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Araştırma Makalesi

Yüksek Kaliteli Kışlık Yulaf Çeşitlerinin Geliştirilmesi

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Öz

Milli yulaf ıslah programının amacı, yüksek verimli, hastalıklara, kurağa, soğuğa, yüksek sıcağa dayanıklı ve farklı kullanıma (gıda, tane yem ve kaba yem) uygun yeni çeşitler geliştirmektedir. Bu amaca ulaşmak için 2008 ile 2012 yılları arasında verim, bölge verim ve tescil ön denemesi kademelerinde toplam 284 yulaf genotipi (232 hat ve 52 standart çeşit) yağışa bağımlı şartlarda test edilmiştir. Ardışık yulaf ıslah döngülerinde, yüksek verimli ve kaliteli genotipler seçilmiştir. Kalite özellikleri arasında, protein oranı (PO), yağ oranı (YO) ve hektolitre ağırlığı (HA) seleksiyon kriteri olarak tercih edilmiştir. Kalıtım derecesi (H) ve korelasyon katsayıları test edilen genotiplerin tane verimi (TV) ve kalite özellikleri için hesaplanmıştır. TV için H değeri düşük (0.38) fakat kalite özellikleri için orta (sırasıyla 0.66, 0.68 ve 0.57) düzeyde tahmin edilmiştir. Özelliklerarası korelasyon katsayıları incelendiğinde TV ile YO arasında, TV ile HA arasında ve YO ile HA arasında pozitif, TV ile PO arasında, PO ile YO arasında, PO ile HA arasında ise negatif önemli korelasyon katsayıları belirlenmiştir. İncelenen özellikler arasındaki olumsuz korelasyonlar ve düşük-orta H değerleri milli yulaf ıslah programının en önemli zorlukları olarak karşımıza çıkmaktadır. Bu zorlukları aşmak için ivedilikle yulaf melez bahçesinde yer alan ebeveynlerin (gen havuzu) karakterize edilmesi ve yeni yulaf materyalinin (yurt içinden ve dışından) melez bahçesine katılarak gen havuzunun genişletilmesi önerilebilir. Bu şekilde yüksek verimli ve kaliteli yulaf çeşidi geliştirme olasılığı artırılabilir.

Anahtar kelimeler: Yulaf, çeşit, kalite, kalıtım derecesi, korelasyon, ıslah

Breeding Winter Oat (*Avena sativa* L.) Varieties with High Quality

Abstract

The objective of national oat breeding program is to develop the oat varieties with high yielding, resistant to diseases, drought, cold, and heat stresses and suitable for different usages (food, feed, and forage). To achieve that goal, a total of 284 (232 lines + 52 checks) oat genotypes were tested under rain-fed conditions at the yield, advanced yield, and elite yield trials conducted between 2008 and 2012. During the consecutive oat breeding cycles, genotypes with high yielding and acceptable quality were promoted. Among the quality traits, protein content (PC), oil content (OC), and test weight (TW) were preferred as selection criteria. Heritability (H) and correlation coefficients were estimated for the GY and quality characteristics of the genotypes tested. While the H for GY was low (0.38), Hs for quality traits (PC, OC, and TW) were medium (0.66, 0.68, and 0.57, respectively). As for the correlations between the traits of interest, the statistically significant positive relationships were observed between GY and OC, GY and TW, and OC and TW. In contrast, statistically significant negative associations were measured between GY and PC, PC and OC, and PC and TW. Negative relationships and low-medium H values calculated for the traits studied appear to be the most critical obstacles for national oat breeding program. To tackle these obstacles, the parents, i.e., gene pool, used in the oat crossing block should be characterized as soon as possible and enriched with introducing new exotic germplasm. We believe that by doing so, we can develop high yielding and high-quality oat varieties.

Key words: Oat, variety, quality, heritability, correlation, breeding

Introduction

Oat is the third in ranging after wheat and barley in the world as well as in Turkey, in terms of cultivated areas. It was grown in 9.85 million ha area in the world in 2018, with a production of 23 million tons. In the case of Turkey, in 2019, it was cultivated in 0.365 million ha area (0.109 million ha for grain + 0.256 million ha for forage (hay)), with grain production of 0.265 million tons and forage (hay) production of 3.155 million tons. On the other hand, in 2018, the world grain oat average yield was 2.34 tons ha^{-1}, while that of Turkey was 2.46 tons ha^{-1} (http://www.fao.org/faostat and http://www.tuik.gov.tr). As a result, Turkey's grain oat average yield was above that of the world.

In some countries, inadequate and unbalanced nutrition causes a decline in health and productivity and thus an increase in disease incidences (especially in low-income families) (Wiesler, 2012). Oat is very versatile in term of quality characteristics. It can help meet the daily needs of the developing world for calories (carbohydrates), nutrients, vitamins, protein, and lipids (mainly unsaturated forms: oleic and linoleic acids). It is unique functional food, feed, and forage that can help people (against obesity, diabetics, and heart diseases) and animals to feed healthier in the developed world (Strychar, 2011).

The grain and plant (leaf + stem) of oat have many uses. It has high palatability for feeding ruminants as grain (feed) and forage (hay). Forage oat has a high feed quality (high fiber and energy value). Color, odor, aroma, taste (sugary), and texture (fine) of forage oat attract animals (Mazumder et al., 2004). Oaten hay is preferred as fodder for dairy cattle due to high digestibility and palatability. Since it contains high water-soluble carbohydrates (about 25%), it meets the energy needs of dairy cattle in a short time. At the same time, it maintains the rumen microflora of the animal and provides an increase in milk yield and, consequently, in live weight gain (Favre et al., 2019).

Hull reduces the use of oat in animal nutrition. Approximately 84% of the hull consists of lignocellulose (i.e., hemicellulose 35.1%, lignin 25.4%, and cellulose 23.4%) (Schmitz et al 2020). Hulled oat varieties with low fiber (i.e., low lignin) are used in ruminant feeding because they prevent acidosis. In contrast, hull-less ones are preferred for monogastrics such as horses and pigs and poultry, which do not have an enzyme system to digest the hull. Meanwhile, oat varieties with low digestible fiber, i.e., beta-glucan, are more suitable for monogastrics (horse and pig) and poultry feeding (Zwer, 2017).

Oat groat (caryopsis) is called as a natural functional food. Rolled oat is used as human food, especially for breakfast. In addition to being a staple food, it has many health benefits. It lowers the level of cholesterol, regulates sugar in the blood, reduces the risk of heart disease, and helps in weight loss (Mazumder et al., 2004).

Oats are used in the production of cosmetics, lotions, shampoos, and furfurals in the industry (Zwer, 2017). Furfural is used for making inks, plastics, antacids, adhesives, nematicides, fungicides, fertilizers, and flavoring compounds (Mathew et al., 2018).

The quality of oat (grain and hay) is a complex set of quantitative characters. Many physical and chemical components make up the quality of oat. Genetics (variety) and the environment (agronomy, soil, and climate) have a significant influence on those (Wiesler, 2012).

In groat, the protein content (PC) varies between 6% and 18%, and the amino acid balance is high, especially lysine content about twice as compared to other cereals (Walters et al., 2018). Starch content in oat groat ranges from 65% to 85% depending on the PC. Oat starch granule is smaller in size than those of wheat, maize, and potato but similar in size to that of rice (Zwer, 2017).

Oat has the highest oil content (OC) among cereals. OC can vary between 2% and 11% depending on oat variety. Oat contains fatty acids of 95%, consisting of oleic+linoleic (unsaturated)+palmitic (saturated) acids, in the oil composition. High OC oat in animal nutrition is preferred because it provides high energy value to animal metabolism. Low OC oat is desirable as human food because high OC leads to rancidity and bitter taste in oat derived foods (Zwer, 2017).

Beta-glucan (BG) content mostly ranges from 3% to 6%, depending on the oat variety. More than 50% of the dietary fiber of oat consists of BG, which is a water-soluble fiber. BG can decrease cardiovascular disorders, regulate blood sugar levels (type 2 diabetes), and reduce serum cholesterol levels (Jones and Engleson, 2010).

Test weight (TW), also called hectoliter weight or specific weight, is recognized as the most important physical quality criterion. It is universal in the grading standards of oat as well as in the international oat trading. It also provides information on the hull percentage (HP) of the grain. Oat varieties with high HP generally have low TW values (grain density). If groat, or caryopsis, is not plumb, but thin, TW values are expected to be low (Doehlert et al., 2006; Rines et al., 2006).

Oat breeding activities in Turkey started in 1926. Until the 1980s, varieties mostly were developed from landraces by pure line selection and rarely from a few crosses. However, the old varieties are, unfortunately, not used in commercial oat production today; they are kept in the gene bank and are used only as parents in crossing. From 1980 to 2020, 24 oat varieties have been registered in Turkey, seven by the private sector, and the rest by public institutions.

Even today, new oat varieties are registered in Turkey considering only a few quality characteristics (protein content, thousand kernel weight, and test weight). However, those are not sufficient to determine the end-use quality features (food, feed, and forage) of the oat varieties to be registered.

This study aimed to determine which quality criteria should be used during the selection cycles repeated in our oat breeding program to develop oat genotypes with high quality. On the other hand, it aimed to determine the weakest links of our oat breeding program in terms of quality and make suggestions on how to strengthen them.

Materials and Methods

Experimental layout

This study was conducted over nine field trials in four cropping seasons (from 2008-2009 to 2011-2012). A total of 284 oat genotypes (232 breeding lines and 52 checks) were used in the trials (Table 1). The trials consisted of oat yield, advanced yield, and elite yield trials.

All trials were set up in three replications. In the trials, incomplete blocking designs such as lattice (if entry number, more than # 25) and complete blocking designs (if entry number, up to # 25) were applied.

Table 1. Oat yield, advanced yield and elite yield trials conducted

Cropping season	Trial†	Number of genotype (breeding line + check)	Number of replication	Trait studied‡
2008-2009	OAYT	25 (19 + 6)	3	GY, PC, OC, TW
2009-2010	OYT	18 (12 + 6)	3	GY, PC, OC, TW
	OAYT-1	25 (19 + 5)	3	GY, PC, OC, TW
	OAYT-2	25 (19 + 6)	3	GY, PC, OC, TW
2010-2011	OYT	30 (24 + 6)	3	GY, PC, OC, TW
	OAYT	25 (18 + 7)	3	GY, PC, OC, TW
2011-2012	OYT	81 (75 + 6)	3	GY, PC, OC, TW
	OAYT	30 (25 + 5)	3	GY, PC, OC, TW
	OEYT	25 (20 + 5)	3	GY, PC, OC, TW
Total	9	284 (232 + 52)		

†OYT, Oat yield trial; OAYT, Oat advanced yield trial; OEYT, Oat elite yield trial;
‡GY, Grain yield (kg ha^{-1}); PC, Protein content (%); OC, Oil content (%); TW, Test weight (kg hl^{-1})

Soil properties

The experiments were carried out in Konya, Turkey. The soil had a clayey loam texture. pH was high (7.6-8.1). Organic matter was low (1.2-1.6%). Zn concentration (DTPA-extractable) was lower (0.35-0.46 ppm) than the critical value (0.50 ppm) (Cakmak et al., 1999).

Climate data

Where we have conducted our oat breeding program is called the Central Anatolian Plateau (CAP) of Turkey. According to the Koppen-Geiger's climate classification system, cold semi-arid climate (mostly cold and less precipitation occurring in winter, and heat and drought stresses in summer) dominates in the CAP region.

While the trials conducting, the minimum, maximum, and mean temperature and monthly precipitation values for each cropping season were recorded and given in Table 2.

Considering the amount of precipitation (266-487 mm) received in the four cropping seasons conducted oat yield, advance yield and elite yield trials (Table 2), two cropping seasons (329 mm for 2009-2010 and 487 mm for 2010-2011) received higher precipitation than the long term average (301 mm). Existing precipitation of 221 mm between the lowest one (266 mm in 2008-2009) and the highest one (487 mm in 2010-2011) adversely affects both grain yield and quality traits. It reveals that the genotypes (or lines) developed by our oat breeding program were exposed to drought stress.

Regarding high grain yield (4.68 tons ha^{-1}) and high-quality values, the best cropping season was 2010-2011 (Table 2). In this season, both the amount of precipitation was high (487 mm), and its distribution by months was balanced. Precipitation was low (4 mm) only in November and it led to tillering terminating. However, due to high precipitation in October and December, the tillering resumed and developed as usual.

The worst cropping season was 2011-2012, in terms of low grain yield (1.56 tons ha^{-1}) and low-quality values (Table 2). In January and February of this season, temperatures decreased to -17 °C and -18 °C, respectively. So, winter killed almost all genotypes, except for a few ones, in all trials. In March, most of the oat genotypes tested were recovered. But the lack of precipitation (5 mm) in April led to the stem elongation and booting stages interrupting. The precipitation received in May positively affected the flowering stage. In June, owing to insufficient precipitation (11 mm), grain filling stages were negatively affected. Therefore, the average grain yield of 1.56 tons of ha^{-1} was obtained in this season.

Table 2. Temperature and precipitation values recorded during the cropping seasons

Season:	2008-2009				
	Temperature (°C)			Precipitation (mm)	
Month	Min	Max	Mean	Season	Long Term
Jan	-15	16	4	58	38
Feb	-5	15	6	38	28
Mar	-3	20	10	22	29
Apr	3	23	12	49	32
May	4	32	19	30	43
Jun	13	33	21	3	26
Jul	Harvest has been done				
Agu	Out of cropping season for winter oat				
Sep	Out of cropping season for winter oat				
Oct	5	25	16	22	30
Nov	-2	19	8	12	32
Dec	-16	19	5	32	43
Total				266	301

Season:	2010-2011				
	Temperature (°C)			Precipitation (mm)	
Month	Min	Max	Mean	Season	Long Term
Jan	-5	12	0	47	38
Feb	-7	15	-1	52	28
Mar	-7	22	5	35	29
Apr	-1	20	15	67	32
May	4	27	16	64	43
Jun	11	33	24	62	26
Jul	Harvest has been done				
Agu	Out of cropping season for winter oat				
Sep	Out of cropping season for winter oat				
Oct	3	28	12	76	30
Nov	2	23	11	4	32
Dec	-2	20	3	80	43
Total				487	301

Season:	2009-2010				
	Temperature (°C)			Precipitation (mm)	
Month	Min	Max	Mean	Season	Long Term
Jan	-10	17	3	44	38
Feb	-6	20	4	28	28
Mar	-2	24	6	12	29
Apr	0	25	11	41	32
May	2	31	15	19	43
Jun	12	33	20	40	26
Jul	Harvest has been done				
Agu	Out of cropping season for winter oat				
Sep	Out of cropping season for winter oat				
Oct	6	29	13	13	30
Nov	-1	20	7	57	32
Dec	-3	18	6	75	43
Total				329	301

Season:	2011-2012				
	Temperature (°C)			Precipitation (mm)	
Month	Min	Max	Mean	Season	Long Term
Jan	-17	11	3	83	38
Feb	-18	12	6	38	28
Mar	-6	17	9	14	29
Apr	4	27	13	5	32
May	6	26	19	51	43
Jun	10	35	23	11	26
Jul	Harvest has been done				
Agu	Out of cropping season for winter oat				
Sep	Out of cropping season for winter oat				
Oct	1	27	16	40	30
Nov	-6	16	3	8	32
Dec	-7	14	5	23	43
Total				273	301

Agronomic practices

All trials were conducted under rain-fed conditions. Regular agronomic practices were applied to each experimental plot during all cropping seasons. The seeding rate was 550 seeds m^{-2}. In October, seeds were planted to plots with an experimental drill (Wintersteiger, Austria). At planting, plot size consisted of 7.2 m^2 in total, and six rows, 6 m long each row and 20 cm between rows. At planting, diammonium phosphate (18% N and 46% P) was incorporated as 150 kg ha^{-1}. In spring, ammonium nitrate (33% N) was spread as 130 kg ha^{-1} at growing stage 30 of Zadoks scale. Weeds were controlled with herbicide (2,4-D) treatment. Pests and diseases were not controlled with chemicals even if damages occurred on plants, so that oat genotypes which seem to be resistant to disease infection or pest infestation should be selected under the field conditions.

Grain yield

In July, the harvest was done by a plot combine (Wintersteiger, Austria). At harvest, plot size consisted of 6 m^2 in total, and six rows, 5 m long each row and 20 cm between rows. Before statistical analyses, grain yield data (grams per 6 m^2) from each plot were converted into tons per hectare.

Quality analyses

Test weight (TW) was measured using a test weight filling hopper (Seedburo, USA). Protein content (PC) was determined using a combustion nitrogen/protein determinator (Leco FP 528, USA). Oil content (OC) was determined using a semi-automatic solvent extractor (Velp, Italy), running based on the Soxhlet technique.

Quality analyses were done using grains from two replications to reduce the cost, and previous research indicated little additional benefit by having a third replication (Fufa et al., 2005).

Statistical analyses

Analyses of variance (ANOVA) were made for grain yield and quality traits (PC, OC, and TW) data obtained from nine oat trials set up in incomplete and compete blocking designs. A total of 36 ANOVA tables were created but were not included in this article due to the page limitation.

Broad sense heritability values and phenotypic correlation coefficients for grain yield and quality traits (PC, OC, and TW) were estimated according to the formulas suggested by Holland et al. (2003) and Holland (2006). Hereafter the former was called 'Heritability (H)' and the latter as 'Correlation' shortly throughout this paper (Table 3 and Table 4, respectively). All statistical analyses were performed in the SAS software (https://www.sas.com).

ANOVA results of grain yield and quality characteristics in all trials were found to be statistically significant (P≤0.01). A total of 36 ANOVA tables constructed for grain yield and quality characteristics (PC, OC, and TW) measured in nine trials conducted in four growing seasons were not given in this paper due to limited space.

Results and Discussion

Comparing field trials

One of the most challenging issues in an oat breeding program is genotype by environment interaction (GEI) because of affecting grain yield and quality characteristics. In a dynamic oat breeding program, for example, low yielding genotypes are discarded from the trials conducted each year, and new genotypes are added continuously into the list of promoted genotypes to test with together in the next cycle. With this dynamic process, the genetic component of GEI is made more predictable. But its environment component is entirely unpredictable (Kaya and Ayranci, 2016; Yan et al., 2016; Sadras et al., 2019).

Average grain yields obtained from our oat yield, advanced yield and elite yield trials varied between 1.56 tons ha^{-1} for the 2011-2012 season and 4.68 tons ha^{-1} for 2010-2011. The reason why grain yield gap (3-fold) occurred among the cropping seasons was due to unpredictable GEI, mainly environmental factors (drought, cold, and heat stresses) (Table 2). However, when the climatic conditions were favorable, as in the 2010-2011 cropping season, the average grain yields of our oat breeding trials could be higher than both that of the world and that of Turkey, respectively, 2.34 ton/ha and 2.46 ton/ha in 2018 (http://www.fao.org /faostat).

Both genotype and environment affect quality characteristics because quality features are under the control of quantitative genetics (Kaya and Ayranci, 2016). The protein content (PC) values measured in our oat breeding trials varied between 11.24% and 15.39%. Like our findings, Rasane et al. (2015) also reported that PC values in oat ranged from 11% to 15%. On the other hand, Peterson et a.l (2005), Marshall et al. (2013), and Martin (2018) highlighted that the PC values in oat varied from 12% to 20%. The main reason for the differences between the research findings was that oat genotypes tested in each trial and environment conducted each trial were different. Our oat breeding program aims to develop high-yielding and high-quality varieties adapted to rain-fed conditions. So, we discard low-yielding and low-quality genotypes from oat breeding trials. On the other hand, we test low-yielding and high-quality genotypes or vice versa one more year. By doing so, we try to understand how much GEI affects grain yield and quality traits and make selections based on GEI data in oat breeding trials.

Oil content (OC) is one of the essential quality criteria, like PC. One of the most important reasons why oats are grown is that they have a unique oil composition (Zhou et al 1999; Holland et al 2001). OC values in our oat breeding trials ranged from 3.57% to 6.19%. Like our findings, Kourimska et al. (2018) and Sunilkumar et al. (2017) determined that the OC values in oat varied between 2.9% and 6.5%. Generally, OC values in a classic oat breeding program range from 3% to 11%. Moreover, OC reached up to 18% in such studies that aimed to develop high-oil oat varieties (Peterson and Wood 1997; Peterson et al., 2005; Marshall et al., 2013; Gorash et al., 2017). The aim of our oat breeding program was not only to develop a high-OC variety. On the contrary, it was able to create ones with PC and OC values above a certain level together with the grain yield.

Like GY, test weight (TW) measured in our oat breeding trials was negatively affected by drought stress. TW values were recorded as 35 kg hl^{-1} in the 2008-2009 season, when the lowest precipitation received, whereas determined as 52 kg hl^{-1} in a high rainfall season (2010-2011). The variation within TW values resulted from environmental and genotypic differences. For example, TW values of oat genotypes with thin grain vs. ones with plump grain (genotypic difference) were lower (Peterson et al., 2005; May et al., 2020).

Heritability

Heritability (H), based on its magnitude (range: 0.00-1.00), was categorized as low (H<0.50), medium (H>0.50 and H<0.70), and high (H>0.70) (Roy and Shil, 2020). The lowest H value (0.19, also categorically low H) was estimated for the grain yield (GY) obtained from yield, advanced yield, and elite yield trials (abbrv., OYT, OAYT, and OEYT, respectively) conducted in the driest season (2008-2009). Interestingly, the highest H value (0.58, but categorically medium H) for GY was estimated from oat breeding trials conducted in the second driest season (2011-2012) (Tables 2 and 3). H values for GY varied between 0.19 and 0.39 in the 2008-2009 and between 0.21 and 0.58 in 2011-2012. We believe that the cold damage (from -15 °C to -18 °C) occurred in both seasons caused H estimates for GY different, together with intraspecific differences in winter hardiness of oat. In the remaining two seasons (2009-2010 and 2010-2011), there was no significant change in H values, despite higher precipitation. In our oat breeding trials, the mean H value measured for GY was estimated to be 0.38. As a result, we can say that the main reason for the differences in H values for GY was due to both genotypic and environmental effects. For instance, Yan et al. (2016) estimated H values for GY in oat as 0.00-0.44 (zero H to low H), in their study in Canada, so did Nava et al (2010) as 0.48 (low H) in Brazil. On the contrary, Svobodova et al. (2019) estimated the H value for GY as 0.81. Svobodova et al. (2019) conducted their research in countries with a humid and cool climate and good soil fertility (stress-free conditions for oat) such as the Czech Republic and Estonia. Under those conditions, since oat genotypes showed their better performances, higher H values for GY could be expected. But Svobodova et al. (2019) stated that in regions where the Mediterranean climate dominates (due to drought and high temperature stresses), the H value for GY could generally be estimated as low or medium level. Because, in the drought and heat stressed conditions of the Mediterranean climate, oat could not reveal the GY potential. Instead, they could activate the mechanisms of resistance to drought and heat stresses, which prevents the expression of the genes controlling GY potential, also called genotype × environmental interaction. In this way, the H value for GY could reduce up to low or medium level (Campos et al., 2004). Of course, there was an exception for this situation. Ceccarelli et al. (1998) in Blum (2011) reported that plant genotypes with satisfactory GY under semi-arid conditions could be derived from hybrids carrying drought resistance genes. Considering the above information, it was evident that both genotypic and environmental effects could cause the differences in H values for GY of oat.

Our oat breeding program aims to develop high-protein oat varieties for both human food and animal feed. The breeding strategy concerned mainly relies on the degree of H value for PC. If the H value for PC is high, success in breeding is immediate. However, if it is low or medium, the breeding process becomes long and complicated (Holland et al., 2001). In our study, H values for PC ranged from 0.48 (medium) to 0.83 (high), with an average of 0.66 (medium) (Table 3). H values estimated for PC in our oat experiments differed regarding both the trial per se (genotype) and the year per se (season). This result revealed that GEI effects on PC were significant (Martin, 2018). At first, Frey (1975) announced that H values for PC in oat were between 0.09 and 0.90, with a mean of 0.41. Later, Herrmann et al. (2014) underlined that they were from 0.72 to 0.77. Tanhuanpaa et al. (2012) and Herrmann et al. (2014) reported that the number of QTLs associated with PC was between 2 and 5, explaining about 50% of the genotypic variation. Meanwhile, they stated that the higher the H value for the PC was unlikely because of the environmental interaction with the QTL. Herrmann et al. (2014), Tanhuanpaa et al. (2012), and our findings showed that the H value for PC could be estimated as a medium, but not high.

Although low OC oat varieties are preferred in human nutrition (food), high OC varieties, providing higher energy, are essential in animal nutrition. The way to develop high OC oat varieties depends on the level of H value. In our study, the H values calculated for OC over oat breeding trials ranged from 0.53 (medium) to 0.82 (high), with a mean of 0.68 (medium) (Table 3). In our oat breeding program, we could say that the breeding procedure for OC would be longer and more complicated since the average H values were at the medium level. Branson (1987) estimated H value for OC in oat as 0.68, so did Herrmann et al. (2014) as 0.80. In the first study, the reason why H values for OC differed was attributed to GEI effects, and only to the genotype effects in the second study. However, the temporal (over the years) and genotypic differences (over trials) present in our oat breeding trials caused H values for OC to fluctuate between 0.53 (medium) and 0.82 (high).

TW in oat is determined by (1) packing factor, i.e., the shape and size of the grain, and (2) grain density, i.e., the hull properties such as thickness, wrapping caryopsis loosely or tightly, space between caryopsis and hull. Oat genotypes with shorter and plumper grain generally have higher TW values, ones with the thin and tightly wrapped hull do as well (Doehlert, 2002). In an oat breeding program, TW is one of the primary quality criteria, specifically in making selection to discard or promote genotypes. Success in selection depends on the H value of TW. In our study, H values for TW varied between 0.41 (low) and 0.71 (medium), with a mean of 0.57 (Table 3). Like our findings, Nava et al. (2010) found the H value for GY as 0.51 (medium) in their study in Brazil. But Holland et al. (2001) and Herrmann et al. (2014) determined the H values for TW between 0.45 and 0.85 (low to high) in their studies. Consequently, the fluctuations in H values for TW were attributed to both the studied genotypes (genetic background) and the environmental conditions (year, climate, and soil conditions) (Svobodova et al., 2019; May et al., 2020).

Table 3. Heritability estimates for traits studied

Cropping season	Trial†	GY‡	PC	OC	TW
2008-2009	OAYT	0.19	0.48	0.56	0.44
2009-2010	OYT	0.35	0.75	0.61	0.49
	OAYT-1	0.39	0.63	0.78	0.58
	OAYT-2	0.46	0.69	0.82	0.61
2010-2011	OYT	0.29	0.59	0.54	0.41
	OAYT	0.52	0.75	0.79	0.63
2011-2012	OYT	0.21	0.62	0.53	0.69
	OAYT	0.42	0.83	0.81	0.58
	OEYT	0.58	0.59	0.72	0.71
Mean		0.38	0.66	0.68	0.57
Min.		0.19	0.48	0.53	0.41
Max.		0.58	0.83	0.82	0.71

†OYT, Oat yield trial; OAYT, Oat advanced yield trial; OEYT, Oat elite yield trial;
‡GY, Grain yield (kg ha^{-1}); PC, Protein content (%); OC, Oil content (%); TW, Test weight (kg hl^{-1})

Correlations between traits studied

Our study showed that an inverse relationship existed between GY and PC (Table 4). It was confirmed in seven out of our nine oat breeding trials. PC is mostly related to starch content (SC) in oat grain. In other words, low PC often brings about high SC in oat grain and then high GY (Holland, 1997).

The direction of the relationship between GY and PC is a controversial issue. Like ours, many studies underlined that the relationship between them was negative (Martinez et al., 2010; Herrmann et al., 2014; Yan et al., 2016; Sadras et al., 2019). Naturally, it means that most high-yielding oat breeding lines have low PC values. It points to an obstacle to be overcome in terms of our oat breeding program (Yan et al., 2016). On the other hand, a positive relationship between PC and GY was found in a study (Martin, 2018). However, Martin (2018) concluded that a positive relationship could only be achieved with increased N doses. Martin (2018) was able to reach this conclusion in agronomy studies, but not in oat breeding trials.

We identified statistically significant positive relationships between GY and OC (Table 4). Thro and Frey (1984), Peltonen-Sainio and Peltonen (1993), and Herrmann et al. (2014) also reported correlations consistent with our findings. On the one hand, Holland (1997) and Yan et al. (2016) pointed out the research findings showing that the correlations between GY and OC were insignificant. On the other hand, Zhou et al. (1999) indicated studies showing that there were negative relationships between GY and OC. The reason why the research findings differed could be related to the wide variation in OC of oat genotypes and the effect of the environment on OC to a certain extent. Like GY, OC was also a polygenic character, so it was almost impossible to capture one direction of correlation (Zhou et al. 1999).

Table 4. Correlations between grain yield and quality traits studied

Cropping season	Trial†	GY‡ v PC	GY v OC	GY v TW	PC v OC	PC v TW	OC v TW
2008-2009	OAYT	0.233	-0.345	0.183	0.351	-0.093	-0.072
2009-2010	OYT	-0.564**	0.438*	0.299	-0.473*	-0.253	0.257
	OAYT-1	-0.421*	0.382	0.401*	-0.398	0.227	0.344
	OAYT-2	-0.629**	0.554**	0.342	-0.487*	-0.411*	0.453*
2010-2011	OYT	-0.399	-0.285	0.489*	0.263	0.158	-0.211
	OAYT	-0.487*	0.543**	0.539**	-0.502**	-0.339	0.402*
2011-2012	OYT	0.292	0.462*	-0.247	0.375	-0.421*	0.371
	OAYT	-0.581**	0.302	0.435*	-0.607**	0.363	0.581**
	OEYT	-0.698**	0.567**	0.408*	-0.477*	-0.445*	0.263
Mean		-0.362	0.291	0.317	-0.217	-0.135	0.265
Max.		-0.698	0.567	0.539	-0.607	-0.445	0.581
Min.		0.233	-0.285	0.183	0.263	-0.093	-0.072

*, ** significant at P<0.05 and P<0.01, respectively

†OYT, Oat yield trial; OAYT, Oat advanced yield trial; OEYT, Oat elite yield trial

‡GY, Grain yield (kg ha^{-1}); PC, Protein content (%); OC, Oil content (%); TW, Test weight (kg hl^{-1})

In this study, we calculated statistically significant positive correlations between GY and TW (Table 4). Like our findings, Holland and Munkvold (2001), Long et al. (2006), Herrmann et al. (2014), and Sadras et al. (2019) found that there was a positive relationship between GY and TW. Rocquigny et al. (2004) reported that the reason why the positive relationship between GY and TW in oat existed could be related to the decrease in thousand-grain weight through increased grain plumpness and grain number per hectare.

We determined significant negative relationships between PC and OC (Table 4), and so did Sadras et al. (2019). Meanwhile, Yan et al. (2016) stated that depending on the genotype used in oat hybridization, the direction of the correlation between PC and OC could change (non-significant to negatively significant). However, in the studies conducted by Schipper and Frey (1992) and Peterson and Wood (1997) on the lines developed from the hybridization between *Avena sativa* and *Avena sterilis*, significant positive relationships between PC and OC were found. Correspondingly, in the same oat breeding materials, Holland et al. (2001) determined that when selecting lines with high OC and PC, some quality properties (e.g., TW) and agronomic properties (e.g., TGW and biomass) were regressed owing to an adverse selection effect.

In six out of our nine oat breeding trials, correlations between PC and TW were negative, but only significantly negative in three (Table 4). In the remaining trials, they were positive but not significant. Like ours, Sadras et al. (2019) found significant negative relationships between PC and TW, but Herrmann et al. (2014) identified significant positive associations. There was no consensus among studies examining correlations between PC and TW. There could be two main reasons why the direction of the correlation between PC and TW (genotypic background and environment) was incompatible. For example, like our findings, the PC values of most of the genotypes used in the study conducted by Sadras et al. (2019) were less than 15%. On the other hand, the fact that the PC values of the parents used in the study conducted by Herrmann et al. (2014) were relatively high (>20%) resulted in a significant positive correlation between PC and TW. Besides, environmental conditions (good soil and climate conditions of Germany, in the case of Herrmann et al. (2014) versus stressful soil and climate conditions of Australia and Turkey, in the case of Sadras et al. (2019) and ours) could have caused fluctuations in PC and TW values.

Correlations between OC and TW were positive in seven of the nine trials in our study, but just only two of them were significant (Table 4). In the remaining trials, they were negative but not significant. Like ours, Sadras et al. (2019) found a significant positive correlation between OC and TW. In contrast, Herrmann et al. (2014) calculated significant negative correlations between them. Doehlert (2002) reported that the groat and hull properties led to the TW values of oat to be different. In general, plump shaped grains had high TW, while long ones had low TW due to allowing more air spaces between grains. On the other hand, Peterson and Wood (1997) reported that as grain morphology changed from plump to long, its oil concentration increased. It was due to the increase in the surface: volume ratio of longer and slimmer grain compared to that of shorter and plumper grain because the aleurone and subaleurone layers of the grain endosperm expanded since oil was accumulated mainly in those. Holland et al. (2001) continued to work on the oat breeding materials studied by Peterson and Wood (1997), and they concluded that high OC genotypes generally had low TW values and, therefore, the breeding process for quality in oat was negatively affected.

Conclusions

Our oat breeding program has many obstacles to overcome. Making quality analysis is not the only way to develop high-quality oat varieties. In practice, it is necessary to ensure that oat should be resistant to drought, cold, high temperature, and diseases as well as high quality. All efforts considered, we are trying to improve and manipulate oat by means of classical approaches. In this regard, we attempted to summarize the goals and achievements of our oat breeding program:

1. Quality in oat is a complex issue. We should redesign the oat breeding program in terms of quality because the food, feed, and forage oat quality features are quite different from each other.
2. The H values and correlation coefficients calculated on our oat breeding trials are generally at a level that will slow down the breeding processes. It may be possible to solve these problems with targeted studies (e.g., characterization of parents) in the oat crossing block.
3. An optimum selection index should be developed for simultaneous improvement in both GY and quality traits.
4. More budget, personnel, equipment, and lab facility are required to strengthen oat breeding activities.

Conflict of Interest: The authors declare no conflict of interest.

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