J. Agr. Sci. Tech. (2022) Vol. 24(6): 1331-1343

Using Nanotechnology in Food Production: Ensuring Food Security Development in Iran

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ABSTRACT

In recent years, nanotechnology has been increasingly used in the food industry, especially to increase the food security. Nanotechnology provides the grounds to understand the food components on a small scale in the food industry. The present study aimed at analyzing the application of nanotechnology to improve the food security. The study sample included all experts (N= 90) of Iran's Nanotechnology Innovation Council selected by a census. This study used a descriptive-survey method. A questionnaire was developed based on the study's theoretical framework and used for data collection. The validity (content and face) and reliability (factor loading, coefficient of composite reliability, and Cronbach's Alpha coefficient) of the questionnaire were confirmed. The results of testing the hypotheses using Smart PLS, i.e., t-test and path coefficients (β), showed that the food packaging mechanisms directly and significantly affected food security improvement through using nanotechnology. The findings also displayed that the food preservation, processing, and production mechanisms influenced food security improvement through using nanotechnology. By using nanotechnology, the results indicated a direct relationship between foods' taste and color improvement as well as food safety and health improvement.

Keywords: Food-packaging mechanisms, Food safety, Iran's Nanotechnology Innovation Council.

[DOI: 10.52547/jast.24.6.1331]

INTRODUCTION

In today's world, the food security and safety are among the most important priorities of many countries (Hosseini Nejad and Samadi, 2012). Food security is a condition in which all people have physical and economic access to adequate, healthy, and nutritious food. This available food provides individuals all dietary requirements compatible with their preferences for an active and healthy life [Food and Agriculture Organization (FAO), 2019; Tiwari Pandey *et al*., 2020] and has four main dimensions, including availability, access, utilization, and stability (FAO, 2010; Varis *et al*., 2017).

However, several studies indicate that, currently, millions of people in the world lack a satisfactory level of food security. Moreover, there will be a serious risk of nutrition shortages in more than nine billion people in 2050 (Smyth *et al*., 2015; See *et al*., 2015). Evidence shows that food insecurity is a prevalent phenomenon in developing countries and is gradually increasing (Bala *et al*., 2014). Based on the FAO's estimation, up to 113 million people experienced severe hunger in 53 countries in 2019. The Global Report on Food Crises (GRFC) (2020) estimated that around 75 million stunted children were living in 55 food-crisis countries. These children had

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limited access to sufficient dietary energy, nutritionally diverse diets, clean drinking water, sanitation, and health care, which weakened their health and nutrition status, with negative consequences for their development and long-term productivity. Therefore, the need for new technologies to protect the food chain is currently felt more than ever (Fanar *et al*., 2017).

Considering the inevitable demand intensification and because of the population growth and increased income in developing nations, nanotechnology has become more significant as a part of the value chain in many companies of the food sector (Fanar *et al*., 2017).

Various studies (Krishnan *et al.*, 2018; Pathakoti *et al.*, 2017; Fanar *et al*., 2017, Hosseini Sadr *et al*., 2017; Faraji, 2016; Salimi and Motakef Kazemi, 2016;d He *et al.*, 2015) have confirmed nanotechnology influence on the food security. For instance, Krishnam *et al.* (2018) stated that nanotechnology was widely used in many sectors, including healthcare, pharmaceutical industries, agriculture, food processing, transportation, energy, and information technology. In addition, this technology could change the structure of food and agriculture industries, where it can be used to identify the molecular behavior, rapid detection, and plants' ability to absorb nutrients.

Considering the above-mentioned studies and according to the Food and Nutrition Monitoring Information System, half of the population in Iran suffer from food insecurity (Morshedi and Maarefvand, 2014).

According to Kolahdoz and Najafi (2018), Tehran, Yazd, Fars, and Isfahan are classified in the secure food state category. Nevertheless, the studies carried out in 2004-2005, revealed that there was 30% food insecurity in Yazd (Karam Soltani *et al*., 2007), 36% in Isfahan (Mohammadzadeh *et al*., 2010), 55.5% in Fars (Morshedi *et al*., 2015), and 43.7% (Mohammadi *et al*., 2012) to 53% (Qomi *et al*., 2012) in Tehran. Furthermore, the results of Savari *et al*. (2014) and Ghadiri *et al*. (2015) exhibited an unfavorable food security state in rural households.

No study was found in the literature focusing on the role of nanotechnology in improving Iran's food security. Therefore, this study aimed to examine experts' opinions about mechanisms that could be used for improving the food security by applying nanotechnology. Accordingly, the main objectives of this study were: Identifying and analyzing nanotechnology application mechanisms to improve the food preservation, processing, production, taste, safety and packaging from the viewpoint of experts.

MATERIALS AND METHODS

This study was an applied research aiming at identifying effective mechanisms that contribute to nanotechnology utilization for food security improvement. Moreover, it was a quasi-experimental study, which utilized a quantitative method. The statistical population included the experts from Iran's Nanotechnology Innovation Council (N= 90), selected through a census. This study used a questionnaire developed by the authors as the main research instrument to collect the required data. A five-point Likert scale was used for measuring the responses' values, ranging from "very low" to "very high", and scored from one to five.

The questionnaire consisted of two components: application of nanotechnology and food security. In the application of nanotechnology, six dimensions (food preservation, food processing, food production, improvement of food taste and color, food health and food packaging) and in the food safety section, four dimensions (accessibility, existence, stability, and use) were examined (Table 1)

Three validity types, including the content validity, convergent validity, and divergent validity, were used to confirm the validity of developed questionnaire. The content validity indicates the compatibility among

[DOI: 10.52547/jast.24.6.1331]

Table 1. Reviewing the significant coefficients of applying nanotechnology in the food security.

Variable	Dimensions		Questions	Factor loading	t-Value
Applying nanotechnology	Food preservation	X1	Disinfecting the coating's surface	0.841	21.144
		X2	Controlling enzyme activity	0.849	24.111
		X3	Using Silver Nanoparticles (AgNps) as antimicrobial factors	0.753	15.669
		X4	Coating fruits and vegetables using copper nanocytosanes	0.840	28.350
		X5	Using polymer nanoparticles and liposomes	0.912	52.689
		X6	Using nanoemulsions and micromulsions	0.744	10.995
		X7	Using nanosensors and nanobots	0.797	14.821
		X8	Using nanofilters	0.771	14.110
	Food processing	X9	Protecting nutrients against oxidation	0.830	17.338
		X10	Bad aroma trapped in food	0.916	45.745
		X11	Using Nanosized food through nanoencapsulation	0.877	27.081
		X12	Nanoencapsulation of vitamins in fortified beverages containing vitamins or biomaterials	0.880	21.397
		X13	Degradation protection during processing	0.884	32.034
	Food production	X14	Analysis and identification of agricultural products to detect various pests and genes	0.798	14.698
		X15	Production of biocompatible pesticide formulations	0.879	30.372
		X16	Using new gelatinizing or viscous compounds	0.839	20.291
		X17	Using recombinant DNA technology to produce new proteins with distinctive properties that do not exist in nature	0.817	21.271
		X18	Production of medical foods and supplements and necessary vitamins	0.812	20.924
	Flavor and aroma improvement	X19	Detection of any changes in the food (reaction to light, heat, moisture, gas, and chemicals) using nanoparticles and nanofibers	0.848	25.648
		X20	Using nanosensors to show changes in food's color and smell	0.842	20.463
		X21	Production of food additives using emulsions, such as natural extracts, to disinfected foods	0.889	39.373
		X22	Nanoencapsulation of various aromas and flavors in the food to control the release of aromas and flavors	0.870	21.117
	Food safety	X24	Using nanosensors to detect any fraud in food industry	0.826	19.520
		X25	Using intelligent conduction systems to fight against viruses and pathogens of agricultural products	0.829	20.799
		X26	Using nanosensors to ensure the food safety	0.892	27.989
		X27	Using nanosensors to detect pathogens in the food	0.900	31.865
		X28	Disinfection of the food factory equipment by antimicrobial nanoemulsion	0.854	23.019
Food security		X29	Using nanosensors in smart packaging to monitor the food temperature and humidity	0.798	16.106
		X30	Using nanoparticles with antimicrobial property for packaging	0.912	39.161
		X31	Using Silver Nanoparticles (AgNps) as antimicrobial factors in the food packaging	0.792	16.076
	Packaging	X32	Using zinc oxide as an antimicrobial factor in the food packaging	0.826	20.936
		X33	Using plastic layers with nanostructures to prevent the invasion of pathogens and microbes	0.891	32.609
		X34	Using smart packaging to respond to microbial and biochemical changes	0.865	24.275
		X35	Using nanocomposites in the food packaging	0.871	26.234
		X36	Using packages emitting sulfur dioxide to avoid the mold growth and development	0.789	15.779
		X37	Increasing food's bioavailability and effectiveness	0.823	16.558
		X38	Production of biopolymer nanocomposites from starch for food and industrial applications	0.834	22.677
		X39	Using ethylene-absorbent bags to delay the product ripening and growth	0.854	18.991
		X40	Using nanoclay in plastic bottles to reduce the gas and oxygen permeation	0.777	11.856

Table 1 Continued…

[DOI: 10.52547/jast.24.6.1331]

Continued of Table 1. Reviewing the significant coefficients of applying nanotechnology in the food security.

Variable	Dimensions		Questions	Factor loading	t-Value
Food security	Accessibility	X41	Food hygiene	0.974	126.757
		X42	Food's quality and security	0.978	141.237
		X43	Access to clean water and health facilities	0.960	75.275
	Availability	X44	Production (domestic supply) and import of the food	0.916	33.506
		X45	Availability of food reserves and food aids	0.962	106.816
		X46	Increasing food reserves	0.933	58.695
	Stability	X47	Sufficient supply	0.900	41.409
		X48	Increasing revenue	0.932	53.751
		X49	Reducing fluctuations in agricultural production	0.918	41.194
		X50	Offering reasonable price	0.955	100.714
		X51	Access to shopping centers (Local markets, department stores, grocery stores)	0.915	35.979
		X52	Properly functioning of the country's transportation system	0.926	49.310
	Use	X53	Food price control	0.921	36.074
		X54	A sustainable food production system	0.950	78.557
		X55	Political stability	0.947	63.725
		X56	Lack of fluctuations in domestic food prices	0.920	33.906

measurement indices and the existing literature, which was confirmed by the university professors in our research. Divergent validity was measured by comparing the square root of AVE with the correlation among latent variables (Table 2). It should be noted that the square root of AVE must be higher than the correlation among the structure and other structures of each model's reflective structure (Choua and Chen, 2009). The current study also used two criteria i.e., Cronbach's Alpha coefficient and coefficient of composite reliability to determine the reliability of the questionnaire according to Fornell and Larcker (1981). The Cronbach's Alpha coefficient was calculated for all variables and was at least 0.7. Tables 2 and 3 demonstrate the reliability and validity of the measurement instrument in detail.

According to the output of Smart PLS3, the instrument has satisfactory validity (content, convergent, and divergent validity) and reliability (factor loading, coefficient of composite reliability, Cronbach's Alpha coefficient) (Tables 2 and 3).

Table 2. The convergent validity and measurement instrument's reliability.

	Research variables	Average Variance Extracted (AVE)	Coefficient of Composite Reliability (CR)	Cronbach's Alpha coefficient
Nanotechnology application	Food preservation	0.664	0.940	0.927
	Food processing	0.770	0.944	0.925
	Food producing	0.688	0.917	0.886
	Taste and color improvement	0.762	0.927	0.895
	Food safety	0.741	0.935	0.912
	Packaging	0.701	0.966	0.961
Food security	Accessibility	0.942	0.980	0.969
	Availability	0.878	0.956	0.931
	Stability	0.855	0.972	0.966
	Utilization	0.874	0.965	0.952

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Table 3. The correlation matrix and divergent validity investigation.

	Food preservation	Food processing	Food production	Taste and color improvement	Food health	Packaging	Utilization	Availability	Accessibility	Stability
Preservation	0.814*									
Processing	0.801	0.877*								
Food producing	0.272	0.651	0.829*							
Taste and color improvement	0.627	0.192	0.326	0.827*						
Food safety	0.139	0.071	0.624	0.751	0.860*					
Packaging	0.422	0.548	0.484	0.285	0.156	0.837*				
Utilization	0.060	0.172	0.86	0.536	0.270	0.538	0.970*			
Availability	0.424	0.518	0.349	0.504	0.376	0.661	0.526	0.937*		
Accessibility	0.498	0.400	0.153	0.375	0.206	0.048	0.106	0.130	0.924*	
Stability	0.353	0.348	0.514	0.254	0.118	0.074	0.233	0.571	0.415	0.934*

$\sqrt{AV}$= *, AV= Average Variance extracted.

RESULTS AND DISCUSSION

The results of descriptive analysis showed that the majority of respondents had expertise in food industry. The average years of experts' experience in Iran's Nanotechnology Innovation Council was nine. In the next stage, the relationships among variables were investigated using PLS method’s structural model. The results were obtained in two states, consisting of t-values and standardized estimation. At first, bootstrapping in Smart PLS was used to confirm the hypotheses, showing that the output has been resulted from t coefficients (Figure 1). According to the findings, the t coefficients were above 1.96, which confirmed the hypotheses. Table 1 shows the results of the model's significant coefficients in terms of t-values.

After the standardized estimation, the causal relationships among the variables were measured by Smart PLS. Based on the results presented in Figure 2, it is determined that there were significant relationships among the main variables. With a standardized coefficient of 0.968, the food packaging mechanisms had a positive and significant effect on the improvement of food security.

The results show that food preservation, processing, production, taste and color, and safety mechanisms with a standardized coefficient of 0.951, 0.947, 0.923, 0915, and 0.951, respectively, have a positive and significant effect on food security improvement.

Table 4 presents the results of the model implementation in two states of t-values and standardized coefficients' estimation.

Table 4 illustrates that in applying nanotechnology model in food security improvement, the food packaging mechanisms using nanotechnology with R^2= 0.937 had the greatest impact on food security. Then, the food storage mechanisms with R^2= 0.903, food processing mechanisms with R^2= 0.895, food production mechanisms with R^2= 0.850, food taste and color improvement

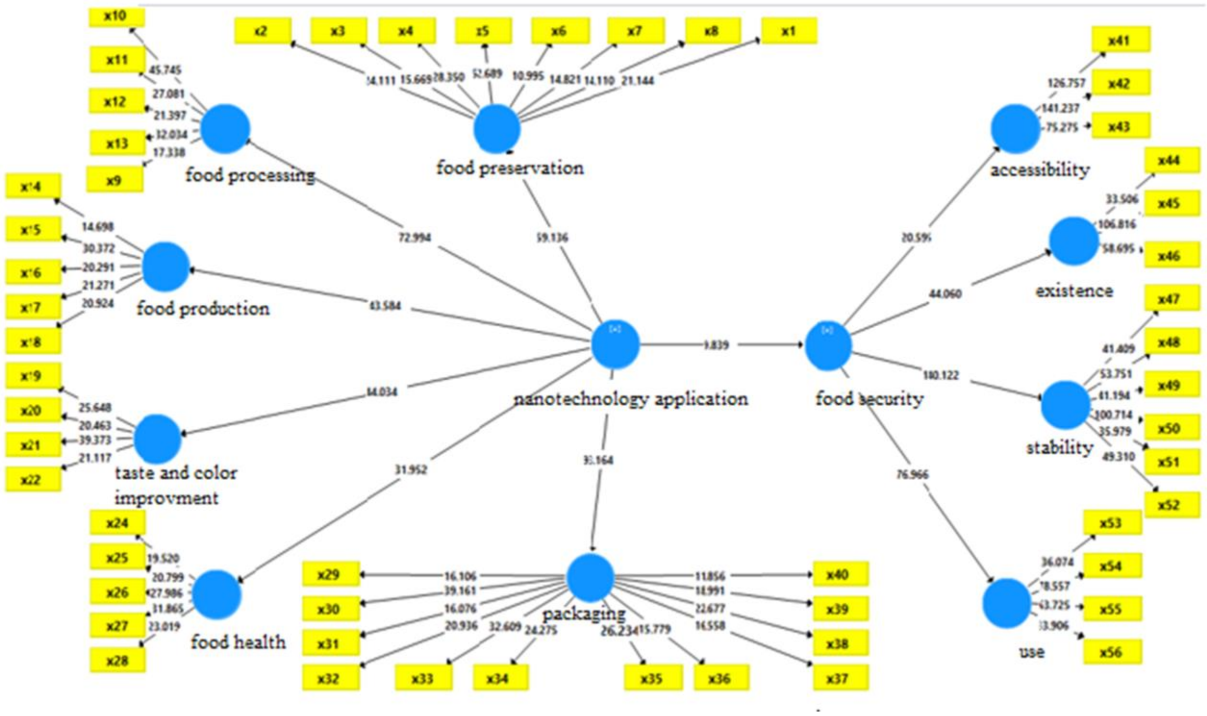

Figure 1. Model implementation in the t-values' state.

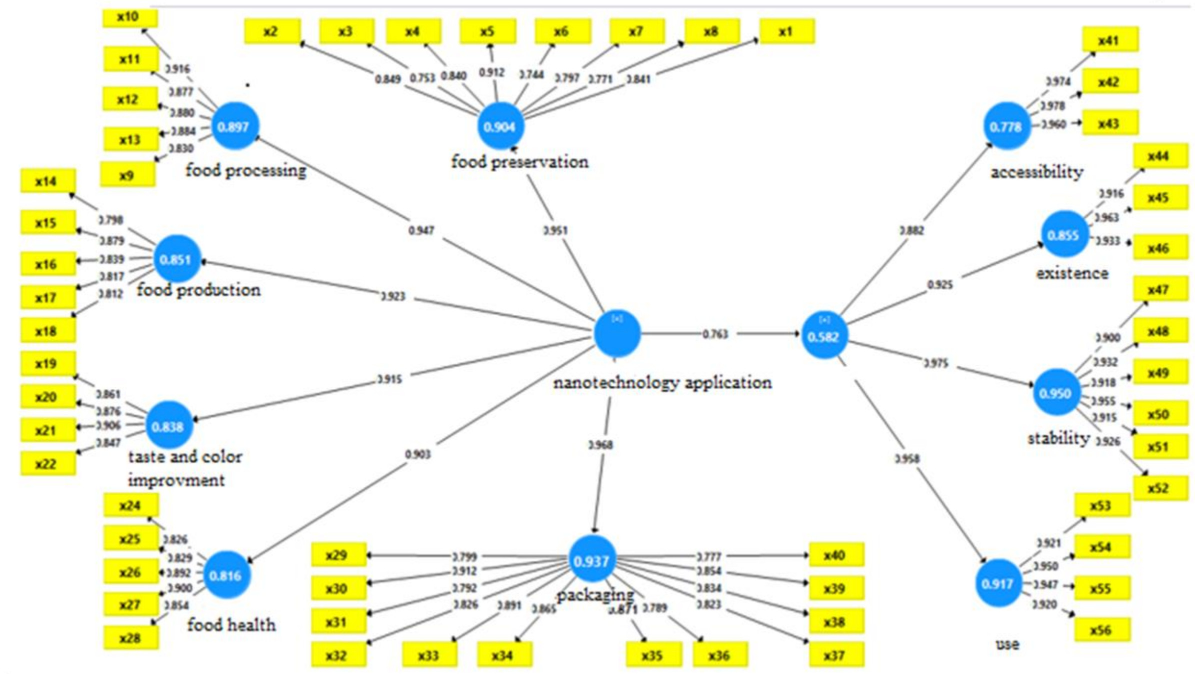

Figure 2. Model implementation in standardized estimation state.

[DOI: 10.52547/jast.24.6.1331]

Table 4. The results of hypotheses testing.

Hypothesis	Variables' path	Standardized coefficients	t-Value	R^2	Result
H6	Food packaging mechanisms using nanotechnology → food security improvement	0.968	93.164	0.937	Confirmed
H1	Food preservation mechanisms using nanotechnology → food security improvement	0.951	59.136	0.903	Confirmed
H2	Food processing mechanisms using nanotechnology → food security improvement	0.947	72.994	0.895	Confirmed
H3	Food production mechanisms using nanotechnology → food security improvement	0.923	43.584	0.850	Confirmed
H4	Food taste and color improvement mechanisms using nanotechnology → food security improvement	0.915	44.034	0.846	Confirmed
H5	Food safety mechanisms using nanotechnology → food security improvement	0.903	31.952	0.813	Confirmed

mechanisms with R^2= 0.846 and food safety mechanisms with R^2= 0.813 using nanotechnology were placed at the next ranks in terms of their impact on improving the food security.

Finally, to determine whether this prediction is sufficiently strong or not, the last test, which is the general model test, was performed.

According to the following formula, model's goodness of fit was investigated using the Goodness Of Fit (GOF) criterion:

$$\text{GOF}=\sqrt{\sum Comunality * \sum R^2}$$

$$\text{GOF}=\sqrt{0.591 * 0.873 = 0.718}$$

In current study, the value of 0.718 was obtained for GOF, which shows the model's goodness of fit (Wetzels *et al*., 2009).

The use of innovative technologies in the food industry is a new approach that has received much attention. Undoubtedly, turning to new technologies including nanotechnology can solve many problems in this area. Due to the widespread prevalence of foodborne illnesses, the need to use sensitive and prompt methods to diagnose pathogens is essential. Therefore, one of the new techniques of food security improvement is the nanotechnology application.

The results of the study indicated that the packaging mechanisms had an impact on improving the food security. It is important to use nanoparticles with antimicrobial properties in copper packaging; generally, the consumers prefer to use nanotechnology in food packaging. This result is consistent with the findings of Krishnan *et al*. (2018); Hosseini Sadr *et al*. (2017); Pathakoti *et al*. (2017); Omanović-Mikličanin *et al*. (2016); Faraji (2016); Rashedi *et al*. (2016); Huanga *et al*. (2015); Berekaa (2015); Eshghi *et al*. (2013); Mir Saeed Ghazi *et al*. (2013); Liaghati *et al*. (2012); Fathi and Mohebbi (2010); DehYouri and Farajollah Hosseini (2009) and Azeredo and Henriette (2009).

It was found that the preservation mechanisms had a direct relationship with food security improvement. It should be noted that coating fruits and vegetables using copper-chitosan nanoparticles is considered as an important nanotechnology application in the food industry. Edible coatings are also among the most innovative methods to maintain the quality and extend the freshness of fruits and vegetables. This is because such coatings act as a barrier against moisture, oxygen, and UV. This result is in line with the findings of Fanar *et al*. (2017); Salimi and Motakef Kazemi (2016); Berekaa

[DOI: 10.52547/jast.24.6.1331]

(2015); Maghabl *et al*. (2014), and Costa *et al*. (2011).

Moreover, the results confirm that the nanotechnology-based food processing mechanism has an impact on improving the food security. Oxidation destabilizes oil drops in emulsified food products, which changes the oil chemical structure, and will ultimately spoil the food. This oxidation happens in a wide range of food products and reduces their shelf-life. This finding is consistent with the results of Fanar *et al*. (2017), Salimi and Motakef Kazemi (2016), Kumar and Pathera (2014), and Mir Saeed qazi *et al*. (2013).

According to the respondents, the food production mechanisms using nanotechnology have an impact on food security improvement as well. Using ineffective pesticide formulations may lead to serious and irrevocable dangers, such as losing agricultural products, increasing the cost of pests' control, and unwanted pesticides consumption. Therefore, producing biocompatible pesticide formulations using nanotechnology not only increases pesticides' effectiveness in controlling agricultural pests, but it would also decrease environmental pollution. Therefore, it is clear that applying this type of nano formulation would not add any new pollution to the environment; instead, it would also help removing the rest of the pesticides from the environment.

Nowadays, nanotechnology has entered all processes from food production to transportation, packaging and, eventually, reaching the hands of the consumers. It also plays a remarkable role in ensuring the health of these materials and eliminating various microbial contaminants. One of the functions of nanotechnology in the food industry is the removal of microbial contamination in various stages of the production and packaging and, finally, the consumption. The use of nanocomposites impregnated with nanoparticles, nanofilms, etc. has improved the shelf life of foods. In fact, increasing foods shelf life, eliminating microbial contaminants, and preventing their spoilage and many other things can be improved with the help of this technology, hence, a safe, secure, and sustainable food chain and healthy society could be achieved.

This result is in congruent with the findings of Mehravaran *et al*. (2019), Vikram Singh *et al*. (2021), Salimi and Motakef Kazemi (2016), Mir Saeed Ghazi *et al*. (2013), and Sastry *et al*. (2011).

The outcomes of the current study also revealed that the food taste and color improvement mechanisms positively enhance food security. In fact, nanoencapsulation of different aromas and tastes in foods to control their release is very significant. Consequently, it would be possible to add the desired aroma and taste to different types of foods and drinks using nanoencapsulation. Encapsulation is usually performed by wrapping a thin polymer layer around materials. Accordingly, the specific color, taste, or aroma of the considered material will not gradually decrease or disappear due to their reaction with other existing materials in foods, drinks, or environment. In other words, the particular color, taste, or aroma will remain until they are consumed. Hence, the food color and taste improvement through nanotechnology is effective in food security improvement. This result is in accordance with the results of Salimi and Motakef Kazemi (2016) and Mir Saeed Ghazi *et al* (2013).

Finally, yet importantly, the findings underlined that the food safety mechanisms using nanotechnology improve the food security. The results also showed that using nanosensors is very vital in terms of the food health in order to detect pathogenic factors in food products. To clarify such a role, nanotechnology is used in many agricultural and dietary applications, such as developing biosensors at nanoscale and controlling materials and food processing. Developing bio-nanosensors is of great importance to detect pathogenic factors and food contaminants, and to produce food products using mechanical, thermal, and antimicrobial materials. This technology is also used in food security to protect the food

[DOI: 10.52547/jast.24.6.1331]

quality against unfavorable effects of external microbial and mechanical factors. This result is consistent with the results of Krishnan *et al*. (2018), Pathakoti *et al*. (2017), Salimi and Motakef Kazemi (2016), Kumar and Pathera (2014), Mir Saeed Ghazi *et al*. (2013), and Hosseini Nejad and Samadi (2012).

In more detail, and based on the results of the study, the following recommendations can be presented:

Considering the confirmation of the first hypothesis indicating the effect of food preservation mechanisms using nanotechnology on food security improvement, the following issues are suggested:

Coating fruits and vegetables with copper-containing nanocytosans (due to their special properties) is one of the promising methods for preventing moisture loss and aroma as well as inhibiting oxygen penetration into the plant tissue or microbial growth. Consequently, it could increase the shelf life of the fresh products and reduce their wastes.

Placing antimicrobial substances and coating them on the surface of the packaging polymer, such as using antifungal agents in wax. This is spread as a layer around the fruits and vegetables in the package.

Using antimicrobials such as silver compounds or antimicrobial enzymes such as lactose peroxidase in direct mixture with the polymer.

Considering the confirmation of the second hypothesis indicating the effect of food processing mechanisms using nanotechnology on food security improvement, the following issues are suggested:

Deficiencies of vitamins and minerals are widespread in different groups of our society. One of the approaches for compensation of these deficiencies is to enrich foods through vitamins' encapsulation in beverages or fortified biomaterials and producing fortified products for the consumers at a reasonable cost.

Considering the approval of the third hypothesis referring to the effect of food production mechanisms using nanotechnology on improving the food security, the following proposals are suggested:

Using portable nanosensors for finding harmful chemicals, pathogens and toxins in food (Good Food) and detecting different destructive bacteria in meat, fish or fruit fungi, as well as controlling fruits and vegetables pesticides.

In food analysis systems, nanoelectromechanical systems, which include nano and millimetersized dimensions, are designed that can control the food storage environment and are used as a tool in food protection. A digital spectrometer using nanoelectromechanical systems technology is able to determine the amount of trans fat in food.

Considering the verification of the fourth hypothesis indicating improvement mechanisms of food's taste and color using nanotechnology on improving the food safety, the following activities are proposed:

The optimization and modification of sensory properties of food products using nanoencapsulation that creates a new feeling in the consumer (such as texture, consistency, development of new taste or flavor coating, flavor enhancement, and color change).

The use of nanocapsules to mask the taste and smell of tuna oil, due to the trapping of proteolytic enzymes in liposomes.

Encapsulation of essential oils in zein nanostructures (the main protein of corn) that results in dispersing them in water and increasing their potential to be used as oxidants and antimicrobial agents in food storage.

Using biosensors to increase the food safety and to detect pathogens among other microorganisms in animals and plants.

Regarding the validation of the fifth hypothesis which demonstrates the effect of food health mechanisms using nanotechnology on improving food safety, these issues are suggested:

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The use of biosensors in food packages, which can be a warning if the food spoilage begins. In addition, through using these nanosensors, it would be possible to find out how much nutrients and toxins are needed in each part of the farm, which leads to prevention of environmental pollution and increasing food health and, eventually, increasing economic efficiency.

The use of nanosensors in tracking water flow, food movement, and even the presence of contaminants in the soil can play a key role in modern agriculture, which in turn is crucial in resource use management.

Placing nanosensors in the production line to ensure that non-contaminated foods are produced.

Considering the confirmation of the sixth hypothesis referring to the effect of food packaging mechanisms using nanotechnology on food security improvement, these issues are recommended:

Using nanofiltration in food industry to detect the quality control metabolites, pathogens, and fundamental changes in food packaging and storage.

Use of silver nanoparticles in packaging with antimicrobial properties and in order to address the food security and reduce the growth and proliferation of food pathogens by disrupting the translation of cellular RNA, microbial respiratory system, and cell's internal electron transfer for using in polymers of disposable tableware, processed polymer baskets of fruits and vegetables, and wrapping papers.

Using intelligent food packaging in the food industry. This method uses nanosensors that are sensitive to the release of spoilage chemicals in smart packaging. In other words, the color of the package is changed as soon as the food begins to spoil and this is how it alerts the customer. This system is far more accurate and reliable than the packages with an expiration date.

Abbreviations

PLS: Partial Least Squares

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[DOI: 10.52547/jast.24.6.1331]

استفاده از فناوری نانو در تولید مواد غذایی: تضمینی برتوسعه امنیت غذایی در ایران

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چکیده

در سالهای اخیر ، فناوری نانو به طور فزآینده ای در صنایع غذایی بخصوص برای افزایش بهبود امنیت غذایی مورد استفاده قرار گرفته است. فناوری نانو زمینه را برای درک اجزای غذایی در مقیاس کوچک در صنایع غذایی فراهم می کند. مطالعه حاضر با هدف تجزیه و تحلیل کاربرد فناوری نانو برای بهبود امنیت غذایی انجام شده است. نمونه مورد مطالعه شامل کلیه کارشناسان (۹۰ نفر) ستاد ویژه توسعه فناوری نانوی ایران بود که با روش سرشماری انتخاب شدند. این مطالعه از روش توصیفی-پیمایشی استفاده کرده است. پرسشنامه ای بر اساس چارچوب نظری مطالعه توسط نویسندگان تهیه و برای جمع آوری داده ها مورد استفاده قرار گرفت. روایی (محتوا و صورت) و پایایی (بارگذاری عاملی ، ضریب پایایی ترکیبی و ضریب آلفای کرونباخ) پرسشنامه تأیید شد. نتایج آزمون فرضیه ها با استفاده از(β) وضرایب مسیرSmart PLS، t-test نشان داد که مکانیسم های بسته بندی مواد غذایی با استفاده از فناوری نانو به طور مستقیم و به طور قابل توجهی بر امنیت غذایی تأثیر می گذارد. یافته ها همچنین نشان می دهد که مکانیسم های نگهداری ، فرآوری و تولید غذا با استفاده از فناوری نانو بر بهبود امنیت غذایی تأثیر می گذارد. نتایج نشان داد که بین طعم و بهبود رنگ غذا و همچنین ایمنی و سلامت غذا با استفاده از فناوری نانو رابطه مستقیم وجود دارد.

[DOI: 10.52547/jast.24.6.1331]