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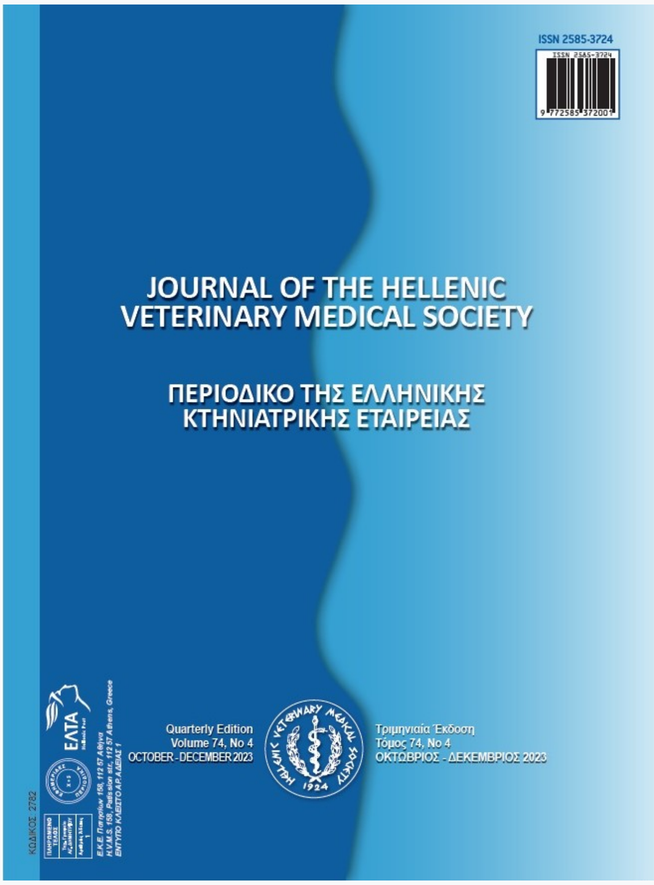


# Buckwheat Forage as a Ruminant Feed: The Effects of Different Harvesting Stages on the Nutritive Value and Yield of Two Cultivars

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# Buckwheat Forage as a Ruminant Feed: The Effects of Different Harvesting Stages on the Nutritive Value and Yield of Two Cultivars

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**ABSTRACT:** This study was performed to investigate the effects of harvesting stages on the chemical constituents, energy values, *in vitro* true dry matter digestibility (IVTDMD), forage yield, and relative feed values (RFV) of buckwheat (*Fagopyrum esculentum* Moench) cultivars, Aktaş and Güneş, developed in Turkey. Buckwheat forage was harvested at following three stages: the early dough (ED) stage, the soft-to-hard dough (SHD) stage, and the fresh stover (S) stage. The forage dry matter (DM) yields of the Aktaş and Güneş cultivars were 458.63 and 479.02 kg/da respectively, and no significant difference was found between the cultivars in terms of the forage DM yield, chemical constituents, energy values, IVTDMD and RFV (P>0.05). The forage yield was primarily affected by the harvesting stage. The forage DM yield for the average of the two cultivars increased by about 27% from the ED to the SHD stage, but decreased by about 62% from the ED to the S stage. Significant differences were observed between the S stage and the other two harvest stages in terms of chemical constituents, energy values, IVTDMD and RFV, and the lowest nutritive values were obtained at the S stage (P<0.05). In both buckwheat cultivars, the highest crude protein (CP) and IVTDMD were obtained at the ED stage, but CP yield and digestible dry matter yield were found to be highest at the SHD stage. Therefore, it is strongly recommended that the buckwheat cultivars Aktaş and Güneş should be harvested at the SHD stage. The CP content of the fresh stover was 8.90% since the fresh buckwheat stover, remained in the field after the grain harvest, contained flowers, green seeds and mature seeds besides leaves and stems, which were green during this period. However, the IVTDMD value was found to be as low as 47.92%, indicating a reduction in forage quality.

***Keywords:*** Buckwheat; Digestibility; Forage; Harvesting stage; Nutritive value

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## INTRODUCTION

Buckwheat, a dicotyledon belonging to the *Polygonaceae* family and the *Fagopyrum* genus (Campbell 1997), is not a cereal; however, it is often grouped among cereals due to its agronomic traits, cultivation practices, and utilization (Eggum et al., 1980). Although there are approximately 15 species belonging to this genus; the two species are cultivated: common buckwheat (*Fagopyrum esculentum* Moench) and Tartary buckwheat (*Fagopyrum tataricum* (L.) Gaertn.). Buckwheat blooms within 30 days of sowing, and the flowering period continues for 30 to 60 days due to the indeterminate nature of the inflorescences (Kara 2014; Płàzek et al., 2019) therefore, the plant does not all mature simultaneously. The flowering starts from the lower branches and progresses upwards (Radics and Mikóházi 2010), thus flowers, green grains, and mature grains are found on the plant concurrently (Campbell 1997). The protein content of fresh buckwheat forage changes in a range from 11 to 24% during growth, depending on the cultivar and environmental factors (Leiber et al., 2012; Görgen et al., 2016). At the onset of the flowering period (5 to 6 weeks after sowing), the protein content (from 15 to 20%) and the digestibility of the plant are high. Late harvesting increases the fiber content and reduces quality; however, it does not substantially increase the yield. For this reason, the plant should be harvested before full maturity to produce forage (Björkman and Chase 2009; Kälber et al., 2014). Nevertheless, the optimal harvest time for buckwheat forage remains ill-defined. Because buckwheat is indeterminate in its growth habits and flowering patterns. It produces flowers continuously from four-week after sowing until the end of the cycle (Mariotti et al., 2015).

Buckwheat is potentially highly important in the future for the development of sustainable animal feeding systems since it reduces methane gas emissions without affecting the microbial product content in the rumen (Leiber et al., 2012). It also improves the fatty acid profiles in cow milk since it is rich in high phenolic and tocopherol concentrations and increases the product quality (Leiber 2016) through α-linoleic acid transfer from feed to milk leading to an improvement in cheese quality (Kälber et al., 2013). Other than that, it potentially prevents feed-food competition as well (Leiber 2016).

In ruminant nutrition, both the whole buckwheat plant and the fresh stover remaining in the field after the grain harvest might be potential feeds. Owing to its indeterminate flowering habit, buckwheat seeds mature over a long period (Campbell 1997). Therefore, scientific information on the optimal harvest time to achieve high-quality quantitative production in buckwheat plants is still very inadequate especially in terms of the fresh stover feed value. The leftovers of the buckwheat in the field after the grain harvest include in the flowers, the green seeds and the mature seeds as well as leaves and stems, unlike the commonly used cereal stover and their residues. At this stage, the plant remains green and, moreover, its hay (Lardy et al., 2022) and its straw have been reported as palatable (Acar et al., 2015; Lardy et al., 2022). In addition, compared to wheat and corn straw, buckwheat straw increases the dry matter consumption and daily live weight gain in ruminants (Acar et al., 2015). Therefore, buckwheat might be considered as a fresh stover in terms of nutritional value. In this study, it was aimed to determine the chemical constituents, energy values, *in vitro* true dry matter digestibility (IVTDMD), yields and relative feed values (RFV) of two buckwheat (*Fagopyrum esculentum* Moench) cultivars, Aktaş and Güneş, developed in Turkey. In this respect, buckwheat forage was obtained as a whole crop at the early dough (ED), soft-to-hard dough (SHD) harvest stages, and the fresh stover (S) stage after the grain harvest.

## MATERIALS AND METHODS

### Feed Material

The Aktaş and Güneş buckwheat (*Fagopyrum esculentum* Moench) cultivars were used as the plant materials. The experiment was designed in a randomized block design with three replications in the experimental area of Bahri Dağdaş International Agricultural Research Institute, Konya, Turkey. Seeds were sown at a depth of 4 to 5 cm in plots of 2.4 × 4 meters (9.6 $m^2$) on April 15, 2018. During sowing, 6 kg of seeds were used per decare. Also, 15 kg/da of diammonium phosphate were applied, and irrigation was carried out twice during the growing period.

Buckwheat plants were harvested at three stages: the ED stage, the SHD stage, and the S stage. The whole buckwheat plant was harvested 53 and 81 days after sowing, respectively, when the first grains formed on the plant were at the ED and SHD stages. Additionally, the remaining plant material in the field, known as fresh stover (S), was harvested 102 days after sowing, following the grain harvest.

The crop harvest was conducted at a cutting height of 10 cm using a sickle-bar mower. Prior to obtaining the fresh stover, grain harvesting was carried out with Hege 140 parcel harvester. The harvested forage was immediately weighed, and the yield of wet forage was recorded. Then the forage was dried for about 48 hours in an oven at 60 °C. The samples were weighed and dry forage yields were calculated.

**Chemical Analysis of Samples**

The samples were ground through a 1 mm screen in a Wiley mill and then used for the chemical analyses. Dry matter (DM), crude protein (CP) and ash analyses were carried out according to AOAC (1998). The contents of the neutral detergent fiber (NDF), acid detergent fiber (ADF) and acid detergent lignin (ADL) were determined according to Van Soest et al., (1991) using an Ankom 2000 Fiber Analyzer (Ankom Technology Corporation, Fairport, NY, USA). Sodium sulfite and α-amylase were used to determine the NDF contents. The neutral detergent insoluble nitrogen (NDIN) and acid detergent insoluble nitrogen (ADIN) contents of the samples obtained from the NDF and ADF analyses were carried out according to Licitra et al., (1996). Ether extract (EE) analysis was carried out using the Ankom XT15 Extraction System device according to AOCS (2005). The non-fiber carbohydrate concentrations (NFC) were calculated using equation 1, developed by Nocek (1986) and described by Van Soest et al., (1991).

$$NFC\% = 100\% - [CP\% + (NDF\% - NDICP\%) + EE\% + Ash\%] \quad (1)$$

The relative feed value (RFV) of forages was calculated according to the equation 2 described by Sanson and Kercher (1996).

$$RFV = (DDM\ \% \times DMI\ \%) / 1.29 \quad (2)$$

DDM % (Digestibility Dry Matter) = 88.9 - (0.779 × ADF %)

DMI % (Dry Matter Intake (as a % of Body Weight)) = 120 / NDF

**Prediction of Energy Values in Samples**

The total digestible nutrients (TDN%), digestible energy (DE), metabolizable energy (ME) and net energy lactation (NEL) values based on the dry matter contents were calculated according to 3, 4, 5, and 6 equations, reported by NRC (2001).

$$TDN(\%) = tdNFC + tdCP + (tdFA \times 2.25) + tdNDF - 7 \quad (3)$$

$$DE\ (Mkal/kg\ DM) = (0.04409 \times TDN) \quad (4)$$

ME (Mkal/kg DM) = (1.01 × DE) - 0.45 for feeds with less than 3 percent EE (5)

$$NEL\ (Mkal/kg\ DM) = (0.0245 \times TDN\%) - 0.12 \quad (6)$$

**Determination of *In Vitro* True Dry Matter Digestibility of Samples**

The Ankom DaisyII *in vitro* fermentation system (Ankom Technology Corp. Fairport, NY, USA) was used to determine the IVTDMD of the feed samples. Buffer solution and rumen fluid, which was collected from three healthy male Holstein cattle, (1.5 years old and 400-450 kg live body weight), slaughtered in a private slaughterhouse, were added to the digestion jars. At the end of the 48-hour incubation period at 39 ºC, the jars were removed from the chamber, the incubation solution was discarded and the bags were rinsed four times with distilled water. To determine the *in vitro* true digestibility, the bags were placed in an Ankom fiber (NDF) analyzer and boiled in a neutral detergent solution for 75 minutes. The bags were then removed, soaked twice in acetone for 5 minutes and dried at 100 °C for 24 hours. The final bag weight after NDF analysis was recorded as the final weight (W3), which was used for estimating the digestibility. The IVTDMD value was calculated using the following equation 7 described in Ankom Technology Method 3.

$$IVTDMD\ (\%) = 100 - [(W3 - (W1 \times C1))\ 3 \times 100)] / (W2 \times \%DM_{Feed}) \quad (7)$$

W1: the weight of the filter bag, W2: the weight of the sample, W3: the final weight (filter bag + sample), $DM_{Feed}$: the percentage of dry matter contained in the feed, and C1: the correction factor for a blank filter bag.

**Statistical Analyses**

For statistical analysis, the data, designed as a 2 x 3 factorial completely randomized block design, were analysed by using General Linear Models (GLM) procedure. The harvest stage was put into main plots and cultivars into subplots. Comparisons between the means were made using Duncan's Multiple Range test, supplied by the Statistical Analysis System (SAS, 1998).

## RESULTS

### Chemical Composition of Buckwheat Forage

The chemical compositions of the buckwheat cultivars harvested at three different phenological stages were presented in Table 1.

There was no significant difference between cultivars for DM contents (P>0.05). The DM content of buckwheat forages increased as the harvest period progressed (P<0.05).

The ash and organic matter (OM) contents of the cultivars studied were similar (P>0.05). The harvest stage had an effect on the ash and OM content, and the highest OM value was determined at the SHD stage, followed by the ED and S stages, respectively (P<0.05). The effects of the harvest stages on the cultivars were significant in terms of ash and OM (P<0.05), and the Aktaş cultivar exhibited the highest ash ratio (14.59%) and the lowest OM ratio (85.42%) at the S stage (P<0.05).

The CP contents of Aktaş and Güneş cultivars in the study were similar (P>0.05). As the harvest stage progressed, the CP content decreased (P<0.05) and was determined to be 13.21%, 12.55% and 8.90% at the ED, SHD and S stages, respectively. The CP content decreased with successive harvesting stages in both cultivars (Table 1).

This study revealed no statistically significant differences in the concentrations of EE and NFC among the cultivars (P>0.05). Similarly, differences were insignificant between the ED and SHD stages in terms of EE and NFC concentrations (P>0.05). However, the EE and NFC values were found to be lower at the S stage compared to the ED and SHD stages (P<0.05).

The NFC content did not change (P>0.05) during the maturation period from the ED stage to the SHD stage despite a significant decrease (P<0.05) at the S stage (Table 1).

### Fiber Composition of Buckwheat Forage

The results of the fiber composition of the buckwheat forages were presented in Table 2. The effect of the cultivar on the fiber composition of the buckwheat forages was insignificant (P>0.05), whereas the effect of the harvest stage was significant (P<0.05). Cell wall components did not change from the ED to the SHD stage whilst increasing at the S stage (P<0.05). The harvest stage had no significant effect on the cultivars in terms of cell wall components (P>0.05).

**Table 1.** Mean chemical analysis of triplicate* buckwheat forage (DM %)

| Cultivar | | DM | Ash | OM | CP | EE | NFC |
|---|---|---|---|---|---|---|---|
| Aktaş | | 39.47 | 12.44 | 87.56 | 11.40 | 1.51 | 40.03 |
| Güneş | | 40.21 | 12.23 | 87.77 | 11.70 | 1.54 | 40.18 |
| | *SE* | 0.623 | 0.221 | 0.221 | 0.162 | 0.050 | 0.875 |
| | *P* | 0.422 | 0.521 | 0.521 | 0.221 | 0.729 | 0.908 |
| Harvest stage | | | | | | | |
| ED | | 29.83$^{c}$ | 12.14$^{b}$ | 87.86$^{b}$ | 13.21$^{a}$ | 1.80$^{a}$ | 42.97$^{a}$ |
| SHD | | 36.58$^{b}$ | 11.15$^{c}$ | 88.85$^{a}$ | 12.55$^{b}$ | 1.83$^{a}$ | 42.79$^{a}$ |
| S | | 53.10$^{a}$ | 13.72$^{a}$ | 86.28$^{c}$ | 8.90$^{c}$ | 0.94$^{b}$ | 34.56$^{b}$ |
| | *SE* | 0.764 | 0.270 | 0.270 | 0.199 | 0.062 | 1.072 |
| | *P* | 0.0001 | 0.0002 | 0.0002 | 0.0001 | 0.0001 | 0.0003 |
| Cultivar × Harvest stage | | | | | | | |
| Aktaş | ED | 29.73 | 11.80$^{bcd}$ | 88.20$^{abc}$ | 12.88 | 1.75 | 43.93 |
| | SHD | 36.71 | 10.93$^{d}$ | 89.07$^{a}$ | 12.47 | 1.90 | 42.79 |
| | S | 51.97 | 14.59$^{a}$ | 85.42$^{d}$ | 8.85 | 0.89 | 33.38 |
| Güneş | ED | 29.93 | 12.49$^{bc}$ | 87.51$^{bc}$ | 13.53 | 1.85 | 42.00 |
| | SHD | 36.46 | 11.36$^{cd}$ | 88.64$^{ab}$ | 12.63 | 1.77 | 42.79 |
| | S | 54.24 | 12.85$^{b}$ | 87.15$^{c}$ | 8.94 | 0.99 | 35.74 |
| | *SE* | 1.080 | 0.382 | 0.382 | 0.281 | 0.087 | 1.516 |
| | *P* | 0.487 | 0.019 | 0.019 | 0.571 | 0.321 | 0.400 |

* Triplicate samples were sub-samples on which the analyses were performed; DM: Dry matter; OM: Organic matter; CP: Crude protein; EE: Ether extract; NFC: Non-fiber carbohydrate; SE: Standard error; ED: Early dough; SHD: Soft-to-hard dough; S: Fresh stover; a,b,c,d Values within the same column with different superscripts are significantly different (P<0.05)

**Table 2.** Mean fibre composition of triplicate* buckwheat forage (DM %)

| Cultivar | | NDF | ADF | ADL | HC | C |
|---|---|---|---|---|---|---|
| Aktaş | | 43.49 | 35.51 | 10.06 | 7.98 | 25.45 |
| Güneş | | 42.83 | 35.06 | 9.63 | 7.78 | 25.43 |
| | *SE* | 1.020 | 0.475 | 0.158 | 0.702 | 0.476 |
| | P | 0.659 | 0.520 | 0.087 | 0.838 | 0.973 |
| Harvest stage | | | | | | |
| ED | | 39.90[b] | 33.95[b] | 9.15[b] | 5.95[b] | 24.80[b] |
| SHD | | 39.91[b] | 32.77[b] | 9.65[b] | 7.14[b] | 23.13[b] |
| S | | 49.66[a] | 39.14[a] | 10.74[a] | 10.52[a] | 28.40[a] |
| | *SE* | 1.249 | 0.582 | 0.194 | 0.859 | 0.583 |
| | *P* | 0.0003 | 0.0001 | 0.0005 | 0.0098 | 0.0001 |
| Cultivar × Harvest stage | | | | | | |
| Aktaş | ED | 39.63 | 34.25 | 9.21 | 5.38 | 25.04 |
| | SHD | 40.57 | 33.01 | 9.97 | 7.55 | 23.05 |
| | S | 50.26 | 39.27 | 10.99 | 10.99 | 28.28 |
| Güneş | ED | 40.17 | 33.64 | 9.08 | 6.52 | 24.56 |
| | SHD | 39.26 | 32.53 | 9.32 | 6.73 | 23.21 |
| | S | 49.06 | 39.01 | 10.49 | 10.05 | 28.52 |
| | *SE* | 1.767 | 0.824 | 0.274 | 1.215 | 0.825 |
| | *P* | 0.846 | 0.978 | 0.627 | 0.643 | 0.891 |

* Triplicate samples were sub-samples on which the analyses were performed; DM: Dry matter; NDF: Neutral detergent fiber; ADF: Acid detergent fiber; ADL: Acid detergent lignin; HC: Hemicellulose; C: Cellulose; SE: Standard error; ED: Early dough; SHD: Soft-to-hard dough; S: Fresh stover; [a,b] Values within the same column with different superscripts are significantly different (P<0.05)

**Table 3.** Mean total digestible nutrients (DM%), energy values (Mcal/kg DM) and *in vitro* true dry matter digestibility (DM%) of triplicate* buckwheat forage

| Cultivar | | TDN | DE | ME | NEL | IVTDMD |
|---|---|---|---|---|---|---|
| Aktaş | | 52.29 | 2.31 | 1.88 | 1.16 | 62.52 |
| Güneş | | 53.16 | 2.34 | 1.92 | 1.18 | 63.18 |
| | *SE* | 0.501 | 0.022 | 0.022 | 0.012 | 0.430 |
| | *P* | 0.247 | 0.247 | 0.245 | 0.242 | 0.302 |
| Harvest stage | | | | | | |
| ED | | 53.94[a] | 2.38[a] | 1.95[a] | 1.20[a] | 71.54[a] |
| SHD | | 54.50[a] | 2.40[a] | 1.98[a] | 1.22[a] | 69.10[b] |
| S | | 49.73[b] | 2.19[b] | 1.76[b] | 1.10[b] | 47.92[c] |
| | *SE* | 0.614 | 0.027 | 0.027 | 0.015 | 0.526 |
| | *P* | 0.0005 | 0.0005 | 0.0005 | 0.0005 | 0.0001 |
| Cultivar × Harvest stage | | | | | | |
| Aktaş | ED | 54.27 | 2.39 | 1.97 | 1.21 | 71.07 |
| | SHD | 54.21 | 2.39 | 1.96 | 1.21 | 68.98 |
| | S | 48.40 | 2.13 | 1.71 | 1.07 | 47.53 |
| Güneş | ED | 53.62 | 2.36 | 1.94 | 1.19 | 72.01 |
| | SHD | 54.80 | 2.42 | 1.99 | 1.22 | 69.22 |
| | S | 51.07 | 2.25 | 1.82 | 1.13 | 48.32 |
| | SE | 0.868 | 0.038 | 0.039 | 0.021 | 0.744 |
| | *P* | 0.205 | 0.204 | 0.206 | 0.208 | 0.886 |

* Triplicate samples were sub-samples on which the analyses were performed; DM: Dry matter; TDN: Total digestible nutrients; DE: Digestible energy; ME: Metabolizable energy; NEL: Net energy lactation; IVTDMD: *In vitro* true dry matter digestibility; SE: Standard error; ED: Early dough; SHD: Soft-to-hard dough; S: Fresh stover; [a,b,c] Values within the same column with different superscripts are significantly different (P<0.05)

**Table 4.** Mean yields (kg/da) of buckwheat forage and relative feed values (%)

| Cultivar | | DM yield | CP yield | IVTDDM yield | RFV |
|---|---|---|---|---|---|
| Aktaş | | 458.63 | 55.53 | 306.73 | 147.0 |
| Güneş | | 479.02 | 59.42 | 321.51 | 148.7 |
| | *SE* | 23.764 | 2.879 | 17.149 | 4.672 |
| | *P* | 0.558 | 0.362 | 0.556 | 0.806 |
| Harvesting stage | | | | | |
| ED | | 530.88[b] | 70.10[b] | 379.96[b] | 162.6[a] |
| SHD | | 673.48[a] | 84.32[a] | 456.76[a] | 160.8[a] |
| S | | 202.13[c] | 18.01[c] | 96.66[c] | 120.2[b] |
| | *SE* | 29.105 | 3.526 | 21.003 | 5.722 |
| | *P* | 0.0001 | 0.0001 | 0.0001 | 0.0005 |
| Cultivar × Harvest stage | | | | | |
| Aktaş | ED | 527.46 | 68.01 | 374.79 | 164.0 |
| | SHD | 662.49 | 82.13 | 457.53 | 158.2 |
| | S | 185.95 | 16.45 | 87.88 | 118.8 |
| Güneş | ED | 534.29 | 72.19 | 385.12 | 161.1 |
| | SHD | 684.47 | 86.50 | 473.98 | 163.4 |
| | S | 218.30 | 19.56 | 105.42 | 121.5 |
| | *SE* | 41.160 | 4.987 | 29.702 | 8.093 |
| | *P* | 0.953 | 0.990 | 0.991 | 0.880 |

[*] Triplicate samples were sub-samples on which the analyses were performed; DM: Dry matter; CP: Crude protein; IVTDDM: *In vitro* true digestible dry matter; RFV: Relative feed value; SE: Standard error; ED: Early dough; SHD: Soft-to-hard dough; S: Fresh stover; [a,b,c] Values within the same column with different superscripts are significantly different (P<0.05)

### Total Digestible Nutrients, Energy Value, and *In Vitro* True Dry Matter Digestibility

The mean TDN, energy values and IVTDMD of the buckwheat forage were presented in Table 3. The effects of cultivar and cultivar×harvest stage interaction on the results were insignificant (P>0.05). Although the TDN values were close to each other at the ED and SHD stages, it was lower at the S stage compared to those at these stages (P<0.05). The cultivars exhibited similar energy values (P>0.05). Also, the energy values did not change during maturation from the ED to the SHD stage; however, it decreased at the S stage (P<0.05). The IVTDMD values of both Aktaş and Güneş cultivars did not differ significantly (P>0.05). The IVTDMD values decreased as the harvest period progressed (P<0.05).

### Yields of Buckwheat Forage and Relative Feed Values

The results of the mean yields of buckwheat forage and RFV were presented in Table 4. The effects of cultivar and cultivar×harvest stage interaction on the mentioned parameters were insignificant (P>0.05), whereas the effect of the harvest stage was significant (P<0.05). The highest buckwheat forage yield values were determined at the SHD stage (P<0.05). The RFV were close to each other at the ED and SHD harvest stages, but lower at the S stage (P<0.05).

## DISCUSSION

### Chemical Composition of Buckwheat Forage

The increase in cell-wall contents is due to maturation in plants but the decrease in cell growth and proliferation leads to an increase in DM levels (Nelson and Moser 1994; Taiz and Zeiger 2008). In this study, the DM content of buckwheat forages was 29.83% at the ED stage and increased to 36.58% at the SHD stage as the harvest period progressed and to 53.10% at the S stage (Table 1). The optimal harvest time for buckwheat forage is not well-defined; although some studies have indicated that the flowering period was the optimal harvesting time (Kälber et al., 2012), the previous researches have contradicted over the best harvest times. The DM value obtained at the ED stage in the study was higher than those reported by Amelchanka et al., (2010), Mariotti et al., (2015), Er and Keles (2021), Omokanye et al., (2021) for the same harvest stage. The DM value at the SHD stage was in agreement with the values reported by Mariotti et al., (2015), Dias and Oliveira (2017), and Yavuz and Kara (2018). The DM value obtained at the S stage was lower than those reported by Acar et al., (2015) and

Mu et al., (2019) for buckwheat straw and by Mariotti et al., (2015) for buckwheat hay. Compared to that of hay, fresh forage results in a substantial decrease in DM (Mariotti et al., 2015). These differences in DM content can be associated with factors such as soil, fertilization, cultivar, climate and diseases having effects on both plant growth and composition. Even if the forages are harvested over the same maturation period, environmental factors might change the DM content (Van Soest 1994).

Ash, representing the inorganic matter or total mineral content of feed material, is mostly found in the leaves of the plant. Minerals dissolved in water and transported from the roots to the leaves gather in leaves by the transpiration of water. The ash level also increases as the amount of mineral contents in the leaf increase (Kacar and Katkat 2010). As the harvest period progresses, the ash level decreases in line with the decrease in the leaf/stem ratio. In this study approximately 8.15% change was determined in the ash content during the maturation of the buckwheat forage from the ED to the SHD stage (Table 1). The decrease in ash content observed at the SHD stage was consistent with the findings of Kara (2014) and Yavuz and Kara (2018), who studied on Güneş cultivar harvested at different stages of maturity. The ash value at the ED stage in the study was comparable to those reported by Amelchanka et al., (2010), Mariotti et al., (2015), and Er and Keles (2021) for the same period, but it exceeded the value reported by Leiber et al., (2012). The ash ratio determined at the S stage was similar to that reported by Mu et al., (2019) for the buckwheat straw and higher than that reported by Mariotti et al., (2015) for buckwheat hay. The high ash content at the S stage can be associated with the presence of large and wide leaves on the plant during this period.

The CP contents determined for the Aktaş and Güneş cultivars (11.40% and 11.70%, respectively) were lower than those reported by Mariotti et al., (2015) for Leija and Bamby cultivars because one of the many factors affecting the nutrient content is the plant cultivar (Bárta et al., 2004). Nitrogen accumulation in plants is the fastest in the early vegetation period. It decreases as the vegetation period progresses, and this decrease continues over the maturation period (Girma et al., 2010). In this study, the CP content at the ED stage was lower than those reported by Mariotti et al., (2015), Görgen et al., (2016), and Dias and Oliveira (2017) for the same stage. The nutritive value of forage is considerably influenced by the plant environment. However, the CP value determined at the SHD stage was similar to those reported by Amelchanka et al., (2010), Dias and Oliveira (2017), Herremans et al., (2018), and Omokanye et al., (2021) for the same stage.

Harvest time is an effective factor in the CP content of forages, and the CP content of several forages has been reported to decrease by 1 g/kg per day as the harvest period progresses (Minson, 1990). The decrease in CP concentration with advancing maturation is associated with both reduced CP in leaves and stems, and the fact that stems, which have lower CP concentrations, constitute a larger portion of the plant in more mature forages. Leaves generally have twice as much CP as stems (Buxton, 1996). In fact, among different morphological parts of the buckwheat plant such as flowers, leaves, stems, and grains, Leiber et al., (2012) reported that the highest protein concentration was in leaves. In this study, extending the harvest time from the ED to the SHD stage by 28 days resulted in a 5% decrease in the CP content of the forage (Table 1). This decrease in CP content due to the extended harvest period was consistent with previous studies (Mariotti et al., 2015; Görgen et al., 2016; Dias and Oliveira 2017; Sürmen and Kara 2017; Herremans et al., 2018; Güllap et al., 2021). In this study, at the S stage, the CP value of buckwheat forage was consistent with the values reported by NRC (2001) for wheat, sorghum, and oat hay, as well as with those reported by Mariotti et al., (2015) for buckwheat hay. The fact that buckwheat fresh stover contains flowers, green seeds, and mature seeds, leads to a higher CP content than those of commonly used cereal stover. This is attributed to wide leaves and thin-stem structure of buckwheat throughout its growing period (Güllap et al., 2021). The CP value in this study, determined at the S stage, was higher than those reported by Acar et al., (2015) and Mu et al., (2019) for buckwheat straw and by Mariotti et al., (2015) for buckwheat hay. Considering that the CP requirement in diets is 70 g/kg (NRC 1984) for mature beef cows, fresh stover of the buckwheat plant may be regarded as a sustainable feed ingredient.

The EE content of buckwheat forage, as the average of the two cultivars and three harvesting stages, was in the range from 0.2 to 1.8%, as reported by Heuzé et al., (2019). In this study, the EE contents were 1.80% and 1.83%, respectively, at the ED and SHD stages where the leaf/stem ratio was high, and it decreased to 0.94% at the S stage, where the stem ratio was high (Table 1). In general, the total content of EE in plants decreases with growth, and the leaves of the plants contain higher levels of EE than their stems (Koutsoukis et al., 2016). Previous studies also reported that the lowest EE concentration was found in the stems (Leiber et al., 2012; Vojtíšková et al., 2014). The EE content at the S stage was in a range from 0.7 to 1.7% as reported by Heuzé et al., (2019) for the EE content of the buckwheat straw, but lower than those reported by Mariotti et al., (2015), and Er and Keles (2021) for buckwheat hay.

The maturity of the plants at the time of harvest is one of the main factors reducing the nutritional value of forages; however, some studies reported conflicting results on the changes in the NFC content. Martin et al., (2004) stated that the NFC value decreased as alfalfa matured; however, MacAdam (2020) reported that it remained stable from the vegetative to the early bloom stage in alfalfa. Mariotti et al., (2015) found an increase in the NFC content in buckwheat's fresh forage and its hay as the harvest period progressed. Conversely, in this study, the NFC content did not change ($P>0.05$) during the maturation period from the ED stage to the SHD stage despite a significant decrease ($P<0.05$) at the S stage (Table 1). This decrease may be explained by either the harvesting of starch-rich achenes or by the significant decrease in inflorescences. The NFC content at the S stage was similar to that of Er and Keles (2021) for buckwheat hay.

**Fiber Composition of Buckwheat Forage**

The fiber composition of the buckwheat forages at the ED and SHD stages was slightly less than those for the forages in other studies (Amelchanka et al., 2010; Kälber et al., 2011, 2012, and 2014; Leiber et al., 2012; Görgen et al., 2016; Omokanye et al., 2021). Since the plant environment, agronomic factors, and geographical location affect the quality of the forage (Buxton 1996), the results differs considerably across the studies. In this study, the NDF, ADF, and ADL contents of buckwheat forage at the ED and SHD stages were consistent with the values reported by Er and Keles (2021) for fresh forage grown under similar environmental conditions. The nutritive value of forages decreases with increasing plant maturity due to the accumulation of structural carbohydrates (NDF) and to the decreasing leaf-to-stem ratio (Villalba et al., 2021). However, in this study, the fiber concentration of buckwheat forage did not change due to the simultaneous flowering, green and mature grains on the plants during the 28-day period between the ED and SHD stages (Table 2). Mariotti et al., (2015) reported that the concentration of NDF, ADF, and cellulose in buckwheat forage decreased depending on the progress of harvest period. However, some studies reported that NDF and ADF concentrations increased depending on the maturity of the plant (Sürmen and Kara 2017; Herremans et al., 2018; Güllap et al., 2021). In this study, the fiber contents increased significantly at the S stage as a result of the decrease in the leaf/stem ratio because stems contain higher levels of hemicellulose, cellulose and lignin compared to leaves (Lyons et al., 1999) and the thickness of the cell walls and the fiber content increase as plant cells mature. The NDF and ADF contents in buckwheat forage at the S stage were lower than those reported by Acar et al., (2015) and Mu et al., (2019) for buckwheat straw.

As an estimation of the cell wall concentration, NDF is negatively related to the intake potential of forages, and ADF is associated with the digestibility of the forage inversely (Buxton, 1996). In this respect, buckwheat forage with a 49.66% NDF and a 39.14% ADF content at the S stage is comparable to a mid-maturity/mature grass hay (NRC 2001) and the forage quality is much higher than straw.

**Total Digestible Nutrients, Energy Value, and *In Vitro* True Dry Matter Digestibility**

The TDN values, the indicators of forage quality and represent the usable energy content of feedstuffs, were found to be 52.29% and 53.16% for Aktaş and Güneş cultivars, respectively, which were similar to those reported by Fekadu et al., (2018) for the alfalfa cultivar. The TDN values determined at the ED and SHD stages in this study were lower than those reported by Omokanye et al., (2021) and by Billman et al., (2022), but similar to those reported by Mariotti et al., (2015), Er and Keles (2021) and Zhou et al., (2022) for fresh buckwheat forage. The TDN values decreased at the S stage as a result of the increase in the ADF and ADL contents, and of the decrease in the NFC content of the plant ($P<0.05$). Previous studies reported that the TDN values were associated with the ADF, ADL (Lithourgidis et al., 2006) and NFC (Mariotti et al., 2015) contents of the plant. The TDN value determined at the S stage in this study was similar to that reported by Mariotti et al., (2015) for buckwheat hay.

The ME values determined at the ED and SHD stages were found to exceed those reported by Er and

Keles (2021) for fresh buckwheat forage, while remaining below the values reported by Yavuz and Kara (2018). The NEL values for the same stages were consisted with values reported by Omokanye et al., (2021) and slightly lower than those reported by Billman et al., (2021). The lower energy values (2 Mcal/kg ME) of the buckwheat forage may be associated with higher ash content than leguminous feeds (NRC 2001). The decline in energy values observed at the S stage could be attributed to the starch-rich achenes being harvested as a primary source of energy, as well as the concurrent rise in ash content (Table 3). However, even at this stage, buckwheat forage contained higher levels of energy compared to commonly used cereal straw and stover. The ME values at the S stage were found to be higher than those reported by Acar et al., (2015) for buckwheat straw.

The decrease in the IVTDMD values was consistent with the findings of Billman et al., (2022) who worked with buckwheat forage harvested at different stages of maturity. In this study, the highest IVTDMD value was determined to be 71.54% at the ED stage and was found to be similar to that reported by Billman et al., (2022) at the same stage. Since the cell wall concentration of the plant did not change from the ED stage to the SHD stage, the IVTDMD value decreased by only 3%. According to Buxton (1996), the cell wall concentration of the plant has a substantial effect on forage digestibility. The lowest IVTDMD value was determined to be 47.92% at the S stage where the cell wall concentration was the highest in the plant, and this value was close to the IVTDMD values reported by Çelik and Selçuk (2019) for vetch and alfalfa hay. The high NDF content of the plant at the S stage led to a decrease in the IVTDMD value.

### Yields of Buckwheat Forage and Relative Feed Values

Forage yields obtained in this study were higher than those reported by Kälber et al., (2012) in Switzerland (4.4 t/ha), by Mariotti et al., (2015) in Italy (4 t/ha) and by Billman et al., (2022) in the United States (6 t/ha). The DM yield of 530.88 kg/da determined at the ED period of this study was similar to the DM yield of 551 to 590 kg/da reported by Keleş et al., (2012) for buckwheat harvested at the milk stage whereas the DM yield of 673.48 kg/da at the SHD stage was close to the DM yield of 711.6 to 756.7 kg/da reported by Kara (2014) for the end of the flowering stage. El Bassam (2010) reported that the DM yield of buckwheat was 5.5 t/ha under common cultivation practices; however, it can reach up to 8.5 t/ha. Accordingly, it can be argued that the harvest time, environmental conditions and cultivation techniques affect the forage yield. The present study found that the DM accumulation continued from the ED stage to the SHD stage, and this result was in accordance with findings of Dias and Oliveira (2017), Billman et al., (2021), and Güllap et al., (2021) who reported that the total biomass yields increased depending on the progress of the harvest period. The increase in the DM yield during maturation resulted in higher CP and IVTDMD yield values, but the CP and IVTDMD rates decreased at the SHD stage. The CP yield values at the ED and SHD stages were similar to those reported by Sürmen and Kara (2017), and higher than those reported by Alkay and Kökten (2020), and Erol et al., (2022). The variability in yield values can be explained by the differences in DM yields across different ecologies. In this study, the DM yield at the S stage was 202.13 kg/da, the CP yield was 18.01 kg/da and the IVTDMD yield was 96.66 kg/da (Table 5). The grain yield under common cultivation practices, ranges from 1 to 2 t/ha, and can even approximate to 3 to 4 t/ha (El Bassam 2010). Therefore, the main reason for the decrease in the yield values at the S stage is the removal of the grain.

A RFV greater than 100 indicates a higher nutritive potential of the forage crop and is widely used as an index to assess roughage quality. In this study, the RFV at the ED and SHD stages were 162.6 and 160.8, respectively, indicating that the forages met the prime quality standards (Table 4). Consisting with the results of this study, the previous studies have also identified the plant's prime quality based on the RFV at different harvest periods (Mariotti al. 2015; Yavuz and Kara 2018; Zhou et al., 2022). However, other studies have reported lower quality standards (Alkay and Kökten 2020; Omokanye et al., 2021). With an RFV of 120.2 at the S stage, the plant conformed to the second quality standard. This value was higher than that reported by Mariotti et al., (2015) for buckwheat hay. The high forage quality in this study can be attributed to freshness of the plant at this stage.

## CONCLUSION

In this study, it was aimed to assess the nutritional characteristics and yield of buckwheat forage in relation to the growth stage of the plants and the cultivars used. The results revealed no significant differences between the Aktaş and Güneş cultivars. Harvest timing was found to be significant for both forage yield and forage quality. The findings of the study indicated that harvesting buckwheat at the SHD stage significantly increased the forage yield compared to the ED stage. The highest CP and IVTDMD rates were obtained at the ED stage in the two buckwheat cultivars; however, protein yields and digestibility were at the highest at the SHD stage. Therefore, the results suggest that the both buckwheat cultivars, Aktaş and Güneş, should be harvested at the SHD stage. Furthermore, the results showed that the feed value of fresh stover, left in the field after the grain harvest, was higher than the commonly used cereal straws and plant residues. This can be attributed to the uncertain growth and flowering period of the plant, which started producing flowers three weeks after planting and continued to produce flowers continuously while remaining green until the end of the cycle. Based on these findings, this study concludes that fresh stover can serve as an alternative roughage for ruminant nutrition, taking into food resources between humans and farm animals consideration.

In conclusion, buckwheat roughage showed satisfactory nutritional properties compared to some other roughages used in animal nutrition. Buckwheat's resilience to challenging climatic conditions, short vegetation period and rapid growth make it a potential sustainable forage source for the ruminants. However, further animal trials are required to determine the effect of buckwheat plants on yield and product quality for ruminants.

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