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Morphological Diversity of Wild Oat (*Avena fatua* L.) in Wheat Cultivation Areas of Iğdır Province, Türkiye

Iğdır İli Buğday Yetiştirilen Alanlarında Yabani Yulafın (*Avena fatua* L.) Morfolojik Çeşitliliği, Türkiye

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ABSTRACT

Avena fatua L. (wild oat) is a major weed species that causes yield losses in wheat fields and threatens agricultural production. In order to develop effective management strategies, it is essential to understand the morphological diversity of this species. Morphological differences between populations reflect the plant's ability to adapt to environmental conditions and its competitiveness, which can help in the selection of appropriate control methods. This study was conducted to reveal the morphological diversity of *A. fatua* populations, which are common and constitute an important weed problem in wheat cultivation areas of Iğdır province and its surroundings. For all parameters except stem diameter, statistically significant differences were found at the 1% level ($p<0.01$). The plant height ranged from 163.00 cm to 83.25 cm, leaf length from 32.50 cm to 15.75 cm, spike length from 43.75 cm to 24.00 cm, flower count from 57.50 to 24.00, fresh weight from 26.50 g to 15.75 g, and dry weight from 13.50 g to 2.75 g. Particularly, populations such as IĞR22 and IĞR30 stood out with high plant height and flower count. Furthermore, through multivariate analysis, similarities and differences between the populations were visually assessed, and it was observed that populations such as IĞR8, IĞR30, IĞR7, IĞR22, and IĞR18 were distinctly separated from others. The study demonstrates that there is significant morphological diversity among *A. fatua* populations. This diversity allows it to have the capacity to adapt to different environmental conditions and to spread more effectively in agricultural areas. In this context, a more detailed study of the morphological characteristics of *Avena fatua* will contribute to the development of effective weed control strategies.

Keywords: *Avena fatua,* Wheat, morphological diversity, weed

ÖZ

Avena fatua L. (yabani yulaf), buğday tarlalarında verim kayıplarına neden olan ve tarımsal üretimi tehdit eden önemli bir yabancı ot türüdür. Etkili yönetim stratejileri geliştirebilmek için bu türün morfolojik çeşitliliğini anlamak önemlidir. Popülasyonlar arasındaki morfolojik farklılıklar, bitkinin çevre koşullarına uyum sağlama yeteneğini ve rekabet gücünü yansıtır ve uygun mücadele yöntemlerinin seçiminde yardımcı olabilir. Bu çalışma, Iğdır ili ve çevresindeki buğday ekim alanlarında yaygın olarak bulunan ve önemli bir yabancı ot sorunu oluşturan *A. fatua* popülasyonlarının morfolojik çeşitliliğini ortaya koymak amacıyla yürütülmüştür. Gövde çapı hariç tüm parametrelerde %1 düzeyinde istatistiksel olarak anlamlı farklılıklar bulunmuştur ($p<0,01$). Bitki boyu 163,00 cm ile 83,25 cm arasında, yaprak uzunluğu 32,50 cm ile 15,75 cm arasında, başak uzunluğu 43,75 cm ile 24,00 cm arasında, çiçek sayısı 57,50 ile 24,00 arasında, taze ağırlık 26,50 g ile 15,75 g arasında ve kuru ağırlık 13,50 g ile 2,75 g arasında değişmiştir. Özellikle IĞR22 ve IĞR30 gibi populasyonlar yüksek bitki boyu ve çiçek sayısı ile ön plana çıkmıştır. Ayrıca çok değişkenli analiz ile populasyonlar arasındaki benzerlik ve farklılıklar görsel olarak değerlendirilmiş ve IĞR8, IĞR30, IĞR7, IĞR22 ve IĞR18 gibi populasyonların diğerlerinden belirgin bir şekilde ayrıldığı görülmüştür. Çalışma, *A. fatua* popülasyonları arasında önemli morfolojik çeşitlilik olduğunu ortaya koymaktadır. Bu çeşitlilik, farklı çevre koşullarına uyum sağlama ve tarım alanlarında daha etkili bir şekilde yayılma kapasitesine sahip olmasını sağlar. Bu bağlamda, *A. fatua*'nın morfolojik özelliklerinin daha detaylı bir şekilde incelenmesi, etkili yabancı ot kontrol stratejilerinin geliştirilmesine katkıda bulunacaktır.

Anahtar Kelimeler: *Avena fatua,* buğday, morfolojik çeşitlilik, Yabancı ot

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INTRODUCTION

Wheat (Triticum aestivum L.), a member of the Poaceae family, is an annual crop with a rich and significant historical background, dating back over 10,000 years to the ancient region of Mesopotamia. Today, it is considered one of the most important and widely cultivated staple grains in the world and plays a central role in global food security and agricultural economies. Wheat has been integral to the development of human civilisations, providing sustenance and contributing to cultural and technological advances throughout history. Today, it remains a primary source of nutrition, used in a wide variety of foods including bread, pasta and bakery products, and continues to be a critical crop for feeding the world's growing population. (Shiferaw et al., 2013; Feldman, 2001). Wheat plays a critical role in global food security and is a fundamental food source for both humans and animals, accounting for approximately 35-40% of the global population's primary food source (Curtis et al., 2002; Ramírez-González et al., 2018). Although global production continues to rise to meet the food needs of the growing population, As in other cultivated plants, Alptekin and Gürbüz, 2022; Bozhüyük et al., 2022; Alptekin et al., 2022; Tülek et al., 2022; Alptekin et al., 2023; Gürbüz et al., 2024; et al., Gürbüz and Alptekin, 2024; Akelma et al., 2022; Gurbuz et al., 2025), wheat yield is threatened by numerous biotic and abiotic factors, with weeds being a major concern. Weeds can cause yield losses ranging from 10% to 50% during wheat development by competing for resources, which negatively impacts global food security (Mennan, 1998; Chhokar et al., 2012). Particularly, species such as *Avena fatua* L. (wild oat) are commonly found in wheat fields and are among the most harmful weeds, reducing both yield and quality (Aibar et al., 1991; Bajwa et al., 2017).

A. fatua, a self-pollinating, tall annual weed in the Poaceae family, is a major threat to agricultural areas worldwide (Yu et al., 2013; Holm et al., 1977). This species spreads rapidly due to its high growth rate and seed production (Martín and Scursoni, 2018). *A. fatua* is particularly widespread in subtropical and temperate regions of Asia, Australia, Europe, the U.S., and Canada (Holm et al., 1977; Balyan et al., 1991; Fernandez-Quintanilla et al., 1990; Beckie et al., 2012; Ahmad-Hamdani et al., 2013; Harker et al., 2016). In Turkey, studies on the prevalence and density of weeds in wheat fields have highlighted wild oat species (Avena spp.). Studies in Çukurova have identified wild oat as a significant problem in wheat production (Uygur et al., 1986). Studies in the Pasinler Plain also identified a high prevalence of this species (Kaya and Zengin, 2000). Studies in Diyarbakır wheat fields have revealed that wild oat species are among the dominant weeds (Pala and Mennan, 2017). Apart from this, many studies carried out in different regions of Turkey have determined that wild oat is the main common and problematic weed in wheat agriculture (Sönmez, 1973; Karasu and Sönmez, 1978; Kadıoğlu, 1989; Taştan and Erciş, 1991; Boz, 1992; Uludağ, 1993; Orel, 1996; Uygur, 1997; Boz et al., 2000; Tursun, 2002; Kitiş and Boz, 2003; Sırma and Kadıoğlu, 2010; Kordali and Zengin, 2011; Özaslan, 2011; Gökalp and Üremiş, 2015; Sizer and Tepe, 2016; Güncan, 2019; Ücrak et al., 2019).

A. fatua seeds usually mature and shed before the crop is harvested, and these seeds mix into the soil (Almaghrabi, 2012). These seeds can remain viable in the soil seed bank for several years and germinate under favorable conditions (Khan et al., 2008). This characteristic complicates its control and makes it a persistent problem in field management (Aibar et al., 1991; Harker et al., 2016). Wheat yield losses due to *A. fatua* density can range from 10% to 80%. Additionally, wild oats often have a growth advantage over wheat in the late season, leading to shading and subsequent yield reduction (Cudney et al., 1991). For these reasons, it is quite challenging to keep this weed species under control and maintain it below acceptable economic thresholds (Bajwa et al., 2017). This species exhibits a wide range of morphological diversity, and this diversity is an important parameter for understanding population differences. Studies have shown that various morphological traits of wild oats can change significantly depending on environmental conditions, and these traits play a key role in the spread and competitive ability of populations (Holm et al., 1977; Barroso et al., 2004).

Among the various morphological parameters, characteristics such as plant height, leaf length, spike length, spikelet count, flower count, fresh weight, and dry weight are crucial in revealing the differences between *A. fatua* populations. For instance, populations with a wide range of plant heights highlight the species' success in adapting to environmental conditions and its competitive strength (Pala and Mennan, 2017). Parameters like leaf length and spike length are directly linked to the species' photosynthetic efficiency and growth capacity (Wang et al., 2018). The morphological diversity observed in wild oat populations indicates that they have different adaptation strategies in field conditions, making it an important factor influencing management strategies in agricultural areas (Kaya and Zengin, 2000). Numerous studies have been conducted on the morphological characteristics of *Avena fatua*. Characters such as plant height, tillering capacity, panicle length, number of spikelets and awn length are widely used in the identification of the species and in determining differences among populations. Beckie et al.i (2012) described the general morphology of in Canadian populations in detail and revealed the main characters used to distinguish this species from other Avena species. Pavlović et al. (2020), reported significant morphological variations by measuring spikelets and awns in different populations in Bosnia and Herzegovina. In another study conducted in Romania, it was stated that the strong correlation between panicle length and number of spikelets (r = 0.829) is important in understanding morphological diversity (Ionescu, 2016). Also, Somody et al. (1984) compared *A. fatua* and A. sterilis in terms of morphological characters, showing that awn length and panicle structure are particularly distinctive. Recent studies have also shown that seed size, mass, and morphological variation in populations collected from different regions are related to environmental conditions (Ņečajeva et al., 2021). In particular, detailed evaluations using morphological analyses contribute to understanding the structural differences between populations and guide the determination of appropriate management approaches. The purpose of this study is to examine the morphological diversity of *A. fatua* populations.

MATERIALS AND METHODS

In this study, *A. fatua* seeds were collected from 50 wheat fields in Iğdır province and its districts. Efforts were made to select fields that were representative of the region and sufficient in number for sampling. The number of survey sites was determined according to the proportion of wheat cultivation areas in each district. However, due to the absence or insufficient quantity of *A. fatua* in some wheat fields visited, samples were only collected from those fields where *A. fatua* was present in sufficient amounts. Additionally, consultations with pesticide dealers and farmers who had reported issues with *A. fatua* led to further sampling from those areas. Control samples were taken from non-agricultural areas such as pastures and meadows that had never been treated with herbicides. This location was selected from a natural pasture area free of any agricultural activity or herbicide application. The aim was to determine the morphological characteristics of populations away from agricultural pressures as a reference and to compare them with other populations. Davis (1965-1988) was used in the identification of plant samples. The wheat cultivation areas and the number of samples collected from each district in Iğdır province are provided in Table 1.

Table 1. Wheat cultivation areas in Iğdır province and the number of samples collected from each district.

District	Planting area (ha)	%	Sample size (number)
Aralık	17,400	8.6	1
Karakoyunlu	9,155	4.5	5
Centre	65,000	32.4	29
Tuzluca	110,000	54.5	15
Total	201,555	100	50

The sampling points and field data were recorded using a GPS (Global Positioning System) device for the purpose of mapping. The locations of the wheat fields where *A. fatua* seeds were collected, recorded with the GPS device, are presented in Table 2.

Collection and Cleaning of *Avena fatua* L. Seeds

In the districts of Iğdır Province, seeds of *A. fatua* were collected from fields where the weed density was above 10%. A total of 50 wheat fields were sampled, with approximately 1 kg of *A. fatua* seeds collected from each field. The collected seeds were placed in sacks, and the location information was recorded using GPS devices. These sacks were then transported to the Herbology Laboratory of the Faculty of Agriculture, Iğdır University, and the seeds were spread out to dry for 20 days. After drying, the seeds were cleaned. To break the dormancy of the seeds, they were stored at 4°C for 2 months in the university's refrigerator (Kon et al., 2007).

Table 2. Locations of wheat fields where *Avena fatua* seeds were collected, recorded with the GPS device

Code	Village	N	E	Code	Village	N	E
IĞR0	Meadow Pasture	39° 57″ 43	43° 57″ 17	IĞR26	Ali Kamerli, Central	39° 57″ 43	43° 57″ 17
IĞR1	Ali Kamerli, Central	39° 57″ 00	43° 58″ 25	IĞR27	Ali Kamerli, Central	39° 57″ 52	43° 57″ 04
IĞR2	Yukarıçarıkcı Central	39° 58″ 08	43° 55″ 54	IĞR28	Yukarıçarıkcı Central	39° 58″ 03	43° 57″ 04
IĞR3	Yukarıçarıkcı Central	39° 57″ 36	43° 56″ 48	IĞR29	Yukarıçarıkcı Central	39° 57″ 53	43° 56″ 55
IĞR4	Yaycı Central	39° 56″ 28	43° 58″ 35	IĞR30	Obaköy Central	39° 58″ 04	43° 57″ 13
IĞR5	Hoşhaber Central	39° 55″ 40	43° 59″ 46	IĞR31	Obaköy Central	39° 58″ 11	43° 57″ 27
IĞR6	Karakoyunlu	39° 58″ 28	44° 11″ 13	IĞR32	Obaköy Central	39° 58″ 16	43° 57″ 50
IĞR7	Melekli Central	39° 56″ 47	44° 06″ 35	IĞR33	Obaköy Central	39° 58″ 09	43° 57″ 57
IĞR8	Akyumak Central	39° 58″ 31	44° 03″ 02	IĞR34	Taşburun, Karakoyunlu	39° 59″ 01	44° 15″ 35
IĞR9	Çakırtaş Central	40° 01″ 03	44° 04″ 16	IĞR35	Tuzluca	40° 04″ 11	43° 39″ 53
IĞR10	Zülfikarköy/Karakoyunlu	40° 01″ 03	44° 04″ 16	IĞR36	Aşağı, Tuzluca	40° 04″ 13	43° 39″ 50
IĞR11	Zülfikarköy/Karakoyunlu	40° 01″ 13	44° 06″ 59	IĞR37	Aşağı, Tuzluca	40° 05″ 52	43° 39″ 22
IĞR12	Mürşitali/Karakoyunlu	39° 59″ 12	44° 09″ 26	IĞR38	Çıyrıklı/Tuzluca	40° 04″ 37	43° 39″ 43
IĞR13	Enginalan, Central	39° 57″ 55	44° 01″ 44	IĞR39	Aşağı, Tuzluca	40° 03″ 56	43° 40″ 16
IĞR14	Enginalan, Central	39° 58″ 56	44° 01″ 32	IĞR40	Köprübaşı/Tuzluca	40° 02″ 24	43° 45″ 42
IĞR15	Akyumak Central	39° 59″ 03	44° 01″ 36	IĞR41	Üçkaya/Tuzluca	39° 57″ 12	43° 65″ 90
IĞR16	Akyumak Central	39° 59″ 09	44° 01″ 35	IĞR42	Üçkaya/Tuzluca	39° 58″ 11	43° 39″ 42
IĞR17	Hakveyis, Central	39° 57″ 06	44° 01″ 21	IĞR43	Buruksu/Tuzluca	39° 58″ 17	43° 40″ 43
IĞR18	Kasımcan Central	39° 57″ 49	44° 00″ 39	IĞR44	Buruksu/Tuzluca	39° 57″ 46	43° 41″ 08
IĞR19	Kasımcan Central	39° 57″ 47	44° 00″ 33	IĞR45	Üçkaya/Tuzluca	39° 57″ 22	43° 39″ 33
IĞR20	Kasımcan Central	39° 57″ 47	44° 00″ 24	IĞR46	Köprübaşı/Tuzluca	40° 03″ 03	43° 43″ 40
IĞR21	Enginalan Central	39° 57″ 57	44° 00″ 44	IĞR47	Köprübaşı/Tuzluca	40° 03″ 01	43° 43″ 46
IĞR22	Kasımcan Central	39° 57″ 43	44° 00″ 12	IĞR48	Turabi/Tuzluca	40° 04″ 26	43° 45″ 33
IĞR23	Obaköy Central	39° 57″ 50	43° 59″ 59	IĞR49	Turabi/Tuzluca	40° 04″ 34	43° 45″ 34
IĞR24	Hakveyis, Central	39° 57″ 10	44° 00″ 19	IĞR50	Hacıağa/Aralık	40° 04″ 30	43° 45″ 30
IĞR25	Yaycı Central	39° 57″ 27	43° 57″ 32				

Establishment of the Experiment

The study on the morphological characteristics of *A. fatua* populations was designed as a randomized block design with 4 replications. For determining the morphological traits, *A. fatua* seeds were sown on 12.04.2022 in pots measuring 15x15 cm, with 10 plants per pot. The first five plants to germinate in each pot were tagged, and these plants were transferred to pots filled with a sterilized soil, sand, and sifted manure mixture (1:1:1 ratio). The biological stages of the plants were monitored from seed to seed, and morphological data were collected. The morphological parameters measured were plant height (cm), stem diameter (mm), leaf length (cm), spike length (cm), spikelet count, flower count, and fresh/dry biomass (g). The harvest was carried out between 10.06.2022 and 21.06.2022, as all populations did not mature simultaneously. During the harvest, mature plants were cut from the soil surface using scissors and transported to the laboratory separately. In the laboratory, the fresh weights of the harvested plants were measured, and to determine the dry weight, the plants were dried in an oven at 70°C for 3 days (Boylu and Altop, 2021). After drying, the dry weights were recorded.

Data Analysis

In this study, the morphological characteristics of *A. fatua*, including plant height, stem diameter, leaf length, spike length, spikelet count, flower count, fresh weight, and dry weight, were evaluated. The data were subjected to one-way analysis of variance (ANOVA) to assess significant differences between the means of different groups. Means were compared using Duncan's multiple comparison test ($p < 0.05$) (SPSS 20). The Duncan test was used to determine which groups differed from each other (SPSS, 1991). In addition to one-way analysis of variance, a series of statistical analyses were conducted to determine the magnitude and correlation of estimated parameters related to independent operations. The morphological traits of *A. fatua* plants evaluated in this study include plant height, stem diameter, leaf length, spike length, spikelet count, branch length, flower count, fresh weight, and dry weight. Various statistical methods were used to understand the relationships between these traits and to reveal the morphological differences and similarities among populations. After transforming/normalizing the data for morphological analysis, Initially, correlation analysis was performed between the variables, and this analysis identified the relationships between each morphological trait. Correlation analysis aims to measure the strength and direction of linear relationships between variables. Furthermore, hierarchical clustering analysis was performed, and populations with similar traits were grouped together. Hierarchical clustering is an effective method for forming groups based on the proximity of examples in the data set (PAST Software). Additionally, network analysis was used to visualize the interactions between morphological traits, and principal component analysis was conducted to provide more information by reducing the dimensionality of the data. Principal component analysis helps to identify the key components of the data by reducing multidimensional data sets to fewer dimensions (PAST Software).

RESULTS and DISCUSSION

When the morphological characteristics of *A. fatua* populations were examined, statistically significant differences at the 1% level ($p<0.01$) were found for all parameters except for stem diameter. These results indicate that there are significant morphological differences between *A. fatua* populations, except for stem diameter, where no differences were observed. The morphological characteristics of *A. fatua* plant height, stem diameter, leaf length, spike length, spikelet count, and their differences between populations are presented in Table 3, while branch length , flower count, fresh weight, and dry weight differences between populations are presented in Table 4.

Table 3. Morphological characteristics of *Avena fatua* and differences among populations (plant height, stem diameter, leaf length, spike length, spikelet count)

Code	Plant height (cm)	Stem diameter (mm)	Leaf length (cm)	Spike length (cm)	Spikelet count (number)
IĞR0	113.25±5.46^{j-n}	3.75±0.31^{a}	18.25±1.25^{e-l}	34.00±3.46$^{a-ı}$	17.00±1.45^{d-l}
IĞR1	110.00±2.27^{l-p}	3.05±0.10^{a}	18.50±0.29^{f-l}	32.75±1.65$^{b-ı}$	18.25±0.25^{c-k}
IĞR2	123.75±1.65^{f-k}	4.10±0.23a	18.50±1.32^{f-l}	39.50±3.12^{a-d}	16.25±2.06^{f-l}
IĞR3	104.50±5.44^{p-u}	3.58±0.28^{a}	18.00±1.29^{g-l}	30.00±2.97$^{d-ı}$	18.25±1.38^{c-k}

Table 3. Continued

IĞR4	106.00±5.2^{p-t}	2.46±0.04^{a}	19.88±1.71^{c-l}	31.00±2.35^{c-i}	20.25±1.18^{c-g}
IĞR5	146.50±4.56^{bc}	4.13±0.31^{a}	21.75±1.31^{b-j}	38.50±2.40^{a-f}	19.75±1.38^{c-h}
IĞR6	107.50±3.59^{m-t}	2.96±0.13^{a}	20.00±1.22^{c-l}	31.00±1.35^{c-i}	18.50±0.50^{c-j}
IĞR7	118.25±3.33^{i-n}	3.78±0.75 ^{a}	21.00±1.58^{b-k}	36.00±3.58^{a-g}	15.50±1.26^{g-l}
IĞR8	112.00±1.47^{k-p}	2.90±0.20 ^{a}	19.75±1.25^{c-l}	28.25±1.31^{f-i}	16.50±0.65^{f-l}
IĞR9	127.50±2.63^{e-i}	4.73±0.58a	22.00±4.18^{b-i}	30.25±6.64^{c-i}	14.50±2.22^{j-l}
IĞR10	111.25±3.50^{l-p}	3.55±0.20a	22.00±1.68^{b-i}	36.00±4.02^{a-g}	20.50±0.87^{b-f}
IĞR11	113.50±2.84^{j-n}	3.73±0.19^{a}	17.50±0.65^{h-l}	33.75±1.65^{b-i}	22.00±1.58^{b-d}
IĞR12	113.00±2.65^{j-n}	2.90±0.13^{a}	18.75±0.25^{e-l}	28.00±1.47^{g-i}	16.50±0.65^{fg-l}
IĞR13	109.50±2.60^{l-r}	3.45±0.33^{a}	23.00±0.71^{b-g}	32.25±0.25^{b-i}	16.50±1.32^{f-l}
IĞR14	132.00±5.67^{d-h}	3.18±0.09^{a}	21.25±1.60^{b-k}	31.25±0.75^{c-i}	15.75±1.65^{f-l}
IĞR15	142.50±5.32^{bd}	3.88±0.58^{a}	18.00±1.41^{g-l}	29.00±4.49^{d-i}	17.50±2.60^{d-l}
IĞR16	107.00±2.58^{n-t}	3.18±0.12^{a}	16.25±1.31^{kl}	28.50±1.85^{f-i}	17.25±0.25^{d-l}
IĞR17	139.75±11.68^{b-e}	3.98±0.55^{a}	19.00±2.12^{d-l}	32.25±5.54^{b-i}	18.50±2.78^{c-j}
IĞR18	117.50±9.39^{i-n}	4.15±0.62^{a}	32.50±1.89^{a}	36.50±3.86^{a-g}	18.75±1.25^{c-j}
IĞR19	150.25±2.93^{a-c}	4.33±0.23^{a}	19.75±0.85^{c-l}	31.00±1.58^{c-i}	19.50±1.19c^{-i}
IĞR20	127.50±4.44e-1	3.23±0.36^{a}	23.75±1.31^{b-e}	34.25±2.53^{a-i}	22.75±2.14^{a-c}
IĞR21	112.25±2.17^{j-p}	3.41±0.16^{a}	23.75±1.55^{b-e}	27.25±3.15^{g-i}	17.00±0.91^{e-l}
IĞR22	163.00±7.36^{a}	5.35±0.56^{a}	25.50±2.75^{b}	42.25±7.00^{ab}	25.00±1.47^{ab}
IĞR23	122.75±3.04^{g-l}	3.75±0.20^{a}	23.25±1.31^{b-f}	30.25±0.63^{c-i}	21.50±0.65^{b-e}
IĞR24	121.50±2.96^{h-m}	3.23±0.09^{a}	18.75±0.48^{e-l}	32.00±0.82^{c-i}	19.50±0.87^{c-i}
IĞR25	116.00±6.79^{j-n}	3.73±0.19^{a}	22.00±1.96^{b-i}	30.75±1.75^{c-i}	18.75±1.49^{c-j}
IĞR26	136.50±3.62^{c-g}	4.83±0.42^{a}	20.50±1.19^{c-l}	37.50±3.23^{a-g}	21.50±1.19^{b-e}
IĞR27	152.50±4.01^{ab}	4.38±0.25^{a}	20.50±0.96^{c-l}	34.00±1.87^{a-i}	21.75±1.31^{b-e}
IĞR28	126.75±7.45^{e-j}	3.23±0.22^{a}	19.25±1.11^{d-l}	31.00±4.53^{c-i}	13.50±1.19^{kl}
IĞR29	112.75±2.63^{j-p}	3.13±0.29^{a}	20.00±2.04^{c-l}	31.00±2.35^{c-i}	13.25±1.55^{l}
IĞR30	137.50±3.40^{c-f}	4.55±0.49^{a}	24.50±1.85^{bc}	43.75±2.17^{a}	26.50±0.87^{a}
IĞR31	112.50±5.24^{j-p}	2.95±0.29^{a}	18.25±0.63^{f-l}	31.75±2.02^{c-i}	17.25±1.89^{d-l}
IĞR32	123.25±5.85^{f-k}	3.85±0.14^{a}	21.75±1.70^{b-j}	38.50±4.05^{a-f}	23.00±1.78^{a-c}
IĞR33	121.00±1.68^{i-n}	2.98±0.15^{a}	20.00±1.08^{c-l}	31.75±1.31^{c-i}	19.00±1.41^{c-j}
IĞR34	104.50±5.69^{p-u}	3.08±0.19^{a}	24.00±2.74^{b-d}	32.00±5.12^{c-i}	15.00±0.41^{h-l}
IĞR35	107.75±1.80^{m-r}	3.13±0.08^{a}	17.00±0.82^{i-l}	28.00±0.41^{g-i}	17.50±0.50^{d-k}
IĞR36	124.50±4.77^{f-k}	3.81±0.28^{a}	17.50±0.65^{h-l}	33.00±1.08^{b-i}	22.75±1.03^{a-c}
IĞR37	106.50±4.70^{n-t}	3.25±0.22^{a}	17.75±1.31^{h-l}	29.25±2.25^{d-i}	17.00±1.47^{e-l}
IĞR38	112.25±1.38^{j-p}	4.23±0.18^{a}	22.25±0.85^{b-h}	39.25±1.25^{a-e}	19.75±0.75^{c-h}
IĞR39	94.75±1.80^{s-v}	3.40±0.32^{a}	20.00±1.68^{c-l}	31.50±2.72^{c-i}	19.25±1.65^{c-j}
IĞR40	144.25±7.17^{bd}	4.00±0.20^{a}	19.25±0.48^{d-l}	35.25±1.80^{a-h}	17.25±1.03^{d-l}
IĞR41	97.50±0.96^{r-v}	2.45±0.13^{a}	15.75±0.85^{l}	24.75±1.89^{i}	16.25±1.65^{f-l}
IĞR42	145.75±3.54^{bd}	4.53±0.37^{a}	21.75±0.95^{b-j}	40.50±4.66^{a-c}	17.75±1.38^{d-l}
IĞR43	88.75±1.89^{v}	2.40±0.02^{a}	16.75±0.85^{jkl}	24.50±1.55^{i}	14.75±1.25^{i-l}
IĞR44	83.25±3.28^{v}	2.40±0.27^{a}	16.25±1.03^{kl}	25.50±1.85^{hi}	15.50±1.26^{g-l}
IĞR45	93.00±2.86^{tv}	2.70±0.13^{a}	18.50±0.65^{f-l}	28.50±0.96^{e-i}	15.00±0.91^{h-l}
IĞR46	84.00±1.68^{v}	2.16±0.12^{a}	17.50±0.87^{h-l}	25.00±1.35^{hi}	14.50±1.04^{j-l}
IĞR47	110.25±4.99^{l-p}	3.06±0.15^{a}	18.25±0.75^{f-l}	32.25±2.10^{b-i}	20.25±1.44^{c-g}

Table 4. Morphological characteristics of *Avena fatua* and differences between populations (branch length, flower count, fresh weight, dry weight)

Code	Branch length (cm)	Flower Count (number)	Fresh Weight (g)	Dry Weight (g)
IĞR0	11.50±1.05^{c-h}	38.00±3.55^{d-l}	19.00±0.7^{0j-p}	6.50±0.58^{i-p}
IĞR1	12.75±0.75^{b-e}	43.25±3.22^{a-h}	19.75±0.85^{h-p}	6.75±0.85^{h-p}
IĞR2	11.75±1.11^{c-h}	32.75±5.02^{g-l}	18.25±0.48^{l-p}	5.25±0.48^{l-p}
IĞR3	10.25±0.85^{e-i}	48.50±3.62^{a-f}	20.00±0.41^{g-m}	7.00±0.41^{g-m}
IĞR4	10.50±1.26^{e-i}	42.75±5.76^{b-h}	19.50±0.29^{i-p}	6.50±0.29^{i-p}
IĞR5	12.00±1.00^{c-g}	37.50±3.93^{e-l}	22.75±0.48 ^{de}	9.75±0.48^{de}
IĞR6	11.25±0.75^{c-i}	34.00±2.35^{e-l}	20.25±0.48^{f-l}	7.25±0.48^{f-l}
IĞR7	11.25±1.25^{c-i}	29.75±4.46^{h-l}	18.25±0.75^{l-p}	5.25±0.75^{l-p}
IĞR8	10.50±0.65^{e-i}	38.75±1.11^{c-l}	15.75±0.85^{r}	2.75±0.85^{r}
IĞR9	13.75±1.89^{a-d}	29.25±4.57^{h-l}	18.50±0.65^{k-p}	5.50±0.65^{k-p}
IĞR10	12.25±1.03^{c-f}	48.75±3.77a^{-f}	19.00±0.41^{j-p}	6.00±0.41^{j-p}
IĞR11	11.75±0.85^{c-h}	53.50±4.44^{a-c}	19.75±0.48^{h-p}	6.75±0.48^{h-p}
IĞR12	9.25±0.48^{f-j}	29.75±1.25^{h-l}	18.75±0.6^{3j-p}	5.75±0.63^{j-p}
IĞR13	10.75±0.95^{d-i}	24.00±3.08^{l}	17.75±0.25^{p}	4.75±0.25^{p}
IĞR14	10.00±0.71^{e-i}	28.50±2.60^{h-l}	18.50±0.29^{kl-p}	5.50±0.29^{k-p}
IĞR15	9.25±0.95^{f-j}	29.00±6.72^{h-l}	20.75±0.48^{fg-j}	7.75±0.48^{f-j}
IĞR16	5.50±0.50^{k}	33.25±1.60^{g-l}	18.50±0.29^{k-p}	5.50±0.29^{k-p}
IĞR17	11.50±1.19^{c-h}	39.50±9.68^{b-k}	24.50±0.65^{bc}	11.50±0.65^{bc}
IĞR18	11.25±1.31^{c-i}	54.50±7.80^{ab}	22.00±0.71 ^{ef}	9.00±0.71^{ef}
IĞR19	11.75±0.63^{c-h}	38.25±1.65^{d-l}	22.75±0.48^{de}	9.75±0.48^{de}
IĞR20	11.75±1.11^{c-h}	41.25±3.50^{b-i}	20.75±0.48^{f-j}	7.75±0.48f^{j}
IĞR21	10.00±0.41^{e-i}	41.50±5.56^{b-i}	19.75±0.48^{h-p}	6.75±0.48h-p
IĞR22	15.50±1.76^{ab}	57.50±5.33^{a}	26.50±0.29^{a}	13.50±0.29^{a}
IĞR23	10.00±0.41^{e-i}	49.25±3.7^{1a-e}	20.75±0.48^{f-j}	7.75±0.48^{f-j}
IĞR24	10.00±0.71^{e-i}	39.50±3.28^{bc-k}	22.00±0.71 ^{ef}	9.00±0.71^{ef}
IĞR25	12.00±0.82^{c-g}	43.00±4.32^{a-h}	21.75±0.63 $^{e-g}$	8.75±0.63^{e-g}
IĞR26	10.25±0.63^{e-i}	46.50±5.01^{a-g}	22.00±0.41^{ef}	9.00±0.41e^{f}
IĞR27	10.50±0.65^{e-i}	38.25±5.25^{d-l}	21.00±0.41^{e-i}	8.00±0.41^{e-i}
IĞR28	10.25±1.11^{e-i}	29.25±2.78^{h-l}	19.00±0.41^{j-p}	6.00±0.41^{j-p}
IĞR29	10.25±1.11^{e-i}	30.50±3.30^{h-l}	18.25±0.25^{l-p}	5.25±0.25^{l-p}
IĞR30	14.00±0.91^{a-c}	52.75±2.87^{a-d}	25.75±0.63^{ab}	12.75±0.63^{ab}
IĞR31	10.75±0.95^{d-i}	30.50±4.73^{hi-l}	19.50±1.26^{i-p}	6.50±1.26^{i-p}
IĞR32	11.00±1.08^{c-i}	54.00±6.49^{ab}	24.00±1.47^{cd}	11.00±1.47^{cd}
IĞR33	8.75±0.75^{h-j}	29.50±3.40^{h-l}	19.50±0.65^{i-p}	6.50±0.65^{i-p}
IĞR34	15.75±1.31^{a}	29.50±3.40^{h-l}	19.75±0.85^{h-p}	6.75±0.85h^{-p}
IĞR35	9.75±0.48^{e-i}	33.50±1.26^{f-l}	18.50±0.29^{k-p}	5.50±0.29^{k-p}
IĞR36	9.00±0.41^{g-j}	41.00±2.04^{b-j}	20.50±0.65^{f-k}	7.50±0.65^{f-k}
IĞR37	10.50±0.96^{e-i}	29.50±2.50^{h-l}	21.25±0.25^{e-i}	8.25±0.25^{e-i}
IĞR38	14.00±0.41^{a-c}	48.75±3.73^{a-f}	20.75±0.48^{f-j}	7.75±0.48^{f-j}
IĞR39	11.00±1.08^{c-i}	42.25±8.09^{b-h}	20.75±0.48^{f-j}	7.75±0.48^{f-j}
IĞR40	12.00±0.41^{c-g}	36.25±3.97^{e-l}	21.50±0.29^{e-h}	8.50±0.29^{e-h}
IĞR41	9.00±0.71^{g-j}	26.75±4.33^{i-l}	20.00±0.41^{g-m}	7.00±0.41^{g-m}
IĞR42	11.75±1.38^{c-h}	39.50±6.03^{b-k}	25.25±0.48^{a-c}	12.25±0.48^{a-c}
IĞR43	8.75±0.48^{h-j}	25.75±2.84^{j-l}	18.00±0.41^{mp}	5.00±0.41^{mp}
IĞR44	6.25±0.63^{jk}	24.00±3.44^{l}	18.75±0.25j^{-p}	5.75±0.25^{j-p}

Table 4. Continued

IĞR45	10.50±0.29e-1	35.75±0.85^{e-l}	18.50±0.29^{k-p}	5.50±0.29^{k-p}
IĞR46	8.75±0.48h-j	29.25±2.02^{h-l}	18.00±0.41^{mp}	5.00±0.41^{mp}
IĞR47	9.25±0.48f-j	35.50±4.35^{e-l}	20.50±0.87^{f-k}	7.50±0.87^{f-k}
IĞR48	9.75±0.75e-1	28.50±5.42^{h-l}	19.00±0.41^{j-p}	6.00±0.41^{j-p}
IĞR49	10.00±0.71e-1	40.00±4.14^{b-k}	21.75±0.48^{e-g}	8.75±0.48^{e-g}
IĞR50	8.25±0.251j	25.00±4.06^{kl}	18.25±0.25^{l-p}	5.25±0.25^{mp}
	4.473		4.198	
	0.000**	0.000**	0.000**	0.000**

$p<0.01$ The differences between means marked with the same letter are not significant at the 0.05 level.

The average plant height of *A. fatua* plants varies between 163.00 cm and 83.25 cm. The highest plant height was observed in the IĞR22 population, and the lowest in the IĞR44 population. The average stem diameters range from 5.35 mm to 2.16 mm. The highest stem diameter was determined in the IĞR22 population, while the lowest value was found in the IĞR46 population. Leaf length ranged from 32.50 cm to 15.75 cm, with the longest leaves found in the IĞR18 (32.50 cm) and the shortest in IĞR41 (15.75 cm) populations. Spike lengths ranged from 43.75 cm to 24.00 cm, with the longest spikes in IĞR30 (43.75 cm) and IĞR22 (42.25 cm) populations, while the shortest spike lengths were found in IĞR43 (24.50 cm) and IĞR50 (24.00 cm) populations. The highest spikelet count was observed in the IĞR30 (26.50 units) and IĞR22 (25.00 units) populations, while the lowest spikelet counts were found in IĞR28 (13.50 units) and IĞR29 (13.25 units) populations. The IĞR30 population, with the highest spike length and spikelet count, demonstrates a potentially higher seed production capacity (Table 3).

In the literature, *A. fatua* plant height ranges from 25.00 cm to 120.00 cm (Holm et al., 1977). The plant height can reach up to 130.00 cm (Uygur et al., 1986). Generally, the plant height varies between 30.00 cm and 150.00 cm. The leaves are dark green and can grow up to 40.00 cm (Rooney, 1990). Additionally, the plant height has been reported to range between 80.00 cm and 143.00 cm (Miller et al., 1982). Dai et al. (2012) determined the plant height between 65.00 cm and 95.00 cm. Mahajan et al. (2020) reported that the average plant height ranged from 78.00 cm to 108.00 cm. Morikawa (1989) stated that the plant height ranges from 63.00 cm to 99.00 cm. Both in our study and in the literature, the height of *A. fatua* plants ranges between 25.00 cm and 150.00 cm. Additionally, sources like Uygur et al. (1986) and Holm et al. (1977) also report plant heights within this range. In our study, leaf length ranged from 15.75 cm to 32.50 cm. These values align with the statement by Rooney (1990), who indicated that dark green leaves can grow up to 40.00 cm. Therefore, while there are similarities and differences when comparing the morphological characteristics of *A. fatua* in our study with existing literature, there are noteworthy variations.

Significant differences were observed among the *A. fatua* populations in terms of morphological characteristics such as branch length, flower count, fresh weight, and dry weight. The highest branch lengthwas found in the IĞR34 population, with a value of 15.75 cm, while the lowest branch lengthwas 5.50 cm in the IĞR16 population. There was considerable variation in flower count, with the highest flower count recorded at 57.50 units in IĞR22, and the lowest flower count recorded at 24.00 units in IĞR44. Fresh weights ranged from 15.75 g to 26.50 g, with the highest fresh weight in the IĞR22 population and the lowest fresh weight in the IĞR8 population. Dry weight values showed a similar distribution. The highest dry weight was found in the IĞR22 population (13.50 g), while the lowest values were recorded in the IĞR13 (4.75 g) and IĞR8 (2.75 g) populations (Table 4.3). Consequently, the IĞR34 population has the highest branch length, suggesting a higher potential for seed production. The IĞR22 population has the highest flower count, which may increase its reproductive success. On the other hand, low fresh and dry weights were observed in populations such as IĞR46 and IĞR43 (Table 4).

In the literature, spike length has been reported to range from 10.00 cm to 40.00 cm (CABI, 2024). This study shows similarities with the existing literature on spike length values; however, the 15.75 cm spike length in the IĞR34 population is close to the upper limit of the range predicted by previous studies. Dry weight averages have been reported to range from 10.10 g to 13.60 g (Dai et al., 2012). On the other hand, Mahajan et al. (2020) reported an average dry weight of 8.90 g and a fresh weight average of 31.50 g. Comparing the fresh weight of 26.50 g in our study with this, it can be seen that the fresh weight in our study is higher. Gibson and Prigge (2024), branch lengths vary between 2.5 cm and 16 cm. Although different values for leaf length are found in the literature, the averages identified in this study are consistent with the existing data. In conclusion, when comparing the morphological characteristics of *A. fatua* plants in our study with the existing literature, there are both similarities and differences.

Multivariate Analysis of Populations and Morphological Traits

All these statistical analyses formed an important basis for understanding the plant diversity by examining the relationships among the morphological traits of *A. fatua* populations.

In the study, it was determined that the morphological traits of *A. fatua* are positively correlated with each other. Although the statistical levels of the parameters vary, the relationship level was generally found to be significant. The highest correlation was found between fresh and dry weight parameters, while the lowest correlation was observed between flower count and stem diameter. The correlation analysis of *A. fatua* morphological traits is shown in Table 5.

Hierarchical clustering analysis was performed to evaluate the morphological traits of *A. fatua* and identify similarities among different populations. The analysis revealed two main groups. In one of these groups, the IĞR22 and IĞR30 populations were grouped together, while in the other main group, the IĞR18 population formed a distinct cluster. Similarly, the IĞR7 population was also evaluated as a separate group. The dendrogram of the hierarchical clustering analysis of *A. fatua* morphological traits is shown in Figure 1.

An network graph analysis was conducted to determine the relationships and interactions among the morphological traits of *A. fatua*. In this analysis, the thickness of the lines between the nodes represents the strength of the relationships; thin lines indicate weak relationships, while thick lines represent strong relationships. The results obtained are consistently showing clear separations in line with the heatmap clustering. As a result of the analysis, the IĞR8, IĞR30, IĞR7, IĞR22, and IĞR18 populations did not form any relationships with other populations. On the other hand, the IĞR34 and IĞR9 populations formed a relationship with each other, while the other populations were found to be somewhat related to each other and the control population (IĞR0) to a certain extent (Figure 2).

Table 5. Correlation analysis of morphological traits of *Avena fatua*

Variable	Plant height	Stem diameter	Leaf length	Spike length	Spike count	Branch length	Flower count	Fresh weight	Dry weight			
Plant height	r	—										
	p	—										
Stem diameter	r	0.396	**	—								
	p	0.004		—								
Leaf length	r	0.376	**	0.346	*	—						
	p	0.007		0.013		—						
Spike length	r	0.658	***	0.588	***	0.551	***	—				
	p	< .001		< .001		< .001		—				
Spike count	r	0.486	***	0.388	**	0.343	*	0.617	***	—		
	p	< .001		0.005		0.014		< .001		—		
Branch length	r	0.446	**	0.392	**	0.574	***	0.658	***	0.317	*	—
	p	0.001		0.004		< .001		< .001		0.023		—

Table 5. Continued

Flower count	r	0.372	**	0.300	*	0.506	***	0.621	***	0.780	***	0.465
	p	0.007		0.033		< .001		< .001		< .001		< .001
Fresh weight	r	0.642	***	0.396	**	0.396	**	0.632	***	0.679	***	0.436
	p	< .001		0.004		0.004		< .001		< .001		0.001
Dry weight	r	0.642	***	0.396	**	0.394	**	0.635	***	0.679	***	0.439
	p	< .001		0.004		0.004		< .001		< .001		0.001

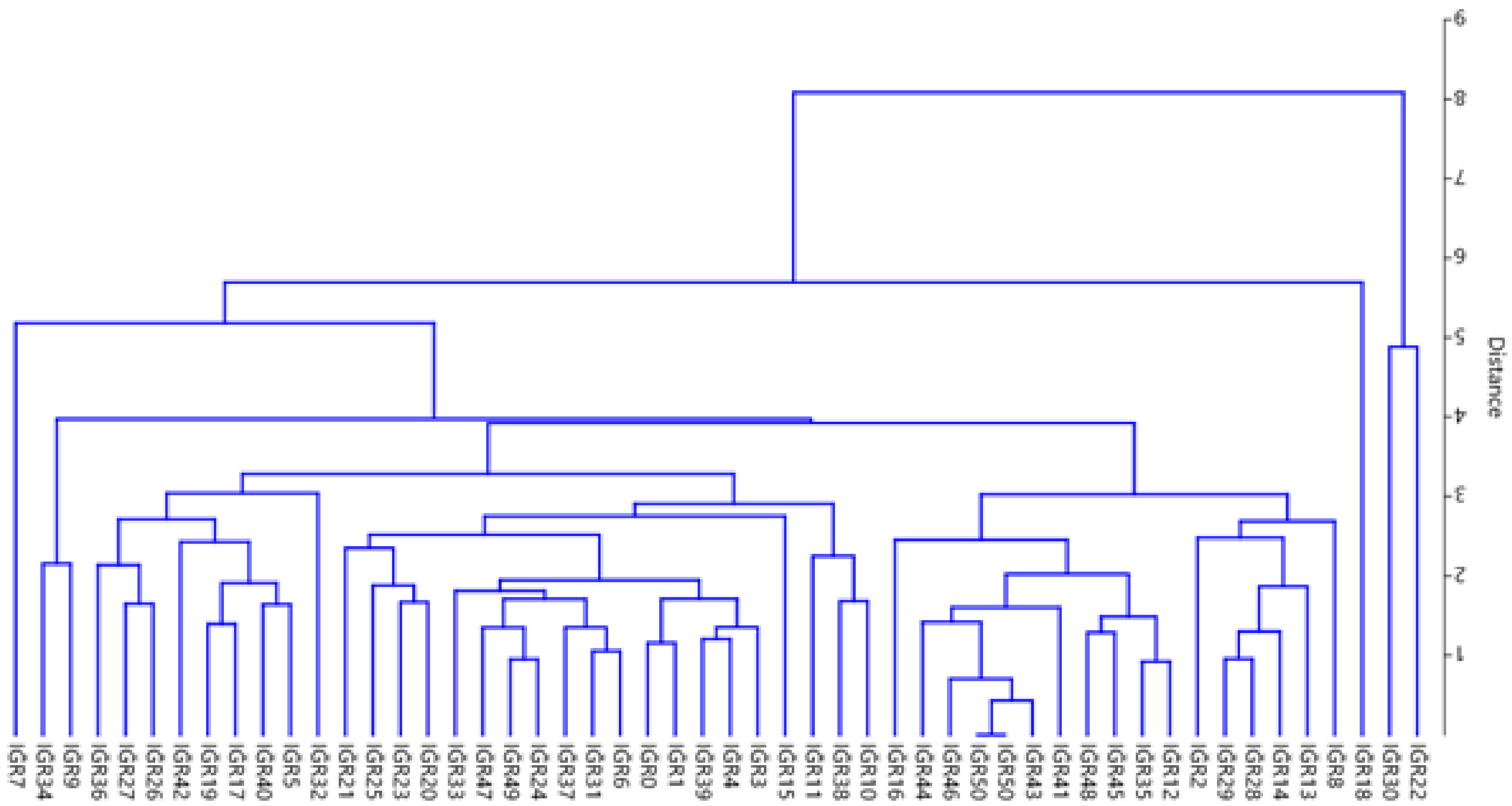

Figure 1. Dendrogram of hierarchical clustering analysis of *Avena fatua* morphological traits

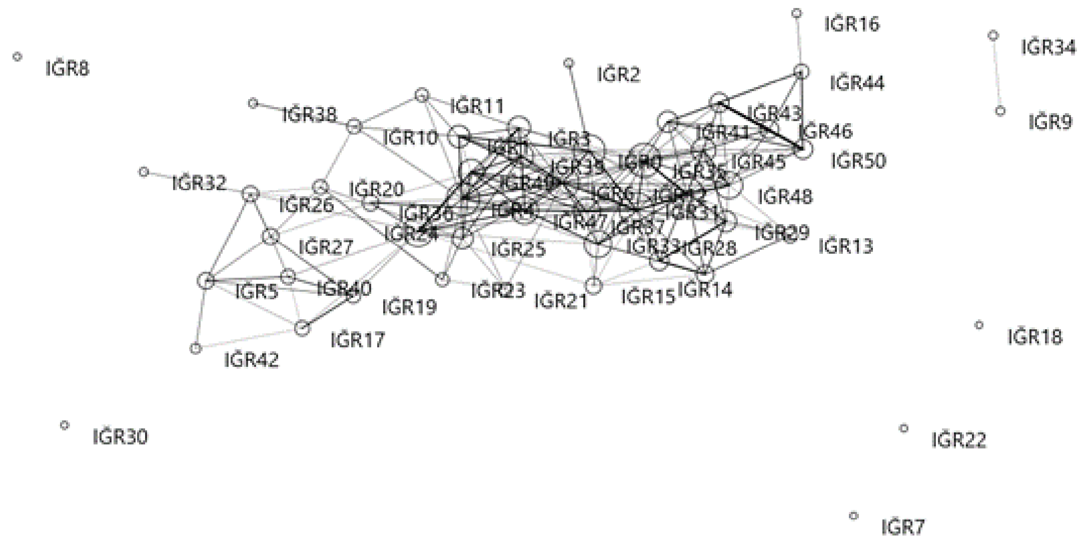

Figure 2. Network graph analysis of *Avena fatua* morphological traits

Principal component analysis (PCA) was conducted to reduce the variance among the morphological traits of *A. fatua* and to identify the principal components that explained the most variability in these traits. Additionally, the PCA aimed to better understand the differences between populations and reveal groups with similar traits. The A. fatua populations were scattered on a biplot based on the PCA of their morphological traits. The first two components obtained in this analysis (PC1: 78.35% and PC2: 14.65%) explained 93% of the original data's variability. This high variance ratio demonstrates the effectiveness of the PCA in assessing the impact of the predicted parameters. As a result of the analysis, the first component (PC1) showed a positive correlation with the following populations: IĞR5 (+1.06), IĞR7 (+0.07), IĞR10 (+0.36), IĞR11 (+0.35), IĞR17 (+0.86), IĞR18 (+1.28), IĞR19 (+0.73), IĞR20 (+0.69), IĞR22 (+2.94), IĞR23 (+0.47), IĞR24 (+0.23), IĞR25 (+0.42), IĞR26 (+0.94), IĞR27 (+0.66), IĞR30 (+3.05), IĞR32 (+1.43), IĞR36 (+0.18), IĞR38 (+0.88), IĞR40 (+0.48), and IĞR42 (+1.44). Other populations showed a negative correlation with the control population (-0.20). When examining the biplot, the IĞR30 population stands out with the highest positive score (+3.05), while IĞR22 (+2.94) and several other populations also exhibit positive relationships. Furthermore, the control population reveals its distinctiveness by showing a negative correlation with the others (Figure 3).

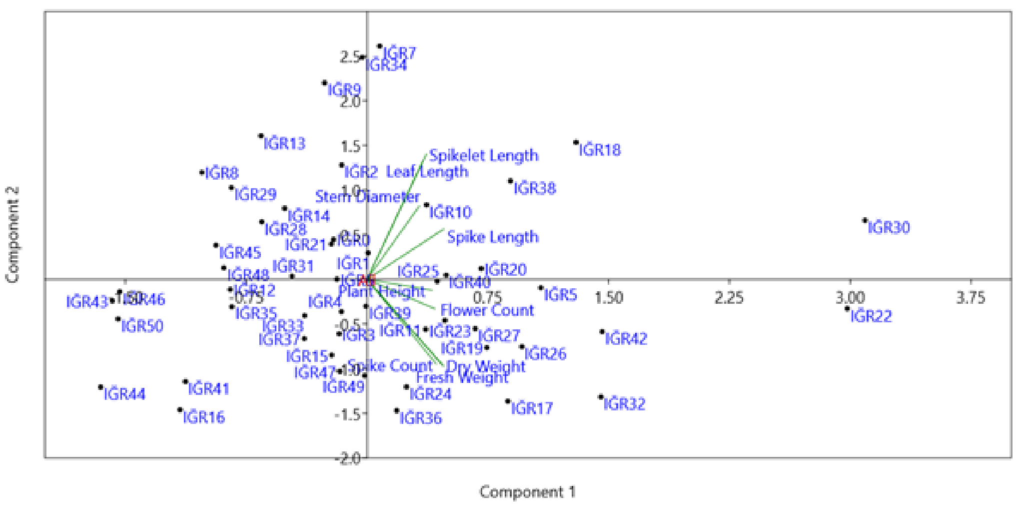

Figure 3. Principal component analysis of *Avena fatua* morphological traits Figure 3. Principal component analysis of *Avena fatua* morphological traits

With the multivariate analysis of populations and morphological traits, a comprehensive assessment of the morphological characteristics of *A. fatua* populations was conducted. Various analyses revealed significant relationships and differences among these populations.

Phenotypic diversity in wild oat populations is largely due to agricultural practices, environmental conditions, and genetic adaptation processes. Indeed, different crop rotation systems, harvest dates, and intensive herbicide use can exert selective pressure on populations, leading to changes in morphological traits (Beckie et al., 2012; Délye et al., 2013). This increases the competitiveness of some populations, facilitating their dominance under field conditions. Furthermore, environmental factors are known to contribute to morphological differences among populations. Morrison (1982) reported that *Avena fatua* populations exhibited wide variation in plant height, tillering capacity, and panicle structure under different ecological conditions. Similarly, Lehnhoff et al. (2013) demonstrated that environmental stress conditions can rapidly alter the phenotypic fitness of wild oat. Long-term genetic adaptation processes may also contribute to these differences. Heap (2014) and Travlos and Giannopolitis, (2010) showed that weed populations in different regions gained genetic diversity under herbicide pressure and this was reflected in phenotypic traits.

First, it is important to monitor early-emerging populations in areas where *A. fatua* is abundant and to implement cultural measures consistent with planting times. Armin and Asghripour (2011) reported that early planting and the use of competitive wheat varieties reduced wild oat density. Similarly, Sarwar et al. (2013) showed that increasing planting density was effective in suppressing *A. fatua*. Furthermore, integrated management strategies need to be developed to address the risk of herbicide resistance. Hatcher and Melander (2003) and Délye et al. (2013) emphasized that chemical control alone may be unsuccessful in the long term and that cultural and mechanical methods should also be integrated into the system. Furthermore, the high tillering capacity and seed yield of some populations increases the importance of practices aimed at reducing post-harvest seed drop. Walsh & Powles (2007) demonstrated that reducing the seed bank by crushing *A. fatua* seeds during harvest is an effective method. Therefore, the morphological differences identified in our study directly contribute to predicting the success of such practices. In conclusion, our findings not only reveal the biological diversity of *A. fatua* but also provide important clues for the integration of cultural, mechanical, and chemical control methods to be applied in the field.

CONCLUSION

This study comprehensively examined the morphological diversity of *A. fatua* populations found in wheat cultivation areas around Iğdır and its surrounding regions. As a result, statistically significant differences were observed among *A. fatua* populations in all parameters, except for stem diameter. These findings indicate that there are significant morphological differences between *A. fatua* populations, with the exception of stem diameter, where no differences were found. Notably, populations such as IĞR22 and IĞR30 stand out with characteristics like high plant height and flower count, differentiating them from other populations. These traits suggest that IĞR22 and IĞR30 populations may have a higher seed production capacity and could potentially become more dominant in agricultural areas. Therefore, it is recommended to develop more intensive monitoring and management strategies, particularly targeting these populations. Additionally, molecular and genetic analyses, alongside morphological traits, could further enhance the understanding of inter-population relationships. Such holistic approaches, which account for both morphological and genetic diversity, may facilitate the development of more effective strategies for weed management.

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