



Yield and Quality Effects of Co-cultivating Barley and Triticale with Legumes in Hydroponic Fodder Production

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10.18805/LRF-841

ABSTRACT

Background: The rising demand for sustainable farming practices, especially in regions with constrained land and water resources, has led to the spread of hydroponic systems for green fodder production. Cereals are commonly used in these systems due to their high adaptability, biomass production and ability to meet livestock energy requirements. However, integrating legumes into these cereal-based systems offers potential nutritional benefits, such as increased protein content and improved feed digestibility, which are essential for optimizing livestock productivity.

Methods: This study evaluated the effects of co-cultivating barley and triticale with various legumes (common vetch, forage pea, soybean and sunn hemp) on the yield and quality in hydroponic fodder production. The experiment was conducted using a randomized complete block design with three replications, involving mixture ratios of 0%, 5%, 10% and 20% legumes. Some parameters were evaluated: vegetation height, forage yield, dry matter, crude protein, crude ash, crude fat, neutral detergent fiber, acid detergent fiber, metabolizable energy, digestible dry matter, dry matter intake, relative feed quality and some mineral contents (Ca, Mg, K, P). Data were analyzed using ANOVA to determine significant effects of treatments.

Result: The inclusion of legumes, particularly at 5% and 10% mixture ratios, significantly improved forage yield and key quality traits, such as crude protein content, digestible dry matter, metabolizable energy and relative feed value. Mixtures containing 10% legumes consistently performed best, balancing yield and quality traits. Both barley- and triticale-based mixtures containing 10% soybean and forage pea demonstrated the most promising results, offering high yields and a favorable nutrient composition. Legume supplementation also increased mineral content while reducing neutral detergent fiber and acid detergent fiber, thereby improving overall digestibility. Additionally, triticale was also found to be a suitable substitute for barley in hydroponic systems. These findings suggest that the co-cultivation barley and triticale with legumes can enhance the nutritional composition and productivity of hydroponic fodder, providing a sustainable solution for livestock feed production.

Key words: Hydroponic fodder, Legumes, Mixture, Quality, Yield.

INTRODUCTION

The increasing demand for sustainable agricultural practices has led to the development of innovative methods for producing animal feed, particularly in regions where land and water resources are scarce. Hydroponic green fodder production has emerged as a practical alternative in areas facing these constraints (Gumisiriza *et al.*, 2020; Kostadinović, 2023; Singh *et al.*, 2024). It significantly contributes to sustainable livestock production by addressing the challenges of food security and resource conservation, especially in arid and semi-arid regions due to limited water supplies and persistent droughts (Al-Karaki and Al-Hashimi, 2012; Saidi and Abo Omar, 2015; Badran *et al.*, 2017). The advantages of hydroponic green fodder include increased fat and solid non-fat content of milk, improved health and conception rates in dairy animals, a 25% reduction in cattle feed requirements, enhanced taste (sweetness) of the milk, reduced labor costs, less space and water requirements, as well as greater freshness and high palatability of the fodder (Kumar *et al.*, 2018). In addition, this positively contributes to animal welfare, enhances digestibility and increases milk yield by 10% (Sneath and McIntosh, 2003; Sharif *et al.*, 2013).

Hydroponic fodder production, despite the availability of advanced auxiliary systems (e.g., lighting, climate control,

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How to cite this article: Ozkan, S.S. (2025). Yield and Quality Effects of Co-cultivating Barley and Triticale with Legumes in Hydroponic Fodder Production. *Legume Research*. 48(3): 414-422. doi: 10.18805/LRF-841.

Submitted: 26-10-2024 **Accepted:** 31-12-2024 **Online:** 05-02-2025

irrigation), is a rudimentary technique (Bakshi *et al.*, 2017). Its basic principle is that the seeds of cereals or other plant species are exposed to water or nutrient-rich solutions, enabling germination and growth to produce green plants within a short period of 7-10 days (Baytekin, 2015; Farghaly *et al.*, 2019; Wang *et al.*, 2019). Hydroponic fodder is grown in a soilless environment using water as the primary medium. Although nutrient solutions can be used, they are not necessary; potable water free of heavy metals is sufficient. Additionally, this production system is often free from soil-borne insects, pests, diseases and weed infestations, as plants are nourished directly through

their roots under controlled conditions (Ozkan, 2022; Kumar *et al.*, 2023).

Hydroponic fodder is typically fed to animals as a fresh, whole feed, including both the green shoots and the root mat, which are highly palatable and easy to digest. It is usually cut into smaller portions to match the animal's dietary requirements and offered directly, either alone or as a supplement to conventional feed (Naik, 2014; Joshi *et al.*, 2024). The hydroponic fodder can be mixed with other feed ingredients to balance the overall ration and ensure optimal nutrient intake. For ruminants like cattle, sheep and goats, hydroponic fodder is often incorporated into total mixed rations (TMR), while for non-ruminants like poultry and swine, it may be given as a fresh green supplement alongside their standard diet (Badran *et al.*, 2017; Hynd, 2019; Chethan *et al.*, 2022).

Cereals are particularly well-suited to hydroponic systems due to their rapid growth rates, high biomass production and adaptability (Soto *et al.*, 2012; Emam, 2016; Ozkan, 2023). They also provide a dense source of carbohydrates and energy for ruminants (McGrath *et al.*, 2018). Barley (*Hordeum vulgare* L.) is the most preferred crop species in hydroponic fodder systems worldwide due to its suitability, consistent yields, rapid maturation and energy efficiency (Sneath ve McIntosh, 2003; Naik, 2014; Afzalnia and Karimi, 2020). Triticale ($\times$ *Triticosecale* Wittmack), a hybrid of wheat (*Triticum*) and rye (*Secale*), is gaining popularity for its robust growth and nutritional value under hydroponic conditions (Uyutova *et al.*, 2023).

In recent years, there has been increased interest in growing legumes alone or co-cultivating them with cereals in hydroponic fodder production systems (Akman *et al.*, 2012; Dogrusoz *et al.*, 2020; Jolad *et al.*, 2020; Soufan, 2023; Elghalmi *et al.*, 2024). Integrating legumes into cereal-based hydroponic fodder systems enhances nutritional quality by significantly increasing protein content, improving digestibility and enriching essential nutrients. This combination not only contributes essential proteins and micronutrients but also improves the balance of amino

acids, optimizes fiber composition and increases the relative feed value of the fodder (Murphy-Bokern *et al.*, 2017; Liu *et al.*, 2023).

Despite these promising results, more comprehensive research is still needed to investigate the specific effects of different legume species and mixture ratios in hydroponic fodder production. Optimizing the legume-to-cereal ratio and identifying the best combinations of crops for hydroponic fodder production are essential to achieving maximum yield and nutritional quality. This study evaluates the effects of co-cultivating barley and triticale with various legumes on the yield, quality and digestibility of hydroponically produced green fodder.

MATERIALS AND METHODS

The study was conducted in 2024 at the Seed Laboratory of Department of Field Crops, Faculty of Agriculture, Ege University, Izmir, Türkiye. The objective of this study was to assess the impacts of co-cultivating barley (*Hordeum vulgare*) and triticale ($\times$ *Triticosecale* Wittmack) with some legume species on forage yield and quality parameters in hydroponically grown green fodder. A randomized complete block design was employed for the experimental layout, with three replications of each treatment. The treatments comprised different mixture ratios of cereals and legumes: pure barley, pure triticale and combinations of cereals with legumes at ratios of 0% (control), 5%, 10% and 20% legumes (Table 1).

Seeds of barley cv. Akhisar-98 and triticale cv. Ege Yildizi were procured from a local seed distributor, while legume seeds were obtained from certified vendors. The legume species selected for this study included common vetch (*Vicia sativa*) cv. Kubilay-82, forage pea (*Pisum arvense*) cv. Kirazli, soybean (*Glycine max*) cv. Mona and sunn hemp (*Crotalaria juncea*) cv. Tillage Sun.

A controlled growth chamber was utilized for the research, ensuring precise regulation of environmental conditions. The growth chamber maintained a temperature of 22±2°C and relative humidity levels of 65-70%, which

Table 1: The mixture combinations in the present study.

The mixture combinations	
Barley 100%	Triticale 100%
Barley 95% + Common vetch 5%	Triticale 95% + Common vetch 5%
Barley 90% + Common vetch 10%	Triticale 90% + Common vetch 10%
Barley 80% + Common vetch 20%	Triticale 80% + Common vetch 20%
Barley 95% + Forage pea 5%	Triticale 95% + Forage pea 5%
Barley 90% + Forage pea 10%	Triticale 90% + Forage pea 10%
Barley 80% + Forage pea 20%	Triticale 80% + Forage pea 20%
Barley 95% + Soybean 5%	Triticale 95% + Soybean 5%
Barley 90% + Soybean 10%	Triticale 90% + Soybean 10%
Barley 80% + Soybean 20%	Triticale 80% + Soybean 20%
Barley 95% + Sunn hemp 5%	Triticale 95% + Sunn hemp 5%
Barley 90% + Sunn hemp 10%	Triticale 90% + Sunn hemp 10%
Barley 80% + Sunn hemp 20%	Triticale 80% + Sunn hemp 20%

are optimal for the germination and growth of hydroponic crops. Two pairs of fluorescent lamps provided continuous lighting throughout the seven-day sprouting period, as adequate light exposure is crucial for photosynthetic processes in young plants. The seedlings were subjected to spray watering twice daily, in the morning and late afternoon, to maintain optimal moisture levels during the germination phase.

Prior to placement in the hydroponic system, germination rates of cereal (barley and triticale) and legume (common vetch, forage pea, sunn hemp and soybean) seeds were evaluated. Seeds were thoroughly cleaned to remove foreign contaminants and were sterilized by soaking in a 0.5% (v/v) sodium hypochlorite solution for 30 minutes to prevent mold formation. Following disinfection, seeds were washed to eliminate bleach residues and re-soaked in tap water for approximately 24 hours to promote germination.

The seeds were then placed in plastic containers at a density of approximately 5 kg m⁻². The experimental design was a randomized complete block design with three replications, utilizing 96 plastic containers (size 22×16×5 cm). At the conclusion of the sprouting period, the sprouts were carefully removed, drained for at least 5 minutes and placed on absorbent cloths to eliminate surface moisture. Fresh sprouts were weighed and vegetation heights were measured using a steel measuring tape. Samples collected on the seventh day were dried at 65°C for 48 h and ground to pass through a 2 mm mesh screen. The quality parameters and mineral contents of the ground samples were analyzed using a commercial NIR spectrometer (SupNIR-2750, Focused Photonics Inc., Hangzhou, China).

Metabolizable energy was estimated using the equation outlined by Kirchgeßner and Kellner (1981). The digestible dry matter (DDM), dry matter intake (DMI) and relative feed value (RFV) of the samples were determined according to the equations provided by Morrison (2003).

Metabolizable energy (MJ kg⁻¹ DM) = 14.70 - 0.150 × % ADF

Digestible dry matter (%) = 88.9 - (0.779 × % ADF)

Dry matter intake (% of body weight) = 120 / % NDF

Relative feed value = (DDM × DMI) / 1.29

Statistical analyses were performed using SAS/STAT software version 9.3 to determine significant treatment effects. The fixed effects included cereals, legumes and mixtures, while the block effect was treated as a random effect (SAS Institute, 2012). According to the analysis of variance (ANOVA) results, the data were combined across treatments and the main effects were presented in the tables. Significance was set at a probability of 0.05 or less. If ANOVA indicated significant differences among treatment means, the least significant difference (LSD) test was employed for mean separation (Johnson and Bhattacharyya, 2019). Pearson correlation analysis was

utilized to evaluate the relationships between the studied parameters (Schober *et al.*, 2018).

RESULTS AND DISCUSSION

The main effects of cereals and legume species, along with their mixtures on vegetation height, forage yield, dry matter, crude protein, crude ash and crude fat in hydroponic fodder production are summarized in Table 2. The results indicated that vegetation height was significantly influenced by the cereal treatments ($p < 0.05$). Barley-based mixtures exhibited the tallest vegetation height at 13.81 cm, while triticale-based mixtures showed a significantly lower value of 12.68 cm. The legume species in the mixtures did not exhibit significant differences in vegetation height, with values ranging from 13.00 cm (mixtures containing forage pea) to 13.61 cm (mixtures containing soybean). In mixture treatments, the 0% legume mixtures (100% cereals) achieved the highest vegetation height (13.35 cm), indicating that legume species and mixture ratios did not significantly affect this parameter. Forage yield varied significantly between treatments, with barley-based mixtures (21.26 kg m⁻²) and triticale-based mixtures (21.44 kg m⁻²) exhibiting similar yields. Among legumes, mixtures containing common vetch yielded the highest biomass (21.60 kg m⁻²). The 5% legume mixtures produced the highest yield (22.00 kg m⁻²), suggesting that moderate legume inclusion boosts forage productivity. Dry matter content was significantly higher in barley-based mixtures (19.36%) compared to triticale-based mixtures (15.30%), while mixtures containing soybean exhibited the highest dry matter among legumes (17.49%). The 0% legume mixtures also produced the highest dry matter (18.41%). Crude protein content was highest in triticale-based mixtures (18.46%), with the addition of legumes at higher proportions (20%) significantly enhancing the crude protein levels in the mixtures. Crude ash content in triticale-based mixtures reached the highest value (3.56%), while mixtures containing soybean ranked highest among legumes (3.47%). Crude fat content was also highest in triticale-based mixtures (3.56%), mixtures containing soybean (3.85%) and 20% legumes mixtures (3.62%).

The main effects of cereals, legume species and their mixtures on neutral detergent fiber, acid detergent fiber, metabolizable energy, digestible dry matter, dry matter intake and relative feed value in hydroponic fodder production are presented in Table 3. Neutral detergent fiber (NDF) content was significantly affected by treatments ($p < 0.05$). Barley-based mixtures exhibited the highest NDF value (39.49%), while triticale-based mixtures had a lower NDF (31.45%). Among legumes, mixtures containing common vetch produced the highest NDF (36.43%) and in mixture treatments, the 5% legume mixtures resulted in the highest NDF (38.82%). As legume inclusion increased, NDF decreased, with the 20% legume mixtures having the lowest NDF (31.09%). Acid detergent fiber (ADF) content followed a similar trend, with barley-based mixtures

(23.57%) showing the highest value and triticale-based mixtures (19.14%) the lowest. Mixtures containing common vetch also showed the highest ADF among legumes (21.76%). Increasing legume proportions lowered ADF, with the 20% legume mixtures reducing ADF to 20.02%. Metabolizable energy was significantly higher in triticale-based mixtures (11.83 MJ kg⁻¹) compared to barley-based mixtures (11.17 MJ kg⁻¹) and the 20% legume mixtures (11.70 MJ kg⁻¹) had the highest energy content among mixture treatments. Digestible dry matter (DDM) was significantly higher in triticale-based mixtures (73.99%) compared to barley-based mixtures (70.54%) and among legumes, mixtures containing soybean had the highest DDM (72.85%). Dry matter intake (DMI) was highest in triticale-based mixtures (3.87%) and mixtures containing forage pea (3.57%) among legumes, with the 20% legume mixtures (3.90%) exhibiting the highest intake.

The main effects of cereals, legume species and their mixtures on the calcium, magnesium, potassium and phosphorus contents in hydroponic fodder production are presented in Table 4. Calcium (Ca) content was significantly affected by cereals, legume species and mixture treatments ($p < 0.05$). Triticale-based mixtures exhibited higher Ca content (0.56%) than barley-based mixtures (0.51%) and mixtures containing common vetch showed the highest Ca content among legumes (0.56%). The 5% legume mixtures had the highest Ca concentration

(0.60%). Magnesium (Mg) content was highest in mixtures containing soybean (0.51%) and triticale-based mixtures (0.49%) showed higher Mg than barley-based mixtures (0.48%). Potassium (K) content was highest in triticale-based mixtures (1.09%) and mixtures containing soybean (1.01%), with the 20% legume mixtures (1.02%) producing the highest K value. Phosphorus (P) content was also highest in triticale-based mixtures (0.30%) and mixtures containing soybean (0.29%), with the 20% legume mixtures (0.29%) having the highest P content.

Hydroponic systems, recognized for their efficient use of limited water and soil resources, are increasingly considered vital for sustainable feed production (Naik *et al.*, 2015). In such systems, species selection plays a critical role in maximizing yield and feed quality (Ansari *et al.*, 2019; Thomas and Thomas, 2021; Upreti *et al.*, 2022; Alemnew and Mekuriaw, 2023). Cereals, particularly barley, exhibit superior growth and biomass production in hydroponic conditions, making them a preferred species due to their rapid growth and high yield (Nikkhah, 2013; Gebremedhin *et al.*, 2015; Emam, 2016; Ozkan, 2022). The findings of the present study align with the literature, confirming that the choice of cereal species is a pivotal factor influencing productivity in hydroponic fodder systems.

However, feed composed solely of cereals may be nutritionally limited, particularly with respect to protein content. To address this issue, incorporating legumes into

Table 2: The main effects of cereals, legumes and their mixtures on digestible vegetation height, forage yield, dry matter, crude protein, crude ash and crude fat in hydroponic fodder production.

Treatments	VH (cm)	FY (kg m ⁻²)	DM (%)	CP (%)	CA (%)	CF (%)
Cereals (C)						
Barley	13.81 ^a	21.26	19.36 ^a	13.39 ^b	2.41 ^b	3.39 ^b
Triticale	12.68 ^b	21.44	15.30 ^b	18.46 ^a	3.56 ^a	3.56 ^a
Legumes (L)						
Common vetch	13.16	21.60 ^a	17.36	15.85 ^c	2.77 ^c	3.38 ^b
Forage pea	13.00	21.50 ^{ab}	17.34	15.59 ^d	2.54 ^d	3.37 ^b
Soybean	13.61	21.04 ^c	17.49	16.30 ^a	3.47 ^a	3.85 ^a
Sunn hemp	13.21	21.26 ^{bc}	17.14	15.95 ^b	3.15 ^b	3.31 ^c
Mixtures (M)						
0%	13.35	20.81 ^b	18.41 ^a	14.73 ^d	2.74 ^d	3.26 ^d
5%	13.10	22.00 ^a	16.91 ^{bc}	15.63 ^c	2.92 ^c	3.50 ^c
10%	13.16	21.85 ^a	16.80 ^c	16.01 ^b	2.96 ^b	3.53 ^b
20%	13.37	20.74 ^b	17.22 ^b	17.33 ^a	3.32 ^a	3.62 ^a
ANOVA						
C	**	ns	**	**	**	**
L	ns	**	ns	**	**	**
M	ns	**	**	**	**	**
C × L	ns	ns	ns	**	**	**
C × M	**	**	**	**	**	**
L × M	ns	ns	ns	**	**	**
C × L × M	ns	*	ns	**	**	**

ANOVA: Analysis of variance, * $p < 0.05$, ** $p < 0.01$, ns: Not significant.

a,b,c Means followed by different letters are significantly different ($p < 0.05$) according to LSD's test.

VH: Vegetation height, FY: Forage yield, DM: Dry matter, CP: Crude protein, CA: Crude ash, CF: Crude fat.

cereal-based hydroponic systems has been shown to enhance feed nutritional value and contribute to the sustainability of production (Ganguly *et al.*, 2020; Akman *et al.*, 2021; Badran *et al.*, 2023; Soufan, 2023; Elghalmi *et al.*, 2024). In this study, the inclusion of legumes in cereal-based hydroponic systems positively impacted both yield and feed quality. Mixtures containing 5-10% legumes, in particular, significantly increased forage yield, likely due to synergistic plant interactions and improved nutrient availability. These results are in agreement with existing literature, which highlights the potential of moderate legume supplementation to enhance overall forage yield.

The findings related to feed nutrient content are also noteworthy. The inclusion of legumes, especially soybeans, in the mixtures significantly enhanced crude protein, ash and fat levels, which can be attributed to the protein-rich nature of legumes. These results align with previous studies that emphasize the high protein content and superior digestibility of legumes in comparison to cereals (Contreras *et al.*, 2015; Jemimah *et al.*, 2018; Ganguly *et al.*, 2020; Jolad *et al.*, 2020; Kabir *et al.*, 2021; Soufan, 2023).

The effect of legume supplementation on the dry matter content of the feed presented a complex dynamic. In the present study, while cereals, especially barley-based mixtures, generally contributed higher dry matter content

due to their substantial biomass production capacity, the addition of legumes often led to a reduction in the overall dry matter content. Therefore, achieving a balance between dry matter and protein content is crucial for optimizing feed nutritional value. Careful management of legume and cereal proportions is necessary to maintain this balance (Eskandari *et al.*, 2009; Santos *et al.*, 2012; Baghdadi *et al.*, 2016).

In terms of fiber content, the results of present study showed that legume inclusion significantly lowered levels of neutral detergent fiber (NDF) and acid detergent fiber (ADF), improving feed digestibility and making it a more efficient feed source for livestock. These findings are consistent with studies that highlight legumes' role in enhancing feed digestibility and efficiency (Baghdadi *et al.*, 2016; Iqbal *et al.*, 2018; Soufan and Al-Suhaibani, 2021; Badran *et al.*, 2023; Soufan, 2023; Elghalmi *et al.*, 2024). Thus, incorporating legumes into cereal-based hydroponic feeds not only enhances nutrient content but also improves the overall digestibility of the feed, allowing for more efficient livestock nutrition.

Moreover, the present study demonstrated that legume supplementation significantly increased metabolizable energy levels in the feed. The ability of cereals to increase energy density and the addition of protein-rich legumes

Table 3: The main effects of cereals, legumes and their mixtures on NDF, ADF, metabolizable energy, digestible dry matter, dry matter intake and relative feed value in hydroponic fodder production.

Treatments	NDF (%)	ADF (%)	ME (MJ kg ⁻¹)	DDM (%)	DMI (%)	RFV
Cereals (C)						
Barley	39.49 ^a	23.57 ^a	11.17 ^b	70.54 ^b	3.11 ^b	170.42 ^b
Triticale	31.45 ^b	19.14 ^b	11.83 ^a	73.99 ^a	3.87 ^a	222.38 ^a
Legumes (L)						
Common vetch	36.43 ^a	21.76 ^a	11.44 ^d	71.95 ^d	3.36 ^d	188.02 ^d
Forage pea	34.63 ^d	21.46 ^c	11.48 ^b	72.18 ^b	3.57 ^a	200.92 ^a
Soybean	35.60 ^b	20.60 ^d	11.61 ^a	72.85 ^a	3.50 ^c	198.71 ^b
Sunn hemp	35.21 ^c	21.59 ^b	11.46 ^c	72.08 ^c	3.53 ^b	197.94 ^c
Mixtures (M)						
0%	38.00 ^b	22.58 ^a	11.31 ^d	71.31 ^d	3.31 ^c	184.59 ^c
5%	38.82 ^a	22.08 ^b	11.39 ^c	71.70 ^c	3.14 ^d	174.82 ^d
10%	33.97 ^c	20.74 ^c	11.59 ^b	72.75 ^b	3.61 ^b	204.31 ^b
20%	31.09 ^d	20.02 ^d	11.70 ^a	73.31 ^a	3.90 ^a	221.87 ^a
ANOVA						
C	**	**	**	**	**	**
L	**	**	**	**	**	**
M	**	**	**	**	**	**
C × L	**	**	**	**	**	**
C × M	**	**	**	**	**	**
L × M	**	**	**	**	**	**
C × L × M	**	**	**	**	**	**

ANOVA: Analysis of variance, *p<0.05, **p<0.01, ns: Not significant.

a,b,c Means followed by different letters are significantly different (p<0.05) according to LSD's test.

NDF: Neutral detergent fiber, ADF: Acid detergent fiber, ME: Metabolizable energy, DDM: Digestible dry matter, DMI: Dry matter intake, RFV: Relative feed value.

further boosted the overall nutritional value of the feed (Lithourgidis and Dordas, 2010; Soufan and Al-Suhaibani, 2021; Soufan, 2023).

Notably, a 20% legume supplementation significantly enhanced dry matter intake (DMI), digestible dry matter (DDM) and relative feed value (RFV), indicating that legumes positively influence feed intake and improve feed efficiency in livestock (Zhang *et al.*, 2015; Murphy-Bokern *et al.*, 2017; Akman *et al.*, 2021).

Concerning mineral content, legumes significantly enhanced the levels of calcium (Ca), magnesium (Mg), potassium (K) and phosphorus (P) in the feed. Legumes such as soybean and common vetch contributed essential minerals, enriching the feed's nutritional profile and providing critical nutrients for livestock. These findings suggest that well-balanced cereal-legume mixtures can improve both yield and nutrient composition in hydroponic systems. These results are consistent with literature that underscores the importance of legumes in enhancing the mineral profile of cereal-based systems, thereby promoting animal health and productivity (Murphy-Bokern *et al.*, 2017).

The correlation coefficient of the studied parameters was analyzed by Pearson's correlation. The Pearson correlation matrix illustrates the relationships between various measured parameters, with correlation coefficients ranging from -1.00 to 1.00. A positive correlation is shown

in red, while a negative correlation is shown in blue, with darker colors indicating stronger correlations (Fig 1).

The Pearson correlation analysis highlighted significant relationships between key traits in hydroponic fodder production. Forage yield (FY) was negatively correlated with dry matter (DM, $r = -0.36$), dry matter intake (DMI, $r = -0.27$) and relative feed value (RFV, $r = -0.25$), suggesting that higher yields slightly reduced these parameters. Additionally, forage yield was positively linked to fiber components (NDF, $r = 0.23$; ADF, $r = 0.10$), indicating that increased yield could also raise fiber content, potentially reducing digestibility. Dry matter (DM) demonstrated a negative correlation with macronutrients such as magnesium (Mg, $r = -0.25$), calcium (Ca, $r = -0.40$), potassium (K, $r = -0.75$) and phosphorus (P, $r = -0.76$), suggesting that higher DM content was associated with reduced mineral levels in the fodder. Crude protein (CP) was strongly negatively correlated with NDF ($r = -0.68$) and ADF ($r = -0.88$), emphasizing that protein-rich fodder was typically associated with lower fiber content, which enhanced digestibility. Additionally, digestible dry matter (DDM) and relative feed value (RFV) were negatively correlated with fiber components (DDM and NDF, $r = -0.90$; RFV and ADF, $r = -0.92$), underscoring the importance of low fiber content in improving fodder quality. Mineral contents, especially potassium (K, $r = 0.93$ and 0.86 ,

Table 4: The main effects of cereals, legumes and their mixtures on calcium, magnesium, potassium and phosphorus contents in hydroponic fodder production.

Treatments	Ca (%)	Mg (%)	K (%)	P (%)
Cereals (C)				
Barley	0.51 ^b	0.48 ^b	0.78 ^b	0.25 ^b
Triticale	0.56 ^a	0.49 ^a	1.09 ^a	0.30 ^a
Legumes (L)				
Common vetch	0.56 ^a	0.47 ^c	0.89 ^c	0.27 ^b
Forage pea	0.52 ^c	0.46 ^d	0.89 ^c	0.27 ^b
Soybean	0.53 ^c	0.51 ^a	1.01 ^a	0.29 ^a
Sunn hemp	0.54 ^b	0.49 ^b	0.94 ^b	0.27 ^b
Mixtures (M)				
0%	0.52 ^b	0.47 ^c	0.88 ^c	0.26 ^c
5%	0.60 ^a	0.49 ^a	0.89 ^c	0.27 ^b
10%	0.51 ^c	0.48 ^b	0.94 ^b	0.27 ^b
20%	0.52 ^b	0.49 ^a	1.02 ^a	0.29 ^a
ANOVA				
C	**	**	**	**
L	**	**	**	**
M	**	**	**	**
C × L	**	**	**	**
C × M	**	**	**	**
L × M	**	**	**	**
C × L × M	**	**	**	**

ANOVA: Analysis of variance, * $p < 0.05$, ** $p < 0.01$, ns: Not significant.

a,b,c Means followed by different letters are significantly different ($p < 0.05$) according to LSD's test.

Ca: Calcium, Mg: Magnesium, K: Potassium, P: Phosphorus.

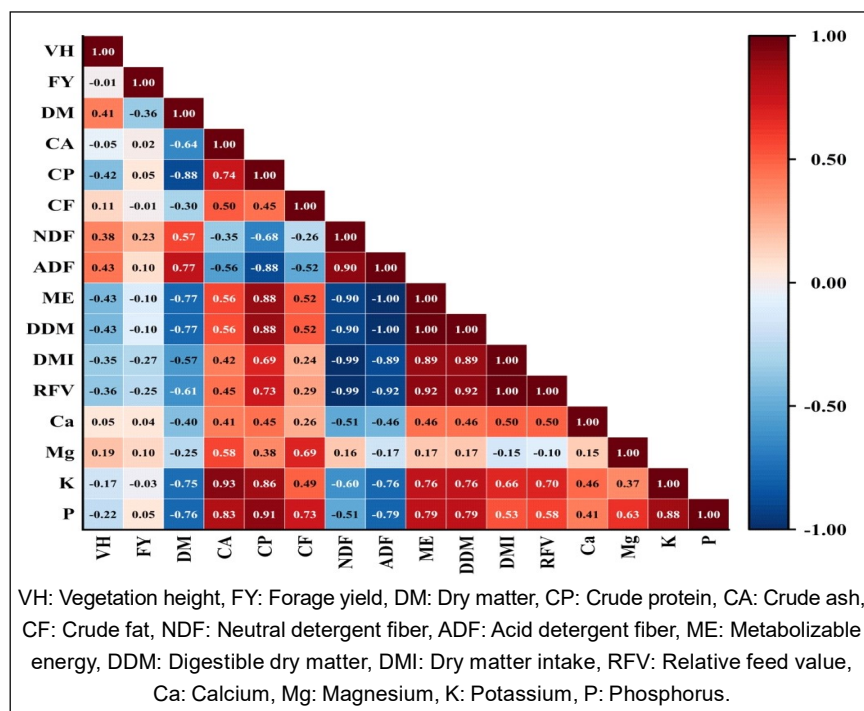


Fig 1: The correlation coefficient of the studied parameters.

respectively) and phosphorus (P, $r = 0.83$ and 0.91 , respectively), showed strong positive links with crude ash (CA) and crude protein (CP), indicating that these elements contributed to enhanced nutritional value in the fodder. These findings suggested that careful management of legume-cereal mixtures could improve both the yield and quality of hydroponic fodder.

CONCLUSION

The findings of present study demonstrated that co-cultivation barley and triticale with different legume species (common vetch, forage pea, soybean, sunn hemp) in hydroponic green fodder production significantly improved both yield and quality parameters. Among the tested combinations, mixtures containing 10% legumes consistently performed best, balancing forage yield and quality traits. Both barley-and triticale-based mixtures containing 10% soybean and forage pea demonstrated the most promising results, offering high yields and a favorable nutrient composition. Triticale was also found to be a suitable substitute for barley in hydroponic green fodder production.

The inclusion of legumes, particularly at 5% and 10% mixture ratios, enhanced forage yield and improved key quality traits such as crude protein content, digestible dry matter, metabolizable energy and relative feed value. Additionally, legumes enriched the nutritional composition by increasing mineral content and reducing neutral detergent fiber and acid detergent fiber levels, which improved digestibility and overall feed quality.

In conclusion, the integration of cereals with legumes in hydroponic fodder production can provide synergistic benefits in terms of both yield and quality. Optimizing legume-to-cereal mixture ratios can further maximize forage yield while enhancing nutritional value. The potential of cereal-legume mixtures should be considered as an effective strategy to produce economically viable and nutritionally superior feed in hydroponic systems.

ACKNOWLEDGEMENT

Special thanks are extended to undergraduate student Murat NAL for his valuable assistance and contributions to the laboratory studies.

Conflict of interest

The author declares that there are no conflicts of interest regarding the publication of this article. No funding or sponsorship influenced the design of the study, data collection, analysis, decision to publish, or preparation of the manuscript.

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