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Screening Turkish maize landraces for kernel oil content and oil quality traits

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Abstract

In this study, maize landraces, previously collected from different regions of Turkey through a national maize breeding project, were screened for kernel oil content and oil quality. After a seed reproduction in 2017, the screening trial was conducted in 2018, using an Augmented Experimental Design with 192 local maize populations along with seven check hybrids. Data were collected on oil, oleic acid, linoleic acid, monounsaturated (MUFA), polyunsaturated and saturated fatty acids, total carotenoid and total tocopherol contents. The results showed that there was a considerable amount of genetic variation among the Turkish maize landraces for almost all the traits investigated in this study. Some of the evaluated landraces are available that could be considered as high oil variety or special genotypes in terms of certain oil quality traits. Landraces had significantly higher values than checks for oil content, oleic acid, MUFA and tocopherol contents. Genetic analyses suggest that the kernel quality traits could be successfully manipulated using the investigated plant material. Heritability values were found high for all the traits of interest, except for saturated fatty acid and total carotenoid content. The promising landraces detected in this study could be exploited in future breeding programmes upon further evaluations at the population level.

Keywords: fatty acids, genetic variation, secondary metabolites, Turkey, *Zea mays*

Introduction

Maize has an important place in world grain production and consumption. In the last decade, global maize production has increased by 30% (FAO, 2017). Being equally important for human and animal nutrition, maize has a number of different end uses. Although not classified as an oil crop due to low oil content in the grain (Watson, 2003), maize ranks higher than many oil crops in providing plant-based oils (Mittaine and Mielke, 2012; Ash and Matias, 2018).

Since it provides more energy, high oil content is desirable in maize especially when used as animal feed. Studies have shown that livestock fed high-oil maize have a faster increase in body weight (Lambert, 2001). To meet the demand for maize oil, it is desirable to increase the oil ratio of the maize kernel and develop high oil maize lines/hybrids. Oil ratio varies between 3.5 and 5% in normal hybrids, while hybrids with 7–8% oil can be obtained through classical breeding studies (Lambert, 2001). Valuable high-oil germplasms (e.g. Illinois High-Oil (IHO) and Alexho Synthetic and Beijing High-Oil (BHO)), and hybrids are available for use throughout the world (Yang and Li, 2018), despite the yield penalty associated with elevated oil levels (Thomison *et al*., 2002, 2003).

Improving the quality of oil is another research area in maize. The primary factor affecting oil quality is its fatty acid composition. Hence, developing hybrids with special fatty acid composition is a legitimate pursuit for breeders. Different fatty acids offer advantages for different purposes. For example, oleic acid is sought for its resistance to

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oxidation (Yodice, 1990), while linoleic acid is considered valuable in nutrition (McVetty and Scarth, 2002). Amounts of carotenoids and tocopherols in maize are also among the evaluation criteria for nutritional quality. Thanks to their antioxidant effect, these compounds are known to extend the shelf life of maize oil (Chow and Draper, 1974), and reported to be effective against many diseases (Hallfrisch *et al.*, 1994; Block, 1999). Studies on carotenoids and tocopherols have shown a considerable genetic diversity in maize genotypes, which can be used for human benefit through breeding studies (Egesel, 2001; Rocheford *et al.*, 2002; Egesel *et al.*, 2003).

The variation of oil content and composition of secondary components have been investigated on maize inbreds, hybrids and landraces (Cheesbrough *et al.*, 1997; Berardo *et al.*, 2009; Kuhnen *et al.*, 2011; Öner, 2011; Ryu *et al.*, 2013). Recently, interest in maize landraces has increased due to the high genetic variability they harbour (Newton *et al.*, 2010; Strigens *et al.*, 2013), which could alleviate the bottleneck effect and narrowed gene pools caused by yield-focused breeding programmes (Tanksley and McCouch, 1997; Fu, 2015). In this respect, research on the oil content and oil quality of landraces has a special importance for breeding programmes.

This study was conducted to evaluate the performance of Turkish maize landraces for oil content and oil quality traits. The potential of using these materials in breeding programmes was evaluated based on the inheritance values calculated.

Materials and methods

One hundred ninety-two Turkish maize landraces stored in Turkish National Gene Bank were used as experimental material in this study. General information about experimental material (provincial information and stock numbers of National Gene Bank records) is presented in Table 1. After a seed increase in 2017, the field trial was carried out in 2018 at the Crop Production Research and Application Unit of Çanakkale Onsekiz Mart University. The soil of experimental plots was low in organic matter (1.22%), slightly alkaline (pH = 8.2), nonsalty (0.53 mS/cm) and had a fair amount of potassium (570 kg/ha). The season was compatible with long-term averages climatically, which can be considered suitable for irrigated maize cultivation. The field experiment used an augmented design with six blocks, each one containing 32 landraces and seven check hybrids. Planting was made by hand in the first week of May 2018. Each genotype was planted in 4 m single-row plots with 0.7 × 0.2 m spacing. Standard fertilization and irrigation processes required for maize were applied throughout the field trial (BÜGEM, 2018). Selected plants in each plot were hand pollinated to prevent xenia effect on kernel quality traits (Kahriman, 2016). Harvest was made by hand when the plants had reached physiological maturity, which was observed through the formation of black layer on the kernels.

Oil, oleic acid, linoleic acid, total monounsaturated fatty acid (MUFA), total polyunsaturated fatty acid (PUFA) and total saturated fatty acid contents were determined by near-infrared (NIR) spectroscopy. For the NIR measurements, grains from five ear samples from each plot were shelled and ground in a laboratory mill (Fritsch pulverisette 14, Germany) with a 0.5 mm sieve diameter. The flour sample was placed in a rotating vessel of the NIR device (Spectrastar 2400D, USA). Afterwards, the spectra, taken from these samples between 1200 and 2400 nm with 1 nm intervals, were applied to the local calibration model previously developed by Egesel and Kahrıman (2012), to estimate the oil ratio of the samples on dry matter basis. The same samples were kept in diethyl ether overnight in a refrigerator, and cold extraction method was applied to elute crude oil. After the oil extraction process, the crude oil samples were obtained from the solvent + oil mixture with a rotary evaporator (Hahnvapor, Hahnshin S&T Co., Korea) at 35°C. The fatty acid contents (%) of the crude oil samples were determined using NIR instrument (Spectrastar 2400D, Unity Scientific, USA) with the help of a local calibration model developed by Egesel *et al.*, (2016). This calibration is able to calculate each fatty acid as a percentage within a crude oil sample through prediction models developed based on gas chromatography analyses.

Total carotenoid content (TCC) of the samples was determined according to the method proposed by Rodriguez-Amaya and Kimura (2004). TCC on dry weight basis was calculated based on the following formula:

$$\text{TCC } (\mu g/g) = \frac{25 \times A1 \times 10^4}{2500 \times W}$$

where $A1$ is the absorbance value and W is the sample weight.

Tocopherol content was determined according to the method proposed by Jargar *et al.* (2012). Total tocopherol content (TTC) in 100 ml sample was calculated in mg by applying the following formula:

$$\text{TTC } (\text{mg}/\ 100\ \text{ml}) = \frac{A1 \times 100}{1.5 \times 1000}$$

where $A1$ is the concentration value obtained from the standard curve. The results from this formula were converted to amount of tocopherol of a sample in dry weight basis by using the sample weights.

Statistical analyses

Because of the large number of genotypes to be analysed and limited amount of seeds available for the entries, the

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Table 1. The information about the origin and gene bank codes of 192 maize landraces investigated in this study

Province	Number	National Gene Bank Code
Mediterranean	5	TR38101, TR38141, TR38341, TR42948, TR50131
Eastern Anatolia	3	TR48893, TR50547, TR55492
Aegian	32	TR37006, TR37603, TR37720, TR37924, TR37955, TR37984, TR37986, TR38128, TR38172, TR38243, TR38439, TR38451, TR42641, TR42877, TR45102, TR48454, TR48891, TR49171, TR49579, TR50130, TR50216, TR50559, TR50642, TR50798, TR54197, TR55476, TR55479, TR55480, TR55485, TR55486, TR55506, TR55545
Southeast Anatolia	6	TR37573, TR37918, TR37995, TR42725, TR49168, TR55510
Central Anatolia	2	TR38064, TR49245
Black Sea	87	TR36986, TR37115, TR37543, TR37583, TR37600, TR37605, TR37611, TR37618, TR37630, TR37719, TR37746, TR37810, TR37861, TR37882, TR37912, TR37940, TR37941, TR37953, TR37958, TR37969, TR37974, TR37998, TR38008, TR38026, TR38040, TR38104, TR38147, TR38208, TR38240, TR38256, TR38323, TR38329, TR38389, TR38401, TR38422, TR38457, TR42576, TR42703, TR42750, TR42856, TR42868, TR42949, TR42985, TR44385, TR48461, TR49197, TR49225, TR49234, TR49260, TR49271, TR49313, TR49323, TR50220, TR50513, TR50515, TR50516, TR50549, TR50550, TR50555, TR50558, TR50564, TR50670, TR50816, TR51727, TR52003, TR54192, TR54193, TR54196, TR54217, TR54712, TR55452, TR55461, TR55463, TR55464, TR55471, TR55484, TR55488, TR55491, TR55502, TR55507, TR55508, TR55513, TR55521, TR55522, TR55527, TR55533, TR57654
Marmara	57	TR37105, TR37596, TR37597, TR37601, TR37653, TR37735, TR37754, TR37876, TR37932, TR37970, TR38024, TR38100, TR38289, TR38292, TR38337, TR38339, TR38343, TR38350, TR38375, TR38435, TR40604, TR42591, TR42689, TR42712, TR44410, TR44501, TR48449, TR48477, TR49277, TR49303, TR49318, TR49578, TR50125, TR50126, TR50250, TR50505, TR50511, TR50524, TR50551, TR50566, TR50585, TR50587, TR50588, TR50641, TR50683, TR51719, TR53247, TR53254, TR54199, TR54216, TR55481, TR55518, TR55528, TR55534, TR55540, TR55542, TR57658

experiment used an augmented design (Venugopalan *et al.*, 2008), and the data were analysed accordingly. Analysis of variance (ANOVA) was performed in R program (R Core Team, 2018) using the augmentedRCBD package (Aravind *et al.*, 2019). Descriptive statistics such as mean, standard deviation, standard error, skewness and kurtosis values were calculated. Genotypic, phenotypic and environmental variance (GV, PV and EV) and respective variation coefficients (GCV, PCV and ECV) were determined. Using these values; broad sense heritability (hBS), genetic advance (GA) and genetic advance over the mean (GAM) values were estimated according to Aravind *et al.* (2019). PCA-Biplot and boxplot graphics were used to show the differences among the genotypes for the investigated traits. These graphics were created in the R program with the help of the ggpubr package (Kassambara, 2019).

Results

ANOVA results are presented in Table 2. There were significant differences among the landraces for all traits except for carotenoid content. The differences between averages of checks and landraces were also found to be statistically significant, with the exception for carotenoid content. Check hybrids were also a significant source of variation for most of the variables investigated in this study (Table 2).

Descriptive statistics are shown in Table 3. In terms of oil content, genotypes ranged from 2.31 to 8.34%, with a mean of 4.75%. Genotypes had remarkable ranges for fatty acids, carotenoids and tocopherols. Oil, carotenoid and tocopherol data showed significant skewness values, indicating a violation of normal distribution.

The variation within the landraces and checks is shown in Fig. 1. All of the variation could be explained with a total of seven dimensions in PCA-Biplot analysis, and the first two dimensions explained 77.6% of the total variation for the investigated traits (Fig. 1). According to PCA-Biplot, it was seen that the variation for oil, oleic acid, linoleic acid, MUFA, PUFA and SFA contents was explained in the first dimension, while the carotenoid and tocopherol contents were explained in the second dimension. Considering the correlations between the dimensions and the variables (data not shown), it was understood that oil content, oleic acid, MUFA and SFA content had positive correlations, while carotenoid, PUFA and linoleic acid contents had negative correlations with the first dimension. The tocopherol and carotenoid contents had positive and significant relationships with the second dimension; however, there was a negative correlation between this dimension and

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Table 2. Mean squares from the ANOVA of the investigated traits for 192 landraces and seven check hybrids

SoV	df	Oil	Oleic	Linoleic	MUFA
Block[a]	5	0.73ns	18.98**	20.23**	18.09**
Block[b]	5	0.61ns	4.92ns	5.68ns	5.2ns
Genotypes (G) [c]	198	0.97**	34.60**	36.56**	34.34**
Genotypes (G) [d]	198	0.98**	34.96**	36.92**	34.67**
Checks (C)	6	1.42**	12.76 *	14.74 *	12.93 *
Landraces (L)	191	0.86**	30.39**	31.75**	30.17**
C and C versus L	192	0.96**	35.29**	37.24**	35.01**
C versus L	1	21.57**	1040.06**	1158.09**	1024.88**
Error	30	0.31	4.35	4.53	4.38
SoV	df	PUFA	SFA	TCC	TTC
Block[a]	5	17.89 *	0.31	1590.37 *	1371.05**
Block[b]	5	6.07ns	0.10	1154.16 *	326.89 *
Genotypes (G) [c]	198	37.68**	0.38**	530.89ns	250.38**
Genotypes (G)[d]	198	37.97**	0.39**	541.91ns	276.75**
Checks (C)	6	14.8 *	0.27	1033.18ns	105.41ns
Landraces (L)	191	32.43**	0.34**	523.99ns	253.31**
C and C versus L	192	38.39**	0.38**	515.19ns	254.91**
C versus L	1	1236.28**	9.9**	1017.2ns	5781.32**
Error	30	4.88	0.15	441.46	95.98

SoV, source of variation; df, degrees of freedom; MUFA, monounsaturated fatty acids; PUFA, polyunsaturated fatty acids; SFA, saturated fatty acid; TCC, total carotenoid content; TTC, total tocopherol content.
[a]Estimation adjusted by ignoring treatment effect.
[b]Estimation adjusted by eliminating treatment effect.
[c]Estimation adjusted by eliminating block effect.
[d]Estimation adjusted by ignoring block effect.
*, ** indicate significance level at 0.05 and 0.01, respectively.

Table 3. Descriptive statistics calculated based on the data from 192 landraces and seven check hybrids for the investigated traits

Trait	*n*	Mean	Std. Dev.	Min.	Max.	Skewness	Kurtosis
Oil (%)[a]	199	4.75	0.07	2.31	8.34	0.46**	3.73ns
Oleic (%)[b]	199	34.13	0.39	19.99	49	0.08ns	2.78ns
Linoleic (%)[b]	199	49.73	0.4	34.74	64.28	−0.05ns	2.72ns
MUFA (%)[b]	199	34.6	0.39	20.4	49.36	0.07ns	2.78ns
PUFA (%)[b]	199	51.16	0.41	36.08	66.03	−0.03ns	2.75ns
SFA (%)[b]	199	14.23	0.59	12.4	15.59	−0.21ns	2.95ns
TCC (µg/g)[a]	199	37.08	1.83	0	130.31	0.76**	3.16ns
TTC (µg/g)[a]	199	55.88	1.27	22.62	106.09	0.77**	3.12ns

MUFA, monounsaturated fatty acids; PUFA, polyunsaturated fatty acids; SFA, saturated fatty acid; TCC, total carotenoid content; TTC, total tocopherol content.
[a]On dry basis.
[b]On percentage of crude oil.

the oil content. When the correlation coefficients between the dimensions and the traits were examined along with the vector directions, the correlations among the investigated traits could also be evaluated on the PCA-Biplot. Accordingly, it was understood that there were positive relationships between PUFA and linoleic acid, as well as

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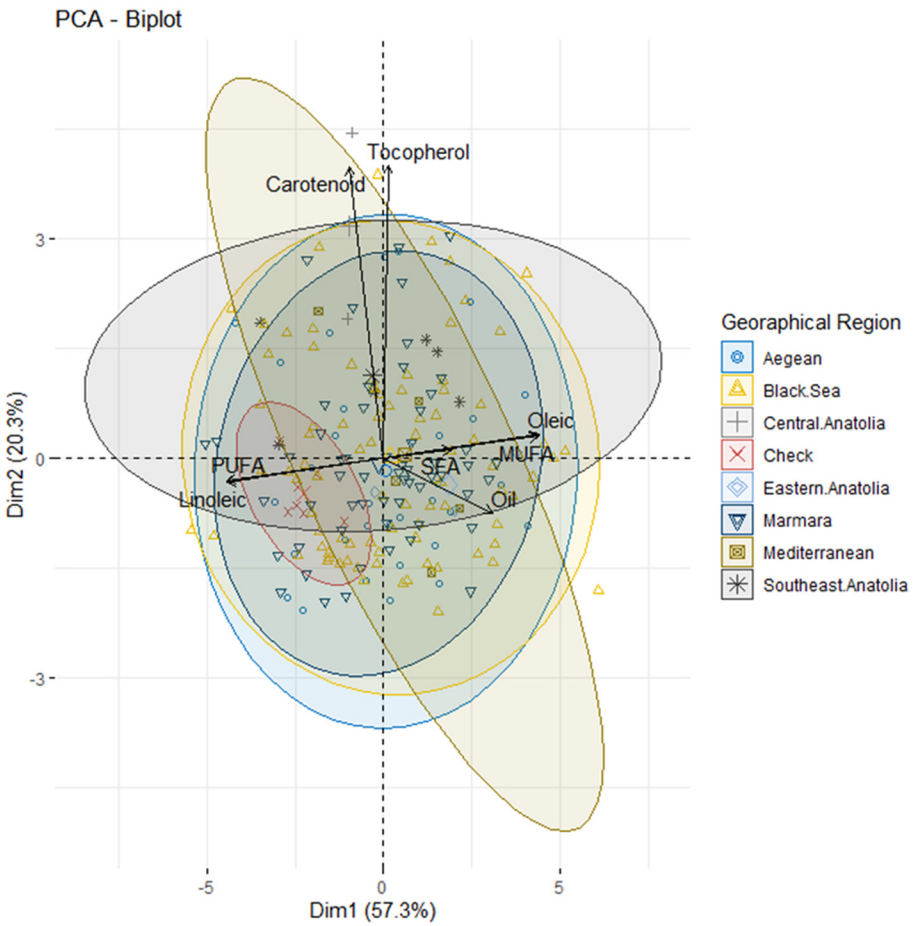

Fig. 1. PCA-Biplot of the genotypic variation for 192 landraces and seven check hybrids for the investigated traits as analysed by the geographic regions of Turkey.

tocopherol and carotenoid contents. The remaining variables were positively correlated with each other. There was a negative correlation between the first group of traits (PUFA and linoleic acid) and second group of traits (oil, MUFA, SFA and oleic acid) whose vectors are in the opposite direction. In addition to these findings, the PCA-Biplot also provided information about the variation of the traits present within the local maize landraces based on the regions they were collected. Positioning of the ellipses representing the genotype groups helps us to interpret the differences among those groups for the investigated traits. The shapes and widths of the ellipses provide information about the genotypic variation for these traits. It is understood that the landraces collected from Southeastern Anatolia and Mediterranean regions had high variability. The small size of the ellipse of the check varieties indicated that the variation in terms of the variables was limited (Fig. 1). The maize landraces for all regions had much larger variation than the check hybrids. Boxplot graphics (Fig. 2), which were created to compare differences between the check varieties and maize landraces in detail, also confirmed this situation. In boxplot charts, the most important differences between check varieties and maize landraces were evident for oil, oleic acid, linoleic acid, MUFA, PUFA and SFA. Although not separate in PCA-Biplot charts, it was observed that the checks had higher means than landraces in terms of PUFA and linoleic acid contents. However, it is shown that many landraces had superiority to check varieties in terms of oil content (TR36986, TR38147 and TR48893), oleic acid (TR37912, TR36986 and TR577654), MUFA (TR37912, TR36986 and TR57654) and SFA (TR54197, TR48454 and TR38258). Especially, the landraces originated from the Black Sea and Aegean regions had higher contents of oil, oleic, MUFA and SFA as compared to check hybrids.

Inheritance related calculations are shown in Table 4. For all traits, PV was found higher than GV. The carotenoid and tocopherol content had higher GCV and PCV values than other traits. The heritability values were between 15.8 and 85.7%. Low heritability was observed for carotenoid content (15.8%), while fatty acids were highly heritable traits based on broad-sense heritability values (>80%).

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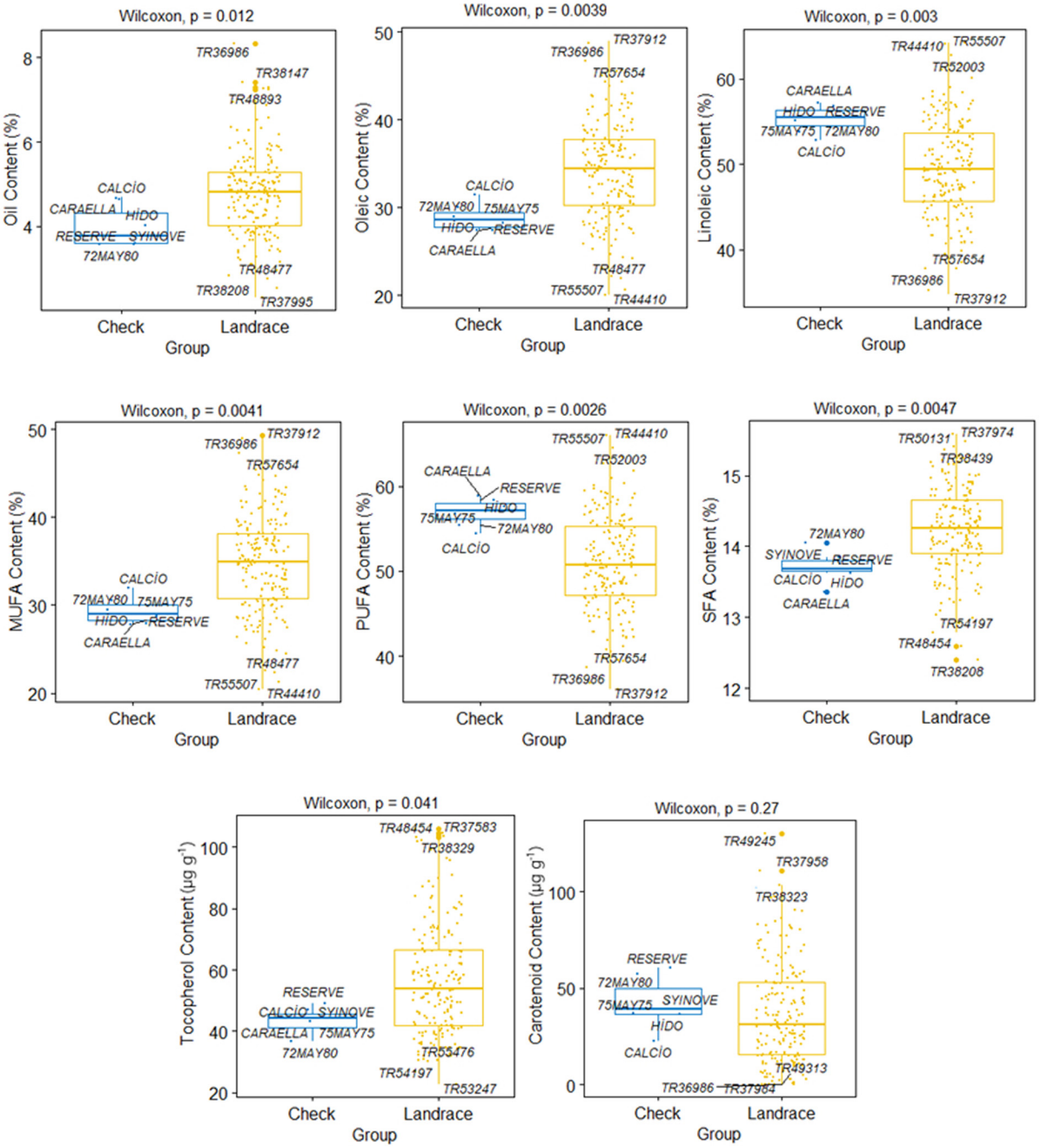

Fig. 2. Boxplots for comparison of the landraces and check hybrids according to the investigated traits.

Theoretical GAM values ranged between 0.67 and 20.39. GAM corresponding to these values varied between 4.72 and 36.5% for the investigated traits.

Discussion

Quality breeding has become a popular objective in maize and increasing oil content is one of the common targets in breeding programmes (Sharma and Carena, 2016). Oil content is a quantitative trait controlled by many genes, and generally associated with larger embryo sizes in maize kernel (Yang *et al.*, 2012). Although different limit values have been specified in the literature, a genotype should contain more than 7% oil in its kernel to be considered as high oil maize (Lambert, 2001). In the current study, it was observed that there is a significant variation within the genotypes screened for oil content (2.31–8.34%), and most

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Table 4. Inheritance parameters of the investigated traits as calculated from 192 landraces and seven check hybrids

Trait	Mean	PV	GV	EV	GCV	PCV	ECV	hBS	GA	GAM
Oil (%)[a]	4.75	0.86	0.55	0.31	15.6^{M}	19.5^{M}	11.7	63.9^{H}	1.22	25.7^{H}
Oleic (%)[b]	34.13	30.39	26.05	4.35	14.9^{M}	16.15^{M}	6.11	85.7^{H}	9.75	28.6^{H}
Linoleic (%)[b]	49.73	31.75	27.22	4.53	10.5^{M}	11.33^{M}	4.28	85.7^{H}	9.96	20.0^{H}
MUFA (%)[b]	34.6	30.17	25.78	4.38	14.7^{M}	15.87^{M}	6.05	85.5^{H}	9.68	27.9^{H}
PUFA (%)[b]	51.16	32.43	27.55	4.88	10.3^{M}	11.13^{M}	4.32	84.9^{H}	9.98	19.5^{M}
SFA (%)[b]	14.23	0.34	0.19	0.15	3.06^{L}	4.10^{L}	2.72	55.8^{M}	0.67	4.72^{L}
TCC (µg/g) [a]	37.08	523.99	82.52	441.5	24.5^{H}	61.74^{H}	56.67	15.8^{L}	7.44	20.1^{H}
TTC (µg/g) [a]	55.88	253.31	157.33	95.9	22.5^{H}	28.48^{H}	17.53	62.1^{H}	20.39	36.5^{H}

MUFA, monounsaturated fatty acids; PUFA, polyunsaturated fatty acids; SFA, saturated fatty acid; TCC, total carotenoid content; TTC, total tocopherol content; PV, phenotypic variance; GV, genotypic variance; EV, environmental variance; GCV, genotypic coefficient of variability; PCV, phenotypic coefficient of variability; ECV, environmental coefficient of variability; hBS, broad-sense heritability; GA, genetic advance; GAM, genetic advance over the mean; H, high; M, moderate; L, low.
[a]On dry basis.
[b]On percentage of total fatty acids.

Turkish landraces have higher oil content than the check varieties. It was determined that there are three landraces (TR36986, TR48893 and TR48461) among these populations that can be classified as high-oil maize (>7%).

Quality breeding for maize oil also focuses on improving the fatty acid composition (Pollak and Scott, 2005). There are three main objectives on the improvement of fatty acid composition in maize: (i) reducing total saturated fatty acids below 6%, (ii) increasing the total fatty acids for margarine manufacturing and (iii) increasing the oleic acid content for making maize oil compatible with the major oil crops such as canola, soybean and olive. Fat soluble compounds such as carotenoids and tocopherols have an important role against oxidation (Singh *et al.*, 2014). Although there are no limits set on the fatty acids and fat-soluble compounds, there are findings that make it possible to classify maize landraces for these properties. Burt *et al.* (2011) reported that maize accessions with high carotenoid content contained 50–101 µg/g carotenoids. The TCC of the genotypes used in our study was determined in the range of 0–130 µg/g, and it was observed that there are a considerable number of maize landraces with carotenoid content over 50 µg/g (Fig. 2).

The ecology of the region where the plant material was collected and the farmers who selected these genotypes should have important effects on the genetic variation found in these landraces. Fig. 1 indicates that geographic region is a factor on the distinctive characteristics possessed by Turkish landraces. Indeed, the seven geographical regions of Turkey diverge significantly in terms of the environmental factors sculpting plant architecture. The landraces collected from these regions show certain plant characteristics based on the long-term adaptation to the climatological effects of those areas. Grain quality traits are no exception in this regard. More importantly, the selection processes applied by farmers throughout generations must have played a decisive role in the genetic make-up of these materials (Mwololo, 2010). In fact, landraces are genetic resources grown in and adapted to a certain area for a long time (Hellin *et al.*, 2014). It is unlikely that oil and oil quality traits have been taken into consideration by the local farmers, but certain traits such as appearance, taste and colour seem to be conserved during this selection process. The presence of genotypes with low and high levels of carotenoids is an indication of divergent selection processes applied by humans with different preferences.

Number of the essential fatty acids found in nature are known to be around 20–25 (Kenar *et al.*, 2017), whereas maize oil mostly contains palmitic, stearic, oleic, linoleic and linolenic acids (Weber, 1987). Among these, oleic and linoleic acids make up most of the total fatty acids in maize oil. It has been reported earlier that oil content is positively correlated with oleic acid, but a negative correlation exists between oil and linoleic acid (Orhun and Korkut, 2011). The results from our study are in agreement with this information. Biosynthesis of unsaturated fatty acids occurs at the expense of one another. Oleic acid is known to be the precursor of the linoleic acid, which, in turn, is converted to linolenic acid through enzymatic activity (Belo *et al.*, 2008). Due to the nature of this pathway, there is a negative correlation between these fatty acids. Oleic and linoleic acids are the main sub-components in MUFA and PUFA, respectively. Generally, MUFA and PUFA show negative correlation with each other. In our study, the correlations detected between those fatty acids also confirm these evaluations. Several studies have investigated the relationship of carotenoids and tocopherols with fatty acids in maize. Goffman and Böhme (2001) reported a positive ($r = 0.41$) and moderate correlation between tocopherol content and PUFA in maize kernel.

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Considering the proximity of the trait vectors in the PCA-Biplot graphs, similar correlations exist for MUFA and PUFA with tocopherol and carotenoid contents in Turkish maize landraces. We also detected a high correlation between tocopherol and carotenoid contents. This finding agrees with the results of Kahriman *et al*. (2019).

The estimated broad-sense heritability for oil content (hBS = 63.9%) is within the limits specified in the literature. Rosulj and Husic (2002) reported that heritability varied between 13 and 85% in four different maize populations. In this study, all the traits had high heritability values (hBS > 60%), except for the carotenoid content. This indicates that genetic effects have an important role in the phenotypic variation for these traits. GA values calculated based on heritability estimates provide useful information for breeding programmes. However, the inclusion of dominance and epistatic interactions should be considered at this point (Wray and Visscher, 2008). Additionally, the heritability estimates here were calculated for all genotypes; in other words, they were not population-specific calculations. In order to make a better use of these genetic materials in the future breeding programmes, it may be necessary to calculate heritability values at the population level, especially for the promising landraces for one or more of the investigated traits. It would be possible to use the selected populations as donor germplasm in the efforts of developing inbred lines. Breeding studies assisted with *in vivo* doubled haploid technique have shown that the genetic variation carried in such populations could be successfully exploited (Strigens *et al*., 2013).

In conclusion, a comprehensive screening of Turkish maize landraces was carried out for oil content and oil quality-related traits. The results indicate the presence of a considerable genetic variation within the maize landraces for most variables. Exploiting this variation would require testing the promising landraces in replicated trials with advanced experimental designs over different environments.

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Conflict of interest
The authors declare no conflict of interest.

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