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Evaluation of the Relationship between Harmonization Ratio and Some Yield Traits with Grain Yield in Oat Varieties

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Abstract
It was aimed to calculate grain filling period (GFP) / vegetative period (VP) before and after the flowering period depending on the thermal times in oat and to determine the relationship between the harmonization ratio (HR) and grain yield (GY) with the formula $HR_{tt} = GFP_{tt} / VP_{tt}$ and to determine the use of these values as criteria. HR values were calculated depending on thermal times. The experiment was conducted in Kahramanmaraş conditions between 2014 and 2016 for 2 successive years with 3 replications according to the randomized completed block design. Phenological traits were measured in relation to thermal times and significant differences were observed among cultivars. The highest grain yields were determined in Yeniçeri (507.4 kg da^{-1}) and Kahraman (489.2 kg da^{-1}) varieties, the lowest grain yields were determined in Faikbey (376.7 kg da^{-1}) and Seydişehir (386.3 kg da^{-1}) varieties, the highest harmonization ratios were determined in Arslanbey (0.517) and Kırklar (0.456) varieties, the lowest harmonization ratios were determined in Sebat (0.345) and Yeniçeri (0.350) varieties. There were significant differences between varieties and years in terms of grain yields and harmonization ratios, but no correlation relationship was found between grain yield and harmonization ratio. The results obtained will be useful in agricultural production activities and will be useful in terms of being determinant in oat breeding programs.

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1. Introduction

Oat (*Avena sativa* L.) is a cereal crop used worldwide for human nutrition and animal feed (Hoffmann, 1995; Peterson et al., 2005). Compared to other cereals, it is famous for its ability to be grown in marginal areas, including cool, wet climates and low fertility soils (Hoffmann, 1995). In the world, oats have a cultivation area of about 9.5 million ha, a production of 22.5 million tons and a yield of 236 kg da^{-1} (FAO, 2021). In Türkiye, oat cultivation area is 137.655 ha, production is 365.000 tons and yield is 266 kg da^{-1}. In addition, oat production in our country increased by 32.2 % compared to the previous year (276.000 tons) (TÜİK, 2022), and oat consumption per capita was determined as 1.4 kg in 2021 (TÜİK, 2021). In our country, oat production has been limited compared to wheat and barley due to problems such as not being resistant to cold and drought, grain shedding, lodging and not maturing simultaneously.

In recent years, oat consumption in the human diet has increased due to the nutritional value of oats (Food and Drug Administration, 1997). Both in our country and in the world, oats have come to the forefront in healthy nutrition due to the increasing awareness of healthy nutrition as well as the income and welfare levels of people. In the studies conducted on this subject, it is reported that oats should be preferred in healthy diets because they contain simple phenolic compounds (ferulic, caffeic, p-coumaric, sinapic and vanillic acid) (White and Xing, 1997) and avenanthramides (Dokuyucu et al., 2003), which are antioxidant substances, and they have high fiber and iron content that have a cholesterol-lowering effect (Wood, 2001). It has been reported that if oat bran is consumed daily, cholesterol and triglyceride levels in the blood will decrease significantly (Gold et al., 1988). Oat is also an important plant in the nutrition of livestock in terms of providing maximum energy due to its high protein content (Wood, 2001).

It was reported that the effect of environmental stresses on grain yield during grain filling in summer oats under two contrasting field conditions varied among genotypes, and that environmental conditions affected grain yield according to the relationship between spike duration, grain filling rate and grain filling period (GFP) using 20 oat genotypes, and that there was an increase in grain yield from the first to the second year in early spiking genotypes compared to late spiking genotypes (Wych et al., 1982).

It was found that the response of oat (*Avena sativa* L.) genotypes to delayed sowing dates (both in terms of escaping from high temperature and tolerating high temperature) can be used in variety development, genotypes were found to be significantly different in terms of days and GDD (Growing Degree Days), genotypic differences were found to be significant in terms of plant height, grain yield and hectoliter weight, GDD was found to be less variable between sowing dates than the number of days in the development periods and therefore CHU (corn heat units) used in maize (*Zea mays* L.) can be used in oats (Corville Baltenberger and Frey, 1987). The effect of day and night temperature and day-night temperature difference on oat yield and other agronomic traits during the grain filling period and the thermo-periodic response of these traits were determined (Hellewell et al., 1996). In 1998-2002 with 101 oat varieties originating from Germany, Sweden, Canada and USA, it was reported that genetic and environmental variations affected oat grain yield, oat grain yield decreased due to drought and extreme heat conditions, excessive wind and rain caused lodging in oats and reduced grain yield (Tamn, 2003). In Pakistan, it was reported that flowering time, ripening time, 1000-grain weight, plant height and flowering time of different oat varieties were significantly different on grain yield (Nawaz et al., 2004).

The development of new high yielding varieties depends on determining the effects of phenological periods on yield. There are many studies showing that phenological periods such as sowing-days to maturity (DM), vegetative period (VP) and grain filling period (GFP) have significant effects on grain yield (GY) (Gebeyehou et al., 1982; Lopez Castaneda and Richards, 1994). In our country, for the first time, GFP_{tt} /VP_{tt} was evaluated in durum wheat varieties and it was concluded that the harmonization ratio (HR) obtained by proportioning them was significantly related to grain yield (Akkaya et al., 2006).

2. Material and Methods

The research was carried out for 2 successive years in 2014-2015 and 2015-2016 growing seasons under Kahramanmaraş conditions with 3 replications according to the randomized completed block design based on rainfall and 8 oat cultivars (Checota, Sebat, Kahraman, Yeniçeri, Arslanbey, Seydişehir, Kırklar, Faikbey).

HR formula was used to examine the relationship between phenological periods (VP, GFP, DM) and grain yield and harmonization ratio and to determine the traits that can be used as selection criteria in the region. Days to maturity (DM), grain filling period (GFP) and vegetative period (VP) were rated by Gebeyehou et al. (1982); Lopez Castaneda and Richards (1994). Celsius scale was used with a base 0°C for thermal time calculations for VP, DM and GFP. HR (harmonization ratio) values were calculated with the formula $HR=GFP_{tt} / VP_{tt}$ depending on thermal times.

Sowing was carried out with a 6-row plot seeder with a spacing of 20 cm on plots 8.30 m in length, with a sowing depth of 3-4 cm and plot size of 1.2 m x 8.3 m = 9.96 m^2 in both years, with 350 grains per oat based on 1000-grain weight.

In the soil in the experiment, phosphorus and potassium among macro plant nutrients were moderately sufficient, calcium and magnesium were too much. Micronutrients except manganese were low or insufficient. Organic matter content was low, lime content was high and slightly alkaline (Anonymous, 2015). In the 2014-2015 period, the lowest temperature was 1.7 ^oC in January and the highest temperature was 32 ^oC in June (Table 1). In the 2015-2016 period, the lowest temperature was 1.6 ^oC in January and the highest temperature was 33.7 ^oC in June (Anonymous, 2016).

Table 1. Minimum and maximum temperature averages in the study years

	Min. Temperature Averages (^0C)		Max. Temperature Averages (^0C)	
Months	**2014-2015**	**2015-2016**	**2014-2015**	**2015-2016**
December	6.8	3.8	12.4	14.3
January	1.7	1.6	9.8	7.3
February	4.2	7.0	9.8	16.2
March	6.7	8.0	16.9	18.4
April	9.3	12.6	19.8	27.1
May	15.0	15.5	22.2	26.9
June	19.6	20.5	32.0	33.7

Fertilization was completed in both years by applying commercial fertilizer 20-20-0 (compound) at 7 kg da^{-1} pure N and 7 kg pure P_2O_5 as base fertilizer at sowing and 33 % Ammonium Nitrate (NH_4NO_3) at 7 kg da^{-1} pure N at the end of tillering.

Weeds in the plots were controlled by hand pulling and narrow and broadleaf weeds were controlled with herbicide (2,4 - D Amine).

1.15 meters from the beginning and end of each parcel, 1 row from the edges of the parcels as edge effect when approaching the harvest time, the remaining part was adjusted to be (0.8 m x 6 m = 4.8 m^2) and threshing was carried out with a parcel threshing machine.

The analysis of variance of the data belonging to the mentioned characters was performed using SAS package program (SAS, 1999) and the comparison of the means was performed using Duncan multiple comparison test.

3. Results and Discussion

As a result of the evaluation of the genotypes in terms of the traits examined by considering the two-year averages; the genotypes examined were found to be significantly different in terms of grain protein ratio, vegetative period, sowing-days to maturity, heading duration, harmonization ratio, grain filling period, hectoliter weight, 1000-grain weight and grain yield.

When the two-year averages were analyzed, the values in terms of heading duration varied between 131.6 and 143.3 days; the varieties with the highest average were Sebat (143.3) and Faikbey (141.6), and the varieties with the lowest average were Arslanbey (131.6) and Kahraman (133.6) (Table 2). When early maturity is mentioned, it is often understood that the variety matures early and comes to harvest. In fact, the short life span of the plant does not provide an advantage in terms of yield. Therefore, in cereals, not the short-lived ones, but the ones with early spike are preferred, and earliness refers more to the date of spike (Kırtok, 1984). It is known that there is generally a significant and positive relationship between heading date, which is a measure of earliness, and yield and yield components (Blum et al., 1989). Heading duration is a genotypic trait and is also affected by environmental conditions (Sönmez, 2020).

Grain yield varied between 376.7-507.4 kg da^{-1}, the highest values were observed in Yeniçeri (507.4) and Kahraman (489.2) varieties and the lowest values were observed in Faikbey (376.7) and Seydişehir (386.3) varieties (Table 2). Although a variety has genotypically high yield potential, its adaptation to environmental conditions is very important since grain yield is controlled by many genes (Yaşar, 2021). It has been reported that sowing norm, climate, moisture content and genotypic structure of varieties determine the adaptability to different growing conditions and have significant effects on oat grain yield (Batalova and Gorbunova, 2009). It has been observed that climatic conditions have a significant effect on oat grain yield and high temperature and drought reduce grain yield (Tamn, 2003). Heavy wind and rainfall were reported to reduce grain yield because they cause oats to lodging (Inan et al., 2005).

Harmonization ratio varied between 0.345-0.517. The highest values were observed in Arslanbey (0.517) and Kırklar (0.456) varieties, while the lowest values were observed in Sebat (0.345) and Yeniçeri (0.350) varieties (Table 2). In a study in which it was determined that the genotype with the highest grain yield had the highest harmonization ratio and the genotype with the lowest grain yield had the lowest harmonization ratio in durum wheat, days to maturity, grain yield, GFP_{tt} and VP_{tt} traits were examined and it was determined that there were significant differences between genotypes in terms of harmonization ratio and there was a positive and significant relationship between grain yield and harmonization ratio (Akkaya et al., 2006). In this study, similar results were not found for oat genotypes; however, it should not be ignored that Arslanbey genotype (the earliest), which has the shortest heading duration, days to maturity and vegetative period, has the highest harmonization ratio among all genotypes.

Table 2. Result of 2 years of some examinated traits

Varieties	Harmonization Ratio			Grain Yield			Heading Duration		
	2014-15	2015-16	Average	2014-15	2015-16	Average	2014-15	2015-16	Average
Checota	0.448^{c}	0.349^{b}	0.398^{c}	317.9^{c}	471.2^{ab}	394.6^{b}	154.3^{c}	125.6^{b}	140.0^{c}
Sebat	0.382^{d}	0.309^{c}	0.345^{d}	464.6^{ab}	505.5^{ab}	485.1^{a}	157.3^{a}	129.3^{a}	143.3^{a}
Kahraman	0.529^{b}	0.355^{b}	0.442^{b}	422.9^{b}	555.5^{a}	489.2^{a}	148.0^{d}	119.6^{cd}	133.8^{d}
Yeniçeri	0.414^{cd}	0.286^{c}	0.350^{d}	518.5^{a}	496.2^{ab}	507.4^{a}	155.6^{b}	124.3^{b}	140.0^{c}
Arslanbey	0.578^{a}	0.456^{a}	0.517^{a}	467.3^{ab}	472.2^{ab}	469.7^{a}	145.3^{e}	118.0^{d}	131.6^{e}
Seydişehir	0.444^{c}	0.372^{b}	0.408^{c}	330.1^{c}	442.5^{b}	386.3^{b}	153.6^{c}	125.6^{b}	139.6^{c}
Kırklar	0.563^{ab}	0.348^{b}	0.456^{b}	469.3^{ab}	508.3^{ab}	488.8^{a}	148.0^{d}	120.3^{c}	134.1^{d}
Faikbey	0.391^{d}	0.377^{b}	0.384^{c}	272.9^{c}	480.5^{ab}	376.7^{b}	157.0^{a}	126.3^{b}	141.6^{b}
Averages	**0.468^{a}**	**0.356^{b}**	**0.412**	**407.9^{a}**	**491.5^{b}**	**449.7**	**152.4^{a}**	**123.6^{b}**	**138.0**
Coeff Var (CV)	4.632	4.110	4.510	7.880	11.348	9.949	0.463	0.944	0.680

The vegetative period varied between 134.5-147.3 days, the highest values were observed in Sebat (147.3) and Faikbey (145.6) varieties, while the lowest values were observed in Arslanbey (134.5) and Kırklar (138.1) varieties (Table 3). In previous studies, flowering of oat cultivars was reported to be a genotypic trait (Matiello et al., 1999; Nawaz et al., 2004; Locatelli et al., 2008). However, these differences were reported to be due to environmental conditions (Gautam et al., 2006). Therefore, year x genotype interaction was found to be significant due to climate terms in this study. In addition, since the first year was wetter than the second year in this study, the vegetative period was longer in the first experimental year.

Grain filling period varied between 25.3-33.6 days; the highest values were found in Arslanbey (33.6) and Kırklar (31.0) varieties and the lowest values were found in Sebat (25.3) and Yeniçeri (25.5) varieties (Table 3). It is known that genetic yield increase in oat cultivars grown in high meridian regions leads to changes in yield components and can also change the grain filling period. It has also been reported that grain filling period is the only period that can be changed by breeding (Peltonen-Sainio and Rajala, 2007). It is known that year x genotype interaction is significant in terms of grain filling period (Sharma, 1992; Öztürk and Akkaya, 1994). It was also reported that selection for varieties with long grain filling period can be used as a selection criterion in terms of yield (Sharma, 1994). It was reported that the 1000-grain weight of lines with long grain filling period was higher than that of lines with short grain filling period (Sharma, 1994). It was found that there were significant differences between years in terms of grain filling period of genotypes (Wych et al., 1982) and moisture deficiency and high temperatures occurring during this period significantly limited the grain filling period (Öztürk and Akkaya, 1994a).

Days to maturity varied between 168.1-173.6 days. The highest values were found in Faikbey (173.6) and Checota (173.0) varieties, while the lowest values were found in Arslanbey (168.1) and Kahraman (168.5) varieties (Table 3). It was reported that there was a significant difference in days to maturity in terms of genotype, year and year x genotype interactions (Dumlupınar, 2010) and days to maturity was caused by genotypes (Nawaz et al., 2004).

Table 3. Result of 2 years of some examinated traits

Varieties	Vegetative Period			Grain Filling Period			Days to Maturity		
	2014-15	2015-16	Average	2014-15	2015-16	Average	2014-15	2015-16	Average
Checota	158.3[b]	129.6[bc]	144.0[c]	31.6[b]	26.3[c]	29.0[cd]	190.0[a]	156.0[b]	173.0[ab]
Sebat	161.6[a]	133.0[a]	147.3[a]	27.3[c]	23.3[e]	25.3[e]	189.0[ab]	156.3[b]	172.6[b]
Kahraman	152.3[c]	124.3[d]	138.3[d]	35.3[a]	25.0[cd]	30.1[c]	187.6[cd]	149.3[c]	168.5[cd]
Yeniçeri	159.3[b]	128.0[c]	143.6[c]	29.3[b]	21.6[f]	25.5[e]	188.6[bc]	149.6[c]	169.1[c]
Arslanbey	149.6[d]	119.3[e]	134.5[e]	37.3[a]	30.0[a]	33.6[a]	187.0[d]	149.3[c]	168.1[d]
Seydişehir	158.0[b]	128.3[bc]	143.1[c]	31.3[b]	28.0[b]	29.6[c]	189.3[ab]	156.3[b]	172.8[b]
Kırklar	151.6[c]	124.6[d]	138.1[d]	37.3[a]	24.6[de]	31.0[b]	189.0[ab]	149.3[c]	169.1[c]
Faikbey	161.3[a]	130.0[b]	145.6[b]	28.0[c]	28.0[b]	28.0[d]	189.3[ab]	158.0[a]	173.6[a]
Averages	**156.5[a]**	**127.1[b]**	**141.8**	**32.2[a]**	**25.8[b]**	**29.0**	**188.7[a]**	**153.0[b]**	**170.8**
Coeff Var (CV)	0.695	0.750	0.766	4.093	3.412	3.877	0.329	0.334	0.364

1000-grain weight varied between 23.6-36.3 g; the highest values were determined in Checota (36.3) and Kahraman (34.7) varieties and the lowest values were determined in Sebat (23.6) and Yeniçeri (26.4) varieties (Table 4). 1000-grain weight was found to be a variable trait according to genotypes (Yanming et al., 2006; Kara et al., 2007; Maral, 2009). 1000-grain weight values were reported to vary between 20.9 and 38.2 g (Buerstmayr et al., 2007). It was reported that the highest 1000-grain weight was obtained from Checota variety and the 1000-grain weights varied between 23.3-37.0 g (Yılmaz, 1996; Gül et al.,

1999) and Checota variety was the highest variety in terms of 1000-grain weight (İnan et al., 2005). In another study conducted in wheat, 1000-grain weight values varied between 27.7-46.1 g (Erdem and Sakin, 2023). All these findings are similar to this study.

Hectoliter weight varied between 43.9-55.5 kg; the highest values were obtained from Kahraman (55.5) and Kırklar (53.0) varieties and the lowest values were obtained from Faikbey (43.9) and Arslanbey (47.1) varieties (Table 4). Grain yield and hectoliter weight were found to be due to genotypic differences for many genotypes (Corville Baltenberger and Frey (1987). In a study conducted with 328 oat materials between 2012 and 2016, it was reported that the average hectoliter weight was 44.83 kg (Howarth et al., 2021).

Protein content varied between 14.1-17.6. Kırklar (17.6) and Kahraman (17.1) varieties had the highest protein content while Arslanbey (14.1) and Sebat (15.3) varieties had the lowest protein content (Table 4). Results are in agreement with the findings of Balkan et al. (2023), who determined that protein content in durum wheat genotypes varied between 14.23-16.33 %. It has been reported that environment and genotype have a great effect on protein content in oats (Doehlert et al., 2001). It has also been reported that although protein content depends significantly on genotype, it is largely influenced by environment (Stone and Savin, 2000; Johansson et al., 2003). Or it has been reported that protein content is equally affected by genetic and environmental factors (Doehlert et al., 2001).

Table 4. Result of 2 years of some examinated traits

Varieties	Protein Content in Grain			1000-Grain Weight			Hektoliter Weight		
	2014-15	2015-16	Average	2014-15	2015-16	Average	2014-15	2015-16	Average
Checota	15.4^{bc}	15.8^{b}	15.6^{b}	35.4^{b}	37.3^{a}	36.3^{a}	40.5^{a}	58.6^{bc}	49.5^{bc}
Sebat	14.9^{c}	15.7^{b}	15.3^{b}	24.3^{e}	22.9^{c}	23.6^{f}	41.4^{a}	52.0^{d}	46.7^{cd}
Kahraman	16.2^{b}	17.9^{a}	17.1^{a}	36.2^{ab}	33.2^{ab}	34.7^{ab}	46.3^{a}	64.6^{a}	55.5^{a}
Yeniçeri	16.0^{bc}	15.9^{ab}	16.0^{b}	28.8^{d}	23.9^{c}	26.4^{e}	45.8^{a}	60.0^{ab}	52.9^{ab}
Arslanbey	12.8^{d}	15.5^{b}	14.1^{c}	37.1^{a}	31.8^{b}	34.4^{abc}	39.6^{a}	54.6^{cd}	47.1^{cd}
Seydişehir	15.0^{c}	15.9^{ab}	15.5^{b}	27.4^{d}	31.5^{b}	29.4^{d}	42.0^{a}	59.3^{bc}	50.6^{bc}
Kırklar	18.8^{a}	16.5^{ab}	17.6^{a}	33.2^{c}	31.3^{b}	32.3^{c}	46.1^{a}	60.0^{ab}	53.0^{ab}
Faikbey	14.8^{c}	16.3^{ab}	15.6^{b}	32.1^{c}	33.3^{ab}	32.7^{bc}	40.5^{a}	47.3^{e}	43.9^{d}
Averages	**15.5^{a}**	**16.2^{b}**	**15.8**	**31.8^{a}**	**30.6^{b}**	**31.2**	**42.8^{a}**	**57.0^{b}**	**49.9**
Coeff Var (CV)	3.819	6.540	5.268	2.644	8.118	5.842	9.618	4.515	6.681

4. Conclusions and Recommendations

It is estimated that all these differences determined in terms of the data obtained and the traits examined are due to factors such as the use of different varieties in the research, the different adaptation ability of the varieties, genetic differences between the varieties and the different ecological and environmental conditions of both growing periods. In addition, it was determined that the varieties responded differently to ecological conditions.

It should be taken into consideration that phenological parameters, agricultural characters or quality traits such as protein ratio in grain, vegetative period, days to maturity, heading duration, harmonization ratio, grain filling period, hectoliter weight, 1000-grain weight and grain yield can be used as a selection criterion, that harmonization ratio, grain yield, days to maturity, vegetative period and grain filling period will contribute to the studies and future breeding studies and that it is important to continue to investigate with different plant species, genotypes and locations.

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