NARDI FUNDULEA, ROMANIA
www.incda-fundulea.ro

ROMANIAN AGRICULTURAL RESEARCH, NO. 40, 2023
First Online: January, 2023. DII 2067-5720 RAR 2022-78

ASSESSMENT OF CRESTED WHEATGRASS (*Agropyron cristatum* L. Gaertn.) POPULATIONS FOR THE AGRO-MORPHOLOGICAL AND THE QUALITY TRAITS UNDER SEMIARID CONDITION

Sabahaddin Ünal[1*], Ziya Mutlu[2], Berna Efe[2]

[1]Abant İzzet Baysal University, Faculty of Agriculture, Department of Field Crops, 14280 Bolu, Turkey
[2]Central Research Institute for Field Crops, Ankara, Turkey
[*]Corresponding author. E-mail: sabahaddin2015@gmail.com

ABSTRACT

Crested wheatgrass [*Agropyron cristatum* L. (Gaertn.)] is high adaptability to semiarid and arid regions, and also has good forage quality and palatability. The required new varieties have been improved by effective breeding programs for hay production and rangeland revegetation in arid and semi-arid conditions. The objectives of this study were to identify the agro-morphological and quality traits of the three advanced populations and the control population in crested wheatgrass. The advanced population G-465 was 7.68 and 1.92 t ha^{-1} in overall averages of fresh forage and hay yields, respectively. According to these values, it is seen that the G-465 advanced population is 5.93, and 6.07% higher than the control population in terms of both fresh forage and hay yields, respectively.

Besides, no significant differences seemed among the study populations in crude protein content and relative feed value in 2015 and two-year averages. Consequently, the G-465 advanced population was good performance under semiarid conditions and it is advisable for similar circumstances. For identifying yield-related traits, correlation analysis was performed and high correlation coefficients occurred between fresh forage yield with stem diameter (0.474), internode length (0.469**), flag leaf length (0.761**), and flag leaf width (0.711**). In light of these data, these traits should be taken into account in the selection of phenotypic plants. Moreover, cluster analysis was also done and its results showed that high similarity levels occurred between fresh forage yield and flag leaf length (88.06%), and between plant height and internode length (78.73%).**

Keywords: crested wheatgrass, agro-morphological, quality traits, correlation coefficients, cluster analysis.

INTRODUCTION

Gramineae (*Poaceae*) is a large and nearly present everywhere family of monocotyledonous flowering plants, mostly known as grasses. Crested wheatgrass (*Agropyron cristatum* L. Gaertn.), a forage plant of the *Poaceae* family, is commonly used to improve the artificial pastures and natural rangelands in arid and semiarid areas of Turkey (Açıkgöz, 2021a). Grasses, especially crested wheatgrass, have important features such as drought resistance, perennial, delicious, and early growth in spring under semiarid conditions (Yu et al., 2012; Bayat et al., 2016; Baral et al., 2020; Açıkgöz, 2021a). In addition, the crested wheatgrass is a versatile plant such as high adaptation ability in semiarid conditions, good hay yield, and high quality (Rogler and Lorenz, 1983; Hofmann et al., 1993; Baral et al., 2020). Moreover, the features of this species are summarized as being palatable, persistent under hard conditions, highly competitive ability, good seed production, easy establishment, and good seedling vigor to desired stand density (Bayat et al., 2016; Robins and Jensen, 2020).

There is a wide range of dry forage yield in crested wheatgrass that changes from 0.42 to 6.27 t ha^{-1} (Hull, 1972; Unal and Eraç, 2000). A high variation also commonly appears for crude protein, an important quality factor (George and Lorenz, 1969), which occurs between 6.06% and 15.82% (Unal and Eraç, 2000; Demirbağ et al., 2014). Those variations may be explained by genetic and environmental factors such as various varieties, different growth stages, climatic conditions, locations, and years (Loaiza et al.,

Received 25 October 2022; accepted 16 January 2023.

2017; Habermann et al., 2019). Thus, it is important to develop and sustain efficient and quality variety development studies for semi-arid conditions.

Most rangelands under the semiarid conditions in Turkey have had low quality and quantity values because of being misused such as early, late, and overgrazing (Unal et al., 2014; Gökkuş, 2020). For this reason, rangeland improvement and management implements immediately must be made a realize (Unal et al., 2012; Unal et al., 2013). In addition to artificial rangeland establishment and increased forage production area can reduce the pressure on rangeland usage (Tan and Yolcu, 2021). Therefore, there is a need for new cultivars, and breeding programs should be carried out in order to develop these new cultivars.

Breeding programs should have a rich and broad genetic resource. They have to have an effective breeding method in time, money, and implementation. Choosing a breeding method is significant for achieving a successful target and aim. The mass selection method is extensively implemented for cross-pollinated crops (Demir and Turgut, 1999; Açıkgöz, 2021a). Its aim is to increase the frequencies of the desired traits in a population. For this, the desired plants are selected and brought together, but it takes a long time (Robins and Jensen, 2020; Açıkgöz, 2021a).

In this crested wheatgrass breeding study, the mass selection process was performed with two selection cycles in 13 years for population improvement (GEPSCA, 2014). As recommended by Robins and Jensen (2020), each selection cycle included establishment, phenotypic evaluation, hybridization, and seed production. After that period, three populations were advanced for rangeland rehabilitation, artificial pasture, and marginal lands under the semiarid condition.

The objectives of this study were (1) to determine the traits of agro-morphological and quality of the advanced populations under the semiarid condition, (2) to compare the advanced populations with the control population to reveal the effects of mass selection, (3) to search relationship and similarity between the observed traits.

MATERIAL AND METHODS

Soil characters

The soil characteristics of Gölbaşı location are presented as follows. In particular, the soil of Gölbaşı location was clay-loam, pH slightly alkaline (8.04), poor (1.32) in organic matter, medium (63.7 kg ha^{-1}) in phosphorus content, high (2074.6 kg ha^{-1}) in the potassium content, very high (27.86%) in lime content (Anonymous, 2014).

Climatic data

During the experimental seasons of 2014, 2015, and 2016, total precipitation, average temperatures, and average relative humidity were 532.3 mm, 537.2 mm and 363.0 mm; 13.4°C, 10.5°C, and 10.6°C; 59.2%, 64.0% and 61.6% at Gölbaşı, respectively (Anonymous, 2016).

Also, long term average precipitation, temperatures, and relative humidity are 389.9 mm, 12.5°C, and 58.8% at Gölbaşı, respectively.

In conclusion, the experimental seasons were higher average relative humidity than in the long term and they had also higher total precipitation in 2014 and 2015 than the long term. In terms of temperatures, the first year was a higher average temperature than the long term but subsequent years became the opposite.

Materials

The study materials were the three advanced populations called G-465, G-466, and G-467 and the control genotype such as the control population. Apart from this, the advanced populations were received from The Project of Germplasm Enhancement of Some Plant Species for Use in the Rehabilitation of the Central Anatolia Rangelands (GEPSCA, 2014). Besides, all these populations were improved from 2000 to 2013 by the mass selection method in that project.

Methods

The study was established in a randomized complete block design with 5 replications in a fallow field of the substation Gölbaşı town (altitude 1088 m, 30°37'17''N and 32°40'57''E) of The Central Research Institute for the Field Crops, Ankara, in the years of 2014 to 2016.

Besides, seeds were sown by hand on 19 of March 2014. The plot size was 5.0 m x 0.8 m = 4.0 m^2, consisting of 2 rows spaced at 40 cm for fresh forage.

In addition, weed control was done as a manual hoe when needed. Also, in the blooming period in each trial material, 5 or 10 plants randomly selected were taken as samples, and measurements were recorded.

Morphological features (plant height, tiller diameter, internode length, node numbers, flag leaf length, and flag leaf width) and agronomic traits (fresh forage yield and hay yield) were identified in 2015 and 2016 (Anonymous, 2001; Unal and Fırıncıoğlu, 2009). Plant height (PH) was determined, after anthesis, by measuring the distance to the top of the spike on the tallest tiller (Anonymous, 2001). Tiller diameter (TD) was found by measuring with composing stick (0.1 mm) the thickness of the tallest tiller. The length of the internode (LI) is the distance between the second node and the third node of the tallest tiller. Node number (NN) is the count of all nodes of the tallest tiller. Flag leaf width (FLW) is measured on the flag leaf by a ruler. Flag leaf length (FLL) is measured between the place of the flag leaf blade connected to the sheath and its endpoint.

After that, 9.6 m^2 of 16.0 m^2 of each parcel were harvested for fresh forage and the samples (500 g each) were dried at 70°C for 48 hours. Their quality properties such as neutral detergent fiber (NDF), acid detergent fiber (ADF), and relative feeding value (RFV) were studied.

Latter, dry matter content was determined according to the method used by Tekkanat and Soylu (2005), then crude protein, ADF, and NDF were detected with near-infrared reflectance (NIR) (Kutlu, 2008), after that RFV was calculated with a formula as DDMx(120)/ NDF% (Starkey et al., 1993).

Analysis of variance (ANOVA) was performed for all studied traits of crested wheatgrass materials in this experiment in excel software program of Microsoft office 2010. The significance of the main effects was estimated by the F test. Differences among crested wheatgrass genotypes were compared using the Least Significant Difference (LSD) test a 5% level of probability. Correlation analysis was also performed in the excel software program of Microsoft office 2010. Cluster Analysis was made a realization in Minitab 16 software.

RESULTS AND DISCUSSION

Morphological traits

Plant height (PH)

Significant differences (P <0.01) were observed among crested wheatgrass populations in plant height (PH) in 2015, 2016, and two-year averages in Gölbaşı location (Table 1). The difference between years was also found to be significant (P <0.01). The G-466 advanced population and control population had the lowest and the highest PHs such as 40.0 and 52.8 cm; 47.2 and 59.5 cm; and 43.6 and 56.2 cm in 2015, 2016, and two-year averages, respectively (Table 1). There were 46.0 cm, 51.2 cm, and 48.6 cm in the means of 2015, 2016, and two-year in PH.

Table 1. Plant height (PH) (cm), tiller diameter (TD) (mm), and internode length (IL) (cm) in studied populations

Populations	Plant Height +			Tiller Diameter			Internode Length		
	2015	2016	Ave.	2015	2016	Ave.	2015	2016	Ave.
G-465	47.1 b	49.7 b	48.4 b	1.5	1.5	1.5	9.8 b	9.3	9.6 b
G-466	40.0 c	47.2 b	43.6 c	1.5	1.4	1.5	8.8 b	8.7	8.7 b
G-467	44.1 bc	48.4 b	46.3 bc	1.7	1.7	1.7	9.5 b	9.4	9.4 b
Control	52.8 a	59.5 a	56.2 a	1.7	1.5	1.6	11.8 a	10.7	11.2 a
Mean	46.0	51.2	48.6	1.6	1.5	1.6	10.0	9.5	9.7
$F_{(pop.)\ (0.05)}$	11.4**	28.2**	32.2**	2.0	1.2	2.5	6.6**	3.0	9.5**
$LSD_{(0.05)}$	4.9	3.3	2.8	0.2	0.3	0.2	1.5	1.5	1.0
$F_{(year)\ (0.05)}$			29.6**			4.1			1.7
$F_{(pop.x\ year)\ (0.05)}$			1.3			0.6			0.5
CV (%)	7.8	4.6	6.2	10.7	15.0	12.6	11.3	11.6	11.3

*, **Significant at 5 and 1 % probability levels, respectively.

Under the semiarid condition, the temperature and precipitation in the spring, especially in April and May, directly affect plant growth. In the same period, the precipitation (92.2 mm) in 2015 was higher than in 2016 (71.0 mm), but the plant height remained smaller due to the low-temperature value (6.9°C). Since it was lower than the long-term temperature value (11.6°C), this temperature value limited the growth of plant height.

PHs were measured as 55.78 cm (Gökkuş, et al., 2001), 79.28 cm (77,80-81,09 cm) (Unal and Eraç, 2000), 57.54 cm (40.50-72.66) (Unal and Fırıncıoğlu, 2009), 87-97 cm in 1999 and 54-65 cm in 2000 (Mellish and Coulman, 2002), 58.5 cm (G-466 = advanced population) - 56.3 cm (control population) (Unal and Mutlu, 2016), 61.4 cm in Tokat province, 73.1 cm in Sivas province (Karadağ et al., 2017), 52.5 cm (advanced population) - 52.2 cm (control population) (Unal, 2018). The average values above were higher than those of this trial. Moreover, PH was measured from 38.5 to 68.4 cm in a previous study (Erdoğdu et al., 2016). Besides, the difference between years was found to be significant in this study, the same result was reached in the previous trial conducted by Unal and Mutlu, (2016). In addition, Tandoh et al. (2019) reported PH values such as 72.6 cm in North America, 54.9 cm in Europe, and 56.1 cm in Asia. The highest and the lowest PHs in all populations in 2015, 2016, and the two-year average became the control population and the advanced population, G-466, respectively.

Tiller diameter (TD)

No significant differences appeared among crested wheatgrass populations in stem diameter (TD) in 2015, 2016, and two-year averages (Table 1). There were 1.6 mm, 1.5 mm, and 1.6 mm in the means of 2015, 2016, and two-year in TD, respectively.

When observed in previous studies, tiller diameter was determined as 2.1-2.7 mm (Açıkgöz, 1982), 2.15 mm (Unal and Eraç, 2000), and 2.39 mm (1.60-3.16 mm) (Unal and Fırıncıoğlu, 2009), 2.1 mm (G-466 = advanced population) - 1.8 mm (control population) (Unal and Mutlu, 2016), 1.1-3.0 mm (Erdoğdu et al. 2016), 1.9 mm (advanced population) - 1.9 mm (control population) (Unal, 2018) in the former trials. Those experiment values were higher than this trial results except Erdoğdu et al. (2016)'s data. While an increase was observed in plant height, there was a decrease in stem diameter in the second year.

Internode length (IL)

Significant differences ($P<0.01$) were found among crested wheatgrass populations in length internode in main stem (IL) in 2015, and two-year averages (Table 1). The means in 2015, 2016, and two-year in IL were 10.0 cm, 9.5 cm, and 9.7 cm, respectively. No significant differences seemed between years and population x year interaction. In the second year, while the internode length decreased, the number of nodes increased.

In some former studies, it was measured as 13.2 cm (G-466 = advanced population) -

11.4 cm (control population) (Unal and Mutlu, 2016), 12.2 cm (advanced population) - 11.7 cm (control population). When the extending plant height and the increasing number of nodes, the internode length was also shortened.

Node number (NN)

Significant differences (P<0.05) were obtained among crested wheatgrass populations in node numbers (NNs) in 2015, 2016, and two-year averages (Table 2). The means in 2015, 2016 and two-year in NNs were 3.7, 4.4, and 4.0, respectively. Significant differences appeared between two years (P<0.01), and interaction (population x year) (P<0.05). An increase in the number of nodes appeared depending on the lengthening of the plant.

In former studies on this subject, it was detected as 3.7 (G-466 = advance population) - 4.0 (control population) (Unal and Mutlu, 2016), 2.9-4.2 (Erdoğdu et al., 2016), 3.5 (advanced population) - 3.3 (control population) (Unal, 2018). This trial data was similar to the results of Unal and Mutlu (2016) and Erdoğdu et al. (2016), higher than the results of Unal (2018).

Flag leaf width (FLW)

There appeared significant differences among crested wheatgrass populations in flag leaf width (FLW) in 2016 (P<0.05), and two-year averages (P<0.01) (Table 2). The means in 2015, 2016 and two years in FLW were 4.8 mm, 3.9 mm and 4.3 mm, respectively. Significant difference detected between two years (P<0.01). There was more precipitation in June 2015 than in the same period of 2016, which encouraged higher biomass or greater vegetative production, thus there has been quite a lot of growth in FLW and FLW.

Table 2. Node number (NN) (number), flag leaf width (FLW) (mm), and flag leaf length (FLL) (cm) in studied populations

Populations	Node Number			Flag Leaf Width			Flag Leaf Length		
	2015	2016	Ave.	2015	2016	Ave.	2015	2016	Ave.
G-465	4.1 a	4.6 a	4.3 a	5.1	4.4 a	4.8 a	12.9	7.3	10.1
G-466	3.4 b	4.7 a	4.0 ab	4.4	3.2 c	3.8 c	12.3	6.1	9.2
G-467	3.7 b	4.1 b	3.9 b	4.9	3.7 bc	4.3 b	12.5	6.5	9.5
Control	3.6 b	4.3 ab	3.9 b	5.0	4.0 ab	4.5 ab	13.1	7.6	10.3
Mean	3.7	4.4	4.0	4.8	3.9	4.3	12.7	6.9	9.8
$F_{(pop.)\ (0.05)}$	5.8*	4.8*	3.0*	1.3	5.6*	6.1**	0.5	3.0	2.9
$LSD_{(0.05)}$	0.4	0.4	0.3	0.8	0.7	0.5	1.5	1.2	0.9
$F_{Year\ (0.05)}$			37.3**			39.6**			385.3**
$F_{(pop.x\ year)\ (0.05)}$			3.1*			0.6			0.3
CV (%)	8.1	6.0	9.3	11.4	12.4	11.5	8.7	12.4	9.6

*, **Significant at 5 and 1 % probability levels, respectively.

In the literature review, it was found as 4.9 (G-466 = advanced population) - 6.0 (control population) (Unal and Mutlu, 2016), 2.2-5.1 mm (Erdoğdu et al., 2016), 6.5 mm (advanced population) - 6.9 mm (control population) Unal (2018). This trial data was lower than the results of Unal and Mutlu (2016) and Unal (2018) but they were similar to the results of Erdoğdu et al. (2016).

Moreover, leaf growth (including in FLL and FLW) was influenced by environmental factors such as especially higher temperatures caused by greater leaf mass and leaf surface area for all plant species (Leffler et al., 2011). In addition, prolonged photoperiod time generally increases leaf length, and sometimes leaf width, but reduces the production of leaves (Ryle, 1966). The same researcher stated further that leaf appearance rate, number of live leaves, number of actively-growing leaves, and leaf length were risen up through a high N level and high temperature, but high temperature decreased leaf width and, in some instances, tiller numbers. Besides, flag leaves would have higher photosynthetic capacity and performance (Hamerlynck et al., 2019).

Flag leaf length (FLL)

No significant differences were observed among crested wheatgrass populations in flag length (FLL) in 2015, 2016, and two-year averages (Table 2). The means in 2015, 2016 and two-year in FLL were 12.7 cm, 6.9 cm and 9.8 cm, respectively. The significant difference seemed between years (P<0.01). The second year's value was lower than the first year's due to less precipitation amount.

In some past studies, it was determined as 8.4 cm (G-466 = advanced population) - 9.4 cm (control population) (Unal and Mutlu, 2016), 3.9-9.6 cm (Erdoğdu et al., 2016), 11.2 cm (advanced population) - 11.8 cm (control population) (Unal, 2018). In conclusion, this trial data was similar to the earlier study results above.

Agronomic traits

Fresh forage yield (FFY)

Significant differences were observed among crested wheatgrass populations in fresh forage yield (FFY) in the first year (P<0.01), the second year (P<0.05), and two-year averages (P<0.01) (Table 3). The means of the first year, the second year, and the two-year in FFY were 8.34 t ha^{-1}, 4.22 t ha^{-1}, and 6.28 t ha^{-1}, respectively. A significant difference was detected between years (P<0.01). The highest FFYs were obtained such as 7.68 t ha^{-1}, and 7.25 t ha^{-1} in the advanced population, G-465 and control population. Those high yields resulted from plant height, internode length, flag leaf length, and flag leaf width (Table 4).

Table 3. Fresh forage yield (FFY) (t ha^{-1}) and hay yield (HY) (t ha^{-1}) in studied populations

Populations	Fresh Forage Yield			Hay Yield		
	2015	2016	Ave.	2015	2016	Ave.
G-465	10.26 a	5.11 a	7.68 a	2.56 a	1.27 a	1.92 a
G-466	5.84 c	2.45 b	4.15 c	1.46 c	0.61 b	1.03 c
G-467	7.58 b	4.51 a	6.05 b	1.89 b	1.12 a	1.51 b
Control	9.68 a	4.82 a	7.25 ab	2.42 a	1.20 a	1.81 ab
Mean	8.34	4.22	6.28	2.08	1.05	1.57
$F_{(pop.)\ (0.05)}$	14.6**	5.7*	14.3**	14.6**	5.7*	14.3**
LSD $_{(0.05)}$	1.63	1.56		0.40	0.39	0.30
F $_{(year)\ (0.05)}$			96.7**			21.4**
F $_{(pop.x\ year)\ (0.05)}$			1.5			1.5
CV (%)	14.2	26.8	21.1	14.2	26.8	21.1

*, **Significant at 5 and 1 % probability levels, respectively

In some previous studies, FFYs were found such as 14.85 t ha^{-1} (Unal and Eraç, 2000); 4.82 t ha^{-1} (G-466) - 5.45 t ha^{-1} (population) (Unal and Mutlu 2016) and 6.24 t ha^{-1} (advanced population) - 6.00 t ha^{-1} (control population) (Unal, 2018). This trial data was lower than the results of Unal and Eraç (2000) but they were similar to the results of Unal and Mutlu (2016), Unal (2018). The difference between the two years was found to be significant (P <0.01) (Unal and Mutlu, 2016; Unal, 2018).

The temperature and precipitation in the spring, especially in April and May, directly affect plant growth and biomass production. In the same period, the precipitation in 2015 was higher than in 2016, but the plant height remained smaller due to the low-temperature value (6.9°C). Since it was lower than the long-term temperature value (11.6°C), this temperature value limited the growth of plant height.

As compared to the yield years of study for climatic data, the first year (2015) had higher total precipitation (537.2 mm), and relative humidity (64.0%) than the second year (2016) (363.0 mm; 61.6%) (Anonymous, 2016). But it had almost the same temperature

(10.5°C in 2015; 10.6°C in 2015) in both years. Another important issue is the precipitation amount for the first 6 months in 2015 and 2016, and the precipitation amounts in these years were 411.3 mm and 230.2 mm, respectively. A high difference appeared between the two years in annual precipitation. For this reason, the high yield difference in two years resulted from total precipitation amount and average relative humidity. Plant species show various responses to different environmental factors. The lower total precipitation may negatively influence the plant growth of crested wheatgrass. In addition, specific precipitation patterns accounted for 87% or more of the variation in forage yields of crested wheatgrass grazed at different seasons (Currie Pat and Peterson, 1966). Moreover, high fresh or dry herbage yield in crested wheatgrass is closely associated with plant vegetative growth and total biomass of the plant (Albayrak and Ekiz, 2004; Unal and Mutlu, 2016; Unal, 2018).

Evaluations of the influence of the mass selection method

FFYs in the advanced populations of the G-465 and the control population were 7.68 and 7.25 t ha^{-1}, respectively (Table 3). Those yield values were 0.43 t ha^{-1} and 5.93% higher in fresh forage yield of the advanced population of G-465 compared to the average of the control population, respectively. This increase in FFY was the result of the mass selection method.

Hay yield (HY)

Significant differences were observed among crested wheatgrass populations in hay yield (HY) in the first year (P<0.01), the second year (P<0.05), and two-year averages (P<0.01) (Table 3). The difference between years was found to be significant (P <0.01) but the year x population interaction was not significant. HYs in 2015, 2016, and two-year averages were 2.08 t ha^{-1}, 1.05 t ha^{-1}, and 1.57 t ha^{-1}, respectively. The difference between years was also found to be significant in former trials (P <0.05; P<0.01) (Unal and Mutlu, 2016; Unal, 2018).

Hay yields in crested wheatgrass were obtained in former trials such as 0.42 to 2.13 t ha^{-1} (Hull, 1972), 3.06 t ha^{-1} (Altın, 1982), 3.04 t ha^{-1} (1.95-4.06 t ha^{-1}) (Serin, 1991), 6.27 t ha^{-1} (Unal and Eraç, 2000), 1.20 t ha^{-1} (G-466) - 1.36 t ha^{-1} (population) (Unal and Mutlu, 2016), 1.88 t ha^{-1} (advanced population) - 1.78 t ha^{-1} (control population) (Unal, 2018). Furthermore, it displayed a wide variation based on genetics (cultivar) and environmental factors (year and location impacts). Hay yield had 1.37 t ha^{-1} in perennial grass mixture (Hull, 1971) and its stem yield was 3.88 t ha^{-1} (Gökkuş et al., 2001). Those different results can be explained by the difference in genotypes tested and environmental variations.

Evaluations of the influence of the mass selection method

HYs in the advanced populations of G-465, and the control population were 1.92 and 1.81 t ha^{-1}, respectively (Table 3). Those yield values were 0.11 t ha^{-1} and 6.07% higher in hay yield of the advanced population of G-465 compared to the average of the control population, respectively. This increase in HY was the result of the mass selection method.

Correlation coefficients of plant traits

At the initial stage of a breeding program, there should be many individual plants in the source or base population for having a wide variation in study materials. During that period individual plants are selected based on their phenotypic appearance, therefore it is necessary and significant to know the yield-related traits and to select plants with these traits for successful breeding programs.

It's commonly known high fresh or dry herbage yield closely is associated with plant vegetative growth and biomass of plant (Albayrak and Ekiz, 2004; Unal and Mutlu, 2016; Unal, 2018). It is necessary to investigate and know the morphological traits associated with yield. For this reason, the relations were measured with Pearson correlation between the observed traits (Table 4). There found high correlation coefficients between FFY with TD (0.474**), IL (0.469**), FLL (0.761**) and FLW (0.711**) (Table 4). In the previous studies, there also occurred high correlation between HY and some traits such as PH (Gökkuş et al., 1997; Albayrak and Ekiz, 2004; Unal, 2018), IL (Unal and Mutlu, 2016; Unal, 2018), NN (Unal and Mutlu, 2016), FLL, FLW, GHY (Unal, 2018). As a result, some morphological traits such as PH, TD, IL, NN, FLL and FLW should be observed earlier in breeding programs in crested wheatgrass. This saves us time and ensures the right plant selection.

Table 4. The correlation coefficients among 7 traits measured on 4 crested wheatgrass populations evaluated in 2015, and 2016

	PH	TD	IL	NN	FLL	FLW	FFY
PH	1	0.148	0.575**	0.392*	-0.28	-0.062	0.135
TD		1	0.429**	-0.197	0.362*	0.425**	0.474**
IL			1	-0.197	0.248	0.375*	0.469**
NN				1	-0.604**	-0.337*	-0.236
FLL					1	0.728**	0.761**
FLW						1	0.711**
FFY							1

*, **Significant at 5 and 1 % probability levels, respectively. PH: Plant height, TD: Tiller diameter, IL: Internode length, NN: Node number, FLL: Flag leaf length, FLW: Flag leaf width, FFY: Fresh foliage yield.

Cluster analysis

Knowing and examining plant agro-morphological traits related to high forage yield and good quality at the beginning periods of breeding programs. During these periods, making a realize correct phenotypic selection in many individual plants of nursery plots for successful breeding programs is a key factor. For this reason, cluster analysis was performed among measured traits.

According to cluster analysis results, the seven observed traits were divided into four clusters (Figure 1). Cluster 1 had two traits, consisting of PH and IL. Cluster 2 owned only one trait TD. Cluster 3 possessed also only one trait such as NN. Cluster 4 included two subgroups, the first subgroup covering two traits, FLL, and FFY, and the second subgroup consisting of one trait, FLW.

The similarity levels of FLL with FFY, FLW, and PH were found as high at 88.06%, 86.41%, and 73.69%, respectively (Table 5). Moreover, the similarity levels of PH with IL, TD and NN became also 78.73%, 73.47%, and 69.62%, respectively. The least and the longest distances occurred between FLL, and FLW (0.23); between PH, and NN (0.60), respectively (Table 5).

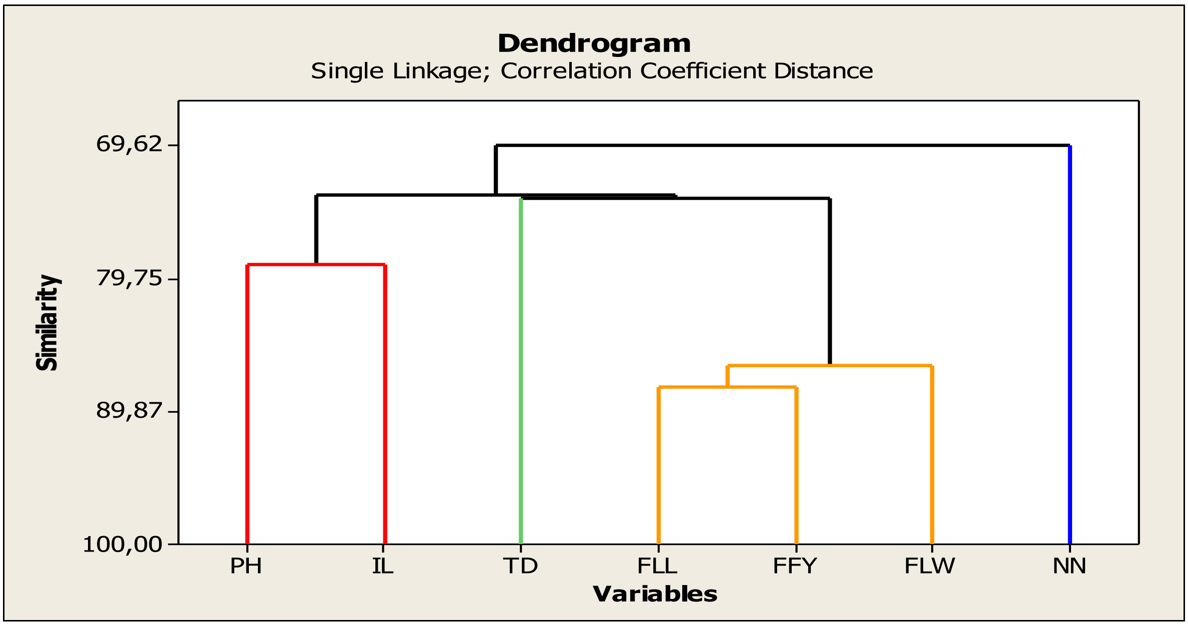

Figure 1. Dendogram of the crested wheatgrass populations revealed by cluster analysis based on agro-morphological values

Table 5. Similarity and distance levels of agro-morphological values revealed by cluster analysis (single linkage) based on the crested wheatgrass populations

Step	Traits	Traits	Similarity level (%)	Distance level
1	FLL	FFY	88.06	0.23
2	FLL	FLW	86.41	0.27
3	PH	IL	78.73	0.42
4	PH	FLL	73.69	0.53
5	PH	TD	73.47	0.54
6	PH	NN	69.62	0.60

As a result, PH and FLL of the plants must be taken into account at initial periods of crested wheatgrass breeding programs. Thus it could be possible for achieving high yield materials and reaching successful breeding results.

Hay quality traits

In this study, characteristics such as crude protein content, digestible crude protein content, ADF, NDF, and relative nutritional value were investigated as hay quality characteristics. All those traits may be considered key selection criteria for high quality genotypes. Moreover, the nutrient contents of the forage have an important role in animal feeding. Less work on nutritive values in crested wheatgrass has been become because of considering other traits more important so far (Robins and Jensen, 2020).

Crude protein content (CPC, %)

No significant differences were observed among crested wheatgrass populations in crude protein content (CPC) in 2015 and two-year averages (Table 6). But significant difference ($P<0.05$) was found between them in CPC in 2016. There was found to be significant difference ($P <0.01$) between two years but the year x variety interaction was not a significant. CPCs in 2015, 2016, and the two-year averages were 13.6%, 15.1%, and 14.4%, respectively. The high heritability of protein content (Ray et al 1996) is the reason why the year x population interaction is not significant. Crude protein has been considered a measure of quality in forage crops for a long time (George and Lorenz, 1969). The grass is famous for its nutritious feed production, especially in the early spring, but leaf aging later in the season causes a rapid decline in forage quality (Asay, 1995). Besides, the right cutting time is very important for producing high-quality forage and to store also important without losing quality values.

Table 6. Crude protein content (CPC) (%), and digestible protein content (DPC) (%) in studied populations

Populations	Crude Protein Content			Digestible Protein Content		
	2015	2016	Ave.	2015	2016	Ave.
G-465	13.4	14.8 b	14.1	10.8	11.1 ab	11.0
G-466	14.2	15.6 a	14.9	11.1	11.6 a	11.4
G-467	13.1	15.7 a	14.4	10.3	11.7 a	11.0
Control	14.0	14.5 b	14.2	10.7	10.8 b	10.8
Mean	13.6	15.1	14.4	10.7	11.3	11.0
$F_{(pop.)\ (0,05)}$	0.6	4.9*	1.0	0.7	4.2*	1.4
$A.Ö.F._{(0,05)}$	2.2	0.8	1.1	1.2	0.6	0.6
$F_{(year)\ (0,05)}$			16.3**			7.5*
$F_{(pop.x\ year)\ (0,05)}$			1.4			1.6
D.K. (%)	11.7	4.0	8.1	8.2	3.7	6.0

*, **Significant at 5 and 1 % probability levels, respectively

Protein contents varied based on the genetic characteristics of cultivars and cutting time in the growth season (Turk et al., 2009; Chand et al., 2022). They were found as 29.59%-33.78% in the grazing period, and 8.98%-11.96% in the flowering period (Açıkgöz, 1982). Moreover, crude protein contents were differently found in various studies as 8.93% in 1975 and 6.51% in 1976 (Altın, 1982); 12.20% (10.28-14.47%) (Serin, 1991); 6.08% (Unal and Eraç, 2000); 6.09-15.82% (Demirbağ et al., 2014); 120 g kg^{-1} DM in North America, 122 g kg^{-1} dry matter (DM) in Europe, 120 g kg^{-1} DM in Asia (Tandoh et al., 2019). Those variations may be explained by genetic and environmental factors such as various varieties, different growth stages, climatic conditions, locations, and years (Loaiza et al 2017; Habermann et al 2019).

Digestible crude protein content (DCPC, %)

No significant differences were among crested wheatgrass populations in digestible crude protein content (DCPC) in the first-year and two-year averages (Table 6). But significant difference (P<0.05) was found between them in DCPC in the second year. The difference between the two years was found to be significant (P<0.05) but the year x population interaction was not significant. DCPCs in 2015, 2016 and two-year averages were 10.7%, 11.3% and 11.0%, respectively.

Acid detergent fiber content (ADFC, %)

There seemed significant differences (P<0.01) among crested wheatgrass populations in ADFC in the second-year and two-year averages (Table7). No significant differences were found between years and the year x variety interaction. ADFCs in 2015, 2016 and two-year averages were 40.4%, 40.9%, and 40.7%, respectively. Due to the high heritability of ADF (Ray et al 1996), the year x population interaction was not significant.

Table 7. Acid detergent fiber (ADFC) (%), neutral detergent fiber (NDFC) (%) and relative feeding value (RFV) in studied populations

Populations	Acid Detergent Fiber Content			Neutral Detergent Fiber Content			Relative Feeding Value		
	2015	2016	Ave.	2015	2016	Ave.	2015	2016	Ave.
G-465	39.6	39.8 c	39.7 b	63.8	74.5	69.1	84.7	72.4 a	78.5
G-466	40.4	42.0 a	41.2 a	64.7	75.9	70.3	82.6	68.9 b	75.8
G-467	40.8	40.5 bc	40.6 a	65.6	75.4	70.5	81.1	70.8 ab	75.9
Control	40.8	41.4 ab	41.1 a	63.0	75.5	69.2	86.3	69.8 b	78.1
Mean	40.4	40.9	40.7	64.3	75.3	69.8	83.7	70.5	77.1
$F_{(pop.)\ (0.05)}$	1.2	10.1**	5.3**	0.3	1.7	0.5	0.3	5.3*	0.5
$LSD_{(0.05)}$	1.6	0.9	0.9	6.4	1.5	3.0	12.5	2.0	5.8
$F_{(year)\ (0.05)}$			2.9			111.0**			43.5**
$F_{(pop.x\ year)\ (0.05)}$			1.7			0.3			0.4
CV (%)	2.9	1.7	2.4	7.2	1.4	4.8	10.8	2.0	8.2

*, **Significant at 5 and 1 % probability levels, respectively

Acid detergent fibers were determined such as 307-364 g kg^{-1} (Albayrak and Türk, 2011); 33.63-46.05% in 2007; 32.94-47.25% in 2008 (Demirbağ et al., 2014); 359 g kg^{-1} DM in North America, 342 g kg^{-1} DM in Europe, 342 g kg^{-1} DM in Asia (Tandoh et al., 2019). In addition, it was positively correlated with forage yield (Tandoh et al., 2019). As the rate of ADF increases in the feed, the digestibility, and energy value decrease (Açıkgöz, 2021b). When crested wheatgrass plants mature, they have a low leaf-to-stem ratio, and also contain high fiber concentrations (Daugherty et al., 1982).

Neutral detergent fiber content (NDFC, %)

No significant differences were observed among crested wheatgrass populations in NDFC in the first year, the second year, and two-year averages (Table 7). The difference between years was found to be significant (P<0.01) but the year x population interaction was not significant. NDFCs in 2015, 2016 and two-year average were 64.3%, 75.3% and 69.8%, respectively. The high heritability of NDF (Ray et al 1996) led to the fact that year x variety of interaction was not important.

Besides, neutral detergent fibers contents were measured such as 576-626 g kg^{-1} (Albayrak and Türk, 2011); 48.65-62.37% in 2007; 48.59-64.57% in 2008 (Demirbağ et al., 2014); 596 g kg^{-1} DM in North America, 584 g kg^{-1} DM in Europe, 584 g kg^{-1} DM in Asia (Tandoh et al., 2019). In addition, NDF is an indicator of the maturity stage of the plant and is effective in the feed consumption of animals (Açıkgöz, 2021b). When the NDF content in feed decreases, the animal's feed consumption increases (Açıkgöz, 2021b).

Relative feeding value (RFV)

No significant differences were observed among crested wheatgrass populations in relative feeding value (RFV) in the first-year, and two-year averages (Table 7). Significant differences were detected between them in RFV in the second year (P<0.05) and between the two years (P<0.01). RFVs in 2015, 2016, and the two-year averages were 83.7, 70.5, and 77.1, respectively.

High rainfall in 2015 affects positively directly on RFV, but higher NDFC in 2016 influenced negatively on RFV. Moreover, Turk et al. (2009) reported that climate, season, weather, and soil moisture led to influence RFV. The RFV is an index that is used to predict the intake and energy value of the forages and it is derived from the digestible dry matter (DDM) and dry matter intake (DMI) (Albayrak and Türk, 2011). Relative feeding values were identified such as 90.3-105.2 (Albayrak and Türk, 2011); 79.10-119.94 in 2007; 75.05-121.07 in 2008 (Demirbağ et al. 2014).

CONCLUSIONS

In this study, the three advanced populations were observed and assessed for agro-morphological and quality traits. One of these populations, the G-465 population, had the highest fresh forage and hay yields of all populations. It also had the highest relative feed value, even though there are no significant differences seemed among the study populations for crude protein content and relative feed value in two-year averages. So, the G-465 advanced population showed good performance under semiarid conditions, and it is advisable for similar circumstances.

Although reached present yield level is satisfactory, future breeding studies should be enriched with genetic resources having a wide variation. Moreover, future projects should be focused on special ecological zones (especially, climate, soil, topography, etc.) under semi-arid conditions for higher yield, quality, and adaptation. In addition, high correlation coefficients existed between fresh forage yield and some traits as stem diameter, internode length, flag leaf length, and flag leaf width.

Thus, these traits mentioned above should be used in the phenotypic selection of plants in the initial stages of crested wheatgrass breeding studies. Therefore, the right selection leads to the shortening of the breeding process and achieving successful ends.

These results of the present research study are also promising the infrastructure for future breeding studies in crested wheatgrass.

REFERENCES

Açıkgöz, E., 1982. *The researches on some morphological and agronomical characters with flower biology in crested wheatgrass (Agropyron cristatum L. Gaertn.).* Ankara University, Agriculture Faculty Publications, 802, Ankara.

Açıkgöz, E., 2021a. *Forage crops breeding.* Forage crops, Ministry of Agriculture and Forestry, General Directorate of Plant Production, 2: 717-777.

Açıkgöz, E., 2021b. *Factors affecting hay quality*. Forage crops, Ministry of Agriculture and Forestry, General Directorate of Plant Production, 2: 587-603.

Albayrak, S., and Ekiz, H., 2004. *Determination of related characters with hay yield using correlations coefficients and path analysis insome perennial grasses*. Journal of Agriculture Faculty, Ankara University, 10(3): 250-257.

Albayrak, S., and Turk, M., 2011. *Effects of fertilization on forage yield and quality of crested wheatgrass (Agropyron cristatum L. Gaertn.).* Bulg. J. Agric. Sci., 17: 642-648.

Altın, M., 1982. *The yields of hay and crude protein on various sowing methods some forage crops and their mixtures, crude protein content of plant species and botanical compositions of mixtures*, *2. crude protein contents and botanical compositions of mixtures*, Turk. J .Agric. For., 6: 109-125.

Anonymous, 2001. *Wheatgrass species (Agropyron spp. (Gaertn.). Technical Instructions Instructions for Measuring Agricultural Values.* Ministry of Agriculture and Forestry of Republic of Turkey. Variety Registration and Seed Certification Center Directorate, Ankara. https://www.tarimorman.gov.tr/BUGEM/TTSM/Belgeler/Duyuru%20Belgeleri/2019/%C3%A7ay%C4%B1r%20mera/bu%C4%9Fdaygil%20yem%20bitkileri.pdf

Anonymous, 2014. *Soil analysis results of trait in Gölbaşı*. Central Soil, Fertilizer, and Water Resources Research Institute, Ankara. https://www.tarimorman.gov.tr/Announcement/201/Soil-Fertilizer-And-Water-Resources-Central-Research-Institute-Is-On-The-Way-To-International-Excellence

Anonymous, 2016. *The climatic data of Gölbaşı, and Yenimahalle*. The General Director of State Meteorological, Annual Climatic Observation Table Report. https://mgm.gov.tr/eng/forecast-cities.aspx

Asay, K.H., 1995. *Wheatgrasses and wild- ryes: The perennial Triticeae*. In: Barnes, R.F., Miller, D.A., Nelson, C.J. (eds.), Forages. An Introduction to Grassland Agriculture. Iowa University Press, Ames, AI: 373-394.

Baral, K., Coulman, B., Biligetu, B., Fu, Y.-B., 2020. *Advancing crested wheatgrass [Agropyron cristatum (L.) Gaertn.] breeding through genotyping-by-sequencing and genomic selection*. PLoS One, 15(10): e0239609. https://doi.org/10.1371/journal.pone.0239609 (Accessed date: 13.07.2021)

Bayat, H., Nemati, H., Tehranifar, A., Gazanchian, A., 2016. *Screening different crested wheatgrass [Agropyron cristatum (L.) Gaertner.] accessions for drought stress tolerance*. Archives of Agronomy and Soil Science, 62(6): 769-780. DOI: 10.1080/03650340.2015.1094182 https://profdoc.um.ac.ir/articles/a/1056997.pdf (Accessed date: 09.02.2022)

Chand, S., Indu Singhal, R.K., Govindasamy, P., 2022. *Agronomical and breeding approaches to improve the nutritional status of forage crops for better livestock productivity*. Grass Forage Sci., 77(1): 11-32. https://ma.x-mol.com/paperRedirect/1483491719462010880" \t "_blank

Currie Pat, O., and Peterson, G., 1966. *Using growing-season precipitation to predict crested wheatgrass yields*. Journal of Range Management, 19(5): 284-288. http://www.jstor.org/stable/3895721 (Accessed date: 15/09/2011)

Daugherty, D.A., Britton, C.M., Turner, H.A., 1982. *Grazing management of crested wheatgrass range for yearling steers.* J. Range. Manage., 35: 347-350.

Demir İ., and Turgut, İ., 1999. *Plant Breeding*. Ege University, Agriculture Faculty publications, 96: 451.

Demirbag, N.S., Ekiz, H., Ozkan, U., 2014. *Effects of different harvest time of crested wheatgrass which is in artificial range mixture on forage yield and hay quality under central Anatolia conditions.* Journal of Applied Biological Sciences, 8(1): 14-21.

Erdoğdu, İ., Atalay, A.K., Sever, A.L., 2016. *Determination of the characteristics of breeding importance in grassland leaves (Agropyron cristatum L. Gaertn.) collected from natural areas in Eskişehir.* Journal of Field Crops Central Research Institute, 25(special number 2): 200-205. DOI: 10.21566/tarbitderg.281896

George, A.R., and Lorenz, R.J., 1969. *Pasture productivity of crested wheatgrass as influenced by nitrogen fertilizatıon and alfalfa*. Agricultural Research Service U.S. Department of Agrıculture, Department of Animal Science North Dakota Agricultural Experiment Station, 1402: 1-33.

GEPSCA, 2014. *The project report of germplasm enhancement of some plant species for use in the rehabilitation of the central Anatolia rangelands (unpublished).* Central Research Institute for Field Crops, Ankara, Turkey.

Gökkuş, A., Koç, A., Bakoğlu, A., 1997. *The change of some morphological, agronomic and chemical characteristics of crested wheatgrass (Agropyron cristatum Gaertn.) with respect to time, plant height and aboveground biomass.* Journal of Field Crops Central Research Institute, 6(2): 49-61. https://dergipark.org.tr/en/pub/tarbitderg/issue/11516/137202

Gökkuş, A., Serin, Y., Koç, A., Tan, M., 2001. *The effects of different row spacings, cutting heights and stubble burning on seed yield and yield components of Crested Wheatgrass (Agropyron cristatum L. Gaertn.).* Turk. J. Agric. For., 25: 71-78.

Gökkuş, A., 2020. *A Review on the Factors Causing Deterioration of Rangelands in Turkey* . Turkish Journal of Range and Forage Science, 1, 1: 28-34. https://dergipark.org.tr/en/pub/turkjrfs/issue/57216/774544 (Accessed date: 02.02.2022)

Habermann, E., Dias de Oliveira, E A., Contin, D.R., Delvecchio, G., Viciedo, D.O., de Moraes, M.A., de Mello Prado, R., de Pinho Costa, K.A., Braga, M.R., Martinez, C.A., 2019. *Warming and water deficit impact leaf photosynthesis and decrease forage quality and digestibility of a C4 tropical grass.* Physiologia Plantarum, 165, 2: 383-402. https://doi.org/10.1111/ppl.12891

Hamerlynck, E.P., Denton, E.M., Davies, K.W., Boyd, C.S., 2019. *Photosynthetic regulation in seed heads and flag leaves of sagebrush-steppe bunchgrasses*. Conserv Physiol., 7(1): coz112. doi: 10.1093/conphys/coz112. PMID: 31949896; PMCID: PMC6956783.

Hofmann, L., Ries, R.E., Karn, J.F., Frank, A.B., 1993. *Comparison of seeded and native pastures grazed from mid-May through September*. J. Range Management, 46: 251-254. https://repository.arizona.edu/bitstream/handle/10150/644530/8833-8714-1-PB.pdf?sequence=1 (Accessed date: 14.07.2021)

Hull, A.C., 1971. *Grass mixtures for seeding sage brush lands*. Journal of Range Management. 24(2): 150-152.

Hull, A.C., 1972. *Growth characteristics of crested and fairway wheatgrasses in Southern Idaho.* Journal of Range Management, 25(2): 123-125.

Karadağ, Y., Çınar, S., Taşyürek, T., Gökalp, S., Özkurt, M., Hatipoğlu, R., 2017. *Development of suitable Crested Wheatgrass (Agropyron cristatum (L.) Gaertn.) varieties for intermediate and transitional zones*. KSU Journal of Natural Sciences, 20 (Special Issue): 83-87. DOI: 10.18016/ksudobil.348928 (Accessed date: 08.03.201)

Kutlu, R.H., 2008. *Feed assessment and analysis methods (Lecture note).* Çukurova University, Agricultural Faculty, Livestock Department: 10.

Leffler, A.J., Monaco, T.A., James, J.J., 2011. *Morphological and physiological traits account for similar nitrate uptake by Crested Wheatgrass and Cheatgrass.* Natural Resources and Environmental Issues, 17: Article 10. http://digitalcommons.usu.edu/nrei/vol17/issl/1 0 (Accessed date: 25.05.2015)

Loaiza, P.A., Balocchi, O., Bertrand, A., 2017. *Carbohydrate and crude protein fractions in perennial ryegrass as affected by defoliation frequency and nitrogen application rate*. Grass and Forage Science, 72(3): 556-567.

Mellish, A.E., and Coulman, B.E., 2002. *Morphological characteristics of crested wheatgrass populations of diverse origin*. Canadian Journal of Plant Science, 82: 693-699.

Ray, I.M., Karn, J.F., Dara, S.T., 1996. *Heritabilities of nutritive quality factors and interrelationships with yield in tetraploid crested wheatgrass*. Crop Sci., 36: 1488-1491.

Robins, J.G., and Jensen, K.B., 2020. *Breeding of the Crested Wheatgrass Complex (Agropyron spp.) for North American temperate rangeland agriculture and conservation*. Agronomy, 10: 1134. https://doi.org/10.3390/agronomy10081134

Rogler, G.A., and Lorenz, R.J., 1983. *Crested Wheatgrass-Early history in the United States*. Journal of Range Management, 36(1): 91-93.

Ryle, G.J.A., 1966. *Effects of photoperiod in the glasshouse on the growth of leaves and tillers in three perennial grasses*. Ann. Appl. Biol., 57(2): 57-268.

Serin, Y., 1991. *The effects of different row spacing and fertilizers on forage and crude protein yields of Crested Wheatgrass (Agropyron cristatum (L.) Gaertn.) under the semiarid conditions in Erzurum*. Atatürk University, Agriculture Faculty Journal, 22(1): 1-12.

Starkey, D.L., Shroyer, J.P., Fick, W.H., Harbers, L.H., 1993. *Effects of early-cutting management on forage yıeld and quality of alfalfa in Northeast Kansas.* Kansas Agricultural Experiment Station Research Reports, v.0(12). https://doi.org/10.4148/2378-5977.7272

Tan, M., and Yolcu, H., 2021. *Current status of forage crops cultivation and strategies for the future in Turkey: A review*. Journal of Agricultural Sciences, 27(2): 114-121. DOI: 10.15832/ankutbd.903732 (Accessed date: 09.02.2022)

Tandoh, S., Coulman, B.E., Biligetu, B., 2019. *Assessment of crested wheatgrass (Agropyron cristatum L.) accessions with different geographical origins for agronomic and phenotypic traits and nutritive value.* Euphytica, 215: 161. https://doi.org/10.1007/s10681-019-2476-4 (Accessed date: 28.01.2022)

Tekkanat, A., and Soylu, S., 2005. *Determination of seed yield and major quality properties in popcorn cultivars*. Selçuk University, Journal of Agricultural Faculty, 19(37): 51-60.

Turk, M., Albayrak, S., Yuksel, O., 2009. *Effects of fertilisation and harvesting stages on forage yield and quality of hairy vetch*. New Zealand J. of Agric. Research, 52: 269-275.

Ünal, S., and Eraç, A., 2000. *The researches on effects of mixture sowing rates of Cicer milkvetcth (Astragalus cicer L.) - Wheatgrass (Agropyrou Gaertn.) for forage yield, and botanical composition*. Journal of Field Crops Central Research Institute, 9(1-2): 32-54. https://dergipark.org.tr/tr/pub/tarbitderg/issue/11512/137133

Ünal, S., and Fırıncıoğlu, H K., 2009. *Variations in some populations of Crested Wheatgrass (Agropyron cristatum L.) under the semi-arid conditions of Central Highlands of Turkey*. 1st National Drought and Desertification Symposium, 16-18 June 2009, Konya.

Ünal, S., Mutlu, Z., Mermer, A., Urla, Ö., Ünal, E., Aydoğdu, M., Dedeoğlu, F., Özaydın, K., Avağ, A., Aydoğmuş, O., Şahin, B., Aslan, S., 2012. *A study on the evaluation of Ankara Province rangelands*. Journal of Field Crops Central Research Institute, 21(2): 41-49. https://dergipark.org.tr/tr/pub/tarbitderg/issue/11499/13698

Ünal, S., Mutlu, Z., Urla, Ö., Yıldız, H., Şahin, B., 2013. *Evaluation and determination of rangeland vegetation in Kayseri Province*. Journal of Field Crops Central Research Institute, 22(2): 86-95. https://dergipark.org.tr/tr/pub/tarbitderg/issue/11497/137104

Ünal, S., Mutlu, Z., Urla, Ö., Yıldız, H., Aydoğdu, M., Şahin, B., Aslan, S., 2014. *Improvement possibilities and effects of vegetation subjected to long-term heavy grazing in the steppe rangelands of sivas*. Journal of Field Crops Central Research Institute, 23(1): 22-31. DOI: 10.21566/tbmaed.40290

Unal, S., and Mutlu, Z., 2016. *Morphological and agronomical characteristics of a Rhizomatous Crested Wheatgrass (Agropyron cristatum L. Gaertn.) collected from Ankara Province*. Journal of Field Crops Central Research Institute, 25(1): 1-10.

Unal, S., 2018. *Determination of agronomic performances in Crested Wheatgrass (Agropyron cristatum L. Gaertn.) under semiarid conditions*. Fresenius Environmental Bulletin, 27(10): 7595-7603.

Yu, X., Li, X., Ma, Y., Yu, Z., Li, Z., 2012. *A genetic linkage map of crested wheatgrass based on AFLP and RAPD markers*. Genome, 55: 327-335. https://cdnsciencepub.com/doi/pdf/10.1139/g2012-014 (Accessed date: 09.02.2022)