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AGRONOMIC CHARACTERISTICS OF TURKISH MAIZE LANDRACES HAVING THE LEVEL OF DIFFERENT OPACITY

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Abstract: Maize (*Zea mays* L.), a warm season cereal with high adaptability, can grow under various climatic conditions and has been cultivated in Türkiye for many years to meet diverse needs. While opacity is closely linked to protein quality in maize, studies evaluating agronomic performance in Turkish landraces with varying opacity levels are limited. This study utilized six local maize populations with opaque endosperm types and three standard genotypes, with field trials conducted in 2021 and 2022 using a randomized block design with three replications. During the first year, agronomic traits of the genotypes were examined, and harvested seed samples were categorized into five opacity levels (0%, 25%, 50%, 75%, and 100%) using a light table. In the second year, these samples were subjected to field trials, and agronomic measurements were repeated. Two-year averages revealed significant variations among genotypes in plant height (165.33–224.92 cm), first ear height (75.03–127.95 cm), ear length (15.69–19.56 cm), ear diameter (34.11–44.99 mm), number of rows per ear (10.43–21.33), number of grains per row (20.75–40.72), ear weight (88.76–258.37 g), and ear grain weight (64.12–204.91 g). Variance analysis showed significant effects of opacity level, genotype, and their interaction on the traits examined. An increase in opacity level was associated with decreases in plant height, first ear height, and ear weight. Compared to standard genotypes, populations POP2 and POP6 demonstrated promising agronomic traits at high opacity levels, indicating potential for breeding genotypes with high-quality protein. It has been evaluated that these populations can be used as source material in the development of genotypes with high quality protein.

Keywords: Opaque, Agronomic measurement, Light table, Protein quality, *Zea mays*

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1. Introduction

Maize (*Zea mays* L.), native to the Mexico-Guatemala region in Central America, has been cultivated as a staple grain in these areas for thousands of years. Globally, it is the third most cultivated crop after rice and wheat, with its cultivation area and production volume increasing annually. Approximately 70 million farming families worldwide rely on maize farming for their livelihood (Dowswell et al., 1996). Depending on its maturity period, maize plants can grow to a height of 2.5–4.5 meters within 4–6 months and produce 600–1000 seeds per ear. Its high yield potential compared to other cereals is attributed to the grain's efficient energy storage capacity and the plant's ability to utilize natural energy factors effectively through its roots, stems, leaves, and reproductive organs (Kırtok, 1998). Additionally, maize plays a critical role in meeting global demands for food, animal feed, industrial raw materials (e.g., starch, oil, sugar, protein, cellulose, and ethanol), and energy (Cerit et al., 2016).

Maize grain is composed of approximately 80–82% endosperm, 12–14% embryo, 5–6% shell, and 1% pedicel (Kırtok, 1998; Hallauer, 2001). Its biochemical composition includes about 70% starch, 10% protein, 5% oil, 2% sugar, and 2% ash (Öztürk, 2017). While maize shares a similar protein content with other cereals, this characteristic significantly influences its grain quality. The protein content of normal maize varieties typically ranges between 8% and 11%. Despite being adequate in quantity for nutritional purposes, the protein quality of maize is considered poor. This deficiency is primarily attributed to the proportional distribution of its protein fractions, which include albumin, globulin, glutelin, and zein (Osborne, 1987). Among these fractions, zeins are the predominant type and are notably deficient in essential amino acids such as lysine and tryptophan (Vasal, 2000). Consequently, normal maize genotypes exhibit low protein quality. However, reducing the proportion of zein fractions in the grain increases the levels of lysine and tryptophan, enhancing its protein quality (Prasanna et al., 2001). Thus, most research aimed at improving maize protein quality focuses either on directly increasing essential amino acid levels or on decreasing zein content.

Efforts to enhance the protein quality of maize began in the mid-1960s with the introduction of the opaque-2 mutant, which significantly increased lysine and tryptophan levels amino acids that are deficient in maize endosperm proteins. However, the use of the opaque-2 mutant was hindered by adverse pleiotropic effects, which limited its practical application (Krivanek et al., 2007). Subsequent interdisciplinary research addressed these challenges by improving the negative traits associated with the opaque phenotype, resulting in the development of Quality Protein Maize (QPM) varieties. These varieties are characterized by higher levels of lysine and tryptophan and enhanced protein quality compared to conventional maize (Atlin et al., 2010; Bressani, 1991; National Research Council, 1998). Research has shown that the protein in QPM has a nutritional value approximately 90% that of breast milk, compared to just 40% in conventional maize (Twumasi-Afriyie et al., 2016). Consequently, QPM varieties have proven beneficial for humans, pigs, and other monogastric animals, including poultry, due to their improved nutritional profile.

Existing literature highlights several studies focusing on various agronomic traits of maize. Özata and Kapar (2014) examined changes in grain yield, grain moisture at harvest, plant height, first ear height, protein content, and oil content in 20 hybrid dent maize varieties. Similarly, Çağlar (2016) investigated the grain yield and quality of maize genotypes grown across different locations. Yılmaz and Han (2016) analyzed the yield and yield components of eight maize varieties (TK6063, Calcio, Hido, Everest, Carella, Cadiz, Sagunto, and Tavascan), while Yılmaz et al. (2020) evaluated plant characteristics in silage maize varieties. Despite these contributions, studies focusing specifically on protein quality in local maize genotypes in Türkiye remain limited. Notably, agronomic traits have not been comprehensively studied in materials categorized by different opacity levels. Moreover, most existing research has been conducted for screening purposes rather than detailed characterization. To date, no studies have systematically separated local maize populations based on opacity levels to identify promising materials for both protein quality and agronomic traits. Consequently, there is a lack of source materials tailored for breeding efforts aimed at improving maize protein quality. In Türkiye, breeding studies predominantly focus on yield per unit area, often overlooking protein quality critical factor given maize's substantial role in human and animal nutrition. Addressing this gap by enhancing protein quality in maize is essential to meet nutritional demands effectively.

The aim of this study is to evaluate local maize populations collected from various regions of Türkiye which were previously characterized as having opaque features, in terms of their agronomic traits. Additionally, the study seeks to develop breeding materials with enhanced protein quality.

2. Materials and Methods

2.1. Material

2.1.1. Field experiment

The experiments were conducted in accordance with the randomized block trial design with 3 replications during the 2021 and 2022 summer main crop growing periods. The field experiment was carried out in Sarıcaeli Village, Çanakkale Province. The study utilized six opaque maize landraces (POP1, POP2, POP3, POP4, POP5, POP6) and three standard genotypes, including two normal and one opaque genotype (Table 1).

Table1. Six opaque local maize populations and three standard genotypes were used in the study

Genotypes	Characteristic	Source
POP1	Opaque population	ÇOMU
POP2	Opaque population	ÇOMU
POP3	Opaque population	ÇOMU
POP4	Opaque population	ÇOMU
POP5	Opaque population	ÇOMU
POP6	Opaque population	ÇOMU
*CADIZ (STD1)	Normal standard	Semilas Fito
*BODEGA (STD2)	Normal standard	May Tohum
*PI608781 (STD3)	Opaque standard	ÇOMU

ÇOMU: Çanakkale Onsekiz Mart University

2.1.2. Soil and Climatologic Features of Experimental Area

Soil analysis results, presented in Table 2, were obtained from the experimental field prior to the start of the study. The analysis revealed that the soil was poor in organic matter but high in clay content (Table 3). The soil analyses were performed in COBİLTUM (Çanakkale Onsekiz Mart University Science and Technology Application and Research Center).

The field experiment was designed using a randomized complete block design with three replicates. Each genotype was planted in two-row plots with a spacing of 70 × 20 cm and a row length of four meters. Sowing was performed manually on May 18, 2021, for the first year and on May 18, 2022, for the second year. Weed control was carried out manually in the experimental area during both years. Irrigation was applied weekly using a drip irrigation system installed at the site, and fertilization was delivered through the same system based on the results of soil analysis.

Table 2. The experimental material used in this study

Soil Analysis	Results	Class
pH	7.39	Neutral
Soil Properties (%)	67.70	Clay-loam
E.C. (mS/cm)	89.30	Low
Organic matter (%)	1.87	Low
Lime (%)	8.50	Medium chalky
P (kg/da)	2.83	Low
K (kg/da)	80.80	Low

Table 3. The climatological conditions of the experimental field (*1:2021, 2:2022)

Months	May		June		July		August		September		October	
Years	1	2	1	2	1	2	1	2	1	2	1	2
Average Temperature (°C)	19.9	18.4	24.1	24.1	28.2	26.2	28.3	26.6	23.1	22.0	18.1	17.6
Total Rainfall (mm)	57.3	7.6	57.1	7.4	2.0	44.8	0.0	111.6	8.9	1.2	75.9	0.6
Highest Temperature (°C)	36.6	33.1	38.5	33.4	39.1	35.4	39.7	36.1	32.8	31.8	24.6	28.5
Lowest Temperature (°C)	11.2	7.8	13.8	17.3	19.8	17.7	21.5	18.8	12.0	9.2	11	7.3
Temperature for Many Years (°C)	17.5		22.2		25.0		24.9		21.05		16.18	
Long Years of Rainfall (mm)	30.1		24.6		11.7		6.6		22.8		54.1	

The Çanakkale province, located in the northwest of Türkiye, shares similar climatic characteristics with the central areas of the province where the experiment was conducted. The average temperatures during the experimental period were comparable to the long-term averages; however, they were slightly higher than historical values. Summers in the region are typically dry, with no precipitation recorded in August. Fertilization was carried out on June 23, 2021, for the first year and on May 7, 2022, for the second year. The experimental area was deeply ploughed with a mouldboard plough once in every two years. After ploughing, 15-15-15 compound fertilizer was applied by hand, 10 kg nitrogen, 10 kg phosphate and 10 kg potassium per decare. Then, the cultivator was pulled and mixed into the soil. Then, the test area was made ready for planting by pulling a coulter. After planting, drip irrigation system was laid lateral to each row and irrigation was carried out by drawing water from the canal next to the trial field with a motor pump. Each irrigation was done by operating the motor pump for 8 hours at 15-day intervals. According to the soil analysis results, urea was applied in addition to the base fertilizer to provide 10 kg of pure nitrogen per decare.

2.2. Method

2.2.1. Agronomic measurements

The agronomic characteristics examined in the genotypes included plant height, first ear height, ear length, ear diameter, number of rows per ear, number of grains per row, ear weight, and grain weight per ear. Measurements were performed on 10 plants per replication for each population. The evaluation of agronomic traits followed the methodologies described by Kırtok (1998) and Kün (1978).

Plant Height (cm): The height of the plants, including the top tassel, was measured at harvest.

First Ear Height (cm): Measured as the distance from the soil surface to the first ear formed on the plant.

Ear Length (cm): Determined as the length from the base to the tip of the ear after removing the husks.

Ear Diameter (mm): Measured at the midpoint of the ear using a digital caliper.

Number of Rows on the Ear (number/ear): Counted visually to determine the number of grain rows across the ear's width.

Number of Grains per Row (number): Counted visually along the length of the ear from two representative points.

Single Ear Weight (g): Determined by weighing each dehusked ear individually on a precision scale.

Grain Weight per Ear (g): Grain samples obtained after dehusking were weighed on a precision scale.

2.3. Statistical Analysis

The data collected during the study were analyzed using the R software (R Core Team, 2019). Statistical models were applied in alignment with the randomized complete block design, utilizing one-way analysis of variance (ANOVA) in the first year and two-way ANOVA in the second year. Mean differences were compared using the Least Significant Difference (LSD) test.

3. Results and Discussion

3.1. Plant Height (cm)

In the first year of the experiment, the average plant height of the genotypes ranged from 208.20 cm to 251.80 cm. The highest plant height, 251.80 cm, was recorded in the POP2 genotype. Additionally, the POP4, STD1, and STD2 genotypes were statistically grouped with the POP2 genotype. The lowest plant height was observed in the STD3 genotype at 208.20 cm (Table 4). In 2022, the average plant height values varied between 165.33 cm and 224.92 cm. The highest plant height, 224.92 cm, was measured in the STD2 genotype at 0% opacity, while the lowest, 165.33 cm, was observed in the POP2 genotype at 75% opacity (Table 4). When averages across opacity levels were considered, the highest plant height was 205.06 cm at 0% opacity, and the lowest was 189.94 cm at 100% opacity (Table 4). These results indicate that plant height decreased as opacity levels increased. The observed variation in plant height across genotypes and opacity levels suggests a potential physiological impact of endosperm opacity on overall plant vigor. Specifically, the decreasing trend in plant height with increasing opacity may be related to pleiotropic effects of the opaque gene, particularly opaque-2, which has been reported to influence not only grain quality but also plant architecture and growth dynamics (Wessel-Beaver et al., 1988). Similar reductions in plant height in opaque or modified endosperm maize have been reported by Krivanek et al. (2007), indicating that these genotypes may allocate more metabolic resources to kernel composition rather than vegetative growth. Furthermore, our findings align with previous studies on Turkish maize landraces, which showed plant height values ranging from approximately 160 to 280 cm (Ayrancı and Sade, 2004; Özata and Kapar, 2014; Kuşvuran and Nazlı, 2014), highlighting the wide genetic variability within local populations. Such variability underscores the importance of evaluating opacity-associated traits not only for kernel quality but also for their agronomic implications in breeding programs.

Table 4. Average plant height by year and maize genotypes with variance analysis results

	2021	2022					
Genotype	Average	%0	%25	%50	%75	%100	Average
POP1	214.22 c	209.97 a-f	199.51 d-h	200.93 c-h	211.52 a-e	198.93 d-h	204.17 ab
POP2	251.80 a	210.62 a-e	220.29 ab	206.88 b-g	165.33 j	213.83 a-d	203.39 b
POP3	209.95 c	191.85 g-i	198.70 d-h	185.23 hi	182.28 h-j	187.26 hi	190.51 b
POP4	224.40 a-c	184.85 hi	186.04 hi	185.27 hi	180.82 ij	191.49 g-i	185.69 b
POP5	219.35 bc	197.02 e-i	206.28 b-g	203.73 c-g	193.62 g-i	193.07 g-i	198.74 b
POP6	214.57 c	216.63 a-c	199.18 d-h	198.20 d-h	200.95 c-h	193.93 f-i	201.78 b
STD1	227.45 a-c	204.65 b-g	-	-	-	-	204.65 ab
STD2	246.65 ab	224.92 a	-	-	-	-	224.92 a
STD3	208.20 c	-	-	-	-	180.84 ij	180.84 b
Average	-	205.06 a	201.67 ab	197.38 abc	194.19 bc	189.94 c	-
Variance Analysis	Genotype: 975.47**	Genotype; 939.66** , Opacity: 475.24**, G × O: 314.37**					

P value <0.05*, 0.01**

3.2. First Ear Height

Table 5 presents the average first ear heights for 2021 and 2022. In 2021, the longest first ear height was recorded in the POP2 genotype at 127.95 cm, while the shortest was observed in the POP1 genotype at 75.03 cm. In 2022, no significant interaction was found between the first ear height and the opacity levels of the populations. Although numerical differences were observed across opacity levels, these differences were not statistically significant (Table 5). The variation in first ear height across genotypes and years, along with the absence of statistically significant differences among opacity levels in 2022, suggests that this trait may be influenced more strongly by genetic background and environmental factors than by endosperm opacity alone. The reduction in ear height observed in the second year could be partially attributed to differences in experimental setup, particularly the lack of genotype separation based on opacity in the first year. This observation is consistent with previous findings that emphasize the sensitivity of ear placement to planting density and genotype × environment interactions (Sofi et al., 2009). Moreover, the generally lower ear heights recorded in 2022 correspond with the reduction in plant height during the same period, reflecting the well-established positive correlation between plant height and ear height (Sofi et al., 2009; Liu et al., 2010). The values observed in this study, ranging from 75 to 128 cm, are in line with prior reports on Turkish maize populations, confirming the considerable genetic diversity and plasticity among landraces (Ayrancı and Sade, 2004; Özata and Kapar, 2014; Acar et al., 2017). Although no direct statistical link to opacity was established for this trait, the ear position may still hold indirect importance in evaluating the agronomic performance of genotypes with different kernel types. he first ear height values obtained in this study are consistent with these ranges reported in the literature. However, a significant decrease in population averages was observed in the second year compared to the first. This discrepancy may be attributed to the fact that materials were not planted separately according to their opacity levels during the first year. A similar trend was observed for plant height, which aligns with the known positive correlation between first ear height and plant height in maize.

3.3. Ear Length (cm)

In 2021, the average ear length of the genotypes ranged from 15.69 cm to 19.56 cm, with no statistically significant differences observed between populations (Table 6). In 2022, ear length values varied from 12.80 cm to 19.76 cm among the populations, but no significant differences were found based on genotypes or opacity levels. The average ear lengths according to opacity levels ranged between 15.80 cm and 17.29 cm (Table 6). The relatively stable ear length observed across genotypes, years, and opacity levels in this study highlights the low phenotypic plasticity of this trait under varying conditions. Consistent with prior reports, ear length exhibited limited variation, which is largely governed by the genetic makeup of the material rather than environmental factors or kernel opacity (Sönmez et al., 2013; Saygı and Toklu, 2017). The ear length values recorded in this study (12.80–19.76 cm) were generally lower than those reported by Sönmez et al. (2013) and Kılınç et al. (2018), but aligned with the range provided by Saygı and Toklu (2017), suggesting that Turkish maize landraces may harbor moderate to short ear types. The absence of statistically significant differences, despite some numerical variation, reinforces the notion that ear length is a relatively stable trait, as also stated by Lauer et al. (2004), and therefore may be less responsive to selection pressure when compared to traits like ear diameter or kernel number. Nonetheless, it remains an important yield component and should be considered in combination with other traits in multi-trait selection strategies.

Table 5. Averages of first ear height by years and maize genotypes with variance analysis results

	2021	2022					
Genotype	Average	%0	%25	%50	%75	%100	Average
POP1	75.03 c	72.23	64.59	70.11	68.36	61.70	67.40
POP2	127.95 a	91.66	94.59	92.83	80.17	96.17	91.08
POP3	91.20 bc	67.95	74.75	75.82	63.23	77.70	73.00
POP4	101.55 b	80.01	73.34	74.38	71.37	80.59	75.94
POP5	101.12 b	77.70	87.01	85.52	74.80	79.49	80.91
POP6	103.25 b	99.73	91.69	83.82	92.25	90.52	91.60
STD1	88.33 bc	71.77	-	-	-	-	71.77
STD2	108.98 ab	93.37	-	-	-	-	93.37
STD3	87.35 bc	-	-	-	-	63.06	63.06
Average	-	81.80	81.00	80.68	76.50	78.46	-
Variance Analysis	Genotype: 923.83**	Genotype; 1095.66**, Opacity: 103.82, G × O: 74.46					

P value <0.05*, 0.01**

Table 6. Ear length averages by years and maize genotypes with variance analysis results

	2021	2022					
Genotype	Average	%0	%25	%50	%75	%100	Average
POP1	19.56	17.46	19.76	17.77	18.27	16.57	17.97
POP2	17.81	18.23	15.88	14.17	12.80	17.40	15.70
POP3	17.32	16.90	19.76	15.57	18.07	16.58	17.41
POP4	17.29	15.22	13.38	15.53	18.10	15.74	15.60
POP5	18.56	16.00	18.47	16.21	17.57	16.38	16.92
POP6	15.69	17.81	16.50	15.50	16.80	18.08	16.94
STD1	19.45	17.04	-	-	-	-	17.04
STD2	18.55	17.58	-	-	-	-	17.58
STD3	17.18	-	-	-	-	16.20	16.20
Average	-	17.03	17.29	15.80	16.79	16.71	-
Variance Analysis	Genotype: 6.0	Genotype; 8.35, Opacity; 5.31, G × O: 7.23					

P value <0.05*, 0.01**

3.4. Number of rows on the ear

In 2021, the genotypes STD1 (16.43 rows/ear) and STD2 (16.60 rows/ear) exhibited the highest number of ear rows (Table 7). The lowest number of rows was recorded in the POP2 genotype with 12.38 rows/ear. Apart from POP2, eight other genotypes were statistically grouped together in 2021. In 2022, no statistically significant differences were observed in the population × opacity interaction data. The highest number of rows (21.33 rows/ear) was observed in the POP6 genotype at 50% opacity, while the lowest (10.43 rows/ear) was recorded in the POP2 genotype at 0% opacity. When evaluated independently, the highest average number of rows per ear in 2022 was found in the POP6 genotype (18.54 rows/ear), and the lowest was in the POP2 genotype (13.45 rows/ear). The average number of rows across opacity levels ranged from 14.46 rows/ear at 100% opacity to 16.51 rows/ear at 75% opacity (Table 7). The number of rows on the ear, a trait primarily under genetic control, exhibited moderate variability across genotypes and opacity levels. The consistency in ranking of genotypes such as POP2 for lower values and STD1/STD2 for higher values across years supports the idea that this trait is relatively stable but still responsive to genetic background. While no significant interaction was observed between genotype and opacity in 2022, the differences among genotypes remained evident, suggesting that opacity level alone may not exert a strong influence on this trait. The values obtained in this study—ranging from 10.43 to 21.33 rows/ear—are broadly in line with those reported by Bozokalfa et al. (2004) and Öner (2017), although some genotypes slightly exceeded previously reported upper limits. This can likely be attributed to the broader genetic diversity represented in the present study, including a greater number of local landraces. Similar findings have been noted by Betrán et al. (2003), who emphasized the importance of evaluating ear traits in diverse germplasm pools, as these traits significantly contribute to grain yield and kernel set. Given its moderate heritability, the number of rows per ear remains a valuable selection criterion in maize breeding, especially when combined with other yield components.

Table 7. Averages of the number of rows on the ear by years and maize genotypes with variance analysis results

	2021	2022					
Genotype	Average	%0	%25	%50	%75	%100	Average
POP1	15.85 ab	16.20	17.97	16.00	14.93	16.00	16.22 ab
POP2	12.38 b	10.43	11.94	14.56	18.00	12.33	13.45 c
POP3	15.30 ab	15.65	14.10	14.00	14.67	13.56	14.38 bc
POP4	15.75 ab	16.00	15.33	16.00	16.00	13.00	15.27 bc
POP5	15.70 ab	13.56	14.00	12.89	14.67	15.33	14.09 bc
POP6	16.22 ab	18.50	16.67	21.33	19.56	16.67	18.54 a
STD1	16.43 a	16.20	-	-	-	-	16.20 a-c
STD2	16.60 a	14.78	-	-	-	-	14.78 bc
STD3	16.00 ab	-	-	-	-	14.33 e-i	14.33 bc
Average	-	15.16	15.00	15.90	16.51	14.46	-
Variance Analysis	Genotype: 6.40*	Genotype: 32.47**, Opacity: 9.82, G × O: 8.24					

P value <0.05*, 0.01**

3.5. Number of Grains in the Row

Table 8 presents the average number of grains per row for 2021 and 2022. In 2021, the values ranged from 24.22 to 39.94, with the highest number of grains observed in the STD1 genotype (39.94 grains/row) and the lowest in the POP6 genotype (24.22 grains/row). All other genotypes, except POP2 and POP6, were grouped statistically together. In 2022, the number of grains per row varied between 20.75 and 40.72. The average values ranged from 27.36 to 40.72 grains/row, but no statistically significant differences were found between the highest and lowest values. The number of grains per row showed a wide range of variation across genotypes and years, indicating that this trait is highly influenced by genotypic potential and possibly by environmental conditions affecting pollination and kernel set. Although statistical differences were not significant in 2022, the observed numerical variation—ranging from 20.75 to 40.72 grains per row—aligns with or exceeds values reported in previous studies. For example, Bozokalfa et al. (2004) and Nar (2023) reported values within the range of 31.0–49.5 grains per row, while Albayrak (2019) noted broader variability, extending as low as 12.33 grains. These differences likely reflect the diversity in plant architecture, ear morphology, and source–sink balance among genotypes. High-performing genotypes such as STD1 consistently exhibited superior kernel number, suggesting that traits related to ear fertility and grain set are crucial for yield improvement. According to Vasal et al. (2000), kernel number per row is strongly associated with assimilate partitioning and silk pollination efficiency, which in turn are sensitive to both genetic and environmental factors. Therefore, even in the absence of strong statistical separation among opacity levels, the genotypic variability observed in this study points to promising genetic resources for improving ear productivity in local maize breeding programs.

3.6. Ear Diameter

The average ear diameter values obtained from the populations in 2021 showed significant variation, ranging from 34.11 mm to 49.99 mm. The highest ear diameter was observed in the STD2 genotype (49.99 mm), while the lowest was recorded in the POP2 genotype (34.11 mm). Genotypes with higher ear diameters were predominantly standard varieties (Table 9). In 2022, ear diameter values ranged from 35.49 mm to 49.16 mm, with statistically significant differences between populations. The highest ear diameter (49.16 mm) was observed in the STD1 genotype, while the lowest (36.56 mm) was measured in the STD3 genotype. Genotypes POP1, POP3, POP4, and POP6 were found to have high ear diameter values and were statistically grouped with the standard varieties. Although not statistically significant, the highest numerical ear diameter (49.16 mm) was recorded in the STD1 genotype at 0% opacity, and the lowest (35.49 mm) was observed in the POP2 genotype at 100% opacity. Across opacity levels, the average ear diameters ranged from 41.14 mm (100% opaque) to 43.96 mm (75% opaque) (Table 9). The significant variation observed in ear diameter across genotypes and years highlights the influence of both genetic structure and environmental conditions on this yield-related trait. Consistently higher ear diameters in standard varieties, such as STD1 and STD2, compared to local landraces suggest that commercial breeding lines have been selected for enhanced sink capacity and kernel-bearing surface, as noted in previous studies (Sönmez et al., 2013; Saygı and Toklu, 2017). The results of the present study, ranging from 34.11 mm to 49.99 mm, are in agreement with the upper values reported by Sönmez et al. (2013) and Saygı and Toklu (2017), but surpass the lower limit reported by Öner (2017), likely due to differences in genetic materials and sample sizes. Although opacity levels did not significantly affect ear diameter, a numerical trend was observed whereby the lowest mean diameter corresponded to 100% opacity. This may imply a weak negative association between kernel opacity and cob development, possibly due to pleiotropic effects influencing both endosperm structure and ear morphology (Krivanek et al., 2007).

3.7. Ear weight (g)

Ear weight is a critical parameter among yield components. In 2021, ear weights ranged from 88.76 g to 258.37 g, with the highest value recorded in the STD2 genotype (258.37 g) and the lowest in the POP2 genotype (88.76 g) (Table 10). In 2022, ear weight values varied between 91.65 g and 222.45 g. The highest ear weight was observed in the STD1 genotype, while the lowest was again recorded in the POP2 genotype. Although no statistically significant differences were observed between opacity levels, the highest ear weight was associated with 0% opacity, and the lowest with 100% opacity. Ear weight, being a direct contributor to grain yield, demonstrated notable variability across genotypes in both years of the study. As expected, standard varieties such as STD1 and STD2 outperformed local landraces in terms of ear weight, highlighting the yield potential of commercially bred genotypes. The lowest ear weight values consistently belonged to the POP2 genotype, suggesting genotypic limitations in kernel set or ear filling capacity. Although differences among opacity levels were not statistically significant, a numerical decline in ear weight was observed as opacity increased, with the highest values recorded at 0% opacity. This trend may point to an indirect association between endosperm transparency and resource allocation for ear development. Previous research has emphasized the importance of ear weight as a reliable indicator of overall productivity, especially under well-managed conditions (Bozokalfa et al., 2004; Eşiyok et al., 2004). The ear weight values reported here (88.76–258.37 g) fall within or near the ranges provided in earlier studies (e.g., 198.7–257.7 g by Bozokalfa et al., 2004; 160–320 g by Yıldız et al., 2017), but are slightly lower than those reported by Eşiyok et al. (2004), likely due to differences in genotype pools and environmental factors. Our results indicating a decline in ear weight and grain yield at higher opacity levels are in line with findings by Erdal et al. (2021), who reported that opaque-2 and DZR1 inbred lines showed reduced grain yield compared to normal endosperm types, despite improved protein quality. These findings reaffirm ear weight as a critical selection criterion in maize breeding, particularly when targeting opaque local landraces for yield improvement.

Table 8. Averages of the number of grains in the row by years and maize genotypes with variance analysis results

	2021	2022					
Genotype	Average	%0	%25	%50	%75	%100	Average
POP1	29.03 ab	30.50	35.77	30.67	32.12	20.75	29.96
POP2	25.31 b	30.10	25.64	25.25	27.00	28.83	27.36
POP3	26.32 ab	27.00	23.32	30.50	27.67	36.59	29.12
POP4	29.79 ab	27.00	21.78	29.67	31.50	31.42	28.27
POP5	32.20 ab	32.67	35.00	32.44	33.33	32.06	33.10
POP6	24.22 b	32.92	27.67	31.67	31.00	34.33	31.52
STD1	39.94 a	40.05	-	-	-	-	40.05
STD2	36.65 ab	40.72	-	-	-	-	40.72
STD3	29.73 ab	-	-	-	-	33.90	33.90
Average	-	32.62	28.20	30.00	30.78	31.13	-
Variance Analysis	Genotype 108.34*	Genotype: 124.41,Opacity: 17.77, G × O: 46.41					

P value <0.05*, 0.01**

Table 9. Averages of ear diameter by years and maize genotypes with variance analysis results

	2021	2022					
Genotype	Average	%0	%25	%50	%75	%100	Average
POP1	44.19 ab	46.86	48.68	45.47	47.09	43.75	46.37 a
POP2	34.11 c	37.89	39.16	41.47	43.26	35.49	39.45 b
POP3	42.79 a-c	43.49	42.61	39.69	42.51	45.57	43.08 ab
POP4	44.85 ab	44.87	45.99	46.89	45.36	44.54	45.53 a
POP5	42.64 a-c	38.16	40.91	39.00	40.92	43.33	40.46 b
POP6	37.46 bc	42.09	41.39	46.85	43.68	38.74	42.55 ab
STD1	48.12 a	49.16	-	-	-	-	49.16 a
STD2	49.99 a	43.70	-	-	-	-	43.70 ab
STD3	36.94 bc	-	-	-	-	36.56	36.56 b
Average	-	43.28	43.12	43.44	43.96	41.14	-
Variance Analysis	Genotype: 111.34**	Genotype: 99.14**, Opacity: 11,.7, G × O: 16.20					

P value <0.05*, 0.01**

Table 10. Averages of ear weight by years and maize genotypes with variance analysis results

	2021	2022					
Genotype	Average	%0	%25	%50	%75	%100	Average
POP1	162.55 a-c	164.12	204.31	157.31	188.33	107.17	164.25 ab
POP2	88.76 c	108.70	116.95	126.22	104.00	91.65	109.50 c
POP3	130.78 bc	146.84	124.72	135.61	136.67	134.92	135.61 bc
POP4	172.64 a-c	155.41	121.93	156.32	169.07	141.25	148.80 a-c
POP5	153.89 a-c	130.48	136.81	120.73	158.33	137.49	136.77 bc
POP6	103.98 c	151.12	105.17	134.56	127.38	122.88	128.22 bc
STD1	229.83 ab	222.45	-	-	-	-	222.45 a
STD2	258.37 a	192.04	-	-	-	-	192.04 ab
STD3	89.77 c	-	-	-	-	97.30	97.30 c
Average	-	158.90	134.98	138.62	148.63	118.95	-
Variance Analysis	Genotype: 14241.63**	Genotype: 7568.15**, Opacity: 1594.33, G × O: 1123.71					

P value <0.05*, 0.01**

3.8. Grain weight per ear

In 2021, the average grain weight per ear ranged from 64.12 g to 204.91 g. The highest grain weights were recorded in the STD1 (204.91 g) and STD2 (203.36 g) genotypes, while the lowest value (64.12 g) was observed in the POP2 genotype (Table 11). The highest grain weight values were associated with the standard varieties, and all other populations, except for POP2 and POP6, were statistically grouped with the standard genotypes. In 2022, ear grain weight values ranged from 65.27 g to 199.37 g. Among the populations, average values varied from 74.87 g to 199.37 g, with the highest weight recorded in the STD1 genotype and the lowest in the STD3 genotype. Additionally, the POP1 genotype was statistically grouped with the standard varieties for grain weight. While no statistically significant differences were found between opacity levels, the highest numerical grain weight (199.37 g) was observed in the STD1 genotype at 0% opacity, and the lowest (65.27 g) in the POP2 genotype at 100% opacity. Grain weight per ear, a primary component of grain yield, exhibited considerable genotypic variation in both study years. As expected, standard hybrid varieties such as STD1 and STD2 consistently produced the highest values, reflecting their superior sink strength and grain-filling capacity. In contrast, the consistently low grain weights recorded in the POP2 genotype suggest limited yield potential, possibly linked to reduced kernel number or poor kernel development. Although no statistically significant differences were detected among opacity levels, the numerical pattern showing decreasing grain weight with increasing opacity—especially the lowest values observed at 100% opacity—may imply a subtle physiological link between kernel opacity and assimilate partitioning efficiency. When compared to the literature, the grain weights recorded in this study (64.12–204.91 g) fall below those reported by Ayrancı and Sade (2004), who evaluated hybrid cultivars under favorable conditions (134.66–242.33 g), but are closer to the findings of Atakul (2011) (108.12–139.25 g), who worked with more diverse genotype sets. These differences reinforce the importance of both genetic structure and experimental context in determining yield performance. Despite the lower average values, the ability of some landraces (e.g., POP1 in 2022) to statistically group with high-performing standards suggests potential for selection and genetic improvement in local germplasm.

Table 11. Averages of grain weight per ear by years and maize genotypes with variance analysis results

	2021	2022					
Genotype	Average	%0	%25	%50	%75	%100	Average
POP1	123.32 ab	142.41	173.36	128.64	156.12	78.61	135.83 ab
POP2	64.12 b	98.47	98.94	89.89	91.00	65.27	88.71 c
POP3	100.55 ab	120.68	73.17	103.67	101.33	138.03	108.69 bc
POP4	143.14 ab	112.43	94.33	127.78	140.83	118.57	118.79 bc
POP5	132.98 ab	120.43	102.51	97.48	133.67	116.27	114.07 bc
POP6	74.13 b	109.09	78.83	109.35	93.90	96.11	97.46 bc
STD1	203.36 a	199.37	-	-	-	-	199.37 a
STD2	204.91 a	163.21	-	-	-	-	163.21 ab
STD3	70.00 b	-	-	-	-	74.87	74.87 c
Average	-	133.26	103.52	109.81	121.74	98.25	-
Variance Analysis	Genotype: 11414.82**	Genotype: 6919.76**, Opacity: 1226.27, G × O: 1400.99					

P value <0.05*, 0.01**

4. Conclusion

The results of this two-year field study demonstrate that increasing kernel opacity levels have a negative impact on plant height, first ear height, and ear weight, whereas traits such as ear length, row number per ear, grains per row, grain weight per ear, and ear diameter were not significantly affected. These findings are consistent with previous research indicating that opaque kernel types, particularly those associated with opaque-2 or related mutations, may alter assimilate distribution patterns and reduce vegetative growth and ear development (Wessel-Beaver et al., 1988; Krivanek et al., 2007)

Among the genotypes tested, local landraces POP2 and POP6, along with the standard genotype STD3, were identified as promising genetic resources for breeding quality protein maize (QPM). While Türkiye has a wide range of registered maize cultivars, high-protein, nutritionally enriched maize types remain scarce. This study contributes to filling this gap by identifying genotypes with both agronomic adaptability and potential for nutritional enhancement. As highlighted in previous studies (Erdal et al., 2021), enhancing protein quality through opaque-2 and related genetic mechanisms often results in yield penalties. However, the identification of landraces such as POP2 and POP6 with relatively stable agronomic traits suggests that it may be possible to select genotypes that balance yield and nutritional quality.

Furthermore, although numerous studies have been conducted in Türkiye on local maize diversity and biochemical grain quality (e.g., protein, oil, and fatty acid composition) (Cömertpay et al., 2009; Öner, 2011), there is still a lack of research exploring how endosperm opacity influences morphological traits and how this relationship can be utilized in developing improved maize cultivars.

The integration of traditional landrace diversity with modern breeding approaches offers a strategic opportunity to develop high-quality protein maize adapted to local agro-ecological conditions and nutritional needs.

Author Contributions

Percentages of the authors' contributions are present below. All authors reviewed and approved final version of the manuscript.

	G.K.B	F.K
C	50	50
D	50	50
S		100
DCP	70	30
DAI	50	50
L	50	50
W	50	50
CR	50	50
SR	50	50
PM	50	50
FA	50	50

C= concept, D= design, S= supervision, DCP= data collection and/or processing, DAI= data analysis and/or interpretation, L= literature search, W= writing, CR= critical review, SR= submission and revision, PM= project management, FA= funding acquisition.

Conflict of Interest

The author declared that there is no conflict of interest.

Ethical Consideration

Since no studies involving humans or animals were conducted, ethical committee approval was not required for this study.

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References

Acar N, Yılmaz MF, Kara R. 2017. Kahramanmaraş koşullarına uygun tane mısır (Zea mays L.) çeşitlerinin belirlenmesi. Tarla Bitkileri Merkez Arastirma Enstit Derg, 26(Özel Sayı): 80–85.

Albayrak Ö. 2019. Bazı yerel mısır populasyonlarının kurağa tepkilerinin belirlenmesi. Dicle Üniversitesi, Fen Bilimleri Enstitüsü, Diyarbakır, Türkiye pp: 175.

Atakul Ş. 2011. Diyarbakır koşullarında farklı ekim zamanlarının beş şeker mısırı (Zea mays L. saccharata Sturt.) çeşidinde taze koçan ve tane verimi ile bazı tarımsal özelliklere etkisi. Çukurova Üniversitesi, Fen Bilimleri Enstitüsü, Adana, Türkiye, pp: 56-96.

Atlin GN, Palacios N, Babu R, Twumasi-Afriye S, De Groote H, Vivek B, Friesen D, Pixley KV. 2010. Quality protein maize: progress impact, and prospects. Plant Breed Rev, 34: 83-130.

Ayrancı R, Sade B. 2004. Konya ekolojik şartlarında yetiştirilebilecek atdişi melez mısır (Zea mays L. indentata Sturt.) çeşitlerinin belirlenmesi. Bitkisel Arast Derg, 2: 6–14.

Betran FJ, Beck D, Banziger M, Edmeades GO. 2003. Genetic analysis of inbred and hybrid grain yield under stress and nonstress environments in tropical maize. Crop Sci, 149.

Bozokalfa MK, Eşiyok D, Uğur A. 2004. Ege bölgesi koşullarında ana ve ikinci ürün bazı hibrit şeker mısır (Zea mays L. var. saccharata) çeşitlerinin verim kalite ve bitki özelliklerinin belirlenmesi. Ege Univ Zir Fak Derg, 41(1): 11-19.

Bressani R. 1991. Protein quality of high-lysine maize for humans. Cereal Foods World, 36(9): 806-811.

Cerit İ, Cömertpay G, Oyucu R, Çakır B, Hatipoğlu R, Özkan H. 2016. Melez mısır ıslahında in-vivo katlanmış haploid tekniğinde kullanılan farklı inducer genotiplerin haploid indirgeme oranlarının belirlenmesi. Tarla Bitkileri Merkez Arastirma Enstit Derg, 25(Özel Sayı): 52-57. URL: https://dergipark.org.tr/tr/pub/tarbitderg/issue/25622/280162 (accessed date: September 29, 2024).

Cömertpay GC, Ülger A, Hatipoğlu R, Özkan H. 2009. SSR DNA markörü ile yerel mısır popülasyonlarının moleküler karakterizasyonu. Türkiye VIII. Tarla Bitkileri Kongresi, 19-22 Ekim, Hatay, Türkiye, pp: 45-56.

Çağlar H. 2016. Farklı lokasyonlarda yetiştirilen mısır genotiplerinin tane verimi ve kalitesinin belirlenmesi. Aydın Adnan Menderes Üniversitesi, Fen Bilimleri Enstitüsü, Aydın, Türkiye, pp: 42-46.

Dowswell RC, Paliwal RL, Cantrell RP. 1996. Maize in the Third World. Westview Press, Colorado, USA, pp: 268.

Erdal Ş, Öztürk A, Cengiz R, Pamukcu M, Dinçer C, Cengiz B. 2021. Interaction of DZR1, Opaque-2 and normal endosperm maize inbred lines for grain yield and protein quality. Turk J Field Crops, 26(2): 207–214.

Eşiyok D, Bozokalfa MK, Uğur A. 2004. Farklı lokasyonlarda yetiştirilen şeker mısır (Zea mays L. var. saccharata) çeşitlerinin verim kalite ve teknolojik özelliklerinin belirlenmesi. Ege Univ Zir Fak Derg, 41(1): 1-9.

Hallauer AR, Lamkey KR, White PR. 2001. Registration of B115 inbred line of maize. Crop Sci, 41: 1991.

Kılınç S, Karademir Ç, Ekin Z. 2018. Bazı mısır (Zea mays L.) çeşitlerinde verim ve kalite özelliklerinin belirlenmesi. KSÜ Tarim Dogal Derg, 21(6): 809-816.

Kırtok Y. 1998. Mısır üretimi ve kullanımı. Kocaoluk Basım ve Yayınevi, İstanbul, Türkiye, pp: 445.

Krivanek AF, Groote HG, Gunaratna NS, Diallo AO, Friesen D. 2007. Breeding and disseminating quality protein maize (QPM) for Africa. Afr J Biotechnol, 6(4): 312-324.

Kuşvuran A, Nazlı R. 2014. Orta Kızılırmak havzası ekolojik koşullarında bazı mısır (Zea mays L.) çeşitlerinin tane mısır özelliklerinin belirlenmesi. YYU J Agr Sci, 24(3): 233-240.

Kün E. 1978. Sıcak iklim tahılları. Ankara Üniversitesi Yayınları, Ankara, Türkiye, pp: 57-70.

Lauer MJ, Anderson SR, Schoper JB, Shibles RM. 2004. Pollination timing effects on kernel set and silk receptivity in four maize hybrids. Crop Sci, 44(2): 464.

Liu E, Yan C, Mei X, He W, So HB, Linping D, Liu Q, Liu S, Fan T. 2010. Long-term effect of chemical fertilizer, straw, and manure on soil chemical and biological properties in northwest China. DOI: 10.1016.

Nar D. 2023. Ünye ilçesi yerel mısır (Zea mays L.) genotiplerinden bazı agronomi ve verim parametrelerinin karşılaştırılması. Ordu Üniversitesi, Fen Bilimleri Enstitüsü, Ordu, Türkiye. URL: http://earsiv.odu.edu.tr:8080/xmlui/handle/11489/3976 (accessed date: September 30, 2024).

National Research Council. 1988. Quality protein maize. National

Academy Press, Washington DC, USA, pp: 78-91.

Osborne TB. 1987. The amount and properties of the proteins of the maize kernel. J Am Chem Soc, 19: 525-532.

Öner F. 2011. Karadeniz bölgesindeki yerel mısır genotiplerinin agronomik ve teknolojik özelliklerinin belirlenmesi. Ondokuz Mayıs Üniversitesi, Fen Bilimleri Enstitüsü, Samsun, Türkiye.

Öner F. 2017. Karadeniz bölgesindeki yerel mısır genotiplerinin agronomik ve teknolojik özelliklerinin belirlenmesi. Int J Agric Wildlife Sci, 3(2): 108–119.

Özata E, Kapar H. 2014. Bazı atdişi hibrit mısır (Zea mays indentata Sturt.) genotiplerinin Samsun koşullarında kalite ve performanslarının belirlenmesi. Tarim Bilim Arastirma Derg, 7(2): 1-7.

Öztürk A, Özata E, Erdal Ş, Pamukcu M. 2017. Türkiye'de özel mısır tiplerinin kullanımı ve geleceği. Turk J Spec Maize, 2(1): 75–90.

Prasanna BM, Vasal SK, Kassahun B. 2001. Quality protein maize. Curr Sci, 81: 1308–1319.

R Core Team. 2019. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL: https://www.R-project.org/ (accessed date: September 10, 2024).

Saygı M, Toklu F. 2017. Çukurova bölgesinde birinci ürün koşullarında yetiştirilen bazı danelik mısır (Zea mays indentata Sturt.) çeşitlerinin dane verimi, bazı bitkisel özellikler ve karakterler arası ilişkiler yönünden değerlendirilmesi. KSÜ Dogal Bil Derg, 20(Özel Sayı): 308-312.

Sofi PA, Wani SA, Rather AG, Wani SH. 2009. Quality protein maize (QPM): Genetic manipulation for the nutritional fortification of maize. J Plant Breed Crop Sci, 1(6): 244-253.

Sönmez K, Alan Ö, Kınacı E, Kınacı G, Kutlu İ, Budak Başçiftçi Z, Evrenosoğlu Y. 2013. Bazı şeker mısırı çeşitlerinin (Zea mays saccharata Sturt.) bitki, koçan ve verim özellikleri. SDU Zir Fak Derg, 8(1): 28-40.

Twumasi-Afriyie S, Palacios-Rojas N, Friesen D, Teklewold A, Wegary D, De Groote H, Prasanna BM. 2016. Guidelines for the quality control of quality protein maize (QPM) seed and grain. CIMMYT, Addis Ababa, Ethiopia, pp: 102-130.

Vasal SK. 2000. High quality protein corn. In: Hallauer AR (ed) Specialty corns, 2nd ed. CRC Press, Boca Raton, USA, pp: 59-98.

Wessel-Beaver L, Cardona-Castro C, Hepperly PR. 1988. Agronomic performance of hard endosperm opaque-2 corn populations in Puerto Rico. J Agric Univ Puerto Rico, 72(2): 309-317.

Yıldız H, İlker E, Yıldırım A. 2017. Bazı silajlık mısır (Zea mays L.) çeşit ve çeşit adaylarının verim ve kalite özelliklerinin belirlenmesi. SDU Zir Fak Derg, 12(2): 81-89.

Yılmaz N, Akman O, Öner F. 2020. Bazı silajlık mısır çeşitlerinde (Zea mays L.) bitkisel özelliklerinin belirlenmesi. Akad Zir Derg, 9(1): 103-110.

Yılmaz N, Han E. 2016. Giresun ekolojik koşullarında bazı mısır çeşitlerinin tane verimi ve verim öğelerinin belirlenmesi. Igdir Univ J Inst Sci Technol, 6(3): 171-176.