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The effect of different harvest stages on yield and quality of Triticale grown under rainfed conditions

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ABSTRACT

Triticale (× *Triticosecale* Wittmack) is recognized for its tolerance to abiotic stress and adaptation to suboptimal soils, demonstrating significant potential for fodder production in dry environments. The harvest stage is essential for preserving the nutritional content of triticale, ensuring higher fodder yields, and effective implementation of crop rotation. However, the optimum harvest stage is unknown for triticale in the Muş province of Türkiye under rainfed conditions. This two-year study investigated the impact of the harvest stage on hay yield and quality of the triticale genotype. The experiment consisted of two factors, i.e., 18 triticale genotypes and three harvest stages (i.e., flowering, milking, and dough). Data relating to dry matter yield and quality attributes, i.e., crude protein ratio, neutral and acid detergent fiber, digestible dry matter, and relative feed value, were collected. Results showed significant variations in yield and quality across harvest stages and genotypes. Delaying harvest increased dry matter yield from 7.11 t/ha (flowering) to 12.00 t/ha (dough) but reduced crude protein and digestibility. Genotypes such as 'Presto' and 'BC Goran' achieved the highest dry matter yields, while 'Esin' and 'Line 1' excelled in quality metrics like crude protein ratio and relative feed value (RFV). The milking stage emerged as the optimal balance between yield and quality, particularly for forage quality indicators like digestibility and protein content. It is concluded that harvesting at the milking stage is optimal for triticale in the Muş province and similar continental climates, with 'Presto' and 'Esin' genotypes being the most suitable for producing high-quality hay. These findings address critical knowledge gaps in regional forage crop management and provide actionable insights for improving livestock feed sustainability in resource-limited environments.

1. Introduction

Triticale (× *Triticosecale* Wittmack) has been developed by crossbreeding wheat (*Triticum* sp.) and rye (*Secale cereale* L.), which is resistant to drought and pests, has good environmental adaptation and requires fewer inputs (Pozo et al., 2023; Yang et al., 2022). It is a versatile crop that permits grazing throughout vegetative growth and is later harvested for grain production. It may also be cut for silage production. Triticale grains provide an alternative source of animal feed and shows promising growth potential in the human food industry (Mirza and Çopur Doğrusöz, 2023; Santana et al., 2019). Triticale exhibits higher feed yields, more nutritional value, favorable amino acid balance, and enhanced resilience to abiotic stressors such as drought and frost compared to wheat (Liebert et al., 2023; Wang et al., 2024). It has advantageous characteristics, such as the ability to adapt to low-quality soils and exhibit enhanced tolerance to pathogens and soil acidity (Yang et al., 2022). Triticale is a hybrid cereal that combines the quality parameters of wheat and the tolerance characteristics of rye to stress conditions, showing great potential as an alternative roughage crop (Mergoum et al., 2019). Compared with other cereals, triticale is a high-yielding cereal that can be grown on low-fertility soils (De Zutter et al., 2023). Triticale produces a greater amount of green feed compared to oats, wheat, and barley, particularly in arid environments (Ciha, 1983; De Zutter et al., 2023). Therefore, triticale is considered an alternative plant that can be grown under stressful environmental conditions (Yang et al., 2022).

Harvesting stages of cereal crops used as roughage are important for hay yield and quality (Jang et al., 2022). While hay yield increases with delayed harvesting, the decrease in crude protein and digestibility rates accelerates with maturation. Therefore, it is recommended that the harvesting should be done until the milking stage (Aziza et al., 2013; Lyu et al., 2018; Ross et al., 2004; Schwarte et al., 2005). Delaying the harvest is a prevalent technique in Türkiye to enhance hay production. Nevertheless, this did not help farmers to produce superior quality hay from the given area. The delayed harvesting results in a lower total crude protein output from the unit area. Several investigations have shown that there is inherent degradation in quality as the harvest period advances (Pozo et al., 2023).

The Muş province has an important animal husbandry potential in Türkiye. Animal husbandry in the province is based on rangelands, which constitute 46% of the total land area (371,635 ha). It was reported that the rangelands in Muş are being degenerated, and their productivity is very low (Kökten and Tanrıverdi, 2020). The roughage needs are generally met by silage maize and alfalfa. Therefore, it is necessary to increase the production of forage crops to reduce the pressure on pastures. Given the limited water availability resulting from global

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climate change and warming, drought-resistant plants may serve as a viable substitute for alfalfa, a prevalent forage crop in the region. Their primary advantage is their capacity to guarantee water safety (Santana et al., 2019). Triticale is distinguished by several beneficial traits, including early harvest, winter planting ability, adaptability to dry environments, and resilience to abiotic stresses (Santana et al., 2019). Furthermore, apart from the adverse growth conditions that prevent optimum yield and quality in plant development, the use of proper growing methods is also crucial. An essential aspect of cultivation is the identification of the optimum harvest stage. Delaying the harvest stage has a detrimental impact on the digestibility of the plant, particularly on quality parameters (Coblentz and Ottman, 2022).

An inherent limitation is the lack of research on the hay production and optimum harvest stage of triticale in the specific conditions of Muş. The objective of this study was to determine the impact of the harvest stage on the yield and quality of different triticale genotypes.

2. Material and Methods

This two-year study was conducted during 2019-2020 and 2020-2021 at the experimental area of Muş Alparslan University (38° 46' N latitude, 41° 25' E longitude, and 1.350 m above sea level). The triticale genotypes used in the study have been given in Table 1.

The physical and chemical properties of the soil samples taken from 0-30 cm depth were determined. The soil was clayey, with 7.9 pH, 1.74% organic matter, 8.9% lime, 32.1 kg ha^{-1} available phosphorus, 7620 kg ha^{-1} potassium, and 0.3% salt.

The study was carried out using a split-plot design with three replications. The main plots consisted of 18 triticale genotypes, whereas harvest stages (i.e., flowering, milking, and dough) were organized in subplots. The genotypes were sown in six-row plots with a length of 5 m, a seeding rate of 200 kg ha^{-1} (500 plants m^{-2}), and 20 cm interrow spacing (Kir et al., 2023). The seeds were sown on November 6th during 2019 and November 12th during 2020. The crop was manually harvested, and one row from the edges and 50 cm from each edge of the plots were left as edge effects. The harvest area was 0.8 m × 4 m (3.2 m^2). The harvested plants were weighed on a precision scale to determine green forage yield. Afterward, the forage yield was converted to kg ha^{-1} by the unitary method. Approximately 500 g of fresh forage samples were first dried in the shade and then in an oven at 60 °C until constant weight. The dried samples were ground through a sieve (1 mm) and prepared for chemical analysis. The prepared samples were kept at 105 °C oven for 4 hours, and the dry matter ratios were calculated. The hay yields were then converted into dry matter yields per hectare. The dry matter yield was determined by multiplying the dry matter rate by the dry hay yield.

The crude protein (CP) content, acid detergent fiber (ADF) content, and neutral detergent fiber (NDF) content were determined by using Near Infrared Reflectance Spectroscopy (NIRS, Foss6500) using IC-0904FE software program coded IC-0904FE using the DDMR and DMC, which were calculated as follows:

Digestible Dry Matter Ratio (DDMR) = 88.9-(0.779× ADF %)

Dry Matter Consumption (DMC) = 120/(NDF%)

Relative Feed Value (RFV) was calculated as below.

RFV = (DDMR* DMC)/1.29

The collected data were analyzed using the MSTAT-C statistical software by two-way Analysis of Variance (ANOVA) and the differences among treatment means were compared by Duncan's multiple range test at 95% probability. The differences between the years were tested first, which were non-significant. Therefore, data from both years were pooled for analysis.

3. Results

The individual and interactive effects of genotypes and harvest stage significantly affected all measured traits during the study (Tables 2-10). Plant height increased with the delay in harvesting and the highest and the lowest plant height was recorded for dough and flowering stages, respectively. Similarly, the highest and the lowest plant height was noted for the genotypes 'Presto' and 'BC Goran', respectively. Regarding interactive effect, genotype 'Presto' harvested at milking and dough stages produced longer plants, whereas 'BC Goran' harvested at the flowering stage had the shortest plant height (Table 2).

Dry matter yield was significantly influenced by the stage of harvest. It increased from 7.11 t/ha during the flowering phase to 12.00 t/ha at the dough stage. Interaction between genotype and harvest time indicated that 'BC Goran' and 'Presto' genotypes harvested at dough stages produced the highest dry matter yield. The genotype 'Mehmet Bey' initially had poor dry matter yield, which was improved with the delay in Table 3.

CP decreased with the delay in harvesting; however, 'BC Goran' and 'Presto' genotypes consistently produced higher yields across all harvest stages, suggesting that they were able to hold onto their protein for longer. Most of the genotypes had the highest CP contents at the milking and dough stages (Table 4).

ADF content improved from the flowering to the dough stage, with 'Özer' and 'Alper Bey' genotypes having higher fiber levels with delayed harvesting. Genotypes exhibited varying tendencies in fiber growth, with some reaching their peak early while others accumulated more gradually (Table 5).

Table 1.
Triticale genotypes used in the study, where they were obtained.

No	Genotypes	Supplying institute
1	Mehmet Bey	East Mediterranean Transitional Zone Agricultural Res. Inst
2	Özer	Bahri Dagdas International Agricultural Res. Inst.
3	Esin	GAP International Agricultural Research and Training Center
4	Tatlıcak 97	Bahri Dagdas International Agricultural Res. Inst.
5	Ayşe Hanım	East Mediterranean Transitional Zone Agricultural Res. Inst
6	Ümran Hanım	East Mediterranean Transitional Zone Agricultural Res. Inst
7	Alper Bey	Bahri Dagdas International Agricultural Res. Inst.
8	Mikham 2002	Bahri Dagdas International Agricultural Res. Inst.
9	Karma	Transitional Zone Agricultural Research Institute
10	Line 1	Dicle University Faculty of Agriculture
11	Line 2	Dicle University Faculty of Agriculture
12	Line 3	Dicle University Faculty of Agriculture
13	Line 4	Dicle University Faculty of Agriculture
14	Melih Bey	Olgunlar Tour. Agric. Energy Produc. Trade. Mark. Lim. Comp.
15	BC Goran	BC Institute Agric. Produc. Auto Industry and Trade Lim. Comp.
16	Bera	Yonca Agric. Produc. Engin. and Exp. Mat. Trade Lim. Comp
17	Line 5	GAP International Agricultural Research and Training Center
18	Presto	Eskişehir Anadolu Agricultural Res. Inst.

Table 2.
Plant height (cm) of triticale genotypes harvested at different growth stages.

Genotypes	Harvest stage			
	Flowering	Milking	Dough	Means (G)
Mehmet Bey	75.30 uvw	82.02 m-p	85.82 d-l	81.04 de
Özer	82.92 l-o	86.24 d-j	87.83 b-f	85.66 abc
Esin	75.33 uvw	82.18 mno	84.80 g-m	80.77 de
Tatlıcak 97	82.27 mno	85.30 e-l	88.23 b-e	85.27 abc
Ayşe Hanım	75.45 t-w	78.25 rst	81.66 n-q	78.45 ef
Ümran Hanım	82.95 k-o	84.48 h-n	87.58 b-g	85.00 abc
Alper Bey	79.10 qrs	84.18 ı-n	87.85 b-f	83.71 cd
Mikham 2002	85.70 d-l	87.27 c-h	90.45 ab	87.80 ab
Karma	83.76 j-n	86.13 d-j	88.02 b-e	85.97 abc
Line 1	77.97 r-u	85.33 e-l	89.54 abc	84.28 bcd
Line 2	80.40 o-r	82.25 mno	89.20 abc	83.95 bcd
Line 3	80.46 o-r	85.90 d-k	90.51 ab	85.62 abc
Line 4	77.98 r-u	84.45 h-n	87.95 b-e	83.46 cd
Melih Bey	76.92 s-v	83.57 j-n	86.27 d-j	82.25 cd
BC Goran	73.02 w	77.04 stu	82.27 mno	77.44 ef
Bera	80.47 o-r	86.79 c-i	88.59 a-d	85.28 abc
Line 5	74.17 vw	76.72 s-v	79.35 p-s	76.75 f
Presto	84.90 f-m	91.12 a	90.50 ab	88.84 a
Means (H)	79.39 c	83.84 b	87.02 a	

Means followed by the same letters in the same column are similar P>0.05.
G = genotypes, H = harvest stages

Table 3.
Dry matter yields (t/ha) of triticale genotypes depending on the harvest stage in two years.

Genotypes	Harvest stage			
	Flowering	Milking	Dough	Means (G)
Mehmet Bey	6.87 uvw	8.13 op	11.53 efg	8.85 efg
Özer	7.97 o-s	9.34 kl	11.30 gh	9.53 cd
Esin	6.64 vwx	7.93 o-t	11.29 gh	8.62 fg
Tatlıcak 97	7.58 p-u	8.63 l-o	12.07 def	9.43 cde
Ayşe Hanım	6.49 wx	9.41 k	12.79 cd	9.56 cd
Ümran Hanım	7.27 r-w	8.37 nop	10.68 hi	8.77 fg
Alper Bey	7.34 q-v	10.31 ij	12.30 d	9.98 bc
Mikham 2002	7.94 o-s	9.22 klm	12.79 cd	9.99 bc
Karma	7.15 t-w	10.25 ij	13.25 c	10.22 b
Line 1	7.09 vw	10.32 ij	12.44 d	9.95 bc
Line 2	6.08 xy	7.20 s-w	9.75 jk	7.68 i
Line 3	7.20 s-w	9.06 k-n	11.32 gh	9.19 def
Line 4	7.61 p-u	9.24 klm	12.15 de	9.67 bcd
Melih Bey	6.09 xy	8.58 mno	11.38 fgh	8.68 fg
BC Goran	8.25 op	11.44 efg	15.94 a	11.88 a
Bera	5.72 y	7.96 o-s	9.76 jk	7.81 hi
Line 5	6.66 vwx	8.12 opq	10.31 ij	8.36 gh
Presto	8.03 o-r	12.32 d	14.91 b	11.75 a
Means (H)	7.11 c	9.21 b	12.00 a	

Means followed by the same letters in the same column are similar P>0.05.
G = genotypes, H = harvest stages

Table 4.
Crude protein yield (t/ha) obtained from triticale genotypes examined in this study at different harvest stages.

Genotypes	Harvest stage			
	Flowering	Milking	Dough	Means (G)
Mehmet Bey	1.15 k-s	1.12 m-t	1.24 g-p	1.17 fgh
Özer	1.20 h-q	1.33 d-l	1.21 h-q	1.25 def
Esin	1.12 n-t	1.15 k-s	1.31 e-n	1.19 fgh
Tatlıcak 97	1.16 k-s	1.23 g-q	1.40 c-g	1.27 c-f
Ayşe Hanım	1.01 r-u	1.27 g-n	1.39 c-h	1.23 efg
Ümran Hanım	0.99 stu	1.19 j-r	1.15 k-s	1.11 gh
Alper Bey	1.05 q-u	1.44 c-f	1.31 e-m	1.27 c-f
Mikham 2002	1.32 d-l	1.38 c-i	1.40 c-g	1.37 cd
Karma	1.12 m-t	1.50 cd	1.49 cde	1.37 cd
Line 1	1.18 j-r	1.52 c	1.44 c-f	1.38 d
Line 2	0.91 u	1.06 p-u	1.24 g-p	1.07 h
Line 3	1.08 o-u	1.13 m-s	1.26 f-o	1.16 fgh
Line 4	1.22 g-q	1.33 d-k	1.46 cde	1.34 cde
Melih Bey	0.93 u	1.14 l-s	1.36 c-j	1.14 fgh
BC Goran	1.36 c-j	1.71 b	1.91 a	1.66 a
Bera	0.94 tu	1.15 k-s	1.19 i-r	1.10 gh
Line 5	1.08 o-u	1.18 j-s	1.23 g-q	1.16 fgh
Presto	1.16 k-s	1.71 b	1.68 b	1.52 b
Means (H)	1.11 c	1.31 b	1.37 a	

Means followed by the same letters in the same column are similar P>0.05.
G = genotypes, H = harvest stages

Table 5.
The acid detergent fiber contents (%) of the triticale genotypes at different harvest stages (%).

Genotypes	Harvest stage			
	Flowering	Milking	Dough	Means (G)
Mehmet Bey	30.37 nop	30.54 nop[2]	32.82 d-l	31.24 g
Özer	34.27 cde	31.11 j-o	36.49 ab	33.95 a
Esin	28.77 p	31.65 g-o	34.19 c-f	31.53 fg
Tatlıcak 97	32.03 g-n	31.44 h-o	33.53 c-g	32.33 b-f
Ayşe Hanım	31.12 j-o	31.63 g-o	34.77 bcd	32.51 b-e
Ümran Hanım	34.07c-f	31.32 h-o	33.19 d-i	32.86 bc
Alper Bey	31.64 g-o	30.42 nop	37.24 a	33.10 b
Mikham 2002	30.49 nop	32.05 g-n	32.21 f-n	31.58 efg
Karma	31.40 h-o	30.41 nop	33.59 c-g	31.80 d-g
Line 1	30.77 l-p	30.32 nop	33.27 c-i	31.45 fg
Line 2	32.70 e-m	30.46 nop	34.74 b-e	32.63 bcd
Line 3	31.97 g-n	31.94 g-n	35.23 bc	33.04 b
Line 4	30.87 k-o	32.05 g-o	34.09 c-f	32.34 b-f
Melih Bey	30.74 m-p	32.15 f-n	32.91 d-k	31.93 c-g
BC Goran	30.14 nop	33.24 c-i	34.47 cde	32.61 bcd
Bera	29.74 op	31.09 j-o	32.80 d-l	31.21 g
Line 5	30.67 m-p	31.33 i-o	33.35 c-h	31.78 d-g
Presto	33.03 d-j	30.86 k-o	33.62 c-g	32.50 b-e
Means (H)	31.38 b	31.33 b	34.03 a	32.24

Means followed by the same letters in the same column are similar P>0.05.
G = genotypes, H = harvest stages

Table 6.
The neutral detergent fiber ratios (%) of triticale genotypes in different harvest stages.

Genotypes	Harvest stage			
	Flowering	Milking	Dough	Means (G)
Mehmet Bey	63.98 f-l	59.88 p-u	62.51 h-r	62.12 f
Özer	65.01 d-j	59.56 r-u	68.54 abc	64.37 bcd
Esin	59.76 q-u	62.48 h-r	66.23 b-g	62.82 def
Tatlıcak 97	64.59 e-k	61.15 l-u	63.40 f-n	63.05 c-f
Ayşe Hanım	63.23 f-n	60.05 o-u	63.15 g-o	62.14 f
Ümran Hanım	66.26 b-g	61.76 k-t	64.17 e-l	64.06 b-e
Alper Bey	64.59 e-k	59.07 stu	68.91 ab	64.19 bcd
Mikham 2002	64.00 e-l	62.70 h-q	66.38 b-f	64.36 bcd
Karma	65.12 d-j	58.61 u	69.31 a	64.68 bcd
Line 1	62.72 h-q	58.88 tu	65.58 c-h	62.39 ef
Line 2	67.15 a-e	61.97 j-s	66.26 b-g	65.13 ab
Line 3	66.19 b-g	60.54 m-u	61.94 j-t	62.89 c-f
Line 4	62.95 h-p	61.79 k-t	63.51 f-m	62.76 def
Melih Bey	64.55 e-k	63.58 f-m	63.43 f-m	63.85 b-e
BC Goran	63.62 f-m	63.27 f-n	64.39 e-k	63.76 b-f
Bera	62.27 i-r	65.12 d-j	66.30 b-g	64.56 abc
Line 5	65.18 d-i	64.96 d-k	68.02 a-d	66.05 a
Presto	66.39 b-f	60.28 n-u	64.82 e-k	63.83 b-e
Means (H)	64.31 b	61.42 c	66.21 a	64.00

Means followed by the same letters in the same column are similar P>0.05.
G = genotypes, H = harvest stages

NDF content exhibited a significant interaction between the harvest stage and genotype, with 'Karma' and 'Line 5' displaying the greatest NDF when harvested at the dough stage. The harvesting at flowering stages often exhibited reduced NDF across genotypes (Table 6).

The CP ratio decreased from flowering (14.35%) to dough (10.68%), with the highest reduction observed for the genotypes 'Mehmet Bey' and 'Özer'. Genotypes 'Esin' and 'Line 1' exhibited higher protein retention throughout the harvesting stages, indicating genotype-specific reactions to maturation (Table 7).

Digestibility decreased from flowering to dough stages; however, genotypes 'Bera' and 'Karma' maintained elevated digestibility even at later harvest stages, suggesting that these are the advantageous genotypes for feed quality (Table 8).

Digestible dry matter yield increased with the delay in the harvesting. The genotypes 'BC Goran' and 'Presto' produced superior yield at the dough harvesting stage, indicating a notable genotype-harvest correlation in digestible dry matter yield potential (Table 9).

RFV decreased with the delay in harvesting, and 'Esin' and 'Line 1' genotypes exhibited the highest RFV at flowering and milking phases. Subsequent stages often exhibited a decrease; however, some genotypes, such as 'Alper Bey' and 'Presto', maintained considerable RFV across all stages, demonstrating genetic robustness (Table 10).

4. Discussion

The interaction between genotype and harvest stage significantly influenced plant height, yield, fiber, protein, and digestibility. Certain genotypes, such as 'Presto,' 'BC Goran,' and 'Karma' exhibited more versatility as they consistently excelled across many characteristics and harvest stages. Plant height is crucial for yield attributes since there exists a substantial positive link between plant height and both dry matter and CP (Mbe et al., 2024; Mirza and Çopur Doğrusöz, 2023).

Table 7.
Crude protein ratios (%) of triticale genotypes in different harvest stages.

Genotypes	Harvest stage			
	Flowering	Milk	Dough	Means (G)
Mehmet Bey	15.33	12.61	10.08	12.67 a-d
Özer	13.93	13.06	10.07	12.35 a-d
Esin	15.41	13.42	10.95	13.26 a
Tatlıcak 97	13.71	13.11	10.91	12.58 a-d
Ayşe Hanım	14.30	12.22	10.08	12.20 bcd
Ümran Hanım	12.78	13.17	10.15	12.03 d
Alper Bey	13.03	12.73	9.98	11.91 d
Mikham 2002	15.21	13.75	10.25	13.07 abc
Karma	14.49	13.18	10.56	12.74 a-d
Line 1	15.25	13.48	10.85	13.19 a
Line 2	13.86	13.83	11.81	13.17 a
Line 3	13.73	11.50	10.47	11.90 d
Line 4	14.81	13.28	11.12	13.07 abc
Melih Bey	14.15	12.27	11.11	12.51 a-d
BC Goran	15.07	13.45	10.90	13.14 ab
Bera	15.24	13.25	11.43	13.30 a
Line 5	15.04	13.39	11.22	13.22 a
Presto	13.16	12.63	10.57	12.12 cd
Means (H)	14.35 a	13.02 b	10.68 c	12.69

Means followed by the same letters in the same column are similar P>0.05.
G = genotypes, H = harvest stages

Table 8.
Digestible dry matter ratios (%) of the triticale genotypes in different harvest stages.

Genotypes	Harvest stage			
	Flowering	Milking	Dough	Means (G)
Mehmet Bey	65.25 abc	65.11 abc	63.34 e-n	64.56 a
Özer	62.21 mno	64.67 b-g	60.48 pq	62.45 g
Esin	66.49 a	64.25 b-j	62.28 l-o	64.34 ab
Tatlıcak 97	63.95 c-j	64.42 b-i	62.78 j-o	63.72 b-f
Ayşe Hanım	64.67 b-g	64.26 b-j	61.82 nop	63.58 c-f
Ümran Hanım	62.36 k-o	64.53 b-i	63.05 h-n	63.31 ef
Alper Bey	64.26 b-j	65.20 abc	59.90 q	63.12 f
Mikham 2002	65.15 abc	63.94 c-k	63.81 c-l	64.30 abc
Karma	64.44 b-i	65.22 abc	62.74 j-o	64.13 a-d
Line 1	64.94 a-e	65.28 abc	62.99 h-o	64.40 ab
Line 2	63.43 d-m	65.18 abc	61.84 m-p	63.48 def
Line 3	64.00 c-j	64.02 c-j	61.46 op	63.16 f
Line 4	64.85 b-f	63.94 c-k	62.35 l-o	63.71 b-f
Melih Bey	64.96 a-d	63.86 c-l	63.27 f-n	64.03 a-e
BC Goran	65.43 abc	63.01 h-o	62.06 mno	63.50 def
Bera	65.74 ab	64.66 b-g	63.35 e-n	64.58 a
Line 5	65.01 a-d	64.54 b-h	62.92 i-o	64.15 a-d
Presto	63.18 g-n	64.87 b-f	62.72 j-o	63.59 c-f
Means (H)	64.46 a	64.50 a	63.23 b	

Means followed by the same letters in the same column are similar P>0.05.
G = genotypes, H = harvest stages

Table 9.
Digestible dry matter yield (t/ha) obtained from triticale genotypes examined in this study at different harvest stages.

Genotypes	Harvest stage			
	Flowering	Milking	Dough	Means (G)
Mehmet Bey	4.88 wx	5.76 opq	7.80 fgh	6.15 f-i
Özer	5.38 q-w	6.56 kl	7.29 hij	6.41 d-g
Esin	4.83 wxy	5.50 p-v	7.48 ghi	5.94 hi
Tatlıcak 97	5.34 q-w	6.06 l-p	8.09 def	6.49 c-f
Ayşe Hanım	4.59 x-A	6.62 kl	8.49 def	6.57 c-f
Ümran Hanım	4.92 vwx	5.88 n-q	7.20 ij	6.00 ghi
Alper Bey	5.15 r-x	7.32 g-j	7.88 efg	6.78 bcd
Mikham 2002	5.65 p-s	6.40 k-n	8.76 c	6.94 bc
Karma	5.00 u-x	7.31 g-j	8.87 c	7.06 b
Line 1	5.05 t-x	7.34 g-j	8.38 cde	6.92 bc
Line 2	4.19 zA	5.07 s-x	6.48 klm	5.25 k
Line 3	5.04 t-x	6.29 l-o	7.42 g-j	6.25 e-h
Line 4	5.39 q-w	6.42 k-n	8.13 def	6.65 b-e
Melih Bey	4.30 yzA	5.93 m-q	7.68 f-i	5.97 hi
BC Goran	5.92 m-q	7.89 efg	10.63 a	8.15 a
Bera	4.09 A	5.60 p-t	6.63 kl	5.44 jk
Line 5	4.70 xyz	5.67 pqr	6.90 jk	5.76 ij
Presto	5.58 p-u	8.70 c	9.98 b	8.09 a
Means (H)	5.00 c	6.46 b	7.98 a	

Means followed by the same letters in the same column are similar P>0.05.
G = genotypes, H = harvest stages

Table 10.
Relative feed values of the triticale genotypes in different harvest stages.

Genotypes	Harvest stage			
	Flowering	Milking	Dough	Means (G)
Mehmet Bey	94.96 c-m	101.37 abc	94.47 d-o	96.93 a
Özer	89.01 l-s	101.09 a-d	82.11 tu	90.73 ef
Esin	103.95 a	95.91 c-k	87.60 p-t	95.82 abc
Tatlıcak 97	92.16 g-r	98.05 a-h	92.24 g-r	94.15 a-e
Ayşe Hanım	95.68 c-l	99.66 a-f	91.12 i-r	95.48 a-d
Ümran Hanım	87.64 o-t	97.36 b-i	91.52 g-r	92.17 def
Alper Bey	92.98 g-q	103.78 ab	80.85 u	92.54 c-f
Mikham 2002	94.85 c-n	95.53 c-l	89.50 k-s	93.29 b-f
Karma	92.12 g-r	103.71 ab	84.21 stu	93.34 b-f
Line 1	96.41 c-j	103.24 ab	89.45 k-s	96.36 ab
Line 2	88.03 n-t	97.91 a-i	86.96 q-t	90.96 ef
Line 3	90.00 j-s	98.36 a-g	92.35 g-r	93.57 b-f
Line 4	95.95 c-k	96.49 c-j	91.44 h-r	94.62 a-d
Melih Bey	93.68 f-q	93.85 e-p	92.91 f-q	93.48 b-f
BC Goran	95.74 c-l	92.82 g-r	89.79 j-s	92.78 c-f
Bera	98.27 a-h	92.56 g-r	89.02 l-s	93.28 b-f
Line 5	92.97 f-q	92.53 g-r	86.07 t-u	90.52 f
Presto	88.52 m-s	100.51 a-e	90.14 j-s	93.06 b-f
Means (H)	93.49 b	98.04 a	88.98 c	93.50

Means followed by the same letters in the same column are similar P>0.05.
G = genotypes, H = harvest stages

Earlier studies indicate that plant height rises as the harvest advances (De Zutter et al., 2023; Geren, 2014). An increase in plant height is expected as the harvesting is delayed. Studies indicate that maturity significantly influences plant height in cereals (De Zutter et al., 2023; Geren, 2014).

The genotype 'BC Goran' produced the highest dry matter, also 'Presto' yielded a similar amount. The roughage yield of spring and winter cereals is difficult to evaluate since genotypes grow at different periods (Pozo et al., 2023). Dry matter production should increase with the delay in harvest. The fraction of plant cell wall structural chemicals rises throughout harvest. Consequently, dry matter yield rises. Some studies indicated that delaying harvest may increase dry matter production (Karadağoğlu and Özdüven, 2019). However, sowing density, fertilizer, climatic and soil characteristics, precipitation, irrigation, and ripening duration might alter yield parameters, including green forage yield and dry matter yield.

This two-year study revealed significant variation in genotypes, exceeding 50% between the highest and lowest CP producing genotypes. The dry matter and CP fluctuate based on genetic makeup, temperature, growing season, and fertilization (Kaplan et al., 2015). The mean CP yield after two years for our variety ranged from 0.62 t/ha to 1.55 t/ha (Genç Lermi and Palta, 2018).

Cereal yields increase with delayed harvests; nevertheless, grain quality deteriorates due to a reduction in CP concentration. Delaying harvest may increase dry matter yield, whereas digestibility and CP content decrease more rapidly (Akbağ, 2022; Aydoğan and Demiroğlu Topçu, 2022). The yield of dry matter and CP increased, whereas the CP content decreased with a delay in harvesting. The ADF serves as a metric for plant quality and is expected to be in a certain proportion. Delayed harvesting increases plant fibrousness, leading to increased concentrations of ADF, NDF, and ADL (Salama and Badry, 2021). Mature plants have a higher quantity of stems relative to leaves, and stems are less attractive. As the plant ages, the concentration of water-soluble carbohydrates in the leaves and stems decreases, and the fiber content rises. Numerous studies indicate that ADF rates rise with the maturation of plant tissue at the harvest stage. Several studies have identified the leaf/stem ratio as a critical quality attribute for fodder crops (Kir et al., 2018). The lowest mean NDF ratio (61.42%) was recorded for the harvest during the milk stage (Table 4). The continuation of precipitation after the first form may have caused the increase in the vegetative part and, thus, the petiole rate to increase, resulting in a lower average NDF ratio at the second harvest stage than at the flowering time. Because of the increase in the fiber ratio in the plant with the advancement of the harvest stage, the NDF rate increased.

The 'Bera' genotype had the highest CP ratio. Nonetheless, genotypes 'Line 1,' 'Esin,' 'Line 2,' and 'Line 5' had a comparable CP ratio to 'Bera'. Several investigations have shown that triticale genotypes differ in CP content. This study identified CP ratios ranging from 9.9% to 12.9%, like those reported by Çaçan and Kökten (2019). Young plants produce higher amounts of protein during flowering due to enhanced photosynthetic surfaces, resulting in increased CP content (Geren, 2014; Piltz and Rodham, 2022). However, as plants grow, the concentration of crude cellulose, a fundamental component of the cell wall, increases, whereas the concentration of CP diminishes owing to a reduction in photosynthetic areas. This study indicated that protein ratios decreased with delayed harvesting.

This research found an adverse correlation between the ADF ratio and the digestible dry matter ratio, irrespective of the harvest stage. The digestible dry matter decreased as the ADF ratio increased. Digestible dry matter decreased as lignification increased during harvest. The genotypes with the highest hay dry matter yields also have the greatest digestible dry matter yields, indicating a linear correlation. Genotypes provide markedly diverse digestible dry matter outputs (Dogan et al., 2011; Kendal, 2019). The use of hay yields and digestible dry matter ratios in calculating digestible dry matter yield may elucidate this variation. The increase in digestible dry matter yields in our study is ascribed to the augmentation of hay yields, notwithstanding the fall in digestibility with the stage of harvest. Increased leaf count, stem elongation, and spike development enhance hay dry production. As plants mature, the leaf-to-stem ratio diminishes, leading to decreased digestibility (Aziza et al., 2013; Keles et al., 2016; Schwarte et al., 2005). Prior studies indicate that digestibility diminishes with the harvest stage; nevertheless, this study revealed that the augmentation of dry matter yields in accordance with the harvest stage resulted in an enhancement in digestible dry matter yield (Aydoğan and Demiroğlu Topçu, 2022; Buxton and Fales, 2015; Liebert et al., 2023; Wang et al., 2024). RFV indicates the quality of market roughage. Feed manufacturers and buyers determine feed prices via the relative feed value index. RFV is calculated using the ratio of digestible dry matter to dry matter intake. Ozkurt (2022) asserts that relative feed levels are negatively correlated with ADF and NDF concentrations. The relative feed value method for alfalfa quality assessment was developed in the US with fully bloomed plants. The relative feed value index is established at 100, predicated on all-flower alfalfa hay's 41% ADF and 53% NDF. Elevated precipitation, higher leaf-to-stem ratio, and extended vegetative period enhanced the RFV during the first year of the study.

The RFV is determined by the ADF and NDF ratios. The milk stage with the lowest ADF and NDF ratios has the highest average RFV, illustrating the inverse correlation between these variables.

5. Conclusion

This study assessed the effects of various harvest phases on the production and quality of triticale in the rainfed circumstances of Muş region, Türkiye. Results indicated substantial interactions between harvest stage and genotype, affecting important parameters like dry matter yield, CP content, fiber composition, and RFV. Delaying harvest enhanced dry matter yield but decreased fodder quality, i.e., crude protein and digestibility. The milking stage was determined to be the optimum harvest period, optimizing production and quality parameters. Of the 18 genotypes investigated, 'Presto' and 'BC Goran' produced the greatest dry matter yields, although 'Esin' and 'Line 1' had superior forage quality characteristics, such as CP retention and RFV. The results underscore triticale's potential as a sustainable fodder crop in water-scarce places, meeting the rising need for superior animal feed. The study highlights the significance of genotype selection and harvest timing in enhancing fodder crop management within certain ecological contexts. This study addresses a significant need for information about the geographical adaptation of triticale and offers essential suggestions for enhancing the sustainability of animal feed in regions with comparable continental climates. Further study on long-term agronomic techniques and genotype-environment interactions is recommended to improve the implementation of these results.

CRediT authorship contribution statement

M. Ozkurt: Writing – review & editing, writing – original draft, methodology, investigation, formal analysis, data curation, conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Declaration of Generative AI and AI-assisted technologies in the writing process

The authors confirm that there was no use of Artificial Intelligence (AI)-Assisted Technology for assisting in the writing or editing of the manuscript and no images were manipulated using AI.

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