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Effect of Sprouted Barley on Performance, Nutrient Digestibility, Nitrogen Utilization, Blood Markers and Economic Efficiency in Lambs

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ABSTRACT

Background: This study aimed to investigate the effects of adding sprouted barley in the diet of lambs on growth performance, digestibility, nitrogen utilization, hematological and biochemical blood parameters and economic evaluation over 75 days.

Methods: Thirty-six healthy 3-month-old Awassi lambs were used in this experiment. All lambs were individually divided into four dietary treatments with nine lambs each (T1 to T4: lambs receiving 0%, 25%, 50% and 75% sprouted barley as a replacement for the traditional diet, respectively). The growth performance, dry matter intake and dry matter excretion were assessed. The digestibility of the ingested dry matter and nitrogen, nitrogen balance, blood health markers, hematological and blood biochemical and economic evaluation were estimated.

Result: Lambs fed T3 had a lower body weight on day 75 than those fed the other dietary treatments, with weight gain also being reduced for those fed sprouted barley during both the 45-75 and 1-75 day period. Feed intake generally increases with the sprouting of barley, resulting in a higher feed-to-gain ratio. White blood cell count and hemoglobin concentration reduced in lambs receiving T3 and T4. Total protein, globulin, triglyceride and glucose levels decreased in lambs receiving T3 and T4, whereas total cholesterol and HDL increased. Urea and ALT levels were lower in lambs fed sprouted barley. Sprouted barley had the highest dry matter content and nitrogen digestibility. Economic evaluations, including the profit rate, relative economic efficiency and investment rate, were higher. Overall, this experiment suggests that sprouting barley at 25% (T2) had no negative effect on the hematological and blood biochemical parameters of lambs, whereas economic evaluation indicators were higher at T2. The inclusion of sprouted barley resulted in the highest nitrogen balance and digestibility of dry matter and nitrogen. However, its effects on growth performance require further investigation.

Key words: Blood health marker, Digestibility, Economic analysis, Lambs, Performance, Sprouted barley.

INTRODUCTION

The demand for high-quality lamb meat is increasing; therefore, lamb production plays a crucial role in the global meat supply (Ponnampalam *et al*., 2020). Sustainable production strategies must maximize the health and performance of lambs while maintaining economic profitability (Gómez-Cortés *et al*., 2019). In this context, research into alternative feed sources, such as sprouted barley and strategies to improve the growth, health and economic efficiency of lambs is gaining considerable attention (Hafla *et al*., 2014).

Sprouted barley has attracted considerable interest in recent years because of its potential health benefits (Alharthi *et al*., 2022). In addition, it is a novel method for producing fodder throughout the year, owing to its high germination rate and rapid growth, particularly in areas suffering from water shortages (Saidi and Jamal, 2015). Sprouting barley activates key enzymes, increasing levels of bioactive compounds, which can enhance animal health and feed efficiency Fazaeli *et al*. (2012); Girma and Gebremariam (2018), which improve digestibility (Ikram *et al*., 2021). Farghaly *et al*. (2019) reported that lambs fed sprouted barley consumed less dry matter, with improved nutrient digestibility in sheep. These changes in nutrient composition are associated with improved rumen health, increased bacterial populations associated with fiber digestion and the production of propionic acids, which are

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beneficial SCFA (Alharthi *et al*., 2022). Several studies have investigated the effects of sprouting barley on lamb performance. Ata (2016) showed that lambs fed diets containing sprouted barley had better average daily gain than the control groups. Fayed (2011) reported a better feed conversion ratio in lambs fed a sprouted barley diet than in those fed a traditional diet. These results suggest that sprouted barley positively influences the growth and feed conversion of lambs. In addition, sprouted barley reduces inflammatory markers in the blood of lambs, which can improve their overall health and disease resistance (Sleman *et al*., 2021; Park *et al*., 2021). In addition, the optimal inclusion level and specific characteristics of sprouted barley (such as sprouting duration) may vary depending on the breed, age and production system of the lambs (Arif *et al*., 2023). The economic impact of sprouted barley on lamb production has also gained attention (Emam, 2016). Studies have shown that lambs fed sprouted barley have similar or slightly lower weights with lower feed costs than control animals, possibly leading to higher relative profitability (Al-Saadi and Al-Zubiadi, 2016; Al-Ghamdi *et al*., 2024).

Studies have highlighted the potential benefits of sprouted barley for lambs; however, there are also limitations. Many studies have focused on specific aspects such as performance, rumen health and immunity, with limited investigation of their effects on blood health indicators, digestibility, nitrogen utilization and economic analysis. Therefore, based on the current experiment and the targeted indicators, it was hypothesized that sprouted barley would have a positive impact on performance, nutrient digestibility and blood health markers in lambs and could contribute to a more economical production system compared to a traditional diet based on alfalfa and barley. The primary objective of this study was to evaluate the effects of the inclusion of sprouted barley in the diet of lambs on growth performance, digestibility, nitrogen utilization, hematological and biochemical blood parameters and economic analysis. In addition, this study provides valuable insights into the multiple effects of sprouted barley on lamb performance, health and economic evaluation.

MATERIALS AND METHODS

Animals and design

The current study was performed at the King Saud University Research Station in the Department of Animal Production from October 2022 to March 2023. A total of 36 healthy Awassi lambs (3-month-old) were obtained from local commercial farms in Riyadh, Saudi Arabia. All lambs were subjected to biosecurity measures for 10 days prior to the start of the experiment. These measures included housing, arrival, health examinations and vaccination against peste des petits ruminants, enterotoxemia and septicemia, according to the regional conditions. Lambs with the almost equal initial weight (T1= 27.80 kg, T2= 27.60 kg, T3= 27.63 kg and T4= 27.78 kg; as shown in the results) were individually divided into four dietary treatments, with nine lambs per treatment. Each lamb was housed in a pen (150 × 120 cm) as an experimental unit using a completely randomized design. The experiment was conducted over 75 days.

Diets

In this study, a hydroponic system with a controlled environment was used to produce sprouted barley (Al-Saadi and Al-Zubiadi, 2016; Al-Baadani *et al*., 2022). The system consists of a special steel chamber located (3 m^2) at the College of Food and Agriculture Science at King Saud University, Saudi Arabia. The chamber contained 140 trays (70 cm × 30 cm) arranged to allow for seven consecutive growth stages (7 days each). Each tray was equipped with an automatic sprinkler system to provide a precise water supply. The environmental parameters of the chamber were closely controlled. An air conditioning and circulation system ensured a constant temperature (18-20°C) and relative humidity (75%). Vertically arranged fluorescent tubes provided continuous illumination throughout the growth cycle (1 watt/cm^3) and promoted optimal leaf development. Local barley seeds were used in this study. After thorough cleaning and washing, approximately 2 kg of seeds per tray were soaked for 24 h. After 7 days of growth, when the shoots reached a height of approximately 20 cm, the trays were removed from the chamber and ventilated for 24 h to facilitate drying. Sprouted barley was harvested by cutting and fed to animals. This production cycle was repeated daily throughout the experimental period to ensure continuous supply of fresh feed.

The dietary treatments were as follows: T1, lambs that received a 100% traditional diet based on 70 barley grains and 30% alfalfa hay; T2, lambs that received a 75% traditional diet and 25% sprouted barley; T3, lambs that received a 50% traditional diet and 50% sprouted barley; and T4, lambs that received a 25% traditional diet and 75% sprouted barley. The nutrient contents of sprouted barley and all dietary treatments were analyzed according to the Association of Official Analytical Chemists (AOAC, 2012) method, as shown in Table 1.

Performance measurements

The performance parameters were measured during the experiments. Body weight (kg) was recorded for all lambs in the beginning and on days 45 and 75 to calculate the difference between body weight at the end and that at the beginning of each period, according to a previously described formula (Tayeb *et al*., 2023). Cumulative feed intake was determined as the difference between the rejected feed and the feed offered during the experimental period using a previously described formula (Bhat *et al*., 2018). Finally, the feed-to-gain ratio was determined to assess the feed efficiency. This ratio was calculated by dividing feed intake by weight gain (Zhang *et al*., 2023).

Digestibility and nitrogen balance indicators

The digestibility trial was performed after 75 days in individual metabolic cages. Five randomly selected lambs were placed in test cages for each dietary treatment and acclimatized for 4 days. Body weight, feed, feces and urine were collected over the following 4 days. During the collection period, 100 g of total feed, excreted feces and urine were collected and immediately stored in a refrigerator at -20°C for later analysis. Feed, feces and urine samples were analyzed to determine dry matter and nitrogen content according to the methods described by the Association of Official Analytical Chemists (AOAC, 2012). The nitrogen balance was calculated using the following formula:

Nitrogen balance = Nitrogen intake - [Nitrogen excreted in feces + Nitrogen excreted in urine] - Basal endogenous nitrogen.

Basal endogenous nitrogen = (0.018 + 0.35) × BW0.75 (Bhat *et al*., 2018; Costa *et al*., 2021).

Digestibility of dry matter and nitrogen =

$$\frac{\text{Ingested fraction - Excreted fraction}}{\text{Ingested fraction}} \times 100$$

(El-Nomeary *et al*., 2021).

Blood sample collection

On day 75, prior to the morning feeding, 9 mL of whole blood was collected from each lamb (n=9 per dietary treatment) *via* jugular vein puncture. For subsequent analysis of hematological parameters, anticoagulant tubes containing ethylenediaminetetraacetic acid (EDTA; BD Company, Franklin Lakes, NJ, USA) were used. Serum was separated via centrifugation at 3500 × g for 15 min. To preserve the integrity of the samples, the separated serum samples were stored at -20°C until the serum was biochemically analyzed.

Blood hematology and biochemical analyses

Within 2 hours of collection, a comprehensive analysis of blood cells was performed to assess various cellular components and oxygen-carrying capacity according to Singh *et al*. (2023). This analysis included the number of blood cells that differentiated into lymphocytes, monocytes and granulocytes. In addition, red blood cell count, hemoglobin concentration, hematocrit and platelet count were measured using a VetScan HM5 hematology analyzer (Abaxis Global Diagnostics, Griesheim, Germany) according to the manufacturer's protocols.

An automated spectrophotometric analyzer (Chem Well, Awareness Technology, USA) was used with commercially available colorimetric kits (Quimica Clinica Aplicada, Tarragona, Spain) to quantify various biochemical parameters in the serum, as described by the manufacturer. These included total protein, albumin, glucose, triglyceride, total cholesterol, high-density lipoprotein (HDL cholesterol), urea, creatinine, aspartate transferase (AST) and alanine transaminase (ALT). Low-density lipoprotein cholesterol (LDL cholesterol) was calculated as the difference between triglycerides and HDL and adjusted for a factor derived from the triglycerides themselves (triglycerides - HDL - (triglycerides/5)) according to a previously described formula (Lobo *et al*., 2020). The albumin-to-globulin ratio was determined by dividing the albumin concentration by the globulin concentration (Sarmin *et al*., 2021). Globulin concentration was determined by subtracting albumin from the total protein (Abdel-Lattif *et al*., 2021).

Economic analysis

At the end of the experiment, the economic parameters per lamb for the different dietary treatments were analysed. These include feed cost, cost of production per unit of product (meat), total revenue, net profit per lamb, relative economic efficiency, return on investment, rate of profit and price safety limit, according to a previously described procedure (Sayed, 2009; Hartwell *et al*., 2010). Total revenue per lamb was calculated as the weight of the empty carcass after slaughter (kg) multiplied by the sale price per kilogram of weight. The net profit per lamb was calculated as the difference between cost and total revenue. Relative economic efficiency was determined by comparing the economic performance of lambs fed varying levels of sprouted barley (T2, T3 and T4) to those fed the traditional diet (T1). It was calculated as the ratio of the net return to total cost for each dietary treatment, divided by the net return to total cost for lambs on the traditional diet (T1). Return on investment was used to assess the profitability of each dietary treatment. The return on investment was calculated by dividing the net profit per lamb by the total cost per lamb and multiplying it by 100%. The profit rate was calculated by dividing the net profit per lamb by total revenue. The price safety limit metric indicates the maximum price per kilogram of feed that can be paid for a given feed treatment without compromising profitability. It is calculated by dividing the total revenue per lamb, excluding feed costs, by the feed intake per lamb.

Data analysis

The normality of data distribution for each parameter was assessed using skewness, kurtosis and boxplot tests. A one-way analysis of variance (ANOVA) was performed with a general linear model using a Statistical Analysis System (SAS, 2008). The following statistical models were used:

$$Y_{ij} = \mu + T_i + \varepsilon_{ij}$$

Where,

Y_{ij}= Observed value.

μ= Overall mean.

T_i= Effect of treatments T1, T2, T3 and T4.

ε_{ij} = Random error.

Tukey's test was employed to identify significant differences ($p<0.05$) between dietary treatments. Results are presented as the mean ± standard error of the mean (SEM) for each parameter.

RESULTS AND DISCUSSION

Growth performance

The effects of dietary treatments on the body weight of lambs over a feeding period of 75 days are shown in Fig 1. On day 1, there were no significant differences ($p>0.05$) in body weight among the lambs fed the dietary treatments (T1= 27.80 kg, T2= 27.60 kg, T3= 27.63 kg and T4= 27.78 kg). All lambs had comparable body weights. Lambs fed diets containing sprouted barley (T2–T4) tended to have a higher body weight; however, this difference was not significant ($p>0.05$) when compared to the control group (T1) on day 45. There were statistically significant differences ($p<0.05$) in body weight between lambs fed the control diet (T1) and those fed diets containing sprouted barley (T2-T4) on day 75. Compared to lambs fed T1 diet, no significant differences in body weight were observed between lambs fed T2 and T4 diets, whereas body weight decreased in lambs fed the T3 diet.

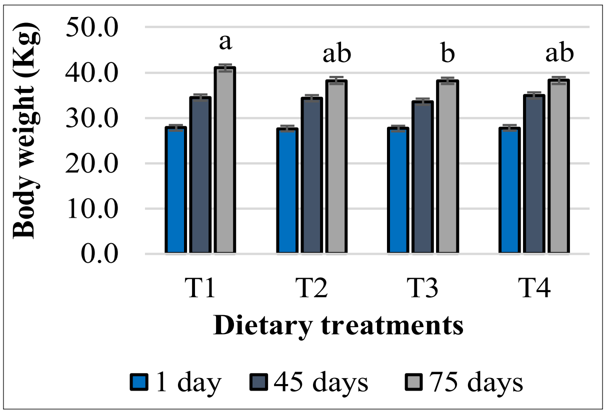

Fig 1: Effect of dietary treatments on body weight of lambs.

The effects of the dietary treatments on the weight gain of lambs throughout the 75-day feeding period are shown in Fig 2. There were no significant differences ($p>0.05$) in weight gain among the dietary treatments (T1-T4) during the first 45 days of the feeding period (days 1-45). Lambs fed diets containing sprouted barley (T2-T4) exhibited lower weight gain from days 45-75 or 1-75 compared to those fed T1 ($p<0.05$).

The effects of dietary treatments on the cumulative feed intake of lambs over 75 days are shown in Fig 3. Lambs fed the T4 diet following the T3 diet had a higher cumulative feed intake than those fed the T1 and T2 diets over the entire feeding period of 75 days ($p<0.05$). However, the differences in cumulative feed intake between T1 and T2 were not significant during this period.

The effects of dietary treatments on the ratio of feed intake to feed gain in lambs over a 75-day feeding period are shown in Fig 4. Lambs fed diets T1 and T2 had a lower feed intake-to-gain ratio in the first 45 days of the feeding period (1-45 days) than those fed diets T3 and T4 ($p<0.05$). In addition, lambs fed T1 had a lower feed-to-gain ratio than those fed the other dietary treatments (T2-T4) on days 45-75 ($p<0.05$). During the overall feeding period (days 1-75), the dietary inclusion of sprouted barley from T2 to

Table 1: Nutrient analysis based on dry matter of sprouted barley and dietary treatments.

Items (g/kg)*	Dietary treatments[1]				Sprouted barley
	T1	T2	T3	T4	
Dry matter	955	767	578	389	201
Crude protein	150	146	144	142	139
Crude fat	16.8	18.1	19.0	20.1	26.9
Ash	52.4	49.5	46.4	43.7	30.5
Non-fibrous carbohydrates	439	436	488	483	435
Neutral detergent fiber	342	350	303	310	369
Acid detergent fiber	198	182	160	176	168
Calcium	6.5	6.5	5.3	4.5	1.9
Phosphorus	2.3	2.5	2.7	3.0	3.9
Potassium	14.7	4.0	12.0	10.4	5.1
Sodium	2.0	1.9	2.0	1.8	1.5
Magnesium	1.8	1.9	1.9	1.8	1.4
Zinc, ppm	330	370	390	410	700
Copper, ppm	50	70	60	50	60
Net energy, Mcal/lb[2]	0.84	0.86	0.88	0.86	0.87

*Nutrient analysis was conducted in two independent replicates to ensure data reliability.

[1]Dietary treatments: T1, lambs fed 100% traditional diet (barley grain and alfalfa hay); T2, lambs fed 75% traditional diet and 25% sprouted barley; T3, lambs fed 50% traditional diet and 50% sprouted barley and T4, lambs fed 25% traditional diet and 75% sprouted barley.

[2]Net energy was determined by calculating net energy from digestible energy, with accounts for metabolic losses, to determine utilizable energy *in vitro*.

T4 resulted in a gradual increase in the feed-to-gain ratio compared with that from T1 ($p<0.05$).

Digestibility and nitrogen balance indicators

The effects of the dietary treatments on the digestibility and nitrogen balance indicators of the lambs are shown in Table 2.

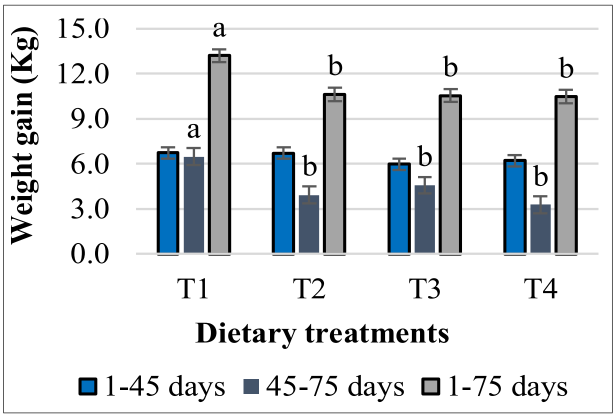

Fig 2: Effect of dietary treatments on weight gain of lambs.

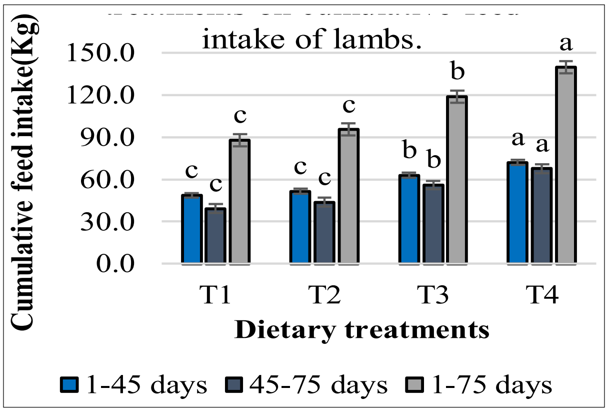

Fig 3: Effect of dietary treatments on cumulative feed intake of lambs.

Lambs fed T2 and T3 had higher and T4 had lower dry matter intake than those fed T1 ($p<0.05$). In addition, lambs fed T4, followed by T3, had the lowest dry matter excretion, fecal nitrogen excretion and total excretion compared to the other dietary treatments ($p<0.05$). Urinary nitrogen excretion was the lowest in T2 compared to T1 but remained unchanged in the other dietary treatments ($p<0.05$). Lambs fed T2 and T3 had a higher nitrogen balance than lambs fed the other diets ($p<0.05$). Thus, the results showed that lambs fed diets containing sprouted barley (T2-T4) had the highest digestibility of dry matter and nitrogen compared to those fed control diet T1 ($p<0.05$).

Hematological parameters

The effects of dietary treatments on the hematological parameters of the lambs are shown in Table 3. Some hematological parameters differed significantly ($p<0.05$) between lambs fed the control diet (T1) and those fed the sprouted barley diet (T2-T4). However, lambs fed the T2 diet had a higher white blood cell count than those fed the T4 diet, whereas there was no significant difference between the lambs fed the T1 and T3 diets ($p<0.05$). Hemoglobin levels were lower when lambs were fed sprouted barley (T3 and T4) than when they were fed T1 and T2 ($p<0.05$). In contrast, no significant differences were observed in other hematological parameters, including lymphocytes, monocytes, granulocytes, red blood cells, hematocrit and platelets, among the dietary treatments ($p>0.05$).

Blood biochemical parameters

The effects of the dietary treatments on the biochemical parameters in the blood of the lambs are shown in Table 4. There were statistically significant differences ($p<0.05$) in several blood biochemical parameters between the lambs fed the control diet (T1) and those fed the sprouted barley diets (T2-T4). Lambs fed the T3 and T4 diets had lower

Table 2: Effect of dietary treatments on digestibility and nitrogen balance indicators in lambs at 75 days of experiment.

Items	Dietary treatment [1]				SEM [2]	P-value
	T1	T2	T3	T4		
Dry matter intake (g/d)	1465^{b}	1631^{a}	1516^{a}	1156^{c}	84.78	0.011
Dry matter excreted (g/d)	267^{a}	244^{a}	152^{b}	92^{c}	30.10	0.004
Nitrogen intake (g/d)	35^{a}	38^{a}	35^{a}	26^{b}	1.99	0.005
Nitrogen excretion (g/d)						
Fecal	8.74^{a}	9.41^{a}	4.63^{b}	2.93^{c}	1.26	0.008
Urine	2.44^{a}	0.76^{b}	1.63^{ab}	1.29^{ab}	0.28	0.009
Total excretion	11.17^{a}	10.17^{a}	6.25^{b}	4.22^{b}	1.36	0.011
Nitrogen-balance (g/d)	17.54^{b}	21.91^{a}	23.44^{a}	16.02^{b}	1.94	0.005
Dry matter digestibility (%)	81.80^{c}	85.15^{b}	90.01^{a}	92.03^{a}	1.45	0.001
Nitrogen digestibility (%)	73.23^{b}	75.51^{ab}	86.73^{a}	88.88^{a}	2.78	0.006

$^{a-b}$, Values within rows for each item with clarification of the significant difference in the form of superscripts ($p<0.05$).

[1]Dietary treatments: T1, lambs fed 100% traditional diet (barley grain and alfalfa hay); T2, lambs fed 75% traditional diet and 25% sprouted barley; T3, lambs fed 50% traditional diet and 50% sprouted barley and T4, lambs fed 25% traditional diet and 75% sprouted barley.

[2]SEM, Standard error of the mean representing the variability in the data around the average value for each dietary treatment.

concentrations of total protein, globulin, triglycerides and glucose than those fed the T1 and T2 diets (p<0.05), whereas there was no significant difference between the lambs fed the T1 and T2 diets. In contrast, the concentrations of total cholesterol and HDL cholesterol were higher in lambs fed T3 and T4 diets than in those fed T1 and T2 diets (p<0.05). Lambs fed the sprouted barley diets (T2-T4) had lower urea and ALT concentrations than those fed T1 (p<0.05). However, there were no significant differences in the albumin albumin/globulin ratio, LDL cholesterol, creatinine and AST levels among the dietary treatments (p>0.05).

Economic evaluation

Economic evaluation of the production of lambs fed different diets is shown in Table 5. The total cost of feed and breeding per lamb were lower in diets T2 and T3, followed by T4, than in the control group (T1), despite the high feed consumption. However, total revenue per lamb, net profit per lamb and profit rate were higher in lambs fed T2 and lower in those fed T3 and T4 than in the control group (T1). In addition, the present results showed that relative economic efficiency increased by 6.7% for lambs fed the T2 diet, while it decreased by 17.1 and 27.0 for the other dietary treatments (T3 and T4, respectively) compared to T1. Diet T2 achieved the highest investment rate of 54.47%, while it was the lowest for T3 and T4 compared to T1. The results show that the price safety limit ratio reached 39.03% for T1 and 40.41% for T2, while the values for T3 and T4 were lower (34.53% and 31.55%, respectively).

Several studies have indicated that many biological processes can occur during germination, which increase the content of nutrients and biological compounds because of the activation of many enzymes during sprouting (Fazaeli *et al*., 2012; Girma and Gebremariam, 2018; Ikram *et al*., 2021). Therefore, in recent years, the use of sprouted barley in feeding growing lambs has gained considerable attention because of its potential health benefits, such as improving rumen health, increasing the number of bacteria involved in fiber digestion and providing short-chain fatty acids (Alharthi *et al*., 2022). Al-Saadi and Al-Zubaidi (2016) also showed that lambs fed sprouted barley had similar or slightly lower weight gains and lower feed costs than control animals, which may lead to higher relative profitability. This has led to an economic impact of sprouted barley on lamb production (Emam, 2016). In addition, the inclusion rate, germination period, animal species, age and production system lead to different results in the feeding of sprouted barley (Arif *et al*., 2023).

The results of the current experiment showed that, compared to lambs fed the T1 diet, the body weights of lambs fed the T2 and T4 diets remained unchanged, whereas body weights decreased in those fed the T3 diet. Additionally, lambs on diets containing sprouted barley (T2-T4) exhibited lower weight gain from days 45 to 75, or over the entire period (days 1-75), compared to lambs fed the T1 diet. These results were partially consistent with those of previous studies. The addition of sprouted barley to a traditional diet negatively affects the growth performance (Muhammad *et al*., 2013). In contrast, the study results

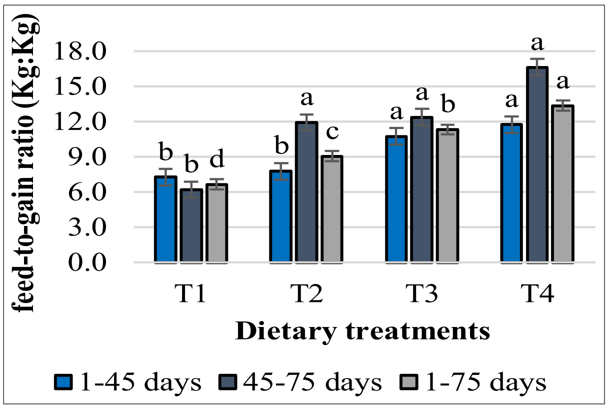

Fig 4: Effect of dietary treatments on feed-to-gain ratio of lambs.

Table 3: Effect of dietary treatments on hematological parameters in lambs at 75 days of experiment.

Items	Dietary treatment[1]				SEM[2]	P-value
	T1	T2	T3	T4		
White blood cell (10^g/L)	12.23[ab]	12.85[a]	11.82[ab]	11.14[b]	0.315	0.006
Lymphocytes (%)	57.06	56.76	53.64	52.79	2.997	0.671
Monocytes (%)	6.72	6.65	7.84	6.92	0.629	0.527
Granulocytes (%)	36.22	36.59	38.52	40.29	2.911	0.741
Red blood cell (10^12/L)	11.97	12.34	12.70	12.62	0.398	0.576
Hemoglobin (g/dL)	10.73[a]	10.78[a]	10.26[b]	10.25[b]	0.112	0.002
Hematocrit (%)	29.26	29.12	28.49	28.27	0.713	0.719
Platelet (10^g/L)	565.86	585.69	505.50	581.32	29.08	0.210

[a-b], Values within rows for each item with clarification of the significant difference in the form of superscripts (*p*<0.05).

[1]Dietary treatments: T1: Lambs fed 100% traditional diet (barley grain and alfalfa hay); T2: Lambs fed 75% traditional diet and 25% sprouted barley; T3: Lambs fed 50% traditional diet and 50% sprouted barley and T4: Lambs fed 25% traditional diet and 75% sprouted barley.

[2]SEM: Standard error of the mean representing the variability in the data around the average value for each dietary treatment.

showed an improvement in growth performance, including body weight and weight gain, when feeding sprouted barley at 62% with the control diet in Awassi lambs (Ata, 2016) and goats (Gebremedhin, 2015). Moreover, feeding lambs sprouting barley on rice straw improved their growth performance (Fayed, 2011). This discrepancy could be due to factors such as the level of sprouted barley, duration of the feeding period and forage quality. Lambs that gradually introduced to sprouted barley had a higher cumulative feed intake and feed-to-gain ratio over 75 days than the control group. This could be due to the better palatability and digestibility of sprouted barley compared to unsprouted

Table 4: Effect of dietary treatments on blood biochemical parameters in lambs at 75 days of experiment.

Items	Dietary treatment[1]				SEM[2]	P-value
	T1	T2	T3	T4		
Total protein (g/dL)	5.94[a]	6.15[a]	5.44[b]	5.43[b]	0.114	0.0001
Albumin (g/dL)	3.97	3.95	3.88	4.00	0.189	0.963
Globulin (g/dL)	1.97[a]	2.19[a]	1.56[b]	1.43[b]	0.173	0.012
Albumin/globulin ratio	2.23	1.92	2.58	3.37	0.453	0.132
Glucose (mg/dL)	69.89[a]	72.20[a]	60.31[b]	58.60[b]	3.223	0.009
Total cholesterol (mg/dL)	75.40[c]	77.35[bc]	80.69[a]	81.95[a]	1.032	0.0003
HDL cholesterol (mg/dL)	34.59[b]	39.19[ab]	42.86[a]	41.60[a]	1.904	0.033
LDL cholesterol (mg/dL)	18.54	15.37	16.68	20.13	1.663	0.192
Triglycerides (mg/dL)	111.4[a]	113.9[a]	105.7[b]	101.1[b]	3.291	0.036
Urea (mg/dL)	13.81[a]	11.37[b]	10.73[b]	10.10[b]	0.546	0.0003
Creatinine (mg/dL)	2.04	2.22	1.96	1.99	0.17	0.651
AST (U/L)	79.01	74.92	74.15	77.91	6.73	0.952
ALT (U/L)	20.15[a]	13.96[b]	15.45[b]	7.85[c]	1.40	<0.0001

[a-b], Values within rows for each item with clarification of the significant difference in the form of superscripts (p<0.05).

[1]Dietary treatments: T1: lambs fed 100% traditional diet (barley grain and alfalfa hay); T2: Lambs fed 75% traditional diet and 25% sprouted barley; T3: Lambs fed 50% traditional diet and 50% sprouted barley and T4: Lambs fed 25% traditional diet and 75% sprouted barley.

[2]SEM, Standard error of the mean representing the variability in the data around the average value for each dietary treatment.

Table 5: Economic evaluation of the production of lambs fed different dietary treatments in lambs.

Items	Units	Dietary treatment[1]			
		T1	T2	T3	T4
Cost of 1 kg of feed	*USD	0.33	0.28	0.23	0.17
Empty body weight after slaughter	Kg	36.30	36.90	33.90	32.40
Feed consumption (1-75 days)	Kg	87.85	95.30	118.72	139.56
Price of 3-month-old lambs	USD	320	320	320	320
Care costs	USD	26.67	26.67	26.67	26.67
Total feed cost per lamb	USD	29.32	26.71	26.94	24.21
Total breeding costper lamb	USD	375.99	373.38	373.60	370.87
Selling price per kg weight	USD	16.00	16.00	16.00	16.00
Total revenue per lamb	USD	580.80	590.40	542.40	518.40
Net profit per lamb	USD	204.81	217.02	168.80	147.53
Economic efficiency ratio	-	0.54	0.58	0.45	0.40
Relative economic efficiency	%	100.0	106.7	82.9	73.0
Return on investment	%	54.47	58.12	45.18	39.78
Rate of profit	-	35.26	36.76	31.12	28.46
Price safety limit	%	39.03	40.41	34.53	31.55

*The prices are given for the year 2024 AD. Barley price per kg, 0.32 USD; alfalfa hay price per kg, 0.37 USD; sprouted barley price per kg, 0.12 USD.

[1]Dietary treatments: T1: Lambs fed 100% traditional diet (barley grain and alfalfa hay); T2: Lambs fed 75% traditional diet and 25% sprouted barley; T3: Lambs fed 50% traditional diet and 50% sprouted barley and T4: Lambs fed 25% traditional diet and 75% sprouted barley.

barley grains. However, the significant decrease in feed efficiency (higher feed-to-gain ratio) indicated that lambs fed sprouted barley required more feed to gain the same amount of weight as the control group. Owing to the lower dry matter content of the sprouted barley, the lambs were unable to meet their dry matter requirements, resulting in lower weight gain during the experimental period (Morales *et al*., 2009).

Lambs fed the T2 and T3 diets had a higher dry matter intake than those fed the T1 diet. This indicates that the lambs fed diets with sprouted barley ate more than those fed T1. Lambs fed T4 had the lowest excretion of dry matter, fecal nitrogen and total excretion compared with the other dietary treatments. This indicated that lambs fed T4 absorbed more nutrients than those fed the other diets. Urinary nitrogen excretion was lowest in the T2 group compared to T1 but remained unchanged across the other dietary treatments, implying that lambs on the T2 diet retained more nitrogen than those on T1. However, there was no difference in nitrogen retention between lambs fed the other diets. Helal (2015) reported that higher nitrogen retention in goats fed sprouted barley might be due to increased dry matter intake and digestibility. Lambs on T2 and T3 diets had a higher nitrogen balance than those on other diets, with nitrogen balance being a measure of the amount of nitrogen retained by an animal. A positive nitrogen balance indicates that the animal retains nitrogen, which is important for growth and development. Devendar *et al*. (2020) indicated that 50% sprouted barley improved the nitrogen balance of lambs during growth. Overall, the results of this study showed that lambs fed diets containing sprouted barley (T2–T4) had higher dry matter and nitrogen digestibility than did lambs fed T1. This suggests that sprouted barley may be a beneficial feed ingredient for lambs because it can improve nutrient absorption and nitrogen retention. Many studies have reported that biochemical changes in barley seeds lead to improved digestibility of dry matter and nitrogen through the activity of hydrolytic enzymes (Al-Saadi and Al-Zubiadi, 2016; Raeisi *et al*., 2018; Ikram *et al*., 2021).

Interestingly, lambs in T2 had a higher white blood cell count than those in T4. There was no significant difference between the T1 and T3 diets. This suggests that T2 induces a mild white blood cell response, possibly due to a specific component or the sprouting process itself (Sleman *et al*., 2021). Hemoglobin levels were lower in lambs fed diets T3 and T4 than in those fed diets T1 and T2. Hemoglobin transports oxygen in red blood cells; therefore, a decrease in hemoglobin could indicate a lower oxygen-carrying capacity (Wang *et al*., 2020). However, the lack of significant differences in red blood cell counts suggests that other factors influence hemoglobin levels. Further investigation is needed to understand the cause of the lower hemoglobin levels at T3 and T4, which have a negative impact on health.

Biochemical indicators in the blood reflect the health and nutritional status of the body and the nutritional content of the diet (Ma *et al*., 2024). However, these indicators were significantly different when sprouted barley was fed. Total protein and globulin concentrations decreased at T3 and T4, indicating decreased protein synthesis or increased protein breakdown, possibly because lambs did not meet their dry matter requirements, resulting in a lower weight (Chouinard and Girard, 2014; Gebrenedhin, 2015). The increased total cholesterol and HDL cholesterol levels at T3 and T4 may seem contradictory. However, considering that LDL cholesterol levels did not change, this suggests a shift toward a potentially beneficial HDL form (Fazaeli *et al*., 2017). The lower concentrations of triglycerides and glucose in the T3 and T4 diets indicated enhanced fat and sugar metabolism in lambs fed higher levels of sprouted barley. These results are consistent with those of Jiaqiang *et al*. (2023), who reported that replacing sprouted barley at a specific level in the basal diet of sheep can regulate fat metabolism by reducing the triglyceride concentration. Lambs fed the T3 and T4 diets had lower urea and ALT concentrations, suggesting improved kidney and liver functions in lambs fed sprouted barley. These results are consistent with those of Mehrez *et al*. (2018), who reported that rabbits fed 20% sprouted barley had lower urea and ALT concentrations.

Sprouted barley exhibits clear economic advantages. The total feed cost per lamb decreased with increasing sprouted barley content (T2-T4), despite the higher feed consumption and lower cost per kg of sprouted barley. These results are consistent with those of Devendar *et al*. (2020), who showed that sprouted barley reduced the feed and production costs of growing lambs. The T2 diet was the most profitable option. Net profit per lamb and rate of profit increased with T2 compared to T1 because of higher in total revenue per lamb. One study found that calves fed hydroponic barley had higher net profits and profit rate (Verma *et al*., 2015). For lambs fed 25% sprouted barley (T2), relative economic efficiency increased by 6.7% compared to the control group (T1), while it decreased by 17.1 and 27.0 for the other dietary treatments (T3 and T4), respectively. Diet T2 achieved the highest investment rate (54.47%), while it was lowest in T3 and T4 compared to T1. This indicates that the funds invested in the lamb project fed T1 generated approximately 54 cents of net income for every dollar of capital invested. The price safety limit was higher for lambs fed the T2 diet. They withstood a price drop of 40.41% before falling into a loss zone. This underlines the economic security provided by T2. These results suggest that a partial replacement of traditional diet with sprouted barley (approximately 25%) may be a cost-effective strategy for lamb production. Studies have shown that diet content 23% sprouted barley could be enhance the economic efficiency (Al-Saadi and Al-Zubiadi, 2016; Alinaitwe *et al*., 2018; Al-Ghamdi *et al*., 2024).

CONCLUSION

In conclusion, lambs may benefit from the inclusion of sprouted barley in their diets in terms of economic efficiency and nutrient digestibility. In contrast, 25% sprouted barley (T2) appeared to be the best choice, combining economic benefits with a minimal impact on growth performance. Nitrogen balance, dry matter digestibility and nitrogen content increased in lambs fed sprouted barley. Nevertheless, further optimization is needed to maximize the benefits of feed efficiency and weight growth. Further studies are required to investigate the long-term effects, optimal levels and physiological mechanisms to gain a more comprehensive understanding of sprouted barley as a potential feeding strategy for lambs.

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Disclaimers

The authors are responsible for the accuracy and completeness of the information provided, but do not accept any liability for any direct or indirect losses resulting from the use of this content.

Informed consent

This study was approved by the Scientific Ethics Committee of King Saud University, Saudi Arabia (KSU-SE-22-01) for all experimental design, diet and training parameters.

Conflict of interest

All authors declare no conflicts of interest among them.

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