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Implications of different barley forms and their antinutritional properties on turkey performance*

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Summary

Global climate change and rising feed costs necessitate the development of sustainable, cost-effective diets for turkey production. This study evaluated three barley forms – barley pasture, hydroponic barley, and soaked grain barley – for their effects on growth performance, feed efficiency, carcass traits, and antinutritional factors in American Bronze turkeys. A total of 180 two-week-old turkey poults were randomly assigned to three dietary treatments (60/treatment; three replicates of 20) and reared for 20 weeks. Weekly live weight gain, feed intake, and feed conversion ratio were recorded; carcass and organ yields were determined at slaughter. Barley β-glucan and phytic acid concentrations were analyzed, and calcium and phosphorus excretion in feces assessed. Results showed that males outperformed females ($P < 0.05$). In the starter phase, the hydroponic and soaked barley groups achieved the highest weight gains, whereas weight gains for the barley pasture group was the lowest ($P < 0.05$). During the grower and finisher phases, performance differences between males were non-significant ($P > 0.05$), but the females on barley pasture continued to perform worse than the other groups ($P < 0.05$). Feed intake was the highest in the hydroponic group in all phases ($P < 0.05$) and the lowest initially in the soaked group and later in the barley pasture group. Feed conversion was optimal with soaked barley early and subsequently with barley pasture in males ($P < 0.05$). Carcass and organ yields did not differ significantly ($P > 0.05$), although hydroponic barley-fed females had more abdominal fat ($P < 0.05$). β-glucan and phytic acid concentrations were significantly lower in barley pasture and hydroponic forms than in dry and soaked forms ($P < 0.05$). The hydroponic group also had the lowest fecal phosphorus concentrations ($P < 0.05$). Overall, hydroponic barley enhanced body weight gain and daily feed intake, whereas the performance of females on barley pasture was inferior. Germinated barley forms (hydroponic and pasture) contained reduced levels of β-glucan and phytic acid. These findings suggest that germinated barley can serve as a sustainable, effective feeding strategy to mitigate antinutritional factors and improve turkey performance.

Keywords: β-glucan, phytic acid, hydroponic system, barley, performance

In response to the increasing global demand for animal protein, turkey production emerges as a sector with high profit potential and adaptability to diverse climatic conditions, warranting further development (14, 29). However, in poultry production, feed costs constitute the largest component of total production expenses, accounting for approximately 60-70% of overall costs (4). This situation necessitates diversification of feed sources and the development of cost-effective alternatives for producers (1, 18, 53).

Barley (*Hordeum vulgare* L.) is a cereal crop distinguished by its ability to adapt to various environmental conditions, short growing period, drought tolerance, high photosynthetic capacity, and high nutritional value as a feed ingredient (59, 63). As the fourth most widely produced cereal worldwide, barley is predominantly used in animal feeding (45).

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In regions lacking adequate pasture infrastructure, hydroponic barley farming is an economic and sustainable alternative, offering the possibility of germination and feed production under controlled conditions without soil (3, 47, 54). This system produces an equivalent amount of feed with only 2-3% of the water required under field conditions and can be implemented in greenhouses, rooftop gardens, and vertical farming systems because of its minimal space requirement (47). During germination, enzymatic reactions enhance nutrient bioavailability and increase protein, mineral, and vitamin content (8, 55), thereby improving feed digestibility and potentially reducing feed costs by 30-50% (12, 54).

Barley contains anti-nutritional compounds, such as β-glucans and phytic acid (5, 24, 64), which require careful consideration in poultry diets. β-glucans increase digesta viscosity, negatively affecting growth performance (30), while phytic acid reduces phosphorus bioavailability. Consequently, low-phytate barley varieties can decrease phosphorus requirements (49).

Processes such as germination, soaking, fermentation, cooking, enzymatic digestion, and gamma irradiation have been reported to reduce anti-nutritional factors and improve the nutritional value of barley (28, 34). However, the high cost of some methods limits their practical application (56), whereas simpler and more economical techniques, such as pasture feeding, germination (21), or soaking, represent effective alternative strategies.

Although previous studies have investigated the effects of differently processed barley forms on growth performance, the simultaneous use of these forms in turkeys and the comparative impact of anti-nutritional compounds on performance have not been sufficiently explored. Changes in anti-nutritional compounds, such as β-glucans and phytic acid, due to different processing methods are expected to significantly influence nutrient utilization and growth performance.

In this study, the comparative effects of barley forage, hydroponic barley, and soaked barley grain on growth performance, feed efficiency, carcass characteristics, and anti-nutritional compounds were evaluated in American Bronze turkeys. In turkeys exhibiting high feed intake, producers often dilute commercial mixed feeds with barley or other cereals (32). In this approach, soaking the cereals increases their volume to reduce feed intake and achieve more efficient feed utilization.

Material and methods

Ethics. All procedures involving animals were approved by the Harran University Local Animal Ethics Committee (Approval number: 2023/007/01-12). The study was conducted at the Poultry Animal Unit, Eyyübiye Campus, Harran University, Şanlıurfa, Türkiye.

Experimental area and housing of animals. A total of 180 American Bronze turkey (*Meleagris gallopavo*) poults aged two weeks were used in the study. The experiment included three feeding groups: barley pasture in an extensive system, supplementation with hydroponic barley, and soaked grain barley. Due to suboptimal temperatures (16-20°C), poults were initially housed not in cages, but in controlled rooms set to 33°C. The poults were weighed individually before allocation to the experimental groups. Two-week-old poults were housed in group-specific rooms for 10 days and fed a starter diet. Each experimental group consisted of three replicates, with 20 poults per replicate, totaling 60 poults per group.

The animals with similar average body weights (approximately 280.8 ± 40.8 g) were housed in cages. During the housing phase, sanitary iron cages, each measuring 10 m^2 in area and 180 cm in height and lined with wood shavings, were used. Lime was placed in front of the cage doors to maintain hygiene and prevent the transfer of microorganisms during entry and exit. Feed and water were provided using automatic plastic feeders and drinkers. Electric heaters were employed to regulate ambient temperature, while light bulbs were used for illumination. During the experiment, feed was offered in measured amounts at regular intervals, and water was provided *ad libitum*.

At the start of the study, due to the insufficient size of the poults, identification leg bands were not attached, and sexing was not performed. Because of the difficulty of sexing the poults and incomplete crest development, their sex was not considered during group allocation. However, sex was recorded at each weighing, and group assignments were adjusted accordingly. At 46 days of age, sex determination and recording were completed.

Although the poults had been vaccinated against infectious bronchitis and Newcastle disease prior to their arrival at the facility, these vaccines were re-administered via drinking water on day 40. On day 80, an inactivated quadrivalent vaccine containing Swollen Head Syndrome (SHS), Infectious Bronchitis, Newcastle disease, and Egg Drop Syndrome (EDS) was administered by intramuscular injection in the neck region. In addition to SHS vaccination, which is a common practice in turkey production, continuous prophylactic support with antibiotics and vitamin supplements was provided.

Feed material. The ration administered in the study was identical across all groups and consisted of turkey poult starter, grower, and finisher diets formulated according to the developmental stages of turkeys. In addition to the nutrients supplied by the concentrate feed, different barley-based treatments were incorporated to meet the nutritional requirements of turkeys in accordance with the National Research Council (42) recommendations. The preparation methods for the barley treatments used in the three experimental groups are described below.

Barley pasture creation and grazing management. The poults grazed on a 300 m² plot located on the agricultural land of Harran University's Eyyübiye Campus. Initially, the soil surface was cleared of stones and weeds to prepare for pasture establishment, followed by deep ploughing with a tractor. Based on the climatic and edaphic conditions of the region, white native barley (*Hordeum vulgare* L.) seed was selected. Due to the limited plot size, approximately

7 kg of seed was sown manually by the broadcasting method over the 300 m^2 area. To ensure optimal seed-to-soil contact, the surface was leveled with a tractor-mounted back trowel. Sprinkler irrigation was performed initially, after which natural rainfall was used. Additionally, approximately 7 kg of a compound fertilizer was applied to the same plot to promote plant growth and improve soil fertility. The fertilizer contained 20% nitrogen (N), 20% phosphorus (P_2O_5), and 20% potassium (K_2O) in equal proportions. Nitrogen supports vegetative growth, phosphorus promotes root and reproductive development, and potassium enhances stress tolerance and disease resistance. The fertilizer included urea, ammonium phosphate, and potassium phosphate.

Hydroponic barley fodder production. Hydroponic barley was grown in a controlled environment in 27 metal trays (60 × 90 × 2.5 cm) arranged on three metal stands. Barley seeds underwent a series of treatments, beginning with washing under tap water, followed by soaking in water for five hours. After draining, the seeds were evenly spread on the trays, with each tray containing 900 g of seeds. The trays were irrigated four times daily using a spray nozzle sprayer and positioned at a slope of approximately 1-2% to prevent excess water accumulation. No fertilizers or chemical additives were used during cultivation. Ambient temperature was maintained between 22 and 25°C, with relative humidity controlled at 70-75%. Illumination was provided by natural light supplemented with fluorescent lamps. After an 8-10 day growth period, when shoots reached 10-15 cm, the fodder was harvested, including roots.

Preparation of soaked grain barley. The grain of barley used in the third group was soaked before feeding. The barley grains were first washed with potable tap water to remove dust and impurities. They were then placed in a plastic container, covered completely with water, and allowed to soak at room temperature (20-25°C) for 12 hours. Barley grains were soaked in tap water at ambient temperature for approximately 12 hours. After soaking, the grains increased in volume by approximately 50% through water absorption, were drained to remove excess water, and then incorporated into the ration without further processing. This practice is based on diluting the compound feed with soaked grains to limit feed intake. The objective is to achieve cost-effective turkey fattening by reducing the consumption of compound feed, which is relatively expensive.

Experimental diets and their composition. The feeding program dvided the turkeys in the experiment into three distinct groups: an extensive group (barley pasture), a hydroponic barley supplemented group, and a soaked grain barley group. All groups were fed turkey poult starter diet from 2 to 8 weeks of age.

In the extensive group, turkeys were grazed on barley pasture during the day and fed turkey grower diet in the evening between 8 and 16 weeks of age. From 16 to 22 weeks of age, they continued grazing on barley pasture during the day and were fed a turkey finisher diet at night.

Similarly, in the hydroponic barley-supplemented group, turkeys received hydroponic barley during the day and turkey grower diet in the evening from 8 to 16 weeks of age. Between 16 and 22 weeks of age, they were given hydroponic barley during the day and a turkey finisher diet at night. Fresh barley shoots harvested daily from the hydroponic system were cut into pieces to facilitate consumption and offered to the animals in feeders.

Tab. 1. The contents and chemical nutrient compositions (DM%) of basal diets used in the study

Contents	Starter[1] (weeks 2-8) (%)	Grower[2] (weeks 8-16) (%)	Finisher[3] (weeks 16-22) (%)
Maize	48.40	59.38	60.86
Soybean meal	46.40	35.98	27.74
Wheat	0.00	0.00	7.50
Vegetable oil	1.60	1.43	1.88
DL-methionin	0.055	0.05	0.05
L-lysine	0.005	0.08	0.00
Limestone	1.01	0.98	0.09
Salt	0.29	0.21	0.14
Dicalcium phosphate	1.99	1.64	1.49
Premix[1,2,3]	0.25	0.25	0.25
Total	100.00	100.00	100.00
Calculated analysis			
Crude protein (%)	24.56	21.04	18.40
Calcium (%)	1.02	0.88	0.80
Available phosphorus (%)	0.48	0.41	0.38
Methionine + cystine (%)	0.82	0.73	0.66
Lysine (%)	1.38	1.19	0.93
Threonine (%)	0.94	0.79	0.68
Linoleic acid (%)	1.88	1.99	1.76
Crude fiber (%)	4.31	3.84	3.49
ME (kcal/kg)	2806.19	2941.21	2937.99

Explanations: [1] – Per 1 kg of the starter diet, premix provides 15.0 IU vitamin A, 3.30 IU vitamin D_3, 25 IU vitamin E, 0.13 mg Cobalt, 15.01 mg Copper, 0.50 mg Iodine, 217.48 mg Iron, 129.23 mg Manganese, 0.38 mg Selenium, and 118.28 mg Zinc. [2] – Per 1 kg of the grower diet, premix provides 15.0 IU vitamin A, 3.30 IU vitamin D_3, 25 IU vitamin E, 0.13 mg Cobalt, 15.01 mg Copper, 0.50 mg Iodine, 217.48 mg Iron, 129.23 mg Manganese, 0.38 mg Selenium, and 118.28 mg Zinc. [3] – Per 1 kg of the finisher diet, premix provides 97.10 IU vitamin A, 21.36 IU vitamin D_3, 161.83 IU vitamin E, 0.81 mg Cobalt, 46.96 mg Copper, 3.24 mg Iodine, 450.51 mg Iron, 671.32 mg Manganese, 1.39 mg Selenium, and 522.90 mg Zinc.

In the soaked grain barley group, a mixture containing 20% of soaked grain barley and a turkey grower diet was administered throughout the day from 8 to 16 weeks of age. The same ratio was maintained from 16 to 22 weeks of age, with a turkey finisher diet provided concurrently.

The chemical nutrient composition and contents of the diets used in the study are presented in Table 1. The crude nutrient contents of barley pasture, hydroponic barley, and soaked grain barley used as feed materials are shown in Table 2.

Performance parameters. A total of 180 turkeys were weighed weekly from two weeks of age throughout the experiment, with body weight (BW) and body weight gain (BWG) recorded regularly until the end of week 22. Daily

Tab. 2. Nutrient content of barley pasture, hydroponic barley, and soaked grain barley (% DM)

Contents	Barley pasture (%)	Hydroponic barley (%)	Soaked barley grain (%)
Dry matter	89.9	92.40	90.6
Crude protein	18.6	15.62	9.6
Crude fiber	12.2	11.40	5.2
Ether extract	4.6	3.60	3.8
Total ash	11.6	10.36	5.6
NFS	42.9	51.40	66.1
ME (kcal/kg)	2583.8	2693.5	3009.5

Explanations: NFS – Nitrogen-free substances; ME – Metabolizable energy

feed intake (DFI) was carefully monitored on a weekly basis, with daily feed provision accurately documented. At the end of each week, residual feed was collected from feeders and weighed to calculate feed intake by subtracting residuals from total feed provided. Efforts were made to minimize feed spillage, and spilled feed was collected and weighed separately. All measurements were performed using a precision scale with 0.01 g accuracy. Performance parameters, including BWG, DFI, and feed conversion ratio (FCR), were evaluated at three intervals: T1 (weeks 2-12), T2 (weeks 13-22), and T3 (weeks 2-22).

Chemical analysis. Samples of pasture grass, hydroponic barley grass, soaked barley grain, and dry barley grain were used for analyses. All samples were air-dried at room temperature and then ground to a particle size below 0.5 mm. Chemical analyses were performed in triplicate for each sample. Additionally, P and Ca analyses were conducted on fecal samples from each experimental group.

Total ash, crude protein, ether extract, and crude fiber analyses were conducted according to AOAC (10) standard methods. Total ash content was determined by incinerating dried barley samples at 550°C for 4 hours in a muffle furnace (Protherm PLF Series, Ankara, Türkiye), and the remaining inorganic residue was weighed to calculate ash content. Crude protein was quantified by the Dumas combustion method (Thermo Fisher Scientific, Waltham, MA, USA), wherein samples were combusted at 950°C, released nitrogen gas was measured by a thermal conductivity detector, and protein content was calculated using a conversion factor of 6.25. The fat content (ether extract) was determined using a Soxhlet apparatus (Gerhardt, Duisburg, Germany) with diethyl ether, and quantified gravimetrically after solvent removal. Crude fiber analysis involved sequential boiling in diluted sulfuric acid and sodium hydroxide, followed by filtration, washing, drying at 105°C, and incineration at 550°C using a crude fiber analyzer (ANKOM 200 Fiber Analyzer, USA). The ash content of the residual material was also determined in a muffle furnace (Protherm PLF Series, Ankara, Türkiye).

Metabolizable energy (ME) values were calculated following Pauzenga (44), considering crude protein, ether extract, and nitrogen-free extract in the ration. ME (kcal/kg) was calculated using the formula $\mathrm{ME} = 37 \times \text{crude protein (\%)} + 81 \times \text{ether extract (\%)} + 35.5 \times \text{nitrogen-free extract (\%)}$. The nitrogen-free extract was determined by subtracting the percentages of crude protein, ether extract, total ash, and crude fiber from the dry matter content of the ration.

β-Glucan determination. The β-glucan content of barley samples subjected to different treatments was determined enzymatically with a Megazyme β-Glucan Assay Kit (Megazyme International Ltd., Bray, Ireland), following a modified protocol based on methods of McCleary and Glennie-Holmes (39), McCleary and Codd (38), and McCleary and Mugford (40). The procedure involves hydrolysis of β-glucan to glucose using lichenase and β-glucosidase, oxidation of the released glucose with glucose oxidase/peroxidase (GOPOD) reagent, and spectrophotometric measurement of the resulting chromophore at 510 nm (UV-1800, Shimadzu, Kyoto, Japan). To assess the effect of soaking, whole dry barley grains were also analyzed for comparison.

Phytic acid determination. Phytic acid content was quantified according to the colorimetric method described by Haug and Lantzsch (23). Ground barley samples were extracted with 0.2 M HCl at 175 rpm for 180 min and then centrifuged at 3000 rpm for 20 min (Universal 320R, Hettich, Tuttlingen, Germany). The supernatant was reacted with bipyridine ($C_{10}H_8N_2$) in the presence of Fe^{3+} to form an iron-phytate complex, and the absorbance was measured at 519 nm with a Biochrom Libra S60 spectrophotometer (Cambridge, UK). Phytic acid concentration was calculated from a standard curve prepared with known phytic acid concentrations. Comparisons were made between dry barley grains and soaked grains to evaluate the effect of soaking.

Phosphorus and calcium determination. Phosphorus and calcium concentrations in barley samples and animal feces were determined after microwave-assisted acid digestion. The digests were analyzed by inductively coupled plasma-optical emission spectrometry (ICP-OES; Optima 5300 DV, PerkinElmer, USA).

Determination of slaughter and carcass characteristics. For carcass evaluation, a total of 54 turkeys, comprising 9 males and 9 females from each group, were selected. They were chosen to represent the group's average live weight, specifically from turkeys whose weights fell within ± 5% of the group mean. All birds were 22 weeks old at slaughter (calculated from the hatching date), and their live weights were measured and recorded prior to slaughter. The turkeys were euthanized via cervical dislocation and exsanguinated, allowing 1-2 minutes for complete blood drainage. To facilitate feather removal, the carcasses were immersed in water at 50-60°C for 60-90 seconds (61). Subsequently, the feathers were manually plucked, and the carcasses were briefly chilled in cold water to initiate the primary cooling process. The feet were removed at the hock joint, and both edible and inedible viscera, along with the cloaca, were excised. The carcasses and their parts (thigh, breast, liver, heart, gizzard, abdominal fat, wing/back/neck) were weighed using a precision balance with an accuracy of 0.01 g. The samples were properly labeled, packaged, and stored at +4°C for 24 hours.

Statistical analysis. All statistical analyses were performed using the R software (version 4.4.2) with the Agricolae package (41). The assumptions of normality and homogeneity of variances were assessed using the Shapiro-Wilk and Levene's tests, respectively ($P > 0.05$). Factorial analysis of variance (ANOVA) was applied to evaluate differences between the groups (Eq. 1). For factors showing significant effects ($P < 0.05$), pairwise comparisons were performed using Tukey's honestly significant difference (HSD) test to identify groups with significant differences. Group means were labeled starting from the highest mean value. Data are presented as means ± standard error of the mean (SEM) in the tables. All statistical tests were considered significant at $P < 0.05$. Graphical visualizations were generated using the Python programming language with the Matplotlib (25) and Seaborn (65) libraries.

$$Y_{ijk} = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij} + \varepsilon_{ijk} \qquad \text{(Eq. 1)}$$

where:
Y_{ijk} – response variable,
I – level i. of factor A,
j – level j. of factor B,
k – observation in replication k,
μ – overall (grand) mean of the data,
α_i – main effect of factor A at level i,
β_j – main effect of factor B at level j,
$(\alpha\beta)_{ij}$ – interaction effect between factors A and B,
ε_{ijk} – independent, normally distributed error term,
n – number of replications for each i, j combination.

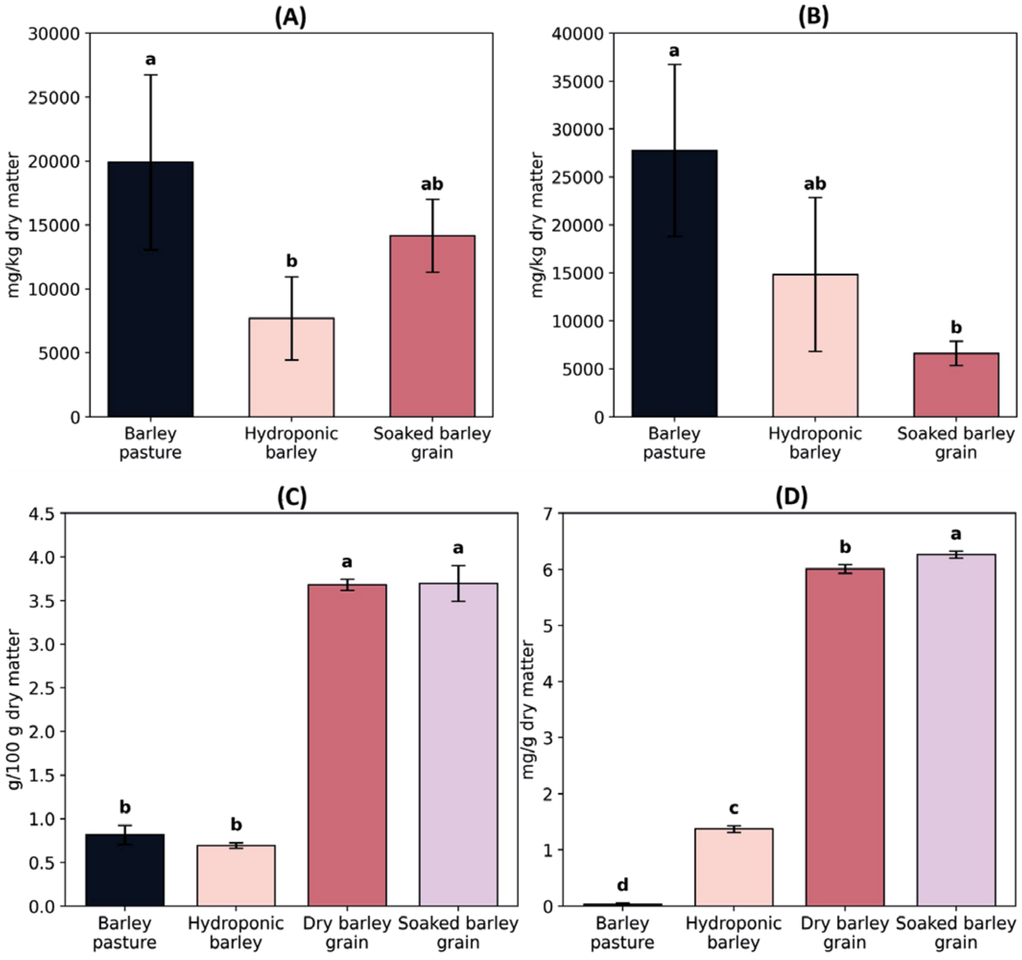

Fig. 1. Beta-glucan (A) and phytic acid levels (B) in different treated barley forms; phosphorus (C) and calcium (D) levels in the feces of turkeys fed different forms of barley (mean ± standard error, $P < 0.05$)

Results and discussion

The turkeys were raised from two weeks of age until slaughter at week 22. Following the initial two-week starter phase, a 20-week growing period ensued, which appeared optimal for turkeys in terms of regional environmental and husbandry conditions. Live weight gain slowed down during the final weeks, and since it continued at a low rate, slaughter was performed at week 22. To evaluate the differences between the experimental groups, anti-nutritional factors in the different forms of barley were analyzed. Beta-glucan and phytic acid levels, as well as fecal phosphorus and calcium, are presented in Figure 1.

β-glucan and phytic acid levels in different barley forms. Analyses of β-glucan ($C_{18}H_{32}O_{16}$) and phytic acid ($C_6H_{18}O_{24}P_6$) contents revealed statistically significant differences between the barley forms ($P < 0.05$). The highest β-glucan concentrations were observed in dry barley grain (3.68 g/100 g DM) and soaked barley grain (3.697 g/100 g DM), with no significant difference between these two forms. In contrast, the lowest β-glucan levels were detected in barley pasture (0.817 g/100 g DM) and hydroponic barley (0.693 g/100 g DM) ($P < 0.05$). With respect to phytic acid content, the highest value was recorded in soaked barley grain (6.264 mg/g DM), whereas the lowest content was observed in barley pasture (0.029 mg/g DM).

These findings indicate that anti-nutritional factors present in barley can be substantially reduced through processes such as germination or soil-based cultivation. In this context, the increased DFI observed in the groups receiving hydroponic barley may be related to reduction in specific anti-nutritional compounds (48). The absence of a similar effect in barley pasture may be attributed to its relatively firmer structure compared with germinated barley.

During germination, enzymatic activities break the (1→3) and (1→4)-β linkages in β-glucan, leading to a reduction in this cell-wall polysaccharide (26). The dense root system characteristic of barley grown under hydroponic conditions is believed to contribute markedly to β-glucan degradation, with enzymatic activity being particularly concentrated in the root zone.

Although bound phosphorus is generally reported to decrease only marginally during germination, the 23% reduction in phytic acid observed in hydroponic barley in this study is noteworthy in terms of improved phosphorus utilization. Previous studies have demonstrated that germination can enhance phosphorus utilization by increasing phytase enzyme activity (20, 36). The reduction in fecal phosphorus levels observed in the turkeys fed hydroponic barley provides tangible evidence supporting this mechanism. This improvement is likely attributable to the increased availability of phosphorus resulting from phytic acid degradation. Conversely, the absence of a similar effect in the barley pasture groups may be related to their lower feed intake and to the coarse fiber structure of pasture plants, which may reduce digestibility.

Although soaking has been reported to reduce phytic acid by 2-58%, several studies have shown that this reduction is not associated with increased phytase activity. This suggests that the decline may result not from enzymatic degradation, but from the leaching of phytate into the soaking water (46). Lemmens et al. (36) reported that soaking wheat in water at 40°C for 8 hours reduced the phytic acid content from 0.65 g/100 g to 0.47 g/100 g. In contrast, Arif et al. (11) observed no significant change in phytic acid levels following 48-hour soaking and subsequent germination of barley grains. On the other hand, Afify et al. (2) reported a 32.40% reduction in phytic acid content after soaking sorghum grains for 20 hours.

In the present study, barley grains were soaked for only 12 hours without the application of heat and were evaluated with their hulls intact. Under these conditions, the 4.16% increase in phytic acid observed after soaking, compared with dry barley, suggests that the discrepancy with the substantial reductions reported in the literature stems largely from methodological differences, such as soaking duration, heat application, and the use of hulled barley. It appears that variation in soaking conditions is closely related to the differences in results reported across studies.

The awned structure of dry barley grains can cause irritation in the crop and esophagus of poultry, a problem frequently reported in practical field observations. The soaking process partially eliminates these awns, thereby improving feed intake and digestive comfort. The findings of the present study suggest that the slightly higher feed intake observed in the group fed soaked barley, compared with the pasture group, may be explained by this improvement.

Phosphorus and calcium levels. Statistically significant differences were identified in fecal P and Ca levels between the turkey groups fed different diets ($P < 0.05$). According to the data, the highest fecal P level was detected in the group fed barley pasture, with an average value of 19.920 mg/kg. In contrast, the lowest fecal P level was recorded in the hydroponic barley group, with an average of 7.703 mg/kg. With respect to calcium, the highest fecal Ca level was observed in the barley pasture group (27.773 mg/kg), whereas the lowest level was found in the soaked dry barley grain group (6.608 mg/kg).

The elevated fecal Ca levels in the pasture group can primarily be attributed to the consumption of additional calcium sources, such as stones and limestone, by turkeys raised under open-pasture conditions. It has been demonstrated that high dietary calcium, particularly that originating from limestone, increases gastric pH, negatively affects nutrient absorption, and leads to insufficient calcium uptake (9). A reduction in gastric acidity decreases the solubility and gastrointestinal absorption of calcium, thereby increasing the excretion of unabsorbed calcium in feces. Moreover, excessive dietary calcium may also adversely affect the absorption of other macrominerals, including phosphorus (35), which can consequently impair overall animal performance (43). The lower BWG, DFI, and FCR values observed in the pasture group appear to be consistent with this mechanism.

The BWG, DFI, and FCR results of turkeys fed barley pasture, hydroponic barley, and soaked barley during the T1 (2-12 weeks), T2 (13-22 weeks), and T3 (2-22 weeks) periods are presented in Tables 3, 4, and 5, respectively. The sample size (n) used in this study was as follows: a total of 67 males and 101 females were evaluated. The distribution among the treatment groups was: 57 birds in the barley pasture group, 56 birds in the hydroponic barley group, and 55 birds in the soaked barley grain group.

The distribution in the treatment × sex interaction was as follows: 18 males and 39 females in the barley pasture group, 23 males and 33 females in the hydroponic barley group, and 26 males and 29 females in the soaked barley grain group. Each experimental group comprised initially 60 birds, but due to the removal or mortality of some individuals during the trial, the study proceeded with the remaining birds. Consequently, all analyses were carried out according to the number of birds remaining in each group.

Body weight gain. Statistically significant differences in BWG (Tab. 3) were detected between the feeding groups and between sexes during the T1 period ($P < 0.001$). However, the group × sex interaction was not significant ($P > 0.05$). In the T2 period, the effects of the group ($P < 0.05$), the sex ($P < 0.001$), and the group × sex interaction ($P < 0.001$) were all significant. Similarly, in the T3 period, the group ($P < 0.01$), the sex ($P < 0.001$), and the group × sex interaction ($P < 0.05$) were statistically significant.

Tab. 3. Body weight gains of turkeys fed diets supplemented with barley pasture, hydroponic barley, or soaked grain barley

BWG (g/day)	Group	Sex		Mean	SEM	P value		
		Male	Female			Group (G)	Sex (S)	G × S
T1	Barley pasture	43.513	33.032	38.273^{b}		< 0.001	< 0.001	0.49
	Hydroponic barley	47.529	35.665	41.597^{a}				
	Soaked grain barley	45.993	35.181	40.587^{a}				
	Mean	45.678^{a}	34.626^{b}	40.152	0.344			
	SEM			0.412				
T2	Barley pasture	55.860^{A}	27.150^{C}	41.505	0.863	0.048	< 0.001	< 0.001
	Hydroponic barley	51.872^{A}	30.875^{B}	41.374				
	Soaked grain barley	54.103^{A}	32.444^{B}	43.274				
	Mean	53.945	30.156	42.051				
	SEM							
T3	Barley pasture	49.557^{A}	30.153^{C}	39.855	0.689	0.008	< 0.001	0.038
	Hydroponic barley	49.655^{A}	33.321^{B}	41.493				
	Soaked grain barley	50.056^{A}	33.841^{B}	41.949				
	Mean	49.759	32.438	41.099				
	SEM							

Explanations: BWG – body weight gain; SEM – standard error of the mean; G – effect of the feed group; S – effect of the sex; G × S – interaction group; T1 – weeks 2-12; T2 – weeks 13-22; T3 – weeks 2-22. Different letters ($^{a, b, c; A, B, C}$) denote statistical differences within the same row or column (P < 0.05). Uppercase letters ($^{A, B, C}$) denote interaction effects, while lowercase letters ($^{a, b, c}$) indicate feed group and sex groups

During the T1 period, the highest BWG values were recorded in the hydroponic barley (41.597 g) and soaked barley (40.587 g) groups, whereas the lowest value was observed in the barley pasture group (38.273 g). In the T2 period, the highest BWG values in males were obtained in the barley pasture (55.860 g), hydroponic barley (51.872 g), and soaked barley (54.103 g) groups, with similar levels across all groups. In contrast, the lowest BWG value in females was recorded in the barley pasture group (27.150 g) ($P < 0.001$). The results for the T3 period showed a distribution similar to that for the T2 period, and the groups were classified accordingly ($P < 0.05$).

Evaluation of body weight gains indicated that males performed significantly better than females in all periods. This finding is consistent with a study conducted by Arslan (13) on American Bronze turkeys and is explained by sex-related differences in energy utilization. Similarly, Tůmová et al. (60) reported that male Hybrid Converter turkeys achieved higher body weights than females throughout all growth stages, attributing this difference to genetic and physiological factors. These observations support the conclusion that male turkeys have an advantage during the fattening period.

According to the experimental design, two-week-old poults were randomly allocated to the groups so that initial body weights were similar. This approach ensured that the effects of different barley forms and sex on subsequent differences could be accurately assessed.

Periodic variations related to the different barley forms became more pronounced as the feeding periods progressed.

During the T1 period, when group means independent of sex were examined, the hydroponic barley and soaked barley groups exhibited higher BWG values. However, this effect did not persist among males during the T2 and T3 periods. Although males in the hydroponic and soaked barley groups showed similar BWG values, a notable difference was observed in the pasture group when compared with females. This finding suggests that female turkeys have a lower capacity to adapt to pasture conditions than males, which may be attributed to the higher adaptive ability of males (58). Furthermore, the results indicate that males demonstrated superior adaptation to the three barley forms used in the study, which had a positive effect on their growth performance. Similarly, Alinaitwe et al. (7) reported that rations supplemented with hydroponic barley improved growth performance and positively influenced BWG in Kuroiler chickens.

Daily feed intake. Subsequent analyses revealed the daily feed intake (DFI) data, with results presented in Table 4. In the T1 and T2 periods, the effects of the group, the sex, and the group × sex interaction were statistically significant ($P < 0.001$). In the T3 period, group and sex effects remained significant ($P < 0.001$), whereas the group × sex interaction was not significant ($P > 0.05$).

During the T1 period, the females (102.432 g) and males (103.032 g) in the hydroponic barley group exhibited similar DFI levels, showing the highest consumption. In the same period, minimal differences were observed between the females (93.903 g) and males (93.103 g) in the soaked barley group, with the lowest DFI. In the T2 period, the highest DFI was observed in the females of the hydroponic barley group (165.129 g), whereas the lowest intake was recorded in the males of the barley pasture group (144.339 g). In the T3 period, as the group × sex interaction was not

Tab. 4. Daily feed intake of turkeys fed diets supplemented with barley pasture, hydroponic barley, or soaked grain barley

DFI (g/day)	Group	Sex		Mean	SEM	P value		
		Male	Female			Group (G)	Sex (S)	G × S
T1	Barley pasture	95.202^{C}	99.112^{B}	97.157	0.246	< 0.001	< 0.001	< 0.001
	Hydroponic barley	103.032^{A}	102.432^{A}	102.732				
	Soaked grain barley	93.103^{D}	93.903^{D}	93.503				
	Mean	97.112	98.482	97.797				
	SEM							
T2	Barley pasture	144.339^{E}	146.565^{D}	145.452	0.280	< 0.001	< 0.001	< 0.001
	Hydroponic barley	160.213^{B}	165.129^{A}	162.671				
	Soaked grain barley	155.995^{C}	160.113^{B}	158.054				
	Mean	153.516	157.269	155.393				
	SEM							
T3	Barley pasture	119.910	122.447	121.178^{c}		< 0.001	< 0.001	0.702
	Hydroponic barley	131.623	133.781	132.702^{a}				
	Soaked grain barley	124.549	127.008	125.778^{b}				
	Mean	125.360^{b}	127.745^{a}	126.553	0.136			
	SEM			0.163				

Explanations: DFI – daily feed intake; T1 – weeks 2-12; T2 – weeks 13-22; T3 – weeks 2-22; SEM – standard error of the mean; G – effect of the feed group; S – effect of the sex; G × S – interaction group. Different letters ($^{a, b, c; A, B, C}$) denote statistical differences within the same row or column ($P < 0.05$). Uppercase letters ($^{A, B, C}$) denote interaction effects, while lowercase letters ($^{a, b, c}$) indicate feed group and sex groups

significant, the groups were analyzed independently. On a group basis, DFI was the highest in the hydroponic barley group (132.702 g) and the lowest in the barley pasture group (121.178 g). In sex comparisons, males consumed an average of 125.360 g, while females consumed an average of 127.745 g.

The consistently high DFI observed in the hydroponic barley group can be attributed to the soft texture and high moisture content of the feed, which enhance nutrient digestibility (54). In particular, the enzymatic breakdown of starch into simple sugars increases palatability and metabolic availability, thereby promoting feed intake (33).

Conversely, the lowest DFI was recorded in the whole barley group during T1, and in the pasture group during T2 and T3. Jacob and Pescatore (27) reported that feeding poultry with barley-based diets during the growth period can negatively affect the digestive system and reduce performance. This adverse effect is attributed primarily to non-starch polysaccharides in barley, particularly β-glucans. β-Glucans increase intestinal viscosity, alter gut structure and microbiota, and consequently reduce nutrient availability (18). Although β-glucans from yeast, fungi, and some cereals may have immune-enhancing effects, their high levels in barley can negatively impact poultry performance (26, 50). Al-Bayati (6) reported that a diet including up to 30% of normal or germinated barley did not adversely affect performance or gut health, whereas the inclusion of 45% of such barley had a negative effect on body weight, feed intake, and intestinal viscosity.

As the T1 period corresponds to the chick growth phase, it is likely that individuals with immature digestive systems could not consume whole barley grains adequately. Therefore, responses observed in the T2 and T3 periods are considered statistically more robust and suitable for analysis. The T1 period is largely characterized by the animals' adaptation to environmental conditions and the feeding regimen applied. Poultry have limited capacity to digest high-fiber feed ingredients, and fiber-rich plant materials can negatively affect feed intake and performance (51). This supports the observation that the increasing fiber content of pasture plants as they mature may restrict feed intake in the T2 and T3 periods.

The higher DFI in the hydroponic barley group can also be linked to the contrast between the soft, fresh tissue of hydroponic plants and the coarse, fibrous structure of pasture barley. Hydroponic barley, which is generally harvested before 10 days of growth, has a soft, palatable texture, whereas pasture barley becomes mature and fibrous, making it more difficult for poultry to digest (51, 54).

Baye et al. (16) reported that the attractive appearance and palatability of hydroponic barley feed increased DFI in broiler chicks. Malama et al. (37) confirmed that germination increases the crude fiber fraction in cereals and improves digestibility. In the present study, the use of hydroponic barley along with its roots was expected to increase DFI because of the taste and palatability of the root portion, and observations confirmed that turkeys showed marked interest in the roots. Similarly, Hassan (22) reported that germinated barley grains increased DFI in ducks. Dastar et al. (19) indicated that replacing 33% of barley in the diet with germinated barley significantly increased DFI in broiler chicks, attributing this effect to a decreased β-glucan content during germination, which reduced

Tab. 5. Feed utilization ratios of turkeys fed diets supplemented with barley pasture, hydroponic barley, or soaked grain barley

FCR (g feed/g)	Group	Sex		Mean	SEM	P value		
		Male	Female			Group (G)	Sex (S)	G × S
T1	Barley pasture	2.204	3.021	2.613^{a}		< 0.001	< 0.001	0.095
	Hydroponic barley	2.181	2.887	2.534^{a}				
	Soaked grain barley	2.036	2.680	2.358^{b}				
	Mean	2.140^{b}	2.863^{a}	2.502	0.023			
	SEM			0.027				
T2	Barley pasture	2.610^{D}	5.410^{A}	4.010	0.070	< 0.001	< 0.001	< 0.001
	Hydroponic barley	3.144^{C}	5.358^{A}	4.251				
	Soaked grain barley	2.939^{C}	4.974^{B}	3.957				
	Mean	2.898	5.247	4.073				
	SEM							
T3	Barley pasture	2.438^{D}	4.074^{A}	3.256	0.051	< 0.001	< 0.001	< 0.001
	Hydroponic barley	2.680^{C}	4.027^{A}	3.354				
	Soaked grain barley	2.519^{CD}	3.774^{B}	3.147				
	Mean	2.546	3.958	3.252				
	SEM							

Explanations: FCR – feed conversion ratio; SEM – standard error of the mean G – effect of the feed group; S – effect of the sex; G × S – interaction group; T1 – weeks 2-12; T2 – weeks 13-22; T3 – weeks 2-22. Different letters ($^{a, b, c; A, B, C}$) denote statistical differences within the same row or column ($P < 0.05$). Uppercase letters ($^{A, B, C}$) denote interaction effects, while lowercase letters ($^{a, b, c}$) indicate feed group and sex groups

intestinal viscosity and increased the passage rate in the digestive tract.

Feed conversion ratio. Across all periods, FCR data exhibited statistically significant differences between the feeding groups and sexes ($P < 0.001$) (Tab. 5). The group × sex interaction was not significant only in the T1 period ($P > 0.05$), whereas significant interactions were detected in the T2 and T3 periods ($P < 0.01$).

During the T1 period, the lowest FCR was observed in the soaked barley grain group (2.358), while the highest values were recorded in the barley pasture (2.613) and hydroponic barley (2.534) groups. When evaluated by sex, the lowest FCR was identified in males (2.140), whereas females exhibited the highest FCR (2.863). In the T2 and T3 periods, the lowest FCR values were recorded in the males of the barley pasture group (2.610 and 2.438, respectively). In contrast, the highest FCR values were observed in the females of the barley pasture group (5.410 and 4.074, respectively) and in the females of the hydroponic barley group (5.358 and 4.027, respectively).

In the T1 period, it is suggested that the poults were unable to consume sufficient quantities of soaked barley grain, which may have suppressed DFI and consequently reduced FCR. This phenomenon can be explained by the fact that intestinal viscosity is a less limiting factor in adult poultry compared to young birds fed barley-based diets (26). Mature birds with a more developed digestive system can mitigate the adverse effects of high β-glucan-induced digesta viscosity. Some studies have reported that intestinal viscosity decreases with age in broilers fed barley-based diets (15, 30). These findings support Bedford's (17) hypothesis that the effects of viscosity should be re-evaluated according to both the cereal type and the age of the birds, which is particularly relevant for barley diets rich in insoluble polysaccharides. The low FCR observed in the whole barley group, indicating more efficient feed utilization, is largely attributed to the high BWG and low DFI observed in turkeys during these periods.

Svihus (57) comprehensively evaluated gizzard function and the feed form, reporting that all whole-grain applications increase gizzard activity and slow down digestion, thereby reducing DFI while improving FCR. This observation aligns with the low DFI and improved FCR recorded in the whole barley group in the present study. In contrast, Viliene et al. (62) reported that FCR values increased in diets diluted with whole barley grains.

The primary motivation for including all whole-grain materials in poultry diets is to reduce feed costs and limit DFI (52). Additionally, our results indicate that a separate soaking application of grains increased grain volume by approximately 45%, suggesting that this approach may effectively reduce DFI in the relevant groups.

In this study, DFI values are presented on a dry matter basis to reflect the actual intake of germinated and soaked barley grains. To control high DFI, turkey and goose producers typically soak grains for one day before inclusion in the feed.

Carcass characteristics. Pre-slaughter live weight, carcass weight, yield, thigh, breast, liver, heart, gizzard, wing + back + neck, and edible carcass weight parameters exhibited statistically significant differences only between sexes ($P < 0.05$). Consequently, the data were analyzed according to sex, and the findings were interpreted accordingly.

Regarding the abdominal fat content, the effects of the group, the sex, and the group × sex interaction were statistically significant ($P < 0.05$). The highest abdominal fat content was observed in the female turkeys fed hydroponic barley (89.11 g), whereas the lowest values were recorded in the males of the barley pasture group (43.62 g), the females of the barley pasture group (35.12 g), the males of the hydroponic barley group (29.20 g), and the males of the soaked barley grain group (41.11 g). According to letter-based group comparisons, these groups were statistically similar ($P < 0.05$).

The elevated abdominal fat content in the females of the hydroponic barley group may be related to their high DFI observed during the T1, T2, and T3 periods. The increased energy intake in this group is believed to have promoted adipose tissue accumulation. Similarly, Dastar et al. (19) reported that abdominal fat increased in birds fed hydroponic barley, which was attributed to enhanced fat digestion and absorption due to the reduction in the β-glucan content during the germination process.

The low fat deposition observed in the males fed pasture may be linked to increased physical activity and energy expenditure associated with the consumption of fiber-rich, low-energy pasture plants. Kaya and Yurtseven (31) similarly reported that Linda geese reared in pasture environments had lower abdominal fat and carcass weights compared to intensively fed counterparts.

This study demonstrates that different forms of barley significantly affect growth performance, daily feed intake, and certain anti-nutritional factors in American Bronze turkeys. A comprehensive literature review supports the effectiveness of short-term hydroponic barley germination and pasture-based systems in reducing anti-nutritional components. The findings also indicate that these barley forms differ in terms of practical applicability and economic outcomes; notably, pasture and hydroponic systems offer limited dry matter intake from barley and require greater labor input, thus providing limited practical advantage. In contrast, soaked barley grains emerge as a more feasible option because of lower operational requirements. Consequently, when appropriate processing methods are applied, barley can be considered a cost-effective and practical alternative feed source.

The design of feeding strategies should consider the physiological characteristics of animals, sex-dependent differences, as well as environmental and economic factors. Producers with sufficient barley reserves may prefer soaking methods to meet short-term feeding needs, whereas transitioning to germination or pasture-based systems under suitable timing and environmental conditions may further optimize feed utilization.

Additionally, high ambient temperatures (36-42°C) observed during the last two weeks of the trial, particularly in the final month, caused significant disruptions in the germination process. These findings indicate that live weight gain reached a plateau, and further weight increases beyond this point would not have been economically efficient. Therefore, feeding programs utilizing germinated barley are recommended to prioritize earlier periods, with the December-January period identified as more favorable under the regional conditions examined.

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