

Economic Analysis of Replacing Dietary Forage Components (Alfalfa Hay and Barley Straw) with Triticale Hay in Fattening Grey Shirazi Lambs

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ABSTRACT

This study evaluated the economic performance and efficiency of replacing conventional forage (alfalfa hay and barley straw) with dried triticale forage in diets of fattening male Grey Shirazi lambs in Fars Province, Iran. Thirty-two weaned male lambs (initial weight: 33.2 ± 1.6 kg; age: 120 ± 15 days) were assigned to four dietary treatments in a completely randomized design. The treatments included T0 (control), T33, T66, and T100, corresponding to 0%, 33.33%, 66.66%, and 100% substitution of conventional forage with triticale on a dry-matter basis. The results showed that the highest total weight gain occurred in T0 (19.37 kg), while the lowest was observed in T33 (16.24 kg). However, the difference between T0 and T100 was not statistically significant. Increasing the proportion of triticale forage in the diet reduced feed intake but improved feed use efficiency (FUE), and the feed conversion ratio (FCR). Economically, T100 yielded the lowest feeding cost, the highest return per 100 monetary units of feed, and the highest benefit–cost ratio. Data Envelopment Analysis (DEA) showed that T100 had the highest allocative efficiency (0.88) and cost efficiency (0.74), whereas T0 achieved the highest technical efficiency (0.94). **Although T100 had lower technical efficiency than T0, its higher allocative efficiency reflected a more cost-effective input mix given input prices, contributing to its higher cost efficiency.** Overall, incorporating triticale forage at full replacement (T100), reduces production costs and improve economic and efficiency indicators, providing a strategy for livestock production under water scarcity and climate change conditions.

Keywords: Cost efficiency, Data envelopment analysis (DEA), Grey Shirazi lamb, Triticale forage.

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INTRODUCTION

Feed costs constitute 60–70% of total expenses in sheep production (Nepali, 2026; Al-Khalasi et al., 2026). Water scarcity causes major challenges to livestock production in arid and semi-arid regions, particularly in Iran (Abarghuei et al., 2021). Iran's rainfall has declined from 264 mm (1970–1980) to 222 mm in recent decades, with an average decrease of 0.6 mm per year (Karami et al., 2025).

Improving feeding strategies and integrating alternative forages can enhance livestock profitability and long-term sustainability (Ashkvari et al., 2024). Conventional forages such as alfalfa and corn silage require substantial irrigation, particularly under climate change, low precipitation, and increasing soil salinity (Ventura and Sagi, 2013; Singh et al., 2014; Santana et al., 2019). Therefore, adopting forage crops with greater tolerance to environmental stresses is essential to reduce pressure on limited water resources (Karimi et al., 2022).

Triticale ($\times$ Triticosecale) is a wheat-rye hybrid with notable tolerance to drought, cold, and salinity, making it a promising forage for arid environments (Manni et al., 2021; Koochaki and Khajeh-Hosseini, 2012). Despite these advantages, triticale cultivation remains limited in Fars Province, and its incorporation into animal feeding systems requires further investigation (Fars Agricultural Jihad Organization, 2025).

Studies indicate that alternative forage resources can improve the economic performance of lamb fattening systems. Low-cost forage-based diets have been shown to reduce feeding costs and improve feed utilization efficiency (Rihawi et al., 2010), while using feeds that do not compete with human food can enhance economic and environmental sustainability (Gaudare et al., 2021). Economic inefficiencies are also associated with suboptimal feed management, highlighting the importance of reducing input costs (Khunchaikarn et al., 2022; Kucukoflaz et al., 2025). In Iran, triticale can technically replace imported feed ingredients and improve economic performance, although subsidy policies may influence its benefits (Rahmani and Agah, 2020). Moreover, triticale can replace conventional forages in dairy diets without compromising performance while reducing costs (Ashkvari et al., 2024; Khamisabadi et al., 2026).

There is limited information on the economic implications and efficiency of complete forage replacement with triticale. To the best of our knowledge, this is the first study to apply Data Envelopment Analysis (DEA) for evaluating the economic efficiency of triticale-based diets in fattening lambs. Therefore, this study investigates the effects of replacing conventional forage

with triticale forage on growth performance, economic indicators, technical, allocative and cost efficiency in Grey Shirazi fattening lambs.

MATERIALS AND METHODS

The experiment was conducted at the Aliabad Kamin Experimental and Educational Station, affiliated with the Fars Agricultural and Natural Resources Research and Education Center, in Pasargad County, Fars Province, Iran (30°01'56" N, 53°08'32" E), in 2024. The study area has a temperate Mediterranean climate with relatively cold winters and mild summers. At the time of planting, growing, and harvesting, the mean annual temperature was 16.6 °C, ranging from −1.3 °C (January) to 30.5 °C (May), with total annual precipitation of 260 mm and relative humidity varying between 20% and 66% (Izadi et al., 2025).

This study evaluated the economic performance and efficiency of incorporating triticale forage into the diets of Grey Shirazi fattening lambs. To optimize the nutritional profile of the diet, the triticale forage used in this study was harvested at the milky-dough stage.

Thirty-two weaned male Grey Shirazi lambs (initial body weight: 33.2 ± 1.6 kg at 120 ± 15 days of age) were assigned to a completely randomized design consisting of four dietary treatments with eight replicates per treatment. Experimental diets were formulated according to NRC (2007) recommendations. Treatments (Table 1) replaced the conventional forage portion (alfalfa hay + barley straw) with triticale forage, while the forage-to-concentrate ratio remained 40:60. Accordingly, the treatments included: T0 (control diet without triticale forage, containing 24.90% alfalfa hay and 15.10% barley straw in the total diet DM), T33 (33.33% of the forage portion replaced with triticale forage, corresponding to 13.30% of the total diet DM), T66 (66.66% of the forage portion replaced with triticale forage, corresponding to 26.50% of the total diet DM), and T100 (100% of the forage portion replaced with triticale forage, corresponding to 40.00% of the total diet DM).

The laboratory-analyzed CP (13.17–13.38% of DM) and ME (10.76–10.92 MJ/kg DM) values confirmed that the diets were isonitrogenous and isoenergetic across all treatments (Table 1). Dry matter, crude protein, and ash were determined using standard AOAC (2012) procedures, while neutral detergent fiber, acid detergent fiber, and lignin were analyzed according to Van Soest et al. (1991) and AOAC (1973.18). Metabolizable energy was estimated using the gas production technique (Menke et al., 1979). Triticale forage had lower

crude protein (8.33% vs. 13.90%) and higher Ash-free neutral detergent fiber (58.12% vs. 49.34%) than alfalfa hay, but higher metabolizable energy (9.13 vs. 8.73 MJ/kg DM). The chemical composition of feed ingredients and complete diets is presented in Tables 2 and 1, respectively.

Table 1. Triticale forage inclusion levels in the experimental diets (based on DM basis).

Items	Treatments ¹			
	T0	T33	T66	T100
Triticale forage in the forage portion (% of DM)	0.00	33.33	66.66	100
Triticale forage total diet (% of diet DM)	0.00	13.30	26.50	40.00
Alfalfa hay in total diet (% of diet DM)	24.90	16.60	8.40	0.00
Barley straw in total diet (% of diet DM)	15.10	10.10	5.10	0.00
Chemical composition of diets				
Crude protein (% of DM)	13.38	13.31	13.27	13.17
Metabolizable energy (MJ/kg DM)	10.76	10.81	10.87	10.92

¹ Treatments T0 (control diet). T33, T66, and T100 correspond to diets that contain 33.33%, 66.66%, and 100% DM of triticale forage replacing the forage portion, respectively.

Table 2. Chemical composition of triticale forage, alfalfa forage, and barley straw.

Chemical composition (% of DM)	Triticale forage	Alfalfa forage	Barley straw
Dry matter (g/100 g fresh weight)	36.32	33.31	94.82
Crude protein	8.33	13.90	3.03
Ash-free neutral detergent fiber	58.12	49.34	73.08
Ash-free acid detergent fiber	37.52	36.70	47.24
Lignin(sa) ¹	6.66	7.54	10.38
Ash	7.00	7.34	9.05
Metabolizable energy (MJ/kg DM)	9.13	8.73	5.91

¹ Lignin(sa) = lignin determined by solubilisation of cellulose with 72 % sulphuric acid solution; ME = metabolisable energy (MJ/kg DM) calculated as $2.20 + (0.136 \times \text{mL gas production after 24 h}) + (0.057 \times \text{CP}) + (0.0029 \times \text{CP}^2)$ (Menke et al., 1979).

Feeding management was standardized across all treatments. Lambs were housed individually in 1.5×1.5 m concrete-floor pens and offered a total mixed ration (TMR) twice daily at 08:00 and 16:00 h *ad libitum*, targeting approximately 5% daily refusals. Feed offered and orts were recorded daily, and weekly feed allocation was adjusted according to the previous week's intake. Fresh water was available at all times. Before the 81-day fattening trial, lambs underwent a 14-day adaptation period. Body weight was recorded every 20 days before morning feeding using a digital scale.

To evaluate the economic performance of the experimental diets, several key indicators were calculated: feed conversion ratio (FCR), feed use efficiency (FUE), feed cost, gross income, net income, benefit–cost ratio (BCR), and efficiency metrics (technical, allocative, and cost

efficiency). Feed use efficiency (FUE), calculated by Equation (1), is expressed as kilograms of body weight gain per 100 kg of dry matter intake (Gaudare et al., 2021).

$$FUE = \frac{\text{Weight Gain (kg)}}{\text{Dry Matter Intake (kg)}} \times 100 \quad (1)$$

Furthermore, the return per 100 monetary units of feed cost for each treatment was calculated **as the monetary value of weight gain during the fattening period relative to the total feed cost**, according to Equation (2) (Arsalanbad, 1991).

$$\text{Return per 100 monetary units of feed cost} = \frac{\text{Monetary Value of Weight Gain}}{\text{Total Feed Cost}} \times 100 \quad (2)$$

The benefit-cost ratio (BCR) for each treatment was calculated as the ratio of the monetary value of **final live weight** (B_i) to the total cost (C_i), including **initial purchase of the lambs and feed cost** (C_i), using Equation (3) (Soltani, 2001).

$$BCR = \frac{B_i}{C_i} \quad (3)$$

Dietary efficiency was evaluated using Data Envelopment Analysis (DEA), a non-parametric linear programming method (Farrell, 1957; Charnes et al., 1978; Mohammadi, 2008). **The 32 experimental replicates (lambs) comprising four treatments with eight replicates per treatment, served as decision-making units (DMUs). The DEA framework assumes that the observed input and output values are non-negative and that each DMU uses (m) feed inputs to produce (s) outputs. In addition to input and output quantities, information on input prices is required to estimate cost efficiency. Input prices were incorporated into the cost efficiency model based on their average purchase prices during the experimental period.**

A linear programming model was formulated to estimate cost efficiency (CE) for the 32 DMUs using input quantities, output quantities, and input prices (Model 4). The objective of this model is to minimize costs by determining the optimal input quantities given their respective prices (Camanho et al., 2024; Öttl and Asmild, 2025). In this model, the decision variable λ^n represents the coefficients of the linear combination of DMUs used to determine the projection of the DMU under evaluation onto the efficiency frontier through the reference (peer) units, while x_k represents the optimal choice of input quantities.

$$CE_j = \min_{(\lambda^n, x^k)} \frac{\sum_{k=1}^m w_k^j x_k}{\sum_{k=1}^m w_k^j x_k^j}$$

Subject to:

$$\sum_{n=1}^n \lambda^n x_k^n \leq x_k; \quad k = 1, \dots, M \quad (\text{Model 4})$$

$$\sum_{n=1}^n \lambda^n y_r^n \leq y_r^j; \quad r = 1, \dots, S$$

$$\lambda^n \geq 0 \quad \forall_n \in N$$

In model 4, y_r^j , x_k^j and w_k^j denote the observed quantity of the r-th output, the quantity of the k-th input, and the price of the k-th input, respectively, for decision-making unit j. Following the solution of this cost-minimization model, the decision variable x_k yields an optimal input vector that minimizes costs given input prices and the level of output. Accordingly, cost efficiency is defined as the ratio of the minimum cost resulting from the optimal allocation of inputs to the observed cost, as reflected in the objective function of Model (4). Cost efficiency (CE_j) for decision-making unit j indicates the relative potential for reducing the costs of that unit while holding its observed output level constant.

Cost efficiency consists of two components: technical efficiency (TE) and allocative efficiency (AE) (Bogetoft and Otto, 2010). Therefore, this measure captures the potential for cost reduction that can be achieved by simultaneously eliminating technical and allocative inefficiencies. These two types of inefficiency refer, respectively, to inefficiency in the production process and the inappropriate allocation of resources given the prevailing input prices. Accordingly, cost efficiency can be expressed as Equation (5):

$$CE_j = AE_j \times TE_j \quad (5)$$

Technical efficiency (TE) refers to the efficiency score that can be obtained from the DEA formulation proposed by Charnes et al. (1978). Accordingly, linear programming model (6) was formulated to estimate technical efficiency (TE). The estimated (θ) represents the technical efficiency score of the decision-making unit. Given the focus on costs, an input-oriented approach is employed:

$$TE_j = \min_{(\lambda^n, \theta)} \theta$$

Subject to:

$$\sum_{n=1}^n \lambda^n x_k^n \leq \theta x_k^j; \quad k = 1, \dots, M \quad (\text{Model 6})$$

$$\sum_{n=1}^n \lambda^n y_r^n \leq y_r^j; \quad r = 1, \dots, S$$

$$\lambda^n \geq 0 \quad \forall_n \in N$$

Based on the relationship between cost efficiency, technical efficiency, and allocative efficiency, allocative efficiency was calculated using Equation (7):

$$AE_j = CE_j / TE_j \quad (7)$$

Models (4) and (6) are based on the assumption of constant returns to scale (CRS). Therefore, no additional constraint is imposed on λ^n , except that this variable must be non-negative. DEA analyses were performed using DEAP, while SPSS was used for ANOVA and Duncan's multiple range test to compare treatment means indicators at $P < 0.05$. During the fattening period, initial and final body weight, weight gain, and feed intake were recorded.

Performance data were analyzed using SAS (SAS Institute, 2002), with ANOVA conducted using the GLM procedure and treatment means compared using Duncan's multiple range test at $P < 0.05$. The statistical model was:

$$Y_{ij} = \mu + T_i + \beta(X_{ij} - \bar{X}) + e_{ijk} \quad (8)$$

Where Y_{ij} is the observation of the j^{th} animal receiving the i^{th} treatment; μ is the overall mean of the measured trait; T_i is the fixed effect of the i^{th} treatment; β is the regression coefficient for initial body weight included as a covariate; X_{ij} is the initial body weight of the j^{th} animal in the i^{th} treatment and $\bar{X}$ is the overall mean of initial body weight across all animals; e_{ijk} is the random error within the treatment. The experimental unit was the individual lamb, with 8 lambs per treatment (total $n = 32$). All lambs were male and of similar age; therefore, sex and age were not included as factors. Treatment means were compared using Duncan's multiple range test at a significance level of $P < 0.05$. For variables measured over time (feed intake, rumen and blood variables), data were analyzed as repeated measures with treatment, time, and their interaction as fixed effects, and animal as a random effect. Polynomial contrasts were used to evaluate the linear and quadratic effects of increasing triticale inclusion levels.

RESULTS AND DISCUSSION

Growth Performance of Lambs Fed Experimental Diets

Table 3 presents the growth performance of lambs across dietary treatments. Initial body weights averaged 33.83, 33.27, 33.14, and 32.70 kg for T0, T33, T66, and T100, respectively, with no significant differences among them ($P > 0.05$).

Final body weights showed a significant quadratic response to increasing dietary triticale levels ($P = 0.002$; Table 3), with T0 yielding the highest final weight (53.20 kg) and T33 the lowest (49.50 kg). The linear contrast was also significant ($P = 0.035$), indicating a general

decreasing trend in final body weight with increasing triticale inclusion, although the quadratic effect suggests that this response was not strictly linear. Total weight gain exhibited a significant quadratic effect ($P=0.002$; Table 3), with T0 showing the highest gain (19.37 kg) and T33 the lowest (16.24 kg), while T100 (18.18 kg) was intermediate. The linear contrast was not significant ($P=0.335$), indicating that the response to increasing triticale levels followed a curvilinear rather than a linear pattern. The non-linear response suggests that partial substitution of triticale forage may induce negative associative effects in the rumen, whereas complete replacement may promote a more stable microbial ecosystem. The pronounced decline in performance at T33 may reflect several interacting mechanisms. First, the simultaneous presence of alfalfa, barley straw, and triticale may have disrupted the synchrony of energy and nitrogen availability, reducing microbial fermentation efficiency (Makkar, 2003; Abarghuei et al., 2013). Second, greater selective sorting at partial inclusion levels may have altered the effective nutrient profile consumed by the lambs (Keles et al., 2016). Third, rumen microbiota may have been in transition at T33, with incomplete adaptation of cellulolytic bacteria and reduced fibrolytic activity (Ashkvari et al., 2024). Finally, phenolic compounds may have been insufficient at T33 to provide beneficial effects while still causing mild digestive disturbances. The recovery at T100 suggests that complete replacement reduced these interactions through a more homogeneous fermentation substrate, potentially facilitating microbial adaptation, fiber degradation, microbial protein synthesis, and nutrient utilization.

Feed intake was categorized into two statistical groups: T0 and T33, which exhibited higher intake (131.18 and 128.53 kg). T66 and T100 showed lower consumption (117.48 and 115.85 kg). Lower feed intake without compromised weight gain indicates improved feed utilization.

The reduction in dry matter intake with increasing triticale inclusion aligns with Keles et al. (2016), Fazaeli et al. (2011), and Ashkvari et al. (2024). However, our findings differ from Santana et al. (2019), likely due to differences in harvest stages. Overall, triticale maintains growth while improving feed efficiency. McCartney and Vaage (1994) attributed reduced performance in heifers fed triticale silage to poor palatability associated with its coarse texture. In the present study, however, the higher ash-free neutral detergent fiber content was likely the main factor limiting feed intake, as this parameter was similar between T0 and T33 but increased in T66 and T100. Overall, these findings agree with previous research,

indicating that triticale can maintain growth while improving feed efficiency and potentially economic returns.

Indices for feed use efficiency (14.77, 12.65, 14.52, and 15.85%), and feed conservation ratio (6.80, 8.05, 6.98, and 6.44), consistently placed treatments into two distinct groups, whereas T33 differed from the other treatments. Collectively, T100 emerged as the most promising substitution strategy. However, a comprehensive assessment requires integrating these performance metrics with economic indicators, such as input costs and market prices for forage, which are addressed in the subsequent section.

Table 3. Growth performance, feed intake, and feed utilization indices of lambs fed the experimental diets.

Variable	Treatments ¹				SEM ²	Linear	Quadratic	Power test
	T0	T33	T66	T100				
Initial body weight (kg)	33.83	33.27	33.14	32.70	1.041	0.228	0.926	0.09
Final body weight (kg)	53.20 ^a	49.50 ^b	50.13 ^b	50.88 ^b	0.780	0.035	0.002	0.80
Total weight gain (kg)	19.37 ^a	16.24 ^b	16.99 ^b	18.18 ^{ab}	0.370	0.335	0.002	0.73
Total feed intake (kg)	131.18 ^a	128.53 ^a	117.48 ^b	115.85 ^b	1.780	0.001	0.850	0.95
Feed conversion ratio	6.80 ^b	8.05 ^a	6.98 ^b	6.44 ^b	0.187	0.150	0.010	0.87
Feed use efficiency (%)	14.77 ^a	12.65 ^b	14.52 ^{ab}	15.85 ^a	0.380	0.098	0.016	0.87

^{a,b}: Within each row, means with common superscript(s) are not different ($P > 0.05$).

¹Treatments T0 (control diet). T33, T66, and T100 correspond to diets that contain 33.33%, 66.66%, and 100% DM of triticale forage replacing the forage portion, respectively. SEM²: pooled standard error of the mean. Linear and quadratic effects were considered significant at $P \leq 0.05$.

The average prices of the 13 feed ingredients are presented in Table 4. Notably, the cost per kilogram of alfalfa DM (**187.05 × 10³ Rials**) was over three times higher than that of triticale forage (**52 × 10³ Rials**), whereas barley straw was the most economical ingredient (**37 × 10³ Rials**). Consequently, replacing alfalfa and barley straw with triticale forage is expected to influence feeding costs and overall profitability, contingent upon the substitution level and its resulting effects on lamb growth performance.

Table 4. Average prices of feed ingredients used in the experimental diets.

Feed ingredient	Price (10 ³ Rials/kg fresh weight)	Price (10 ³ Rials/kg dry matter)
Alfalfa	175.00	187.05
Barley straw	35.00	37.35
Triticale forage	50.00	52.63
Soybean meal	280.00	314.61
Barley grain	115.00	127.78
Corn grain	115.00	127.78
Canola meal	221.60	245.40
Wheat bran	85.00	93.41
Salt	20.00	20.00
Fattening supplement	235.00	235.00
Calcium carbonate	20.00	20.00
Sodium bicarbonate	140.00	140.00
Dicalcium phosphate	550.00	567.01

Source: Experimental data and subsequent calculations.

Feeding costs were significantly lower in the case of T66 (13.41 m Rials) and T100 (13.20 m Rials), compared to the T0 (15.06 m Rials) and T33 (14.72 m Rials) ($P=0.002$). While T0 yielded the highest gross revenue (127.68 m Rials), net income did not differ significantly between T0 (31.43 m Rials) and T100 (30.43 m Rials) (Table 5). Similarly, return rates remained statistically comparable among the groups ($P=0.128$), indicating that substituting alfalfa with triticale forage, particularly at 100% (T100), effectively reduced feeding costs while maintaining economic profitability.

Table 5. Economic performance and profitability of lambs fed with the experimental diets.

Variable	Treatments ¹				SEM ²	P-value
	T0	T33	T66	T100		
Feeding cost (m Rials)	15.06 ^a	14.72 ^a	13.41 ^b	13.20 ^b	0.315	0.002
Initial lamb purchase cost (m Rials)	81.19	79.84	79.54	78.48	1.53	0.755
Total cost (m Rials)	96.25	94.57	92.95	91.68	1.53	0.427
Gross revenue (m Rials)	127.68 ^a	118.81 ^b	120.31 ^b	122.11 ^b	1.53	0.009
Net income (m Rials)	31.43 ^a	24.25 ^b	27.36 ^{ab}	30.43 ^a	1.59	0.045
Return rate (%)	32.78 ^{ab}	25.78 ^b	29.68 ^{ab}	33.63 ^a	0.67	0.128

^{a,b}: Within each row, means with common superscript(s) are not different ($P>0.05$). ¹Treatments T0 (control diet), T33, T66, and T100 correspond to diets containing 33.33%, 66.66%, and 100% DM of triticale forage replacing the forage portion, respectively. ²SEM: pooled standard error of the mean. m: Million.

Source: Experimental data collected during the study period and subsequent calculations.

Return per 100 Monetary Units of Feed Cost and Benefit–Cost Ratio

Table 6 displays the benefit–cost ratio (BCR) and the return per 100 monetary units of feed cost. Regarding returns, values averaged 308.07%, 265.19%, 305.48%, and 334.51% for T0, T33, T66, and T100, respectively, with T100 showing significantly higher performance than T33

($P=0.045$). A similar trend was observed in the BCR, which was highest in T100 (1.34) and lowest in T33 (1.26), based on feed and initial lamb purchase costs. This difference between the two treatments was significant ($P=0.045$). Although T33 performed significantly lower than the other groups, there were no significant differences among T0, T66, and T100. Thus, T100, which represented the complete replacement of the forage portion with triticale, enhanced the BCR and return per unit of feed cost without compromising productive performance.

Table 6. Return per 100 monetary units of feed cost and benefit–cost ratio of the experimental diets.

Variables	Treatments ¹				SEM ²	P-value
	T0	T33	T66	T100		
Return per 100 monetary units of feed cost (%)	308.07 ^{ab}	265.19 ^b	305.48 ^{ab}	334.51 ^a	14.07	0.045
Benefit–cost ratio	1.33 ^{ab}	1.26 ^b	1.30 ^{ab}	1.34 ^a	0.022	0.045

^{a,b}: Within each row, means with common superscript (s) are not different ($P>0.05$). ¹Treatments T0 (control diet), T33, T66, and T100 correspond to diets that contain 33.33%, 66.66%, and 100% DM of triticale forage replacing the forage portion, respectively. ²SEM: **pooled** standard error of the mean.

Source: Experimental data collected during the study period and subsequent calculations.

Efficiency of the Experimental Diets

The efficiency indices for the dietary treatments are presented in Table 7. Under the Data Envelopment Analysis (DEA) framework, benchmark units lie on the efficiency frontier and receive a score of one. In this study, replicate 27 of T100 and replicates 3, 6, and 7 of T0 served as reference units. Replicate 27 (T100) was the primary benchmark, achieving perfect technical, allocative, and cost efficiency with an optimal feed-to-gain ratio (21.68 kg gain from 100.94 kg intake). Inefficient units, particularly in T33, consumed more feed but achieved lower weight gains. Relative to the benchmark, T0 and T33 required approximately 30 and 28 kg more feed, whereas T66 and T100 required only 17 and 15 kg more, respectively.

Table 7. Feed intake, weight gain, and technical, allocative, and cost efficiency scores of individual lambs.

Replicate	¹ Treatment	Dry matter intake (kg)	Weight gain (kg)	Technical efficiency	Allocative efficiency	Cost efficiency	Reference unit(s)
1	T0	133.21	19.20	0.909	0.60	0.54	3, 6, 7
2	T0	126.44	18.40	0.945	0.58	0.55	3, 6, 7
3	T0	138.10	21.40	1.000	0.58	0.58	Reference
4	T0	134.63	17.60	0.831	0.59	0.49	3, 6, 7
5	T0	128.03	18.00	0.900	0.59	0.53	3, 6, 7
6	T0	130.39	21.00	1.000	0.61	0.61	Reference
7	T0	127.46	20.00	1.000	0.59	0.59	Reference
8	T0	131.18	19.37	0.940	0.59	0.56	Near efficient
9	T33	124.47	17.70	0.856	0.67	0.57	27, 3, 6
10	T33	140.62	16.80	0.689	0.70	0.48	27, 3, 6
11	T33	133.23	20.60	0.890	0.70	0.62	27, 3, 6
12	T33	133.23	15.96	0.690	0.70	0.48	27, 3, 6
13	T33	132.11	16.00	0.693	0.70	0.49	27, 3, 6
14	T33	128.53	12.20	0.589	0.65	0.38	27, 3, 6
15	T33	107.50	14.40	0.788	0.68	0.54	27, 3, 6
16	T33	128.53	16.24	0.740	0.69	0.51	27, 3, 6
17	T66	105.99	18.00	0.901	0.81	0.73	7, 27
18	T66	119.36	15.40	0.723	0.77	0.56	7, 27
19	T66	111.28	15.20	0.754	0.78	0.59	7, 27
20	T66	125.23	16.80	0.783	0.74	0.58	7, 27
21	T66	113.38	19.10	0.899	0.81	0.73	7, 27
22	T66	121.54	19.20	0.901	0.76	0.68	7, 27
23	T66	125.60	15.20	0.713	0.73	0.52	7, 27
24	T66	117.48	16.99	0.810	0.77	0.63	7, 27
25	T100	115.85	17.68	0.815	0.87	0.71	27
26	T100	119.53	18.80	0.867	0.85	0.73	27
27	T100	100.94	21.68	1.000	1.000	1.000	Reference
28	T100	113.29	16.80	0.775	0.89	0.69	27
29	T100	106.51	18.20	0.839	0.95	0.80	27
30	T100	127.20	16.10	0.743	0.79	0.59	27
31	T100	127.64	18.00	0.830	0.79	0.66	27
32	T100	115.85	18.18	0.840	0.88	0.74	27

¹Treatments T0 (control diet). T33, T66, and T100 correspond to diets that contain 33.33%, 66.66%, and 100% DM of triticale forage replacing the forage portion, respectively. Units with a technical efficiency score of 1.000 were considered efficient and constitute the reference frontier.

Source: Experimental data and DEA calculations performed in the present study.

Mean technical (TE), allocative (AE), and cost efficiency (CE) indices are summarized in Table 8. In terms of technical performance, T0 exhibited the highest mean TE (0.94), followed by 0.74, 0.81, and 0.84 for T33, T66, and T100. Notably, TE differed significantly between T0 and the triticale-based diets. Regarding economic efficiency, T100 recorded the highest mean AE (0.88) and CE (0.74), while T33 showed the lowest (0.69 and 0.51, respectively). **The overall treatment effect was significant for all three efficiency indices ($P < 0.001$; Table 8). Pairwise**

comparisons using Duncan's multiple range test showed that T100 had the highest allocative (0.88) and cost (0.74) efficiency, while T0 had the highest technical efficiency (0.94).

Differences in efficiency scores were associated with changes in the overall composition of feed inputs across treatments. In T100, complete replacement of the forage portion with triticale forage reduced alfalfa and barley straw intake from 0.404 and 0.245 kg/lamb/day in T0 to zero, while triticale intake increased to 0.572 kg/lamb/day. These changes were accompanied by adjustments in concentrate ingredients, including soybean meal, canola meal, barley grain, corn grain, and wheat bran. Therefore, the higher AE and CE of T100 should be interpreted in relation to the overall input combination and prevailing input prices, rather than as evidence of an inherent efficiency advantage of triticale forage. Its higher AE (0.88) offset lower TE (0.84), resulting in higher CE than T0 (0.74 vs. 0.56). Based on TE scores, potential mean feed-intake reductions without compromising weight gain were estimated at 6%, 26%, 19%, and 16% for T0, T33, T66, and T100, respectively. Thus, T100 improved efficiency and economic returns while supporting lamb productivity.

Table 8. Mean technical, allocative, and cost efficiency of the experimental diets.

Efficiency type	Treatments ¹				SEM ²	P-value
	T0	T33	T66	T100		
Technical efficiency	0.94 ^a	0.74 ^c	0.81 ^{bc}	0.84 ^b	0.028	<0.001
Allocative efficiency	0.59 ^d	0.69 ^c	0.77 ^b	0.88 ^a	0.014	<0.001
Cost efficiency	0.56 ^{bc}	0.51 ^c	0.63 ^b	0.74 ^a	0.029	<0.001

^{a,b}: Within each row, means with common superscript(s) are not different ($P>0.05$). ¹Treatments T0 (control diet), T33, T66, and T100 diets correspond to 33.33%, 66.66%, and 100% DM of triticale forage replacing the forage portion, respectively. ²SEM: pooled standard error of the mean.

Source: Experimental data and DEA calculations performed in the present study.

CONCLUSIONS

The present study demonstrated that replacing traditional forage (alfalfa and barley straw) with triticale in diets of male Grey Shirazi lambs is technically feasible and economically advantageous. Although T0 showed the highest numerical weight gain, the absence of a significant difference between T0 and T100 indicates that complete triticale replacement can maintain growth performance. T100 consistently showed superior economic outcomes, including return per unit of feed cost and benefit-to-cost ratio, and was closest to the cost-efficiency frontier in the Data Envelopment Analysis. While T0 had higher technical efficiency (0.94), T100 achieved greater allocative (0.88) and cost efficiency (0.74). This economic advantage reflects the overall feed-input combination and prevailing prices,

rather than triticale alone. Under semi-arid conditions, triticale may also help reduce pressure on limited water resources; however, application to other regions should consider climate, soil, and cultivar differences. Despite the modest sample size (n=8 per treatment), acceptable statistical power (0.73–0.99) and consistent performance, economic, and DEA results support the findings. Larger studies across diverse production systems are recommended to confirm their generalizability.

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Conflict of interest

The authors declare no conflicts of interest, and certify that there are no financial or personal relationships with other individuals or organizations that could inappropriately influence the work reported in this paper.

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تحلیل اقتصادی جایگزینی بخش علوفه‌ای جیره (یونجه و کاه جو) با علوفه خشک تریتیکاله در پرواربندی بره‌های کبوده شیرازی

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چکیده

این پژوهش با هدف بررسی عملکرد اقتصادی و کارایی جایگزینی بخش علوفه‌ای متداول (یونجه و کاه جو) با علوفه خشک تریتیکاله در جیره‌های پرواربندی بره‌های نر کبوده شیرازی در استان فارس انجام شد. سی و دو رأس بره نر از شیر گرفته‌شده (وزن اولیه: $1/6 \pm 33/2$ کیلوگرم؛ سن: 15 ± 120 روز) در قالب طرح کاملاً تصادفی به چهار جیره غذایی اختصاص داده شدند. تیمارها شامل (T0) شاهد، T33، T66 و T100 به ترتیب معادل صفر، ۳۳/۳۳، ۶۶/۶۶ و ۱۰۰ درصد جایگزینی علوفه متداول با تریتیکاله بر اساس ماده خشک بودند. نتایج نشان داد که بیشترین افزایش وزن کل در تیمار T0، (19/37 کیلوگرم) و کمترین آن در تیمار T33 (16/24 کیلوگرم) مشاهده شد. با این حال، تفاوت بین تیمار شاهد و T100 از نظر آماری معنی‌دار نبود. افزایش نسبت علوفه تریتیکاله در جیره، ضمن کاهش مصرف خوراک، موجب بهبود کارایی مصرف و ضریب تبدیل خوراک شد. از نظر اقتصادی، تیمار T100، کمترین هزینه تغذیه، بیشترین بازده به ازای ۱۰۰ واحد پولی هزینه خوراک و بیشترین نسبت منفعت به هزینه را داشت. نتایج تحلیل پوششی داده‌ها (DEA) نشان داد که تیمار T100 دارای بیشترین کارایی تخصیصی (0/88) و کارایی هزینه‌ای (0/74) بود، در حالی که تیمار T0 بالاترین کارایی فنی (0/94) را داشت. اگرچه کارایی فنی تیمار T100 کمتر از تیمار T0 بود، کارایی تخصیصی بالاتر در این تیمار نشان‌دهنده استفاده از ترکیب بهینه‌تر نهاده‌ها با توجه به قیمت آن‌ها بود و در نتیجه، به بهبود کارایی هزینه‌ای تیمار T100 منجر شد. به‌طور کلی، گنجاندن علوفه تریتیکاله در سطح جایگزینی کامل (T100)، هزینه‌های تولید را کاهش داده و شاخص‌های اقتصادی و کارایی را بهبود می‌بخشد و راهکاری مناسب برای تولید دام در شرایط کم‌آبی و تغییر اقلیم فراهم می‌کند.