای ارزیابی تأثیر پوشش گیاهی، شیب و ارتفاع بر تنوع گونه ها فراهم می کند. ما تنوع آلفا و بتا زنبورهای خانواده Braconidae را در شیب‌های (شمالی و جنوبی)، ارتفاعات (موقعیت‌های بالایی و پایینی) و استان‌های (گیلان، مازندران، قزوین، تهران، البرز) در شمال ایران بررسی کردیم. با استفاده از 31 تله مالیز 276 گونه و 5950 فرد از 20 زیرخانواده جمع‌آوری گردید. شاخص های شانون-وینر و بریلوین تنوع بیشتری را در شیب شمالی نسبت به شیب جنوبی نشان دادند. تنوع گونه‌ای در ارتفاع متوسط (800-1200 متر) به اوج خود رسید. بیشترین تنوع آلفا در گیلان و البرز-تهران بود. تجزیه و تحلیل تنوع بتا نشان داد که شیب، ارتفاع و استان‌ه بر ترکیب گونه تاثیر می گذارد. وضعیت مشابه بین مازندران و گیلان (در شیب شمالی) و البرز-تهران و قزوین (در شیب جنوبی) که دارای پوشش گیاهی و شرایط محیطی مشابهی هستند، مشاهده شد. از سوی دیگر، ترکیب گونه‌ها در موقعیت‌های شیب جنوبی یا شمالی و ارتفاعات بالایی هر دو شیب بیشترین شباهت را داشتند. یافته‌های این پژوهش دلایل مهمی برای حفظ تنوع زنبورهای براکونید به عنوان یک گروه مهم از گونه‌های مفید، در مناطق داغ اکولوژیک در شمال ایران ارائه می‌دهد.

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Life-Stage-Dependent Secondary Responses of Some Biorational Insecticides on *Trichogramma dendrolimi* (Matsumura) (Hymenoptera: Trichogrammatidae)

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ABSTRACT

In this study, lethal and sub-lethal doses of Neem Azal (azadirachtin 10 g L^{-1}), Nimiks (azadirachtin 40 g L^{-1}), Nimbecidine (azadirachtin 0.3 g L^{-1}), Oread (spinosad 480 g L^{-1}), and Nostalgist BL (1.5% *Beauveria bassiana* strain Bb-1-) were tested on different developmental stages of the egg parasitoid, *Trichogramma dendrolimi,* under laboratory conditions. The lowest melanized egg were found on the larval stage of parasitoid in the 200 mL dose of Nimiks (79.17%), on 5 mL dose of Oread (75.25%) and on 250 mL dose of Nimbecidine (79.37%). An approximately 10-fold decrease in emergence rates was determined in the larval, prepupal and pupal stages of the parasitoid at doses of 5 mL and 6.25 mL of Oread. The other doses of the same insecticides resulted in 100% mortality. The longest development time of *T. dendrolimi* was found on Oread with 6.25 mL (11.00 days), on Nimiks with 200 mL (11.04 days), and on Oread with 5 mL (10.90 days). No significant difference was observed in the sex ratio. The longevity of *T. denrolimi* was shorter than that of the control for all insecticides and doses applied to the larval, prepupal, and pupal stages of the parasitoid. Parasitism rates of F_1 and F_2 varied greatly depending on the insecticides, doses, and biological stage of the parasitoid. The new crop protection strategies aim to reduce the use of chemical insecticides while supporting the combined use of biorational insecticides and natural enemies. The study offers helpful data for IPM that is focused on the ecology.

Keywords: Azadirahtin, *Beauveria bassiana*, Egg parasitoids, Spinosad.

INTRODUCTION

Egg parasitoids are known to be very effective against a number of crop pests. Egg parasitoids of the genus *Trichogramma* (Hymenoptera: Trichogrammatidae), are among the most important biological control agents of Lepidoptera pests worldwide (Li, 1994; Mansour *et al.*, 2018; Guo *et al.*, 2019) and are used annually on15 million hectares in 40 countries worldwide (Vinson *et al.*, 2015). *Trichogramma dendrolimi* (Matsumura) (Hymenoptera: Trichogrammatidae) has great economic importance as a biological control agent. The species has a wide host range, including *Spodoptera litura* (Fabricus) (Hamada, 1992), *Mamestra brassicae* (Linnaeus) (Takada *et al.*, 1994), and *Hyphantria cunea* (Drury) and also is mass-produced for biological control programs in Turkey.

"Biorational" or "reduced risk" insecticides was initially used only for products derived from natural sources, i.e., plant extracts, insect pathogens, etc. (Kapoor and Sharma, 2020). Nowadays, azadirachtin is a broad-spectrum insecticide and plays an important role in agriculture worldwide (Aribi *et al.,* 2017). Spinosad is a fermentation product of the Actinomycete bacterium and is a tetracyclic macrolide component containing spinosyns A and D. Spinosad is referred to as a "bio-insecticide", "bio-cyclic pesticide" or "synthetic organic pesticide" because of its particular property

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(Williams *et al.,* 2003). Entomopathogenic fungus *Beauveria bassiana* (Balsamo) Vuillemin (Ascomycota: Hypocreales) can be used instead of synthetic insecticides. Fungal spores are able to mechanically and enzymatically penetrate the cuticle of an insect and infect insect eggs (Al-Deghairi, 2008).

Integrated Pest Management (IPM) programs are used worldwide to control different pests in agriculture and forestry. The combination of biorational insecticides and natural enemies is considered an important component in ecologically based IPM programs (Volkmar *et al.*, 2008). Before using biorational insecticides in IPM, their possible negative impacts on beneficial insects must be assessed. Detailed knowledge of the effects of different insecticides on the immature stages of natural enemies helps to determine the timing of sprays to avoid the most vulnerable stages. However, the efficacy of the parasitoid is affected by the timing of insecticide application before and after the release of the parasitoid (Takada *et al.*, 2001). Therefore, studies on the side effects are essential to improve the combined effectiveness of chemical and biological control method (Asma *et al.*, 2018). The aim of our study was to determine the secondary responses of azadirahtin, spinosad, and *B. bassiana* on different immature stages of *T. dendrolimi* under laboratory conditions.

MATERIALS AND METHODS

Insects Study

The Mediterranean flour moth*, Ephestia küehniella* (Zeller) (Lepidoptera: Pyralidae) was reared in plastic boxes (15×20×7.5 cm) containing corn flour: wheat bran (1:1) and maintained in climate chamber under controlled conditions (25±1°C, 60±10% RH, and 16:8 L:D). A 300-g sterilized diet mixture was weighed and added to disinfected plastic boxes (19×24×7 cm). On average, 1,500-2,000 host eggs were added to the diet mixture. After the development, the adults were collected and transferred to a box. This process was repeated every day. *T. dendrolimi* was reared in a climate chamber at 27±1ºC, 70±5% RH, and 16:8 L:D. The eggs of *E. kuehniella* were used for the production of *T. dendrolimi*. Host eggs were examined under a stereomicroscope and only healthy eggs were used for parasitoid production. An average of 250 healthy flour moth eggs (0-24 hours) were diluted with Arabic gum (30 mL water L^{-1} g^{-1} Arabic gum) on paper strips (1×10 cm) and offered to mated parasitoids in tubes (3×10 cm). The parasitoids were removed one day after parasitism and the parasitized host eggs were allowed to develop in the climate chamber (Kandil, 2022).

Biorational Insecticides

Neem Azal T/S, Trifolio–M GMBH, Lahnau-Germany-VitVerim Beyoğlu-İstanbul (azadirachtin 10 g L^{-1}) 200, 300, 100 and 150 mL, Nimiks®4.5 Certis USA, LLC- Agrikem Ziraat İlaçları ve Endüstri Ürünleri San ve Tic AŞ, İzmir -Türkiye (azadirachtin 40 g L^{-1}) 125 , 150, 200, 62.5, 75 and 100 mL, Oread® Hektaş Ticaret T.A.Ş, Gebze-Kocaeli, Türkiye (spinosad 480 g L^{-1}) 10, 12.5, 25, 30, 5, 6.25 and 15 mL, Nimbecidine (azadirachtin 0.3 g L^{-1}) Agrobest Grup – İzmir, Türkiye 500 and 250 mL and Nostalgist BL®, Agrobest Grup–İzmir, Turkey(*B. bassiana* strain Bb-1 %1.5, 1×108 CFU mL^{-1} min^{-1}) 250 and 125 mL were used in the experiments. The hosts of *T. dendrolimi* are lepidopteran eggs and, therefore, we used commercial application concentrations (mL per 100 L) and half of the commercial concentrations of the products against the lepidopter in the field.

Experiments

Twenty healthy host eggs (0-24 hours) were glued with Arabic gum to 1×9 cm paper strips and placed in 1.5×10 cm tubes. Two honey-fed, mated and non-parasitizing female parasitoids were placed in these tubes. After 24 hours, the adult of *T.*

dendrolimi were removed from the tubes. Two mL of each biorational insecticides were sprayed onto the larval, prepupal, and pupal stages of *T. dendrolimi* (Lu *et al.,* 2019) and left to dry for 15-20 minutes. After parasitism, the parasitoid reached the larval stage after 48 hours, the pre-pupal stage after 96 hours, and the pupal stage after 144 hours. Pure water was used for the control application. Fifteen replicates were performed for each treatment. The aim of this study was to determine the proportion of melanized eggs, emergence rate, development time, longevity, sex ratio, and also the parasitism ratios of F_1 and F_2.

Data Analysis

All data were analyzed with one-way analysis ANOVA followed by Tukey's multiple comparison test. All analyses were carried out considering a significance level of 5%. Statistical analyses were performed using Minitab version 17. The percentage data were normalized using an arcsine transformation (p0= Arcsine√p) (Zar, 1999).

RESULTS

Effect of Biorational Insecticides on the Melanized Eggs of Generations F_0

In the analysis of variance, the difference between the means of the melanized eggs was found to be significant (df= 65, F= 2.94, P≤ 0.05; Table 1). After the larval stage applications, the lowest melanized eggs were found (79.17%) with the 200 mL dose of Nimiks, (75.25%) with the 5 mL dose of Oread, and (79.37 %) with the 250 mL dose of Nimbecidine (Table 1). After the Pre-Pupal Stage (PS) applications, the lowest melanized eggs (80.56 %) were observed with a 200 mL dose of Nimiks (80.45 %) and (80.83 %) with a 500 mL dose of Nimbecidine at the pupal stage (Table 1).

Effect of Biorational Insecticides on the Emergence Rate of F_0 Generation

The emergence rate of parasitoid was significantly reduced after insecticide treatments at the three immature developmental stages (df= 50, F= 21.51, P≤ 0.05) (Table 2). There was a decrease in the larval and pre-pupal period of the parasitoid at 200 mL dose of Neem Azal compared to the control. The emergence rate was significantly reduced after 300 mL dose of Neem Azal in the Prepupal Stage of the Parasitoid (PSP) and 150 mL dose of Nimiks in the larval stage of the parasitoid, 200 mL dose of Nimiks in the larval and PSP, 500mL dose of Nimbecidine in the larval and PSP, and in the 250 mL dose of Nimbecidine in the larval stage of the parasitoid compared to the control. After the application of Oread 5 and 6.25 mL doses, rate of emergence decreased by 10-fold compared to the control in all three pre-imajinal periods of the parasitoid. There was no emergence of the parasitoid treated with other doses of Oread.

Effect of Biorational Insecticides on the Development Periods of F_0 Generation

The development times of the parasitoids were significantly affected by the treatments of insecticide (df= 50, F= 174.15, P≤ 0.05) (Table 3). The longest development time was found at 6.25mL dose (11.00 days) of Oread, 200 mL dose of Nimiks (11.04 days), 5 mL dose of Oread (10.90 days), and 150 mL (10.53 days) dose of Nimiks. The applications of 200 mL and 300 mL doses of Neem Azal, 200 mL doses of Nimiks, and 5 mL and 6.25 mL doses of Oread to the larval stage of the parasitoid prolonged the developmental time of the parasitoid compared to the prepupal and pupal stages. The parasitoid *T. denrolimi* did not show any development in the application of 10-, 25-, 12.5-, 30-, and 15-mL doses of Oread to

Table 1. Melanized egg (%) of *Trichogramma denrolimi*, in the generations F_0 treated with insecticides during the larval, prepupal and pupal stages when developing in *Ephestia kuehniella* egg.

Insecticides and Doses (mL)	Biological stages of *Trichogramma denrolimi*[a]		
	Larval stage	Pre-pupal stage	Pupal stage
Neem Azal 200	85.83 AB	86.11 AB	91.11 A
Neem Azal 300	86.94 AB	85.84 AB	84.72 AB
Neem Azal 100	84.44 AB	88.89 AB	88.06 AB
Neem Azal 150	87.35 AB	89.72 AB	87.78 AB
Nimiks 125	86.11 AB	89.44 AB	91.67 A
Nimiks 150	81.94 AB	90.00 A	92.50 A
Nimiks 200	79.17 B	80.56 B	85.83 AB
Nimiks 62,5	95.77 A	94.17 A	93.06 A
Nimiks 75	92.22 A	94.44 A	93.68 A
Nimiks 100	89.17 AB	88.89 AB	93.07 A
Oread 10	88.00 AB	91.00 A	92.25 A
Oread 25	87.75 AB	83.50 AB	82.75 AB
Oread 12.5	90.00 A	86.00 AB	88.00 AB
Oread 30	88.00 AB	89.00 AB	93.50 A
Oread 5	75.25 B	88.25 AB	90.00 A
Oread 6.25	84.75 AB	85.75 AB	87.25 AB
Oread 15	82.50 AB	87.00 AB	89.50 AB
Nostalgist 250	96.12 A	95.56 A	91.94 A
Nostalgist 125	94.72 A	96.11 A	91.39 A
Nimbecide 500	87.19 AB	85.00 AB	80.83 B
Nimbecidine 250	79.37 B	90.56 A	85.10 AB
Control	91.67 A	93.06 A	87.78 A

[a] Means followed by the same capital letter do not differ statistically differences, $P \leq 0.05$.

Table 2. Emergence rate (%) of *Trichogramma denrolimi*, in the generations F_0 treated with insecticides during the larval, pre-pupal and pupal stages when developing in *Ephestia kuehniella* egg.

Insecticides and Doses (Ml)	Biological stages of *Trichogramma denrolimi*[a]		
	Larval stage	Prepupal stage	Pupal stage
Neem Azal 200	74.44 CD	73.33 CD	82.22 ABC
Neem Azal 300	77.78 BC	67.78D	76.39 BC
Neem Azal 100	77.79 BC	83.61 AB	81.67 ABC
Neem Azal 150	83.53 AB	80.00 BC	79.17 BC
Nimiks 125	76.11 BC	79.72 BC	82.50 ABC
Nimiks 150	73.61 C	83.60 AB	84.17 AB
Nimiks 200	70.28C	74.72 CD	80.28 BC
Nimiks 62,5	88.06 AB	88.89 AB	90.00 A
Nimiks 75	85.28 AB	89.44 AB	89.43 AB
Nimiks 100	79.17 BC	81.94 ABC	88.33 AB
Oread 10	-	-	-
Oread 25	-	-	-
Oread 12.5	-	-	-
Oread 30	-	-	-
Oread 5	6.2 E	6.1 E	6.6 E
Oread 6.25	7 E	9 E	10 E
Oread 15	-	-	-
Nostalgist 250	88.06 AB	87.50 AB	87.60 AB
Nostalgist 125	88.07 AB	91.11 A	87.70 AB
Nimbecidine 500	71.39 C	73.61 C	76.67 BC
Nimbecidine 250	70.29C	82.50 ABC	78.61 BC
Control	88.06 AB	87.50 AB	84.44 AB

Table 3. Development time (±SE) of *Trichogramma denrolimi*, in the generations F_0 treated with insecticides during the larval, prepupal and pupal stages when developing in *Ephestia kuehniella* egg.

Insecticides and Doses (mL)	Biological stages of *Trichogramma denrolimi*[a]		
	Larval stage	Prepupal stage	Pupal stage
Neem Azal 200	9.71±0.04 BC n= 266	9.20±0.02 D n= 261	9.31±0.03 C n= 292
Neem Azal 300	10.21±0.05 B n= 280	9.37±0.03 D n= 247	9.41± 0.03 D n= 274
Neem Azal 100	9.10±0,01 D n= 280	9.07±0.01 D n= 302	9.09±0.01 D n= 294
Neem Azal 150	9.15±0.02 D n= 283	9.11±0.02 D n=288	9.10 ±0.01 D n= 285
Nimiks 125	10.15±0.05 B n= 278	9.50±0.03 BC n=288	9.22 ±0.02 D n= 296
Nimiks 150	10.53±0.05 AB n= 259	9.61±0.03 BC n= 301	9.17±0.02 D n= 303
Nimiks 200	11.04±0.06 A n= 253	9.76±0.04 BC n= 269	9.51 ±0.03 BC n= 289
Nimiks 62.5	9.15±0.02 D n= 317	9.08±0.01 D n= 319	9.14±0.01 D n= 325
Nimiks 75	9.22±0.02 D n= 305	9.13±0.01 D n= 323	9.12±0.01 D n= 323
Nimiks 100	10.10±0.04 B n= 287	9.59±0.03 BC n= 293	9.30±0.02 D n= 319
Oread 10	-	-	-
Oread 25	-	-	-
Oread 12.5	-	-	-
Oread 30	-	-	-
Oread 5	10.90 ± 0.1 A n=10	10.36±0.24 B n=11	10.08±0.22 B n= 12
Oread 6.25	11.00±0.00 A n=7	10.41±0.14 B n= 12	10.40±0.13 B n= 15
Oread 15	-	-	-
Nostalgist 250	9.16±0.02 D n= 320	9.15±0.02 D n= 315	9.18±0.02 D n= 315
Nostalgist 125	9.13±0.02 D n= 318	9.12±0.01 D n= 324	9.10±0.01 D n= 315
Nimbecidine 500	9.15±0.02 D n= 254	9.16±0.02 D n= 265	9.17±0.02 D n= 272
Nimbecidine 250	9.13±0.02 D n= 236	9.21±0.02 D n= 297	9.07±0.01 D n= 284
Control	9.08±0.01 D n= 317	9.03±0.03 D n= 324	9.09±0.01 D n= 314

[a]Means followed by the same capital letter do not differ statistically differences, P≤ 0.05.

all three immature developmental stage of the parasitoid.

Effect of Biorational Insecticides on the Sex Ratio and Longevity of F_0 Generation

In this study, the sex ratio (females %) was determined after each insecticide application at each immature developmental stage of the parasitoid. Difference between the means was not significant (df= 44, F= 0.40, P= 0.999) (Table 4). The longevity of *T. denrolimi* was shorter than that of the control for all insecticides and dosages applied to all immature developmental stages of the parasitoid (df= 50, F= 75.67, P< 0.05). The Oread doses of 5 and 6.25 mL caused the fastest reduction in longevity (Table 5).

Table 4. Sex ratio (% female) of *Trichogramma denrolimi*, in the generations F_0 treated with insecticides during the larval, prepupal and pupal stages when developing in *Ephestia kuehniella* egg.

Insecticides and Doses (mL)	Biological stages of *Trichogramma denrolimi*		
	Larval stage	Prepupal stage	Pupal stage
Neem Azal 200	70.87	74.03	67.92
Neem Azal 300	71.32	70.23	70.95
Neem Azal 100	75.45	68.65	74.94
Neem Azal 150	72.22	79.12	76.39
Nimiks 125	74.75	73.57	76.49
Nimiks 150	75.20	71.01	70.73
Nimiks 200	72.14	71.22	74.47
Nimiks 62,5	74.07	71.62	73.91
Nimiks 75	76.86	73.86	74.83
Nimiks 100	66.83	70.51	75.56
Oread 10			
Oread 25			
Oread 12.5			
Oread 30			
Oread 5			
Oread 6.25			
Oread 15			
Nostalgist 250	75.54	78.07	75.05
Nostalgist 125	78.19	78.65	73.58
Nimbecide 500	73.89	72.83	76.26
Nimbecidine 250	72.22	72.92	79.79
Control	74.31	75.33	75.59

Table 5. Longevity (±SE) of Trichogramma denrolimi, in the generations F_0 treated with insecticides during the larval, prepupal and pupal stages when developing in Ephestia kuehniella egg.

Insecticides and Doses (mL)	Biological stages of *Trichogramma denrolimi*[a]		
	Larval stage	Prepupal stage	Pupal stage
Neem Azal 200	7.24±0.20 F, n=266	7.75±0.15 E, n=261	10.31±0.18 C, n=292
Neem Azal 300	6.77±0.13 F, n=280	7.61±0.12 E, n=247	9.24±0.19 D, n=274
Neem Azal 100	9.22±0.15 D, n=280	10.04±0.15 C, n=302	10.10±0.15 C, n=294
Neem Azal 150	8.10±0.15 E, n=283	8.20±0.14 E, n=288	9.75±0.14 C, n=285
Nimiks 125	9.08±0.15 D, n=278	9.20±016 D, n=288	9.98±016 C, n=296
Nimiks 150	8.37±0.17 E, n=259	9.32±0.17 D, n=301	9.90±0.18 C, n=303
Nimiks 200	7.68±0.16 E, n=253	8.36±0.15 E, n=269	8.53±0.13 D, n=289
Nimiks 62.5	9.11±0.13 D, n= 317	9.73±0.13 C, n= 319	10.23±0.14 C, n= 325
Nimiks 75	9.26±0.13 D, n= 305	9.66±0.15 C, n= 323	9.96±0.15 C, n= 323
Nimiks 100	8.96±0.14 D, n= 319	9.45±0.15 D, n= 293	9.97±0.14 C, n= 319
Oread 10	-	-	-
Oread 25	-	-	-
Oread 12.5	-	-	-
Oread 30	-	-	-
Oread 5	1.0±0.00 G, n= 10	1.0±0.00 G, n= 8	1.0±0.00 G, n= 12
Oread 6.25	1.0±0.00 G, n= 4	1.0±0.00 G, n= 6	1.0±0.00 G, n= 9
Oread 15	-	-	-
Nostalgist 250	9.16±0.14 D, n= 320	10.37±0.15 C, n= 315	10.69 ±0.13 B, n= 315
Nostalgist 125	10.68±0.13 B, n= 318	11.04±0.13 B, n= 324	11.64±0.15 A, n= 315
Nimbecide 500	7.44±0.11 F, n= 254	7.78±0.13 E, n= 265	9.19 ±0.13 D, n=272
Nimbecidine 250	8.03±0.14 E, n= 236	7.96±0.14 E, n= 297	9.13±0.13 D, n= 284
Control	12.06±0.13 A, n= 317	11.90±0.13 A, n= 324	12.11±0.15 A, n= 314

[a]Means followed by the same capital letter do not differ statistically differences, $P \leq 0.05$

Table 6. Parasitism rate (%) of *Trichogramma denrolimi*, in the generations F_1 treated with insecticides during the larval, pre-pupal, and pupal stages when developing in *Ephestia kuehniella* egg.

Insecticides and Doses (mL)	Biological stages of *Trichogramma denrolimi*[a]		
	Larval stage	Prepupal stage	Pupal stage
Neem Azal 200	77.33 CD	77.67 CD	88.00 AB
Neem Azal 300	74.67 CD	82.33 BC	84.00 AB
Neem Azal 100	83.67 BC	89.00 AB	85.33 AB
Neem Azal 150	79.33 C	84.33 AB	87.67 AB
Nimiks 125	77.33 CD	81.33 BC	83.33 BC
Nimiks 150	73.33CD	80.33 BC	84.67 AB
Nimiks 200	69.33 D	79.00 C	83.00 BC
Nimiks 62.5	87.33 AB	89.33 AB	88.00 AB
Nimiks 75	85.00 AB	86.67 AB	88.33 AB
Nimiks 100	82.67 BC	81.67 BC	86.33 AB
Oread 10			
Oread 25			
Oread 12.			
Oread 30			
Oread 5			
Oread 6.25			
Oread 15			
Nostalgist 250	89.00 AB	88.33 AB	87.00 AB
Nostalgist 125	93.67 A	88.00 AB	91.67 A
Nimbecide 500	80.33 AB	84.33 AB	84.67 AB
Nimbecidine 250	89.00 AB	85.67 AB	88.33 AB
Control	92.00 A	90.33 A	92.33 A

[a] Means followed by the same capital letter do not differ statistically differences, P≤ 0.05.

Effect of Biorational Insecticides on the Parasitism Rates of F1 generation

In the analysis of variance for the parasitism rates of the F1 generations, the difference between the means was found to be significant (df= 44, F= 3.48, P≤ 0.05). The applications of 200, 300, 100, and 150 mL doses of Neem Azal and 125, 150, 200, 100 doses of Nimiks in the larval stage of the parasitoid significantly decreased the F_1 parasitism rates. In addition, application of 200 and 300 mL doses of Neem Azal and 200 and 100 mL doses of Nimiks during the prepupal period of the parasitoid also reduced the parasitism rates of the F_1 (Table 6).

Effect of Biorational Insecticides on the Parasitism Rates of F_2 Generation

A similar study was performed for the F_2 generations. Application of 125, 150, 200, and 100 mL doses of Nimiks at the larval stage of the parasitoid resulted in decrease in parasitism rates of F_2. The application of 200 and 300 mL doses of Neem Azal, and 125 and 100 mL doses of Nimiks during the pre-pupal period of the parasitoid also reduced the parasitism rates of the F_2. In addition, application of 75 mL dose of Nimiks to the pupal stage decreased the parasitism rate of the F_2 (Table 7) (df= 44, F= 1.93, P≤ 0.05).

DISCUSSION

It is important to know the different in sensitivities of the various developmental stages of parasitoids to insecticides in order to determine the proper timing for parasitoid release and insecticide treatment (Takada *et al.*, 2001). The larval stage of *T. denrolimi* was found to be more affected by egg melanization than the pre-pupal and pupal stages. It was found that the active substance ratio and dose were important, especially for azadirachtin. Lyons *et al.* (2003) reported that, at 500 g azadirachtin/ha, the number of eggs parasitized by *T. minitum* was greatly

Table 7. Parasitism rate (%) of *Trichogramma denrolimi*, in the generations F_2 treated with insecticides during the larval, prepupal and pupal stages when developing in *Ephestia kuehniella* egg.

Insecticides and Doses (mL)	Biological stages of *Trichogramma denrolimi*[a]		
	Larval stage	Prepupal stage	Pupal stage
Neem Azal 200	87.33 AB	84.67 BC	91.00 A
Neem Azal 300	85.67 AB	84.00 BC	88.67 AB
Neem Azal 100	86.00 AB	89.33 AB	87.67 AB
Neem Azal 150	88.33 AB	86.67 AB	90.67 A
Nimiks 125	82.33 BC	83.33 BC	84.67 BC
Nimiks 150	82.00 BC	86.00 AB	87.00 AB
Nimiks 200	78.33C	88.67 AB	88.00 AB
Nimiks 62.5	85.67 AB	92.00 A	90.67 A
Nimiks 75	86.67 AB	88.67 AB	84.33 BC
Nimiks 100	83.67 B	80.67 BC	88.33 AB
Oread 10			
Oread 25			
Oread 12.5			
Oread 30			
Oread 5			
Oread 6.25			
Oread 15			
Nostalgist 250	91.67 A	91.33 A	93.33 A
Nostalgist 125	88.33 AB	90.67 A	89.67 AB
Nimbecide 500	85.00 AB	90.00 A	87.33 AB
Nimbecidine 250	87.33 AB	89.00 AB	91.00 A
Control	92.33 A	89.33 AB	94.00 A

[a] Means followed by the same capital letter do not differ statistically differences, P≤ 0.05.

reduced by Azatin EC (3.0% azadirachtin) and slightly reduced by Neem EC (4.6% azadirachtin), but was not reduced by an azadirachtin standard.

Researchers reported that the pre-adult stages of egg parasitoids can be protected from the negative effects of many insecticides because they were preserved in the host egg (Orr *et al.*, 1989; Consoli *et al.*, 1998). However, the emergence rates of the parasitoid *T. denrolimi*, especially in the larval and prepupal periods, were significantly reduced compared to the control at the Neem Azal (200 and 300 mL), Nimiks (125, 150, and 200 mL) and Nimbedicine (500 ml and 250 mL) compared to the control. This result shows that the larval and prepupal stages of the parasitoid are more sensitive than the pupal stage. Saber *et al.* (2004) applied an LC_{50} dose of Neem Azal (1330 ppm) to the larval -prepupal and pupal stages of ***T. cacoeciae*** (Hymenoptera: Trichogrammatidae) on two hosts, namely, *Sitotroga cerealella* Olivier (Lepidoptera: Gelechiidae) and *Cydia pomonella* L. (Lepidoptera: Tortricidae) and the emergence rates decreased in both hosts compared to the control. Lyons *et al.* (2003) found that 500 g azadirachtin/ha reduced emergence rates of the parasitoid *Trichogramma minutum* Riley, while 50 g azadirachtin/ha had no negative effect. Silva and Bueno, (2015) applied Neem oil (9.6 ppm) to the pupal stage of *T. pretiosum* and reported that there was no significant difference in the emergence rate (80.4%) compared to the control (89.8%). The parasitoid *T. denrolimi* did not show any development at 10, 25, 12.5, and 30 mL doses of spinosad (480 g L^{-1}). In 5 mL and 6.25 mL doses, parasitoid emergence rates ranged from 6.2 to 10%. Shoeb (2010) reported that there was no emergence in *Trichogramma evanescens* after application of spinosad (24%).

Application of *B. bassiana* (Nostalgist 250 and 125 mL) to the larval, pre-pupa and pupal stages of *T. denrolimi* had no negative effects on emergence rates. However, Potrich *et al*. (2009) reported that *M. anisopliae* reduced the emergence of *T. pretiosum*. Araujo *et al*. (2020) shows that the negative impacts of *B. bassiana* on *T. pretiosum* and *T. atopovirilia* biological parameters were negligible.

In this study, the application of azadirachtin to different stages of the parasitoid affected the development time according to the active ingredient rate and doses. Development time was affected at high doses of Neem Azal and Neemix with high active ingredient. Moreover, both doses (500 and 250 mL) of Neemix had no negative effect on the development time of the parasitoid *T. denrolimi*. The development time of the parasitoid prolonged at low doses of spinosad. On the other hand, application of *B. bassiana* had no negative effect on the development time. LC_{25} and LC_{50} doses of neem extract increased the development time of the larval parasitoid *Hyposoter ebeninus* G. (Hymenoptera: Ichneumonidae) (Matter *et al.*, 2002). Saljoqi *et al.* (2012) reported that 0.2, 0.15 and 0.10% concentrations of spinosad applied to the pupal stage of the parasitoid ***T. chilonis*** resulted in an increase of development time. The development time of *T. atopovirilia* was not affected by *B. bassiana* application (Araujo *et al.*, 2020).

The longevity of *T. denrolimi* was negatively affected by all insecticides and doses. Michel *et al.* (2004) reported that the longevity of males and females of the egg parasitoid *Gryon fulviventre* Crawford (Hymenoptera: Scelionidae) was not affected by the application of 5% neem solution to the larval and prepupal period of parasitized eggs. The dose of 50 g azadirachtin/ha had no effect on the lifetime of *T. minitum* females, whereas the application of 500 g azadirachtin/ha had a negative effect (Lyons *et al.,* 2003). In our study, adults that completed development following the application of spinosad at doses of 5 and 6.25 mL lived for one day. Similar results were obtained by Shoeb (2010) for *T. evanescens*. The longevity of *Trichogramma chilonis* decreased significantly after the application of spinosad doses of 0.2, 0.15, 0.1 0.05 and 0.01% in the egg, larval and pupal periods of the parasitoid, respectively (Saljoqi *et al.,* 2012). The longevity of the parasitoid *Tamarixia radiata* Waterston (Hymenoptera: Eulophidae) was not adversely affected by the application of azadirahtin (0.03 g/l-Azamax) and spinosad (0.07 g L^{-1} 0.07) during pupal period of the parasitoid (Beloti *et al.,* 2015). Martins *et al.* (2014) noted that the longevity of females of the parasitoid *Diaeretiella rapae* McIntoch (Hymenoptera: Braconidae) decreased with the *B. bassiana* application in the pre-adult stage.

Sex ratio is an important parameter for host-parasitoid relationships and the side effect studies. In this study, the sex ratio was not adversely affected by insecticide treatments, with the exception of spinosad. Application of azadirachtin and spinosad to the pupal stage of the parasitoid *Tamarixia radiata* Waterston (Hymenoptera: Eulophidae) showed no difference in sex ratio (Beloti *et al.,* 2015). Similarly, it was reported that the application of 1×10^8 conidial mL^{-1} supplementation of *B. bassiana* in the pre-adult period of *T. radiata* (Waterston) (Hymenoptera: Eulophidae) caused no significant difference in sex ratio (Ramos Aguila *et al.*, 2021). Different applications of insecticides and doses at different stages of the F_0 generation might have a negative effect on the parasitism rate of the F_1 and F_2 generations. In this study, the application of high doses of azadirachtin in the larval and pre-pupal period resulted in a decrease in the parasitism rates of the F_1 and F_2 generations. Beloti *et al.* (2015) reported that 0.03 g L^{-1} azadirachtin caused a 23% reduction in the parasitization rate of F_1 generation of the parasitoid *T. radiata*. Similarly, application of 500 g azadirachtin ha^{-1} by Lyons *et al.* (2003) caused a decrease in parasitization rates of F_1 generation of *T. minitum* compared to 50 g azadirachtin/ha application.

Consequently, it was found that the effect of the biorational preparations used in this study may vary depending on the doses and the biological periods of the parasitoid. Especially, low doses of azadiractin, applied at the pupal stage of the parasitoid are the safest applications for the biological properties of the parasitoid *T. denrolimi*. *B. bassiana*. All doses of spinosad had a strong negative effect on the development of the parasitoid. We believe that the results of this study can be evaluated in integrated pest management programs based on biological control.

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پاسخ‌های ثانویه وابسته به مرحله زندگی برخی از حشره‌کش‌های زیست‌منطقی روی (Matsumura) *Trichogramma dendrolimi* (Hymenoptera: Trichogrammatidae)

کانسو کندیل، و هلال تونکا کوزیچ

چکیده

در این پژوهش، دوزهای کشنده و زیرکشنده (sub-lethal) از Neem Azal (آزادیراختین (azadirachtin) 10 گرم در لیتر)، Nimiks (آزادیراختین (azadirachtin) 40 گرم در لیتر)، Nimbecidine (آزادیراختین 0.3 گرم در لیتر)، Oread (اسپینوزاد 480 گرم در لیتر) و Nostalgist BL (1.5٪ *Beauveria bassiana* سویه Bb-1-) روی مراحل مختلف رشدی زنبور پارازیتوئید تخم، *Trichogramma dendrolimi*، در شرایط آزمایشگاهی آزمایش شدند. کمترین میزان ملانین‌دار شدن تخم روی مرحله لاروی پارازیتوئید در دوز 200 میلی‌لیتری نیمیکس (79.17 ٪) ، دوز 5 میلی‌لیتری اورئد (75/25٪) و دوز 250 میلی‌لیتری نیمبسیدین (79.37٪) مشاهده شد. کاهش تقریباً 10 برابری در سرعت ظهور در مراحل لاروی، پیش شفیرگی و شفیرگی پارازیتوئید در دوزهای 5 میلی‌لیتر و 6.25 میلی‌لیتر Oread مشاهده شد. دوزهای دیگر همین حشره‌کش‌ها منجر به مرگ و میر 100٪ شدند. طولانی‌ترین زمان رشد *T. dendrolimi* روی Oread با 6.25 میلی‌لیتر (11.00 روز)، روی Nimiks با 200 میلی‌لیتر (11.04 روز) و روی Oread با 5 میلی‌لیتر (10.90 روز) مشاهده شد. هیچ تفاوت معنی‌داری در نسبت جنسی مشاهده نشد. طول عمر *T. denrolimi* برای تمام حشره‌کش‌ها و دوزهای اعمال شده در مراحل لاروی، پیش شفیرگی و شفیرگی پارازیتوئید، کوتاه‌تر از کنترل بود. میزان پارازیتیسم F1 و F2 بسته به حشره‌کش‌ها، دوزها و مرحله بیولوژیکی پارازیتوئید بسیار متفاوت بود. استراتژی‌های جدید حفاظت از محصولات کشاورزی با هدف کاهش استفاده از حشره‌کش‌های شیمیایی و در عین حال حمایت از استفاده ترکیبی از حشره‌کش‌های زیستی-منطقی و دشمنان طبیعی طراحی شده‌اند. این مطالعه داده‌های مفیدی را برای مدیریت تلفیقی آفات (IPM) که بر بوم‌شناسی متمرکز است، ارائه می‌دهد.

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Evaluation of Red-Currant Cultivars' Technological Effectiveness for Mechanized Harvesting

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ABSTRACT

This study aimed to identify the optimal redcurrant cultivars for mechanized harvesting by evaluating the bush's morphological structure and the berries' mechanical parameters. Fourteen red currant cultivars were assessed during the 2021-2022 season, and their berry quality indicators and mechanical parameters, including separation Force (Fs) and crushing Force (Fc), were measured. The results showed that the cultivar plays an important role on the bush's morphological structure, while the berries' mechanical parameters impact the efficiency of harvesting process. The high correlation between Fs and Fc allowed for predicting the optimal harvesting periods of the cultivars. Among the cultivars, 'Rolan', 'Jonkheer Van Tets', 'Rovada', 'Red Lake', 'Asya', 'Vika', and 'Niva' were considered as technological cultivars and suitable for mechanized harvesting. This study emphasizes the importance of considering genetic and morphological factors when selecting redcurrant cultivars for mechanized harvesting and provides valuable insights for breeding and developing new cultivars adapted to mechanized harvesting.

Keywords: Bush habit, Efficiency of harvesting, Optimal harvesting, Qualitative characteristics.

INTRODUCTION

Small fruits are highly valued for their biological and nutritional benefits to human's health (Kirina *et al*., 2020; Kahramanoğlu *et al*., 2022) and are widely cultivated for their commercial potential (Asănică, 2019; FAO, 2021). Among the berry crops, red-currants are particularly valuable due to their numerous biological and pharmacological properties (Bilici, 2021). Many European countries (i.e. Poland, Germany, Hungary, United Kingdom, etc.) grow certain red-currant cultivars in industrial volumes. One of the most important factors that negatively affect red currant production is harvesting costs, which can reach up to 60-70% (Wróblewska *et al*., 2019; Brondino *et al*., 2021; FAO, 2021). Many

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modern cultivars of currants do not meet the requirements for intensive cultivation (Wang *et al*., 2009; Sarig, 2012; Čejka *et al*., 2013; Szmajda and Nowakowski, 2020; Perekopskiy *et al*., 2021). The main parameters of suitability for mechanized harvesting are the architectonics of the bush, high yield, resistance to various stressors, simultaneous ripening of berries in the raceme, and the rapid recovery characteristics of shoots after the combine (Sava and Bodiu, 2012; Djordjević *et al*., 2014; Rakonjac *et al*., 2015). The physico-mechanical criteria of currant berries have also been developed to reduce the percentage of berry loss during mechanized harvesting (Gurin, 2000). As a result, adjustments are being made to the breeding programs for currants and an important criterion is the mechanization of harvesting (Wang *et al*., 2009; Rakonjac, 2015; Sasnauskas *et al*., 2019). One of the main criteria is the placement of berries on bushes, simultaneous ripening of berries, the strength of the skin and the separation of berries from the raceme. Secondary features include the habitus of the bush (height, width and compactness of the bush, flexibility of branches), as well as a long harvest period (Masny *et al*., 2018).

The objective of this study is to evaluate the technological qualities of some cultivars based on the architectonics of the bush and the mechanical properties of the berries.

In particular, the research aimed at identifying promising technological cultivars for inclusion in breeding programs, as well as for industrial cultivation.

MATERIALS AND METHODS

This study was conducted over two seasons (2021-2022), at the growing and testing site of the Russian Research Institute of Fruit Crop Breeding (VNIISPK), located at 52°96′ north latitude and 36°07′ east longitude. The two years-old bare rooted plants were planted in 2017 to evaluate the suitability of cultivars for machine harvesting using a planting scheme of 3.5×0.5 m. The experimental design included 3 replications for each cultivar, with 10 plants in each repetition. The experimental site was on loamy haplic luvisol, and the organic horizon was 50-55 cm thick. The soil of the experimental site was medium acidic (pH= 4.82). The content of K and P varied depending on the depth of the soil profile and was low for berry crops. The content of K at a depth of 0-0.2 m was 41.75 mg kg^{-1} and P= 66.50 mg kg^{-1}. The content of K at a depth of 0.2-0.4 m was 12 mg kg^{-1}, and P= 45 mg $\cdot kg^{-1}$.

The weather during the growing seasons of 2021 and 2022 was contrasting. While the weather conditions in 2021 were close to the average annual values for the Central region in terms of temperature and precipitation, 2022 was characterized by a 10-12-day delay in spring, and the average temperature in May was 2.5°C lower than usual. The temperature during the summer months (June-August) was also lower by 3°C compared to the climatic norm for the region. These variations in temperature and precipitation over the years allowed us to calculate the maximum possible duration of the currant harvest.

Redcurrant cultivars of Russian and foreign breeding were selected as the plant materials of the research: 'Red Lake' (USA), 'Lozan' (Slovakia), 'Viksne' (Latvia), 'Jonkheer Van Tets' (Netherlands), 'Rondom' (Netherlands), 'Englische Grosse Weisse' (Netherlands), 'Rovada' (Netherlands), 'Hollandische Rote' (Netherlands), 'Rolan' (Netherlands), 'Natali' (Russia), 'Vika' (Russia), 'Niva' (Russia), 'Osipovskaya' (Russia), and 'Asya' (Russia). Full fruiting of the studied cultivars, when berry harvesting equipment can be used, occurred four years after planting due to the peculiarities of generative bud formation.

Parameters of the Study

The morphological features of each cultivar were assessed in triplicate. Biometric indicators of plants such as the height of the bush, the width of the bush, the height of the laying of berries from the ground surface were determined using a technical ruler with an accuracy of 0.1cm. The determination of the volume of the bush was defined as the product of the height of the bush by the width of the bush along and across the row. The Compactness of the bush (C) was calculated as the ratio of the height of the bush to the width of the bush across the row.

The bush form was compact if the angle between the main fruiting branches and soil surface is 60-75° (coefficient 0.7-0.9) (Sava *et al*., 2012; Utkov, 2015).

The percentage of broken shoots after mechanized harvesting was calculated as the number of broken branches to the total number of shoots of the cultivar on the production plot. Harvesting of berries by the combine harvester was performed at the stage of biological maturity, considering the berries' mechanical characteristics for each cultivar. The weight method determined crop loss from the bush using electronic scales CAS SWN-6 (South Korea). Crop losses refer to undamaged berries left on the bushes after machine harvesting. Repeated mechanized harvesting of the remaining berries on the bushes leads to additional damage to the bush, breakage of annual and perennial shoots, and can result in a prolonged recovery period for the bushes and a significant reduction in yield for the following year. After the combine harvester, the remaining berries on the bushes were harvested by hand from each bush, using plastic containers, and weighed on electronic scales in the field. Accounting was conducted on three bushes of the same cultivar, and the average value was calculated. Mechanized harvesting was carried out by the Joonas-2000 combine harvester (Finland), which has no technical design for lifting shoots from the soil.

The degree of illumination of the bushes was measured using a luxmeter Light Meter H.S. 1010A (China). The mechanical parameters of the berries were evaluated by separation Force (Fs) and crushing Force (Fc) during the period of biological ripening of the berries. Fs was determined using the "Dina-2" device (Russia); Fc by using the "Plodtest-1" device (Russia). The measurement interval was 3 days. The measurement was carried out on 5 racemes of each cultivar (an average of 40 berries) in threefold repetition. The strength of the skin (σ) was determined as the Fc ratio to the cross-sectional area of the crushing plunger (Mikhailova, 2014). The strength Coefficient (C) of berry depended on the crushing force and crushing separation and is given by Equation (1) (Aleynikov and Mineyev, 2016).

$$C = \frac{Fc - Fs}{Fs} \quad (1)$$

If $C \geq 0.8$, then any cultivar of red currant will be suitable for mechanical harvesting. The multiple regression equation was used to determine the duration of the mechanized harvesting period (Draper and Smith, 1998).

Microsoft Excel 2017 was used to calculate the average and standard deviations for the studied indicators and to present the figures. Statistical analysis was carried out using the software package SPSS 22.0 (ANOVA) and Tukey's HSD test ($P < 0.05$). To analyze the similarities and differences between the analyzed groups and build a correlation, the program R 4.2.2 was used. For cluster analysis, the program FactoMineR R was used and the RSA analysis was carried out using the program factoextra R.

RESULTS

The volume of the bush of the studied cultivars varied in the range from 0.37 ('Red Lake') to 5.16 ('Osipovskaya') m^3 (Table 1). The optimal area for placing the bush harvest ranged from 0.30 m to 1.10 m from the soil surface (Korovin, 2011). The cultivars 'Viksne', 'Niva', and 'Osipovskaya' exhibited an optimal berry placement zone in their large and tall bushes. However, the bush shape of 'Viksne' and 'Osipovskaya' was spreading, which might result in

Table 1. Morphometric parameters of the studied redcurrants.[a]

Cultivar	H (m)	B (m)	A (m)	V (m^3)	K	H (m)	B (m)	A (m)	V (m^3)	K
			'Asya'					'Viksne'		
2021	1.45±0.66^{ab}	1.03±0.26^{bc}	1.32±0.19^{b}	1.97±0.90^{c}	1.10±0.31^{bcd}	1.62±0.12^{ab}	1.47±0.50^{ab}	1.79±0.07^{a}	5.51±1.82^{a}	0.70±0.07^{de}
2022	1.15±0.11^{cd}	1.47±0.80^{ab}	1.35±0.76^{bc}	2.28±0.88^{d}	0.85±0.23^{ab}	1.58±0.06^{ab}	1.33±0.38^{ab}	2.13±0.14^{a}	4.48±0.83^{a}	0.74±0.02^{b}
Mean	1.30±0.38^{cd}	1.25±0.53^{c}	1.33±0.47^{abc}	2.13±0.89^{c}	0.98±0.27^{de}	1.60±0.09^{ab}	1.40±0.44^{ab}	1.80±0.11^{a}	5.00±1.33^{ab}	0.72±0.05^{de}
			'Niva'					'Rondom'		
2021	1.72±0.19^{a}	1.57±0.63^{a}	1.40±0.25^{b}	3.78±1.67^{b}	1.23±0.39^{bc}	0.98±0.19^{e}	0.73±0.50^{fg}	0.75±0.16^{fg}	0.54±0.19^{ef}	1.31±0.28^{ab}
2022	1.68±0.19^{a}	1.37±0.81^{ab}	1.80±0.25^{ab}	4.14±2.11^{a}	0.94±0.20^{ab}	1.07±0.19^{de}	0.77±0.38^{de}	0.92±0.26^{dc}	0.75±0.02^{cd}	1.16±0.18^{a}
Mean	1.70±0.19a	1.47±0.72a	1.60±0.25b	3.96±1.89^{b}	1.08±0.30^{de}	1.03±0.19^{df}	0.75±0.44^{de}	0.84±0.21f^{g}	0.65±0.11^{fg}	1.23±0.23^{a}
			'Vika'					'Englische Grosse Weisse'		
2021	1.37±0.14^{bc}	0.88±0.18^{de}	1.03±0.29^{cd}	1.24±0.58^{de}	1.32±0.39^{ab}	1.28±0.19^{cd}	0.89±0.05^{fg}	0.92±0.07^{fg}	1.05±0.24^{de}	1.40±0.22^{ab}
2022	1.35±0.37^{bc}	1.10±0.35^{de}	1.33±0.29^{bc}	1.98±0.39^{cd}	1.01±0.40^{ab}	0.86±0.36^{e}	0.65±0.12^{de}	0.92±0.26^{d}c	0.51±0.11^{cd}	0.94±0.30^{ab}
Mean	1.36±0.25^{bc}	0.99±0.26^{de}	1.18±0.29^{de}	1.61±0.49^{de}	1.17±0.40^{dc}	1.07±0.28^{df}	0.77±0.08^{de}	0.92±0.17^{fg}	0.78±0.18^{fg}	1.17±0.26^{bc}
			'Lozan'					'Red Lake'		
2021	1.02±0.19^{de}	0.60±0.04^{fg}	0.64±0.13^{g}	0.39±0.07^{ef}	1.58±0.51^{a}	0.91±0.07^{e}	0.50±0.38^{g}	0.70±0.24^{fg}	0.32±0.10^{f}	1.29±0.35a^{b}
2022	0.95±0.22^{de}	0.75±0.12^{de}	0.95±0.33^{dc}	0.68±0.18^{cd}	1.00±0.13^{ab}	0.98±0.10^{de}	0.58±0.07^{e}	0.72±0.26^{d}	0.41±0.11^{d}	1.36±0.37^{a}
Mean	0.98±0.20^{f}	0.67±0.08^{de}	0.80±0.23^{g}	0.53±0.13^{g}	1.29±0.32^{a}	0.94±0.09^{f}	0.54±0.23^{e}	0.71±0.25^{g}	0.37±0.11^{g}	1.33±0.36^{f}
			'Rovada'					'Rolan'		
2021	1.02±0.21^{de}	0.79±0.31^{de}	0.93±0.14^{ef}	0.75±0.15^{ef}	1.09±0.37^{bcd}	1.37±0.01^{bc}	0.75±0.39^{df}	1.03±0.16^{de}	1.06±0.28^{de}	1.34±0.21^{ab}
2022	0.97±0.26^{de}	1.18±0.19^{cd}	1.10±0.12^{dc}	1.26±0.42^{cd}	0.88±0.03^{ab}	1.13±0.19^{cd}	0.87±0.19^{de}	1.03±0.52^{dc}	1.01±0.36^{cd}	1.10±0.12^{ab}
Mean	0.99±0.23^{f}	0.99±0.25^{de}	1.02±0.13^{fg}	1.00±0.29^{ef}	0.99±0.20^{de}	1.25±0.10^{cd}	0.81±0.29^{de}	1.03±0.34^{fg}	1.04±0.32^{ef}	1.22±0.17^{ab}
			'Natali'					'Hollandische Rote'		
2021	1.05±0.17^{de}	1.20±0.25^{ab}	1.23±0.35^{bc}	1.55±0.76^{de}	0.85±0.30^{de}	1.07±0.09^{de}	0.83±0.28^{de}	0.77±0.15^{fg}	0.69±0.26^{ef}	1.39±0.37^{ab}
2022	1.02±0.07^{de}	1.43±0.34^{ab}	1.33±0.17^{bc}	1.94±0.72^{cd}	0.76±0.16^{b}	1.05±0.22^{de}	0.93±0.14^{de}	1.27±0.14^{dc}	1.24±0.16^{cd}	0.83±0.27^{b}
Mean	1.03±0.12^{df}	1.32±0.29^{b}c	1.28±0.35^{de}	1.75±0.74^{de}	0.81±0.23^{de}	1.06±0.16^{df}	0.88±0.21^{de}	1.02±0.15^{ad}	0.96±0.21^{fg}	1.11±0.32^{bc}
			'Jonkheer Van Tets'					'Osipovskaya'		
2021	1.19±0.08^{de}	1.02±0.19^{bc}	1.41±0.03^{b}	1.70±0.18^{cd}	0.84±0.05^{de}	1.66±0.15^{a}	1.20±0.43^{a}	2.43±0.29^{a}	4.85±0.91^{ab}	0.68±0.07^{e}
2022	1.08±0.07^{de}	1.38±0.19^{ab}	1.48±0.19^{bc}	2.22±0.49^{bc}	0.73±0.07^{b}	1.50±0.25a^{b}	1.63±0.29^{a}	2.23±0.52^{a}	5.47±1.41^{a}	0.67±0.06^{b}
Mean	1.14±0.07^{df}	1.20±0.19^{cd}	1.45±0.11^{bc}	1.96±0.34^{cd}	0.79±0.06^{de}	1.58±0.20^{ab}	1.42±0.36^{bc}	2.33±0.41^{a}	5.16±1.16^{a}	0.68±0.07^{e}

[a] H – The Height of the bush (m); A – Length of the bush diagonally along the row (m); B – Width of the bush across the row (m); V– Volume of the bush (m^3); and K – Compactness of the bush. The data represent the average values for three repetitions (n=10)±Standard Error (SE). Different letters show significant differences between the parameters of the bush according to Tukey's HSD test ($P< 0.05$).

difficulties during mechanized harvesting. On the other hand, 'Niva' had the highest bushes and an erect habit, but the combined harvester could cause damage to the upper part of the shoots. Such problem resulted in need for additional technical operations such as contour pruning of bushes. This issue was not observed in cultivars such as 'Englische Grosse Weisse', 'Red Lak'e, and 'Lozan', where despite the smaller volume of the bush, the majority of the yield was concentrated in a zone closer to the base of the bush, as shown in Table 1.

In this experiment, the morphological characteristics of the bushes were found to be relatively stable with low Coefficient of Variation (CV) values not exceeding 30%: CV (h) was up to 22.98%, CV(B1) up to 19.74%, and CV(V) up to 22.85%. The phenotypic variability of the red currant bush habit was insignificant. In most of the studied cultivars, the percentage of broken branches after the mechanized harvesting did not exceed 10%. A low percentage of damaged branches was not critical for reducing the duration of plantings exploitation. The high flexibility of the 'Osipovskaya' branches led to significant damage to the bush. The percentage of broken shoots ranged from 24.32 to 27.39%. The sanitary pruning carried out to remove damaged branches showed a high regenerative ability of bushes for most cultivars. Nevertheless, 'Rovada' and 'Englische Grosse Weisse' demonstrated a weak regenerative ability of the bush, and the number of new annual shoots did not exceed 2-3 pieces per bush for 6 months. The complete restoration of these cultivars took place after 24 months.

One of the critical factors determining the suitability of a cultivar for combine harvesting is its ability to produce a stable yield with a minimum density of 2-3 kg of the bush. To assess the performance of various cultivars under mechanized harvesting, we measured their yield and crop losses, as shown in Figure 1. It should be noted that the reduction in yield during the second year of the experiment can be attributed to damage caused by the combine harvester to some of the perennial shoots, which were responsible for producing generative buds.

The berries on the bushes should be positioned in such a way as to ensure maximum efficiency of berry harvesting by a combine harvester and the berries should have a simultaneous ripening period. The simultaneity of maturation is determined by varietal differences and bush lighting. The sparse architectonics of the bush in

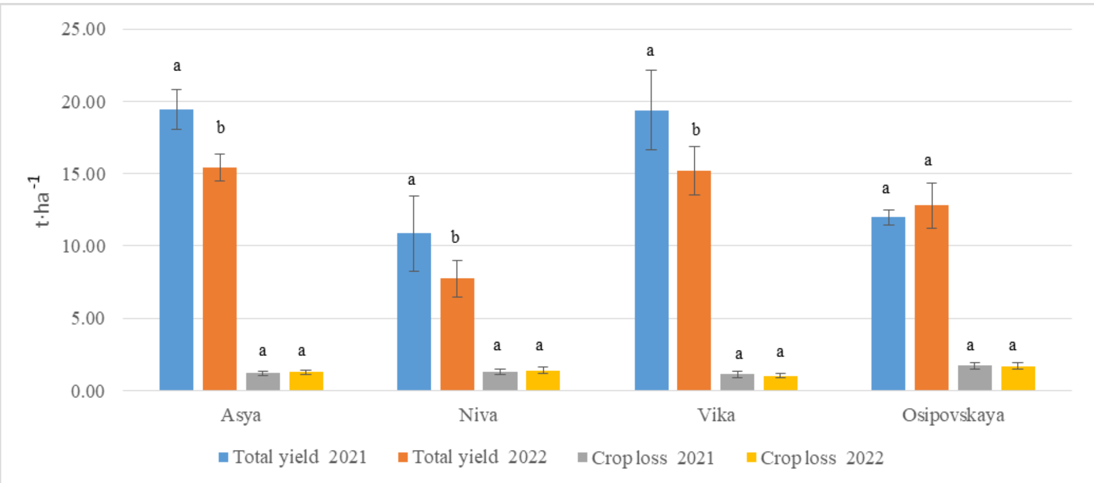


Figure 1. The total yield of cultivars and yield loss after the mechanized harvesting. The letters above the columns are used to compare yield data and its loss for each cultivar. Different letters indicate significant differences between the values according to Tukey's HSD test ($P < 0.05$).

'Jonkheer Van Tets', 'Asya', 'Vika', 'Natali', 'Red Lake' and 'Rovada' provided uniform illumination of berries on the bushes. The illumination values for these cultivars were 687.2 Lx. By the beginning of the mechanized harvesting, more than 90% of the berries at the stage of biological maturation had a uniform color and met the quality standard of berry products. In 'Osipovskaya', the strong thickening of the bushes reduced the intake of sunlight. The illumination values for this cultivar were 425 Lx. In 'Osipovskaya', the strong thickening of the bushes reduced the intake of sunlight (425 Lx). During mechanized harvesting, about 30% of the yield had unripe berries, which were poorly separated from the raceme and a large number of berries remained on the bushes. The mechanical parameters of the berries (Fs and Fc) depend on the cultivar and weather and climatic conditions. Using the example of several red currant cultivars, changes in the Fs and Fc parameters and the duration of the biological maturation period in 2021 and 2022 are shown (Table 2).

The mechanical parameters of the currant berries varied over two growing seasons. In 2022, the ripening period of the berries for many cultivars was quite long and began 7-10 days later than in 2021. In addition, by the period of full biological maturity, the Fs

Table 2. Changes in the mechanical parameters of berries during biological maturation, depending on the cultivar and the study period.[a]

Days	2021		2022	
	Fs (N)	Fc (N)	Fs (N)	Fc (N)
		'Jonkheer Van Tets'		
1	1.47±0.12[a]	6.04±0.80[a]	0.65±0.25[a]	5.57±0.49[a]
4	0.89±0.16[b]	4.71±0.85[b]	0.69±0.07[a]	4.86±0.46[b]
7	0.78±0.09[c]	6.35±0.18[c]	0.68±0.10[a]	4.75±0.69[b]
10	0.62±0.10[d]	4.78±0.90[d]	0.42±0.06[d]	4.38±0.84[c]
13	0.33±0.08[e]	3.43±0.19[e]	-	-
		'Englische Grosse Weisse'		
1	1.53±0.06[a]	3.98±0.97[a]	0.51±0.03[a]	3.19±0.72[a]
4	0.49±0.02[b]	1.64±0.45[b]	0.47±0.07[a]	4.02±0.89[b]
7	-	-	0.54±0.03[a]	3.21±0.21[b]
10	-	-	0.25±0.08[d]	1.59±0.38[d]
		'Lozan'		
1	1.33±0.08[a]	9.06±0.53[a]	0.83±0.19[a]	3.39±0.18[a]
4	1.25±0.08[a]	6.19±0.63[b]	0.60±0.09[a]	4.41±0.50[b]
7	0.14±0.04[c]	4.69±0.50[c]	0.56±0.05[b]	3.74±0.96[b]
10	-	-	0.63±0.08[b]	2.63±0.14[d]
13	-	-	0.26±0.04[e]	2.34±0.03[e]
		Red Lake		
1	0.80±0.08[a]	8.59±0.33[a]	0.52±0.12[a]	3.37±0.36[a]
4	0.69±0.14[b]	4.57±0.46[b]	0.46±0.05[a]	3.24±0.23[a]
7	0.63±0.12[b]	6.03±0.41[c]	0.50±0.08[a]	3.14±0.80[a]
10	0.36±0.04[d]	4.09±0.28[d]	0.26±0.02[c]	2.35±0.41[b]
13	0.29±0.02[e]	3.52±0.47[c]	-	-
		Vika		
1	1.44±0.04[a]	6.57±0.65[a]	0.62±0.09[a]	4.10±0.21[a]
4	0.55±0.07[b]	5.02±0.46[b]	0.60±0.07[a]	5.02±0.58[b]
7	0.51±0.08[b]	5.96±0.48[c]	0.42±0.02[c]	4.19±0.09[a]
10	0.25±0.02[d]	4.02±0.43[d]	0.32±0.08[d]	2.87±0.46[d]

[a] «-»- Berries at the stage of physiological maturity; biosynthetic processes stop; berries lose their characteristic taste and appearance.

and Fc indicators decreased. The duration of the optimal berry harvest period for cultivars depended on the rate of decrease in the mechanical parameters of the berries. The dependence of the harvest duration on Fs and Fc and weather conditions is shown (Table 2).

The high relationship between the mechanical parameters of berries (R= 0.75-0.85) makes it possible to calculate the prediction of the optimal period for berry harvesting, taking into account the cultivar. For ‘Jonkheer Van Tets’, according to the multiple regression equation, the effective period for using the harvester was 7 days in 2021 (R= 0.69) and 4 days in 2022 (R= 0.71).

Fc depends on the strength of the skin and for most cultivars it was more than 2 N. In the process of biological maturation, the strength of the skin decreased in all cultivars. Reducing the strength of the skin during the ripening period of berries reduces the resistance of berries to mechanical damage and the quality characteristics of berries. Changes in the strength of the berry skin during maturation are associated with biochemical changes (for example, hydrolysis of proto-pectin, hemicellulose) (Giongo, L., 2019; Toushik *et al*., 2017; Spinei and Oroian, 2021). Of particular importance in mechanized harvesting is the separation of berries from the raceme without damage. This separation is called "dry berry separation". This separation allows to maintain the appearance and quality characteristics of berries at a high level during transportation (Kazakhmedov *et al.,* 2017; Rivera, 2022). The strength of the attachment of berries to the raceme depends on Fs and Fc. According to the criterion of Aleynikov and Mineev (2016), most of the studied cultivars were considered suitable for mechanized harvesting (C≥ 0.8).

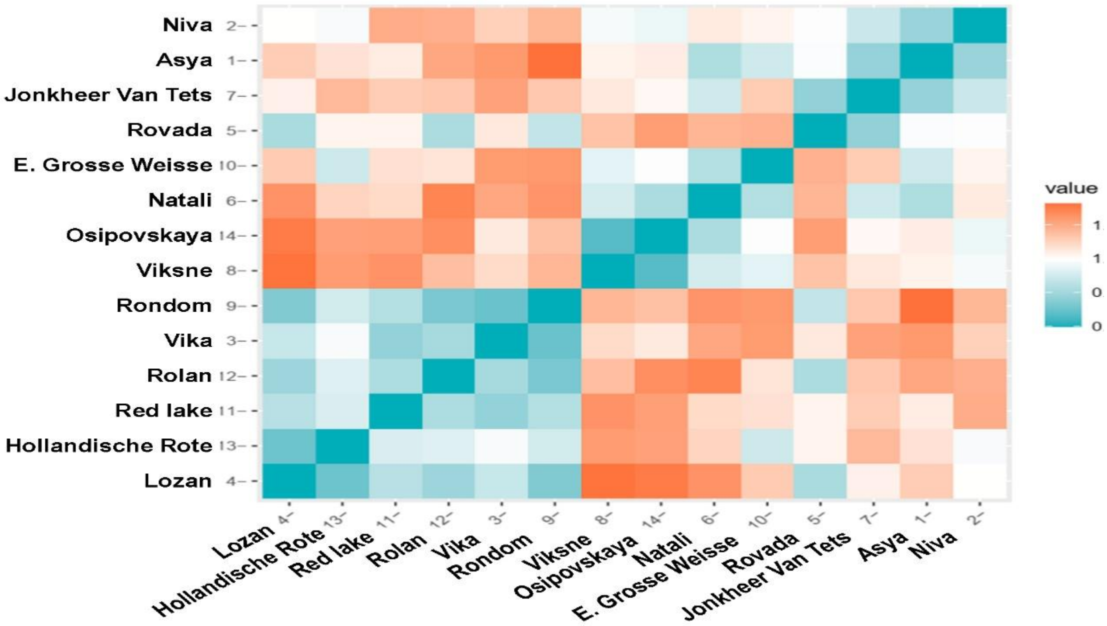
Relationships among Study Cultivars

Distance measures showed that 'Niva', 'Asya' and 'Jonkheer Van Tets' were similar in many studied indicators and differed from 'Rondom'. At the same time, 'Rondom', 'Rolan' and 'Vika' were different from 'Red Lake'. 'Viksne' and 'Osipovskaya' were similar in a number of indicators (Figure 3-A). Cluster analysis combined the cultivars according to the studied parameters into 4 clusters (Figure 3-B).

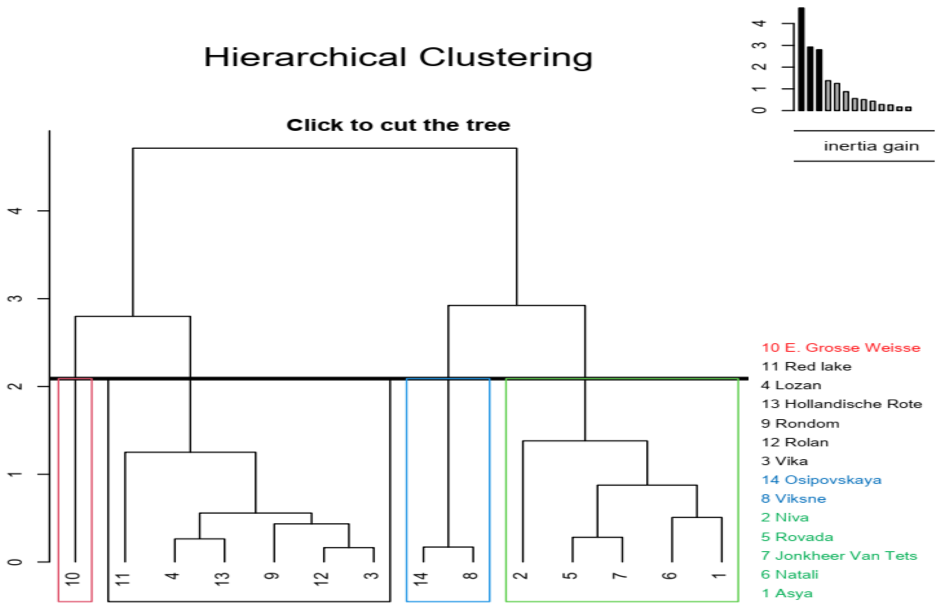
The first cluster included 'E. Grosse Weisse'. According to PCA-Biplot analysis, this cultivar was very different from all the studied cultivars (Figure 4). The second cluster combined cultivars in terms of bush compactness (K). The third cluster consisted of cultivars with high morphological parameters of the bush (A, B, and V) and average K values. The fourth cluster combined cultivars in terms of mechanical parameters of berries (Fc, Fs, σ, and C).

DISCUSSION

In this experiment, the Joonas-2000 combine harvester (Finland) was used, its work was based on the vibration effect on shoots. Therefore, the habitus of the bush is important. For the normal operation of the harvester, the bushes should be either erect or slightly spreading and consist of 10-15 perennial fruiting shoots (Pluta *et al.,* 2008; Sava and Bodiu, 2012). For this trait, "Viksne", "Englische Grosse Weisse", and "Osipovskaya" (Table 1), did not meet these requirements and should not be included in programs for breeding for suitability to mechanized harvesting, as well as industrial cultivation. In experiments with blueberry cultivars, it has also been shown that certain parameters of plant height and bush volume are necessary for the use of berry harvesting equipment. The minimum yield losses were in blueberry varieties with a straight-growing, compact bush shape, which also made it possible to extend the life of these plantations (Patrick, and Li, 2017). The second disadvantage of the combine harvester of this model is the collection of ripe and unripe berries during vibration on shoots. This result was observed in this

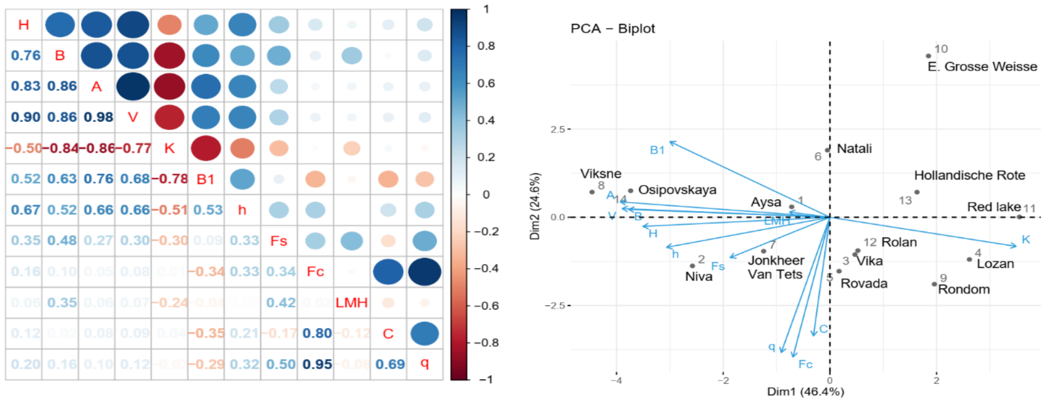


A



B

Figure 3. (A) Distance measure (orange color shows differences, teal – how's similarities) between cultivars, and (B) Hierarchical clustering to group the cultivars.



A **B**

Figure 4. Correlation (A), and PCA: Biplot (B) analyses of characters and cultivars. Note: K: Compactness of the bush, H: The Height of the bush (m), B: Width of the bush across the row (m), A: Length of the bush diagonally along the row (m), and V: The Volume of the bush (m3), Fs: Separation Force, Fc: Crushing Force, C: Coefficient of the relative strength of berries, and σ: Static crushing force.

experiment with 'Osipovskaya' redcurrant and when harvesting sea buckthorn berries (Khabarov. 2014; Zubarev, 2022). When harvesting berries in bulk, it is important to determine the effective period of using the harvester, when berry losses will be minimal and the quality of the berries will meet the quality standard (Yu, 2012; Brondino, 2021). The dependence of the effective harvest period on climatic conditions and the cultivar was proved in this experiment (Table 2), as well as on other cultivars of red and white currants (Paprstein *et al.,* 2016) and grape cultivars (Jobbágy, 2021). This experiment shows the use of mechanical parameters of berries as an informative feature for assessing the quality of berry products (Table 2). For blueberry cultivars, the possibility of using various upgraded combine harvester models is determined by the strength of the berries (Rivera, 2022.). However, it is not entirely correct to recommend using only the mechanical parameters of berries to predict the optimal period of using harvester, since it is also necessary to take into account long-term weather data and biometric characteristics of the bush. A similar conclusion was made by a comprehensive assessment of the mechanical parameters of the berry skin, the morphology of the blueberry bush (Rivera, 2022) and grapes (Zouid, 2010; Brillante, 2015). The current study confirmed the relationship between high Fc values of redcurrant berries and product quality. These indicators tended to decrease during the maturation process. A decrease in the strength of the skin of berries and the quality of products in the process of biological ripeness were noted in grapes (Rolle *et al*., 2012). In addition, the current experiment did not reveal a relationship between Fs and the strength of the berry skin, which is consistent with the data obtained on grape cultivars (Giacosa *et al*., 2013)

CONCLUSIONS

The suitability of red currant cultivars for mechanized harvesting should be assessed by the productivity of a berry harvester. In this study, the cultivars were rejected according to indicators that determine the profitability of berry production, including a high percentage of branch breakage during two years of using the harvester, low regenerative ability of the bush after sanitary pruning, as well as low mechanical parameters of berries. According to the architectonics of the bush, mechanical parameters of berries and testing of the harvester, 'Vika', 'Asya', 'Red Lake', 'Niva', 'Rolan', and 'Jonkheer Van Tets' are technological cultivars suitable for mechanized harvesting and promising for industrial cultivation and breeding programs.

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ارزیابی تکنیک های موثر کولتیوارهای انگورفرنگی قرمز (Redcurrant) برای برداشت مکانیزه

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چکیده

این پژوهش با هدف شناسایی ارقام بهینه انگورقرمز برای برداشت مکانیزه، با ارزیابی ساختار مورفولوژیکی بوته و پارامترهای مکانیکی حبه‌ها انجام شد. چهارده رقم انگورفرنگی قرمز در طول فصل 2022-2021 ارزیابی شدند و شاخص‌های کیفیت حبه و پارامترهای مکانیکی آنها، از جمله نیروی جداسازی (Fs) و نیروی لهیدگی (Fc)، اندازه‌گیری شد. نتایج نشان داد که رقم نقش مهمی در ساختار مورفولوژیکی بوته دارد، در حالی که پارامترهای مکانیکی حبه‌ها بر کارایی فرآیند برداشت تأثیر می‌گذارند. همبستگی بالای بین Fs و Fc امکان پیش‌بینی دوره‌های برداشت بهینه ارقام را فراهم کرد. در میان ارقام، "Rolan، 'Jonkheer Van Tets'، 'Rovada'، 'Red Lake'، 'Asya'، Vika" و 'Niva' به عنوان ارقام تکنولوژیکی و مناسب برای برداشت مکانیزه در نظر گرفته شدند. این مطالعه بر اهمیت در نظر گرفتن عوامل ژنتیکی و مورفولوژیکی هنگام انتخاب ارقام انگورفرنگی قرمز برای برداشت مکانیزه تأکید می‌کند و بینش‌های ارزشمندی برای اصلاح ژنتیکی (breeding) و توسعه ارقام جدید سازگار با برداشت مکانیزه ارائه می‌دهد.

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Exogenous Salicylic Acid Enhances Strawberry Resistance to Crown Rot

Lili Liu[1], Aolin Peng[1], and Bo Shu[1*]

ABSTRACT

Salicylic Acid (SA) contribution to mitigating strawberry crown rot remains unclear due to the microbial isolate-specific sensitivity and cultivar/tissue-specific responses in strawberries. In this study, we aimed to investigate how exogenous supply of SA influenced crown rot in strawberry. Exogenous SA application significantly reduced *C. siamense* infection in strawberry crowns, evidenced by the lesion size and pathological analysis. Transcriptomic data showed that for each sample of SA pretreatment and mock, owing to nearly 50 million reads, the ratio of Q20 ranged from 98 to 99%, and 91.63-94.29% of the reads mapped to the reference genome. The SA pretreatment up-regulated genes encoding MLO-like protein 2, receptor-like kinase, peroxidase, and caffeic acid 3-O-methyltransferase involved in lignin biosynthesis. The SA pretreatment also down-regulated chalcone isomerase, naringenin 3-dioxygenase, bifunctional dihydroflavonol 4-reductase, anthocyanidin synthase, and anthocyanidin reductase expressions involved in flavonoid biosynthesis during *C. siamense* infection. Consistent with gene expression changes, the SA pretreatment remarkably enhanced peroxidase activity and lignin content and decreased flavonoid content and chalcone isomerase activity after *C. siamense* inoculation. The results suggest that exogenous SA enhanced strawberry resistance to crown rot caused by *C. siamense* by up-regulating defense-related genes and lignin biosynthesis.

Keywords: 'Benihoppe' strawberry, Enzyme activity, Lignin biosynthesis, Transcriptome.

INTRODUCTION

Colletotrichum is a hemibiotrophic pathogen, using a composite strategy that comprises biotrophic and necrotrophic processes. Crown rot caused by *C. siamense* is a serious disease in strawberries (*Fragaria × ananassa*), especially in China (Ji *et al*., 2022; Shu *et al*., 2022). Promoting resistance to crown rot caused by *C. siamense* is a very meaningful work for strawberry production. Induced resistance refers to the phenotypic state in which an exogenous stimulus conditions a plant to reduce its susceptibility to future biotic challenges (De Kesel *et al*., 2021). Understanding the effects of exogenous stimuli (especially chemical compounds) on the induced resistance of cultivated strawberries to *C. siamense* infection is important for disease control.

Salicylic Acid (SA) is a key hormone involved in plant defenses against biotrophic and hemibiotrophic pathogens, as it activates systemic acquired resistance (Esmailzadeh and Soleimani, 2008). SA can change enzyme activity, increase defense genes, enhance several defense responses, and/or generate free radicals (De Kesel *et al*., 2021). Exogenous SA reduced the incidence of potato purple top disease caused by *phytoplasma* (biotrophic) in tomatoes (*Lycopersicon esculentum*) (Wu *et al*., 2012) and decreased the severity of citrus canker disease caused by *Xanthomonas axonopodis* (biotrophic) in oranges (*Citrus sinensis*) (Wang and Liu, 2012). Similar to biotrophic

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pathogen, exogenous SA reduced disease incidence of *Fusarium* wilt caused by *F. oxysporum* (hemibiotrophic) in chickpea (*Cicer arietinum*) and tomato (*L. esculentum*), respectively (Saikia *et al*., 2003; Jendoubi *et al*., 2015); decreased disease severity of rice blast caused by *Magnaporthe grisea* (hemibiotrophic) (Daw *et al*., 2008); and anthracnose caused by *C. gloeosporioides* (hemibiotrophic) in tea flower (*Camellia oleifera*) (Wang *et al*., 2006).

A study also showed that SA is involved in the strawberry response to *Colletotrichum* invasion (Grellet-Bournonville *et al*., 2012; Amil-Ruiz *et al*., 2016). Genes involved in SA biosynthesis and free SA release from MeSA were up-expressed for a very early burst of free SA under *C. fructicola*-inoculated strawberry leaves in less-susceptible cultivar 'Jiuxiang' and susceptible cultivar 'Benihoppe' (He *et al*., 2019). Furthermore, after an early SA burst, fast free SA quenching was caused by effectors (CfShy1) of *C. fructicola* interfere with accumulation (He *et al*., 2019). Exogenous SA pretreatment reduced susceptibility and elevated internal SA levels in both varieties, which were sharply reduced in the susceptible cultivar upon inoculation (Zhang *et al*., 2016). In addition to its regulating endogenous SA biosynthesis, studies have shown that exogenous SA promotes the biosynthesis of lignin (i.e., a physical barrier against pathogens) and flavonoids (i.e., antioxidants and signal molecules for resistance) to enhance plant resistance (Dempsey *et al*., 2012; Lee *et al*., 2019; Hou *et al*. 2024). Although the application of SA pretreatment reduced the susceptibility to anthracnose caused by *C. gloeosporioides* in leaves (Zhang *et al*., 2016), the effects of exogenous SA on strawberries in response to *C. siamense* crown infection remain unknown. Furthermore, variations in defense genes and resistance related to the secondary metabolites, e.g., lignin and flavonoids, affected by SA have not been investigated.

The aims of this study were to use lesion size and pathological analysis for the following purposes:

To test the effects of exogenous SA on strawberry resistance to crown rot caused by *C. siamense*,

Use RNA-seq and qRT-PCR to examine gene expression profiles to identify SA-induced physiological responses to antagonize *C. siamense* infection,

Measure the physiological index to understand the potential factors due to the effects of SA on strawberry crown rot.

MATERIALS AND METHODS

Materials and Experiment Design

The aseptic strawberry seedlings (cv. Benihoppe) were transplanted into pots with seedling substrates (Pindstrup, 5-20 mm) in a growth chamber (25/15°C, 16 hours light/8 hours dark). Seedlings were watered thrice per week and fertilized weekly with 30 mL Hoagland nutrient solution (Li *et al*., 2023). Seedlings were prepared to evaluate the effects of SA on strawberry crown rot after 3 months of growth.

This experiment was designed as SA (dissolved in distilled water) and mock (distilled water) pretreatments. Seedlings were sprayed with an atomizer until thoroughly wetted with 5 mM SA, which was applied twice (8 and 1 d before pathogen inoculation) as described by Desmedt *et al*. (2021). Subsequently, 10 μL of the spore suspension of *C. siamense* SCR-7 (10^4 conidia·mL^{-1}) and mock (sterilized water) were squeezed to crowns after being stabbed with sterilized toothpick (Luo *et al*., 2021). Samples were collected on days 0 and 4 post-inoculation. The experiment comprised the following four treatments:

Zero Day Post-Inoculation with *C. siamense* SCR-7 with SA pretreatment (SA0DPI) and mock seedlings (Mock0DPI),

4 Days Post-Inoculation with *C. siamense* SCR-7 with SA pretreatment (SA4DPI) and mock seedlings (Mock4DPI).

The crowns of 10 seedlings were mixed as one biological replicate. Each treatment contained six biological replicates for the observation of infection and physiological index measurements. Two of the six biological replicates from each treatment were mixed as a new biological replicate for transcriptome analysis and qRT-PCR; three biological replicates were used in these two analyses.

Infection Observation of SA and Mock Pretreatment

The length and width of the lesions were measured using a straight edge. Pathological analyses were performed as described by Shu *et al*. (2022). Next, 10 μL wheat germ agglutination storage solution and 20 μL propidium iodide stock solution were added to 970 μL 0.2% Tween-phosphate buffer saline solution and mixed thoroughly (dye preparation). A Carnot fixative was used to fix the crown samples. The crowns were transferred into a 10% KOH solution, and the tube was sealed with Parafilm to prevent collapse. The sample was then incubated at 85°C for 4 hours (fix). The crowns were washed twice or thrice with phosphate buffer saline and sealed with anti-fluorescence quenching, stored at 4°C in the dark, and imaged using a fluorescence microscope (Photographing) (Nikon E400, Melville, NY).

Transcriptome Analysis and qRT-PCR

Total RNA was extracted from freeze-dried samples by using a TRIzol reagent kit (Invitrogen, Carlsbad, CA, USA) per the manufacturer's protocol. RNA quality was assessed using an Agilent 2100 Bioanalyzer (Agilent Technologies, Palo Alto, CA, USA) and verified using RNase-free agarose gel electrophoresis. The fragments were purified using agarose gel electrophoresis, enriched using PCR amplification to create a cDNA library for each sample, and sequenced using Illumina HiSeq2500. For obtaining high-quality clean reads, raw reads from transcriptome sequencing were filtered using Fastp (version 0.18.0). The strawberry 'Camarosa' Genome v2.0 was used as the reference genome. The FPKM (Fragment Per Kilobase of transcript per Million mapped reads) value was calculated to quantify its expression abundance and variation by using StringTie software. FPKM data were directly used to estimate Differentially Expressed Genes (DEGs) between samples. False Discovery Rate (FDR)< 0.05 and |log2FC| > 1 were used as thresholds to identify significant DEGs. Based on these DEGs, Eukaryotic Orthologous Group (KOG) analysis, Gene Ontology (GO) enrichment analysis, and Kyoto Encyclopedia of Genes and Genomes (KEGG) enrichment analysis were performed as described by Shu *et al*. (2022).

qRT-PCR was performed, according to the method described by Luo *et al*. (2020) on three independent biological samples with three technical replicates each. DEGs involved in lignin and flavonoid biosynthesis, MLO-like protein 2, leucine-rich repeat receptor-like serine/threonine-protein kinase and cysteine-rich receptor-like protein kinase, were selected for RNA-seq verification by using a CFX96 real-time PCR Detection System (Bio-Rad Laboratories, USA), and the primers used for qRT-PCR are shown in supplementary file, Table S1. The relative gene expression was calculated using the $2^{-\triangle\triangle Ct}$ method (Rao *et al.,* 2013), where actin-1 was used as the reference gene (Zhang *et al.,* 2018).

Measuring Flavonoid and Lignin Contents

The flavonoid content was determined using a plant flavonoid content assay kit (Solarbio Beijing, China) per the manufacturer's instructions and a UV-5200 spectrophotometer (Shanghai Metash Instruments, China) at 470 nm, as described by Lu *et al*. (2023). The lignin content was determined using a lignin content assay kit (Solarbio, Beijing, China) per the manufacturer's instructions and a spectrophotometer at 280 nm, as described by Ning *et al*. (2023).

Measuring Chalcone Isomerase and Peroxidase Activities

Chalcone Isomerase (CHI) activity was determined, as described by Li *et al*. (2023), using a CHI test kit (TongWei, Shanghai, China). Peroxidase (POD) activity was determined using a peroxidase activity assay kit (Solarbio, Beijing, China) per the manufacturer's instructions, and a spectrophotometer at 470 nm as described by Zhang *et al*. (2023).

Statistical Analysis

Significant differences between the treatments were determined using Duncan's Multiple Range Tests at P= 0.05 with SAS 8.1 (SAS Institute, Inc., Cary, NC, USA). Different letters indicate significant differences between groups.

RESULTS

Effects of SA on *C. siamense* Infection

SA pretreatment decreased the severity of crown rot caused by *C. siamense* (Figure 1-A), reducing lesion size (Figure 1-B). Consistent with the size of the lesion, the density of hyphae in the SA-treated crowns was lower than that in the mock-treated crowns (Figure 1-C). The lesion size and pathological analysis suggested that SA pretreatment inhibited the infection of *C. siamense* to strawberry crown.

Effects of SA on Physiological Responding to *C. siamense* Infection

The transcriptomic data showed that the total number of reads per sample was approximately 50 million. The Q20 ratio of each sample ranged from 98 to 99%, and the ratio of N bases was less than 0.04%. The Guanine and cytosine (GC) content of each sample was approximately 48%

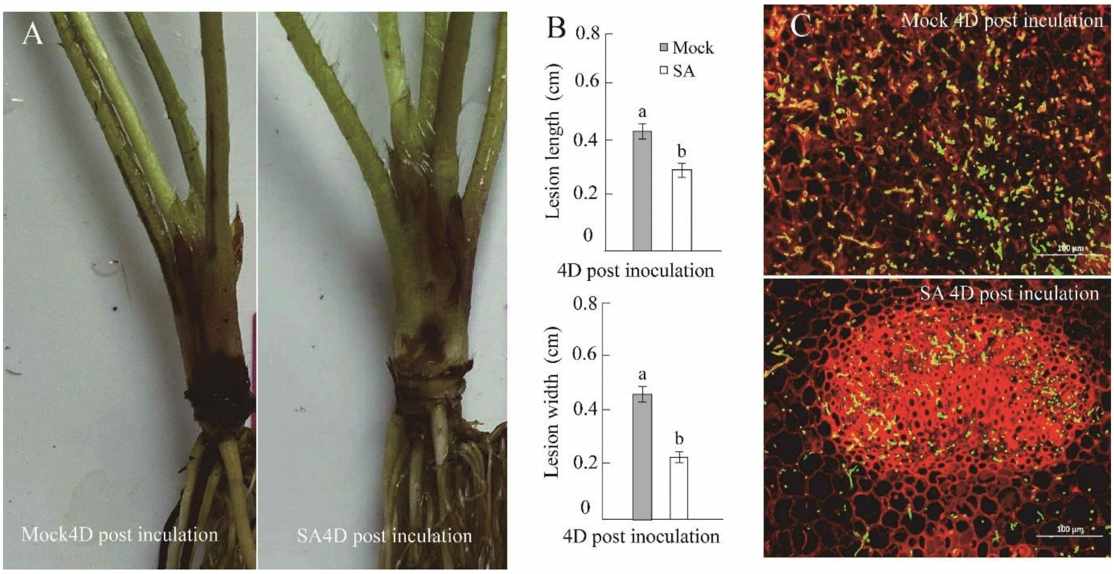


Figure 1. Effect of SA on *Colletotrichum siamense* SCR-7 infection in strawberry crown. (**A**) The lesions after 4 days of pathogen inoculation on strawberry crowns subjected to SA and mock pretreatments. (**B**) The lesion length and width after 4 days of SCR-7 inoculation on strawberry crown treated with SA and mock. (**C**) The hypha after 4 days of SCR-7 inoculation in strawberry crown (green) of SA and mock treatment, respectively. Data (Means±SE, n= 6) followed by different letters above the bars among treatments indicate significant differences.

(supplementary file, Table S2). All clean reads were compared with the reference genome, and most of the reads mapped to the reference genome ranged from 91.63 to 94.29%, the ratio of mapped reads to the sense strand and anti-sense chain was nearly 35%-38%, and nearly 75% of the mapped reads of each sample were uniquely mapped to the genome (supplementary file, Table S3). Furthermore, principal component analysis based on RNA-seq showed that three biological replicates of each treatment were gathered together, and the four treatments were relatively dispersed (supplementary file, Figure S1). These results confirmed the reliability of our data, and the transcriptomic data were uploaded to the NCBI Sequence Read Archive as PRJNA1021273.

The SA pretreatment regulated transcripts in strawberry crowns. The SA0DPI vs. Mock0DPI showed 990 up-regulated and 520 down-regulated genes. The number of DEGs in SA4DPI vs. Mock4DPI was lower than that in SA0DPI vs. Mock0DPI, which included 448 significantly up-regulated and 434 down-regulated genes (Figure 2).

GO enrichment analysis revealed that most DEGs were enriched in biological processes. In biological process subcategory, the metabolic process, biological regulation and cellular process contained the most differentially expressed transcripts in SA0DPI vs. Mock0DPI. In cellular component subcategory, the organelle, cell and cell part possessed the most differentially expressed transcripts in SA0DPI vs. Mock0DPI. And in molecular function subcategory, the transporter activity, catalytic activity and binding contained the most differentially expressed transcripts in SA0DPI vs. Mock0DPI.

Response to stimulus clustering into biological process and catalytic activity clustering into molecular function was increased even more in SA4DPI vs. Mock4DPI than that in SA0DPI vs. Mock0DPI (Figure 3).

The enrichment map of GO showed regulation of cellular macromolecule biosynthetic process, regulation of cellular biosynthetic process, cell wall organization or biogenesis, xylan biosynthetic process, and plant−type secondary cell wall biogenesis enriched most DEGs in SA0DPI vs. Mock0DPI (Figure 4-A). By contrast, flavonoid metabolic process, chalcone isomerase activity, and salicylic acid catabolic process were enriched in most DEGs in SA4DPI vs. Mock4DPI (Figure 4-

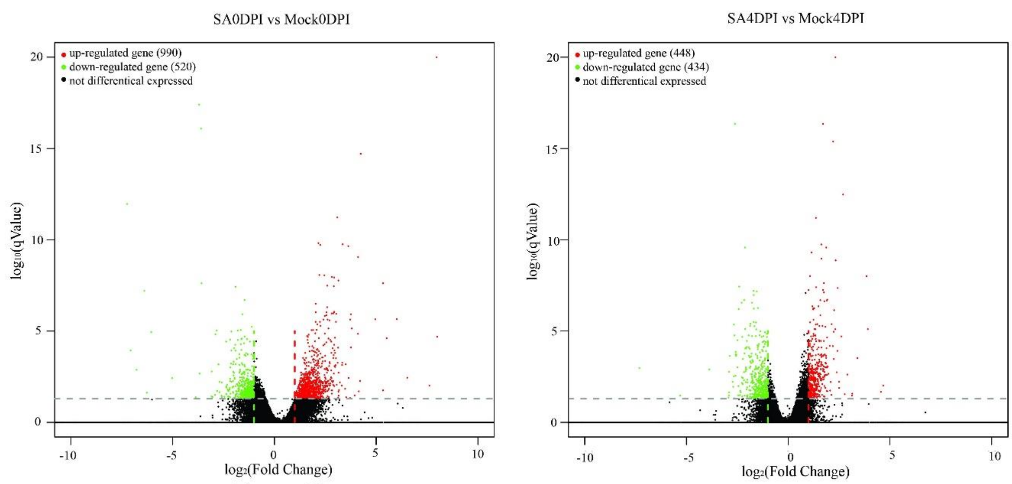


Figure 2. Effect of Salicylic Acid (SA) on differentially expressed transcript number in *Colletotrichum siamense* infected strawberry crown.

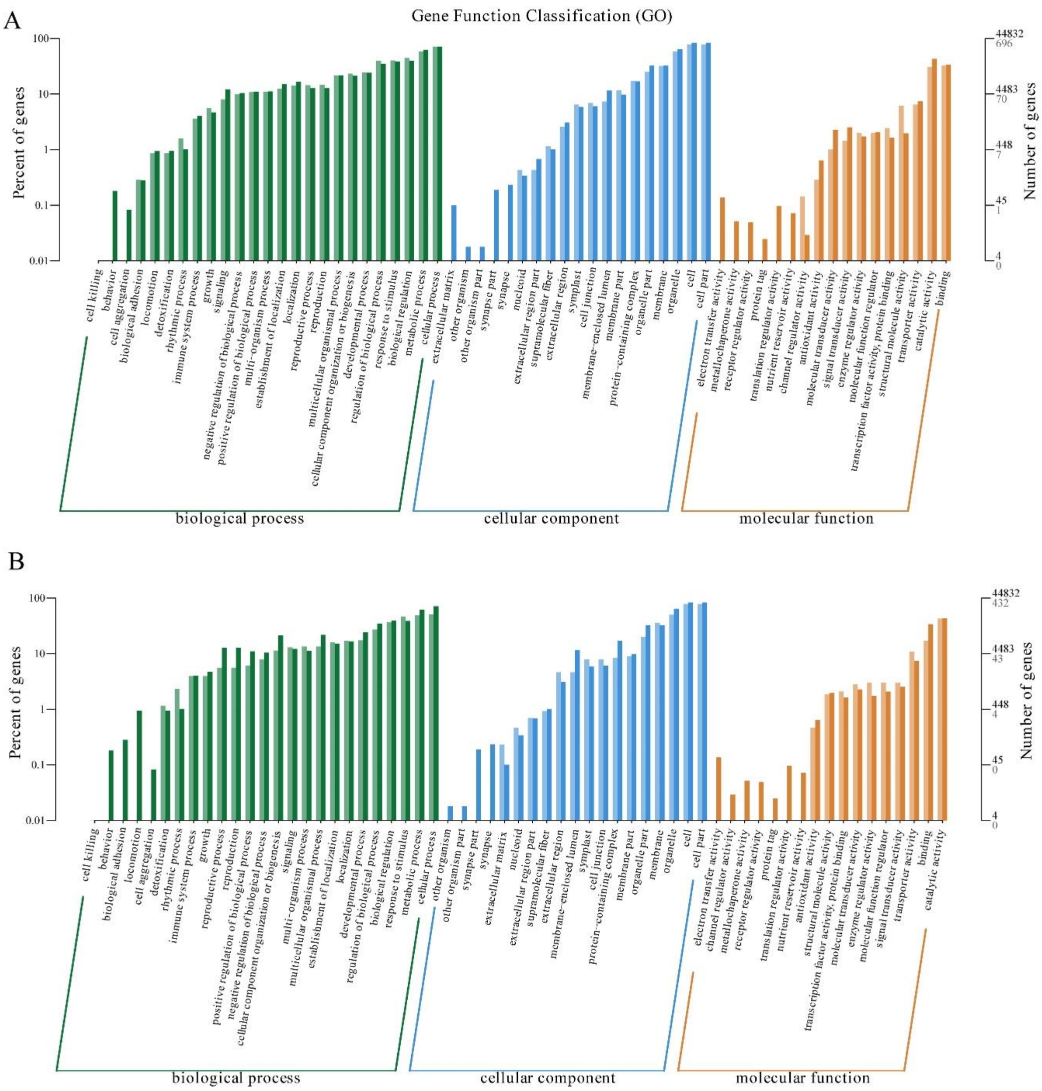


Figure 3. The gene function classification (GO) of differentially expressed transcripts in strawberry crown caused by Salicylic Acid (SA). (**A**) Was analyzed based on the differentially expressed transcripts in SA vs mock treatment at 0 day after *Colletotrichum siamense* SCR-7 inoculation. (**B**) Was analyzed based on the differentially expressed transcripts in SA vs mock treatment at 4 days after *Colletotrichum siamense* SCR-7 inoculation.

B). KOG function classification showed posttranslational modification, protein turnover, chaperones, general function prediction only, and signal transduction mechanisms were mapped for most DEGs in SA0DPI vs. Mock0DPI and SA4DPI vs. Mock4DPIs (Figure 5-A and 5B). An enrichment map of KOG function classification showed FxaC_14g15990, FxaC_11g32110, FxaC_13g23280, FxaC_11g26150, FxaC_12g20520, and FxaC_13g23960 transcripts enriched in cell wall/membrane/envelope biogenesis, or extracellular structures were significantly differentially expressed in SA0DPI vs. Mock0DPI (Figure 6-A). FxaC_16g02820, FxaC_26g03630, and FxaC_18g45220, which were enriched in secondary metabolite biosynthesis, transport, and catabolism, were significantly and differentially expressed in SA4DPI vs. Mock4DPI (Figure 6-B).

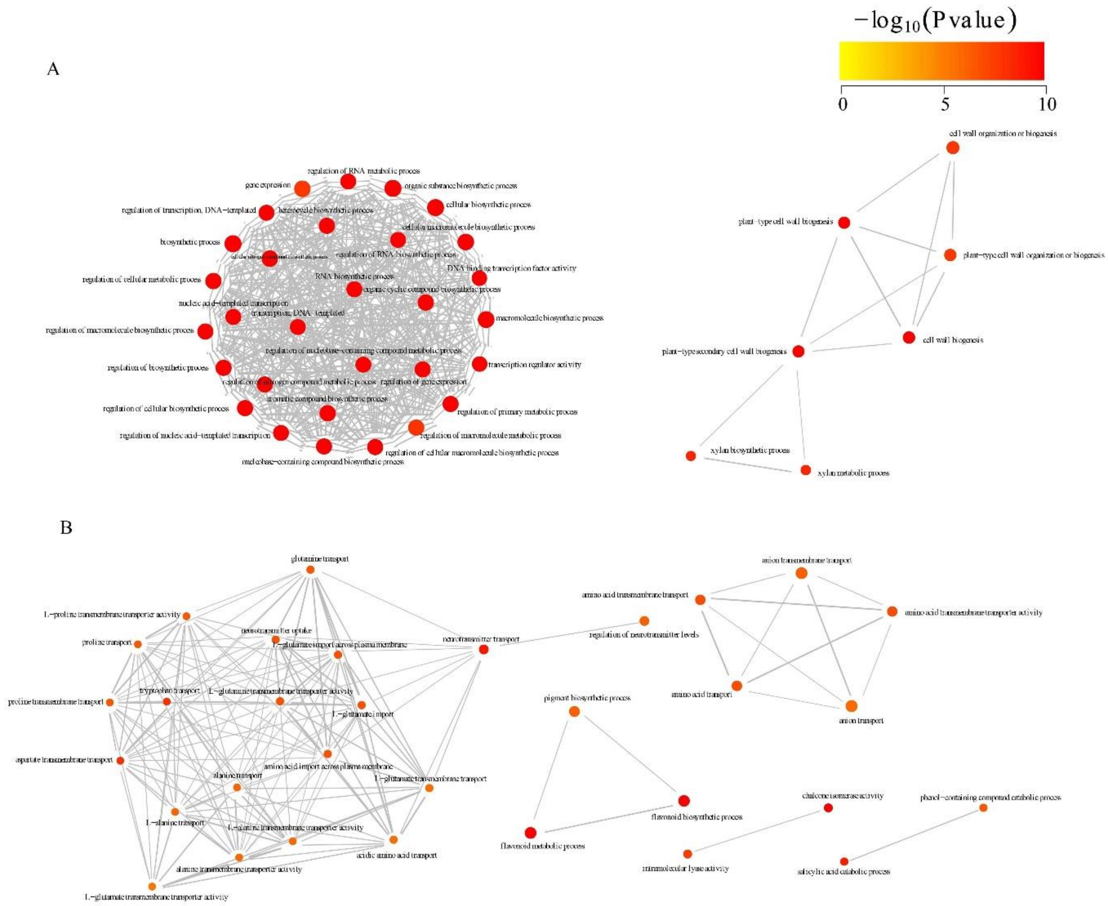


Figure 4. The GO enrichment map of differentially expressed transcripts in strawberry crown caused by Salicylic Acid (SA). (**A**) Was analyzed based on the differentially expressed transcripts in SA vs mock treatment at 0 day after *Colletotrichum siamense* SCR-7 inoculation. (**B**) Was analyzed based on the differentially expressed transcripts in SA vs mock treatment at 4 days after *Colletotrichum siamense* SCR-7 inoculation.

The expression level of genes enriched in oxidative phosphorylation and protein processing in endoplasmic reticulum pathways were suppressed by SA based on KEGG enrichment analysis of SA0DPI vs. Mock0DPI (Figure 7-A), and the genes involved in pathways e.g. phenylpropanoid biosynthesis and flavonoid biosynthesis were all suppressed in SA4DPI vs. Mock4DPI (Figure 7-B). An enrichment map showed that the expression of genes encoding CHI, naringenin 3-dioxygenase (F3H), Anthocyanidin Synthase (ANS) and Anthocyanidin Reductase (ANR) involved in flavonoid biosynthesis KEGG pathways were all suppressed by SA, but the expressions of *POD* and *Caffeic acid O-Methyltransferase* (COMT) genes in lignin biosynthesis were elevated (Figure 8-A). Additionally, defense related genes like *MLO-like protein 2* (FxaC_25g37891), leucine-rich repeat receptor-like serine/threonine-protein kinase (FxaC_10g18870), and cysteine-rich receptor-like protein kinase (FxaC_12g47880) were up-regulated by SA. The qRT-PCR results were in accordance with the transcriptomic data for the expression of structural genes involved in flavonoid biosynthesis and lignin biosynthesis (Figure 8-B).

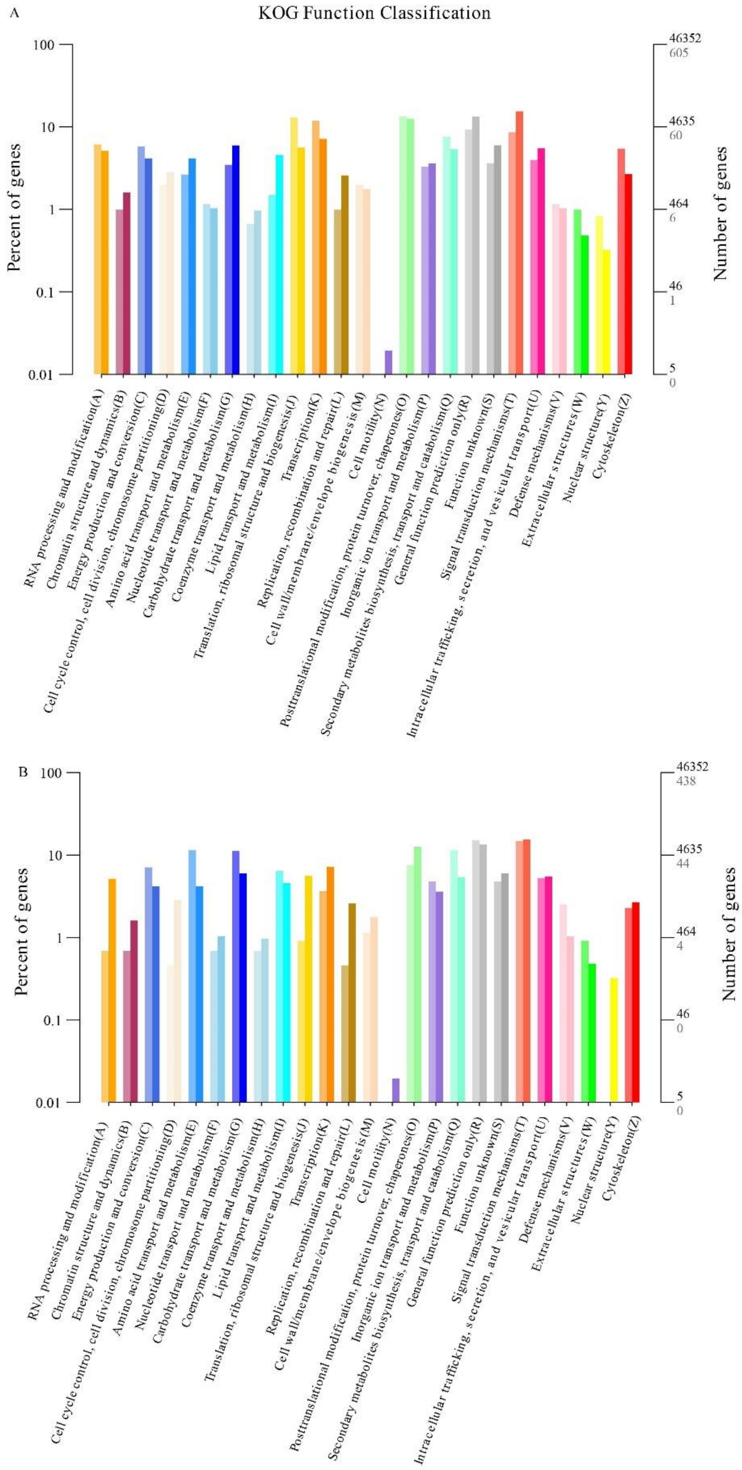


Figure 5. The KOG function classification of differentially expressed transcripts in strawberry crown caused by Salicylic Acid (SA). (**A**) Was analyzed based on the differentially expressed transcripts in SA vs mock treatment at 0 day after *Colletotrichum siamense* SCR-7 inoculation. (**B**) Was analyzed based on the differentially expressed transcripts in SA vs mock treatment at 4 days after *Colletotrichum siamense* SCR-7 inoculation.

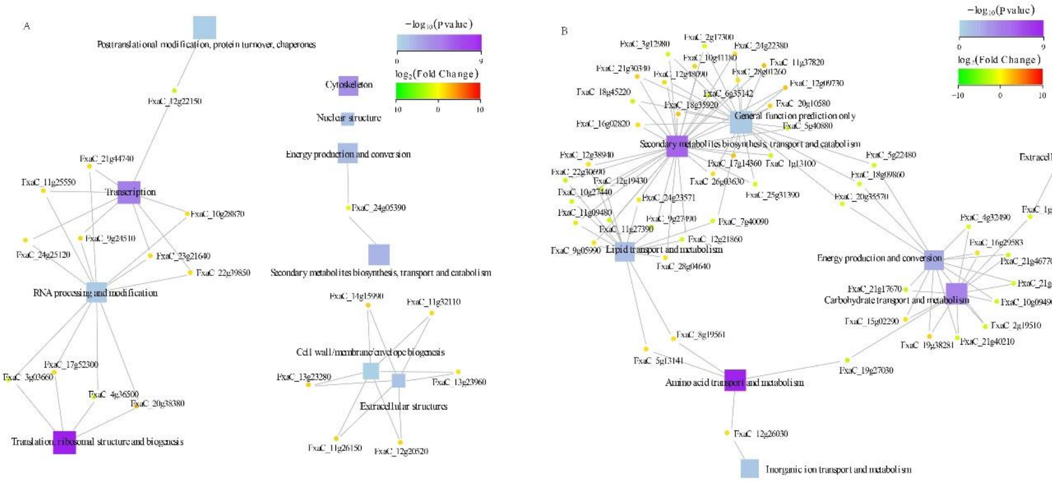


Figure 6. The KOG enrichment network of differentially expressed transcripts in strawberry crown caused by Salicylic Acid (SA). (**A**) Was analyzed based on the differentially expressed transcripts in SA vs mock treatment at 0 day after *Colletotrichum siamense* SCR-7 inoculation. (**B**) Was analyzed based on the differentially expressed transcripts in SA vs mock treatment at 4 days after *Colletotrichum siamense* SCR-7 inoculation.

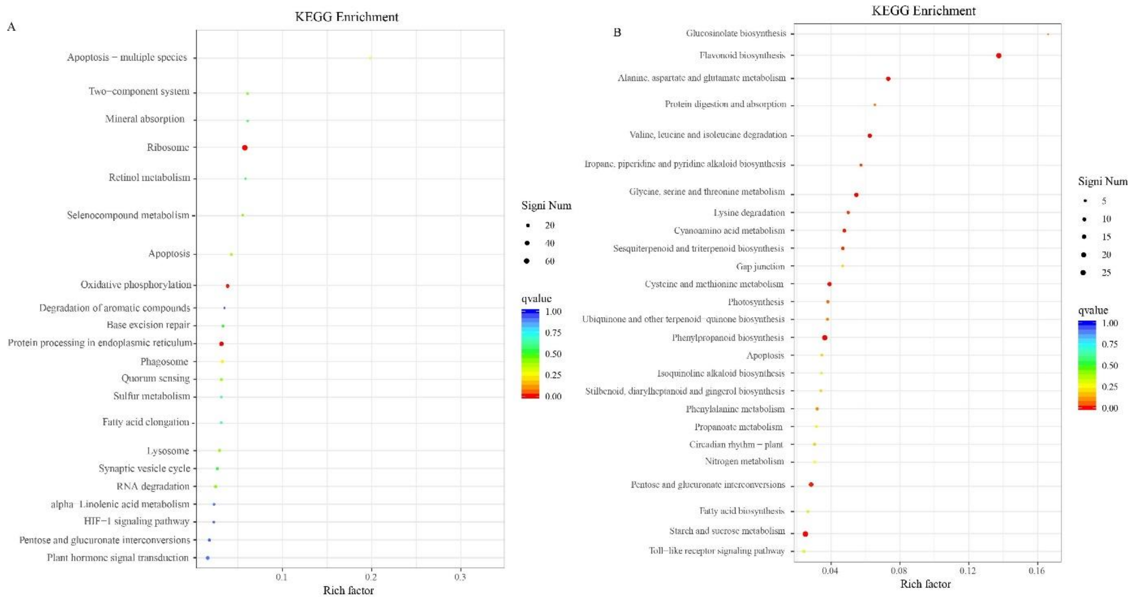


Figure 7. The KEGG enrichment map of differentially expressed transcripts in strawberry crown caused by Salicylic Acid (SA). (**A**) Was analyzed based on the differentially expressed transcripts in SA vs mock treatment at 0 day after *Colletotrichum siamense* SCR-7 inoculation. (**B**) Was analyzed based on the differentially expressed transcripts in SA vs mock treatment at 4 days after *Colletotrichum siamense* SCR-7 inoculation.

Effects of SA on Flavonoid and Lignin Biosynthesis under *C. siamense* Infection

For further analysis, this study performed POD and CHI activity assays. The results indicated that on day zero after *C. siamense* inoculation, there was no significant difference in lignin and flavonoid content, so did POD and CHI activities, between the SA and mock pretreatments. The flavonoid content of the mock was 6.72 mg g^{-1} FW, which was higher than that of the SA pretreatment (5.54 mg g^{-1} FW) 4 days post *C. siamense* inoculation. As confirmed by

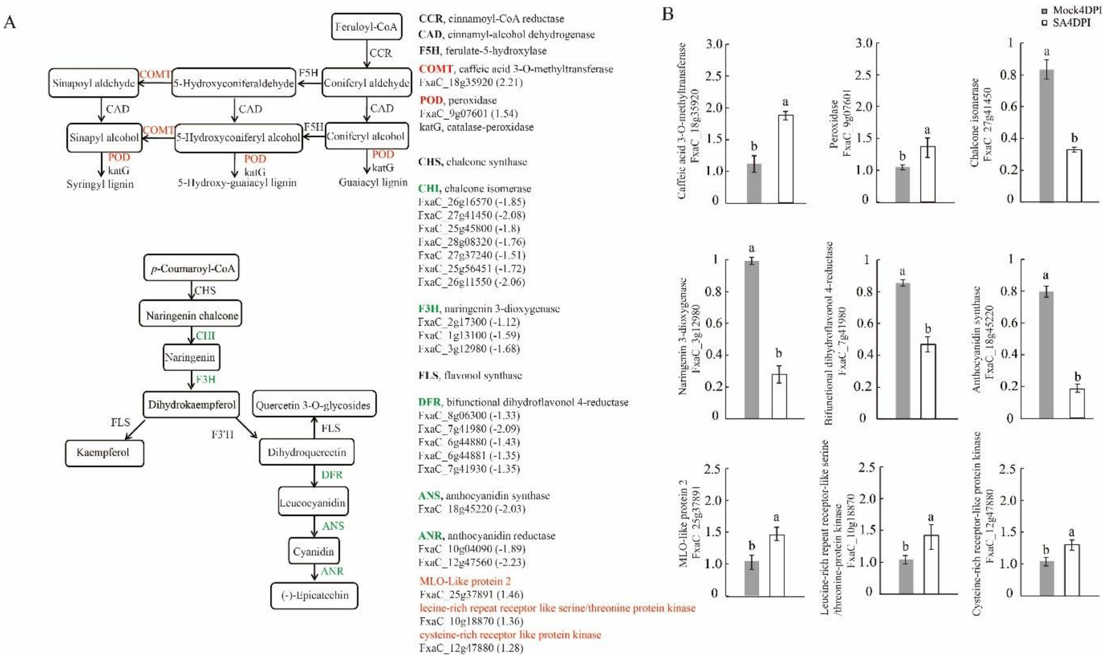


Figure 8. Effect of Salicylic Acid (SA) on potential genes involved in resistance to crown rot caused by *Colletotrichum siamense* SCR-7. (**A**) The variation in the expression of structural genes related to "lignin biosynthesis" and "flavonoid biosynthesis" in SA vs mock treatment 4 days after *Colletotrichum siamense* SCR-7 inoculation. (**B**) qRT-PCR results of structural gene expression related to 'lignin biosynthesis' and 'flavonoid biosynthesis' 4 days after *C. siamense* SCR-7 inoculation. Data (Means±SE, n= 6) followed by different letters above the bars among treatments indicate significant differences at the 5% level.

flavonoid content, SA pretreatment significantly down-regulated CHI activity 4 days after *C. siamense* inoculation. Different from flavonoids and CHI activity, the SA pretreatment remarkably promoted the POD activity (122.32 U g^{-1} FW in Mock4DPI and 131.14 U g^{-1} FW in SA4DPI, respectively) and lignin content (67.11 mg g^{-1} FW in Mock4DPI and 74.82 mg g^{-1} FW in SA4DPI, respectively) after 4 days of *C. siamense* inoculation (Figure 9).

DISCUSSIONS

SA is an important signal for pathogen-associated molecular pattern triggered immunity and effector-triggered immunity (Saleem *et al*., 2021; Hou *et al*., 2023). Endogenous SA-mediated disease-resistance stress responses usually prevent biotrophic or hemibiotrophic pathogen infections through a hypersensitive response, causing rapid cell death for systemic acquired resistance (Koo *et al*., 2020). The results of this study showed that SA pretreatment decreased the severity of crown rot caused by *C. siamense*. As expected, a decrease in lesion size and hyphal density were observed (Figure 1). Two reasons may explain why *C. siamense* infection was inhibited by SA-pretreated crowns. First, *C. siamense* is a hemibiotrophic pathogen that uses a composite strategy, including biotrophic and necrotrophic processes for pathogenesis (Pokotylo *et al*., 2022). Similar to other biotrophic and hemibiotrophic pathogens, the SA pretreatment inhibited the infection of *C. siamense* to strawberry crown, which may be due to *C. siamense* having biotrophic processes of pathogenesis. Second, 'Benihoppe' strawberry is susceptible to crown rot caused by *C. siamense*, and it cannot accrue hypersensitive response (rapid cell death) as a resistant plant responding to pathogen does (Saleem *et al*., 2021). Thus, the reason that the SA pretreatment inhibited the infection of *C. siamense* to strawberry crown might be because of defense genes and secondary metabolites.

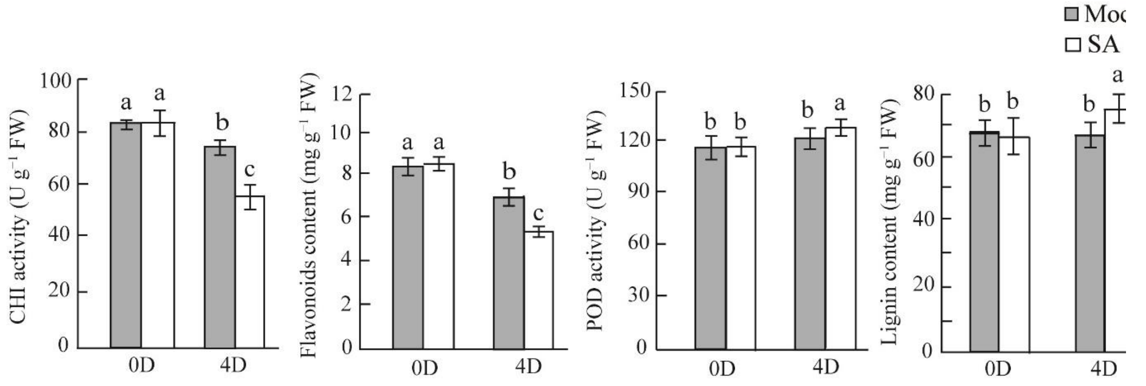


Figure 9. Effect of Salicylic Acid (SA) on flavonoid and lignin contents and the activities of Chalcone Isomerase (CHI) and Peroxidase (POD). Data (Means±SE, n= 6) followed by different letters above the bars among treatments indicate significant differences at the 5% level.

Studies have suggested that endogenous SA-mediated disease-resistant stress responses usually prevent pathogen infection by activating PR proteins, ROS-scavenging enzymes (polyphenol oxidase and peroxidase), enzymes involved in defense (chitinase), and secondary metabolism (phenylalanine ammonia-lyase) (Wang and Liu, 2012; Kaltdorf and Naseem, 2013). Our enrichment map showed that SA suppressed expression of *CHS, CHI*, *F3H*, *ANS,* and *ANR* involved in flavonoid biosynthesis and elevated expression of *POD* and *COMT* in lignin biosynthesis (Figures 3 to 8). SA significantly down-regulated CHI activity and flavonoid content but promoted POD activity and lignin content after *C. siamense* inoculation (Figure 9), which verified the gene expression results. These results suggest that lignin biosynthesis is important for SA to enhance the resistance to strawberry crown rot caused by *C. siamense*. Existing studies have suggested that lignin acts as a physical barrier against pathogens (Cesarino, 2019) and is important for disease resistance (Xiao *et al*., 2021; Onohata and Gomi, 2020). *Arabidopsis* knockout mutants of *COMT* and *cinnamyl alcohol dehydrogenase*, which have low lignin content, showed a reduction in basal resistance and/or effector-triggered resistance against various microbial pathogens, including the necrotrophic fungal pathogens *Alternaria brassicicola* and *Botrytis cinerea* and the biotrophic fungal pathogen *Blumeria graminis* (Quentin *et al*., 2009; Huang *et al*., 2010; Tronchet *et al*., 2010). Peroxidase is located in the monolignol pathway (synthesized from *p*-Coumaroyl-CoA) (Bonawitz and Chapple, 2010; Lee *et al*., 2019) and is promoted by SA pretreatment, which suggests that it plays an important role in inducing resistance. By contrast, flavonoids, the most well-described secondary metabolites in plant defense systems synthesized from *p*-Coumaroyl-CoA (Sarbu *et al*., 2019; Li *et al*., 2021), were significantly down-regulated by the SA pretreatment after *C. siamense* inoculation in our study. Thus, the balance of lignin and flavonoids from *p*-Coumaroyl-CoA biosynthesis requires further research in strawberry on the response to *C. siamense* infection.

CONCLUSIONS

The effects of exogenous SA on strawberry crown rot caused by *C. siamense* were investigated. The SA pretreatment inhibited the infection of *C. siamense* to strawberry crown not only by promoting MLO-like protein 2 and receptor-like

Supplementary Table 1. Primer sequences used for qRT-PCR analysis

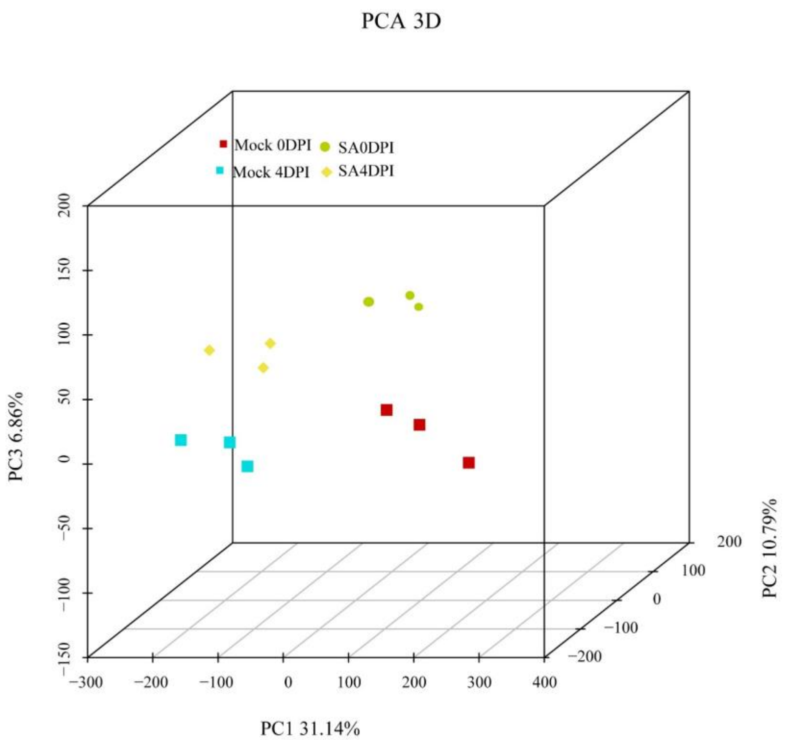
Predicted	Gene ID	Forward primer sequence	Reverse primer sequence
Caffeic acid o-methyltransferase	FxaC_18g35920	TCACTCCCAATATGCCATGC	ATGTCGAGCACACCAAGTTC
Peroxidase	FxaC_9g07601	CAACAACAACAAGCGCGAAC	TTGTCCAATGGTGTGAGCAC
Chalcone isomerase	FxaC_27g41450	AATGCCAATGTGGTCGAGAC	TTGGCCAATTCAGCAGACAG
Naringenin 3-dioxygenase	FxaC_3g12980	TTGTTGATCACGGCATCCAC	TTTTTGCCACCGGACATGTC
Bifunctional dihydroflavonol 4-reductase	FxaC_7g41980	TGTCGCCATTGAAGAGCATC	AACTTCCATGCTGCTTGCTC
Anthocyanidin synthase	FxaC_18g45220	TGAGCAGAAGGAGAAGTATGCC	TTGCCCGGAAGCATTGTTTG
MLO-like protein 2	FxaC_25g37891	ATTGCACAAGGCCAACAACC	CCAACATTGTTCTTCGGGGAAC
leucine-rich repeat receptor-like serine/threonine-protein kinase	FxaC_10g18870	AGCATGCTTGAAGGCAAAGC	CGGTTGACATAGTTTGCCTCTG
cysteine-rich receptor-like protein kinase	FxaC_12g47880	CCAGAGAAGAGACCTACAATGC	AGGCAATGGCATAGTAACCG

Supplementary Table 2 Basic information of transcriptome reads

	Mock0DPI1	Mock0DPI2	Mock0DPI3	Mock4DPI1	Mock4DPI2	Mock 4DPI3	SA0DPI1	SA0DPI2	SA0DPI3	SA4DPI1	SA4DPI2	SA4DPI3
Total Reads Count(#)	58740096	46035566	44195740	48213018	48128920	55133998	45742852	56439168	50485974	49938866	52342348	56005406
Total Bases Count(bp)	8.81E+09	6.91E+09	6.63E+09	7.23E+09	7.22E+09	8.27E+09	6.86E+09	8.47E+09	7.57E+09	7.49E+09	7.85E+09	8.4E+09
Average Read Length(bp)	150	150	150	150	150	150	150	150	150	150	150	150
Q10 Bases Count(bp)	8.81E+09	6.9E+09	6.63E+09	7.23E+09	7.22E+09	8.27E+09	6.86E+09	8.46E+09	7.57E+09	7.49E+09	7.85E+09	8.4E+09
Q10 Bases Ratio(%)	99.96%	99.96%	99.97%	99.98%	99.98%	99.97%	99.96%	99.96%	99.96%	99.97%	99.97%	99.97%
Q20 Bases Count(bp)	8.68E+09	6.81E+09	6.54E+09	7.16E+09	7.15E+09	8.17E+09	6.76E+09	8.35E+09	7.46E+09	7.4E+09	7.76E+09	8.3E+09
Q20 Bases Ratio(%)	98.51%	98.64%	98.68%	99.01%	99.00%	98.79%	98.46%	98.58%	98.45%	98.75%	98.80%	98.84%
Q30 Bases Count(bp)	8.44E+09	6.64E+09	6.37E+09	7.04E+09	7.01E+09	7.99E+09	6.56E+09	8.13E+09	7.24E+09	7.22E+09	7.57E+09	8.12E+09
Q30 Bases Ratio(%)	95.78%	96.10%	96.16%	97.28%	97.08%	96.60%	95.63%	96.03%	95.62%	96.42%	96.45%	96.62%
N Bases Count(bp)	3519171	2748626	2317689	1747090	1771258	2637357	2944473	3161022	3034125	2484801	2372217	2457059
N Bases Ratio(%)	0.04%	0.04%	0.03%	0.02%	0.02%	0.03%	0.04%	0.04%	0.04%	0.03%	0.03%	0.03%
GC Bases Count(bp)	4.26E+09	3.31E+09	3.2E+09	3.55E+09	3.53E+09	3.98E+09	3.28E+09	4.1E+09	3.63E+09	3.6E+09	3.76E+09	4.02E+09
GC Bases Ratio(%)	48.38%	47.92%	48.29%	49.03%	48.88%	48.12%	47.85%	48.41%	47.93%	48.02%	47.92%	47.91%

Supplementary Table 3. Basic information of strawberry crown transcriptome mapped strawberry genome.

	Mock0DPI1	Mock0DPI2	Mock0DPI3	Mock4DPI1	Mock4DPI2	Mock 4DPI3	SA0DPI1	SA0DPI2	SA0DPI3	SA4DPI1	SA4DPI2	SA4DPI3
Total reads	55473220(100.00%)	44157968(100.00%)	42448738(100.00%)	46860746(100.00%)	46458072(100.00%)	53172322(100.00%)	43594472(100.00%)	54110708(100.00%)	48472224(100.00%)	48191440(100.00%)	50480972(100.00%)	54076224(100.00%)
Total mapped	52303371(94.29%)	41590446(94.19%)	39269709(92.51%)	43415792(92.65%)	42568649(91.63%)	49706596(93.48%)	41035540(94.13%)	50797012(93.88%)	45317109(93.49%)	44097064(91.50%)	46003594(91.13%)	49394853(91.34%)
Mutiple mapped	9207315(16.60%)	7175654(16.25%)	7569922(17.83%)	10165296(21.69%)	9743085(20.97%)	10262080(19.30%)	7084449(16.25%)	9330984(17.24%)	8202410(16.92%)	8611119(17.87%)	9350425(18.52%)	10044243(18.57%)
Uniquely mapped	43096056(77.69%)	34414792(77.94%)	31699787(74.68%)	33250496(70.96%)	32825564(70.66%)	39444516(74.18%)	33951091(77.88%)	41466028(76.63%)	37114699(76.57%)	35485945(73.64%)	36653169(72.61%)	39350610(72.77%)
Read-1 mapped	21554431(38.86%)	17212259(38.98%)	15854561(37.35%)	16626015(35.48%)	16414799(35.33%)	19724363(37.10%)	16982751(38.96%)	20737472(38.32%)	18563664(38.30%)	17747377(36.83%)	18328692(36.31%)	19679229(36.39%)
Read-2 mapped	21541625(38.83%)	17202533(38.96%)	15845226(37.33%)	16624481(35.48%)	16410765(35.32%)	19720153(37.09%)	16968340(38.92%)	20728556(38.31%)	18551035(38.27%)	17738568(36.81%)	18324477(36.30%)	19671381(36.38%)
Reads map to '+'	21583960(38.91%)	17230534(39.02%)	15869747(37.39%)	16622978(35.47%)	16412432(35.33%)	19738941(37.12%)	17002213(39.00%)	20753666(38.35%)	18579941(38.33%)	17758765(36.85%)	18338743(36.33%)	19688473(36.41%)
Reads map to '-'	21512096(38.78%)	17184258(38.92%)	15830040(37.29%)	16627518(35.48%)	16413132(35.33%)	19705575(37.06%)	16948878(38.88%)	20712362(38.28%)	18534758(38.24%)	17727180(36.78%)	18314426(36.28%)	19662137(36.36%)
Non-splice reads	27953782(50.39%)	21693044(49.13%)	21294515(50.17%)	23023570(49.13%)	22442219(48.31%)	26495083(49.83%)	22473015(51.55%)	28101059(51.93%)	24787118(51.14%)	24150814(50.11%)	24688418(48.91%)	26318805(48.67%)
Splice reads	15142274(27.30%)	12721748(28.81%)	10405272(24.51%)	10226926(21.82%)	10383345(22.35%)	12949433(24.35%)	11478076(26.33%)	13364969(24.70%)	12327581(25.43%)	11335131(23.52%)	11964751(23.70%)	13031805(24.10%)
Reads mapped in proper pairs	41130680(74.15%)	32847542(74.39%)	30168828(71.07%)	31642552(67.52%)	31067536(66.87%)	37602866(70.72%)	32380520(74.28%)	39527752(73.05%)	35346088(72.92%)	33839528(70.22%)	34742416(68.82%)	37396974(69.16%)



Supplement Figure 1. Principal component analysis of all samples. SA0DPI and Mock0DPI represent 0 day post-inoculation with *C. siamense* SCR-7 of SA pretreatment and mock samples, respectively. SA4DPI and Mock4DPI represent 4 days post-inoculation with *C. siamense* SCR-7 of SA pretreatment and mock samples, respectively.

kinase-encoding gene expression, but also by improving POD activity and lignin content owing to the up-regulation of *POD* and *COMT* genes in lignin biosynthesis. However, SA pretreatment reduced CHI activity and flavonoid content due to the suppression of *CHS*, *CHI*, *F3H*, *ANS*, and *ANR* involved in flavonoid biosynthesis during *C. siamense* infection. Thus, exogenous SA enhanced strawberry resistance to crown rot caused by *C. siamense* by up-regulating the expression of defense genes and balancing lignin and flavonoid biosynthesis.

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اسید سالیسیلیک برون‌زا (خارجی) مقاومت توت فرنگی را در برابر پوسیدگی طوقه افزایش می‌دهد

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چکیده

سهم اسید سالیسیلیک (SA) در کاهش پوسیدگی طوقه توت‌فرنگی به دلیل حساسیت خاص جدایه میکروبی و پاسخ‌های خاص رقم/بافت (ز Cultivar/Tissue-Specific Responses) در توت‌فرنگی، هنوز مشخص نیست. در این پژوهش، هدف ما بررسی چگونگی تأثیراستفاده از SA بیرونی بر پوسیدگی طوقه در توت‌فرنگی بود. کاربرد خارجی SA به طور قابل توجهی عفونت *C. siamense* را در طوقه‌های توت‌فرنگی کاهش داد، که با اندازه ضایعه و تجزیه و تحلیل پاتولوژیک مشهود بود. داده‌های رونویسی (Transcriptomic Data) نشان داد که برای هر نمونه پیش‌تیمار SA و شبیه‌سازی (mock)، با توجه به تقریبا 50 میلیون خوانش (Reads)، نسبت Q20 از 98٪ تا 99٪ متغیر بود و 91/63٪ تا 94/29٪ از خوانش‌ها به ژنوم مرجع نگاشت (Mapped) شدند. پیش تیمارکردن با SA موجب افزایش ژن‌های کدکننده پروتئین 2شبه MLO، کیناز شبه گیرنده (Receptor-Like Kinase)، پراکسیداز و کافئیک اسید 3-O-متیل ترانسفراز دخیل در بیوسنتز لیگنین شد. پیش تیمارکردن با SA همچنین بیان چالکون ایزومراز، نارینجنین 3-دی‌اکسیژناز، دی‌هیدروفلاونول 4-ردوکتاز دوعاملی (Dihydroflavonol)، آنتوسیانیدین سنتاز و آنتوسیانیدین ردوکتاز دخیل در بیوسنتز فلاونوئیدها در طول عفونت *C. siamense* را کاهش داد. مطابق با تغییرات بیان ژن، پیش تیمار SA به طور قابل توجهی فعالیت پراکسیداز و محتوای لیگنین را افزایش و محتوای فلاونوئید و فعالیت ایزومراز چالکون را پس از تلقیح *C. siamense* کاهش داد. نتایج نشان می‌دهد که SA برون‌زا با افزایش بیان ژن‌های مرتبط با دفاع و بیوسنتز لیگنین، مقاومت توت‌فرنگی را در برابر پوسیدگی طوقه ناشی از *C. siamense* افزایش می‌دهد.

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Morpho-Molecular Characterization of Rice Genotypes for Resistance to Bacterial Leaf Blight (BLB)

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ABSTRACT

Bacterial Leaf Blight (BLB) is one of the most devastating diseases of rice (*Oryza sativa* L.), causing substantial yield losses and posing a serious threat to food and livelihood security across rice-dependent regions of Asia and Africa. In this study, 71 rice genotypes developed through crosses among elite and improved lines, were evaluated for bacterial leaf blight (BLB) resistance using artificial clip inoculation at maximum tillering stage, with resistant (Improved Samba Mahsuri) and susceptible (Taichung Native-1, Krishnaveni) checks, under field conditions at Bapatla and Maruteru, Andhra Pradesh, India. Phenotypic screening identified nine genotypes exhibiting disease reaction towards resistance (disease scores 1–3) at both sites. Molecular screening for five BLB Resistance (R) genes, namely, *Xa21*, *xa13*, *xa5*, *Xa4*, and *Xa2,* revealed BPT-3170 carried four R genes (*xa13+xa5+Xa4+Xa2*), while eight genotypes had two genes, and 30 genotypes carried one gene. Phylogenetic analysis using 14 R gene-linked markers grouped the genotypes into three major clusters. BPT-3170 exhibited phenotypic resistance along with multiple R genes, indicating its potential to confer broad spectrum resistance and can serve as a valuable donor in BLB resistance breeding. The study also revealed the breakdown of single-gene resistance and low frequencies of *xa5, xa13*, and *Xa21.* These findings highlight the importance of pyramiding multiple R genes to achieve durable resistance against BLB.

Keywords: Genetic diversity, Microsatellite markers, Molecular screening, R genes.

INTRODUCTION

Rice (*Oryza sativa L.*) is a vital staple crop for billions of people worldwide and serves as a cornerstone of global food security and nutrition. Its productivity is challenged by as many as 60 known rice diseases (Ou, 1972), with Bacterial Leaf Blight (BLB) caused by *Xanthomonas oryzae* pv. *oryzae* (Xoo), being one of the most destructive. BLB leads to yield losses ranging from 20% to 50% (Singh *et al.*, 2011), with severity depending on the rice cultivar, environmental conditions, and management practices. *Xoo* causes wilt, yellowing, and death of rice plants. This disease has become a major concern, particularly in Asian countries, due to the congenial climatic conditions that contribute to frequent epidemics and the lack of effective control measures, making the use of resistant cultivars as the only reliable management strategy. However, the

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durability of resistance is often compromised due to the rapid evolution of *Xoo* races under selection pressure, necessitating continuous efforts to explore and identify new resistant resources (Xia *et al.*, 2012).

The *Oryza* base repository currently lists 44 resistance genes (Xa1 to Xa44) conferring varying levels of resistance to diverse *Xoo* strains, highlighting the genetic complexity of the pathogen-host interaction. In this study, the genotypes are screened for the resistance genes *Xa21, xa13, xa5, Xa4*, and *Xa2,* exhibiting complementary resistance mechanisms. Gene *Xa21*, identified in *Oryza longistaminata*, provides broad-spectrum resistance to diverse *Xoo* strains worldwide. Also, *xa13*, found in the variety BJ1, confers race specific resistance and xa5 imparts resistance to *Xoo* isolates from India and Nepal at all growth stages (Adhikari *et al*, 1995). Xa4 is known for its durable resistance and is widely employed in commercial breeding programs. (Ma *et al.*, 1999; Sun *et al.*, 2003). Xa2, identified in cultivars *Tetep* and *Rantai Emas II*, offers strong resistance across diverse backgrounds (Sakaguchi, 1967).

We screened 70 diverse rice genotypes for resistance to BLB using a combination of phenotypic screening through artificial inoculation and molecular marker analysis. By integrating these complementary approaches, this study aimed to identify robust resistant genotypes that could serve as valuable donors in breeding programs, ultimately contributing to the development of durable BLB-resistant rice varieties for sustainable rice production.

MATERIALS AND METHODS

Plant Material

The experimental material comprised 74 genotypes with Improved Samba Mahsuri (ISM) as BLB resistant check, Taichung Native-1 and Krishnaveni as BLB susceptible checks, and Samba Mahsuri as yield check. These genotypes are developed and provided by ARS, Bapatla, Andhra Pradesh, India. Their pedigree is presented in Table 1.

Pathogen Inoculation and Screening of Germplasm

Screening for BLB was carried out in wet season of 2020, at two locations in Andhra Pradesh, India, namely, Agricultural College Farm, Bapatla (15° 54' 29.88" N; 80° 28' 7.3092" E) and RARS, Maruteru (15° 59' 12.984" N; 80° 6' 7.848" E). The rice genotypes were grown under irrigated conditions in a block with each entry planted in two rows of 2 m length, adopting a spacing of 20×15 cm. To ensure strong disease pressure, the block was flanked by two border rows of the susceptible check: Taichung Native-1. Inoculum was prepared from BLB-infected leaves collected from local fields. The leaves were cut into 1 cm pieces, and surface sterilized with 1% sodium hypochlorite. Smaller leaf bits of 5 x 5 mm size were placed in test tube having sterile distilled water for 15 to 20 min, to allow the bacteria to ooze out of the leaf tissue. A loopful of bacterial suspension was streaked onto Nutrient Agar (NA) media plates and incubated at 27±1°C for 3 days. Single yellow, round and smooth margin, non-flat, mucous colonies were picked and purified on fresh NA plates. For field inoculation, the two-day old *Xoo* cultures were suspended in sterile distilled water and adjusted to ~10^8 CFU mL^{-1} (Optical Density (OD) at 600= 0.5) using spectrophotometer. Plants were inoculated at 75 days after sowing (DAS) by leaf clipping method (Kauffman *et al.*, 1973). Disease severity was recorded three weeks post-inoculation and scored based on Standard Evaluation System for Rice (SES) (IRRI, 2013) (Table 2).

$$\text{Per cent diseased leaf area} = \frac{\text{Total lesion length}}{\text{Total leaf area}} \times 100$$

Identification of R Genes

DNA was isolated from young leaves of all the genotypes using the modified Cetyl

Table 1. List and pedigree of the genotypes used in the study.

S. No.	GENOTYPE	PEDIGREE	S. No.	GENOTYPE	PEDIGREE
1.	BPT-1235	SARBARMATI/W-12708	38.	BPT-3129	BPT-5204/MTU-1075
2.	BPT-2231	BPT-4358/IR-64	39.	BPT-3130	BPT-5204/MTU-1075
3.	BPT-2295	BPT-1768/NLR-33641	40.	BPT-3133	BPT-5204/MTU-1001
4.	BPT-2411	BPT-5204/BPT-4358	41.	BPT-3135	BPT-5204/MTU-1001
5.	BPT-2595	MUTANT OF BPT-2270	42.	BPT-3136	RP-BIO-226/IRGC-48493
6.	BPT-2620	MTU-1061/N-22	43.	BPT-3137	RP-BIO-226/IRGC-48493
7.	BPT-2677	MTU-2077/AJAY/MTU-2077	44.	BPT-3145	RP-BIO-226/IRGC-48493
8.	BPT-2764	MUTANT OF BPT-2270	45.	BPT-3147	B-95-1/RPHR-1005/B-95-1
9.	BPT-2766	BPT-2270/NLR-145	46.	BPT-3148	RP-BIO-226/IRGC-23385/NIDHI/MTU-1081
10.	BPT-2776	BPT-2231/NLR-145	47.	BPT-3150	RP-BIO-226/JARAVA
11.	BPT-2782	NLR-145/MTU-2077	48.	BPT-3151	RP-BIO-226/JARAVA
12.	BPT-2808	BPT-2231/NLR-145	49.	BPT-3159	CULTURE-0910023/RP-BIO-226/CULTURE-0910023-8/BPT-5204/TETEP
13.	BPT-2824	MTU-7029/NLR-34449	50.	BPT-3164	B-95-1/RPHR-1005/B-95-1
14.	BPT-2846	MTU-1061/IR-78585-64-2-4-3	51.	BPT-3168	MTU-7029/IRGC-18195/MTU-1081
15.	BPT-2848	SWARNA/IRGC-18195/MTU-1081	52.	BPT-3170	RP-BIO-226/JARAVA
16.	BPT-2849	NLR-34449/MTU-5249	53.	BPT-3172	RP-BIO-226/IRGC-48493
17.	BPT-2854	MTU-1061/IR-78585-64-2-4-3	54.	BPT-3178	CULTURE-01120305/CULTURE-0910025-7
18.	BPT-2863	MTU-2077/NLR-34449	55.	BPT-3208	NLR-34449/ANNADA/NLR-34449
19.	BPT-2950	NLR-34449/BM-71	56.	BPT-3244	BPT-5204/RAMAPPA
20.	BPT-2954	NLR-34449/ANNADA/NLR-34449	57.	BPT-3260	MTU-7029/IRGC-18195/MTU-1081
21.	BPT-2958	BPT-5204/IR-50	58.	BPT-3261	MTU-70291/IRGC-18195/MTU-1081
22.	BPT-3032	BPT-5204/IR-50	59.	BPT-3262	MTU-7029/IRGC-18195/MTU-1081
23.	BPT-3033	BPT-5204/MTU-1075	60.	BPT-3263	MTU-7029/IRGC-18195/MTU-1081
24.	BPT-3061	BPT-1768/NLR-145	61.	BPT-3264	CULTURE-01120305/CULTURE-0910025-7
25.	BPT-3068	NLR-34449/RAMAPPA	62.	BPT-3269	RP-BIO-226/IRGC-23385/NIDHI/MTU-1081
26.	BPT-3074	BPT-5204/MTU-1075	63.	BPT-3270	RP-BIO-226/IRGC-23385/NIDHI/MTU-1081
27.	BPT-3081	BPT-5204/MTU-1075	64.	BPT-3274	BPT-5204/BPT-2605
28.	BPT-3086	BPT-2270/IR-64/MTU-1081	65.	BPT-3275	CULTURE-01120305/CULTURE-0910025-7
29.	BPT-3092	NLR-34449/ANNADA/NLR-34449	66.	BPT-3276	CULTURE-01120305/CULTURE-0910025-7
30.	BPT-3095	MTU-5249/IR-50	67.	BPT-3277	BPT-5204/O.-LONGISTAMINATA/B-95-1/SWARNA-SUB1
31.	BPT-3111	MTU-7029/IRGC-18195/MTU-1081	68.	BPT-3279	RP-BIO-226/JARAVA
32.	BPT-3113	BPT-2270/NLR-145	69.	BPT-3291	SONA/MAHSURI
33.	BPT-3114	BPT-2270/NLR-145	70.	BPT-4358	SONA-MAHSURI/ARC-6650
34.	BPT-3115	BPT-2270/NLR-145	71.	SAMBA MAHSURI (BPT-5204)	GEB-24/TN1/MAHSURI
35.	BPT-3118	JGL-3855/RAMAPPA	72.	IMPROVED SAMBA MAHSURI (ISM) RP BIO-226	MAS FROM BPT-5204 AND SS1113
36.	BPT-3120	JGL-3855/ANNADA	73.	KRISHNAVENI (MTU-2077)	SOWBHAGYA/ARC-5984
37.	BPT-3121	BPT-3291/RAMAPPA	74.	TAICHUNG NATIVE-1 (TN1)	DWARF CHOW WU GEN/TSAI YUAN CHUNJ

Table 2. Disease scoring scale for bacterial leaf blight in rice as per SES (IRRI, 2013).

Scale	Diseased leaf area (%)	Description
1	1-5	Resistant (R)
3	6-12	Moderately Resistant (MR)
5	13-25	Moderately Susceptible (MS)
7	26-50	Susceptible (S)
9	51-100	Highly Susceptible (HS)

Tri Methyl Ammonium Bromide (CTAB) protocol adapted from Dellaporta *et al.* (1983). A total of 16 molecular markers, previously reported, were used to screen R genes (Table 3). PCR amplification was carried out in a 14 µL reaction mixture, consisting of 3 µL of DNA (50 ng μL^{-1}), 1.50 µL of 10X Taq buffer, 0.35 µL of dNTPs (2.5 mM), 0.75 µL of each forward and reverse primers (10 pmol), 7.40 µL of double-distilled water, and 0.25 µL of Taq polymerase (5 U μL^{-1}). The thermal cycler was set with an initial denaturation at 94°C for 5 minutes, followed by 35 cycles of denaturation at 94°C for 40 seconds, annealing at 55°C for 40 seconds, and extension at 72°C for 1 minute, and final extension at 72°C for 10 minutes. PCR products were separated on 3% agarose gel, stained with ethidium bromide by gel electrophoresis. Distinct and unambiguous polymorphic bands were scored against a standard 100-bp DNA ladder.

The allelic data was subjected to estimation of genetic distances among the genotypes using DARwin v6.0 (Perrier and Jacquemond, 2006). For each SSR marker, genetic diversity parameters, including the total number of alleles (Na), the effective Number of alleles (Ne) were calculated using POPGENE version 1.32. (Yeh *et al.*, 2000) and Polymorphic Information Content (PIC) was analyzed using the following formula

$$PIC = 1 - \sum_{f=1}^{n} P_{ij}^2$$

Where:

pij= Frequency of the ith allele of the jth marker

n= Total number of alleles detected at that marker

Σ= Summation over all alleles

The calculation was based on the number of alleles per locus.

RESULTS

Morphological Screening for BLB

The genotype's response to BLB artificial disease screening conducted at Bapatla and Maruteru are presented in Table 4. Comparative analysis revealed that, out of 74 lines (including checks), 37 performed similarly at both locations. For the remaining genotypes, the disease scores at Maruteru exceeded those at Bapatla. Specifically, at Bapatla 7 genotypes showed resistance, 12 moderately resistance, 45 moderately susceptible and 7 susceptible. At Maruteru 9 genotypes showed moderately resistance, 32 moderately susceptible and 28 susceptible and 2 highly susceptible. Notably, 9 genotypes consistently exhibited their disease reaction towards resistance (with a score of 1-3) at both locations, while 52 genotypes showed susceptibility (with score 5–9).

Molecular Characterization of Rice

Polymorphism Information Content (PIC)

Among the 16 markers used in this study, two SSR markers *i.e.*, RM144 and RM13 markers, were not amplified, hence these markers were excluded from the analysis.

Polymorphism and marker efficiency

Analysis of the 74 rice genotypes with 14 polymorphic SSR markers revealed 47 alleles, averaging 3.22 per locus (Table 5). Alleles per locus ranged from 2 to 7, with effective allele counts from 1.05 (RM167) to

Table 4. Phenotypic and genotypic screening for bacterial leaf blight resistance in 74 rice genotypes.[a]

S. No.	Genotypes	Disease reaction at		*Xa21*	*xa13*	*xa5*	*Xa4*	*Xa2*	Total R genes expressed	Positive compatibility
		Bapatla	Maruteru							
1.	BPT-1235	S	S	--	--	--	++	--	1	X
2.	BPT-2231	MS	S	--	--	--	++	--	1	X
3.	BPT-2295	S	S	--	--	--	--	--	0	✓
4.	BPT-2411	MS	S	--	--	--	--	--	0	✓
5.	BPT-2595	MS	S	--	--	--	--	--	0	✓
6.	BPT-2620	MS	MS	--	--	--	--	++	1	X
7.	BPT-2677	MS	MS	**0**	--	--	--	--	0	✓
8.	BPT-2764	S	S	--	--	--	--	++	1	X
9.	BPT-2766	MS	MS	--	--	--	--	--	0	✓
10.	BPT-2776	MS	S	--	--	--	--	--	0	✓
11.	BPT-2782	S	S	--	--	--	--	--	0	✓
12.	BPT-2808	MS	MS	--	--	--	--	++	1	X
13.	BPT-2824	MS	S	--	--	--	--	--	0	✓
14.	BPT-2846	MR	MR	**0**	--	--	--	--	0	X
15.	BPT-2848	R	MS	--	--	+-	++	++	2	X
16.	BPT-2849	MS	S	--	--	--	++	--	1	X
17.	BPT-2854	MS	HS	--	--	--	++	--	1	X
18.	BPT-2863	MS	S	--	--	--	--	--	0	✓
19.	BPT-2950	MS	S	--	--	--	++	--	1	X
20.	BPT-2954	MS	S	--	--	--	--	--	0	✓
21.	BPT-2958	MR	MR	--	**0**	**0**	++	--	1	✓
22.	BPT-3032	MR	MS	--	**0**	--	++	--	1	X
23.	BPT-3033	MS	S	**0**	**0**	--	--	--	0	✓
24.	BPT-3061	MR	MS	**0**	+-	+-	--	--	0	X
25.	BPT-3068	R	MR	+-	+-	+-	--	++	2	✓
26.	BPT-3074	R	MR	**0**	--	--	++	--	1	✓
27.	BPT-3081	MS	MS	--	--	--	++	--	1	X
28.	BPT-3086	MS	MS	--	--	--	--	--	0	✓
29.	BPT-3092	R	MR	--	--	--	++	--	1	✓
30.	BPT-3095	MS	MS	--	--	--	--	--	0	✓
31.	BPT-3111	MS	MS	--	--	--	++	--	1	X
32.	BPT-3113	MS	HS	**0**	+-	--	++	--	1	X
33.	BPT-3114	MS	S	--	--	**0**	++	--	1	X
34.	BPT-3115	MR	S	--	--	--	--	--	0	X
35.	BPT-3118	MS	MS	--	--	--	--	--	0	✓
36.	BPT-3120	MS	MS	**0**	--	--	--	--	0	✓
37.	BPT-3121	MS	S	--	--	--	++	++	2	X
38.	BPT-3129	MS	MS	--	--	--	--	--	0	✓
39.	BPT-3130	MS	MS	--	--	--	++	--	1	X
40.	BPT-3133	MS	MS	**0**	**0**	--	++	++	2	X
41.	BPT-3135	R	MS	--	--	--	--	--	0	X
42.	BPT-3136	MR	MS	--	++	--	--	++	2	X
43.	BPT-3137	R	MR	--	--	--	++	++	2	✓
44.	BPT-3145	MS	S	--	--	++	++	--	2	X
45.	BPT-3147	MS	MS	--	--	--	++	--	1	X
46.	BPT-3148	MS	S	--	--	--	++	--	1	X
47.	BPT-3150	S	S	--	--	+-	--	--	0	✓
48.	BPT-3151	MS	MS	--	+-	--	--	++	1	X
49.	BPT-3159	MR	MR	+-	--	--	++	--	2	✓
50.	BPT-3164	MS	MS	--	--	--	--	--	0	✓
51.	BPT-3168	MS	MS	--	**0**	--	++	--	1	X
52.	BPT-3170	R	MR	--	++	++	++	++	4	✓
53.	BPT-3172	MR	MS	**0**	--	--	++	--	1	X
54.	BPT-3178	MR	MR	--	**0**	--	--	++	1	✓
55.	BPT-3208	MS	S	--	--	--	++	--	1	X
56.	BPT-3244	MS	S	--	**0**	--	--	--	0	✓
57.	BPT-3260	S	S	--	--	--	--	--	0	✓

Table 4 Continued …

Continued of Table 4.

S. No.	Genotypes	Disease reaction at		*Xa21*	*xa13*	*xa5*	*Xa4*	*Xa2*	Total R genes expressed	Positive compatibility
		Bapatla	Maruteru							
58.	BPT-3261	MR	S	++	--	--	--	--	1	X
59.	BPT-3262	MR	MS	--	--	--	--	--	0	X
60.	BPT-3263	MS	MS	--	+-	--	--	--	0	✓
61.	BPT-3264	MR	MS	--	--	--	++	--	1	X
62.	BPT-3269	MS	MS	--	--	--	++	--	1	X
63.	BPT-3270	MS	MS	--	--	--	--	--	0	✓
64.	BPT-3274	MS	MS	--	--	--	--	--	0	✓
65.	BPT-3275	S	S	--	--	--	--	--	0	✓
66.	BPT-3276	MS	MS	--	--	--	++	--	1	X
67.	BPT-3277	MS	S	**0**	**0**	--	++	--	1	X
68.	BPT-3279	MS	S	--	--	--	++	--	1	X
69.	BPT-3291	MS	MS	--	--	--	--	--	0	✓
70.	BPT-4358	MS	S	--	--	--	--	--	0	✓
71.	Samba Mahsuri	MS	MS	--	--	--	--	--	0	✓
72.	ISM	R	R	++	++	++	--	--	3	✓
73.	Krishnaveni	S	S	--	--	--	--	--	0	✓
74.	Taichung Native-1	HS	HS	--	--	--	--	--	0	✓
75.	**TOTAL**			**4**	**3**	**3**	**31**	**12**	**53**	**38**

Table 5. Genetic diversity parameters of 14 BLB resistance linked markers.[a]

S. No.	SSR marker	Na	Ne	PIC	Amplicon size range (bp)
1.	RM349	7	2.57	0.65	190-871
2.	RM317	4	1.98	0.48	154-174
3.	RM224	3	2.55	0.61	129-163
4.	RM39	3	2.58	0.65	120-820
5.	RM164	4	1.52	0.33	240-290
6.	RM533	2	1.62	0.39	250-270
7.	RM254	3	1.82	0.46	140-170
8.	RM5509	3	2.30	0.57	270-290
9.	RM30	4	2.19	0.54	200-250
10.	RM206	3	2.56	0.61	130-170
11.	RM167	2	1.05	0.06	250-260
12.	*xa13* Prom	2	1.16	0.18	270-470
13.	*xa5*FM-SR	3	2.18	0.55	134-424
14.	*Xa21* pTA248	4	2.51	0.61	639-982
	Maximum	**7**	**2.58**	**0.65**	**982**
	Minimum	**2**	**1.05**	**0.06**	**130**
	MEAN	**3.31**	**2.03**	**0.48**	

[a] Na- Number of alleles, Ne- Number of effective alleles, PIC- Polymorphic Information Content, bp- Base pairs.

2.58 (RM39) with an average of 2.03. ranged from 0.06 (RM167) to 0.65 (RM349, RM39), averaging 0.48. Eight were deemed highly informative, with PIC value exceeding 0.5. The maximum and the minimum allele sizes observed markers were 982 bp (pTA248) and 130 bp (RM206) respectively.

Marker-Assisted Selection (MAS) for BLB Resistance Genes

Molecular data for the genes *Xa21, xa13, xa5, Xa4,* and *Xa2* are presented in the Table 4.

***Xa21*-Linked STS Marker Analysis for BLB Resistance**

The presence of *Xa21* gene in germplasm was detected by the STS marker pTA248, which amplified four alleles of 982bp, 737bp, 715bp and 639bp. The 982bp fragment, associated with resistance, was observed in the positive control, ISM, whereas the 715bp fragment was detected in the negative control, Taichung Native-1. Other variants, 737bp and 639bp, were also linked to susceptibility. Among the 71 genotypes, three genotypes, namely, BPT-3068, BPT-3159 and BPT-3261, showed the 982bp amplicon, indicative of the presence of the Xa21 gene. Notably, BPT-3261 possessed the gene in a homozygous condition (982bp), while BPT-3068 and BPT-3159 displayed the gene in a heterozygous state (982bp and 737bp). The remaining genotypes produced amplicons of 737bp, 715bp, or 639bp, confirming the absence of the *Xa21* resistance gene. The amplification pattern of pTA248 marker is represented in the (Figure 1).

***Xa13*-Linked STS Marker Analysis for BLB Resistance**

The *Xa13* gene in germplasm was detected by the marker *Xa13*prom. The positive control, ISM, showed a 470bp fragment, while the negative control, Taichung Native-1, exhibited a 270 bp fragment. BPT-3136 and BPT-3170 produced amplicon of 470bp, carried *Xa13* in homozygous condition. The genotypes BPT-3061, BPT-3068, BPT-3113, BPT-3151 and BPT-3263 produced heterozygous bands of 470 and 270bp, where *Xa13* the recessive gene was not expressed, while the remaining 64 genotypes produced amplicon of 270bp (similar to Taichung Native-1).

***Xa5*-Linked STS Marker Analysis for BLB Resistance**

The STS marker *Xa5*FM-SR linked to recessive X*a5* gene amplified 424 (common),

Table 7. Clustering of R genes for bacterial leaf blight resistance.

Cluster No	*Xa21*	*xa13*	*xa5*	*Xa4*	*Xa2*	Total
Cluster I	1	-	1	15	4	21
Cluster II	2	2	2	3	2	11
Cluster III	1	1	-	13	6	21
Total	4	3	3	31	12	53

Table 8. Clustering of positively compatible R genes for bacterial leaf blight based on phenotypic and genotypic marker data.

Cluster No	*Xa21*	*xa13*	*xa5*	*Xa4*	*Xa2*	Total
Cluster I	-	-	-	2	1	3
Cluster II	2	2	2	1	2	9
Cluster III	1	-	-	3	1	5
Total	3	2	2	6	4	17

134 (resistance specific) and 313bp (susceptibility specific) fragments. Genotypes BPT-3145 and BPT-3170 showed 424 and 134bp fragments (similar to the ISM), indicating the presence of the resistant gene. BPT-2848, BPT-3061, BPT-3068, and BPT-3150 were heterozygous, producing 424, 134, and 313bp fragments. The remaining 65 genotypes produced only 313 and 134bp bands.

Xa4-Linked SSR Marker Analysis for BLB Resistance

The *X*a4 gene was identified using the marker RM224, with resistant genotypes producing a 160bp fragment and susceptible genotypes a 150bp fragment (Panwar *et al.*, 2018; Chen *et al.,* 1997). In this study, 31 genotypes carried Xa4, producing a 160bp amplicon.

Xa2-Linked SSR Marker Analysis for BLB Resistance

The *Xa2* gene was detected using the SSR marker RM317, with a 154bp DNA fragment indicating resistance (Hasan *et al.*, 2020; He *et al.*, 2006). In this study, 12 genotypes, namely, BPT-2620, BPT-2764, BPT-2808, BPT-2848, BPT-3068, BPT-3121, BPT-3133, BPT-3136, BPT-3137, BPT-3151, BPT-3170, and BPT-3178 amplified the154bp fragment, and considered to possess *Xa2*.

R Genes Expressed

A total of 53 R genes were expressed from all the cultivars, for the five genes *Xa21, xa13*, *xa5, Xa4* and *Xa2* studied. The gene *Xa4* was found to be most frequent, carried by 31 genotypes, followed by *Xa2* (12) and *Xa21* (3), while *Xa5* and *X a13* were found in only two genotypes. BPT-3170 possessed combination of four multiple resistance genes (*X a13+ X a5+Xa4+Xa2*). Two gene combinations were found in eight genotypes, namely, BPT-2848, BPT-3068, BPT-3121, BPT-3133, BPT-3136, BPT-3137, BPT-3145 and BPT-3159. Single genes were detected in 30 genotypes, and, 32 genotypes did not express any *R* genes.

Compatibility between Genotypic and Phenotypic Expression of BLB Resistance

Positive compatibility between phenotypic and genotypic expression of BLB resistance was observed in 38 rice lines, including checks, of which nine exhibited resistance (score 1-3), and 29 showed susceptibility (score 5-9) (Table 4). Among the resistant genotypes, namely, BPT-3068, BPT-3074, BPT-3092, BPT-3137, BPT-3170, BPT-2846, BPT-2958, BPT-3159, and BPT-3178, all, except BPT-2846, showed positive compatibility with R gene expression. BPT-3170 carried four resistance genes (Xa13+ Xa5+Xa4+Xa2), while BPT-3068 (Xa21+Xa2), BPT-3137 (Xa4+Xa2), and BPT-3159 (Xa21+Xa4) carried two genes. BPT-3074 (Xa4), BPT-2958 (Xa4), BPT-3178 (Xa2), and BPT-3092 (Xa4) carried a single gene.

Molecular Diversity Analysis

The phylogenetic tree was constructed using 14 markers linked to BLB resistance based on neighbour-joining method (Figure 2). The genotypes were grouped into three major clusters (Table 6). Cluster I, containing 32 genotypes, was further subdivided into four sub-clusters (IA, IB, IC, ID) and possessed the highest number of resistance genes (21), of which only 3 were positively compatible (Tables 7 and 8). Cluster II, the smallest with 7 genotypes and resistant check, was divided into sub-clusters IIA and IIB. Sub-cluster IIA contained exclusively resistant genotypes exhibiting multiple resistance genes, namely, BPT-3068, BPT-3170 and resistant check ISM. This cluster expressed 11 R genes, 9 of which were positively compatible. Cluster III was the largest with 32 genotypes, mostly showing susceptibility reaction (with score 5-9) including both the susceptible checks (Taichung Native-1 and Krishnaveni). It was divided into four sub-clusters (IIIA, IIIB, IIIC, IIID) and possessed the highest number of R genes (21) with only 5 being positively compatible.

DISCUSSION

This study evaluated the genetic resistance to Bacterial Leaf Blight (BLB) in 71 rice genotypes developed from diverse elite and improved breeding lines across multi-location, and revealed significant variability in disease response. Disease severity was higher at Maruteru, a known BLB hotspot, compared to Bapatla, likely due to Maruteru's favourable environment for pathogen spread. This variation can be attributed to the polygenic nature of BLB resistance, governed by over 40 R genes, and strongly influenced by environment. Genotypes showed a wide range of responses, from resistant to highly susceptible, consistent with findings of Rahman *et al.* (2017), Qudsia *et al.* (2019), and Majumder *et al.* (2019).

Using 14 gene-linked markers, 47 alleles, including rare and null alleles, were detected across 74 rice genotypes. Rare alleles identified with markers RM349, RM30, and RM164 likely result from structural variations or mutational events (Victoria *et al*., 2007). The informativeness of SSR markers in assessing genetic diversity aligns with Ashiba *et al.* (2020) and Khan *et al.* (2015).

Molecular characterization of five resistance genes *Xa21*, *xa13*, *xa5*, *Xa4* and *Xa2* was conducted with ISM (*Xa21*+*xa13*+*xa5*) as a positive control.

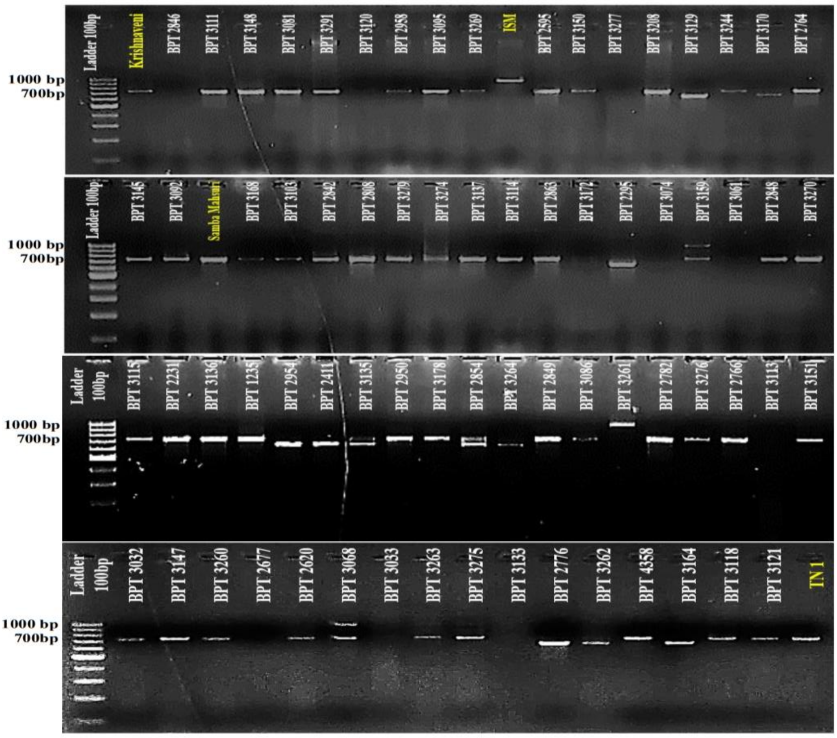

Figure 1. Expression of *Xa21* gene amplification using marker pTA248.

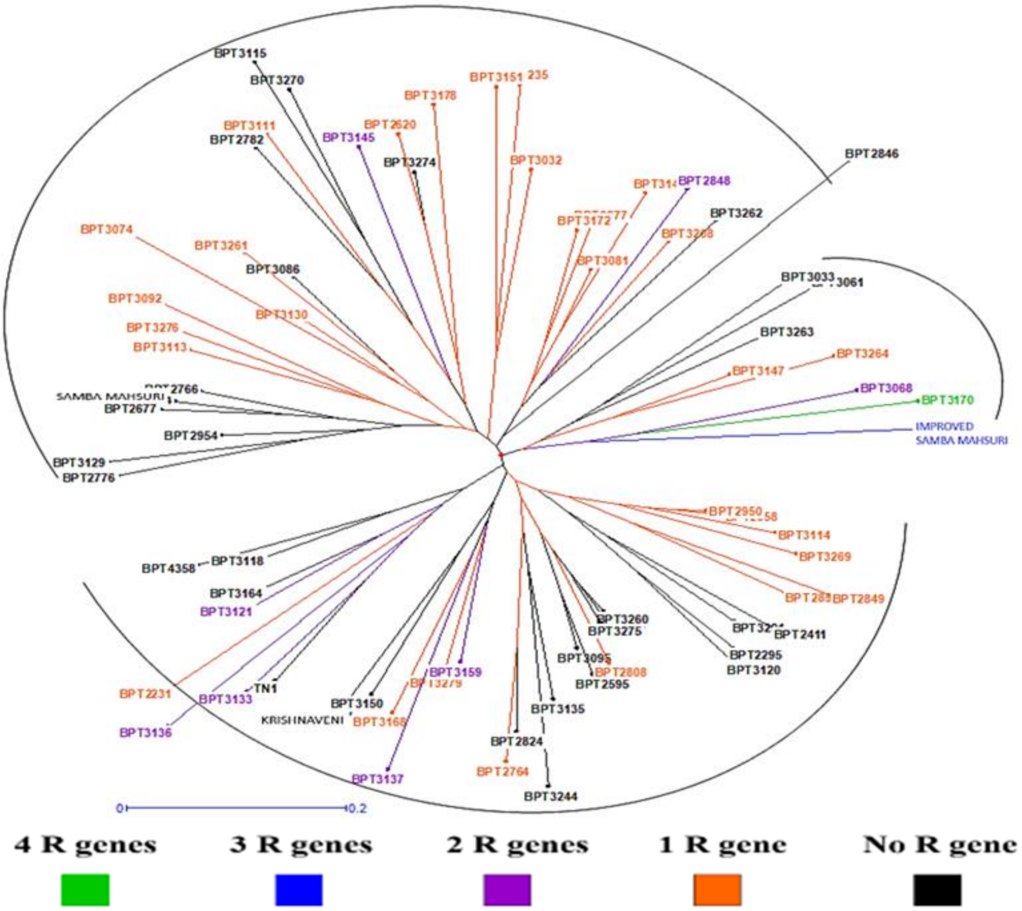

Figure 2. Phylogenetic tree constructed based on BLB linked markers representing resistance genes.

Table 6. Grouping of genotypes into different clusters based on molecular diversity.

Name of the cluster	Name of the sub-cluster	Number of genotypes	Name of the Genotypes
I	IA	13	BPT-2776, BPT-3129, BPT-2954, BPT-2677, Samba Mahsuri, BPT-2766, BPT-3113, BPT-3276, BPT-3092, BPT-3074, BPT-3130, BPT-3261, BPT-3086
	IB	8	BPT-2782, BPT-3111, BPT-3115, BPT-3270, BPT-3145, BPT-2620, BPT-3274, BPT-3178.
	IC	3	BPT-3151, BPT-1235, BPT-3032
	ID	9	BPT-3172, BPT-3277, BPT-3081, BPT-3148, BPT-2848, BPT-3208, BPT-3262, BPT-2846
II	IIA	5	BPT-3033, BPT-3061, BPT-3263, BPT-3147, BPT-3264
	IIB	2	BPT-3068, BPT-3170, **ISM**
III	IIIA	10	BPT-2950, BPT-2958, BPT-3114, BPT-3269, BPT-2849, BPT-2854, BPT-2411, BPT-3291, BPT-2295, BPT-3120
	IIIB	10	BPT-3260, BPT-2863, BPT-3275, BPT-2808, BPT-2595, BPT-3095, BPT-3135, BPT-3244, BPT-2824, BPT-2764
	IIIC	5	BPT-3159, BPT-3279, BPT-3137, BPT-3168, BPT-3150, **Krishnaveni**
	IIID	7	**Taichung Native-1**, BPT-3133, BPT-3136, BPT-2231, BPT-3121, BPT-3164, BPT-3118, BPT-4358

BPT-3170 carrying *Xa13+ Xa5+Xa4+Xa2* may confer broad spectrum resistance and serve as a valuable donor for BLB resistance breeding. BPT-3061 and BPT-3068 possess the recessive resistance genes *Xa13* and *Xa5 in* heterozygous condition, requiring homozygosity for expression. Advancing these lines through selfing can facilitate allele fixation and enhance resistance to BLB.

Among the 74 genotypes screened, 38 showed concordance between phenotypic and genotypic resistance to BLB, while 36 showed discrepancies. The genotypes showing resistant reaction without detected R genes may harbour additional resistance genes not included in this study. Conversely, the susceptibility observed in some *Xa4*-carrying genotypes suggests pathogen adaptation, likely driven by wide spread use of *Xa4*-based cultivars in India and Southeast Asia (Ma *et al.*, 1999 and Sun *et al.*, 2003). This study shows that genotypic screening correlates with phenotypic screening in most genotypes and it also underscore the importance of combining genotypic and phenotypic data for accurate resistance evaluation.

Cluster analysis based on 14 R-gene-linked markers grouped genotypes into three major clusters, with the resistant check (ISM) and susceptible checks (Taichung Native-1 and Krishnaveni) occupying distinct clusters. The eight genotypes, namely, BPT-3068, BPT-3074, BPT-3092, BPT-3137, BPT-3170, BPT-2958, BPT-3159 and BPT-3178, which exhibited phenotypic disease reaction towards resistance (score 1-3) for BLB at both the locations and demonstrated positive R gene compatibility, were distributed across clusters, highlighting their genetic diversity. These resistant genotypes are promising resources for developing durable BLB-resistant varieties. Similar studies on phylogeny analysis in rice using SSR markers were reported by Ashiba *et al.* (2020), Khan *et al.* (2015), and Khannetah *et al.* (2021).

CONCLUSIONS

This study assessed genetic resistance to Bacterial Leaf Blight (BLB) in 71 rice genotypes through multi-location screening and molecular characterization. BPT-3170, exhibiting phenotypic resistance and carrying multiple resistance genes (*Xa13+ Xa5+Xa4+Xa2*), shows strong potential as a donor for broad-spectrum BLB resistance. Additionally, genotypes BPT-3068, BPT-3074, BPT-3092, BPT-3137, BPT-3170, BPT-2958, BPT-3159, and BPT-3178 showed consistent phenotypic resistance (disease score 1–3) across locations and positive compatibility with R-gene expression, making them valuable genetic resources for BLB resistance breeding. The findings underscore the ineffectiveness of single gene resistance and emphasizes the need for pyramiding multiple R genes to achieve durable and broad-spectrum resistance. Deploying diverse R-gene combinations in elite cultivars will enhance the resilience of rice crops against evolving BLB pathotypes, ensuring sustainable production and food security, particularly in areas where BLB is a persistent threat to rice cultivation.

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بررسی مورفولوژیکی-مولکولی ژنوتیپ‌های برنج برای مقاومت به بیماری سوختگی باکتریایی برگ (BLB)

باروگالا جیوتسنا، ویراگاتاپو روجا، بادوگو کریشناونی، وی. پراسانا کوماری، ووتوکوری بووانشواری، چالو پرانایا، و کالورو سودامانی

چکیده

سوختگی باکتریایی برگ (BLB) یکی از مخرب‌ترین بیماری‌های برنج *Oryza sativa)* (L. است که باعث کاهش قابل توجه عملکرد شده و تهدیدی جدی برای امنیت غذایی و معیشت در مناطق متکی به برنج در آسیا و آفریقا محسوب می‌شود. در این پژوهش، 71 ژنوتیپ برنج که از طریق تلاقی بین لاین‌های ممتاز و اصلاح‌شده ایجاد شده بودند، برای مقاومت به بیماری سوختگی باکتریایی برگ (BLB) با استفاده از تلقیح مصنوعی در مرحله حداکثر پنجه‌زنی، با شاهدهای مقاوم (Samba Mahsuri اصلاح‌شده) و شاهد حساس (-Taichung Native 1،Krishnaveni)، درشرایط مزرعه‌ای در باپاتلا (Bapatla) و ماروترو(Maruteru)، در آندراپرادش هند، ارزیابی شد. غربالگری فنوتیپی، 9 ژنوتیپ را که واکنش بیماری به سمت مقاومت (نمرات بیماری 1 تا 3) را در هر دو محل نشان می‌داد، شناسایی کرد. غربالگری مولکولی برای پنج ژن مقاومت (R) BLB، یعنی *Xa21*، *Xa13*، *Xa5*، *Xa4* و *Xa2*، نشان داد که BPT-3170 چهار ژن R (*Xa13+Xa5+Xa4+Xa2*) را حمل می‌کرد، در حالی که هشت ژنوتیپ دو ژن و 30 ژنوتیپ یک ژن داشتند. تجزیه و تحلیل فیلوژنتیکی با استفاده از 14 نشانگر مرتبط با ژن R، ژنوتیپ‌ها را در سه گروه اصلی دسته‌بندی کرد. BPT-3170 مقاومت فنوتیپی را همراه با چندین ژن R مشخص کرد که نشان‌دهنده پتانسیل آن برای ایجاد مقاومت در طیفی گسترده است و می‌تواند به عنوان یک دهنده (donor) ارزشمند در اصلاح نژاد مقاوم به بیماری سوختگی باکتریایی برگ (BLB) عمل کند. این پژوهش همچنین شکست مقاومت تک ژنی و فراوانی پایین *Xa5*، *Xa13* و *Xa21* را نشان داد. این

یافته‌ها اهمیت هرمی کردن (Pyramiding) چندین ژن R را برای دستیابی به مقاومت پایدار در برابر بیماری سوختگی باکتریایی برگ (BLB) مشخص می‌کند.

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Organic Carbon and Nitrogen Stock Indices and Mechanical Properties of Soils in Two Land Uses in Northeastern Iran

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ABSTRACT

This study aimed to investigate the effect of land use type on some soil characteristics, including Carbon stock (Cs), Nitrogen stock (Ns), S-Index, Structural Stability Index (SSI), soil pore size distribution, soil shear strength (τ), internal friction angle (φ°), shear Cohesion (C), Soil Water Characteristic Curve (SWCC), Relative Field Capacity (RFC), Available Water (AW), Aeration Porosity (AP), and effective Porosity (P_e) in Shandiz City, Khorasan Razavi Province, northeast Iran. For this purpose, 60 soil samples were taken from the surface layer (0-20 cm) in pasture and agricultural land uses. The results showed that S-Index, SSI, RFC, AW, P_e, C_s, and N_s in the Pasture Land Use (PLU) were significantly higher than in agricultural land use. The values of τ, C, and φ° in the pasture land use were significantly ($p<0.01$) less than the agriculture land use. The relationship between soil organic carbon stock index and bulk density (r= -0.69), coarse fragments (r= -0.73), cohesion (r= -0.70), and φ° (r= -0.52) were significant and negative. The amounts of C and N stock indices in pasture land use were 61.6% and 33.1 % greater than agricultural lands, respectively. Therefore, as a result of land use change, C and N stock, S-index, RFC, SSI, AW, AP, P_e, and, consequently, the soil quality decrease, and soil degradation increase in agricultural land use.

Keyword: Carbon stock, Internal friction angle, Relative field capacity, S-Index, Shear strength.

INTRODUCTION

The type of land use is one of the most important factors of land destruction that affects the quality and quantity of soil organic carbon and is very influential on the stock or loss of soil carbon and nitrogen (Dwibedi *et al*., 2022; Gholoubi *et al*., 2019). Land use is the second leading factor for carbon emissions after the combustion of fossil fuels. It significantly affects the dynamics of organic carbon and soil nitrogen and environmental pollution (Parras *et al*., 2013).

Soil is a fundamental source of organic carbon and nitrogen in terrestrial ecosystems. One of the most important land ecosystems for carbon stock is pastures, which make up half of the world's land and contain more than a third of the terrestrial biosphere's carbon reserves. Although the amount of carbon stock in pastures per unit area is small, due to their large size, these lands have a great ability to store carbon (Yimer *et al*., 2007). Poeplau and Don (2013) reported that carbon stock in pasture land use was more than agricultural land use. Breuer *et al*. (2006) found that the average difference of carbon and nitrogen stock in the 20 cm layer of the soil surface in pasture and agricultural lands was about 22 t ha^{-1}.

Soil shear strength is one property that affects the traction capacity of off-road devices and strengthens force against tillage tools (Zhao *et al*., 2009). Soil shear strength affects other inherent soil characteristics,

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including erodibility and machine-soil relationships. Johnson *et al*. (1987) found that the soil surface's shear strength controls the soil's erodibility. Yamaguchi *et al*. (2022) found that rill erodibility decreased with increasing shear strength and it could be represented by a linear function of shear strength. They demonstrated that shear strength measurement could be used to quickly estimate the effect of soil conditioners on rill erodibility in the field.

Soil conditions are controlled by the shear strength of the soil surface when it reaches the threshold of erosion by the furrow flow (Raus and Govers, 1988; Svoboda and McCartney., 2014). Soil shear (mechanical) strength changes rapidly when the soil moisture varies (Bachman *et al.,* 2006). The shear strength of the soil is related to the soil structure, and it’s considered as the most important properties of soil engineering. A change in these parameters can affect soil resistance to agricultural machines (Zhao *et al*., 2009). The shear strength of soil is a function of management and land use type. Changing the dynamic properties of soil, including structure, pore size distribution, moisture, total porosity, compaction, and bulk density in agricultural land use due to tillage operations and the agricultural machinery, can change the mechanical resistance of the soil (Ouyang *et al*., 2018). Also, the destruction of soil structures reduces the soil's water-holding capacity. It increases the cohesion coefficient and internal friction angle, which leads to an increase in the shear strength of the soil (Amiri *et al*., 2018; Bachman *et al*., 2006).

The slope of the characteristic curve of soil water at the inflection point (S-Index) is one of the indicators of soil physical quality (Dexter, 2004; Emami *et al*., 2012). The S-Index is sensitive to the type of land use change and also the management factors such as tillage, compaction, and cropping (Dexter and Czyz, 2007; Reynolds *et al*., 2008). Soil organic matter is often expressed as organic carbon of soil, and its amount is influenced by land use and management practices. Soil is the main reservoir of carbon in terrestrial ecosystems (Scharlemann *et al*., 2014). Human activities, land use, and management have led to a significant reduction of soil carbon. Also, the type of land use usually has long-term effects on the soils physical, mechanical, hydraulic, biological, and chemical properties. Investigating the impact of land use on soil function is possible through changes in the soil quality indicators. The type of land use usually has long-term effects on the soils physical, mechanical, hydraulic, biological, and chemical properties, especially organic matter. Evaluating the effect of land use on soil function is necessary to achieve sustainable soil management in agricultural ecosystems.

Therefore, the objectives of this research were to: (I) Compare the organic carbon and nitrogen stock indices in pasture and agricultural land uses, and (II) Compare some physical and mechanical properties of soil in two land uses of pasture and agriculture in semi-arid regions in northeastern Iran.

MATERIALS AND METHODS

Characteristics of the Study Area and Soil Sampling

This research was carried out in Shandiz City, northwest of Khorasan Razavi Province, with a longitude of 59˚ 25′ 0″ E and latitude of 36˚ 25′ 0″ N, in two land uses of pasture (natural and virgin with little grazing) and agriculture (15 years of rainfed wheat cultivation). Plowing, irrigation, and fertilization were not made in the pasture land use because the pasture was natural and virgin, but the agriculture lands were plowed by moldboard and rainfed wheat was cultivated for years. Nitrogen and phosphorus fertilizers are applied in agricultural lands: 100 kg ha^{-1} mono ammonium phosphate in autumn and 100 kg ha^{-1} urea in spring. The selected points (in each pair of sampling points for agricultural and pasture lands) had similar geology, climate, physiography, and topography. Based on the soil taxonomy key, the studied soils were aridisols Soil Survey Staff (SSS, 2022). The crops in pasture and agricultural land were Alhagi maurorum and Triticum aestivum, respectively. The soil samples were randomly taken using a soil core to obtain a sample for each land use (Figure 1). A total of 120 soil samples were collected from agricultural and pasture land uses (60 undisturbed and 60 disturbed samples of each land use) from the soil surface layer (0-20 cm).

Laboratory Analyses

Soil organic carbon was determined through the Walkley-Black method (Nelson and Summers, 1982), bulk density by using undisturbed core samples (Blacke and Hartge, 1986), and the coarse fraction (> 2 mm) by passing through a 2 mm sieve (Wiesmeier *et al*., 2012; Simon *et al*., 2018). Total soil nitrogen was determined using Kjeldahl (Page *et al*., 1982). The Carbon stock (C_S) and the Nitrogen stock (N_S) indices were calculated using Equations (1) and (2), respectively (Simon *et al*., 2018), as follows:

$$C_s\ (mg\ ha^{-1}) = (\%SOC)(BD\ in\ g\ cm^{-3})(1-CF)(D\ in\ cm) \quad (1)$$

$$N_s\ (mg\ ha^{-1}) = (\%N)\ (BD\ in\ g\ cm^{-3})\ (1-FC)\ (D\ in\ cm) \quad (2)$$

Where, CF is Coarse Fraction, D is soil Depth (0–20 cm), BD is Bulk Density, N and SOC are total nitrogen and soil organic carbon percentage, respectively (Simon *et al*., 2018).

To determine the S-Index, the Van Genuchten equation was fitted to the laboratory data of the water characteristic curve using the software program (RETC) (Dexter, 2004). In order to measure the water characteristic curve, the amount of moisture in the matric suctions of 0, 20, 40, 60, 80 100, 330, 500, 1,000, 1,500, 3,000, 5,000, 10,000 and 15,000 hectopascals was

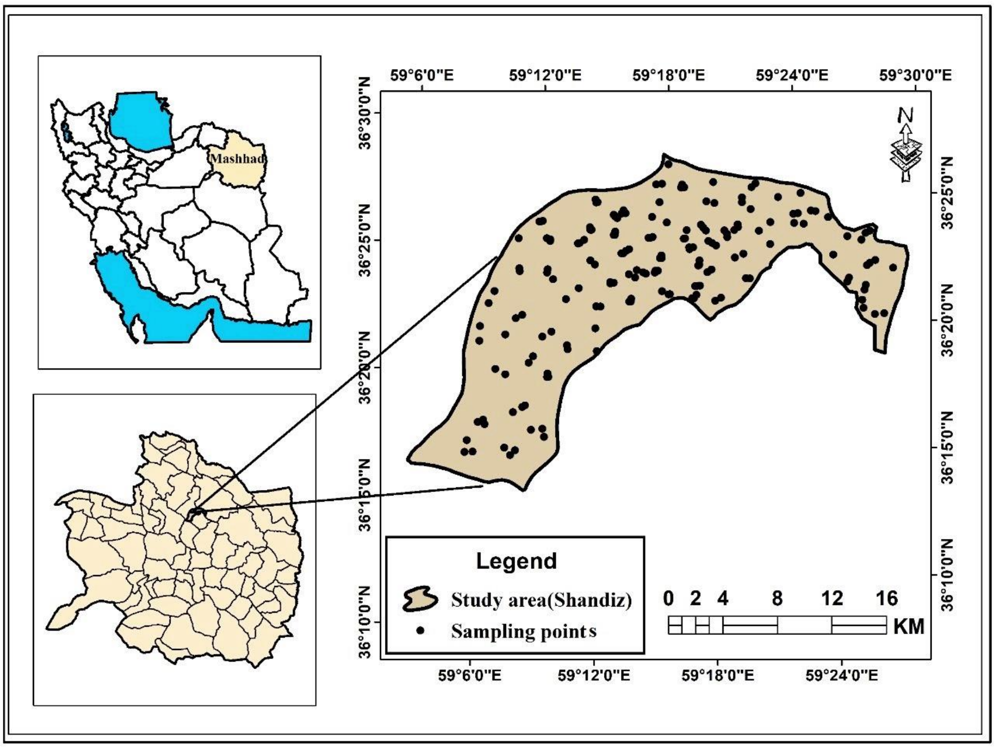

Figure 1. Location of the study area.

determined using the sand box and the pressure plate apparatus. Then, S index was calculated using Eq. 3.

$$\mathrm{S_{Index}} = \left| -n\,(\theta_s - \theta_r)\left[1 + \frac{1}{m}\right]^{-(1+m)} \right| \quad (3)$$

Where, S is the Slope of the soil moisture characteristic curve at the inflection point, and θ_s and θ_r are the gravimetric saturated and residual moisture, respectively. n and m are the parameters of the soil moisture curve in the Van Genuchten equation. (eq3)

The stability of the Soil Structure Index (SSI) was calculated using the values of organic matter, silt and clay as follows (Pieri, 1992):

$$SSI = \left(\frac{OM}{\mathrm{Clay + Silt}}\right) \times 100 \quad (4)$$

The pore diameter corresponding to each suction was calculated from the capillary relationship (Equation 5), then, the percentages of Macro-Pores (MacP, > 75 μm), Meso-Pores (MesP, 30 to 75 μm) and Micro-Pores (MicP, < 30 μm) were determined using the Equations (6), (7), and (8), respectively (Danielson and Sutherland, 1986).

$$d = 0.3/h \quad (5)$$

Where, h (cm) is the applied suction and d (cm) is the diameter of the pore corresponding to each suction.

$$\mathrm{MacP} = \left(\frac{\theta_S - \theta_{0.04}}{\theta_S}\right) \times 100 \quad (6)$$

$$\mathrm{MesP} = \left(\frac{\theta_{0.04} - \theta_{0.1}}{\theta_S}\right) \times 100 \quad (7)$$

$$\mathrm{MicP} = \left(\frac{\theta_{0.1} - \theta_{\infty}}{\theta_S}\right) \times 100 \quad (8)$$

Where, θ_s (m^3 m^{-3}) is the saturated moisture, $\theta_{0.04}$, $\theta_{0.1}$ and θ_∞ (m^3 m^{-3}) are the moisture contents at the suction of 40 hPa, 100 hPa, and the infinity suction (θ_∞= 0), hPa is equal to cm and it's the unit of matric suction, so it's true here. (Danielson and Sutherland, 1986).

A direct shear apparatus was used to measure the shear strength of the soil. The gravimetric moisture content of the samples was determined before and after the shear strength test (Blake and Hartge, 1986). The soil samples were placed in the direct shear box (internal cross section of 6×6 cm and a height of 2 cm). First, a mass of 10 kg was applied to measure soil shear stress, then, masses of 20 and 30 kg were applied to measure the shear stress of the soil. The Mohr-Coulomb failure criterion (Equation 9) was used to calculate shear strength parameters (Zhang *et al.*, 2001). To find shear cohesion and the soils internal friction angle and establish the Mohr-Coulomb linear failure criterion, shear stress was plotted as a function of the normal stress (at loads of 10, 20, and 30 kg).

$$\tau_{(\mathrm{kPa})} = \mathrm{C}_{(\mathrm{kPa})} + \sigma_{(\mathrm{kPa})} \tan \varphi_{(°)} \quad (9)$$

Where, τ (kPa) is shear strength, C (kPa) is shear Cohesion, σ (kPa) is the normal stress applied on the soil sample (applied load divided by the area), φ (˚) is the internal friction angle and tan φ is the coefficient of friction and indicates the slope of the line, which is denoted by μ.

Relative Field Capacity (RFC) was calculated using Equation (10) (Reynolds and Topp, 2008).

$$RFC = \frac{\theta_{FC}}{\theta_S} \quad (10)$$

Where, θ_{FC} is the soil moisture content at the field capacity (h= 100 hPa) and θ_s is the saturated soil moisture (h= 0).

Available Water (AW) was calculated using Equation (11) (White, 2006).

$$AW_{(m^3 m^{-3})} = \theta_{FC} - \theta_{PWP} \quad (11)$$

Where, θ_{FC} is the soil moisture at the Field Capacity (h= 100 hPa) and θ_{PWP} is the soil moisture at the Permanent Wilting Point (h= 15,000 hPa).

Aeration Porosity (AP) was calculated using Equation (12) (White, 2006).

$$A_P = \theta_S - \theta_{FC} \quad (12)$$

Where, θs is the Saturated soil moisture content and θ_{FC} is the soil moisture content at the Field Capacity.

The effective Porosity (Pe) was calculated using Equation (13) (White, 2006).

$$P_e = P_t - \theta_{FC} \quad (13)$$

Where P_t (%) is total Porosity, θ_{FC} (m^3 m^{-3}) is the soil moisture content at the Field Capacity (h= 100 hPa), BD (g cm^{-3}) is Bulk Density, and DP (2.65 g cm^{-3}) is Particle Density.

Statistical Analysis

Before the statistical analysis, the Kolmogorov-Smirnov test checked the data's normality. The independent-sample t-test evaluated soil characteristics in pasture and agricultural land uses. Statistical analyses were performed using JMP version 8 software (SAS Institute Inc. 2009). The graphs were plotted using Excel software.

RESULTS AND DISCUSSION

Carbon and Nitrogen Stock Indices

The type of land use had a significant effect ($P< 0.001$) on the C and N stock indices, which in pasture land use was significantly greater than the agricultural land (Figure 2), i.e. in pasture land were 61.6 and 33.1% more compared to the agriculture land, respectively. The lower C and N stock indices in agricultural land use can be due to the low content of organic carbon and harvesting of plant residues in agricultural land, total soil N, and more coarse fragments compared to the pastures (Table 1). The value of organic C and total N in agricultural land was 31.8% and 14.3% lower than the pasture, respectively, and coarse fragments in agriculture was 34.8% higher than in the pasture (Table 1).

Agricultural operations, massive cultivation, and removal of plant residues from the soil surface in agricultural land increase soil degradation and erosion, and decrease soil organic matter due to runoff and erosion; as a result, the amount of soil organic C and soil total N decreases (Deneve and Hofman, 2000). Carbon and N stock indices in soil are affected by land use, soil organic matter, soil texture, structure, porosity, and bulk density. An increase in organic matter improves the structure and porosity of the soil and reduces the bulk density, which reduces runoff and erosion and increases the storage of C and N in the soil (Gebeyehu and Soromessa, 2018). The stock of organic C and N directly affects soils physical, mechanical, chemical, and biological characteristics. Also, the self-restoration capacity of the soil significantly depends on the amount and quality of soil organic C (Martin *et al*., 2016). In general the stabilization mechanisms of SOC are three key ways: (1) Occlusion of organic carbon within soil aggregates (Six *et al*. 2002); (2) Interaction of SOC with the soil mineral particles particularly clay and silt (Mikutta *et al*., 2007), and (3) Molecular structure of organic carbon influenced by environmental factors, which, in turn, affects the relative resistance to decomposition (Assunção *et al*., 2019). The increased amount of soil aggregates facilitates the physical protection of SOC from microbial

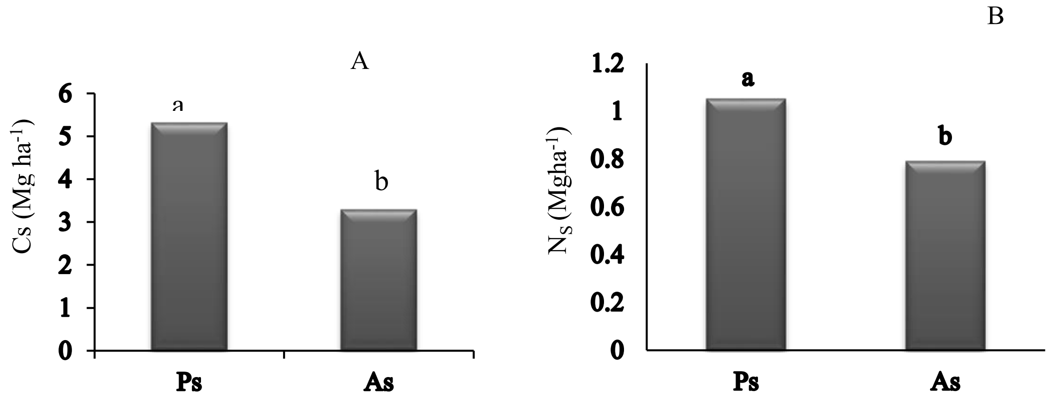

Figure 2. The effect of land use type on: (A) C stock index (C_S) and (B) N stock index (N_S) in Pasture land use (P_s), and Agricultural land use (A_s).

decomposition and mineralization (Razafimbelo *et al*., 2008).

There was a positive and significant correlation between C and N stock indices with soil porosity. However, these two had a significant negative correlation with the bulk density. Land use often determines the amount of C input to the soil. The soils C and N stocks are variable due to the net balance between input and output by carbon emission dioxide, dissolved organic matter, and C loss through soil erosion. Management practices, such as tillage and plowing, cause to break down the soil aggregates and expose organic matter to microbial decomposition. Because of agricultural soils aeration being more than that of pastures, oxidation of organic matter accelerates and increases, consequently, it reduces soil C and N stock (Don *et al*., 2011). Zach *et al*. (2006) found that soil C decreased by 35- 56% after 3-5 years of agriculture practices. Therefore, land use and management practices can prevent the destruction of soil structure and increase the ability to stock organic C and N in the soil. Also, it is valuable to estimate the amount of organic carbon stock in the soil as the main source of carbon stock in the terrestrial ecosystem and to study the amount and distribution of soil organic C in different regions using various methods, because soil organic carbon has a high temporal and spatial variability (Francaviglia *et al*., 2017).

The crop cover is one of the important and main factors of C and N inputs into the soil and increases these stocks in the long term. Also, the presence of crop cover improves the soil quality (physical, hydraulic, biological and chemical properties) by reducing the erosion of fine soil particles and compaction of compacted soil (Samaei *et al*., 2024; Derner and Schuman, 2007). In arid and semi-arid regions, due to the low content of the plant residues and their oxidation in agricultural lands, the amount of these stocks is generally low (Wang, *et al*., 2012).

Physical and Hydraulic Properties of Soil

The results of statistical analysis showed that the values S-Index, effective porosity, structural stability index, and available water in agricultural land use were significantly ($P< 0.001$) lower than the pasture land use (Table 1). The values of S-Index, effective porosity, structural stability index and available water in pasture land use were 40, 19.4, 52.7, and 15.3% higher than the agricultural land use, respectively. These higher values can be due to the high percentage of soil porosity in pasture land use (Table 1). Because the S-Index, effective

Table 1. Statistical description of some soil characteristics in pasture and agriculture land uses at a depth of 0-20 cm.[a]

Soil Characteristics	Unit	Pasture land use					Agricultural land use				
		Min	Mean	Max	SD	CV	Min	Mean	Max	SD	CV
Clay	%	17.50	19.69*	22.86	1.57	7.97	15.55	18.73*	21.58	1.66	8.86
Silt	%	30.32	34.71**	39.52	2.11	6.09	25.48	31.96**	38.77	2.91	9.08
Sand	%	37.62	45.59**	50.04	2.98	6.54	41.69	49.31**	57.73	3.75	7.60
BD	g/cm^3	1.31	1.39**	1.47	0.04	2.88	1.44	1.52**	1.65	0.05	3.28
SOC	g/kg	1.76	2.67**	3.9	0.47	17.60	0.98	1.82**	2.53	0.36	19.78
FC	%	26.70	34.70**	43.16	4.17	12.01	39.81	46.78**	59.25	5.24	11.20
P_t	%	44.41	47.16**	48.76	1.25	2.65	38.34	40.99**	43.55	1.51	3.68
N	ppm	525	556.96**	595	18.81	3.37	441	477.40**	511	18.05	3.78
θ_m	%	6.10	6.74**	7.50	0.54	8.34	5.50	5.60**	5.70	0.08	1.43

[a] BD: Bulk Density, SOC: Soil Organic Carbon, FC: Coarse Fraction, P_t: Soil Total Porosity, N: Soil total Nitrogen, Θ_m: Gravimetric water content, Min: Minimum, Max: Maximum, SD: Standard Deviation, CV: Coefficient of Variation. **: Significant at 1%, *: Significant at the 5% probability.

porosity, and available water are directly related to soil porosity and soil moisture curve, the soil structure stability index is indirectly associated with soil pore volume through the amount of organic carbon and soil texture (Dexter, 2004; Reynolds *et al*., 2009, Farahani *et al*., 2022). Small structural pores mainly cause the S-Index, which directly affects many critical soil characteristics. Physical quality in soils with dominant textural pores is very weak; therefore, the presence of structural pores and, as a result, large amounts of S are necessary for proper soil quality. Using the S-Index as an index of physical soil quality allows for direct comparison of different soils and the impacts of different treatments and management conditions (Dexter, 2004). Also, the amount of organic matter and soil porosity were correlated positively. There was a positive significant correlation (Table 3) between soil organic C, N stock indices and soil porosity ($r= 0.68$, $P< 0.01$ and $r= 0.70$, $P< 0.01$). With time, organic compounds (containing low density) decay, and mineral materials with a high density remain, which changes the soil porosity. The S-Index and total porosity had a significant positive correlation ($r= 0.37$). Also, the total porosity of the soil in pasture land use was higher (15.1%) than in agricultural land use. In soils under cultivation, due to the agricultural practices and traffic of agricultural machines on soil surface, soil structure is destroyed, and soil porosity is reduced.

On the other hand, coarse aggregates are broken, turn into smaller aggregates, and fill the pore space, as a result, the number of air-filled pores and the S-Index decrease. In pasture soils, stable, coarse and developed soil aggregates, the structural porosity of the soil and the S-Index increase due to the plant residues, higher organic matter, and lower traffic. The results of this study confirmed that the S- index differentiates the effect of land use and soil management systems. S-Index is especially useful for evaluating and monitoring land use and management systems' impact on soil structure destruction, recovery, and soil quality (Imaz *et al*., 2010). Soils with coarse aggregates and interconnected pores generally have a higher S-Index than soils with small individual pores (Tormena *et al*., 2008). Celik (2005) showed that the density caused by cultivation in agricultural lands increases bulk density and decreases porosity compared to pasture lands.

Dexter (2004) has divided the soils into 3 classes based on the soil physical quality index (S-Index): (1) $S< 0.02$ very weak and no root growth, (2) $0.02\leq S\leq 0.035$ weak and root growth is low, and (3) $S> 0.035$ is good and the root grows sufficiently. According to the classification of Dexter (2004) and the obtained results (Table 1), the studied soils of both pasture and

Table 2. Mean comparisons of soil characteristics in pasture and agriculture land uses at a depth of 0-20 cm.

Soil characteristics	Unit	Pasture land use				Agricultural land use			
		Min	Mean	Max	SD	Min	Mean	Max	SD
S-Index	-	0.04	0.07[a]	0.13	0.02	0.03	0.05[b]	0.08	0.01
Pe	%	12.11	22.97[a]	29.60	3.46	14.66	19.24[b]	24.35	2.70
SSI	%	0.61	0.86[a]	1.22	0.12	0.22	0.56[b]	0.80	0.11
AP	$m^3 m^{-3}$	7.27	10.97	16.46	2.85	7.32	10.11	13.56	1. 56
MacP	%	7.43	14.94	24.34	5.25	10.21	15.97	27.94	4.48
MesP	%	10.18	16.13	23.94	3.80	10.29	15.88	22.66	3.56
MicP	%	57.26	68. 91	80.52	7.16	54.38	68.13	77.06	4.74
RFC	-	0.57	0.69	0.81	0.07	0.54	0.68	0.77	0.04
AW	$m^3 m^{-3}$	0.12	0.15[a]	0.22	0.02	0.09	0.13[b]	0.16	0.01

[a] S-Index: Slope of the soil moisture curve at the inflection point, Pe: Effective Porosity, SSI: Structure Stability Index, AP: Aeration Porosity, MacP: Macro Pores, MesP: Meso Pores, MicP: Micro Pores, RFC: Relative Field Capacity, AW: Available Water, Min: Minimum, Max: Maximum, SD: Standard Deviation, Different letters in each column represent the significant differences between pasture and agriculture land uses.

Table 3. Correlation coefficient between soil organic Carbon stock index (C_S) and some physical and mechanical soil parameters.[a]

Variables	BD	SOC	SII	S-Index	C_*	φ	θ_m	P_t	N_S
SOC	-0.769**								
SII	-0.620**	0.765**							
S-Index	-0. 317*	0.481**	0.486**						
C	0. 687**	-0.851**	-0.669**	-0.409**					
φ	0.626**	-0.734**	0.469**	-0.227	0.572**				
θ_m	-0.742**	0.824**	0.641**	0.343**	-0.801**	-0.630**			
P_t	-0.726**	0.895**	0.647**	0.371**	-0.774**	-0.704**	0.773*8		
N_S	-0.702**	0.797**	0.605**	0.398**	-0.743**	0.703**	0.630**	0.704**	
C_S	-0.699**	0.826**	0.846**	0.557**	-0.702**	-0.521**	0.632**	0.684**	0.780**

[a] BD: Bulk Density, SOC: Soil Organic Carbon, P_t: Soil total Porosity, Ɵm: Gravimetric water content, S-Index: Slope of the soil moisture curve at the inflection point, SSI: Structure Stability Index, C: shear cohesion, φ: The internal friction angle, N_S: Nitrogen stock index, C_S: Carbon stock index. **: Significant at the 1% probability level, *: Significant at the 5% probability level.

agricultural land use had good physical quality. The SSI values in different soils vary from zero to infinity (0-∞), while SSI> 9% indicates stable soil structure. One of the most important factors of soil structure stability is organic C. According to the results, the amount of organic carbon in pasture land was higher than that in agricultural land. Therefore, the stability of soil structure in pasture was higher than that in agricultural land (Table 1). There was a positive and significant correlation between SOC and S-Index (r= 0.48), soil stability index (r= 0.77), and total porosity (r= 0.90). Also, SOC shows the critical role of SOM in soil physical quality (Table 3). It has been demonstrated that, in conditions with the same texture, the soils with proper structure have more available water compared to the soils with weak structure (Asgarzadeh *et al*., 2010; Farahani *et al*., 2020). According to the amount of AW, the soils are classified into three groups: (1) Dry or weak AW< 0.10 $m^3 m^{-3}$, (2) Limited 0.10≤ AW< 0.15 $m^3 m^{-3}$, and (3) good 0.15≤ AW< 0.2 $m^3 m^{-3}$ (White, 2006). According to the results, the AW in the pasture soils was more significant than 0.15 $m^3 m^{-3}$. Therefore, they had no limitation of AW, while agricultural soils had limited AW.

Shear Strength of the Soil

An example of the variation for the horizontal displacement due to the strain stress in two land uses is shown in Figure 3. Due to the compression of the soil, the curve has a specific breaking point and, after that, the amount of shear stress decreases. According to this figure, the value of shear stress reduction in agricultural land use after the breaking point is faster than pasture land use, probably due to greater soil compaction (higher bulk density (90.4%)) in agriculture land use. However, in pasture land, shear stress reduction occurs later at a slow speed after the breaking point. An increase in the applied normal load from 10 to 30 kg increases the soil's compaction and, thus, density, which leads to an increase in particle interaction as a result of an increase in shear stress (Figure 3). If a soil sample is subjected to shear displacement, this strongly depends on the state of soil compaction (Komandi, 1992; Tabari *et al*., 2019).

The results of this research showed that there was a significant difference (P< 0.001) between the values of shear Cohesion (C*), internal friction angle (φ) and gravimetric water content (θ_m) in the pasture and agriculture land. The results of mean comparison showed that shear Cohesion (C) and internal friction angle (φ) in agricultural land use were 42.1 and 11.5% higher than the pasture land, respectively (Figure 4). Therefore, the shear stress in the pasture land use is lower than the agricultural land. By reducing the shear stress of the soil, the force and power required to perform tillage operations are reduced (Yokoi, 1968). Lower soil moisture in agricultural land use can be the reason for the higher indices of soil shear strength, shear cohesion and internal friction angle, compared to pasture land (Table 1).

The shear cohesion of the soil depends on the resistance of water and the amount of water between the soil particles. The texture of the studied soils is loamy, where water molecules reduce the cohesion and internal friction angle. But, in clay and sandy soils, water molecules increase the indices of shear strength (Komandi, 1992; Tabari *et al*., 2019). Increasing shear cohesion with decreasing the water content can create stronger bonds between the mineral particles of the soil. On the other hand, when soil water content increases, the frictional resistance between soil particles decreases. Greater total porosity in pasture (15.1%) compared to agricultural land can be another reason for the lower internal friction angle in pasture, because the internal friction angle decreases when total soil porosity increases (Terzaghi, 1959; Mun *et al*., 2016). Figure 5 shows an example of maximum shear cohesion versus vertical loads. Shear cohesion is the intercept on the Y-axis of the Mohr-Coulomb shear strength line. Shear cohesion is the shear resistance when the compressive stresses are equal to zero. Shear cohesion in pasture was lower than agricultural land (Figure 5). The results showed that there was a significant negative correlation (Table 3) between gravimetric water content and shear cohesion (r= - 0.80) and internal friction angle (r= - 0.63). Also, a significant negative correlation was found between total porosity and shear stress (r= - 0.77) and internal friction angle (r= -0.70).

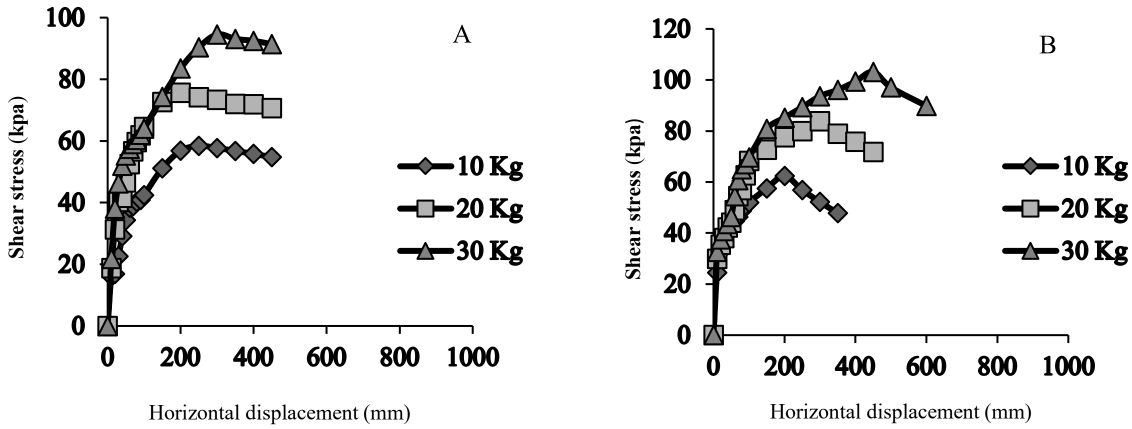

Figure 3. An example of the variation of horizontal displacement due to the strain stress, (A) Pasture land use, and (B) Agricultural land use.

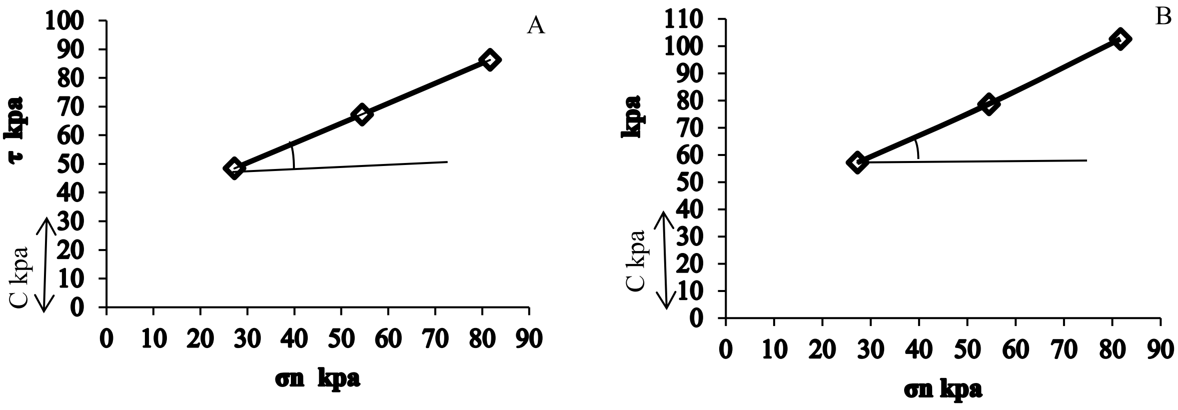

Figure 4. Example of Mohr-Columb failure envelope in two land uses, (A) Pasture land, and (B) Agricultural land.

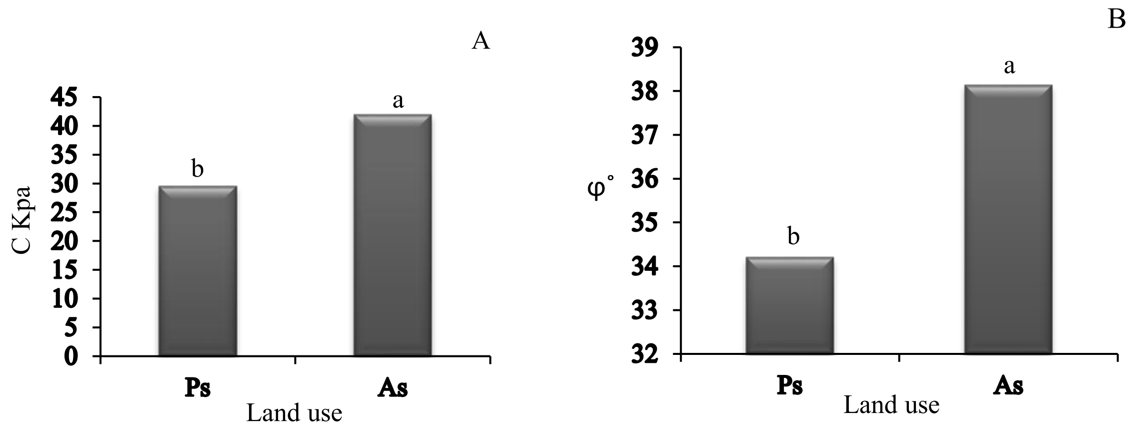

Figure 5. Effect of land use type on shear cohesion (A), and internal friction angle (B).

Zhao *et al.* (2009) found that clay particles swell and disperse more easily when soil moisture increases, thereby shear stress between soil particles reduces. Also, swelling the clay particles with increasing moisture content reduces the internal friction (cohesion forces between the particles), as a result, the shear strength of the soil decreases. As soil moisture increases, water acts as a lubricant between the particles and prevents contraction of the soil particles and reduces the internal friction angle. Some researchers, such as Zhao *et al.* (2009), Amiri *et al.* (2018) and Bachman *et al.* (2006) found that when soil moisture increases, shear strength and internal friction angle decrease. Another factor that affects the internal friction angle of soil is compaction, which is represented by bulk density. According to the results of this research, the value of bulk density in agricultural land was 9.4% higher than the pasture (Table 1). When the bulk density of the soil increases, the compaction and, then, the internal friction angle of the soil particles increases (Maruf, 2012). A positive and significant correlation (Table 3) was found between bulk density and shear stress (r= 0.69) and internal friction angle (r= 0.63). The pasture land had higher moisture content, higher total porosity, and lower bulk density than the agricultural land. As a result, the shear cohesion and internal friction angle in this land were lower than in the agricultural land (Figure 4), and the shear strength in pasture land was less than agricultural land.

CONCLUSIONS

The findings of this research showed that land use type can change soil attributes including soil Carbon Stock (CS), Nitrogen Stock (NS) contents, and indices of soil strength. So that, in agricultural land use due to tillage operations, reduction of vegetation and soil organic matter, the values of the carbon and nitrogen stock indices, soil structure stability index, effective porosity, available water, S-index were lower than pasture land use. Also, due to the higher moisture content, higher total porosity, and lower bulk density, the shear cohesion and internal friction angle in the pasture were lower than agricultural land. The indices of shear strength, organic C and N stock indices are strongly influenced by land use and management practices. The type of land use that does not consider its effects on soil quality can destroy the environment. Unfortunately, land exploitation systems have often been used without recognizing their impact on soil conservation and environmental quality. Therefore, considering the impact of land use on soil properties as one of the critical and essential resources for human life, we should pay more attention to the type of land use and management in order to prevent soil degradation.

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شاخص‌های ذخیره کربن و نیتروژن آلی و ویژگی‌های مکانیکی خاک‌ها در دو کاربری اراضی در شمال شرقی ایران

فریبا سامعی، و حجت امامی

چکیده

این مطالعه با هدف بررسی تأثیر نوع کاربری اراضی بر برخی از ویژگی‌های خاک، شامل ذخیره کربن (CS) ، ذخیره نیتروژن (NS) ، شاخص-S ، شاخص پایداری ساختاری (SSI) ، توزیع اندازه منافذ خاک، مقاومت برشی خاک (τ)، زاویه اصطکاک داخلی(φ°) ، چسبندگی برشی(C) ، منحنی مشخصه آب خاک (SWCC) ، ظرفیت نسبی مزرعه (RFC) ، آب قابل دسترس (AW) ، تخلخل تهویه‌ای (AP) و تخلخل مؤثر (Pe) در شهر شاندیز، استان خراسان رضوی، شمال شرقی ایران انجام شد. برای این منظور، 60 نمونه خاک از لایه سطحی (0-20 سانتی‌متر) در کاربری‌های مرتع و کشاورزی گرفته شد. نتایج نشان داد که شاخصS ، SSI، RFC، AW، Pe، Cs و Ns در کاربری مرتع (PLU) به طور معنی‌داری بیشتر از کاربری کشاورزی بود. مقادیرτ ، C و φ° در کاربری مرتع به طور معنی‌داری (P<0.01) کمتر از کاربری مرتع بود. رابطه بین شاخص ذخیره کربن آلی خاک و جرم مخصوص ظاهری (r= -0.69)، قطعات درشت(r= -0.73) ، چسبندگی (r= -0.70) و (r= -0.52) φ° معنی‌دار و منفی بود. مقادیر شاخص‌های ذخیره کربن و نیتروژن در کاربری مرتع به ترتیب 61.6٪ و 33.1٪ بیشتر از اراضی کشاورزی بود. بنابراین، در نتیجه تغییر کاربری اراضی، ذخیره کربن و نیتروژن، شاخص-S ، RFC، SSI، AW، AP، Pe و در نتیجه کاهش کیفیت خاک و افزایش تخریب خاک در کاربری کشاورزی رخ می‌دهد.

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Pedogenesis and Clay Mineralogy of a Climolithotoposequence in Jazmurian Watershed, Central Iran

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ABSTRACT

Topography, parent material, and climate are critical factors influencing pedogenesis and clay mineralogy of soils. There is a paucity of data regarding the soils and sediments of the Jazmurian Watershed in south-central Iran. This study selected various landforms, including rock and mantled pediments, alluvial fans, piedmont plains, lowlands, and playa characterized by igneous and sedimentary parent materials and situated within aquic, xeric, and aridic soil moisture regimes, to investigate soil genesis and clay mineralogy in the region. The findings indicated that the most significant soil development occurred on rock and mantled pediments, as well as on older alluvial fan sediments, in contrast to the less developed soils found on younger alluvial fan deposits. The clay minerals included smectite, illite, chlorite, palygorskite, and kaolinite. The presence of palygorskite in the sedimentary soils was attributed to inheritance from the parent material, while in soils derived from igneous parent material, it was formed through pedogenic processes. Pedogenic features associated with calcium carbonate were observed in both aridic and xeric soil moisture regimes. The occurrence of clay pedogenic features in the arid regions of the watershed may suggest a historical paleoclimate with greater moisture availability. Conversely, lenticular shapes, interlocked plates, and gypsum infillings were exclusively noted in the arid regions and lower elevations of the watershed, reflecting the current arid climate.

Keywords: Geomorphic surface, Paleoclimate, Paleosols, Soil evolution.

INTRODUCTION

Soil formation and evolution influenced by soil-forming factors have been the focus of many pieces of research (Badia *et al*., 2020; Owliaie *et al*., 2018; Wilson *et al*., 2017; Yousefifard *et al*., 2015, Farpoor *et al*., 2012, Moazallahi and Farpoor, 2012; Saez *et al*., 2003). Soil genesis related to geomorphology helps better understanding of soil forming factors and processes (Moghbeli *et al*., 2019; Sanjari *et al*., 2011). Owliaie *et al*. (2018) reported the impact of parent material and geomorphic position on physicochemical properties, clay mineralogy, and micromorphology of soils in south western Iran.

Lithology, together with other soil forming factors, is reported as a major factor affecting pedogenesis (Wilson *et al*., 2017). Soil characteristics in northwest Iran affected by volcanic and plutonic rocks were studied by Yousefifard *et al*. (2015). They found more evolution in soils derived from volcanic rocks compared to plutonic ones. Soil properties and evolution were mainly affected by particle size and mineralogy of parent material in soils of arid Kapehdagh Basin, northeast of Iran, which is an emphasis on the relationship between soil and parent material in that area.

Climate has a major role on the weathering processes of parent material. Climatic variations influence the type and rate of soil forming processes, which, in turn, affect

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physicochemical properties and clay mineralogy of soils (Phillips *et al*., 2008). Weathering is highly related to the climate and trioctahedral minerals such as mica and chlorite may transform to dioctahedral smectite due to the high rate of weathering (Egli *et al*., 2008). Soil evolution in Nevada was affected by weathering rate and moisture regime (Elliot and Dorhan, 2009).

Soil minerals could be used to understand soil genesis (Graham and O'Geen, 2010), management of arid and wet land soils (O'Geen *et al*., 2008), and interpret paleo-environmental conditions (Sanjari *et al*., 2012; Monafi, 2010; Khormali and Abtahi, 2003). Clay mineralogy of soils in Jiroft area, central Iran, showed that, due to high water table, palygorskite stability decreased and smectite dominated in soils from mantled pediment toward alluvial plain (Sanjari *et al*., 2011). In a soil geomorphology study of the southern parts of central Iran, Sarmast *et al*. (2017) reported chlorite, smectite, illite, palygorskite, and kaolinite clay minerals on different geomorphic positions.

Micromorphology is a useful complementary tool for soil morphology and evolution studies, and seems necessary to better classify and manage soils of an area (Stoops, 2003). In a soil geomorphology study of Sirjan Playa, central Iran, Farpoor *et al*. (2012) reported calcite coatings and infillings in pediments, but lenticular shape and interlocked plates of gypsum in piedmont plain and playa landforms. Clay coating and infilling in the piedmont plain was attributed to the more available humidity of the climate in the past. Soil micromorphology related to geomorphic position in central Iranian soils was studied by Sarmast *et al*. (2019). They reported clay (coating), calcite (nodule, coating, quazicoating, and infilling), anhydrite (nodule), gypsum (lenticular, vermiform, and interlocked plates), and halite (coating) pedo-features in the area under study.

Sixty watersheds were investigated in a study conducted by Krinsley (1970) in central Iranian plateau, and Jazmurian is among the most widespread playas reported in that report. Limited data about soils and environmental factors in this playa are available. The only published report dates back to the study on sediments of the area related to geomorphic positions using aerial photo interpretations and limited field studies (Krinsley, 1970). Since climate, parent material, and geomorphic position are hypothesized to affect soil genesis and evolution, on one hand, and limited data on soils of the study area are reported from the other hand, the present research was conducted to study: (1) Physicochemical soil properties, clay mineralogy, and soil micromorphology in soils of the area, (2) The origin and distribution of clay minerals related to the variation of soil forming factors, and (3) Soil development along a climotopolithosequence.

MATERIALS AND METHODS

Study Area

Jazmurian Watershed as a part of central Iran, Makran, and southeast Iran is located in Kerman and Sistan-Baluchestan Provinces (56° E to 62° E and 26° N to 30° N). It was selected as the study area (Figure 1). The maximum elevation in the area is 4400 m (asl) for the Shah Mountain, Rabor area, and the minimum elevation is only 360 m (asl) at Jazmurian Playa. Two main rivers including non-saline Halilrood, which heads from Kerman Province elevations (north of the watershed), and saline Bampoor, which heads from Iranshahr elevations (east side of the watershed), both end to central lake of Jazmurian Playa (Figure 1), which is a depression of Late Pliocene Era (Namaki 2003). Miocene faulted rocks and evaporites of Upper Red Formations are at the east boundary of the watershed. Jebalbarez igneous mountain (granite, diorite, and andesite) is located at north. Intrusive and external igneous rocks are reported at the west and southeast sides of the area and the Beshagard Paleocene and Cretaceous

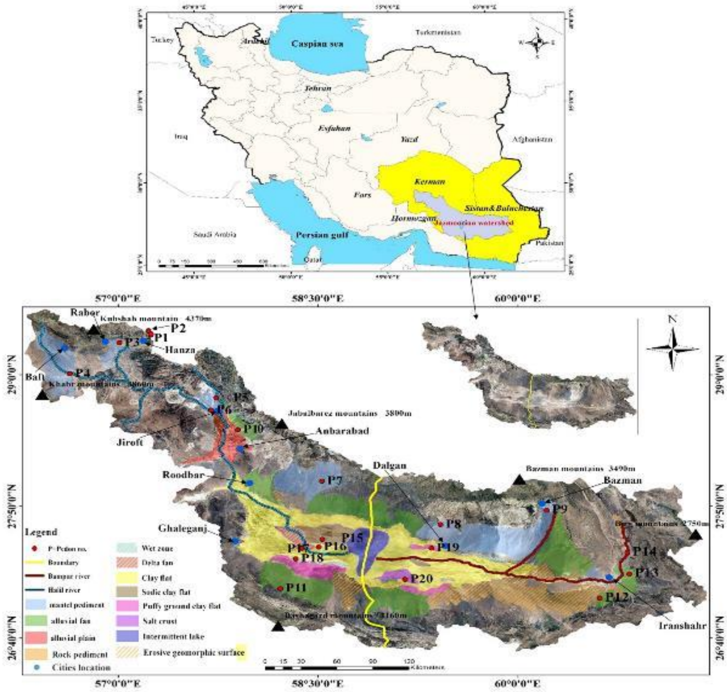

Figure 1. Geomorphological map of the study area, showing location of the representative pedons.

Ophiolite Mountains together with Mokran colored Melange, which separate the watershed from Oman Sea, are located at the south (Mohammadi, 2011). Soil mean temperature varies from 13.1°C in Rabor and Hanza (Mesic soil temperature regime) to 28.9°C in Iranshahr and Dalgan areas (Hyperthermic soil temperature regime). Mean annual precipitation also varies from 287 mm in Rabor and Hanza (xeric) to 82 mm in Roodbar Jonoub areas (aridic).

Field Studies

Alluvial fan, rock and mantled pediments, piedmont plain, playa, and lowland were among dominant landforms studied after detailed field and aerial photo observations (Figure 1). Playa was also divided to clay flat, sodic clay flat, puffy ground clay flat, salt crust, wet zone, fan delta, and lake geomorphic surfaces. Considering variations in elevation, soil moisture and temperature regimes, and parent material, one representative pedon on each geomorphic surface (total of 20 pedons) were selected, described (Schoeneberger *et al*., 2012), and sampled

Various soil moisture regimes included xeric (pedons 1 and 3), aquic (pedons 2, 18) and aridic (other pedons), and temperature regimes included mesic (pedons 1, 3 and 4), thermic (9), hyperthermic (other pedons) related to elevation variations and the vast extent of the area were found (Banaie, 1998).

Laboratory Investigations

After sampling, air-dried ground soil samples passed through a 2 mm sieve and the volumetric percentage of coarse fragments was determined. Particle size distribution was investigated using pipet method (Gee and Bauder, 1986). Jenway pH and EC meters were used to determine the pH and EC of the saturated paste and extract, respectively. The sum of gypsum and anhydrite was analyzed using acetone precipitation (Nelson, 1982). Gypsum was investigated using the Oven method (Artieda *et al*., 2006). Anhydrite was calculated by the subtraction of gypsum from gypsum+anhydrire (Wilson *et al*., 2013). Back titration of excess NaOH by HCl was used for equivalent calcium carbonate determination (Nelson, 1982). Wet oxidation using potassium dichromate (Nelson and Sommers, 1982) was used for organic carbon determination. Substitution of sodium acetate by ammonium acetate pH= 7 was the basis for Cation Exchange Capacity (CEC) determinations (Bower and Hatcher, 1966).

Micromorphological Study

Undisturbed soil samples were impregnated using a Vestapol resin with acetaeric acid as the hardener and cobalt acetate as the catalyst for micromorphological studies, under vacuum. A BK-POL petrography microscope in plain (PPL) and crossed (XPL) polarized lights was used for thin section observations and interpretations performed by the Stoops (2003) guideline.

Clay Mineralogy

Soil samples were prepared (Jackson, 1975; Kittrick and Hope, 1963) for XRD analysis and four treatments including Mg-saturated, Mg-saturated and treated by ethylene glycol, K-saturated, and K-saturated and heated up to 550ºC were performed on each sample. A Broker DH8 Advance diffractometer with Cu as the target at 40 kv and 30 mA with the scan speed of 0.02 degree per second was used for XRD analyses. The area under the first order peaks of Mg saturated-treated by ethylene glycol was used as the reference for semi-quantitative clay mineralogy (Johns *et al*., 1954). Besides, several bulk soil samples were mounted on Al stubs by a carbon glue, coated with gold, and observed by scanning electron microscope (XL 30 ESEM Philips) as a complementary to clay mineralogy investigations.

RESULTS AND DISCUSSION

Table 1 shows the selected physiochemical soil properties and soil classifications based on Soil Taxonomy (Soil Survey Staff, 2022) system.

Piedmont Plain

On this geomorphic position, Pedon 1 is about 3,620 m above sea level (asl) with a xeric moisture regime affected by diorite derived parent material (Figure 1). Mollic and cambic horizons were determined through field studies, but no calcic or gypsic horizon was found. Gleyic condition caused by textural differentiation was the reason for an Oxyaquic Haploxeroll to be formed.

Smectite, illite, chlorite, and kaolinite clay minerals were found in the Bw1 horizon and R layer (Table 2), which are accounted as a proof of the inheritance origin of the minerals from parent material (Yousefifard *et al*., 2015). Palygorskite was also found in the Bw1 horizon (Table 2, Figure 2-a). Since palygorskite was neither present in the parent material (Figure 2-b) nor in the environmental conditions in this pedon (suitable for its formation due to relatively high precipitation), the detrital origin (aeolian source) in this geomorphic surface could be a plausible reason for palygorskite as also supported by other researchers (Sarmast *et al*., 2017; Singer, 1989).

Lowland

This geomorphic position with the elevation of 3,570 m asl and an aquic soil moisture regime was also affected by diorite parent rock (Figure 1). Pedon 2 on this surface with Histic and Cambic horizons showed gleyic properties. Water logging together with a cold climate inhibited organic matter decomposition, which was why about 16% organic carbon with an intermediate decomposition was accumulated and caused Histic Humaquepts.

Table 1. Selected physical and chemical properties of the studied pedons.[a]

Horizon	Depth (Cm)	Sand (%)	Silt (%)	Clay (%)	RF (%)	pH	ECe (dS m^{-1})	CCE (%)	Gypsum (%)	Anhydrite (%)	OC (%)	SAR (mmol $L^{-1})^{0.5}$
Pedon 1, Piedmont plain, 3620 m asl, Diorite, USDA: Oxyaquic Haploxerolls												
A	0-20	15.1	46.6	38.3	2	6.5	1.2	2.0	ng	ng	3.5	1.1
Bw1	20-45	19.1	50.6	30.3	7	6.0	0.7	1.0	ng	ng	1.2	1.6
Bw2	45-80	27.1	48.6	24.3	18	6.4	0.5	0.7	ng	ng	0.7	1.4
Bg	80-100	11.1	51.6	37.3	23	6.5	0.4	1.7	ng	ng	0.9	1.4
C	100-140	37.1	44.6	18.3	46	6.6	0.5	1.2	ng	ng	0.5	1.6
R	>140	-	-	-	-	-	-	-	-	-	-	-
Pedon 2, Low land, 3570 m asl, Diorite, USDA: Histic Humaquepts												
Oe	0-15	25.1	51.1	23.8	-	5.6	1.5	1.0	ng	ng	16.0	1.0
A	15-30	45.1	24.6	30.3	23	5.8	0.8	1.0	ng	ng	2.3	1.1
Bg1	30-65	53.1	16.6	30.3	27	5.8	0.5	0.5	ng	ng	1.4	1.4
Bg2	65-110	65.1	14.6	20.3	18	5.1	0.6	0.75	ng	ng	0.5	2.0
Pedon 3, Mantled pediment, 2247 m asl, Andesite, USDA: Calcic Haploxeralfs												
A	0-13	39.1	39.3	21.6	6	7.2	1.4	8.5	ng	ng	0.5	1.5
Btk	13-45	35.1	37.3	27.6	34	7.9	0.9	26.2	ng	ng	0.6	2.0
Ck	45-85	71.1	13.3	15.6	58	7.8	0.8	17.7	ng	ng	0.3	2.3
C	85-105	77.1	9.3	13.6	66	7.6	0.6	14.0	ng	ng	0.2	2.4
2Btk	105-145	7.1	65.3	27.6	-	7.7	0.6	15.0	ng	ng	0.1	2.5
2Bk1	145-175	23.1	58.6	18.3	-	8.0	0.7	24.0	ng	ng	0.1	3.0
2Bk2	175-215	11.1	68.6	20.3	-	7.9	0.7	44.2	ng	ng	0.1	3.4
Pedon 4, Mantled pediment, 1977 m asl, Limestone, USDA: Typic Natrargids												
A	0-5	37.1	41.3	21.6	1	8.0	0.5	26.5	ng	ng	0.4	0.5
Btk1	5-35	23.1	39.3	37.6	-	8.3	1.2	28.7	ng	ng	0.3	6.2
Btk2	35-72	25.1	35.3	39.6	-	7.8	5.6	28.2	ng	ng	0.3	11.9
C	72-78	57.1	17.3	25.6	19	7.8	5.5	19.5	ng	ng	0.1	12.9
2Btnk	78-100	43.1	27.3	29.6	-	7.9	4.7	22.2	ng	ng	0.1	15.2
2Btnkk1	100-135	1.1	53.3	45.6	-	8.3	2.8	51.2	ng	ng	0.1	15.5
2Btnkk2	135-185	0	58.4	41.6	-	8.2	3.3	50.7	ng	ng	0.1	13.8
2Ckk	>185	0	89.4	10.6	-	8.0	3.6	88.9	ng	ng	ng	12.6
Pedon 5, Mantled pediment, 897 m asl, Diorite, USDA: Calcic Argigypsids												
A	0-20	75.7	12.9	11.4	43	7.6	2.7	15.5	ng	ng	0.2	1.0
Btk	20-55	70.7	14.9	14.4	34	8.0	1.1	16.5	0.7	ng	0.2	1.4
By	55-85	89.7	1.9	8.4	69	8.0	1.3	14.5	5.2	ng	0.2	2.4
C	85-135	90.7	2.9	6.4	60	8.2	1.4	10.0	5.5	ng	0.3	1.2
Pedon 6, Mantled pediment, 860 m asl, Diorite, USDA: Typic Natrargids												
A	0-20	51.4	17.0	31.6	5	7.6	1.6	20.0	ng	ng	ng	4.7
Btn1	20-65	41.4	16.0	42.6	-	7.6	8.2	19.5	ng	ng	0.1	16.5
Btn2	65-80	40.4	18.0	41.6	-	7.5	5.9	19.7	ng	ng	0.1	14.1
Btn3	80-125	39.4	20.0	40.6	-	7.6	5.2	20.5	ng	ng	0.1	13.3
C	125-140	79.4	9.0	11.6	84	7.8	2.4	20.2	ng	ng	0.1	5.7
2Btk	140-170	61.4	15.0	23.6	52	7.8	2.0	20.5	ng	ng	0.1	5.1
2Ck	170-200	85.4	6.0	8.6	72	7.9	1.3	21.2	ng	ng	0.1	2.5
Pedon 7, Mantled pediment, 615 m asl, Diorite, USDA: Typic Haplogypsids												
A	0-10	67.1	16.6	16.3	55	7.4	8.0	11.7	0.6	3.8	0.1	4.3
By1	10-25	79.1	10.6	10.3	49	7.5	4.8	8.7	0.8	13.4	0.1	3.0
By2	25-50	81.8	6.6	11.6	45	7.6	2.9	4.2	23.0	2.7	ng	1.1
By3	50-80	81.8	8.6	9.6	56	7.6	2.9	3.5	14.1	ng	0.1	1.3
By4	80-120	79.8	6.6	13.6	56	7.7	2.9	3.0	14.0	ng	0.1	1.3
Bym	120-150	81.8	4.6	13.6	76	7.4	3.0	4.2	17.3	ng	ng	1.4
Bty	150-180	73.8	4.6	21.6	54	7.6	3.0	3.2	5.5	ng	0.1	1.5

[a] ng: Negligible, RF: Rock Fragment, ECe: Electrical Conductivity of soil saturated extract, OC: Organic Carbon, CCE: Calcium Carbonate Equivalent, asl: Above sea level, SAR: Sodium Adsorption Ratio.

Table 1 continued…

Continued of Table 1. Selected physical and chemical properties of the studied pedons.[a]

Horizon	Depth (Cm)	Sand (%)	Silt (%)	Clay (%)	RF (%)	pH	ECe (dS m^{-1})	CCE (%)	Gypsum (%)	Anhydrite (%)	OC (%)	SAR (mmol L^{-1})$^{0.5}$
Pedon 8, Mantled pediment, 490 m asl, Andesite, USDA: Petrogypsic Haplosalids												
A	0-10	55.8	33.3	10.9	21	7.4	43.5	37.7	0.7	ng	0.4	53.0
Bkyz1	10-35	47.8	41.3	10.9	24	7.1	140.5	27.2	2.0	17.4	0.4	64.5
Bkyz2	35-65	61.8	28.6	9.6	63	7.3	84.7	24.5	24.2	2.5	0.1	59.4
Bym	65-110	53.8	32.6	13.6	61	7.3	99.6	34.0	15.8	2.3	0.2	66.8
Bkyz	110-160	51.8	38.6	9.6	67	7.6	96.1	47.5	7.5	0.8	0.8	92.4
Ck	160-190	69.8	20.6	9.6	67	7.6	9.4	45.0	0.1	ng	0.1	7.0
Pedon 9, Mantled pediment, 860 m asl, Diorite, USDA: Typic Natrigypsids												
A	0-15	79.1	8.6	12.3	22	7.7	5.6	8.2	ng	ng	0.1	14.4
Bk	15-40	76.5	15.3	8.2	26	7.4	9.2	16.0	ng	ng	0.1	11.4
Btk	40-55	56.5	25.3	18.2	35	7.3	25.5	16.2	0.6	ng	0.1	12.5
Btky	55-80	64.5	15.3	20.2	27	7.6	20.9	16.7	7.4	ng	0.1	11.3
Btnky1	80-140	66.5	15.3	18.2	34	7.6	19.8	15.5	5.8	ng	0.1	22.2
Btnky2	140-175	52.5	29.3	18.2	53	7.5	22.3	17.5	6.3	ng	ng	21.3
Pedon 10, Alluvial fan, 700 m asl, young alluvial fan (Granite), USDA: Typic Torrifluvents												
A	0-15	91.4	3.0	5.6	40	8.1	0.5	4.0	ng	ng	0.5	1.0
C1	15-45	95.4	1.0	3.6	50	8.2	0.3	0.5	ng	ng	0.3	0.3
C2	45-75	96.4	1.0	2.6	51	8.2	0.3	6.5	ng	ng	0.1	0.2
C3	75-110	97.4	1.0	1.6	53	8.2	0.3	4.0	ng	ng	0.1	0.2
C4	110-145	97.1	1.0	1.9	74	7.9	0.3	3.7	ng	ng	ng	0.2
Pedon 11, Alluvial fan, 680 m asl, old alluvial fan, USDA: Typic Calciargids												
A	0-30	39.8	24.0	36.2	50	8.0	0.6	8.7	0.1	ng	0.2	4.2
Btk	30-70	29.8	22.0	48.2	48	7.7	0.5	15.5	0.1	ng	0.1	7.9
Bk	70-110	75.8	14.0	10.2	60	8.1	0.7	18.0	0.2	ng	0.1	7.2
C	110-150	87.8	4.0	8.2	69	7.9	0.9	22.7	0.1	ng	0.7	6.1
Pedon 12, Alluvial fan, 635 m asl, old Alluvial fan, USDA: Typic Haplocalcids												
A	0-30	72.4	18.6	9.0	5	8.2	0.7	9.0	ng	ng	0.1	4.6
Bk	30-55	78.4	12.6	9.0	38	7.7	3.1	12.7	ng	ng	0.2	7.5
C1	55-85	80.4	8.6	11.0	53	7.7	3.9	10.5	ng	ng	0.1	8.7
C2	85-110	88.4	2.6	9.0	72	8.0	2.3	11.7	ng	ng	0.2	8.1
C3	110-135	82.4	6.6	11.0	58	8.0	2.6	11.7	ng	ng	0.2	9.7
C4	135-165	62.4	12.6	25.0	83	8.1	2.2	11.7	ng	ng	0.1	14.4
Pedon 13, Alluvial fan, 632 m asl, young Alluvial fan, USDA: Typic Torrifluvents												
A	0-5	80.4	10.6	9.0	51	7.7	0.8	9.0	ng	ng	0.1	0.8
C1	5-25	80.4	12.6	7.0	56	8.1	0.5	12.2	ng	ng	0.1	1.5
C2	25-40	86.4	4.6	9.0	64	8.1	0.5	12.5	ng	ng	0.1	0.9
C3	40-70	82.4	6.6	11.0	62	7.9	0.6	12	ng	ng	0.1	1.5
C4	70-90	68.4	14.6	17.0	77	7.8	0.8	12.5	ng	ng	0.2	3.2
C5	90-130	58.4	22.6	19.0	66	7.8	0.9	11.7	ng	ng	0.2	4.1
Pedon 14, Rock pediment, 793 m asl, limestone, USDA: Typic Gypsiargids												
A	0-40	56.4	34.6	9.0	54	7.8	1.0	19.2	ng	ng	0.1	0.7
Btk1	40-80	50.4	34.6	15.0	43	7.8	0.8	20.0	ng	ng	0.2	1.2
Btk2	80-105	46.4	36.6	17.0	27	7.8	1.8	15.2	ng	ng	0.1	3.9
C	105-110	56.4	28.6	15.0	55	7.8	2.1	16.5	ng	ng	0.1	3.4
2Btk	110-125	48.4	36.6	15.0	4	7.6	3.6	21.0	0.1	ng	0.1	4.1
2Bty	125-150	43.0	38.3	18.7	3	7.6	3.5	10.7	24.0	ng	0.1	3.8
2Cy	150-170	64.5	25.3	10.2	53	7.7	3.8	14.0	17.6	ng	0.1	5.3

[a] ng: Negligible, RF: Rock Fragment, ECe: Electrical Conductivity of soil saturated extract, OC: Organic Carbon, CCE: Calcium Carbonate Equivalent, asl: Above sea level, SAR: Sodium Adsorption Ratio.

Table 1 continued…

Continued of Table 1.

Horizon	Depth (Cm)	Sand (%)	Silt (%)	Clay (%)	RF (%)	pH	ECe (dS m^{-1})	CCE (%)	Gypsum (%)	Anhydrite (%)	OC (%)	SAR (mmol L^{-1})$^{0.5}$
Pedon 15, Playa (sodic clay flat), 368 m asl, Playa deposits, USDA: Typic Haplosalids												
Az	0-15	3.7	60.5	35.8	0	7.3	202.0	12.7	1.1	ng	0.7	359.9
Btnz	15-35	0.0	46.2	53.8	0	7.0	108.1	13.2	0.6	ng	0.4	117.5
C	35-50	0.0	84.2	15.8	0	7.2	60.2	17.5	0.2	ng	0.2	62.0
2Bz1	50-75	1.7	68.5	29.8	0	7.1	87.4	16.2	0.4	ng	0.2	121.2
2Bz2	75-110	13.7	60.5	25.8	0	7.5	58.1	16.5	0.3	ng	0.2	130.2
2Cz	110-145	9.7	78.5	11.8	0	7.9	24.5	18.2	ng	ng	0.1	111.9
Pedon 16, Playa (clay flat), 364 m asl, Playa deposits, USDA: Typic Torriorthents												
A	0-20	8.4	64.6	27.0	0	8.3	3.2	16.2	ng	ng	0.3	67.8
C	20-60	20.4	70.6	9.0	0	7.7	11.1	16.5	ng	ng	0.1	46.8
2Cz	60-90	0.0	76.2	23.8	0	7.6	23.6	16.7	ng	ng	0.2	71.6
3Btnzb1	90-120	1.7	50.0	48.3	0	7.6	27.2	14.7	2.8	ng	0.2	77.3
3Btnzb2	120-150	9.7	42.5	47.8	0	7.7	32.1	14.0	3.1	ng	0.2	104.2
Pedon 17, Playa (fan delta), 378 m asl, Playa deposits, USDA: Typic Torrifluvents												
A	0-20	32.4	46.6	21.0	0	7.5	1.8	13.0	ng	ng	0.2	4.5
C1	20-55	62.4	26.6	11.0	0	7.9	0.5	14.0	ng	Ng	0.1	3.8
C2	55-85	2.4	60.6	37.0	0	8.3	1.2	16.7	ng	ng	0.1	11.0
C3	85-130	28.4	54.6	17.0	0	8.5	1.3	16.2	ng	ng	0.1	20.0
C4	130-160	50.4	36.6	13.0	0	8.4	1.0	14.7	ng	ng	0.2	16.5
Pedon 18, Playa (wet zone), 370 m asl, Playa deposits, USDA: Typic Aquisalids												
Az	0-15	2.4	74.6	23.0	0	7.3	78.2	15.0	0.4	ng	0.5	189.5
Bz	15-30	8.4	70.6	21.0	0	7.5	57.3	16.0	1.2	ng	0.4	120.4
Btnz1	30-45	8.4	60.6	31.0	0	7.5	57.1	15.5	1.3	ng	0.5	118.7
Btnz2	45-95	0.0	71.0	29.0	0	8.2	43.3	15.5	0.6	ng	0.4	179.3
Bzg1	95-125	6.4	68.6	25.0	0	8.4	32.7	15.7	0.6	ng	0.3	151.7
Bzg2	125-170	30.4	48.6	21.0	0	8.1	30.2	17.0	0.5	ng	0.3	77.7
Pedon 19, Playa (clay flat with puffy ground), 374 m asl, Playa deposits, USDA: Typic Haplosalids												
Az	0-30	0.4	47.3	52.3	0	8.3	92.7	11.5	4.8	ng	0.2	813.1
Bz1	30-60	4.4	45.3	50.3	0	8.2	70.6	11.7	4.3	ng	0.2	506.2
Bz2	60-90	0.0	67.7	32.3	0	8.2	99.4	11.0	1.7	ng	0.3	730.8
Bz3	90-135	0.4	59.3	40.3	0	8.3	69.8	13.0	0.5	ng	0.3	512.5
Bz4	135-155	14.4	51.3	34.3	0	8.2	49.5	13.0	ng	ng	0.2	330.6
Pedon 20, Playa (salt crust), 367 m asl, Playa deposits, USDA: Typic Haplosalids												
Az	0-30	3.8	64.6	31.6	0	8.1	222.2	17.2	2.2	ng	0.4	1631.7
Bz1	30-60	1.8	60.6	37.6	0	8.2	138.4	18.0	0.9	ng	0.2	609.2
Bz2	60-90	5.8	58.6	35.6	0	8.0	78.1	15.5	2.0	ng	0.3	367.0
Bz3	90-120	15.8	48.6	35.6	0	8.0	51.4	15.5	1.7	ng	0.1	360.2
Bz4	120-155	17.8	52.6	29.6	0	8.0	35.6	15.0	2.3	ng	0.1	170.0

[a] ng: Negligible, RF: Rock Fragment, ECe: Electrical Conductivity of soil saturated extract, OC: Organic Carbon, CCE: Calcium Carbonate Equivalent, asl: Above sea level, SAR: Sodium Adsorption Ratio.

Illite and kaolinite were the only clay minerals formed in this pedon (Table 2, and Figure 2-c). In this pedon, transformation of smectite to kaolinite due to high precipitation rate and low pH (Table 1) could not be neglected. This could be the reason why the highest kaolinite content was found in this pedon. On the other hand, lack of palygorskite is attributed to high weathering rate and the mineralogy of parent material, which lacks palygorskite (Moazallahi and Farpoor, 2012). Transformation of palygorskite to smectite is reported to take place at the annual rainfalls more than 300 mm (Paquet and Millot, 1972).

Pedons 1 and 2 have the same parent material but different geomorphology and soil moisture conditions. Since the soils formed on the two mentioned locations are

Table 2. Semi-quantitative mineralogical composition of clay minerals of soils and parent rocks in the studied area.[a]

Landforms	Pedons	Parent materials	Soil moistures	Horizons	Smectite	Palygorskite	Illite	Chlorite	Kaolinite
Piedmont plain	1	Diorite	Xeric	Bw1	XXX	XX	XXX	ND	X
				R	XX	ND	XXXX	XX	X
Low land	2	Diorite	Aquic	Bg1	ND	ND	XXXXX	ND	XX
Mantel pediment	3	Andesite	Xeric	2Btk	XXXX	ND	XXX	ND	X
	4	Limestone	Aridic	Btk1	XX	XX	XXX	XXX	X
				2Ck	XX	XX	XXX	XX	X
	5	Diorite	Aridic	Btk	XXX	XX	XXXX	X	X
	6	Diorite	Aridic	Btn1	XXXXX	ND	XX	ND	X
				2Btk	XX	XX	XXXX	XX	X
	7	Diorite	Aridic	Bty	XXX	XX	XX	XX	X
	8	Andesite	Aridic	Bkyz1	XX	XX	XXX	XXX	X
	9	Diorite	Aridic	Btkyz	XXX	XX	XXX	XX	X
Rock pediment	14	Limestone	Aridic	Btk1	XX	XX	XXXX	ND	X
Playa	18	Playa deposit	Aquic	Bzn	XXX	XX	XXX	XX	X
				Btnz2	XXXX	ND	XXX	ND	X

[a] Relative abundance of clay minerals is shown by: X: < 10%; XX: 10-25%; XXX: 25-50%; XXXX: 50-75%; XXXXX: > 75%; ND: Not detected.

different (Haplustolls vs. Humaquepts), it is clear that climate (xeric vs. aridic) and topography (piedmont plain vs. lowland) played an important role on soil genesis and development in the area compared to parent material (both diorite).

Mantled Pediment

Mantled pediment covers a vast area in the region. Soils in this landform were affected by igneous (pedons 3 and 8), diorite (pedons 5-7 and 9), and sedimentary limestone (pedon 4) parent materials (Mohammadi, 2011) with two xeric and aridic soil moisture regimes. Argillic and calcic horizons were found in most pedons, but gypsic horizon was only found in the parts with an aridic soil moisture regime (Table 1). The argillic horizon (Figure 3-a) in the xeric parts of the area (pedon 3) could be due to the humidity of the area, whereas argillic in other pedons, with an aridic moisture regime, could only be attributed to the more available humidity of the past. Evidence of more humid paleoclimate in central Iran was reported by other researchers (Farpoor *et al*., 2012; Khormali *et al*., 2003; Khademi and Mermut, 2003).

Calcium Carbonate Equivalent (CCE) increased with depth (Table 1) in pedon 4 due to the presence of a calcareous parent material (about 89% in 2Ckk horizon). Besides, natric, salic, and anhydritic horizons were also investigated in mantled pediment position. Anhydrite in pedons 7 and 8 was probably formed from dehydration of gypsum at the later stages of evaporation through evolution of the landform. High temperature caused this mineral to be preserved (Sarmast *et al*., 2017; Wilson *et al*., 2013).

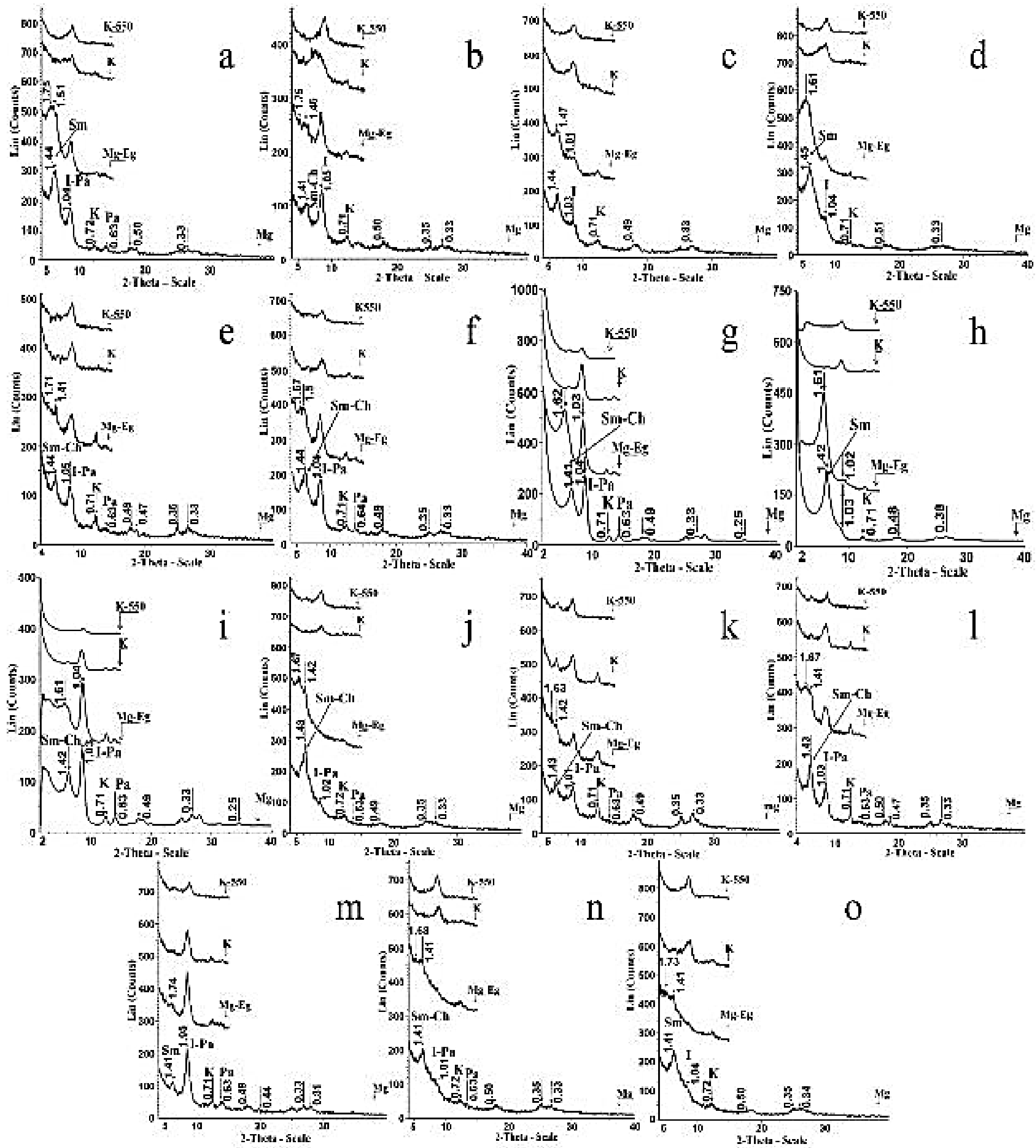

Figure 2. X-Ray diffractograms of the clay fraction: (a) Bw1 horizon of pedon 1, (b) R horizon of pedon 1, (c) Bg1 horizon of pedon 2, (d) 2Btk horizon of pedon 3, (e) Btk1 horizon of pedon 4, (f) 2Ck horizon of pedon 4, (g) Btk horizon of pedon 5, (h) Btn1 horizon of pedon 6, (i) 2Btk horizon of pedon 6, j) Bty horizon of pedon 7, (k) Bkyz1 horizon of pedon 8, (l) Btky horizon of pedon 9, (m) Btk1 horizon of pedon 14, (n) Bz horizon of pedon 18, and (o) Btnz2 horizon of pedon 18. (Sm: Smectite, I: Illite, Pa: Palygorskite, Ch: Chlorite, Ka: Kaolinite, Mg= Mg saturated, Mg-Eg= Mg saturated with Ethylene glycol, K= K saturated, and K-550= K saturated and heated to 550°C).

Pedons 3 and 8 with the same parent material (andesite) showed different evolutions. Pedon 3 in the xeric part of the area had an argillic horizon, whereas no argillic was found in aridic parts with about 1800 m asl. Climate seems to be the only factor controlling soil evolution in these pedons. Pedon 3 is an Alfisol, but the other pedons were classified as Aridisols (Table 1).

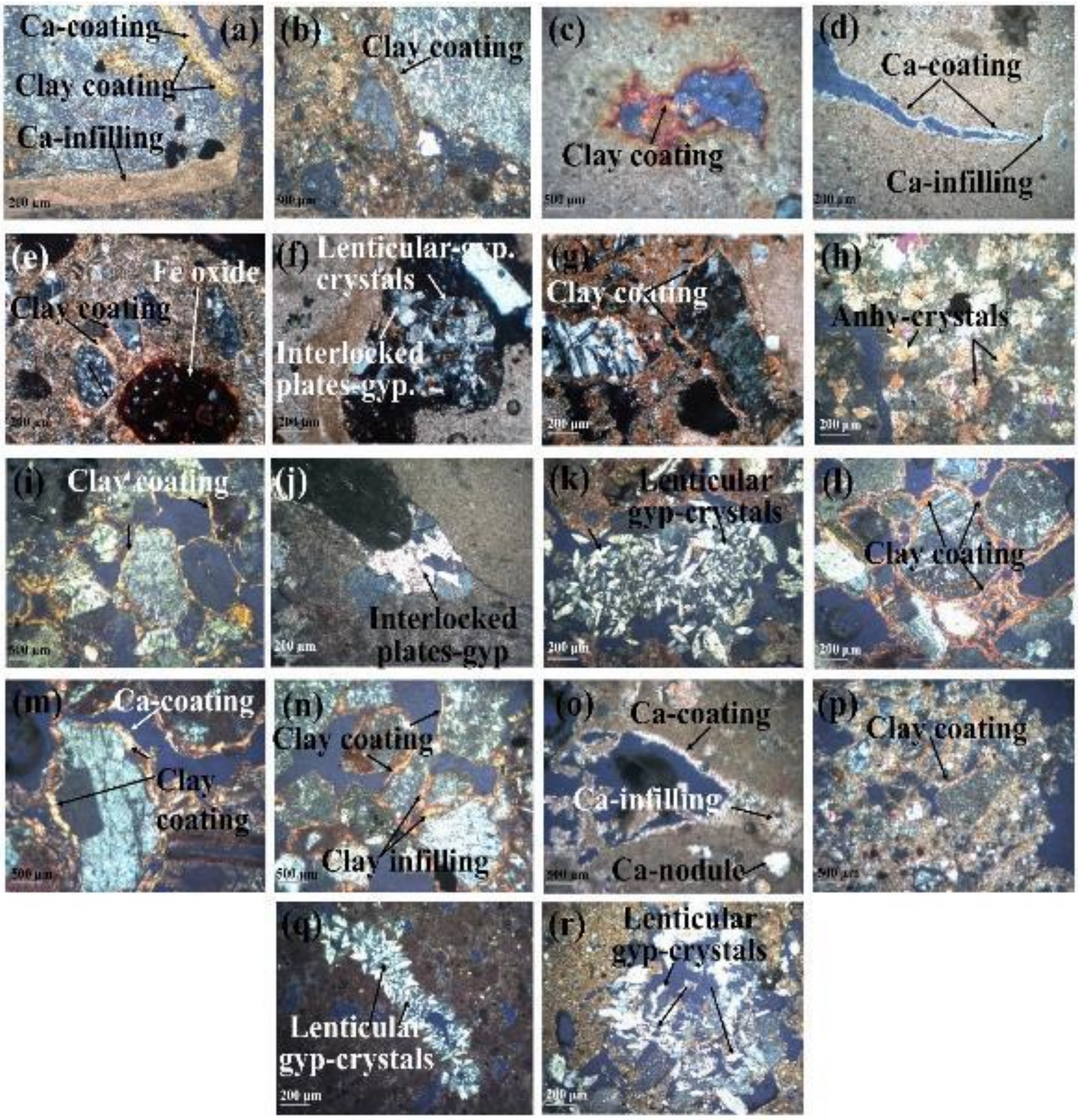

Figure 3. Thin sections of: (a) Clay and calcite coatings and dense incomplete calcite infilling in Btk horizon, pedon 3 (XPL), (b) Clay coating in Btk2 horizon, pedon 4 (XPL), (c) Clay coating in 2Btnkk1 horizon, pedon 4 (XPL), (d) Coating and infilling of calcite in 2Btnkk1 horizon, pedon 4 (XPL), (e) Clay coating and Fe oxide in Btk horizon, pedon 5 (XPL), (f) Interlocked plates and lenticular forms of gypsum crystals in By horizon, pedon 5 (XPL), (g) Clay coating in 2Btk horizon, pedon 6 (XPL),), (h) Anhydrite crystals in By1 horizon, pedon 7 (XPL), (i) Clay coating in Bty horizon, pedon 7 (XPL), (j) Interlocked plates of gypsum in Bkyzn horizon, pedon 8 (XPL), (k) Lenticular gypsum crystals in Btky horizon, pedon 9 (XPL), (l) Clay coating in Btky horizon, pedon 9 (XPL), (m) Clay and calcite coating in Btky horizon, pedon 9 (XPL), (n) Coating and infilling of clay in Bk horizon, pedon 11 (XPL), (o) Calcite coating, infilling, and nodule in Bk horizon, pedon 12 (XPL), (p) Clay coating in Btk1 horizon, pedon 14 (XPL), (q) Lenticular gypsum crystals in 3Btnzb1 horizon, pedon 16 (XPL), and (r) Lenticular gypsum crystals in Bz2 horizon, pedon 20 (XPL).

Micromorphological observations showed clay (pedons 3-7 and 9), calcium carbonate (pedons 3-4 and 9), gypsum (pedons 5, 8-9), anhydrite (pedon 7), and compound (pedons 3 and 9) pedo-features (Figure 3). Clay coating in pedon 3 (Figure 3-a) with a xeric soil moisture regime was probably formed in the present climatic conditions of the area. On the other hand, argillic horizon formation and clay coatings (Figures 3-b, -e, -g, -i, -l, and -m) in other pedons in this landform, with an aridic soil moisture regime, could only be attributed to the presence of a more humid climate in the past. This was also supported by Farpoor *et al*. (2012), Sanjari *et al*. (2011), and Kademi and Mermut (2003) in Sirjan playa, Jiroft, and Isfahan arid areas of central Iran, respectively. A different clay coating in 2Btnkk1 horizon of pedon 4 was observed (Figure 3-c), which was affected by high Na content. This type of clay coatings was reported for the natric horizons where dispersion was induced by Na. The same results were also reported for saline and sodic soils of Fars Province by Khormali *et al*. (2003).

Calcite coatings were observed on the clay coatings in Btk horizon of pedon 3 (Figure 2-a) and Btky horizon of pedon 9 (Figure 2-m). The mentioned order of coatings in pedon 3 could be formed at the climatic situations of the present time, but for the pedon 9 is a proof of clay illuviation during more available humidity of the past, followed by calcite illuviation along later aridity, as was also supported by Bayat *et al*. (2017) and Moghbeli *et al*. (2019). The compound clay-calcite pedo-feature is a proof of the formation of a polygenetic soil that has experienced different formation-development cycles due to climatic fluctuations.

Calcite coatings (Figures 2-a, -d, -m, and -o) are among the most important pedo-features that have formed through re-precipitation of illuviated calcium carbonates originating from upper horizons (Kemp *et al*., 2003). Dissolved calcium carbonate in the arid climate of the present time has formed infillings (Figures 2-d and -o) in the pore spaces (Durand *et al*., 2010). Sarmast *et al*. (2019) reported coating, infilling and nodule pedo-features of calcite in soils of central Iran.

Meanwhile, lenticular and interlocked plates of gypsum (Figure 2-f) in by-horizon of pedon 5 on mantled pediment were investigated. Soils of this pedon were not saline (Table 1) and were composed of high sand and coarse gravel contents. Large pore space content of the soil could facilitate lenticular formation of gypsum, as was also supported by Amit and Yaloon (1996) and Farpoor *et al*. (2012) in Israel and central Iran, respectively. The same mechanism could also be attributed to the lenticular gypsum formation in Btky horizon of pedon 9 (Figure 3-k). Gypsum pendants (macroscopic form) and gypsum interlocked plates (microscopic form) in pedons 5 and 8 were attributed to coarse texture and high gravel content of pediments (Farpoor *et al*., 2003). Meanwhile, anhydrite was also formed in By1 horizon of pedon 7 (Figure 3-h), seemingly during gypsum transformation. The same results were reported by Aref (2003) and Sarmast *et al*. (2019) in soils of Egypt and central Iran, respectively.

Smectite, illite, and kaolinite clay minerals were found in pedon 3 (Table 2, and Figure 2-d). Palygorskite and chlorite could not be formed or had been weathered in this position due to a xeric moisture regime. Smectite was the dominant clay mineral in this pedon (Table 2). Moreover, smectite, illite, chlorite, kaolinite, and palygorskite were found in soil (Btk1) and parent material (2Ck) of pedon 4 (Table 2, Figures 2-e and -f). The presence of the above-mentioned minerals in soils and parent material is a proof of inheritance origin from the sedimentary formations that was also supported by Owliaie *et al*. (2018) for soils located on sedimentary formations of southwest Iran.

On the other hand, smectite, illite, chlorite, palygorskite, and kaolinite clay minerals were identified in other pedons (5-9) on this landform, which were affected by igneous formations (Table 2, and Figures 2-g to -l). No palygorskite was found in the igneous parent material (Figure 3-b), but calcic (Figure 2-i) and gypsic (Figure 2-j) horizons contained palygorskite. Geochemical conditions after the precipitation of calcium as calcium carbonate and gypsum in the arid climate of these pedons seem to have been favorable for palygorskite formation together with the increase of soluble Mg

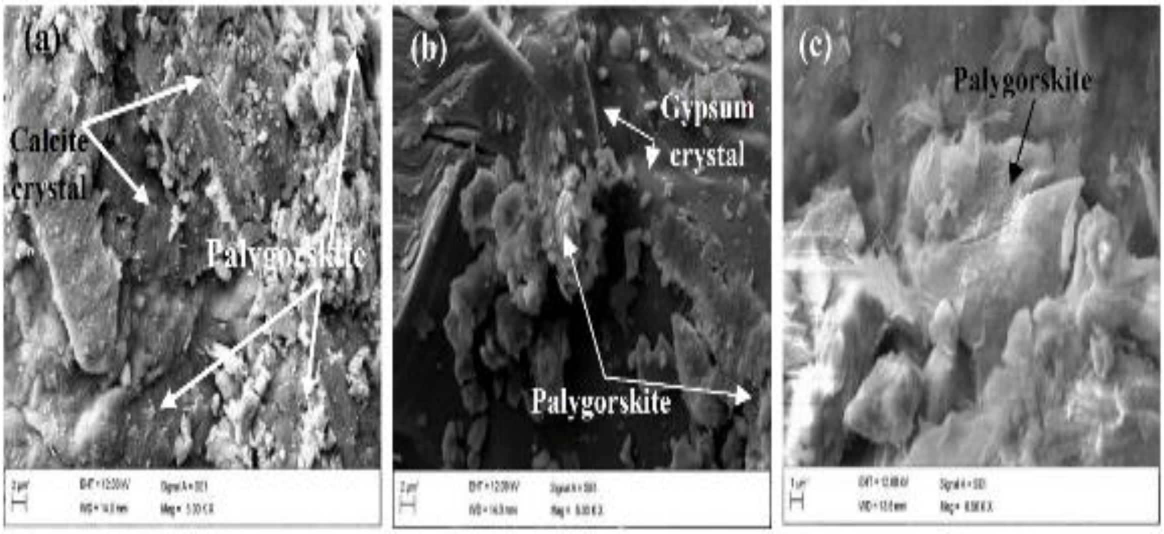

Figure 4. SEM micrographs of: (a) Palygorskite fibers on calcite crystal of the 2Btk horizon of pedon 4, (b) Palygorskite fibers on gypsum crystal of the Bty horizon of pedon 5, and (c) Palygorskite broken fibers of the Bzn horizon of pedon 18.

(Singer and Fine, 1989). A pedogenic origin for palygorskite in calcic (2Btk) horizon of pedon 6 (Figure 4-a) and gypsic horizon (Bty) of pedon 7 (Figure 4-b), both affected by igneous formations proved using electron microscope observations. Preservation of palygorskite around calcite (Khademi and Mermut, 1998) and gypsum (Owliaie *et al*., 2018; Moazallahi and Farpoor, 2012; Khademi and Mermut, 1998) crystals in soils and sediments of central Iran were also reported. Moreover, the lack of palygorskite and chlorite in the modern topsoil of pedon 6 (Figure 2-h) could be attributed to the Halilrood River floods, which may have caused their transformation to smectite (Birkeland, 1999). Smectite is the dominant mineral in the modern topsoil of pedon 6 (Table 2) and is another support for the above-mentioned discussion. Thus, both pedogenic and inherited origins for smectite in soils of the area are plausible (Sanjari *et al*., 2011).

Pedons 3 and 8, with the same parent material and geomorphology, but different soil moisture regime, have different soils. This is a proof for the important role of climate in soil formation compared to p (parent material) and r (relief) as soil forming factors in this part of the area. On the other hand, pedons 4 to 9 have the same geomorphology and climate, but parent material for pedon 4 (limestone) was different with other pedons (diorite). Results clearly show that, somehow, similar soils were formed in these pedons and limited differences in the suborder level were only observed. This, in turn, shows the high effective role of climate and geomorphology on soil formation in this landform.

Alluvial Fan

Similar to mantled pediment, soils with various evolution were found in this landform. Soil moisture regime for alluvial fan is aridic, which is why different soil evolutions (pedons 10-13) could be due to the difference in parent material (Table 1). Pedons 10 (east of Jiroft) and 13 (east of Iranshahr), located on young alluvial fan deposits and affected by granite formations, showed very little soil development. The large distance from Neogene gypsiferous and saline formations on one hand, and the young quaternary alluvial fan deposits on the other hand, are among the inhibiting factors controlling soil development in this geomorphic position. Moreover, the formation of bajada due to rainfall and the erosion of upland mountains in these two locations, which are in the arid zone climate, could be evidence of a more humid climate in the past. The same results were also reported by Sarmast *et al*. (2017) in the study of alluvial fans in the central parts of Iran. Pedons 11 (with argillic and calcic horizons) and 12 (with calcic horizon), respectively, were affected by limestone and diabase (influenced by Mokran colored melange) parent materials showed soils with high and intermediate evolution located on old alluvial fan deposits. Micromorphological observations showed clay coatings and infillings in Btk horizon of pedon 11 (Figure 3-n), which are supporting proofs of argillic horizon formation. Calcite coating, infilling, and nodules were also determined in Bk horizon of pedon 12 (Figure 3-o). Formation of calcite nodule (Figure 3-o) in the Btk horizon of pedon 12 was due to dissolution/recrystallization of calcite in the groundmass. Sarmast *et al*. (2019) reported coating, infilling, and nodule pedo-features of calcite in soils of central Iran. Entisols and Aridisols were formed on this geomorphic position.

Pedons 10 to 13 have the same geomorphology (alluvial fan) and climate (aridic soil moisture regime), but different parent material (igneous in pedons 10 and 13 vs. sedimentary in pedons 11 and 12). Formation of different soils is a proof of the role of parent material and time on soil formation when other soil formation factors are the same.

Rock Pediment

This geomorphic position, about 800 m asl and with an aridic soil moisture regime, is affected by limestone together with shale and marl as parent material. Pedon 14 with argillic, calcic, and gypsic horizons were described and sampled on this position. Due to low SAR content (Table 1) and an aridic soil moisture regime, presence of argillic horizon, similar to other arid parts of Jazmurian Watershed, was attributed to the more available humidity of the past. That is why this soil was accounted as a paleosol. Removal of calcium carbonate from upper horizons with more humidity of the past (Bk horizon formation) followed by clay illuviation caused Btk horizon to be formed (Sanjari *et al*., 2011). Clay coating proved illuviation of clay and argillic horizon formation (Figure 3-p). Clay mineralogy of this soil was similar to mantled pediment position (Table 2, and Figure 2-m). This soil was classified as Typic Calcigypsids.

Playa

Sodic clay flat (pedon 15), clay flat (pedon 16), fan delta (pedon 17), wet zone (pedon 18), puffy ground clay flat (pedon 19), and salt crust (pedon 20) geomorphic surfaces were found in playa about 360 m asl (Figure 1). Salic and natric were the dominant horizons found in soils of this landform. High Na content caused clay dispersion and natric horizon formation in some pedons of this position, as was also supported by Khormali *et al*. (2003). A modern and a buried paleosol were found (pedon 16) on clay flat geomorphic position. The modern soil with A and C horizons was a young soil affected by alluvial deposits, and 2Cz horizon showed the influence of aeolian deposits. Active wind erosion of the upland positions caused wind-blown deposits in this horizon. On the other hand, the buried soil is a developed soil with salic and natric horizons. Meanwhile, a non-saline (Table 1) Fluvisol (pedon 17) was found on fan delta geomorphic surface. Formation processes of fan delta position and the role of Halilrood River, with a non-saline water, could be accounted for a non-saline soil to be formed in pedon 17.

Wet zone with an aquic soil moisture regime was located between alluvial fan and clay flat positions. The same geomorphic position was also reported by Farpoor *et al*. (2012) in Sirjan Playa. High EC in the topsoil of puffy ground clay flat was attributed to evaporation and capillary water movement in this geomorphic position (Sanjari *et al*., 2011). The thickness of salt polygons in the salt crust geomorphic position of the area was less than that reported for other playas (Sirjan, and Lut) of central Iran. Bampour seasonal river, which has passed through evaporate formation of east side watershed, contains more soluble salts compared to non-saline Halilrood River. Salt crust seems to be affected by Bampour River. Soils of this position were classified as Entisols and Aridisols (Table 1).

Lenticular gypsum crystals were observed in 3Btnzb1 (pedon 16) and Bz2 (pedon 20) horizons. Soils in this position were fine textured with small pore spaces and high salinity (Table 1). The reason could be attributed to the NaCl content (Amit and Yaloon, 1996) together with super saturation in respect to calcium sulfate in the fine pore spaces along time periods (Owliaie *et al*. 2006). Since gypsum content was not enough, gypsic horizon was not detected in these pedons.

Palygorskite was not detected in Btnz2 horizon of pedon 18 on wet zone geomorphic position (Figure 2-o). Due to high humidity content in this position (presence of an aquic soil moisture regime), transformation of palygorskite to smectite, which was also reported by Khormali and Abtahi (2003) and Moghbeli *et al*. (2019), could not be neglected in this position. The dominance of smectite in this soil (Table 2) could be another support for the above-mentioned discussion. Since smectite was also determined (Figure 2-n) in the Bz horizon (near the soil surface), it seems that the detrital origin of smectite addition to the surface could be another plausible reason. The intense 0.63 nm peak of palygorskite was also due to the detrital transportation of broken palygorskite crystals from alluvial fan toward this position. That is why palygorskite in this geomorphic position is with a detrital origin, which was also supported by split crystals observed using electron microscopy (Figure 4). Farpoor and Irannejad (2013) and Khademi and Mermut (1998) also came to the same conclusion in Rafsanjan and Isfahan areas, central Iran.

Parent material and climate for pedons 15 to 20 are the same, but geomorphic surfaces have only changed, which caused differences in order and suborder levels of soils formed in playa. This shows the role of topography (r) apart from climate and parent material in soil formation.

CONCLUSIONS

Various soils were formed through the climolithotoposequence studied in Jazmurian Watershed. The electrical conductivity content increased toward playa and the maximum EC content of 222.2 dS/m was determined in salt crust geomorphic position of playa. Soil evolution was highly depended on parent material and the decreasing trend of soil evolution (Granite-young alluvial fan deposits< Playa deposits< Limestone-old alluvial fan deposits< Andesite- diorite) was found in the area. Soils were classified as Mollisols, Alfisols, Aridisols, Inceptisols, and Entisols. Different pedo-features in argillic and calcic horizons in both xeric and aridic soil moisture regimes of the area were found. However, pedo-features related to gypsic and anhydritic horizons were only found in the arid parts of the transect. The presence of a more humid paleoclimate in the history of the area, which was supported by clay coatings, was proved by argillic horizons formed in the arid parts of the area. A dispersed clay coating was found in natric horizons. Smectite, illite, chlorite, palygorskite, and kaolinite clay minerals were identified. Palygorskite was only found in the arid parts of the area and pedogenic and inherited origins were found, respectively, in igneous and sedimentary affected soils. Palygorskite in piedmont plain about 3620 m asl was with an aeolian origin. Illite and chlorite clay minerals were identified in both sedimentary and igneous parent materials with an inherited origin, but lack of these minerals in some of the soils under study could be attributed to their transformation to smectite, which was also supported by smectite peak intensity in such soils. That is why both inherited and transformed (from illite, chlorite, and palygorskite) sources of smectite in the area were plausible.

Results of the study emphasized on the more effective role of climate and relief on soil formation compared to parent material. The role of climate, alone or together with relief on soil formation and evolution in pedons 1 to 9, seems to be greater than that of parent material. Since climate and relief have not changed along pedons 10 to 14, parent material affected soil formation and evolution. Moreover, relief has controlled soil formation and development in pedons 15 to 20, as climate and parent material were the same in these pedons. The hypothesis regarding the effects of climate, topography, and parent material on soil formation and development (climolithotoposequence) in the area was clearly proved.

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خاک‌زایی و کانی‌شناسی رسی یک توالی کلیمولیتوتوپوسنس در حوضه آبخیز جازموریان، ایران مرکزی

صالح سنجری، و محمد هادی فرپور

چکیده

توپوگرافی، مواد مادری و آب و هوا از عوامل حیاتی مؤثر بر خاک‌زایی و کانی‌شناسی رسی خاک‌ها هستند. داده‌های کمی در مورد خاک‌ها و رسوبات حوزه آبخیز جازموریان در جنوب مرکزی ایران وجود دارد. این مطالعه، اشکال مختلف زمین، از جمله پدیمنت‌های سنگی و پوشیده، مخروط‌افکنه‌ها، دشت‌های دامنه‌ای، زمین‌های پست و پلایا که با مواد مادری آذرین و رسوبی مشخص می‌شوند و در رژیم‌های رطوبتی خاک آکوئیک، زریک و آریدیک قرار دارند را برای بررسی پیدایش خاک و کانی‌شناسی رسی در منطقه انتخاب کرد. یافته‌ها نشان داد که برخلاف خاک‌های کمتر توسعه‌یافته یافت‌شده در رسوبات مخروط‌افکنه‌های جوان‌تر، مهم‌ترین توسعه خاک در پدیمنت‌های سنگی و پوشیده و همچنین در رسوبات مخروط‌افکنه‌های قدیمی‌تر رخ داده است. کانی‌های رسی شامل اسمکتیت، ایلیت، کلریت، پالیگورسکیت و کائولینیت بودند. وجود پالیگورسکیت در خاک‌های رسوبی به ارث رسیدن از ماده مادری نسبت داده شد، در حالی که در خاک‌های مشتق شده از ماده مادری آذرین، از طریق فرآیندهای خاکسازی تشکیل شده است. ویژگی‌های خاکسازی مرتبط با کربنات کلسیم در هر دو رژیم رطوبتی خاک آریدیک و زریک مشاهده شد. وجود ویژگی‌های خاکسازی رسی در مناطق خشک حوزه آبخیز ممکن است نشان‌دهنده یک آب و هوای دیرینه تاریخی با رطوبت بیشتر باشد. برعکس، اشکال عدسی شکل، صفحات در هم تنیده و پر شدن گچ منحصراً در مناطق خشک و ارتفاعات پایین‌تر حوزه آبخیز مشاهده شد که منعکس کننده آب و هوای خشک فعلی است.

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