Agronomic and In Vitro Quality Evaluation of Dual-Purpose Cereals Clipped at Variable Ages and Their Utilization in Rabbit Feeding

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Abstract: The present study included two experiments; the first one investigated the forage productivity and in vitro quality of a single cut taken at different plant ages (45, 60, and 75 days after sowing—DAS) from four prominent cereal crops, namely, barley, oat, triticale, and ryegrass, grown during two successive winter seasons in Northern Egypt. In addition, the effect of plant age at forage removal on the crop’s regrowth ability and final grain yield was quantified. The second experiment studied the biological in vivo effects of the four crops’ hay cut at the optimum plant age on growth performance, feed utilization, and apparent nutrients’ digestibility of growing rabbits. Despite the progressive increase in the fresh and dry matter yields produced from the four crops with later forage removal and the relatively high quality of the forage removed at 45 DAS, 1st experiment concluded that forage removal at 60 DAS produced a reasonable amount of fresh and dry matter yields with appropriate in vitro quality. Meanwhile, the gain in forage yield, when forage was removed at 60 DAS, was enough to compensate for the consequent reduction in grain yield of the four evaluated crops. The inclusion of variable percentages (0, 10, and 20%) of the four tested crops’ hay, when cut at 60 DAS, in the rabbit’s diet (2nd experiment), resulted in non-significant variations in the rabbit’s final body weight. Meanwhile, regardless of the percentage, the rabbits that were fed on diets including ryegrass hay and barley hay had the highest significant daily weight gain. The best feed conversion ratios were obtained by the rabbits that were fed on diets containing 10 and 20% ryegrass hay as well as 20% triticale hay. The highest dry matter, organic matter, and crude protein digestibility coefficients were obtained by both groups of rabbits that were fed on diets containing 20% ryegrass hay and barley hay. The inclusion of any of the four crops’ hay in the rabbits’ diet resulted in significantly higher digestibility coefficients for all nutrients compared to the control rabbits except for ether extract digestibility. Among the four evaluated crops’ hay, ryegrass hay was found to have an outstanding impact on the productive performance and digestibility of growing rabbits. In growing dual-purpose cereals, it is recommended to cut the crops at 60 DAS to achieve the optimum balance between forage yield and quality on the one hand and final grain yield on the other hand. Moreover, when cut at 60 DAS, the evaluated hay of the four crops was adequate to be included in the rabbits’ diet up to 20% substitution of the commercial fiber sources.

Keywords: dual-purpose cereals; age at forage removal; forage yield; grain yield; in vitro quality; growing rabbits; productive performance; digestibility coefficients

1. Introduction

The integration of crop and livestock production in the same farming system is a famous strategy of agricultural intensification that is widely recommended, especially in low input systems. However, this mixed agricultural system is often hindered by the seasonal fluctuations in forage supply, especially in the winter [1]. Thus, the cultivation
of dual-purpose cereals is widely practiced in the Mediterranean region to fill a feed gap in the autumn/early winter season [2–4]. This is done by clipping winter cereals early in the season while they are still in the vegetative growth stage to provide an amount of forage for animal husbandry and then leaving them to regrow until grain maturity and harvesting. Although adoption of dual-purpose cereals is well known in some neighboring Mediterranean countries, such as Morocco and Tunisia [2,5], it is not yet widely practiced in Egypt due to the lack of essential knowledge about the proper management practices that support dual-purpose cultivation.

Among the prominent cereals that proved distinction as dual-purpose crops are barley, oat, triticale, and ryegrass [1,4,6]. The management practices for achieving the maximum amount of forage yield from the different cereal crops are different from those recommended for optimum grain production. In the case of dual-purpose utilization of cereals, the determination of the proper age at which forage should be removed is among the most important practices that should be accurately adjusted. In general, removing forage at a later stage of maturity produces a large amount of forage yet negatively affects the crop’s regrowth ability, decreasing the final grain production [7]. Thus, it is crucial to accurately determine the proper age at forage removal in order to achieve a balance between the produced forage on the one hand and the crop’s regrowth ability and final grain yield on the other hand [4].

In addition to the agronomic characterization, the in vivo assessment of a forage crop using an animal model plays an important role in determining its nutritive value and, thus, optimum utilization in animal feeding. Rabbits are famous forage consumers, and since fiber is one of the main constituents in the diets of intensively reared rabbits [8], it is useful to use them in the in vivo feeding evaluation of forage grasses. Despite the relatively low nutritive value of grass hay compared to other forages, they are often incorporated in rabbits’ diets as a convenient, affordable source of fiber. Nevertheless, the fibrous cell wall composition of such materials is greatly variable depending on multiple factors, such as species, age at which forage is removed, and environmental conditions [9,10]. Since the prices of fiber sources to be used in animal diets are sharply increasing, alternatives are required to substitute traditional fiber ingredients in the rabbit’s diet, preferably using local raw materials, available at a lower price [11]. Unlike the sufficient available knowledge on the effects of barley, oat, triticale, and ryegrass grains on the productive performance of growing rabbits, the available information about the impact of using hays of such crops in the diet is very scarce and insufficient to recommend their utilization in the formulation of balanced diets.

The current study involved two experiments. The first experiment was designed to evaluate the forage productivity and its quality of a single cut taken at different plant ages from four prominent cereal crops, namely, barley, oat, triticale, and ryegrass grown in Egypt. In addition, the effect of plant age at forage removal on the crop’s regrowth ability and final grain yield was also quantified. The second experiment was designed to evaluate the biological in vivo effects of the hay of the four crops cut at the optimum age, as concluded from the first experiment, on growth performance, feed utilization, and apparent nutrients’ digestibility of growing rabbits.

2. Materials and Methods
2.1. Field Trials and Agronomic Evaluation

Field trials were carried out during three successive winter growing seasons at the experimental station of the faculty of Agriculture, Alexandria University, Alexandria, Egypt (31°20’ N, 30° E). Data from 2017/2018 and 2018/2019 growing seasons were used for the agronomic evaluation and in vitro quality assessment. Depending on the results, only the superior treatments were planted and harvested during the 2019/2020 season to provide the amount of dry matter needed for carrying out the rabbit in vivo feeding trial. The soil of the experimental location was sandy loam in texture. Average temperature and total precipitation for the three successive growing seasons are presented in Figures 1 and 2, respectively.
provide the amount of dry matter needed for carrying out the rabbit in vivo feeding trial. A randomized complete block design (RCBD), with three field replications, was adopted to evaluate the forage yield and quality, as well as grain yield, and some agronomic parameters of barley (*Hordeum vulgare* L.), oat (*Avena sativa* L.), triticale (*X Triticeae* Wittmack), and annual ryegrass (*Lolium multiflorum* Lam.) when a single cut was taken at three different ages, 45, 60, and 75 days after sowing (DAS), and then the crop was left until maturity and grain harvesting. The experimental plot area was 7.2 m². Each plot consisted of 4 ridges, and one border ridge was left between every two successive plots. Planting of the four crops was done on the 1st of November during the three successive seasons by seed-drilling on the upper third part of one side of the ridge with the recommended seeding rate of 48 kg ha⁻¹ for the four crops. All plots were treated homogeneously and according to the recommendations with regard to the fertilization, irrigation, and weed control treatments.

At the time of forage removal, plots were cut with a sickle 10 cm above the ground surface, and forage fresh matter yield (FMY) was immediately weighed in the field. A sample of approximately 1 kg from each plot was oven-dried at 60 °C for 48 h, and dry matter content (DMC) was determined and used to estimate the forage dry matter yield (DMY). After forage removal, plots were left to regrow and were harvested at grain

Figure 1. Average monthly temperature (°C) for the three experimental seasons.

Figure 2. Total monthly precipitation (mm) for the three experimental seasons.
maturity. Prior to harvesting, fertile spikes were counted in one m², and plant height (cm) was calculated as an average of five random plants in the middle of each plot. At harvesting, plants in the two middle ridges in each plot were cut with a sickle, directly above ground level. Biological yield (grain + straw) was weighed in the field and then threshed using a stable threshing machine. After threshing and winnowing, the grain yield per plot was determined. The harvest index (HI) was calculated as grain yield (kg ha⁻¹) divided by biological yield (kg ha⁻¹) and expressed as a percentage. The number of grains per spike was determined as an average of five randomly chosen spikes, and 1000-grain weight (g) was determined as an average of three random grain samples per plot.

2.2. In Vitro Forage Quality Assessment

Dried samples were ground to a 1 mm particle size, then forage crude protein (CP) was determined as nitrogen content multiplied by 6.25, to determine the variations in fodder quality as affected by the age at forage removal. Nitrogen was analyzed using the Kjeldahl apparatus, according to the Association of Official Analytical Chemists [12]. Fiber fractions were sequentially determined according to [13], as neutral detergent fiber (NDF), acid detergent fiber (ADF), and acid detergent lignin (ADL) using the semiautomatic ANKOM²⁰₀ fiber analyzer (ANKOM, model A200, New York, NY, USA) using two filter bags for each sample (F57-ANKOM Technology Corporation, Macedon, New York, NY, USA). The crude ash (CA) content was determined by incinerating the samples in a muffle oven at 550 °C for 3 h, while crude fat (CF) content was determined using the Soxhlet procedure [12]. Non-fiber carbohydrates (NFC) content (g kg⁻¹) was then calculated as follows:

\[
\text{NFC} = 1000 - (\text{CP} + \text{CF} + \text{NDF} + \text{CA})
\]

All analytical measurements were calculated as an average of two laboratory replications for each field sample.

2.3. In Vivo Rabbit Feeding Trial

The in vivo feeding trial was conducted at a private commercial rabbit farm located in Abu el Matamir, Beheira Governorate, Egypt, for 6 successive weeks during the spring season of 2020. The experimental rabbits were kept in a closed house under controlled environmental conditions (25 °C temperature, 70% relative humidity, and 16 h of illumination).

A total number of 216 unsexed weaned V-line rabbits (6 weeks of age, weighted around 666 ± 41 g on average) were housed in enriched cages (50 × 50 × 60 cm). Rabbits were randomly distributed into 12 treatment groups each of 18 rabbits, with nine replicates of 2 animals each. Experimental diets were formulated to evaluate the four different cereal crops’ hay, namely, barley hay (BH), oat hay (OH), triticale hay (TH), and ryegrass hay (RH). Each hay was evaluated using three dietary substitution levels: 0, 10, and 20%. All the experimental diets were isocaloric and isonitrogenous, providing nearly 2550 kcal kg⁻¹ digestible energy (DE), 17% crude protein (CP), and 150 of DE:CP ratio according to the recommendations of [14]. All rabbits had free access to fresh water and pelleted diets during the whole experimental period. Rabbits’ body weight was individually recorded each week. Body weight gain (BWG) and feed intake (FI) were also determined on a weekly basis. The feed conversion ratio (FCR) was calculated as feed intake (g): weight gain (g). The experimental rabbits were free from any disease symptoms, and the mortality rate was zero throughout the experiment.

At the end of the growth period, 12 rabbits from each experimental group were randomly selected and housed individually in metabolic cages that were equipped with a system for separate collection of feces and urine. An adaptation period of 10 days was followed by a collection period of 4 days, during which feed consumption was accurately determined and total fecal output from each rabbit was collected [15]. Feed that was left out in the feeders and total fecal output were collected at approximately 10:00 a.m. each morning before the next daily ration was provided. The 4-day collected feces from each rabbit were dried at 60 °C for 24 h, and mixed, then representative samples were ground.
for chemical analyses of dry matter (DM; 930.15), CP (N; 954.01), CF (962.09), ether extract (EE; 920.39), and ash (942.05) according to [12].

2.4. Statistical Analyses

Analysis of variance (ANOVA) was conducted using Proc Mixed of SAS 9.4 [16], with only replicates considered random. For the agronomic and in vitro forage quality evaluation, the crop was not considered as an experimental factor, and the statistical analysis was conducted separately for each crop. Data were presented in a combined analysis for the two growing seasons (2017/2018 and 2018/2019) upon homogeneity of variance’s error [17]. The effect of the three tested ages at forage removal on the investigated parameters ($P$) was analyzed according to the following model:

$$P_{ij} = \mu + R_i + AFR_j + e_{ij}$$

where $\mu$ is the overall mean, $R_i$ is the replication ($i = 1,2,3$), $AFR_j$ is the age at forage removal effect ($j = 1,2,3$), and $e_{ij}$ is the experimental error.

Prior to the analysis of variance, the number of fertile spikes per m$^2$ and the number of grains per spike were subject to square root transformation, while the harvest index was arcsine transformed and expressed as a percentage.

For the in vivo rabbit feeding trial, variations in the performance and digestibility variables ($V$) in response to the crop, its percentage in the diet, and their interaction were quantified using the following model:

$$V_{ijk} = \mu + R_i + C_j + P_k + (C \times P)_{jk} + e_{ijk}$$

where $\mu$ is the overall mean, $R_i$ is the replicate effect ($i = 1$ to 18 for the performance parameters, and from 1 to 12 for the digestibility parameters), $C_j$ is the “Crop” effect ($j = 1,2,3,4$), $P_k$ is the “Percentage” effect ($k = 1,2,3$), and $e_{ijk}$ is the experimental error.

Mean comparisons for both experiments were made using the least significant difference (L.S.D) procedure, with significances declared at $p < 0.05$.

3. Results

3.1. Agronomic Evaluation and In Vitro Forage Quality Assessment

3.1.1. Forage Yield and Quality

Analysis of variance revealed significant variations in the forage FMY and DMY ($p \leq 0.01$), its DMC ($p \leq 0.05$), CP, NFC, and fiber fractions ($p \leq 0.01$), of the four crops as affected by the age at forage removal.

According to the means presented in Table 1, the amount of FMY was directly proportional to the age at forage removal; the later the harvest, the more FMY was produced from the four crops. The highest significant amount of FMY was produced when the forage was removed at 75 DAS and amounted to 18.67, 15.94, 13.42, and 13.62 t ha$^{-1}$, for barley, oat, triticale, and ryegrass, respectively. This amount represented an increase of 39.22, 55.36, 68.81, and 31.47% over harvesting at 60 DAS for the four respective crops. A similar trend was observed for forage DMC, where the later the harvest, the more the DMC, and except for triticale, no significant difference in the forage DMC was detected for the three ages at forage removal. Consequently, variations in forage DMY were similar to forage FMY and DMC. The increase in forage DMY from harvesting at 60 DAS to harvesting at 75 DAS amounted to 96.19, 184.62, 71.74, and 43.12%, for barley, oat, triticale, and ryegrass, respectively.
Table 1. Means of fresh matter yield (FMY), dry matter yield (DMY), dry matter content (DMC), crude protein (CP), non-fiber carbohydrates (NFC), neutral detergent fiber (NDF), acid detergent fiber (ADF), and acid detergent lignin (ADL) contents of the forage of the four crops as affected by the age at forage removal (DAS).

| Parameter | Age at Forage Removal | Barley | Oat | Triticale | Ryegrass |
|-----------|-----------------------|--------|-----|-----------|-----------|
| **FMY (t ha⁻¹)** | 45 DAS | 5.02 c | 5.67 c | 2.67 c | 5.59 c |
|          | 60 DAS | 13.41 b | 10.26 b | 7.95 b | 10.36 b |
|          | 75 DAS | 18.67 a | 15.94 a | 13.42 a | 13.62 a |
|          | L.S.D.₀.₀₅ | 2.37 | 2.41 | 2.02 | 2.38 |
| **DMY (t ha⁻¹)** | 45 DAS | 0.49 c | 0.53 b | 0.31 c | 0.57 c |
|          | 60 DAS | 1.05 b | 0.65 b | 0.92 b | 1.09 b |
|          | 75 DAS | 2.06 a | 1.85 a | 1.58 a | 1.56 a |
|          | L.S.D.₀.₀₅ | 0.26 | 0.22 | 0.24 | 0.31 |
| **DMC (g kg⁻¹)** | 45 DAS | 96.84 b | 93.78 b | 117.67 a | 101.66 b |
|          | 60 DAS | 78.77 c | 63.03 c | 116.03 a | 105.05 ab |
|          | 75 DAS | 110.46 a | 116.12 a | 117.95 a | 114.09 a |
|          | L.S.D.₀.₀₅ | 11.61 | 9.64 | 5.62 | 10.41 |
| **CP (g kg⁻¹)** | 45 DAS | 128.64 a | 104.91 a | 102.31 b | 118.87 a |
|          | 60 DAS | 101.50 b | 94.46 b | 125.36 a | 108.38 a |
|          | 75 DAS | 98.23 c | 88.16 b | 134.29 a | 94.72 b |
|          | L.S.D.₀.₀₅ | 3.00 | 8.30 | 8.94 | 13.64 |
| **NFC (g kg⁻¹)** | 45 DAS | 262.70 b | 372.44 a | 256.76 a | 250.92 b |
|          | 60 DAS | 292.77 a | 315.11 a | 262.48 a | 261.68 b |
|          | 75 DAS | 261.63 b | 294.29 a | 269.06 a | 307.28 a |
|          | L.S.D.₀.₀₅ | 19.13 | 98.23 | 38.07 | 40.60 |
| **NDF (g kg⁻¹)** | 45 DAS | 444.77 b | 424.32 b | 435.05 b | 430.77 b |
|          | 60 DAS | 518.51 a | 466.54 ab | 503.82 a | 453.84 a |
|          | 75 DAS | 526.25 a | 512.55 a | 505.40 a | 446.33 a |
|          | L.S.D.₀.₀₅ | 18.00 | 59.23 | 34.34 | 15.39 |
| **ADF (g kg⁻¹)** | 45 DAS | 241.34 b | 231.04 c | 223.50 b | 216.53 b |
|          | 60 DAS | 288.84 a | 254.96 b | 274.41 a | 236.83 a |
|          | 75 DAS | 293.39 a | 284.44 a | 276.91 a | 232.81 a |
|          | L.S.D.₀.₀₅ | 16.48 | 21.21 | 22.26 | 9.82 |
| **ADL (g kg⁻¹)** | 45 DAS | 24.93 b | 25.14 a | 23.28 b | 25.66 a |
|          | 60 DAS | 27.90 a | 23.17 b | 23.80 b | 25.88 a |
|          | 75 DAS | 26.76 ab | 26.47 a | 28.13 a | 23.72 a |
|          | L.S.D.₀.₀₅ | 2.91 | 1.64 | 1.63 | 4.23 |

Means followed by different small letter(s) within the same parameter for each crop are significantly different according to the L.S.D. test at 0.05 level of probability.

Regarding the in vitro forage quality assessment, harvests taken at 45 DAS were characterized by the highest significant CP content for barley (128.64 g kg⁻¹) and oat (104.91 g kg⁻¹), while the highest significant CP content was a character of forage removed at 60 (125.36 g kg⁻¹) and 75 (134.29 g kg⁻¹) DAS for triticale, and at 45 (118.87 g kg⁻¹) and 60 (108.38 g kg⁻¹) DAS for ryegrass. Non-significant variations were detected in NFC content among the three ages at forage removal for oat and triticale. The NFC content reached 327.28 and 261.43 g kg⁻¹ for barley, triticale, and ryegrass, respectively. On the other hand, forage removal at 60 DAS and 75 DAS produced forage with the highest significant NDF content for barley (292.77 g kg⁻¹) and ryegrass (307.28 g kg⁻¹), respectively. The highest significant NDF contents for the four crops were produced when forage was removed at 60 and 75 DAS. In general, the difference between NDF content of the early removed forage (at 45 DAS) and the late removed forage (at 75 DAS) amounted to 81.48, 88.23, 70.35, and 15.56 g kg⁻¹, for barley, oat, triticale, and ryegrass, respectively. Similarly, harvesting barley, triticale, and ryegrass at 60 and 75 DAS resulted in forage with the highest significant ADF contents, while oat harvest
taken at 75 DAS was characterized with the highest significant ADF content. Small, yet significant variations were detected among the crops and the ages at forage removal for the lignin (ADL) content. Forage removal at 60 and 75 DAS resulted in forage with the highest significant ADL content for barley, while harvesting at 45 and 75 DAS produced oat forage with the highest ADL content. Triticale had the highest significant ADL content with harvesting at 75 DAS, while non-significant variations in ryegrass ADL content were detected among the three ages at forage removal. In general, ADL content for the four crops at the three ages at forage removal ranged from 23.17 to 28.13 g kg\(^{-1}\).

3.1.2. Agronomic Parameters and Grain Yield

Statistical analysis revealed that the age of plant at forage removal significantly affected the barley number of fertile spikes and HI \((p \leq 0.01)\), oat plant height, number of fertile spikes, number of grains per spike, 1000-grain weight, and grain yield \((p \leq 0.01)\), all triticale parameters \((p \leq 0.01)\) except the number of grains per spike, and all ryegrass parameters \((p \leq 0.01)\) except 1000-grain weight.

It is clear from Table 2 that early forage removal at 45 DAS resulted in the production of the tallest significant plants of oat, ryegrass, and triticale, while later harvests at 60 and 75 DAS resulted in shorter plants. Forage removal at 45 and 60 DAS for barley, oat, and triticale, as well as at 60 DAS for ryegrass, resulted in the highest significant number of fertile spikes. Differences between the highest and lowest number of fertile spikes reached 26.30, 24.28, 24.91, and 34.10% for barley, oat, triticale, and ryegrass, respectively. Nonetheless, the highest significant number of grains per spike was reached when forage was removed at 45 and 60 DAS for oat and at 45 DAS for ryegrass. Similarly, early and intermediate forage removal at 45 and 60 DAS resulted in the heaviest significant 1000-grain weight for oat and triticale. The highest total yield was achieved with early forage removal at 45 DAS for ryegrass and at 45 and 60 DAS for triticale. Grain yield followed the same trend with forage removal at 45 and 60 DAS resulting in the highest significant grain yield from oat, triticale, and ryegrass. A reduction in grain yield for the three respective crops from forage removal at 45 DAS to forage removal at 75 DAS amounted to 25.81, 44.64, and 30.06%. Harvest index values were the highest significant when barley forage was removed at 45 DAS (19.94%), triticale forage was removed at 60 DAS (15.62%), and ryegrass forage was removed at 45 DAS (10.72%), and 60 DAS (11.98%).

3.2. In Vivo Rabbit Feeding Trial

3.2.1. Performance Parameters

Analysis of variance revealed that the initial and final body weights were non-significantly variable \((p \geq 0.05)\) as affected by the evaluated hay species and percentages as well as their interaction. On the other hand, the daily weight gain was only significantly affected by the hay species \((p \leq 0.01)\). Meanwhile, daily feed intake and feed conversion ratio were significantly \((p \leq 0.01)\) affected by the interaction between hay species and their percentage in the diet.

Means presented in Table 3 showed that, regardless of the hay inclusion percentage, rabbits fed diets containing RH and BH gained the highest significant daily weight, amounting to 35.87 and 35.25 g, respectively. On the other hand, rabbits that were fed diets including OH and TH recorded the lowest significant daily weight gain, which reached 34.78 and 34.79 g, respectively.

Concerning feed intake, means in Table 4 showed that rabbits that were fed diets containing 10% RH and 20% TH consumed the least significant amount of feed, which were lower than the control groups by 5.21 and 4.81%, respectively. Almost the same trend was achieved with the feed conversion ratio (FCR), so that rabbits that were fed diets of RH at both percentages (10 and 20%) along with the rabbits that were fed on 20% TH had the highest significant FCR compared to the other treatments. This represented an improvement over the control by 4.48, 3.79, and 3.07%, respectively.
**Table 2.** Means of agronomic parameters, total and grain yields, and harvest index (HI) of the four crops as affected by the age at forage removal (DAS).

| Parameter                          | Age at Forage Removal | Barley                | Oat                     | Triticale            | Ryegrass          |
|------------------------------------|-----------------------|-----------------------|-------------------------|----------------------|-------------------|
| Plant height (cm)                   | 45 DAS                | 89.11 a               | 143.55 a                | 125.67 a             | 120.44 a          |
|                                    | 60 DAS                | 88.89 a               | 130.00 b                | 127.67 a             | 104.22 b          |
|                                    | 75 DAS                | 87.67 a               | 127.56 b                | 120.00 b             | 105.56 b          |
|                                    | L.S.D. 0.05           | 17.81                 | 10.50                   | 4.06                 | 4.43              |
| Number of fertile spikes (m⁻²)     | 45 DAS                | 217.33 a              | 216.67 a                | 357.33 a             | 286.67 b          |
|                                    | 60 DAS                | 218.00 a              | 233.33 a                | 364.00 a             | 318.67 a          |
|                                    | 75 DAS                | 160.67 b              | 176.67 b                | 273.33 b             | 210.00 c          |
|                                    | L.S.D. 0.05           | 14.10                 | 34.08                   | 63.74                | 30.56             |
| Number of grains per spike         | 45 DAS                | 55.20 a               | 195.33 a                | 90.60 a              | 715.00 a          |
|                                    | 60 DAS                | 57.13 a               | 194.00 a                | 89.22 a              | 685.33 b          |
|                                    | 75 DAS                | 54.33 a               | 146.22 b                | 87.73 a              | 391.67 c          |
|                                    | L.S.D. 0.05           | 3.07                  | 29.40                   | 11.04                | 15.60             |
| 1000-grain weight (g)              | 45 DAS                | 60.50 a               | 31.60 ab                | 39.60 a              | 3.85 a            |
|                                    | 60 DAS                | 59.15 a               | 26.98 ab                | 38.30 a              | 3.75 a            |
|                                    | 75 DAS                | 58.87 a               | 25.23 b                 | 28.95 b              | 3.63 a            |
|                                    | L.S.D. 0.05           | 5.58                  | 6.31                    | 0.74                 |                   |
| Total yield (t ha⁻¹)               | 45 DAS                | 14.21 a               | 44.24 a                 | 27.54 a              | 16.07 a           |
|                                    | 60 DAS                | 14.10 a               | 47.84 a                 | 27.34 a              | 13.45 b           |
|                                    | 75 DAS                | 14.00 a               | 37.65 a                 | 17.46 b              | 11.64 c           |
|                                    | L.S.D. 0.05           | 2.59                  | 12.72                   | 3.14                 | 1.13              |
| Grain yield (t ha⁻¹)               | 45 DAS                | 2.85 a                | 4.30 a                  | 2.89 a               | 1.73 a            |
|                                    | 60 DAS                | 2.35 a                | 4.27 a                  | 2.71 a               | 1.61 a            |
|                                    | 75 DAS                | 2.42 a                | 3.19 b                  | 1.60 b               | 1.21 b            |
|                                    | L.S.D. 0.05           | 0.91                  | 0.50                    | 0.44                 | 0.30              |
| HI (%)                             | 45 DAS                | 19.94 a               | 10.48 a                 | 14.86 b              | 10.72 ab          |
|                                    | 60 DAS                | 16.70 b               | 10.45 a                 | 15.62 a              | 11.98 a           |
|                                    | 75 DAS                | 17.26 b               | 9.23 a                  | 11.20 c              | 10.41 b           |
|                                    | L.S.D. 0.05           | 1.55                  | 2.23                    | 0.45                 | 1.35              |

Means followed by different small letter(s) within the same parameter for each crop are significantly different according to the L.S.D. test at 0.05 level of probability.

**Table 3.** Means of the initial and final weight, daily weight gain (g) as affected by the crop and its percentage in the diet.

| Crop         | Initial Body Weight | Final Body Weight | Daily Weight Gain |
|--------------|---------------------|-------------------|-------------------|
| Barley       | 668.15 a            | 1901.91 a         | 35.25 ab          |
| Oat          | 664.63 a            | 1882.07 a         | 34.78 b           |
| Triticale    | 668.70 a            | 1886.19 a         | 34.79 b           |
| Ryegrass     | 668.33 a            | 1923.76 a         | 35.87 a           |
| L.S.D. 0.05  | 18.41               | 41.94             | 1.07              |
| Percentage   | 0                   | 670.56 a          | 1898.83 a         | 35.09 a            |
|              | 10                  | 666.94 a          | 1890.22 a         | 34.95 a            |
|              | 20                  | 664.86 a          | 1906.39 a         | 35.47 a            |
| L.S.D. 0.05  | 15.94               | 36.32             | 0.93              |

Means followed by different small letter(s) within the same treatment for each studied parameter are significantly different according to the L.S.D. test at 0.05 level of probability.
Table 4. Means of the daily feed intake (g) and feed conversion ratio as affected by the interaction between the crop and its percentage in the diet.

| Treatment  | Daily Feed Intake 0% | 10% | 20% | Feed Conversion Ratio 0% | 10% | 20% |
|------------|----------------------|-----|-----|--------------------------|-----|-----|
| Barley     | 86.52 abA            | 85.23 bB | 87.09 aA | 2.95 aA               | 2.96 aA       | 2.94 aAB |
| Oat        | 86.06 aA             | 87.05 aA | 87.07 aA | 3.00 aA               | 3.00 aA       | 3.09 aA  |
| Triticale  | 87.04 aA             | 86.68 aA | 82.85 bc | 2.93 abA              | 3.07 aA       | 2.84 bb  |
| Ryegrass   | 86.33 aA             | 81.83 bC | 85.33 aB | 2.90 aA               | 2.77 bb       | 2.79 abB |
| L.S.D. 0.05| 1.20                 | 0.16  | 0.16  |                         |               |       |

Means followed by different small letter(s) within the same row and different capital letter(s) within the same column for each studied parameter are significantly different according to the L.S.D. test at 0.05 level of probability.

3.2.2. Digestibility Parameters

Statistical analysis revealed significant variations ($p \leq 0.01$) in the apparent nutrient digestibility of DM, OM, CP, CF, and EE, as affected by the interaction between the hay species and its percentage in the diet.

Means presented in Table 5 showed that rabbits fed diets including a high percentage (20%) of RH and BH along with diets including a low percentage (10%) of OH and TH recorded the highest significant DM and OM digestibility. In addition, it was observed that the digestibility of DM and OM improved by increasing the percentage of BH or RH or by decreasing the percentage of OH or TH in the diet. It was worth noting that all rabbits that were fed diets that included different percentages of either studied crops’ hay had significantly higher DM and OM digestibility than the control rabbits.

Table 5. Means of the digestibility (%) of the organic matter (OM) and dry matter (DM) as affected by the interaction between the crop and its percentage in the diet.

| Treatment  | OM Digestibility 0% | 10% | 20% | DM Digestibility 0% | 10% | 20% |
|------------|---------------------|-----|-----|---------------------|-----|-----|
| Barley     | 62.93 cA            | 65.13 bc | 68.78 aA | 62.91 cA          | 64.11 bb | 67.81 aA |
| Oat        | 63.03 bA            | 66.34 ab | 66.05 ab | 63.11 bA          | 66.20 aA | 65.50 ab  |
| Triticale  | 63.44 cA            | 66.71 ab | 64.20 bc | 63.01 bA          | 66.37 aA | 63.16 bc  |
| Ryegrass   | 62.89 cA            | 67.62 bA | 68.58 aA | 63.13 cA          | 67.05 bA | 68.13 aA  |
| L.S.D. 0.05| 0.90                |       |       |                     |       | 0.95  |

Means followed by different small letter(s) within the same row and different capital letter(s) within the same column for each studied parameter are significantly different according to the L.S.D. test at 0.05 level of probability.

The results of apparent CP, CF, and EE digestibility of rabbits fed on the experimental diets are presented in Table 6. Increasing the percentage of RH or BH in rabbits’ diet significantly improved CP digestibility, whereas increasing OH or TH percentage in the diet did not significantly affect the digestibility of CP. The highest CP digestibility values were recorded for the rabbits fed diets that included 20% RH, 20%BH, or 10% OH, representing an increase of around 5.63, 6.11, and 4.79% over the control rabbits for the three respective treatments. Noticeably, the dietary apparent CF digestibility of the hay of all studied crops significantly increased by increasing their percentage in the diet, except for RH, which recorded the highest value (51.52%) with the rabbits fed on diet with only 10%. The inclusion of the hay of all studied crops in the diet was found to decrease the apparent digestibility of EE as compared to the control diets.
Table 6. Means of the digestibility (%) of crude protein contents (CP), crude fat (CF), and ether extract (EE) as affected by the interaction between the crop and its percentage in the diet.

| Treatment   | CP Digestibility | CF Digestibility | EE Digestibility |
|-------------|------------------|------------------|------------------|
|             | 0%               | 10%              | 20%              | 0%               | 10%              | 20%              | 0%               | 10%              | 20%              |
| Barley      | 70.06 cA         | 73.16 bAB        | 74.34 aA         | 40.60 bA         | 41.64 bC         | 51.49 aA         | 88.94 aA         | 83.28 bbB        | 81.58 cC         |
| Oat         | 70.39 bA         | 73.76 aA         | 73.33 aB         | 41.00 bA         | 42.17 bBC        | 49.86 aAB        | 89.04 aA         | 83.10 cB         | 86.27 bA         |
| Triticale   | 70.45 bA         | 72.70 aB         | 72.16 aC         | 40.75 cA         | 44.02 bB         | 47.08 aC         | 89.10 aA         | 87.21 baA        | 85.75 cA         |
| Ryegrass    | 70.50 bA         | 70.36 bC         | 74.47 aA         | 40.43 cA         | 51.26 aA         | 48.77 bBC        | 88.84 aA         | 87.39 bA         | 83.68 cbB        |
| L.S.D. 0.05 | 0.66             | 2.19             | 1.28             |                  |                  |                  |                  |                  |                  |

Means followed by different small letter(s) within the same row and different capital letter(s) within the same column for each studied parameter are significantly different according to the L.S.D. test at 0.05 level of probability.

4. Discussion

4.1. Agronomic Evaluation and In Vitro Quality Assessment

Clipping winter cereals during their vegetative growth phase provides an amount of forage that would support the integration of the livestock production system in the farming practice. However, the success of this management system is greatly dependent on the age at which the forage is removed [4]. A pronounced effect for the age at forage removal was detected in the current study, not only on the herbage yield and quality but also on the regrowth ability of the evaluated cereal crops and their final grain yield. The achieved increase in forage FMY and DMY with increasing the age at forage removal was in line with the findings of several researchers. Previous studies documented a linear increase in forage FMY when the grass sward was cut at an advanced stage of maturity for barley, oat, and triticale [4,18–21]. Similarly, DMC was also increased with crop maturation. This was probably attributed to the increase in the stem component of the forage and the reduction in the leaf component, where stems are higher in DMC than leaves, thus contributing to the DMC of the produced herbage [4,18].

The proper age at forage removal is basically determined by the stage of apical development, which varies among the different crops [21]. Previous investigations carried out in the Mediterranean region recommended clipping most of the dual-purpose cereals at early jointing [1–4]. In the current study, the investigated crops reached the early jointing stage, i.e., GS31 according to Zadoks scale [22], approximately at 60 DAS. In a similar investigation, [1] achieved around 7.23 t ha\(^{-1}\) FMY from dual-purpose triticale that was cut at the early jointing phase. This was similar to the 7.95 t ha\(^{-1}\) FMY reported for dual-purpose triticale cut at 60 DAS in the current study.

It is evident that the nutritive value of forage grasses decreases with maturation, mainly due to the decrease in CP content accompanied by an increase in fiber content. The decrease in CP content with advanced forage maturation was observed in several forage crops [20,23,24] and could be partially attributed to the dilution of photosynthates accompanying the higher amount of forage yield produced [25]. In the current study, clipping triticale and ryegrass at 60 DAS resulted in forage with high content of CP, while the highest CP content for barley and oat forage was achieved with forage removal at 45 DAS. This was most probably because of the faster growth of barley and oat compared to triticale and ryegrass. While barley and oat needed less time (45 DAS) to reach the stage of maturity with the optimal quality, triticale and ryegrass needed more time to reach the same stage (60 DAS). Meanwhile, the decrease in CP content from clipping at 45 to 60 DAS was minimal for barley and oat, compared to the increase in FMY and DMY, which supported the proposal of 60 DAS as the proper age at forage removal. The content of NFC is another important criterion for forage quality, which had almost the same trend as CP content, with clipping barley, oat, and triticale at 60 DAS, providing forage with an adequate amount of NFC. A high association has been reported between the forage fiber content and crop maturation [4]. In the forage grasses, as the crop matures, the different plant parts become more fibrous, resulting in an increased content of the different fiber fractions (NDF, ADF, and ADL). This is mainly because the older plants are characterized...
by higher stem than leaf component, where stems are generally more fibrous and, thus, less digestible than leaves [24,26]. In addition, while the plant matures, the contents of water-soluble carbohydrates in the leaves and stems decrease, associated with an increase in their content from the different fiber fractions [24]. This explains the increase in fiber fractions with advanced age at forage removal, observed in the current study.

The maturity stage at which the forage is cut (managed in terms of plant age at forage removal) influences not only forage yield and nutritive value but also the regrowth ability of the crop, which determines the final grain yield. In the current study, clipping the cereal crops at an advanced stage of maturity (75 DAS) negatively affected the final grain yield, compared to their clipping at 45 and 60 DAS. Grain yield in cereal crops is a function of the three main yield components, namely, number of fertile spikes per m², number of grains per spike, and 1000-grain weight. It is evident that decreasing one or more of the three yield components would negatively affect the final grain yield. An attempt was made by [27] to explain the negative impact of late forage removal on the yield components and final grain yield of wheat and barley. They suggested that early forage removal would increase the duration of the reproductive growth phase, during which the spike and stem are competing for assimilates, which will result in increasing the number of fertile florets per spike. Applying this suggestion to the current study, it was observed that early forage removal (at 45 and 60 DAS) would allow for an extended period of stem growth after forage removal compared to late forage removal (at 75 DAS). This will result in better assimilates capture and accumulation, and consequently increasing the number of fertile florets and, thus, final grain yield. Another reason behind the reduced grain yield upon late forage removal would be the adverse effects of delayed clipping on shoot and root regrowth, resulting in a more sensitive crop to any induced stress condition that may reduce the final grain yield [28]. Nonetheless, forage removal at advanced maturity leads to a reduction in carbohydrate content between clipping and anthesis, which will decrease both the number of fertile spikes and the number of grains per spike [29].

The harvest index, in the current study, was the highest when forage was removed at 60 DAS for most of the evaluated crops. This result suggests that forage removal at this age allowed for the highest conversion of the photosynthetic assimilates into the economic component, i.e., grain yield. This was true for the components from which the HI was calculated, i.e., biological and grain yields. Nevertheless, the later the forage removal, the shorter the produced plants after clipping. This was true for several dual-purpose grasses, such as triticale, oat, and barley, and was believed to be useful in reducing the risk of lodging [30].

Analysis of the forage yield gain revealed that forage removal at 60 DAS led to 114.29, 22.64, 113.88, 91.23% increase in DMY over forage removal at 45 DAS for barley, oat, triticale, and ryegrass, respectively, in the current study, against the grain yield loss as affected by the age at forage removal. This was accompanied by a small grain yield reduction of around 17.54, 0.70, 6.23, 6.94% for the four respective crops. Thus, supported by the good prices of grass forage in the region [1,4], the dual-purpose utilization of winter cereals proved to be economic.

4.2. In Vivo Rabbit Feeding Trial

The non-significant variations in the final body weight despite the significant differences in the feed intake among the treated groups of rabbits could be attributed to the slight variation in the chemical composition among the experimental diets as affected by the different crop hay species included in the diet. In this case, rabbits attempt to regulate their amount of feed intake to fulfill their nutrients’ requirements [8,31].

The favorable effects of the inclusion of RH and TH in the diet on the growth performance of rabbits may be partially attributed to the better initial DM and CP composition of those types of hay compared to the other studied crops’ hay. Additionally, the nutritive value of feedstuffs for rabbits is mainly dependent on the fiber quantity and quality (lignin, cellulose, hemicellulose, pectin, and their equilibrium), as reported by [32].
The outstanding results of apparent DM, OM, and CP digestibility associated with diets containing RH were probably due to the higher initial DM and CP contents of RH [10], in addition to its relatively lower NDF content, which was reflected on higher apparent nutrients’ digestibility and nutritive value of the diets [33], beside the easy fermentability of the structural carbohydrates (NDF and ADF), as reported by [10]. The high apparent nutrients’ digestibility values of diets that included BH may be explained by the chemical composition of such hay, as it contained high proportions of digestible non-fiber carbohydrates and CP that could be easily degraded by the intestinal microflora [34]. The recorded improvements in apparent nutrients’ digestibility for diets that included RH or BH were directly reflected in higher body weight gained by rabbits that were fed those diets. On the other hand, the deterioration in CF digestibility by increasing RH percentage in the diet could be due to the higher ADL content of the hay, since the excess amount of ADL in the diet tends to reduce the digesta retention time in the whole gastrointestinal tract by around $-20\%$, consequently, leading to lower CF digestibility [35].

The reduction in the diet’s apparent DM, OM, and CP digestibility with increasing OH percentage in the diet (20%) was probably due to the relatively lower DM and CP of the hay. In this regard, [8] reported lower total tract apparent digestibility of oat straw, especially when included in the rabbit diets by 150 g kg$^{-1}$. They associated that detrimental effect on the digestibility to the higher lignin and lower pectin ratio of that diet.

5. Conclusions

The four evaluated cereal crops demonstrated clear potential to be utilized for dual-purpose cultivation to fill a feed gap during the autumn/early winter season. Forage removal at 60 DAS produced a reasonable amount of fresh and dry matter yields with appropriate in vitro quality. Meanwhile, the gain in forage yield, when forage was removed at 60 DAS, was enough to compensate for the consequent reduction in grain yield of the four evaluated crops. According to the biological in vivo evaluation of the studied crops’ hay, all hays were suitable for rabbits’ feeding; up to 20% could be safely incorporated in growing rabbits’ diets without any adverse effects on the performance or digestibility traits. This will contribute to finding affordable alternatives for commercial hays and, thus, optimize the rabbit production costs.

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Abbreviations

ADF  Acid detergent fiber
ADL  Acid detergent lignin
BH   Barley hay
BWG  Body weight gain
CP   Crude protein
CF   Crude fat
DAS  Days after sowing
DM   Dry matter
DMC  Dry matter content
DMY  Dry matter yield
EE   Ether extract
FCR  Feed conversion ratio
FI   Feed intake
FMY  Fresh matter yield
HI   Harvest index
NDF  Neutral detergent fiber
NFC  Non-fiber carbohydrates
OH   Oat hay
OM   Organic matter
RH   Ryegrass hay
TH   Triticale hay

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