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Yield and Quality Stabilities of Waxy Corn Genotypes using Biplot Analysis

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ABSTRACT

This study was conducted to determine the stability of the potential genotypes of waxy Corn (10 candidates, 2 standard varieties) in terms of yield, yield components and quality characteristics in various environments over a period of two years under Samsun conditions. Biplot analysis of GGE and AMMI was used to determine the stability of genotypes. Mean grain yields of genotypes ranged from 8560.6 to 17290.6 kg ha^{-1}, number of days to flowering from 71.3 to 77.5 days, plant height from 251.7 to 295.0 cm, the height of first ear from 85.3 to 98.3 cm, grain ear ratio from 81.3 to 85.5%, grain moisture content from 20.5 to 25.0%, single ear weight from 145 to 286.3 g, the number of ears per plant from 0.9 to 1.0 ear plant^{-1}, 1000 grain weight from 317.7 to 402.2 g, hectoliter from 76.9 to 79.3%, crude protein ratio from 9.4 to 10.4%, crude oil content from 3.3 to 5.0%, total starch ratio from 57.5 to 60.0%, carbohydrate ratio from 69.6 to 71.6%, and energy value from 383.8 to 393.7 kcal. The result of the analysis of variance showed that yield, yield components and chemical composition of corn varieties significantly ($p>0.01$) different between genotypes (G), environments (E) and genotype x environment (GE) interactions. A significant difference in yield, yield components, and quality characteristics of waxy Corn genotypes was shown by the biplot (AMMI and GGE) multivariate analysis. Compared with other genotypes evaluated, the yield and stability of the ADAX11 and ADAX18 genotypes were higher. In addition, in the scientific and precise assessment of the high yield, stability, and adaptations of the waxy Corn hybrids, the AMMI model and GGE biplot analysis provide great ease for Corn breeders.

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Introduction

Waxy Corn (Zea mays L. ceritina) is one of the seven subspecies included in the Corn plant; according to USDA records, this type of Corn was discovered in China in 1908 and was first described by Collins in 1909[1]. Fresh waxy Corn is consumed in most Asian countries (China, Korea, Taiwan, Vietnam, Laos, Myanmar and Thailand) and the growing area continues to expand rapidly [2].

Starch, a complex carbohydrate produced by plants for long-term storage of excess glucose, is found in tiny granular structures in the roots, tubers and seeds of plants. Starch is produced in almost all plants and can be obtained by means of many plants for

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commercial purposes, one of which is obtained by means of corn kernels (dent corn). The starch content in wet corn milling is around 66% of the dry weight. Starch can be measured as a percentage of raw Corn production, which makes starch a profitable material. The yield of starch can be obtained from the wet milling of dent corn, a variety widely grown for starch production. However, starch obtained from waxy Corn by wet milling method has a starch yield of about 90% of dry weight [3].

Some of the starches known as "waxy starches" derive from the endosperm tissue, which is waxy and contains a small amount of amylose in the granular composition (< 15%). Due to its crystalline nature, the energy requirements of waxy starches for gelatinization are very high [4]. In comparison to waxy starch, the amylose content in other types of starch is more than 30%. In addition, researchers have reported that this starch contains other polysaccharide molecules and is slightly deformed from other starches [5].

The starch content present in waxy Corn has a high molecular weight so that it is digested faster than starches of other types. The starch of waxy Corn can be extracted through a wet milling process. Heat treatment causes a loss of starch viscosity in common Corn, but since waxy Corn does not produce amylase, starch maintains its stickiness. Waxy Corn starch can therefore be modified and used in the food industry, in particular in the production of corn snacks with sauce [6]. Apart from food production, waxy Corn starch can be used in the textile industry, the production of glue, corrugated carton, the paper industry as well as animal nutrition due to its high feed quality [7,8].

The main objective of plant breeding is to develop new superior and high quality varieties. Therefore, plant breeders must look for the most appropriate breeding materials and methods to clearly present the results of scientific studies. A graphic technique is a tool commonly used to demonstrate findings obtained in Corn breeding experiments. The visual presentation of the results of the breeding study is essential to better convey the message to readers. Various graphic methods have been introduced and used by researchers as alternatives to traditional methods. The biplot is one of the most preferred techniques for visualizing the results of a breeding experiment.

The additive main effects and multiplicative interaction (AMMI) and genotype main effect (G) and genotype by environment (GE) interaction (GGE) biplot model are excellent tools for visual assessment to demonstrate the combining abilities of parents and crosses. The multivariate models have been frequently used by plant breeders to estimate the adaptability and stability of Corn hybrids in breeding experiments [9,10,11,12,13,14,15].

The genotype of waxy Corn has been intensively cultivated in the production of roasted corn snacks and amylopectin starch in Turkey. However, the waxy Corn varieties used in agricultural production all come from abroad and are not officially registered in Turkey. Consequently, the breeding of new varieties of waxy Corn is required to meet domestic demand for waxy Corn. Research on waxy Corn is relatively new in Turkey and few studies have investigated the stability of yields and the genotypic quality characteristics of waxy Corn. This research was conducted to identify genotypes with high stability in yield, yield components and quality characteristics of potential waxy Corn genotypes in different environments in Samsun during the 2018 and 2019 Corn growing seasons.

Materials and Methods

The materials used in the experimental study consisted of 10 high-yield waxy Corn hybrids provided by the Corn Research Institute (MAEM) and 2 control varieties. The information on experimental plant material is given in (Table 1). Since no genotype of waxy Corn was recorded in Turkey, 2 genotype hybrid Corn varieties which were very common in Turkey were used as control treatments to compare yields of MAEM hybrid waxy Corn.

The soil in the experimental field had clay loamy texture, mildly alkaline, non-salty, mildly calcareous, and low organic matter content. The available phosphorus content for plants is low, while the potassium content is high (Table 2).

The experimental field was located in Samsun province which is characterized by a rainy and temperate climate. The relative humidity and temperature values during growing seasons (2018-2019) were relatively close to each other, whereas differed from the long term averages. Average temperature values in 2018 and 2019 were 1.0 and 1.5 °C higher than the long term averages. Total and monthly precipitation values of the study area were significantly different from the long term precipitation data (Figure 1)

Table 1 Descriptive characteristics of waxy Corn and dent corn hybrids investigated

	Pedigrees					
Genotypes Code	Female Line	Male Line	Origin	Cycles (Maturity)/Colors	Grain texture	Type
ADAX-2	915A	915E	MAEM/ Turkey	Yellow-Portugal/Medium	Waxy	Single Hybrid
ADAX-9R	DH-682	DH-680	MAEM/ Turkey	Yellow/Medium	Waxy	Single Hybrid
ADAX-11	DH-680	DH-684	MAEM/ Turkey	Yellow/Medium	Waxy	Single Hybrid
ADAX-11R	DH-684	DH-680	MAEM/ Turkey	Yellow/Medium	Waxy	Single Hybrid
ADAX-15	DH-681	DH-684	MAEM/ Turkey	Yellow/Medium	Waxy	Single Hybrid
ADAX-16	DH-681	915A	MAEM/ Turkey	Yellow-Portugal/Medium	Waxy	Single Hybrid
ADAX-17	DH-683	DH-682	MAEM/ Turkey	Yellow/Medium	Waxy	Single Hybrid
ADAX-18	DH-684	915A	MAEM/ Turkey	Yellow-Portugal/Medium	Waxy	Single Hybrid
ADAX-19	DH-685	DH-686	MAEM/ Turkey	Yellow/Medium	Waxy	Single Hybrid
Kalumet	Unknown		DU PONT/USA	Yellow/Late	Dent corn	Single Hybrid
P2088	Unknown		DEKALB/ USA	Yellow/Late	Dent corn	Single Hybrid

Table 2 Some of soil physical and chemical properties of the experimental field

Parameter	Bafra-2018	Bafra-2019
pH	7.57	7.65
P_2O_5 (kg da^{-1})	7.92	8.2
K_2O (kg da^{-1})	80	82
Organic Material (%)	2.29	2.34
Lime (%)	4.4	4.4
Electrical Conductivity (%)	0.03	0.03

The experimental layout was a Randomized Complete Block Design with three replications. The seeds were sown in May by hand as placing two seeds in each seed bed. Each plot had four rows with 5 m length and area of each plot was 14 m^2. The interrow and intrarow spacings were 0.7 and 0.18 m, respectively. The seedlings were thinned removing the weak plants when the plants reached V4-V6 leaf stage (40-50 cm). Fertilizer application rate, determined based on soil analyses, was 80 kg P ha^{-1} and 220 kg N ha^{-1}. All phosphorus and half of nitrogen were applied at planting in bands, and the rest of the nitrogen was given at V4-V6 stage [16]. The harvest was carried out by hand in each harvest period.

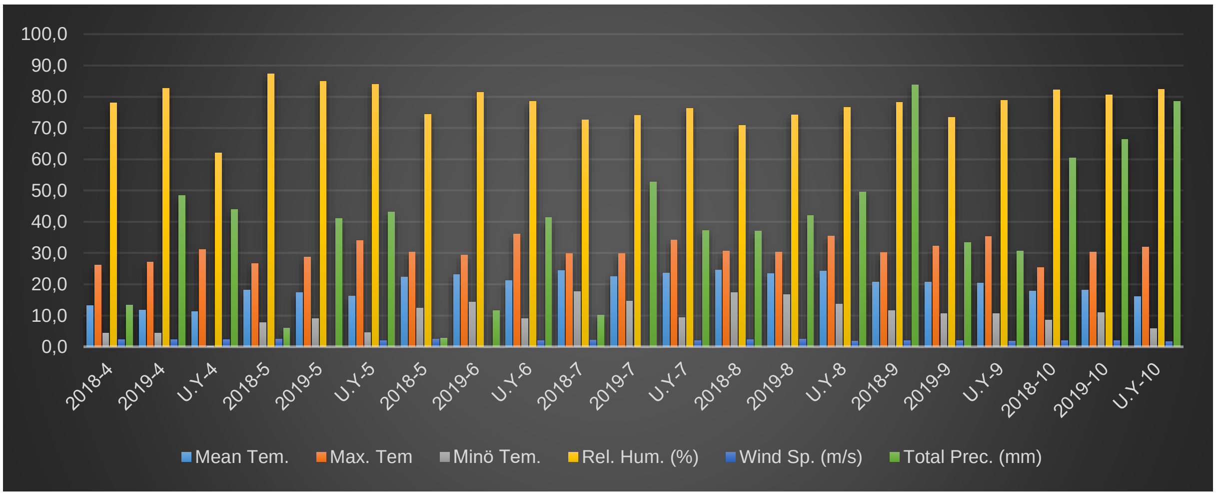

Fig 1 Some climate data for 2018 and 2019 growing seasons and long term (1985-2019)

Physical analyzes (1000 grain weight, hectoliter, grain moisture content, and grain/ear ratio) and morphological observations (plant height, height of the ears, number of ears per plant, flowering) were performed following the Corn Technical Instructions [16] The indicated an important role of pollen effect (xenia) in modifying biochemical compositions of Corn kernels [17]. The selected plants were covered using a kraft paper during the flowering period to prevent changes in the quality characteristics of waxy Corn genotypes due to the pollen effect. The iodine test, that is the most convenient method to determine the purity of the waxy, was used to determine the waxy characteristic of each inducer line and hybrid [18]. The purity of waxy was determined by counting 100 kernels in two replications. The kernels were moistened overnight, and a small portion was cut from the crown end of each kernel. The kernels were sprayed with a 0.5% iodine solution. The color of amylopectin starch in the waxy Corn temporarily turns to a brownish color following the exposure to iodine. In contrast, iodine solution causes a permanent blue or violet color in Corn containing amylose starch. Moisture content of grains was determined by drying the grains in an oven at 130±2ºC temperature under atmospheric pressure, until reaching a constant weight.

Dry matter weight, crude protein, crude oil, crude cellulose, crude ash and starch contents of Corn grains were determined by using both chemical and near infrared spectroscopy (NIRS) methods (FOSS, XDS). Carbohydrate content of samples were calculated using the following equation:

CAR (%) = 100 - (U% + PB %+ GB % + Cel.B % + Cen.B %)

In the equation, CAR (%) is the percent carbohydrates; U (%) is the moisture content of grains; PB (%) is the crude protein content; GB (%) is the crude oil content; Cel.B (%) is the crude fiber content and Cen.B (%) is the crude ash content [19].

The energy value was calculated using the Atwater general factor system Conversion factors were taken as 4.0 kcal g^{-1} for protein and carbohydrates, and 9.0 kcal g^{-1} for oil [20].

Energy = (Protein x 4) + (Oil x 9) + [(Carbohydrate- Dietary fiber) x4]

Statistical analysis

Statistical evaluations of the data were carried out using GenStat (12th Edition) software. Homogeneity and normality tests were applied prior to the combined variance analysis for the mean values obtained in different environments. The data was log-transformed in case of nonnormal distribution, before the analyses to linearize the relationships between the variables [21]. Multiple location test (MLT) data were analyzed without scaling ('Scala 0' option) to create environment centered (centering 2) GE biplots as described by Yan and Tinker 2006. For GE genotype assessment, GE genotype-oriented singular value segmentation (SVP = 1) was used along with the 'Mean versus stability' option of the GE biplot software, whereas environment-oriented singular value segmentation (SVP = 2) (Relation among testers) was used for the evaluation of the locations. The 'The-Which-won-where' option was used to identify the ideal genotype in a given environment and define the mega environments [22]. The significance in the dataset was assessed by analysis of variance (ANOVA) and the least significant difference (LSD) was used to differentiate the means in case ANOVA denoted significant differences.

Result

Yield, yield components and chemical composition performances of waxy hybrid corn genotypes

Grain yield is the most important selection criterion in Corn breeding. Variance analysis indicated that genotype (G), year (Y) and GY interaction had statistically significant impact ($p \leq 0.01$) on grain yield (Table 3). Grain yields ranged from 6481 (ADAX-2) to 17986 (Kalumet) kg ha^{-1} in the first year, and from 7518 (Adax17) to17623 (Kalumet) kg ha^{-1} in the second year. Flowering time is one of the selection criteria used to determine the maturation groups of genotypes (Table 3). Variance analysis showed that G, Y and GY interaction had a statistically significant effect ($p \leq 0.01$) on the number days to flowering. Flowering time of genotypes ranged from 68.0 (ADAX17R) to 77.0 (Kalumet) days in 2018, and from 71.3 (ADAX17R) to 77.5 (Kalumet) days in 2019 (Table 3). Plant height is another important selection criteria in corn breeding. Variance analysis indicated significant ($p \leq 0.01$) differences in plant heights between G, Y and GY interaction. The plant height of the genotypes varied between 228.3 (ADAX17) and 286.7 (ADAX16) cm in the first year, and 251.7 (ADAX17R) and 295.0 (ADAX17) cm in the second year, and the mean plant length of genotypes was 264.2 cm (Table 3). Ear height is another morphological evaluation criterion in Corn breeding. Corn breeders co-evaluate two factors as the criteria in the ear height. The first one is that the ear height should be at the same height for all plants in a plot, and the second one is that the plant height and ear height ratio should be between 1/2 and 1/3. Higher or lower ear/plant ratio may cause plants to lie down and the harvesting becomes difficult. Variance analysis showed that the effect of Genotype, Year, and GY interaction ($p \leq 0.01$) on the ear heights was statistically significant (Table 3). The mean ear height varied between 68.3 (ADAX-11R) and 108.3 (ADAX-17) cm in the first year and between 81.7 (ADAX-2) and 110.0 (ADAX-18) cm in the second year. The mean first ear height in the experiment was determined as 90.9 cm. (Table 3). Grain/ear ratio value is another important characteristic determined in corn harvest, and is calculated together with the grain moisture content right after the harvest. The effects of Genotype and GY interaction on grain/ear ratio was statistically significant ($p \leq 0.01$), while the effect of year was insignificant. The grain/ear ratio in the experiment varied between 80.7 and 84.8% in the first year and between 79.9 and 86.8% in the second year, and the mean grain/ear ratio was determined as 82.3% (Table 4). Grain moisture content is of great importance in corn breeding and is one of the important selection criteria. Moisture content of grains is desired to be low in the Black Sea region, where the relative humidity is high. Therefore, corn breeders focus on genotypes with low grain moisture content or genotypes losing the grain moisture fast. The variance analysis showed that the effects of Genotype and GY interaction on grain moisture content was statistically significant at $p<0.01$ level, while the effect of year was important at $p<0.05$ level. The grain moisture content varied between 19.7 and 25.8% in the first year and between 21.2 and 25.8% in the second year (Table 4).

Ear weight is used as a selection criterion in Corn breeding. The ear weight ranged from 130.6 to 306.0 g in the first year, and from 105.5 to 266.7 g in the second year, and the mean ear weight for combined genotype was between 156.6 and 286.3 g (Table 4). The number of ears per plant varied depending on the subspecies of the Corn. The sugar corn and popcorn subspecies have the potential to form two or more ears in a plant, while dent corn and hard corn subspecies tend to form single ear per plant. The number of ears per plant in the experiment was between 0.89 and 1.01 ear plant^{-1} in the first year, and between 0.84 and 1.01 ear plant^{-1} in the second year, and mean number of ear per plant for the experiment was 0.97 (Table 4). On thousand grain weight is the common selection criterion used in all field crops by the plant breeders. The result of variance analysis showed that the differences in 1000 grain weight significantly ($p<0.01$) differed between Genotype, Year and GY interaction. The 1000 grain weight varied between 310.3 and 411.7 g in the first year of the experiment and ranged from 315.1 to 392.8 g in the second year. The mean 1000 grain weights of both years varied between 312.7 and 402.2 g, and the mean value for the experiment was calculated as 344.5 g (Table 5). Hectoliter weight refers to the weight of 100 L corn in kilogram, and is one of the most commonly used physical quality parameter which has a positive effect on corn quality. The shape, size and homogeneity of corn grains are the most important factors that determine the hectoliter weight of genotypes. Positive relationship has been reported between hectoliter weight and grain yield. The mean hectoliter weight of genotypes ranged from 77.2 to 79.6 kg h^{-1}, and the mean hectoliter weight in the experiment was determined to be 78.1 kg h^{-1} (Table 5). Carbohydrate content is one of the widely used grain chemical content properties in assessing the quality criteria in recent years. Low-energy and nutritious products have become highly preferred in the daily diet. The mean carbohydrate content of genotypes varied between 69.6 and 71.6%, with an average of 70.5% (Table 5). The energy value, considered a criteria to determine the consumption rates of the products in the daily diet, has become an important selection criterion for popcorn, sugar corn and waxy corn which are used in direct consumption. In general, the products with low calorie and high fiber content are recommended to include in the daily diet. The energy values of genotypes ranged from 383.8 to 393.7 kcal 100 g^{-1} (Table 5). The crude protein ratio is a selection criterion used to assess the quality of the product in all field crops. The mean crude protein ratio of genotypes varied between 8.7 and 10.5% in the first year and between 9 and 10.4% in the second year (Table 6). Crude oil ratio varied depending on the subspecies of the waxy Corn. The mean crude oil ratios of genotypes varied between 3.21 and 4.73% in the first year, and between 3.31 and 3.98% in the second year, with a mean value of 3.60% (Table 6). Starch ratios of genotypes varied between 56.6 and 60.3% in the first year, and 57.7 and 60.0% in the second year, and the average starch ratio in the experiment was 58.8% (Table 6).

Table 3 The results of mean and multiple comparison tests for yield, flowering, plant height and ear heights of waxy Corn genotypes

	Yield						**Flowering (day)**						**Plant Height**					**Ear Height**					
Genotypes	2018		2019		Mean		2018		2019		Mean		2018		2019	Mean		2018		2019		Mean	
ADAX-11	13772	bcd	10521	bcd	12147	bcd	68.0	e	72.5	d	74.0	bc	256.7	b-e	251.7	254.2	bcd	68.3	e	100.0	bc	84.2	c
ADAX-11R	11906	de	11171	bcd	11538	cde	68.0	e	72.8	cd	72.8	bc	256.7	b-e	278.3	267.5	ab	83.3	bcd	88.3	de	85.8	c
ADAX-15R	102.0	e	10009	cde	10110	ef	71.7	b	74.7	b	74.7	ab	246.7	d-g	273.3	260.0	abc	83.3	bcd	95.0	cd	89.2	bc
ADAX-16	15495	bc	10944	bcd	13220	bc	70.7	c	74.5	b	75.2	abc	286.7	a	258.3	272.5	a	86.7	bcd	108.3	ab	97.5	a
ADAX-17	1072.5	de	7518	f	9121	f	68.7	de	72.2	de	72.2	c	228.3	g	295.0	261.7	abc	108.3	a	88.3	de	98.3	a
ADAX-17R	123.2	de	9011	def	10662	def	68.0	e	71.3	f	73.5	bc	249.4	efg	251.7	250.6	cd	76.7	de	93.9	cd	85.3	c
ADAX-18	13116	de	12533	b	12824	bc	69.0	d	73.5	c	73.5	bc	276.7	abc	253.3	265.0	ab	80.0	cde	110.0	a	95.0	ab
ADAX-19	12516	cde	12223	bc	12370	bc	72.0	b	73.5	c	73.0	bc	251.3	d-g	270.0	260.6	a-d	81.7	bcd	96.3	cd	89.0	bc
ADAX-2	6481	f	10651	bcd	8566	f	69.0	d	72.5	d	73.3	bc	230.0	fg	253.3	241.7	d	91.7	bc	81.7	e	86.7	c
ADAX-9R	11702	de	78.9	ef	9795	ef	68.0	e	71.5	ef	72.8	bc	261.7	bcd	258.3	260.0	abc	80.0	cde	95.0	cd	87.5	c
KALUMET	17968	a	17623	a	17796	a	77.0	a	77.5	a	76.5	a	260.0	c-f	258.3	259.2	a-d	76.7	de	100.0	bc	88.3	bc
P2088	12400	ab	11585	bc	11993	b	72.0	b	74.7	b	74.3	abc	278.3	ab	268.3	273.3	a	93.3	b	103.3	abc	98.3	a
Mean	12384	A	10973	B	11678		70.7	B	76.7	A	73.8		257.9	B	264.2 A	261.0		84.2	B	97.6	A		
CV (%)	8.59		12.94		10.71		0.71		1.03		0.89		5.64		6.15	5.69		5.31		8.82		7.06	
LSD (0.05) G	183.81**		240.12**		202.21**		0.83**		1.34		1.05**		24.3**		ns	24.54*		9.72**		12.56**		10.22**	
LSD (0.05) Y			116.28*						0.49**						4.68**					4.60**			

Table 4 The results of mean and multiple comparison tests for grain/ear ratio, grain moisture, ear weight and NEPP of waxy Corn genotypes

	Grain/Ear ratio			Grain Moisture (%)			Ear Weight (g)			Number of Ear per plant (piece)		
Genotypes	2018	2019	Mean	2018	2019	Mean	2018	2019	Mean	2018	2019	Mean
ADAX-11	82.9 b	80.3 ef	81.6 cd	21.9 bcd	24.4 ab	23.2 bc	244.9 bc	157.8 bcd	201.3 b	0.94	0.97	1.0
ADAX-11R	80.7 d	81.8 cd	81.3 d	20.7 bcd	23.3 bcd	22.0 cd	205.8 cd	165.6 bcd	185.7 bc	1.03	0.96	1.0
ADAX-15R	82.9 b	81.8 cd	82.3 bcd	21.7 bcd	23.0 bcd	22.4 cd	180.6 de	142.4 cde	161.5 cd	0.96	0.98	1.0
ADAX-16	82.4 bcd	84.3 b	83.4 b	21.6 bcd	23.8 bcd	22.7 bc	263.1 ab	158.3 bcd	210.7 b	1.00	0.97	1.0
ADAX-17	83.0 b	79.9 f	81.5 cd	22.2 bc	23.4 bcd	22.8 bc	203.7 cd	105.5 f	154.6 d	0.89	1.01	1.0
ADAX-17R	83.1 bcd	81.3 de	82.2 cd	19.9 cd	23.1 de	21.5 de	197.0 cd	134.6 def	165.8 cd	0.95	0.95	0.9
ADAX-18	82.7 bc	82.4 c	82.5 bc	21.6 bcd	23.0 bcd	22.3 cd	205.6 cd	185.0 b	195.3 b	1.01	0.97	1.0
ADAX-19	82.5 bcd	82.3 cd	82.4 cd	22.8 b	22.7 cde	22.7 bc	214.6 bcd	182.2 b	198.4 b	1.00	0.94	1.0
ADAX-2	82.3 bcd	81.8 cd	82.0 cd	22.0 bcd	25.8 a	23.9 ab	130.9 e	159.1 bcd	145.0 d	0.94	0.98	1.0
ADAX-9R	82.7 bc	82.1 cd	82.4 bc	19.7 d	21.2 e	20.5 e	202.9 cd	116.6 ef	159.8 cd	0.96	0.97	1.0
KALUMET	84.8 a	86.2 a	85.5 a	25.8 a	24.1 abc	25.0 a	306.0 a	266.7 a	286.3 a	0.99	0.99	1.0
P2088	80.9 cd	82.6 c	81.8 cd	22.2 bc	23.1 bcd	22.7 bc	247.6 bc	173.9 bc	210.8 b	0.98	0.97	1.0
Mean	82.3 B	84.4 A	83.4	21.8 B	23.5 A		209.0 a	162.3 b	185.6	1.0	1.0	1.0
CV (%)	1.3	0.77	1.16	4.32	6.27	5.36	13.88	11.91	13.32	5.15	2.06	4.12
LSD (0.05) G	1.08**	1.46**	0.60**	1.69**	2.32**	1.91**	50.77**	32.68**	40.38**	ns	ns	ns
LSD (0.05) Y		ns			1.36*			19.97**			ns	

Table 5 The results of mean and multiple comparison tests of some quality and yield components of waxy Corn genotypes

	1000 grain weight (g)			Hectolitre (%)			Carbonhyrdrate (%)			Energy (kcal)		
Genotypes	2018	2019	Mean	2018	2019	Mean	2018	2019	Mean	2018	2019	Mean
ADAX-11	354.1 c	318.5 d	336.3 de	78.9 bc	78.5	78.7 abc	69.7 a-d	71.0 bcd	70.3	384.3 bc	387.4 bcd	385.9 de
ADAX-11R	374.1 b	343.8 c	358.9 c	80.1 a	79.1	79.6 a	70.6 abc	71.6 abc	71.1	392.3 ab	395.1 ab	393.7 a-d
ADAX-15R	331.5 d	325.2 d	328.3 efg	79.6 ab	78.2	78.9 abc	70.7 abc	70.3 bcd	70.5	385.0 a	387.9 bcd	386.5 abc
ADAX-16	349.8 c	315.8 d	332.8 def	78.7 bcd	76.9	77.8 cd	71.3 d	70.6 abc	70.9	389.5 ab	391.3 cd	390.4 b-e
ADAX-17	353.5 c	317.2 d	335.3 de	77.5 efg	77.2	77.3 d	71.1 d	70.3 cd	70.7	394.9 ab	387.6 bc	391.3 b-e
ADAX-17R	348.5 d	321.5 d	335.0 g	78.5 cde	78.1	78.3 bcd	69.2 bcd	70.6 cd	69.9	390.8 a	386.0 ab	388.4 ab
ADAX-18	354.1 c	322.7 d	338.4 d	77.7 d-g	78.1	77.9 cd	69.4 cd	69.8 abc	69.6	389.4 ab	389.6 cd	389.5 cde
ADAX-19	323.3 d	323.9 d	323.6 fg	79.2 ab	78.7	79.0 ab	70.0 cd	70.1 d	70.0	390.8 a	392.3 bcd	391.6 abc
ADAX-2	310.3 e	315.1 d	312.7 h	76.8 g	77.5	77.2 d	70.2 cd	70.9 abc	70.5	393.8 bc	385.3 bcd	389.6 ef
ADAX-9R	354.1 c	357.7 bc	355.9 c	78.7 bcd	77.2	77.9 cd	70.2 a-d	69.3 a	69.7	390.2 a	388.7 a	389.5 a
KALUMET	411.7 a	392.8 a	402.2 a	77.3 fg	78.8	78.1 cd	71.7 a	71.4 abc	71.6	385.2 c	388.2 d	386.7 f
P2088	378.8 b	370.7 b	374.7 b	78.0 c-f	79.3	78.7 abc	72.3 ab	70.7 ab	71.5	383.8 bc	383.8 bcd	383.8 de
Mean	353.6	335.4	344.5	78.4	78.1	78.3	70.5	70.5	70.5	389.2	388.6	388.9
CV (%)	1.39	3.07	1.82	0.81	1.7	1.34	1.35	1.04	2.04	0.99	0.78	0.89
LSD (0.05) G	8.30**	17.4**	12.82**	0.25**	ns	1.76**	1.61*	1.24*	ns	7.83*	5.13*	5.54**
LSD (0.05) Y		4.84**			ns			ns			ns	

Table 6 The results of mean and multiple comparison tests for some quality components of waxy Corn genotypes

	Crude Protein (%)			Crude oil (%)			Total Starch (%)		
	2018	2019	Mean	2018	2019	Mean	2018	2019	Mean
ADAX-11	9.5 c	10.0 ab	9.7 c	3.25 fgh	3.45 bcd	3.4 efg	60.0 a	57.7	58.9 a-d
ADAX-11R	9.8 b	10.2 a	10.0 bc	3.15 gh	3.47 bcd	3.3 fg	59.9 a	58.6	59.3 abc
ADAX-15R	10.4 a	9.9 ab	10.2 ab	3.31 efg	3.41 cd	3.4 efg	57.8 c	58.8	58.3 b-e
ADAX-16	10.5 a	9.3 bc	9.9 bc	4.01 b	3.98 a	4.0 ab	58.3 bc	58.0	58.1 b-e
ADAX-17	10.4 a	10.4 a	10.4 a	3.68 cd	3.44 cd	3.6 de	59.3 ab	59.4	59.4 ab
ADAX-17R	10.2 a	10.4 a	10.3 a	3.64 bc	3.71 abc	3.7 c	59.2 ab	58.6	58.9 abc
ADAX-18	10.4 a	9.1 c	9.8 c	3.50 def	3.96 a	3.7 cd	59.2 ab	57.9	58.5 cde
ADAX-19	10.4 a	10.3 a	10.4 a	3.99 b	3.80 ab	3.9 bc	58.1 c	58.6	58.3 de
ADAX-2	9.2 d	9.5 bc	9.3 d	4.73 a	3.68 abc	4.2 a	56.6 d	58.4	57.5 e
ADAX-9R	10.3 a	10.2 a	10.3 ab	3.33 efg	3.40 cd	3.4 efg	58.5 bc	58.3	58.4 b-e
KALUMET	8.7 f	9.3 bc	9.0 e	3.21 h	3.31 d	3.3 g	60.3 a	59.6	59.9 a
P2088	9.0 e	9.5 bc	9.2 de	3.51 de	3.32 d	3.4 ef	60.0 a	60.0	60.0 a
Mean	9.9 A	9.8 bc	9.9	3.61 A	3.58 B	3.6	58.9	58.7	58.8
CV (%)	1.51	3.96	2.93	4.15	5.61	5.01	3.88	2.39	1.86
LSD (0.05) G	0.25**	0.64**	0.47**	0.26**	0.31**	0.6**	1.12**	ns	0.60**
LSD (0.05) Y		ns			ns			ns	

The additive main effects and multiplicative interactions (AMMI) analysis for various characteristics of corn hybrids

The results of AMMI variance analysis using the mean values of yield, yield components and quality characteristics of waxy Corn genotypes, and the statistical differences between genotype (G), environment (E), GE interactions were given in Table 7. The results indicated that 95.15% of the total variance in the experiment was attributable to environmental effect, followed by Genotype effect with 0.49% and GE interaction effect with 4.15%, respectively.

Table 7 Main and interaction effects for waxy Corn hybrids

Source	df	SS	MS	F	Explained %
Total	1079	97999153	90824		
Treatments	179	95427788	533116	235.68	
Genotypes	11	464687	42244	18.67**	0.49
Environments	14	90804025	6486002	689.85**	95.15
Block	75	705149	9402	4.16ns	0.74
G x E Interactions	154	4159077	27007	11.94**	4.36
IPCA1	24	4133151	172215	76.13**	99.38
IPCA2	22	17311	787	0.35ns	0.42
IPCA3	20	6305	315	0.14ns	0.15
IPCA4	18	1019	57	0.03ns	0.02
Residuals	70	1291	18	0.01ns	
Error	825	1866216	2262		

The effect of environment on grain yield, yield components and grain chemical composition was approximately 12 to 14 times higher than the effect of GE interaction. The influence level of factors was ranked as follow; Environment> GE interaction> Genotype.

Table 8 The means, variances and component scores obtained in AMMI model for waxy Corn genotypes

	Mean	Variance	IPCAe[1]	IPCAe[2]	IPCAe[3]	IPCAe[4]
1000 Grain Weight	344.5	0.00185	-0.09611	0.24876	-0.03726	0.00283
Carbohydrate	70.5	0.00002	0.06936	0.03084	0.03408	-0.00463
Crude Oil	3.6	0.00149	0.17588	-0.25927	-0.03515	-0.06068
Crude Protein	9.9	0.0005	0.1394	0.0652	0.05684	-0.1495
Ear Height	90.9	0.00064	0.04937	0.00018	-0.24318	0.02445
Energy	388.9	0.00005	0.08921	0.02713	0.03661	-0.03886
Ear Weight	185.6	0.00636	-0.35626	-0.06801	0.04159	0.00408
Flowering	73.8	0.00005	0.03915	-0.01087	0.03513	0.04158
Grain/Ear Ratio	83.4	0.00001	0.07223	0.0018	0.05001	0.01559
Hectoliter	78.1	0.00002	0.06335	0.01543	0.05787	0.00016
Grain Moisture	22.7	0.00035	0.02081	-0.05217	0.04757	0.19705
NEPP	1	0.00005	0.04591	0.00696	0.02588	0.00973
Plant Height	261	0.00022	0.04516	0.03882	-0.07455	-0.0016
Total Starch	58.8	0.00003	0.04776	0.02605	0.02264	0.02713
Yield	1167.8	0.00795	-0.40522	-0.07086	-0.01807	-0.06734

Table 9 The first four AMMI selections based on data for yield, yield components and chemical analysis of Corn grains

	Mean	Score	1	2	3	4
1000 Grain Weight	344.5	-0.0961	KALUMET	P2088	ADAX-11R	ADAX-9R
Carbohydrate	70.5	0.0694	ADAX-9R	ADAX-17	ADAX-11R	ADAX-15R
Crude Oil	3.6	0.1759	ADAX-2	ADAX-16	ADAX-19	ADAX-18
Crude Protein	9.9	0.1394	ADAX-17R	ADAX-9R	ADAX-11R	ADAX-19
Ear Height	90.9	0.0494	P2088	ADAX-16	ADAX-17	ADAX-18
Energy	388.9	0.0892	ADAX-17R	ADAX-9R	ADAX-19	ADAX-17
First Ear Weight	185.6	-0.3563	KALUMET	P2088	ADAX-11	ADAX-16
Flowering	73.8	0.0392	KALUMET	ADAX-16	ADAX-19	P2088
Grain/Ear Ratio	83.4	0.0722	ADAX-19	ADAX-11R	ADAX-16	ADAX-17R
Hectoliter	78.1	0.0634	ADAX-19	ADAX-11R	ADAX-17R	ADAX-9R
Grain Moisture	22.7	0.0208	KALUMET	ADAX-2	ADAX-11	P2088
NEPP	1	0.0459	KALUMET	ADAX-16	ADAX-19	P2088
Plant Height	261	0.0452	P2088	ADAX-17	ADAX-16	ADAX-18
Total Starch	58.8	0.0478	KALUMET	P2088	ADAX-17	ADAX-11R
Yield	1167.8	-0.4052	KALUMET	P2088	ADAX-16	ADAX-19

Table 10. The mean values of waxy Corn genotypes and IPCA scores

Genotype	Mean	IPCAg[1]	IPCAg[2]	IPCAg[3]	IPCAg[4]
ADAX-11	1214.7	-0.07685	0.00438	0.12004	0.03505
ADAX-11R	1153.8	-0.02137	0.11491	0.08404	-0.02764
ADAX-15R	1011.0	0.11136	0.09746	0.02358	0.02871
ADAX-16	1322.0	-0.03758	-0.11744	-0.11207	-0.0736
ADAX-17	912.1	0.18681	0.1252	-0.12574	0.06129
ADAX-17R	1066.2	0.11602	-0.01047	0.06936	-0.11679
ADAX-18	1282.4	-0.03918	-0.06727	-0.06989	-0.06177
ADAX-19	1237.0	-0.03304	-0.11776	0.05195	-0.10904
ADAX-2	856.6	0.27709	-0.22028	0.03686	0.14907
ADAX-9R	979.5	0.12037	0.17368	0.0229	-0.00755
KALUMET	1779.6	-0.44136	-0.00651	0.03854	0.10155
P2088	1199.3	-0.16228	0.02412	-0.13956	0.02072

The additive variance can be successfully separated from the multiplicative variance using the AMMI analysis which evaluates the major component axis’s together. The impact level of each variable in GE interaction can be determined by AMMI which captures a large part of the GE sum of squares (Gauch, 2006). The result indicated that the first principal component (PC1) explained 99.38% of the total variation in the GE interaction ($p<0.01$) and the rest was explained by PC2 (0.42%), PC3 (0.15%) and PC4 (0.02%). Since the first two PCs accounted up more than 60% of the variance in the data (Yan et al. 2001), the AMMI model is considered adequately elaborating the variability in the GE interaction.

The AMMI model for genotype x environment interactions

The AMMI model is a bi-directional variance analysis in which the main effect of genotype and environment factors is explained in the x axis and the interaction effect is given in the y axis (Fig. 1). The stability of genotypes is interpreted by the distance to the x axis. Closer to the x axis means more stable the genotype. The genotypes are considered stable when they are located close to the x axis, in contrast, they are unstable when located far from the x axis. The AMMI analysis indicated that the genotypes had a high variation and scattered on different regions of the graph.

The AMMI analysis showed a positive interaction with grain yield and single ear weight, grain ratio and 1000 grain weight. In addition, a negative correlation was determined between grain yield and grain moisture, crude protein and crude oil contents (Figure 2). The results revealed that ADAX11, ADAX 9R and ADA18 waxy genotypes had well yield stability, while the stability of ADAX2 and ADAX17R waxy genotypes was low. Kalumet dent genotype was the most productive genotype, however the stability of Kalumet genotype was low, in contrast the stability of ADAX9 genotype was high, while the yield of ADAX9 was low.

The AMMI analysis demonstrated the first four genotypes to be preferred in terms of grain yield, yield components and chemical properties (Table 9). The first preference according to the grain yield and yield components of Corn varieties should be the standard dent corn varieties (Kalumet and P2088). Waxy genotypes were ranked the first places in terms of protein, oil and starch contents. The ADAX11, ADAX 17, ADAX19 and ADAX18 waxy genotypes were identified as genotypes that can be preferred in the first place (Table 9 and 10).

Adaptability analysis of tested genotypes based on GGE biplot

The polygons in a scatter plot (which-won-where) correlates genotypes with each other and the environment with respect to grain yield obtained in multiple environmental conditions and shows which genotype is more compatible with which environment. If the genotypes and environments are placed in the same polygon, this indicates a positive interaction between genotype and environment. In contrast, if the genotype and environment are located in different polygons, this indicates a negative relationship between genotype and environment [22]. The lengths of the vectors and the angle between the vectors provide important clues in the interpretation of the graph [23]. The longer the vector length of the genotypes related to AEC abscess, the more stable the environment or the genotype. If the angle between the vectors is more than 90° the relationship is considered negative, and if the angle is less than 90° the relationship is considered positive. Positive interaction was determined between the grain yield and 1000 grain weight, grain moisture and single ear weight, while a negative relationship was obtained with grain yield and crude oil and crude protein contents (Figure 3 and 4).

The 'which-won-where' biplot is an important biplot graph explaining the mega environment and sector-genotype relationship. The polygonal corners drawn in the graph indicate that genotypes are the most preferred genotypes for that sector. The researcher stated that a positive interaction when genotypes and environments are placed in the same sector, a negative interaction when they are placed in different sectors, a mixed interaction when all are placed in the same sector [23]. The environments consisted of 4 intertwined mega circles in the scatter biplot, drawn using the mean values of grain yield, yield components and grain chemical compositions. Some characteristics located in a mega environment are also located in the clusters of other mega environments (Figure 4 and 5). This intersection cluster indicates an important relationship between the yield and the quality components.

The environments were divided into 5 sectors. The first sector composed of Kalumet> P2088> ADAX11 genotypes with grain yield, single ear weight, 1000 grain weight, grain moisture content, grain/ear ratio, flowering, plant height and first ear weight. The second sector included ADAX-9R>ADAX17>ADAX11R>ADAX15 genotypes and flowering characteristics. The crude protein content and ADAX2>ADAX16>ADAX19 genotypes were included in third sectors. The 4th sector included the oil content and the sector 5 included only the ADAX18 genotype. The BBE plot indicated that stability of the Kalumet variety considering the grain yield and yield components was high, while the stability of ADAX-2 genotype was low. The high number of sectors in a BBE plot is important in the breeding studies to assess the reliability of the selected environments.

Analysis of the high yield and stability of the tested varieties based on GGE biplot

The assessment of yield and stability of genotypes in the GGE biplot (Figure 6) was determined using the average environment (tester) coordinate methods [24]. The ideal genotype should have an average environment coordinate, indicated by the first two components [25]. The mean yield and stability of an ideal genotype, located in the center of the concentric circle, should be high [26]. Ranking biplot graphs showed that the stabilities of genotypes in terms of grain yield, yield components and chemical compositions were different (Figure 7).

Analysis of ideal varieties based on GGE biplots

The comparison of genotypes in biplot model showed the ideal region (indicated by the arrow) representing the mean grain yield values in all locations, and indicated the information on the waxy Corn hybrids located in the ideal region. The most stable characteristics in terms of grain yield, yield components and quality composition were yield and single ear weight, and followed by 1000 grain weight and grain moisture content, respectively. Crude protein and crude oil contents were determined as the low quality properties for stability of waxy Corn genotypes (Figure 7).

Discussion

The coefficient of variations for the yield, yield components and grain chemical characteristics determined in the experiment showed that the reliability of the experiment was within the acceptable limits for Corn experiments, and the values were in consistent with the literature [27,28].

The mean grain yield of 4 candidate waxy Corn genotypes (ADAX-11, ADAX16, ADAX18 and ADAX 19), when years evaluated together, was higher than mean value obtained for the experiment (11678 kg ha^{-1}). The mean grain yields of waxy corn genotypes were 20 to 40% lower than the dent corn varieties (Table 3). The researcher reported that waxy Corn genotypes had a yield of 18 to 27% lower than dent corn varieties [7,29]. The results obtained in the experiment are consistent with the results of previous studies. Control varieties in both years were the latest flowering genotypes with the lowest number of days for flowering. The number of days to flowering recorded in this study complies with the results of previous studies carried out in similar locations [30,31,32].

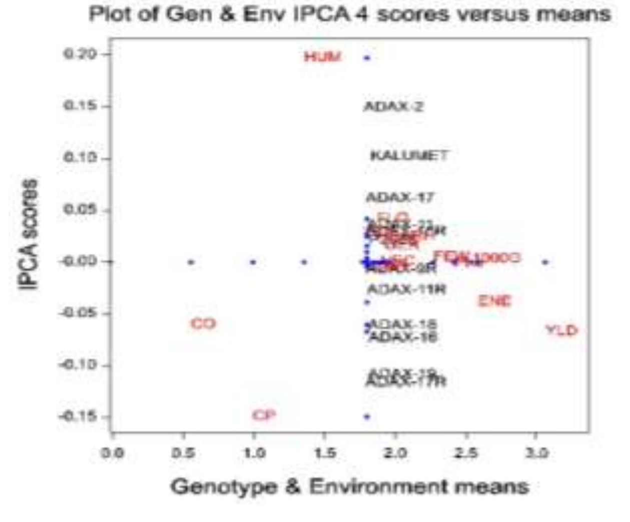

Fig 2 Graphic of AMMI analyses of Waxy Corn cultivars

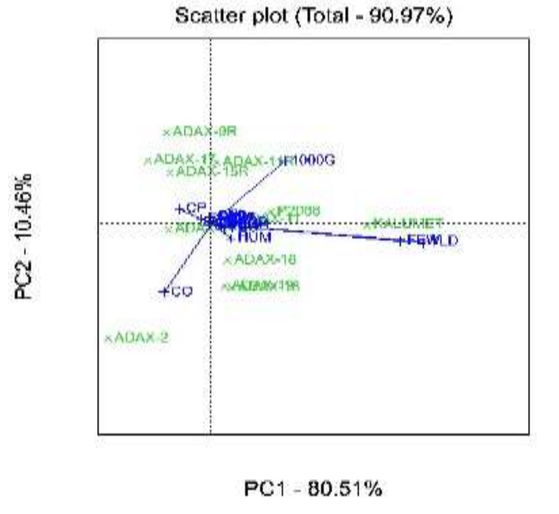

Fig 3 The scatter plot of Waxy Corn (The connect environment scores with origin)

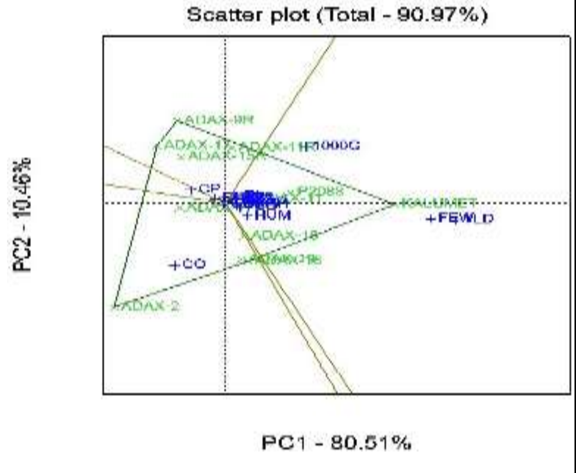

Fig 4 The which-won-where plot of Scatter

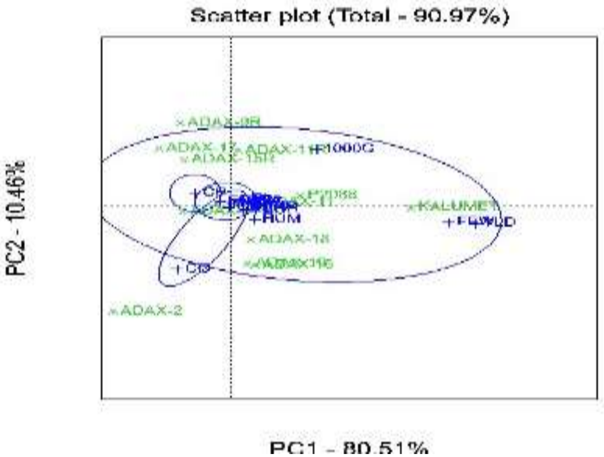

Fig 5 Mega environment scatter plot of waxy Corn genotypes

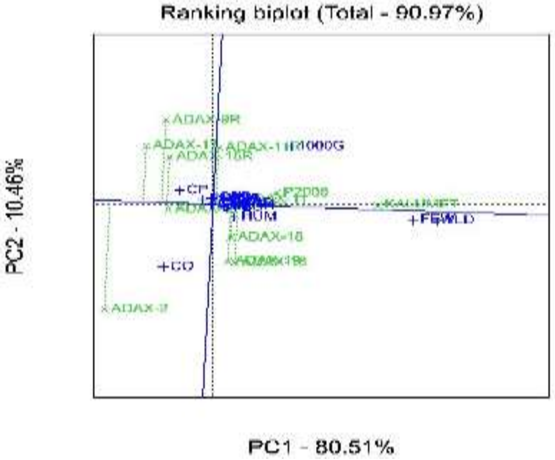

Fig 6 Ranking biplot of waxy Corn genotypes

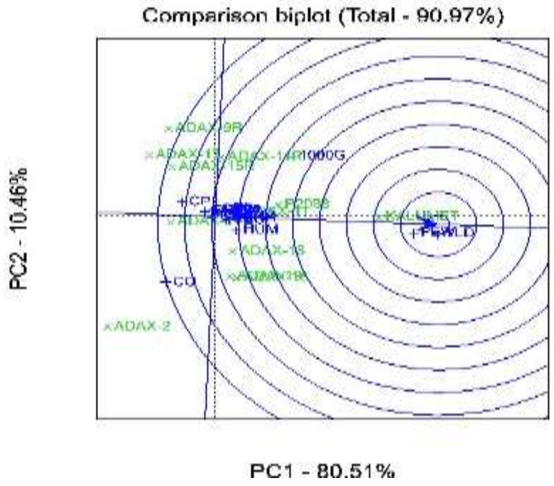

Fig 7 Comparison biplots for waxy Corn genotypes

The researchers reported that the number of days to flowering between 58.5 and 77.5 days. In addition, the variation in flowering period over the years shows that although the flowering period is a genetic feature, it is also affected by the environmental factors (mean temperature during sowing-flowering period and precipitation regime).

The mean plant heights of 4 waxy Corn genotypes (ADAX11R, ADAX15R, ADAX17 and ADAX 19) were higher than the mean plant height recorded in the experiment (Table 7). In addition, the plant heights of waxy Corn genotypes were similar to the plant heights of dent corn (control) varieties. The results obtained in the experiment are similar to the plants heights (255-335.8 cm) reported in the studies conducted under Samsun conditions [30,31,32]. Plant height is a genetic characteristics, though significantly affected by the environmental factors. The lower average temperature and higher precipitation during the vegetation period of the second year caused higher plant heights of the genotypes compared to the first year of the experiment.

The mean ear heights of 3 waxy Corn genotypes (ADAX-16, ADAX-17 and ADAX-18) were higher than the mean value recorded in the experiment. The ear height of waxy corn genotypes was 10 to 20% lower than that of the dent corn varieties. The many researcher reported that the ear height of corn varieties varied between 98.3 and 145 cm, which are partially lower than the ear heights obtained in the experiment [31,32, 33]. The results in the experiment indicated that the ear height is not only affected by the genetic characteristics but also by the environmental factors. The differences in ear height may be related to low ear formation in waxy corn genotypes, and higher sensitivity of waxy corn genotypes to plant density compared to the dent corn.

Grain/ear ratios of 3 waxy Corn genotypes (ADAX-16, ADAX19 and ADAX-2R) were higher than the mean grain/ear ratio of the experiment. Corn breeders desire to have a grain/ear ratio higher than 85%. Waxy genotypes had relatively lower grain/ear ratios than the control varieties. The results obtained in the experiment are in harmony with the grain/ear ratios (78.0-85.8%) reported by [34,31]. The results of the study revealed the strong influence of genetic structure on grain/ear ratio of waxy Corn genotypes. The mean grain moisture content of the genotypes was 22.7% and mean grain moisture content of 5 waxy Corn genotypes (ADAX11R, ADAX15R, ADAX17R, ADAX-18 and ADAX9R) was lower than the mean moisture content of the experiment. The waxy genotypes in both years had lower grain moisture content than the standard varieties (Table 8). The results obtained in the experiment are compatible with the grain moisture contents (19.30-30.9%) recorded in a similar location by [34,31]. In addition, the grain moisture content of waxy Corn genotypes in a five year study varied between 20.7 and 24.0%, which were relatively lower compared to grain moisture contents of dent corn [7].

One thousand grain weight is a genetic trait but also affected by the environmental factors. Positive correlation was obtained between 1000 grain weight and grain yield. Many researcher reported that 1000 grain weights of dent corn varied between 302.7 and -489.0 g. [35,36]. In addition, Hao and Wu (2008) reported that 1000 grain weights of waxy Corn pure lines ranged from 142 to 192 g, while Edy and Baktiar (2017) reported that waxy Corn hybrids ranged from 312 to 332 g. The values obtained in the experiment are higher than those reported [37]. 100 grain weight can be attributed to the genetic structure of hybrid genotypes used in the experiment. The shape, size and homogeneity of corn grains are the most important factors to determine the hectoliter weight of genotypes. The mean hectoliter weights of genotypes was determined as 78.1 kg h^{-1}. Sayaslan et al. (2016) and Saygı and Toklu (2017) reported that hectoliter weights ranged between 65.1 and 80.1 kg h^{-1}. The results showed that the hectoliter weights of waxy Corn genotypes were similar to hectoliter weights of dent corn varieties, and the genetic structure has a significant effect on hectoliter weight of corn varieties. The products with low energy and nutritious have recently become more preferred. The mean carbohydrate content of the genotypes was 70.5% (Table 5). The results revealed that the genetic (genotype potential) effect has predominant influence on carbohydrate content. The carbohydrate content of dent corn varieties varied between 67.9 and 81.2%, and waxy Corn genotypes ranged between 71.5 and 74.5% [37,19,39]. The carbohydrate content obtained in this study are similar to the results reported in previous studies.

Energy content varied depending on Corn genotypes. Ma et al. (2019) reported that the mean energy values of dent corn and waxy corn varieties were 378.5 and 380.5 kcal 100 g^{-1}, respectively, which were slightly higher than the energy values calculated in this study. The difference is probably related to the higher oil and protein contents of waxy Corn genotypes used in the experiment compared to those used by [38]. The energy values, similar to the grain chemical composition, are under the influence of the genetic structure.

Single ear weight was significantly different among Corn genotypes. The researcher reported that single corn weight of dent corn varied between 177 and 224 g, while the other reported that single ear weights of waxy corn genotypes ranged between 98 and 282 g [40,41,42]. The results are similar to the finding reported in the previous studies. The number of ears per plant recorded for waxy and dent Corn genotypes were similar. The number of ears per plant for grain corn was reported between 1.12 and 1.28, for waxy Corn genotypes from 1 to 3 [40,43,44]. The number of ears per plant obtained in this experiment were lower than those reported by Souvandouane et al. (2010), while in harmony with the values given in the previous studies. This difference can be attributed to the difference in genetic structure (waxy x super sweet hybrid) of the waxy genotypes used in the experiment and the differences in fertilizer applications and the sowing density (60x25 cm).

Crude protein ratio is one of the most important quality traits and varies depending on the corn subspecies. The protein ratios in various experiments reported varying between 8 and 13% [19,45]. In addition, the protein ratio of waxy corn varies reported varying between 7.89 and 9.4% [46,41,7,38]. The protein ratios reported in previous studies are compatible with the dent corn, while higher than the waxy corn genotypes. The oil content of waxy and dent Corn genotypes were different. The oil ratio of dent corn varieties was reported varying between 3.4 and 5.0% [17,19,31].

The crude oil ratio of waxy Corn genotypes reported in the previous studies ranges from 4.4 to 5.1% [7,47,41,38]. The crude oil ratios obtained in the experiment were relatively lower compared to those reported in the literature. The difference is related to the low crude oil ratios of the parents of the genotypes used in the experiment, and the crude oil ratios of waxy Corn genotypes were higher than the crude oil ratios of the control varieties. In addition, the results showed that the genetic structure of genotypes significantly affects the crude oil content. Similar to the crude protein and oil contents, the grain starch content slightly differed between the genotypes. The results indicated that starch content of waxy genotypes is significantly affected by the genetic structure.

The starch ratios of waxy corn genotypes have been reported between 69.01 and 73.2% [7,47,38]. The differences between starch ratios reported in the literature and those obtained in this study can be attributed the difference in the genotypes used.

The significance of GY interaction is related to the differences in climate and soil conditions between the years. The significance of GE interaction ($p<0.01$) in both years can be explained by changes in the stabilities of genotypes under different environments. The variation of yield potentials for corn genotypes depending on the environment have been reported also by [48,49,27].

The AMMI biplot is a comprehensive and effective method to classify the genotypes based on their levels in combination with target environments, and graphically ranks the genotypes with their strengths and weaknesses in different environments [20]. GGE biplot method provides convenience in explaining the ideal genotype and environment relationship for breeders [50,51] Both biplot methods (AMMI and GGE) explain the grain yield, yield components and chemical composition interactions, and provide reliable information to the breeders about the candidate genotypes or halfway materials in the gene pool. The AMMI biplot analysis indicated that the highest effect on experimental variance was resulted from the environment (95.15%) followed by genotype (0.49%) and GE interaction (4.15%), respectively. The coassessment of grain yield, yield components and chemical composition showed that the effect of the environment was quite higher than genotype and GE interaction. Similar results on AMMI studies have been reported by [50,51]. The study to determine the yield stability of some corn hybrids, and explained that genotype effect on the experimental variance was 9.17%, the effect of year and environment was 77.13% and GE interaction was 13% [52]. The other reported that the environment effect on the agronomic properties of some corn varieties was 46.67%, the effect of the genotype was 22.26%, and the GE interaction was 31.06% [53]. The results obtained in this study differed from other studies. The difference can be attributed to the type of genotypes (waxy Corn) used in the experiment and narrow genetic diversity of the genotypes. The first four genotypes determined by the AMMI analysis in terms of yield, yield components and chemical compositions were given in Table 5. The dent corn variety (Kalumet) can be preferred in terms of 1000 grain weight, single ear weight, flowering, grain moisture content and number of ears per plant, while, the variation was high in the waxy genotypes (Table 5). One thousand grain weight and single ear weight came to the fore as the most stable traits of the corn varieties (Figure 1). The ADAX11 and ADAX18 waxy genotypes are considered the most fertile and stabile genotypes. In addition, both waxy genotypes can be recommended as good candidates for similar ecologies.

The GGE biplot analysis is used extensively in different test environments to determine the stability of genotypes in terms of yield, yield components and quality characteristics. The representative stability graph of grain yield, yield components, and chemical composition plotted on the mean of the squares showed that Kalumet> P2088> ADAX16>ADAX19 were the first four genotypes which have average yields above the overall average in ideal environments and higher stability. The mean yields of ADAX-2>ADAX-9R>ADAX17 genotypes were lower than the mean yield of the experiment; thus, the stability of genotypes was considered low. Similar results have been reported many researcher [54,55,49,27]. The GGE biplot defines the relationships between all environments based on the general model of MET data, whereas the simple correlation coefficients describe the relationships between the two environments [20,21]. The GGE biplot is considered an efficient method to determine the best genotypes, which are representative across environments [50,51]. The most stable cultivars were Kalumet and P2088, while ADAX-11 and ADAX18 genotypes were determined as the most stable waxy Corn genotypes. Many researchers indicated that the comparison biplot model helps determine the ideal genotype based on the mean yield and quality values [27,49,56]. Placement of the varieties in different sectors indicated that these genotypes were genetically different in terms of yield. The ADAX-9R, ADAX17, ADAX11R and ADAX15 cultivar candidates were genetically similar to each other. Similar results have been obtained in the biplot studies conducted by [50,51]. Highly stable and efficient waxy genotypes (ADAX11 and ADAX18) identified by the GGE biplot analysis have the potential to be used in countries where the ecological conditions are similar.

Conclusion

Waxy Corn is an important Corn subspecies used in many areas of the starch industry and the consumption of fresh ear has recently increased due to the rich nutrient content. This study was carried out in 2018 and 2019 to determine the grain yield, yield components and chemical contents (protein, oil, starch, multiple element contents) of waxy Corn genotypes and to determine the stable genotypes in terms of all traits using the Biplot (GGE and AMMI model) analysis. The mean grain yield of the genotypes ranged from 8560.6 to 17290.6 kg -1ha, the number of days to flowering from 71.3 to 77.5 days, plant height from 251.7 to 295.0 cm, the first ear height from 85.3 to 98.3 cm, crude protein ratio from 9.4 to 10.4%, crude oil ratio from 3.3% to 5.0% , total starch content from 57.5% to 60.0, 1000 grain weight from 317.7 to 402.2 g, hectoliter from 76.9% to 79.3, carbohydrate content from 69.6 to 71.6%, energy content from 383.8 to 393.7 kcal, grain/ear ratio from 81.3 to 85.5%, grain moisture content from 20.5 to 25.0, single ear weight from 145 to 286.3 g, and the number of ears per plant from 0.9 to 1.0 ear. Significant positive correlations were determined between the grain yield, 1000 grain weight and single ear weight of the genotypes. The results revealed that the chemical composition of wax Corn genotypes are within the acceptable limits and their energy values are low. The grain yields of Corn genotypes were 10 to 30% lower than the yields of dent corn varieties. Nevertheless, the enrichment of waxy corn gene pool with new half-way materials will increase the yield. In addition, investigating the fresh ear characteristics, macro and micro nutrient contents, vitamin values and amino acid contents is of great importance. The biplot (AMMI and GGE) analyzes evaluating the grain yield, yield components and chemical composition of waxy Corn together, revealed that ADAX11 and ADAX18 genotypes have the high stability.

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