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The Effect of the Mixing Ratio of Barley and Mung Bean Seeds on the Quality of Sprouted Green Fodder and Silage in a Hydroponic System

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Abstract: Securing good feed and sustaining production is one of the main pillars of the livestock production sector. However, this is difficult to achieve in many different environments or circumstances. The production of fodder in a hydroponic system allows for sustainable production throughout the year and provides many benefits to the animal. However, ways must be found to improve the quality of hydroponic fodder and extend its shelf life. In this study, hydroponic barley fodder was produced by mixing it with mung bean seeds at different mixing ratios. In addition, silage was prepared from the resulting fodder by mixing it with barley straw to reduce the high moisture. The results of this study showed that the proportions of the components of nutritional value in the produced fodder were increased, especially the proportion of proteins, when the percentage of mung beans in the mixture was increased. In addition, the preservation of hydroponic fodder using the silage method resulted in obtaining a higher percentage of dry matter compared to fresh fodder and increased the preservation time. This brings many advantages to farmers and livestock producers, as well as researchers in the field, to expand the scope of experiments to other fodder mixtures and the sustainable production of good fodder in hydroponic systems.

Keywords: hydroponic fodder; nutritive value; fodder mixture; silage

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1. Introduction

Achieving food security is one of the most important challenges that humanity has ever faced due to the ever-increasing population. Sustainable agricultural production, both plant and animal, is the main contributor to food security. The raising and fattening of livestock contributes greatly to the achievement of livestock production and meat production, but this requires the provision of suitable feed of high quality and nutritional value to the animals [1].

Year-round availability of feed is an ongoing challenge for livestock producers, both in terms of the cost and availability of raw materials, the impact of volatile weather factors, and ultimately global disasters and crises that can limit the movement of marketing products across countries. The challenge here was to find sustainable fodder alternatives that are locally produced year-round, and of good quality.

The production of green fodder in a hydroponic system is a modern method of securing feed supply for livestock, as this method first appeared in the twentieth century and became widely used in the 1970s in many countries such as the United Kingdom, Europe, Canada, the United States of America, Mexico, Ireland, South Africa, India, Russia, New Zealand, Australia, and undoubtedly many other countries [2]. This method of producing green fodder has also spread to arid and semi-arid countries, for example, Saudi Arabia. This technique for producing green fodder is of great interest to farmers and livestock producers.

Barley (*Hordeum sativum* L.) is considered one of the most important fodder crops used in the hydroponic system [3] because the grains germinate quickly and grow rapidly

during the early stages of the plant's life [4,5], and its fibrous roots intertwine as they grow to form a continuous layer that retains water during the production period [6].

Hydroponics technology for the production of fresh green fodder has many advantages, which can be summarized as follows [7–10]:

- The ability to produce daily throughout the year, as it happens in a growth chamber isolated from external weather conditions.
- A sustainable system for producing fodder in all environments and regions, as it does not require soil, depending only on water.
- Production speed: the production cycle is only 7 to 8 days from the time the grains are placed in the trays to the time the green fodder is removed from the trays.
- Healthy and organic product, since no fertilizers or pesticides are added to it.
- Savings in the cost of providing feed for animals.

Despite all these advantages of hydroponic barley, there are some disadvantages and challenges during the growing period and after feed production [11,12].

The most important disadvantage during the growth of barley in the growth chamber is the possibility of mold fungi appearing, which leads to the problem of the complete corruption of green fodder. This can lead to digestive problems in livestock when fed with fungus-contaminated hydroponic feed [11]. This occurs, firstly, if the grains are not well sterilized before being placed in the growth chamber, and, secondly, if the temperature and humidity in the growth chamber are irregular. When the temperature rises above 20 °C and the humidity is too high, this will directly lead to the spread of fungi on the hydroponic barley. The above negative effects can be avoided by taking care to sterilize the grain well in terms of the percentage of sterilizing agents and the duration of sterilization. Furthermore, the temperature in the growth chamber must be fully adjusted and automatically controlled, and it must be ensured that the temperature sensor and humidity sensor in the growth chamber are working. In addition, according to Alrefaey 2019 [13], it is possible to improve the hydroponic barley feed and get rid of the root rot fungi by adding Azolla.

The main disadvantage of hydroponic barley after producing and obtaining fresh green fodder is its high moisture content, which ranges from 85 to 88% [7,14]. This means that the percentage of dry matter in the produced fodder is low, and thus the proportions of the components of the nutritional value, which is the basis of animal nutrition, are low, especially the proportion of protein. In addition, the high humidity means that the hydroponic barley does not have a long lifetime, i.e., it must be fed to animals within hours of removal from the growth chamber or it will spoil [15]. This is the major challenge in the production of green fodder in hydroponic systems, especially in barley. Through this study, we will strive to find a suitable and practical solution through which we can achieve an increase in the proportion of dry matter, thus increasing the proportion of nutritional value components, especially protein, in hydroponic barley.

There are not enough studies on the use of sprouted mung bean (*Vigna radiata* L. Wilczek) as fodder, but it is used as a healthy and organic food in many countries, such as Asian countries and Western countries, where it is consumed in salads or as a side dish [16]. The use of many sprouted products, such as (mung bean, broccoli, radish, alfalfa, etc.), has increased due to their high nutritional value [17,18]. Whereas during the germination and sprouting stage, the nutritional value increases and the content of phenolics, flavonoids, and antioxidants increases in the sprouted legumes compared to the seeds [19].

Mixed cultivation of fodders is widespread and has been known for a long time, especially the mixing of cereals and legumes in field farming. The method of fodder production in this way has many advantages, the most important of which are achieving good fodder quality in terms of energy content due to the presence of cereals, as well as increasing the protein content due to the presence of legumes in the mixture [20–22]. There are a few studies in which mixtures of legume seeds with cereal grains were used in the hydroponic system to increase the protein content in the green fodder produced. On the other hand, legume seeds can be used in the production of hydroponic green fodder to achieve high quality [7,23]. How to increase the protein content in green hydroponic barley

fodder has also been presented. This is achieved by mixing legume seeds with barley grains. However, there remains the problem of the high-water content in the fresh green fodder produced, and thus, a low percentage of dry matter, i.e., on the one hand, a low nutritional value, which affects animal health, on the other hand, the health of the animal will be affected if it is fed individually with this fresh fodder without any other additives. This problem can be solved in several ways:

- Leave the hydroponic barley green feed to stand for a few hours (3–5 h) after removing it from the growth chamber to get rid of most of the free water in the root layer.
- Give the animals fresh hydroponic barley feed after mixing it with dry feed such as hay and straw. This reduces the moisture content of the hydroponic barley, but on the other hand it also reduces the quality of the feed, since the nutritional value of straw or dry coarse feed is very low, especially the protein content.
- The transformation of the green fodder of the hydroponic barley into silage brings several advantages:
    - All the components of the nutritional value of the hydroponic barley are preserved.
    - It eliminates the high moisture content by mixing the green hydroponic barley with straw before silage, thereby increasing the percentage of dry matter in the fodder and increasing the percentage of nutritional components in the silage produced.
    - The hydroponic barley feed can be stored for a longer period, as it can remain in the silage pit (trench) or in silage bags for a period of 6–8 months.

Based on the above discussion of the advantages and disadvantages of hydroponic barley, in this study, we work to improve the nutritional value and quality of barley hydroponic green fodder and extend its shelf life by using the method of mixing barley grains with mung bean seeds, we assume that this will increase the protein content, and the resulting green hydroponic barley will be processed into silage. We assume that this will increase the percentage of dry matter, extend the shelf life of the feed, and achieve sustainable feed production.

2. Materials and Methods

2.1. Experimental Material, Treatments, and Design

In this experiment, the local barley cultivar Qasimi (*Hordeum vulgare* L.) and local mung bean cultivar Mash (*Vigna radiata* L. Wilczek) were used in 11 mixing ratios (Table 1). Seeds were purchased from "Salam Market" for selling agricultural supplies in Riyadh / Saudi Arabia. The percentage of germination of barley and mung bean seeds was tested before the start of the experiment and was as follows: barley (99.24%) and mung bean (99.31%). The seeds were cleaned from all impurities to achieve 100% purity. The experiment was laid out in the regular arrangement of a randomized complete block design (RCBD) with three replicates.

2.2. Hydroponic Method

The experiment was conducted in a growth chamber designed for hydroponic feed production (Figure 1). All growth factors (temperature, LED lighting, irrigation, and humidity) were controlled by an automatic control panel. The temperature was set within a range (16–20 °C). Fifteen hours of light and eight hours of darkness were applied. Sprinkler irrigation A (four times/24 h sprinkler cycle) was applied every six hours for one minute each time. The amount of water from each sprayer is 350 mL/min. The growth chamber contains 24 sprayers, so the amount of water in one spray is 8400 mL/min. Humidity was set to a maximum of 80%. The growth chamber accommodates 36 plastic trays (size 70 × 30 × 5 cm).

Table 1. Treatments used in the experiment, mixing ratios (%) of the barley and the mung bean and the amount of grains/seeds of barley and mung bean in each treatment.

Treatments	Barley %	Mung Bean %	Barley Grains (g)	Mung Bean Seeds (g)
T1	100	0	1000	0
T2	90	10	900	100
T3	80	20	800	200
T4	70	30	700	300
T5	60	40	600	400
T6	50	50	500	500
T7	40	60	400	600
T8	30	70	300	700
T9	20	80	200	800
T10	10	90	100	900
T11	0	100	0	1000

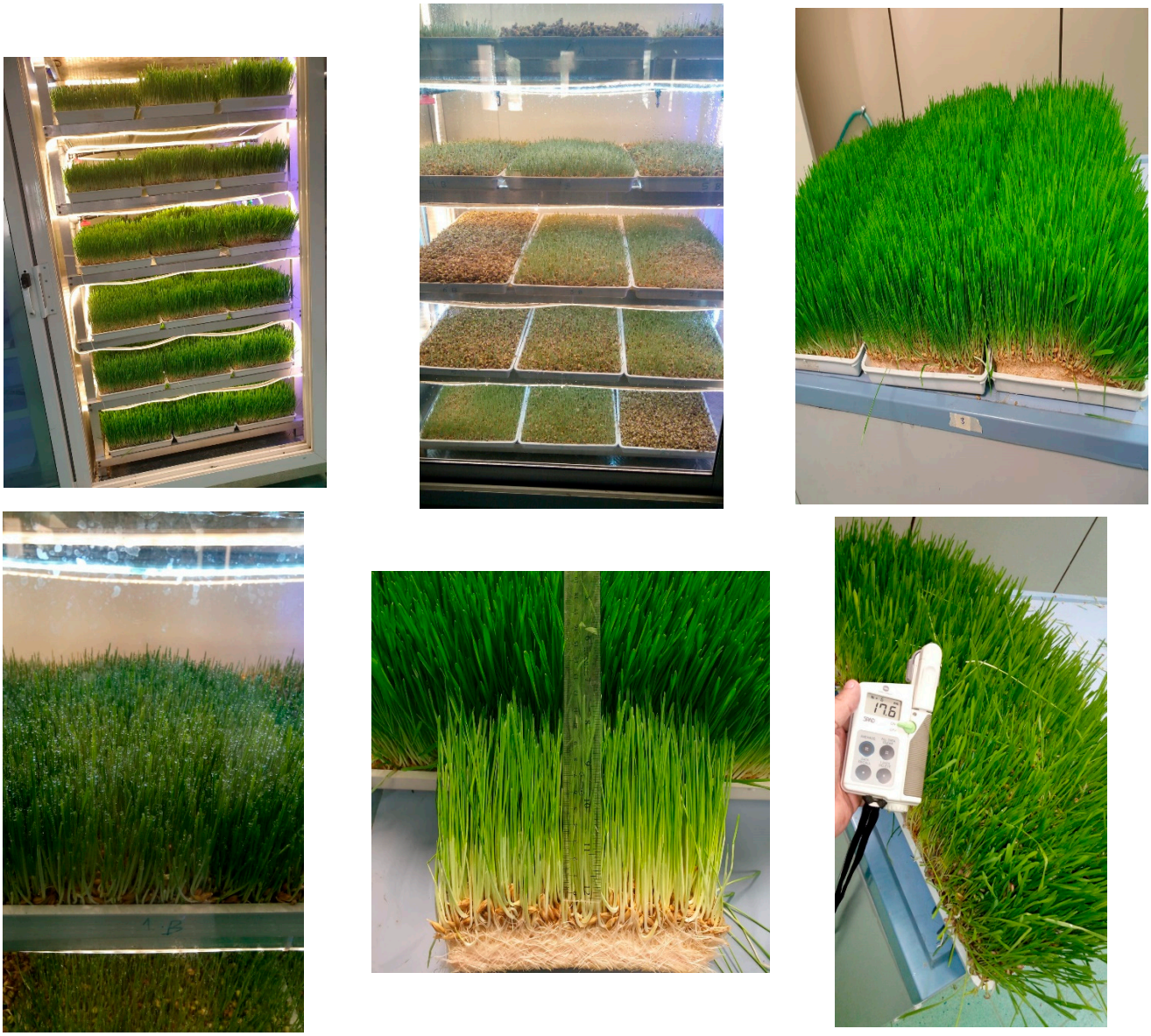

Figure 1. Growth chamber and hydroponic fodder.

After sterilization with 2% sodium hypochlorite (NaOCl), the seeds were soaked in water for 10 h, then the seeds were filtered from the water and 1 kg of grains/seeds were placed in the trays according to the experimental treatments listed in Table 1, distributed, and mixed well. Growth was observed for 8 days.

2.3. Sampling of Green Hydroponic Fodder

On day 8, the trays were removed from the growth chamber and the following morphological measurements were taken for all treatments and replicates:

- Shoot length (cm) for both barley and mung bean;
- Thickness of the root layer (cm);
- Cohesion and hardness of the root layer (scale 1–5), where 1 means cohesion is brittle and low, meaning that the roots are disjointed and not intertwined, and 5 means there is strong cohesion, meaning that the roots are strongly intertwined.

2.4. Chlorophyll Estimation

A SPAD instrument (SPAD502-plus, Minolta Co., Tokyo, Japan) was used to measure the chlorophyll levels directly from the barley and mung bean leaves in all treatments and replicates.

2.5. Estimation of Green Fodder (FM) and Dry Matter (DM)

The trays were weighed after removal from the growth chamber to calculate the fresh weight (kg), then fresh samples were collected from all treatments and replicates and weighed and dried in the oven (with hot air) at a temperature of 65 °C for 48 h, then the samples were weighed after drying to calculate the percentage of dry matter (Equation (1)). Then, the samples were ground to pass through a 1 mm mesh to determine the components of the nutritional value.

$$\text{DM } \% = \text{D} \times 100/\text{F} \quad (1)$$

F = weight of fresh green sample (g);
D = weight of the sample after drying.

2.6. Silage Preparation

For the preparation of the silage, samples were taken only from treatments 1–6, since the morphological measurements showed that the fodder mass and the root layer in treatments 7–11 were not coherent. On the other hand, the cost of increasing the proportion of mung bean in the treatments was high because its seeds are very expensive compared to barley seeds.

The mentioned green samples were cut and then mixed well with dry barley straw to reach a percentage of moisture between 65 and 70% in the samples [24,25]. Then, they were put into 4 L jars, well pressed, and tightly closed. The jars were stored in the dark at laboratory temperature. After 8 weeks, the jars were opened, samples were taken, weighed, and then dried at 65 °C for 48 h. The samples were ground to pass through a 1 mm mesh to determine the components of the nutritional value.

A sample of barley straw (as mentioned above) used for silage was taken and dried at 105 °C to estimate its moisture content. Then, this sample was ground to estimate the components of the nutritional value.

2.7. Estimation of Nutritional Value Components

The nutritional value components crude ash (CA), crude protein (CP), crude fiber (CF), crude fat (CFA), water soluble carbohydrates (WSC), neutral detergent fiber (NDF), acid detergent fiber (ADF), and digestibility (DIG) of the green fodder and silage samples from all treatments and raw material samples (barley grains, mung bean seeds, and barley straw) were determined using near-infrared spectroscopy (NIRS) (Technicon 500, Technicon Industrial Systems, New York, NY, USA) at the laboratories of the Verband Deutscher

Landwirtschaftlicher Untersuchungs- und Forschungsanstalten (VDLUFA) e. V., Speyer, Germany.

The weight of protein produced (g) per 1 kg of fresh green matter was estimated using Equation (2).

$$\text{CP g/kg in FM} = \frac{\text{CP \% in DM} \times \text{DM \%}}{100} \times 10 \quad (2)$$

2.8. Statistical Analysis

Analyses of variance (ANOVA) were applied to determine the significance of the treatment means. Least significant difference (LSD) was used to compare each treatment according to Duncan's multiple range test at $p \leq 0.05$. All statistical tests were performed using the SPSS Statistics 23 software (IBM, Armonk, NY, USA).

3. Results

3.1. Morphological Characteristics

Table 2 shows that there are significant differences between the coefficients of mixture ratios in the morphological traits for barley and mung bean. The root layer thickness (RLT) increased with the increase in barley percentage and decreased with the presence of mung bean. The highest value was in treatment T1 (3.73 cm) and the lowest value was in treatment T11 (1.12 cm). Similarly, the root layer cohesion (RLC) (scale 1–5) was highest in treatment T1 and lowest in treatment T11.

The length of the green part (shoot) increased in the barley (LSB) in the mixture ratio treatments compared to the single treatment in barley, with the highest value in treatment T10 (19.00 cm) and the lowest value in treatment T1 (16.17 cm). In contrast, in mung bean (LSM), the length of the green part (shoot) decreased in the mixture ratio treatments with barley compared to the single treatment, with the highest value in treatment T11 (12.33 cm) and the lowest value in treatment T2 (8.17 cm).

3.2. Chlorophyll Content SPAD of Barley (ChB) and Mung Bean (ChM)

Table 3 shows that the value of SPAD in barley leaves increased with the increase in the percentage of mung bean in the mixture, being the highest in treatment T10 (31.55) and the lowest in the single barley treatment T1 (26.21).

Furthermore, for the value of SPAD in the mung bean leaves, the highest value was in mung bean treatment T11 (25.81) and the lowest in treatment T2 (20.09).

3.3. Fresh and Dry Matter of Hydroponic Green Fodder

The productivity of the fresh green fodder (FM kg/tray) as well as the productivity of the dry matter (DM kg/tray) and the percentage of dry matter in the fodder produced (DM %) increased with the increase in the percentage of barley in the mixture, being the highest in the T1 (100% barley) with the following results: FM (kg/tray) = 9.03, DM (kg/tray) = 1.17 and DM (%) = 12.99. On the other hand, it was lowest in treatment T11 (100% mung bean) with the following results: FM (kg/tray) = 6.16, DM (kg/tray) = 0.69 and DM (%) = 11.23 Table 4.

3.4. Nutritional Value of Hydroponic Green Fodder

The percentage of crude ash (CA), percentage of crude protein (CP), and productivity of crude protein in FM increased with the increase in the percentage of mung bean in the mixture, as they were highest in treatment T11 (15.31%, 28.29%, and 31.79 g/kg FM, respectively) and were lowest in treatment T1 (7.88%, 14.67%, and 19.06 g/kg FM, respectively) (Table 4).

Table 2. Effect of hydroponic mixing ratio (barley–mung bean) on the morphological traits (root layer thickness (RLT) (cm), root layer cohesion (RLC) (scale 1–5), and length of green part (shoot) of barley (LSB) and mung bean (LSM) of green fodder.

Treatments	RLT	RLC	LSB	LSM
	(cm)	(1–5)	(cm)	(cm)
T1	3.73 a	5.00 a	16.17 g	-
SD	0.07	0.00	0.26	-
T2	3.37 b	4.83 a	16.60 f	8.17 h
SD	0.04	0.26	0.15	0.14
T3	2.78 c	4.33 ab	16.83 f	8.53 g
SD	0.02	0.26	0.05	0.05
T4	2.59 d	3.83 bc	17.20 e	8.77 fg
SD	0.02	0.26	0.18	0.05
T5	2.32 e	3.50 cd	17.60 d	8.93 f
SD	0.04	0.00	0.15	0.14
T6	2.15 f	3.17 cd	17.80 cd	9.43 e
SD	0.03	0.26	0.09	0.10
T7	1.92 g	2.83 de	17.93 cd	9.70 de
SD	0.03	0.26	0.05	0.09
T8	1.69 h	2.33 ef	18.07 c	10.00 d
SD	0.02	0.26	0.10	0.18
T9	1.47 i	2.17 ef	18.43 b	10.63 c
SD	0.04	0.26	0.36	0.14
T10	1.22 j	1.67 fg	19.00 a	11.37 b
SD	0.04	0.26	0.18	0.21
T11	1.12 k	1.33 g	-	12.33 a
SD	0.03	0.26	-	0.42
Pr > F	*	*	*	*

SD: standard deviation. Means followed by different letters are statistically different from each other according to Duncan's multiple range test at $p \leq 0.05$. *: significant at $p \leq 0.05$.

Table 3. Chlorophyll content SPAD of barley (ChB) and mung bean (ChM).

SPAD	Treatments											
	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	Pr > F
ChB	26.21 i	27.58 h	28.79 g	29.14 f	29.99 e	30.15 de	30.35 d	30.81 c	31.22 b	31.55 a	-	*
SD	0.24	0.29	0.18	0.17	0.11	0.14	0.06	0.10	0.09	0.08	-	
ChM	-	20.09 j	20.91 i	21.08 h	21.55 g	21.90 f	22.17 e	22.60 d	22.87 c	23.21 b	25.81 a	*
SD	-	0.14	0.04	0.08	0.07	0.05	0.03	0.05	0.08	0.07	0.14	

ChB: chlorophyll content SPAD of barley, ChM: chlorophyll content SPAD of mung bean, SD: standard deviation. Means followed by different letters are statistically different from each other according to Duncan's multiple range test at $p \leq 0.05$. *: significant at $p \leq 0.05$.

Table 4. Effect of hydroponic mixing ratio (barley–mung bean) on the fresh and dry matter and nutritive value of green fodder.

Treatment	FM (kg/tray)	DM (%)	DM (kg/tray)	CA (%)	CP (%)	CP (g/kg FM)	CF (%)	CFA (%)	WSC (%)	NDF (%)	ADF (%)	DIG (%)
T1	9.03 a	12.99 a	1.17 a	7.88 i	14.67 k	19.06 i	24.96 a	3.57 a	10.49 a	59.00 a	33.58 a	67.55 i
SD	0.08	0.19	0.03	0.04	0.19	0.04	0.28	0.03	0.10	0.57	0.39	0.41
T2	8.83 b	12.74 b	1.12 b	7.76 j	16.25 j	20.69 h	23.45 b	3.54 a	9.46 b	54.88 b	33.16 b	71.75 h
SD	0.05	0.12	0.02	0.00	0.08	0.12	0.09	0.01	0.10	0.25	0.14	0.16
T3	8.23 c	12.53 bc	1.03 bc	9.15 h	17.28 i	21.66 g	23.23 b	3.21 b	9.04 c	54.35 c	33.07 b	72.08 gh
SD	0.10	0.14	0.02	0.09	0.08	0.32	0.10	0.05	0.03	0.05	0.19	0.16
T4	7.98 d	12.33 cd	0.98 cd	9.11 h	18.80 h	23.17 f	22.66 c	3.19 b	8.40 d	53.69 d	32.02 c	72.33 g
SD	0.11	0.12	0.02	0.04	0.18	0.41	0.08	0.01	0.05	0.06	0.42	0.10
T5	7.62 e	12.24 d	0.93 d	11.30 g	20.81 g	25.47 e	22.43 cd	2.70 c	8.15 e	52.15 e	31.55 d	72.88 f
SD	0.09	0.11	0.01	0.01	0.02	0.24	0.10	0.01	0.06	0.35	0.01	0.19
T6	7.29 f	12.24 d	0.89 d	11.44 f	21.08 f	25.80 e	22.37 d	2.38 d	7.94 f	51.48 f	31.01 e	73.31 e
SD	0.08	0.08	0.01	0.04	0.17	0.27	0.09	0.00	0.02	0.30	0.04	0.20
T7	7.09 g	12.15 de	0.86 de	12.16 e	22.30 e	27.09 d	22.27 d	2.34 d	7.41 g	50.55 g	30.90 e	74.72 d
SD	0.05	0.08	0.00	0.03	0.15	0.23	0.01	0.01	0.05	0.26	0.11	0.27
T8	6.95 g	12.12 de	0.84 de	12.58 d	23.60 d	28.61 c	21.47 e	2.24 e	7.21 h	50.52 g	30.10 f	75.81 c
SD	0.13	0.07	0.02	0.06	0.02	0.14	0.08	0.02	0.08	0.29	0.09	0.20
T9	6.77 h	11.91 e	0.81 e	12.72 c	25.19 c	30.00 b	20.98 f	2.23 e	7.11 h	48.90 h	29.95 f	77.26 b
SD	0.10	0.12	0.01	0.05	0.16	0.48	0.18	0.02	0.06	0.19	0.07	0.10
T10	6.28 i	11.63 f	0.73 f	13.03 b	25.44 b	29.58 b	20.76 f	2.00 f	6.83 i	45.47 i	29.72 f	77.44 ab
SD	0.03	0.15	0.01	0.05	0.08	0.29	0.10	0.02	0.05	0.17	0.20	0.10
T11	6.16 i	11.23 g	0.69 g	15.31 a	28.29 a	31.79 a	20.29 g	1.81 g	6.13 j	44.54 j	29.15 g	77.69 a
SD	0.05	0.13	0.01	0.01	0.09	0.45	0.08	0.02	0.07	0.08	0.19	0.15
Pr > F	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Significant	*	*	*	*	*	*	*	*	*	*	*	*

FM: fresh matter, DM: dry matter, CA: crude ash, CP: crude protein, CF, WSC: water-soluble carbohydrates, NDF: neutral detergent fiber, ADF: acid detergent fiber, DIG: digestibility, SD: standard deviation. Means followed by different letters are statistically different from each other according to Duncan's multiple range test at $p \leq 0.05$. *: significant at $p \leq 0.05$.

The increase in barley content in the mixture resulted in an increase in crude fiber (CF) and crude fat (CFA) and water-soluble carbohydrates (WSC), which were highest in treatment T1 (24.96%, 3.57%, and 10.49%, respectively) and lowest in treatment T11 (20.29%, 1.81%, and 6.13%, respectively). Furthermore, the increase in barley content in the mixture resulted in an increase in neutral detergent fiber (NDF) and acid detergent fiber (ADF), which were the highest in treatment T1 (59.00%, and 33.58%, respectively) and the lowest in treatment T11 (44.54%, and 29.15%, respectively). In contrast, the digestibility (DIG) of the resulting feed increased with the increase in the percentage of mung bean in the mixture, as it was highest (67.55%) in treatment T11 and lowest (77.69%) in treatment T1 (Table 4).

3.5. Nutritive Value of the Silage

Table 5 shows that in the silage samples, with the increase in barley content in the treatments, the percentage of dry matter (DM), crude fiber (CF), water-soluble carbohydrates (WSC), neutral detergent fiber (NDF), acid detergent fiber (ADF), and digestibility (DIG) increased. The values of these components were highest in treatment T1 (26.79%, 40.90%, 1.83%, 69.79%, 46.32%, and 67.04%) and lowest in treatment T6 (24.93%, 37.30%, 0.21%, 64.21%, 43.34%, and 56.88%). On the other hand, increasing the proportion of mung bean in the mixture resulted in an increase in crude ash (CA), crude protein (CP), and crude protein productivity in FM. It was highest in treatment T6 (12.56%, 11.36%, and 28.31 g/kg FM) and lowest in treatment T1 (10.57%, 8.08%, and 21.53 g/kg FM, respectively). There were no significant differences in the percentage of crude fat (CFA) between treatments.

Table 5. Effect of hydroponic mixing ratio (barley–mung bean) on dry matter and nutritive value of silage.

Treatment	DM	CA	CP	CP	CF	CFA	WSC	NDF	ADF	DIG
	(%)	(%)	(%)	(g/kg FM)	(%)	(%)	(%)	(%)	(%)	(%)
T1	26.79 a	10.57 e	8.04 f	21.53 e	40.90 a	1.80 a	1.83 a	69.79 a	46.32 a	67.04 a
SD	0.11	0.07	0.09	0.33	0.11	0.08	0.04	0.39	0.23	0.25
T2	26.64 a	10.87 d	9.04 e	24.10 d	39.79 b	1.87 a	1.63 b	68.98 b	45.84 b	64.12 b
SD	0.08	0.07	0.12	0.33	0.59	0.05	0.03	0.50	0.11	0.33
T3	26.17 b	11.12 d	9.79 d	25.62 c	38.89 c	1.93 a	1.13 c	66.33 c	45.41 c	62.00 c
SD	0.04	0.12	0.08	0.20	0.69	0.05	0.04	0.08	0.15	0.16
T4	25.86 c	11.45 c	10.09 c	26.09 c	38.14 cd	1.83 a	0.72 d	66.16 c	44.58 d	60.31 d
SD	0.04	0.07	0.09	0.25	0.29	0.07	0.03	0.14	0.16	0.18
T5	25.40 d	11.79 b	10.68 b	27.13 b	38.06 cd	1.80 a	0.50 e	65.92 c	44.23 e	57.92 e
SD	0.07	0.15	0.09	0.28	0.20	0.04	0.05	0.12	0.19	0.16
T6	24.93 e	12.56 a	11.36 a	28.31 a	37.30 d	1.86 a	0.21 f	64.21 d	43.34 f	56.88 f
SD	0.12	0.20	0.13	0.33	0.51	0.07	0.02	0.22	0.10	0.21
Pr > F	0.000	0.000	0.000	0.000	0.000	0.057	0.000	0.000	0.000	0.000
Significant	*	*	*	*	*	n	*	*	*	*

DM: dry matter, CA: crude ash, CP: crude protein, CF: crude fibers, CFA: crude fat, WSC: water-soluble carbohydrates, NDF: neutral detergent fiber, ADF: acid detergent fiber, DIG: digestibility, SD: standard deviation. Means followed by different letters are statistically different from each other according to Duncan's multiple range test at $p \leq 0.05$. *: significant at $p \leq 0.05$, n: no significant differences comparison of nutritional components between the fresh green fodder and silage.

When comparing the nutritional components between the fresh green fodder and the silage, Figure 2 shows that the fresh green fodder was superior to the silage in terms of the following parameters: CP, CFA, WSC, and DIG. On the other hand, silage was superior in: DM, CA, CP (g/kg FM), CF, NDF, and ADF.

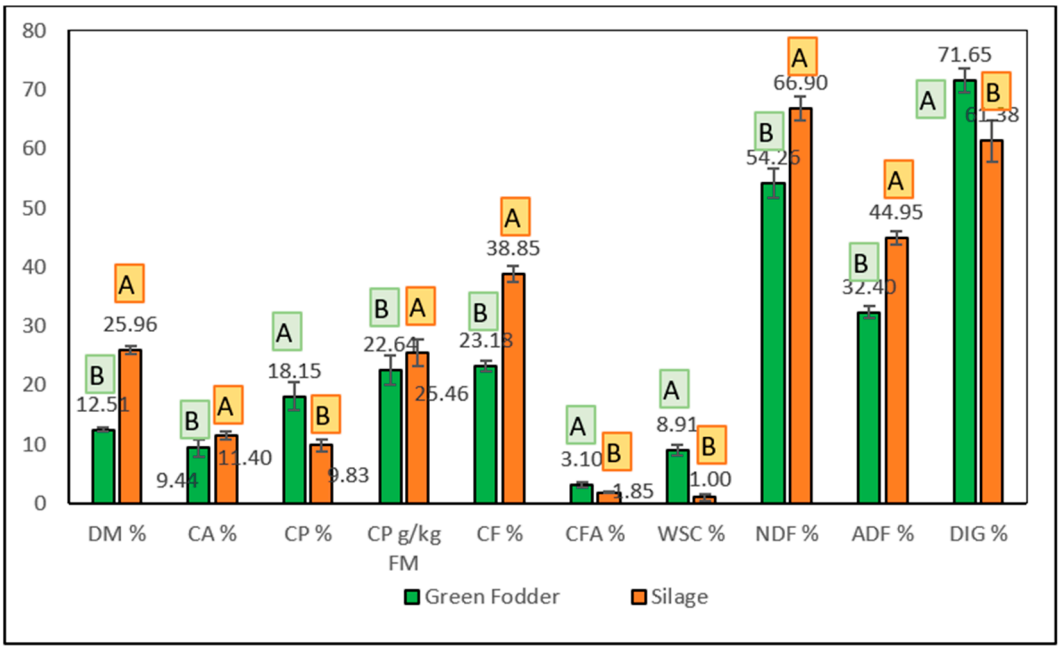

Figure 2. Comparison between green fodder and silage in nutritive value of hydroponic mixing ratio (barley–mung bean) as an average of all mixing ratios. DM: dry matter, CA: crude ash, CP: crude protein, CF: crude fibers, CFA: crude fat, WSC: water-soluble carbohydrates, NDF: neutral detergent fiber, ADF: acid detergent fiber, DIG: digestibility. Means followed by different letters are statistically different from each other according to Duncan's multiple range test at $p \leq 0.05$.

4. Discussion

Many references point out the importance of fodder mixtures in animal feeding, especially mixtures of cereals and legumes, which achieve many benefits for both types of fodder mixtures [26–28]. The references also indicate that mixed cultivation of fodders leads to an increase in productivity as well as an improvement in the quality of the fodder produced and an increase in its nutritional value [20]. All this leads to optimal utilization of fodder by animals, thus increasing the quality and quantity of their products. The production of fodder under hydroponic conditions also leads to an increase in the nutritional value of the fodder [29]. The presence of cereal species in the fodder mixtures leads to an increase in the amount of fresh and dry matter and the percentage of total energy, but at the same time contains less protein compared to legume species, which leads to an increase in the percentage of crude protein in the fodder mixtures [30]. This is consistent with the results of this study, which showed that productivity increased with the increase in barley percentage in the mixture.

As for the effect of the mixture ratio on the nutritional components of the freshly germinated fodder, the results of this study showed that the presence of barley with higher proportions of mung bean resulted in an increase in the proportion of crude fiber, crude fat, water-soluble carbohydrates, NDF, and ADF [20,30]. Since barley is one of the cereals, its content of energy and fiber is high, which led to an increase in the above components [31]. On the other hand, the increase in the percentage of mung beans led to an increase in the percentage of crude protein and crude ash. This is due to the known high protein content of legumes. References also indicate that legumes are characterized by higher digestibility than cereals, and this was also evident in the results of this study. Kataria, (1988) [32] indicated that the digestibility of mung beans increases with soaking of the seeds, and this is exactly what was performed in this study, because the seeds were soaked for several hours before being placed in trays in the growth chamber, so the digestibility was high.

Silage is one of the methods of preserving fodders which ensures the preservation of their nutritional value for a long time [33]. In this study, the silage technique was

used to preserve the germinated fodder. Since the germinated fodder contains a high percentage of moisture [10,14], dry barley straw was added to absorb excess moisture, but the nutritional value of barley straw is low and the percentage of dry matter is high [34]. Thus, this affected the values of the nutritional components of all treatments. That is, the significant differences between the treatments in the study in the silage experiment were influenced, first, by the proportions of barley and mung beans in the feed mixture and, second, by the presence of dry barley straw. Therefore, the results showed an increase in the percentage of dry matter, crude fiber, NDF, ADF, water-soluble carbohydrates, and digestibility in the T1 treatment and a decrease in the T6 treatment. It was found that the digestibility decreased from the T1 treatment to the T6 treatment, although mung beans are characterized by high digestibility [32]. The interpretation is that when the proportion of mung beans was increased from T1 to T6, a greater amount of straw was added because mung beans have a higher moisture content. Many references indicate that the silage process improves the nutritional value of the fodder, so it is important to make a comparison with the germinated fresh fodder [33,35]. Furthermore, when comparing the results of the values of the nutritional components in each of the germinated fresh fodders and the silage from which it was produced, it was found that these results were also influenced by the mixing ratios between barley and mung bean and the presence of straw in the silage experiment. Since this resulted in an increase in the percentages of total dry matter, crude ash, crude fiber, NDF, and ADF in the silage compared to the germinated fresh fodder, this can be explained by the presence of dry barley straw, which contains low percentages of the above components (Table 6). On the other hand, the values of crude fat, water-soluble carbohydrates, and digestibility were low in the barley straw, so their values appeared lower compared to the fresh fodder. It is worth mentioning that the percentage of protein increases during ensiling and the protein value is higher compared to fresh fodder or hay [20,36]. However, the results were lower for silage because the barley straw added during the preparation of the silage contained a very low percentage of crude protein. However, the productivity of crude protein was higher in silage because of the increase in the proportion of dry matter, which is the most important for feeding animals.

Table 6. Nutritional value components of the raw materials used in the experiment (barley grains, mung bean seeds, and barley straw).

Raw Materials	DM	CA	CP	CF	CFA	WSC	NDF	ADF	DIG
	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
Barley grains	95.01	7.21	9.76	18.72	2.38	20.55	59.17	24.30	82.68
Mung bean seeds	95.24	3.72	26.98	6.34	1.81	3.25	47.83	20.38	87.10
Barley straw	97.32	11.60	2.70	43.61	0.49	2.33	77.26	52.05	34.97

DM: dry matter, CA: crude ash, CP: crude protein, CF: crude fibers, CFA: crude fat, WSC: water-soluble carbohydrates, NDF: neutral detergent fiber, ADF: acid detergent fiber, DIG: digestibility.

The estimation of the percentage of chlorophyll in the leaves of the studied plants is very important, as it gives an indication of the health and growth of the plant during the period in which the experiments were conducted, as well as the nitrogen content of the plant [37,38]. The results of the chlorophyll determination in this study showed that the chlorophyll content in mung bean leaves was higher than in barley and that the chlorophyll content in barley leaves was higher when the feed mixture contained a higher proportion of mung beans. The chlorophyll content in mung bean is influenced by various factors of availability of micronutrients such as zinc and other ions in the plant [39,40]. The chlorophyll content in plant leaves is also influenced by the presence of plants in feed mixtures [22,41]. Since no nutrients were used in this study, the obvious effect was the presence of mung beans with barley in the feed mixture, since the chlorophyll content in barley increased with an increase in the proportion of mung beans in the mixture.

The increase in the thickness and cohesion of the root layer with the increase in the percentage of barley in the mixture is related to the type of roots and their growth in both barley and mung bean, as the fibrous and dense roots of barley [42,43] lead to the cohesion of the root layers with each other and an increase in the layer's thickness. The fibrous roots of barley tangle in a hydroponic system and are influenced by the quality of irrigation water (salinity) as well as the genotype of barley [6,44], but no water treatments or genotypes were used in this study, so the growth and tangling of roots were influenced by the proportions of mixing with mung beans. On the other hand, the wedge-shaped roots and a small number of lateral roots of mung bean and their slow growth led to the decay of the root layer and a reduction in its thickness [45,46].

The results of this study showed that the shoot length of barley increased with the presence of mung bean in the mixture, while on the contrary, the shoot length of mung bean was smaller in the mixture with the presence of barley and longer in the treatment with single mung bean. This is because in hydroponic barley seedlings, the first true leaf appears on the third day of germination and competes for light, causing it to grow upward [15,47]. Mung bean is characterized by its aerobic germination (dicotyledons with epigeal germination), i.e., after the fourth day of germination, only the cotyledons appear, from which the first pair of true leaves develop [46,48], and this takes about five days, as documented in our experiments in this study. This results in mung bean remaining shorter than barley due to greater competition from barley, whether due to the strong, dense root system or the rapid growth of seedlings after germination.

5. Conclusions

The results of the experiments in this study led to the achievement of several objectives reflected in the improvement in the quality and quantity of green fodder produced from hydroponic barley. Mixing barley grains with mung bean seeds improved the quality and increased the protein content and digestibility of the fodder. In the production of silage from hydroponic barley fodder, a long shelf life is achieved by adding dry barley straw, which improved the dry matter content and solved the problem of the large amount of water in hydroponic barley fodder. The benefits of the results of this study are, on the one hand, to improve the green fodder production in the hydroponic system for the growers and farmers by applying mixing barley with mung bean at mixing ratios not exceeding 50% to maintain the cohesion of hydroponic green fodder on the one hand, and not to increase production costs on the other hand. This study is also useful for researchers to follow up on work and continue studies through experiments on mixing barley with various legumes such as alfalfa in order to raise the protein content, as well as other types of cereals and legumes, in order to achieve the best productivity and quality of fodder and to reach sustainable fodder production in the hydroponic system.

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