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RESEARCH PAPER

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EVALUATION OF DIVERSITY IN QUANTITATIVE AND QUALITATIVE CHARACTERISTICS OF DIFFERENT WHITE EGGPLANT GENOTYPES UNDER CLIMATIC CONDITIONS OF KARAJ, IRAN

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ABSTRACT

The eggplant (*Solanum melongena* L.) is one of the most consumed and healthiest vegetables in the world. This plant is important both nutritionally and medicinally. This research, based on a randomized complete block design, investigated the quantitative and qualitative traits of nine inbred lines (11111, 11121, 11122, 13411, 13421, 13511, 13521, 24111, and 51311) and one commercial cultivar of white eggplant (Aretussa) in two growing seasons (2021–2022, and 2022–2023) in the climatic conditions of Karaj, Iran. The analysis of variance showed that the interaction of year and genotypes was significant for all studied traits, as plant height, leaf length and width, fruit yield, and content of minerals (P, Ca, K, Fe, Zn, Mg), protein, vitamin C, dry matter, crude fat, crude fiber, and total carbohydrates in the fruit. The comparison of means revealed that genotype 13511 had the tallest plants. Aretussa was the best genotype in terms of yield, vitamin C, crude fiber, and protein, and genotypes 51311 and 11121 were the best in P and K. The variation range of the genotype was not wide in qualitative traits, but as a summary of the two years, the three genotypes of 13421, 51311, and Aretussa can be recommended as the best genotypes in terms of fruit yield per ha, while there were close to one another in fruit quality.

Keywords: crude fiber, mineral elements, protein, *Solanum melongena* L., vitamin C

INTRODUCTION

Vegetables have a special place in the human food regime due to their nutritional value and antioxidants. Eggplant (*Solanum melongena* L.) from the Solanaceae family is native to Southeast Asia and has spread in hot and semi-hot regions [Arivalagan et al. 2013, Bidaramali et al. 2020]. According to FAO's statistics, in the years 2020–2021 the leading eggplant-producing countries were China, India, Egypt, Turkey, Indonesia, and Iran [FAOSTAT 2024].

Eggplant is important nutritionally and medicinally. Its fruits contain phenolic compounds, antioxidants, good quantities of fiber, minerals (mainly Ca, K, P, Fe, Zn, Mg, and Na), vitamins (particularly A, B, C, D, E, and K), proteins, carbohydrates, and small quantities of calories and fats [Turhan and Kuscu 2019, Bidaramali et al. 2020, Yarmohammadi et al. 2021]. It is among the top ten vegetables as a nutritional and antioxidant source and is a healthy food abundant globally, especially in Asian and developing countries. It is also a substitution for meat in vegetarians' food regimes [Bidaramali et al. 2020, Kameli et al. 2020].

The willingness to consume eggplants is increasing due to their effectiveness in health preservation. Thus, various cultivars and genotypes of this plant have been

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produced that are highly diverse in shape (oval, spherical, spear-shaped, and elongated), size (small to big), color (green, white, purple, violet, black, pink, and so on), spine status (spiny and spineless), and fruit yield, as well as in nutritional value and biologically active compounds in addition to their morphological diversity [Arivalagan et al. 2012, Fallahi et al. 2023].

Bidaramali et al. [2020] explored the food value of 20 eggplant genotypes. They reported that the cultivars with white fruits were richer in crude fiber and those with violet fruits were richer in proteins. Sharma and Kaushik [2021] revealed that the local cultivars were richer in minerals (P, Ca, K, Fe, Zn, and Mg) than the commercial cultivars. A research study was conducted in 2014 to assess the food and mineral value of Chinese, Filipino, American, Indian, and Thai eggplant cultivars produced in Mexico. The results showed that the Thai cultivar was richer in proteins and fiber and the Indian cultivar was richer in minerals (P, Mg, Zn, Ca, and K) and vitamin C [Guillermo et al. 2014].

In addition to genotype, the environmental and cultivation conditions of vegetables, influence the concentrations and percentage of primary and secondary compounds and nutritional and organoleptic properties of their edible parts. Therefore, the investigation of the interaction of genetic and ecological conditions in different years can affect the food value and organoleptics of eggplants [San José et al. 2014]. In this regard, the present research investigated the morphological and biochemical variations of 10 different white eggplant genotypes during two growing sesons in the Karaj region, Iran.

MATERIALS AND METHODS

Experimental time and location

The research was conducted in the Seed and Plant Improvement Institute of Karaj (35°55' N, 50°45' E, and Alt. 1312.5 m from sea level) in 2021–2022 and 2022–2023. Karaj is a mountain city with hot and dry weather in summer and cold and dry in winter.

Plant material

The plant materials used in this research were 10 white eggplant genotypes, including nine inbred lines (11111, 11121, 11122, 24111, 13411, 13421, 13511, 13521, 51311), and a commercial cultivar Aretussa. Table 1 presents the features of these genotypes.

Experiment description

To grow the seedlings, the seeds of the target genotypes were cultivated in greenhouse conditions

Table 1. The characteristics of the genotypes explored in the present work

Genotype	Spiny/ spineless	Growth type	Fruit shape	Seed content	Purple color intensity	Edge form	Calyx
Aretussa	spineless	semi-erect	cosh-shaped	very low	moderate to dark	moderately toothed	moderate to small
11111	spineless	semi-erect	pear-shaped	low	moderate to light	moderately toothed	moderate
11121	spineless	erect	spherical	moderate	moderate	moderately toothed	moderate
11122	spineless	semi-erect	spherical	high	moderate	moderately toothed	moderate
13411	spineless	erect	spherical	low	moderate	moderately toothed	moderate
13421	slightly spiny	prostrate	pear-shaped	moderate	moderate	moderately toothed	moderate
13511	spineless	semi-erect	elongated elliptical	moderate	light	moderately toothed	moderate
13521	spineless	semi-erect	ovoid	moderate	moderate to light	lowly toothed	moderate
24111	spineless	prostrate	spherical	moderate	light	moderately toothed	small
51311	spineless	semi-erect	ovoid	moderate	moderate	moderately toothed	moderate

(17–24 °C, 65% relative humidity, and 16/8 hours of day/night photoperiod). In May, when the seedlings were at the 4-leaf stage with an approximate height of 10 cm, they were transplanted in the main farm, which soil characteristics are given in Table 2. The seedlings were transplanted on the basis of a randomized complete block design with three replications. The experimental blocks were 3 × 5 m plowed and fertilized parcels. The rows were spaced by 75 cm, and the plants in the rows were spaced by 70 cm. After transplanting, they were irrigated (by a drip system during the experiment) every other day, and fertilized at two stages: 50 kg ha^{-1} N at flower initiation and 3 kg h^{-1} full fertilizer (WOPROFERT NPK 20-20-20 + TE, Syngenta Co., Swithzerland) at fruit formation as foliar application. The farm was weeded by hand five times during the growth period. The quantitative and qualitative traits were measured with the initiation of fruit formation.

Assessment of traits

Quantitative traits. Plant height, leaf length and width were measured with a ruler, and fruit yield was determined with a 0.001-g high-precision digital scale.

Qualitative traits

Minerals. To measure minerals, 10 g of the fresh fruit tissue was first converted into ash at 550 °C. It was then extracted by concentrated nitric acid. Then, the P content was measured by spectrophotometry (Metash spectrophotometr, UV-6100, China), and the Ca, K, Fe, Zn, and Mg contents were determined by an atomic absorption device (Varian Spectra AA220FS, Gemini BV) [Guillermo et al. 2014].

Fruit protein. The fruit protein content was determined by the Kjeldahl method. First, the N content of the samples was estimated. Then, it was put in the following equation to yield fruit protein content in percent (AOAC International, 2016):

$$\text{Protein (\%)} = \text{N} \times 6.25$$

Vitamin C. The vitamin C content was determined in mg100 g^{-1} fresh weight (FW) by the titration with 2,6-dichlorophenolindophenol using the following equation [Mazumdar and Majumdar 2003]:

$$\text{Vitamin C} = \frac{e \times d \times b}{c \times a} \times 100$$

Where: *a* represents the sample weight, *b* represents the volume of the metaphosphoric used for extraction, *c* represents the volume of the solution taken for titration, *e* represents the volume of the dye solution consumed for each sample, and *d* represents the dye factor that was obtained by the following equation:

$$d = \frac{0.5}{\text{The amount of dye solution used for the titration of the standard sample}}$$

Table 2. Physico-chemical properties of the soil in the experimental site

Parameter	Value	Unit
Electrical conductivity	4.31	dS m^{-1}
Saturated paste acidity (pH)	7.7	–
Organic carbon	0.58	%
Absorbable potassium	274	mg kg^{-1}
Moisture percentage (w/w) at 0.33 atmospheres	19.93	%
Moisture percentage (w/w) at 15 atmospheres	9.30	%
Apparent density	1.66	g cm^{-1}
Clay content	26	%
Silt content	42	%
Sand content	32	%
Texture	loamy	–

Crude fiber. A 100-g sample of the fruit was extracted with chemicals, including sulfuric acid 0.3 N and sodium hydroxide 1.5 N, on a heater. The resulting sample was washed twice with hot water, sulfuric acid, and ethanol alcohol 70%, dried at 105 °C for 6 hours, and weighed (*a*). Then, it was converted to ash at 550 °C, and its weight was recorded (*b*). Finally, the crude fiber percentage was calculated by the following equation [Aryapak and Ziarati 2014]:

$$\text{Crude fiber (\%)} = \frac{a}{b} \times 100$$

Crude fat. Crude fat content was determined using the Soxhlet extraction method. Briefly, 10 g of eggplant fruit powder was placed in a cellulose thimble and extracted with 200 mL of n-hexane for 1 hour using a Soxhlet apparatus. The solvent flask was heated to 55–60°C with an electric heater, allowing the n-hexane to evaporate, condense, and continuously reflux over the sample. The extracted fat was collected in the solvent flask, and after completion, the n-hexane was evaporated under controlled conditions. The remaining fat was dried to a constant weight, and the crude fat content was calculated as a percentage of the initial sample weight.

Total carbohydrates. It was determined by the phenol sulfuric acid method. After the extract was prepared, the absorbance was read at 490 nm with a spectrophotometer (Metash spectrophotometr, UV-6100, China), and the total carbohydrate content was determined in percentage using the glucose standard curve [Nadeeshani et al. 2021].

Experimental design and data analysis. The research was conducted using a randomized complete block design with three replications in two consecutive years. After the traits were measured at the farm and in the laboratory, the data were subjected to the analysis of variance and the comparison of means by the SAS software package. Duncan's multiple range test compared the means.

RESULTS

Morphological traits

The results in Tables 3 and 4 show that leaf length and width, and fruit yield were significantly ($P < 0.01$) higher in the first year than in the second year. The simple effect of the genotype was not significant on fruit yield and average fruit number per plant, but the genotypes differed in plant height, leaf length and width, yield per plant, and fruit weight significantly. The interaction of year and genotype was also significant for yield and the recorded morphological traits (Table 3). The significant effect of the year and genotype on the recorded traits implies the high diversity in the germplasms of the studied eggplants, so the genotypes responded even to year variations.

The plants were taller in the second year than in the first year of the study. Genotypes 13511 and 51311 had the highest 63.70 cm and the lowest 47.66 cm plant heights, respectively. The comparison of means

Table 3. Combined ANOVA of plant height, leaf length and width, fruit yield, fruits number, and average fruit weight of analysed white eggplant genotypes

Source of variance	df	Plant height	Leaf length	Leaf width	Fruit yield	Plant yield	Fruits no/plant	Fruit weight
Year	1	2143**	161**	135**	3393**	17685510**	3.901ns	126.1ns
Replication × year	4	21.4	6.41	5.54	147.9**	1030087**	52.12	874.1**
Genotype	9	219**	12.58*	8.64*	71.2ns	456078*	42.78ns	715.4**
Year × genotype	9	355**	23.4**	9.33*	147.8**	602869**	45.5*	293.1*
Error	36	42.4	2.93	2.11	43.4	203211	24.0	108
CV	–	10.91	11.23	14.2	20.3	19.2	18.43	9.3

*, ** – significant at $P < 0.05$, $P < 0.01$, respectively; ns – insignificant based on Duncan's test

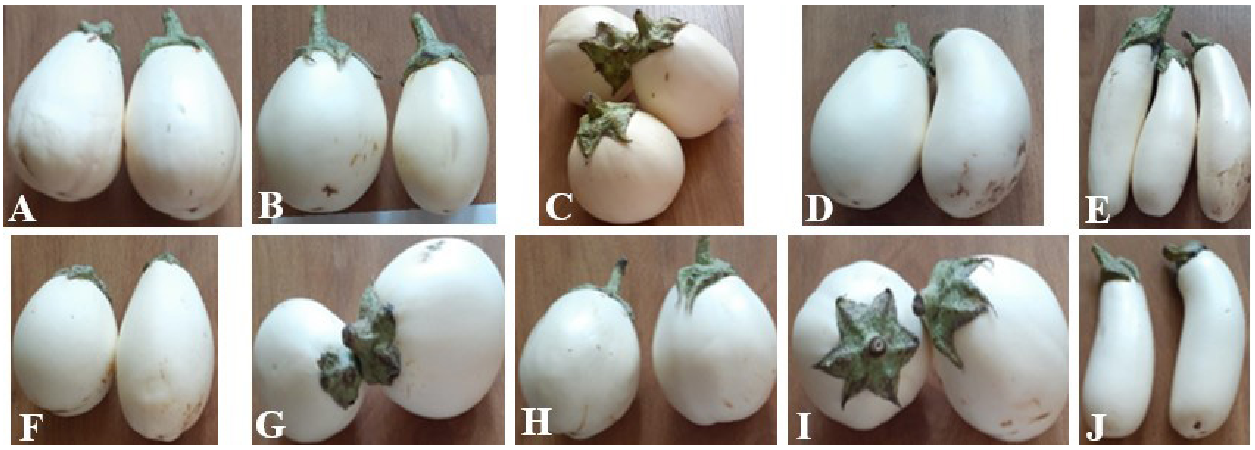

Fig. 1. Morphological characteristics of the genotypes analyzed in the present study. A: 13421, B: 13521, C: 11121, D: 11111, E: 13511, F: 24111, G: 13411, H: 51311, I: 11122, and J: Aretussa

for the interaction of year × genotype revealed that the plant height of the genotypes was in the range 45.9–63.8 cm in the first year and 56.33–79.22 cm in the second year. In both years, the lowest and the highest plant heights were recorded for genotypes 13411 and 24111, respectively (Table 4).

The leaf length of the studied genotypes was higher in the first year than in the second year. The longest leaves 16.66 cm were produced by genotype 13521, but it did not differ from the other genotypes significantly, except for genotype 24111 whose leaves were indeed the shortest 13.65 cm. The mean leaf length of the 10 studied genotypes was higher in the first year than in the second year. In both years, the lowest leaf length was recorded by genotype 24111. Genotypes 13521 and 13421 had the highest leaf length in the first and second year, respectively. They did not differ from the other genotypes significantly except for genotype 24111 (Table 4).

Leaf width was significantly smaller in the second year. Genotypes 13511 and 11121 had the highest (11.40 cm) and lowest (8.28 cm) leaf width, respectively. The comparison of means showed that leaf width was in the range 9.66–14.0 cm in the first year and 7.15–9.28 cm in the second year, showing a decline in this trait in the second year. Genotype 13521 had the highest leaf width in the first year, but four genotypes (13521, 13511, 51311, and Aretussa) were significantly different than genotype 11121 (with the lowest leaf width). In the second year, the highest leaf width was observed in genotypes 13421 and 13511. This year, genotype 13521 exhibited the lowest leaf width (Table 4).

Fruit yield and mean yield per plant were significantly higher in the first year than in the second year. The best three genotypes in fruit yield were 13421 (53.76 t ha^{-1}), 51311 (51.22 t ha^{-1}), and Aretussa (48.77 t ha^{-1}), respectively. The worst genotype was 11122 (33.51 t ha^{-1}) whose yield was (15 t ha^{-1}) lower than that of Aretussa in the same conditions. In terms of mean yield per plant, the highest was related to genotypes Aretussa, 13421, and 51311, and the lowest was 11111. The largest number of fruits per plant was recorded by 13411, and then by 13511, whereas genotypes 51311 and Aretussa produced the heaviest fruits. The results for the interaction of year × genotype revealed that the yield of all genotypes, except for 11122, declined in the second year versus the first year. The range of yield variations in the first and second years was 28.2–53.4 and 15.7–31.13, showing the loss of yield of the studied genotypes in two consecutive years in the same region, which is not optimal. Genotype 13421 had the highest yield in the first year, not differing significantly from genotypes Aretussa, 51311, and 24111. The lowest yield in the second year was recorded by genotype 13421, which was the most successful in yield in the first year. The highest yield in the second year was recorded by Aretussa and then by genotypes 11122 and 13411, but it was no significantly different from genotypes 51311, 13511, 11121,

Table 4. The comparison of means for the effect of year and genotypes on the quantitative traits

Year and genotypes	Plant height (cm)	Leaf length (cm)	Leaf width (cm)	Fruit yield (t ha^{-1})	Plant yield (g)	Fruits no/ plant	Fruit weight (g)
Year							
First	54.5b	17.48a	12.52a	39.8a	2889a	26.36a	110.5a
Second	66.3a	12.86b	8.34b	24.8b	1803b	25.97a	113.4a
Genotype							
Aretussa	60.00ab	14.52ab	9.29bc	48.77ab	2608a	113.0bcd	30.38ab
11111	53.19cde	14.82ab	9.15bc	37.15bc	1835c	107.5cd	24.21c
11121	55.44bcd	14.86ab	8.28c	39.65abc	1959bc	115.0ad	25.38bc
11122	50.55de	14.49ab	9.97abc	33.51c	1999abc	90.1e	26.4abc
13411	48.54e	15.55ab	9.42abc	45.08abc	2397abc	126.16a	26.16bc
13421	56.20bcd	15.90ab	9.66abc	53.76a	2493ab	117.167abc	24.66bc
13511	63.70a	16.59a	11.40a	44.95abc	2203abc	124.8ab	24.55bc
13521	59.80ab	16.66a	11.00ab	41.09abc	2031abc	103.6d	25.71bc
24111	57.29bc	13.65b	9.75abc	45.14abc	2198abc	118.1abc	26.26bc
51311	47.66e	16.40a	10.23abc	51.22ab	2375ab	103.8d	32.4a
First year × genotype							
Aretussa	55.60bc	19.00ab	13.33a	44.63ab	3441ab	32.27ab	106.7b–d
11111	50.10cd	17.30ab	13.0ab	37.13bc	2648c–f	25.13a–f	105.7b–d
11121	56.20abc	16.00ab	9.66b	33.83bc	2392d–g	21.53ef	110.7b–d
11122	56.96ab	18.00ab	12.60ab	28.20c	2396d–g	28.00a–e	85.7e
13411	45.90d	16.30ab	12.30ab	39.06bc	2996a–d	22.77d–f	132.7a
13421	49.90cd	17.60ab	12.30ab	53.40a	3605a	30.13a–d	119.3ab
13511	55.50bc	18.00ab	13.66a	39.46bc	2749b–e	23.07d–f	119.3ab
13521	56.60abc	19.66a	14.00a	37.06bc	2595c–f	24.47b–f	106.7b–d
24111	62.86a	15.66b	11.0ab	41.30abc	2877a–e	24.33b–f	118.3a–c
51311	54.50bc	17.30ab	13.30a	44.70ab	3194a–c	31.90a–c	100.0c–e
Second year × genotype							
Aretussa	73.33ab	13.61ab	8.6abc	31.13a	2309d–h	28.50a–e	119.3ab
11111	71.60abc	13.11ab	7.89bc	19.8bc	1414ij	26.30a–f	101.7c–e
11121	74.11ab	13.22ab	7.67bc	25.06ab	1774g–j	29.23a–e	119.3ab
11122	60.90bc	12.0ab	8.44abc	29.50a	2367d–g	24.80b–f	94.7de
13411	56.33c	12.27ab	7.9bc	29.33a	2150e–i	29.57a–d	119.7ab
13421	60.40bc	13.94a	9.28a	15.70c	1075j	19.20f	115.0a–c
13511	74.10ab	13.33ab	9.22a	27.30ab	1911f–i	26.03a–f	130.3a
13521	72.78abc	12.17ab	7.15c	19.70bc	1423ij	23.97c–f	108.3b–d
24111	79.22a	11.55b	8.01bc	23.10abc	1624hij	28.20a–e	118.0a–c
51311	71.60abc	13.44ab	8.71ab	27.80ab	1989f–i	32.90a	107.7b–d

In each column, means with similar letter(s) are not significantly different ($P < 0.05$) using the Duncan's test.

and 24111 (Table 4). Also, the mean yield per plant varied from 3605 g for genotype 13421 to 2392 g for genotype 11121 in the first year, and from 2367 g for genotype 11122 to 1075 g for genotype 13421 in the second year. The highest fruit weight in the first year was observed in Aretussa 32.27 g, which was not significantly different from genotypes 13421, 51311, and 11111. The highest and the lowest fruit number in the second year was observed in genotypes 51311 (32.90 fruits) and 13421 (19.20 fruits), respectively. The fruit weight of the genotypes in the first year varied from 32.7 g (genotype 13411) to 85.7 g (genotype 11122). The highest and lowest fruit weights in the second year were recorded by genotypes 13511 (130.3 g) and 11222 (94.7 g) (Table 4).

Among the studied genotypes of the eggplant, genotype 11122 had the lowest range of yield variations. Although this genotype was one of those with the lowest yield, it preserved its yield in the second year, making its way into the list of suitable genotypes.

Qualitative traits

The analysis of variance for the qualitative traits (dry matter, carbohydrate, protein, crude fiber, crude fat, and vitamin C) showed that the simple effect of year was significant ($P < 0.01$) only on total carbohydrates and vitamin C, whereas the simple effect of genotype was significant on all qualitative traits, except for vitamin C. The interaction of year × genotype was significant for dry matter, crude fiber, and vitamin C at the $P < 0.05$ level and for carbohydrates, proteins, and crude fat at the $P < 0.01$ level (Table 5).

The mean comparison showed that total carbohydrates and vitamin C were higher in the first year than in the second year of the study (Table 6). Among the genotypes, the highest dry matter was observed in 13521 and Aretussa, which were among the best in terms of crude fiber. Aretussa had the lowest and genotype 13411 had the highest fruit carbohydrates. The highest (0.181%) and lowest (0.133%) protein content was related to the genotype Aretussa and 13411, respectively. The highest crude fat content was noted in genotypes 11121 and 13521, and the lowest in genotype 13421 (Table 6).

It was revealed by the comparison of means for the interaction of year × genotype that genotypes 11111 and Aretussa were superior in dry matter content in both years. The lowest dry matter content in the first year (5.93%) was recorded by genotypes 13411 and 51311, whereas the lowest in the second year (6.30%) was observed in genotype 51311 (Table 6).

The total carbohydrate content varied from 1.94% for genotype Aretussa to 3.12% for genotype 13411 in the first year. However, in the first year, no genotype, except for Aretussa, significantly differed from genotype 13411, whose total carbohydrate content was the highest. In the second year, the lowest total carbohydrate content was recorded by Aretussa (2.17%), and the highest was obtained from genotype 13521 (3.43%) (Table 6).

The protein content in the studied genotypes was in the range 0.130–0.183% and 0.137–0.180% in the first and second year, respectively. In the first year, Aretussa and 13521 had the first and second-highest protein content among the studied genotypes, but they did not differ significantly from genotypes 11121, 11122, 24111, 13421, 13511, and 51311. In the second year, although the highest protein content was recorded for

Table 5. Analysis of variance for the effect of year and genotype on the qualitative traits

Source of variance	df	Dry matter	Carbohydrate	Protein	Crude fiber	Crude fat	Vitamin C
Year	1	1.16ns	1.5843**	0.594ns	0.064ns	0.035ns	60.88**
Replication × year	4	0.904	0.1286	0.102	0.5109	0.0223	5.52
Genotype	9	9.66**	1.585**	34.37**	5.682**	1.379**	6.21ns
Year × genotype	9	0.369*	0.508**	1.107**	1.631*	0.679**	21.67*
Error	36	0.632	0.168	0.284	0.568	0.0138	7.94
CV (%)	–	10.05	15.76	3.13	11.55	4.7	16.9

*, ** and ns – significant at $P < 0.05$, $P < 0.01$, and insignificant based on Duncan's test, respectively

Table 6. The comparison of means for the effect of year and genotypes on the content of dry matter, carbohydrates, protein, crude fiber, crude fat, and vitamin C

Year and genotypes	Dry matter (%)	Carbohydrate (%)	Protein (%)	Crude fiber (%)	Crude fat (%)	Vitamin C (mg 100 g^{-1} FW)
Year						
First	7.77a	3.07a	0.163a	6.68a	0.259a	1.553a
Second	8.04a	2.22b	0.161a	6.53a	0.242a	1.118b
Genotype						
Aretussa	9.60a	2.06b	0.181a	8.40a	0.228bcd	1.661a
11111	8.23b	2.93a	0.171abc	6.34bc	0.190cd	1.261a
11121	8.16b	2.61ab	0.153cd	7.09b	0.303a	1.190a
11122	8.22b	2.99a	0.176ab	7.26b	0.296ab	1.116a
13411	6.66cd	2.97a	0.133d	4.71d	0.213cd	1.488a
13421	7.51bc	2.50ab	0.168abc	5.65cd	0.185d	1.566a
13511	6.40d	2.55ab	0.155bcd	4.91d	0.288ab	1.355a
13521	9.91a	2.53ab	0.151cd	8.38a	0.303a	1.348a
24111	8.26b	2.72ab	0.165abc	7.16b	0.255abc	1.180a
51311	6.11d	2.58ab	0.165abc	6.20bc	0.243a–d	1.186a
First year × genotype						
Aretussa	9.60abc	1.94c	0.183a	5.30e–g	0.233bcd	1.696abc
11111	10.11a	2.45abc	0.147bcd	8.32a	0.310abc	1.596a–e
11121	8.24d	2.78abc	0.153a–d	6.87bcd	0.303abc	1.316c–i
11122	8.10d	2.95abc	0.173ab	7.26abc	0.326ab	1.43c–g
13411	5.93g	3.12ab	0.130d	4.93g	0.263abc	1.946a
13421	7.30def	2.81abc	0.173ab	6.45b–e	0.153d	1.866ab
13511	6.35fg	2.93abc	0.157a–d	5.02g	0.270abc	1.490b–f
13521	8.01d	2.44abc	0.180a	7.50ab	0.160d	1.440c–g
24111	8.10d	2.74abc	0.167abc	7.28ab	0.243a–d	1.336c–i
51311	5.93g	2.55abc	0.170ab	6.02c–g	0.330a	1.410c–h
Second year × genotype						
Aretussa	9.61abc	2.17bc	0.180a	5.41e–g	0.223cd	1.626a–d
11111	9.71ab	2.61abc	0.157a–d	8.36a	0.296abc	1.100f–j
11121	8.08d	2.45abc	0.153a–d	6.36b–f	0.303abc	1.063g–j
11122	8.34cd	3.02abc	0.180a	6.95bcd	0.266abc	0.803j
13411	7.39def	2.82abc	0.137cd	6.84bc	0.163d	1.030h–j
13421	7.71de	2.18bc	0.163abc	6.33b–f	0.216cd	1.266d–i
13511	6.45e–g	2.18bc	0.153a–d	5.87d–g	0.306abc	1.220e–i
13521	8.45bcd	3.43a	0.163abc	7.04bcd	0.220cd	1.083g–j
24111	8.42cd	2.70abc	0.163abc	7.24abc	0.266abc	1.023h–j
51311	6.30fg	2.61abc	0.160a–d	5.20g	0.156d	0.960ij

In each column, means with similar letter(s) are not significantly different ($P < 0.05$) using Duncan's test.

genotypes Aretussa and 11122 (both 0.180%), they were no significantly different from the other genotypes except for 13411, which had the lowest total protein content in both years (Table 6).

The crude fat content in various eggplant genotypes was in the range 0.153–0.330% in the first, and 0.156–0.306% in the second year, respectively. The three genotypes 13421, 13521, and Aretussa had lower crude fat content than the other genotypes. The highest crude fat content in the first year was related to genotype 51311, while it had the lowest crude fat content (0.156%) in the second year. The crude fat content of genotypes 13411 and 51311 was lower in the second year than in the first year, but that of genotypes 13521 and 13421 was higher in the second year than in the first year.

The comparison of means revealed that the amount of crude fiber in the studied genotypes was 4.93–8.32% in the first year and 5.20–8.36% in the second year. The highest crude fiber content was observed in genotypes 11111 and 13521 in the first year. Genotypes 13411 and 13511 were the weakest in this trait in the first year. In the second year, crude fiber was the lowest in genotype 51311, while genotypes 11111 and 24111 were the best in this trait (Table 6).

The vitamin C content was higher in all genotypes in the first year than in the second year. It was in the ranges of 1.316–1.946 and 0.803–1.626 mg 100 g^{-1} FW in the studied genotypes in the first and second year, respectively. The highest vitamin C content was recorded by genotype 13411 in the first year, but it did not differ from genotypes Aretussa, 11111, and 13421, significantly. The lowest in the first year was recorded by genotypes 11121 and 24111. In the second year, the highest was related to Aretussa, and the lowest to genotypes 11122 and 51311 (Table 6).

Minerals

Table 7 presents the analysis of variance for the simple and interactive effects of year and genotype on the minerals of eggplant fruits.

Table 8 shows that the Ca and Fe contents of the fruits were higher in the first year than in the second year, but the K, P, Zn, and Mg contents were higher in the second year. Among the genotypes, 11121 had the highest amounts of K and P. Genotypes 11122 and 51311 had the highest Ca content, and genotypes 13421 and 11111 had the highest Zn content. Genotype 13511 was the richest in Mg, whereas genotypes 13511, 11121, 24111, and 13521 were the richest in Fe (Table 8).

The comparison of means for the interaction of year and genotype revealed significant differences among genotypes in Ca content (1.26–2.807 mg kg^{-1}), K content (0.22–0.292 mg kg^{-1}), P content (26.76–37.16 mg kg^{-1}), Zn content (0.133–0.286 mg kg^{-1}), Fe content (0.704–1.57 mg kg^{-1}), and Mg content (14.47–17.70 mg kg^{-1}). In the first year, genotype 11121 had the highest amounts of Ca, K, and P, and genotypes 13421, 13511, 11121 had the highest amounts of Zn, Fe, and Mg (Table 8). In the second year, the studied genotypes exhibited various ranges of Ca (1.130–2.40 mg kg^{-1}), K (0.235–0.298 mg kg^{-1}), P (21.1–40.46 mg kg^{-1}), Zn (0.200–0.290 mg kg^{-1}), Fe (0.496–1.257 mg kg^{-1}), and Mg (14.93–24.73 mg kg^{-1}). Genotypes 11122, 13521, 11111, and 13511 outperformed the other genotypes in Ca, Zn, Fe, and Mg. Genotype 11121 was the best in K and P content in the second year (Table 8).

Table 7. Analysis of variance for the effect of year and genotype on the mineral content in eggplant fruit

Source of variance	Df	Ca	K	P	Fe	Zn	Mg
Year	1	0.0133**	3.71**	0.0112*	13172**	400.4**	0.00925**
Replication × Year	4	0.00019	0.0051	0.002	26.352	2.328	0.00033
Genotype	9	0.0119**	0.731**	0.0378**	4590**	64.28**	0.000086^ns
Year × Genotype	9	0.0073**	0.0918**	0.0181**	116**	6.72**	0.00045*
Error	36	0.0011	0.0132	0.00226	37.74	1.098	0.00016
CV (%)		15.6	9.013	14.16	5.36	5.3	8.6

*, ** and ns – significant at $P < 0.05$, $P < 0.01$, and insignificant based on Duncan's test, respectively

Table 8. The comparison of means for the effect of year and genotypes on the mineral content of the eggplant fruit

Year and genotypes	Ca (mg kg^{-1})	K (mg kg^{-1})	P (mg kg^{-1})	Zn (mg kg^{-1})	Fe (mg kg^{-1})	Mg (mg kg^{-1})
Year						
First	2.00a	0.223b	28.25b	0.203b	1.38a	16.32b
Second	1.76b	0.326a	37.62a	0.248a	1.01b	19.18a
Genotype						
Aretussa	1.345d	0.230d	32.26bc	0.206ab	0.673ab	16.21b
11111	1.195d	0.238cd	32.55abc	0.255a	0.828ab	16.58b
11121	2.248ab	0.295a	38.81a	0.216ab	1.483a	18.41ab
11122	2.518a	0.267ab	35.88ab	0.223ab	1.178ab	17.83ab
24111	1.926bc	0.266bc	30.30bc	0.208ab	1.426a	17.70ab
13411	1.528cd	0.285ab	31.81bc	0.183b	1.330ab	19.0ab
13421	2.180ab	0.268ab	33.43abc	0.265a	0.976ab	18.130ab
13511	1.876bc	0.264bc	32.90abc	0.238ab	1.486a	20.35a
13521	1.565cd	0.268ab	28.88c	0.226ab	1.381a	16.70b
51311	2.473a	0.283ab	32.55abc	0.233ab	1.228ab	16.60b
First year × genotype						
Aretussa	1.283fg	0.226f	32.70abc	0.210ab	0.704k	17.50c–e
11111	1.667e–g	0.269a–e	26.76c	0.220ab	1.44bc	14.47e
11121	2.807a	0.292ab	37.16ab	0.233ab	1.505ab	17.70b–e
11122	2.637ab	0.2733a–e	35.16abc	0.230ab	1.499c	17.03c–e
24111	2.420a–d	0.268a–f	29.60bc	0.196bc	1.53ab	15.73c–e
13411	1.670e–g	0.2813abc	31.50abc	0.133c	1.295d	15.90c–e
13421	1.993b–e	0.245c–f	33.03abc	0.286a	1.051gh	17.37c–e
13511	1.780d–f	0.251b–f	32.16abc	0.223ab	1.57a	15.97c–e
13521	1.260fg	0.232ef	32.10abc	0.220ab	0.918ij	15.33c–e
51311	2.553a–c	0.280a–c	32.30abc	0.210ab	1.397c	16.20c–e
Second year × genotype						
Aretussa	1.407e–g	0.235d–f	31.8abc	0.203b	0.496l	14.93de
11111	1.463e–g	0.267a–f	25.00d	0.233ab	1.257de	18.93b–d
11121	1.690e–g	0.298a	40.46a	0.200b	1.223f	19.13b–d
11122	2.400a–d	0.262a–f	36.60ab	0.216ab	1.187ef	18.63b–e
24111	1.433e–g	0.264a–f	31.00abc	0.220ab	1.151fg	19.67bc
13411	1.387e–g	0.289ab	21.10d	0.202b	1.012hi	22.10ab
13421	2.367a–d	0.292ab	33.84abc	0.243ab	0.837j	18.90b–d
13511	1.973c–e	0.276a–d	33.63abc	0.253ab	1.189ef	24.73a
13521	1.130g	0.2446c–f	33.0abc	0.290a	0.664k	17.83c–e
51311	2.393a–d	0.287ab	32.8abc	0.256ab	0.943i	17.00c–e

In each column, means with similar letter(s) are not significantly different ($P < 0.05$) using Duncan's test.

Correlation of trait

According to Table 9, the eggplant fruit yield as the most important economic trait had a positive and significant correlation with plant height, leaf length and width, dry matter, and total carbohydrates, whereas its correlation was significant but negative with the minerals, including Fe, K, and Mg, as well as proteins. Therefore, increasing the yield will entail a decline in minerals and protein in the studied genotypes. Significant and positive correlations were found between plant height and Zn and Mg content, between leaf length and Fe content, total fat, and proteins, and between leaf width and Fe content and vitamin C.

DISCUSSION

Fallahi et al. (2023) recorded the plant height of 13 genotypes of white, purple, and green eggplant between 33.41 and 94 cm. In our experiment, among the white eggplant genotypes, the highest plant height (63.70 cm) was recorded for genotype 13511, and the genotype 51311 had the shortest height (47.66 cm). Khaleghi et al. (2019) measured the plant height of 13 local eggplant cultivars between 48 to 71.2 cm. Since plant height is important for producers in terms of management and mechanized harvesting, shorter genotypes with desirable performance are the most suitable choice for commercial cultivation.

Table 9. The correlation of the recorded traits of the different white eggplant genotypes

Measured traits	Crude fibre	Zn	Fe	P	K	Mg	Ca	Vitamin C	Fat	Protein	Carbo-hydrate	Dry matter	Plant height	Leaf length	Leaf width	Yield
Crude fibre	1.000	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Zn	0.215	1.000	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Fe	0.242*	–0.253*	1.000	–	–	–	–	–	–	–	–	–	–	–	–	–
P	–0.312*	0.131	0.024	1.000	–	–	–	–	–	–	–	–	–	–	–	–
K	0.035	–0.180	0.458**	0.078	1.000	–	–	–	–	–	–	–	–	–	–	–
Mg	0.018	0.241*	–0.080	–0.048	0.361*	1.000	–	–	–	–	–	–	–	–	–	–
Ca	–0.051	0.071	0.538**	0.407**	0.540**	–0.043	1.000	–	–	–	–	–	–	–	–	–
Vitamin C	–0.315*	–0.268*	0.023	–0.041	–0.378**	–0.516**	–0.109	1.000	–	–	–	–	–	–	–	–
Fat	0.178	–0.254*	0.620**	0.249*	0.322*	0.046	0.317*	–0.029	1.000	–	–	–	–	–	–	–
Protein	0.032	0.321*	–0.362**	0.472**	–0.654**	–0.276*	0.073	0.011	–0.164	1.000	–	–	–	–	–	–
Carbohydrate	0.153	0.066	0.313*	–0.019	0.103	–0.112	0.085	–0.155	–0.004	–0.281*	1.000	–	–	–	–	–
Dry matter	0.572**	0.071	–0.265*	–0.166	–0.390**	–0.188	–0.325*	–0.036	0.096	0.321*	–0.271*	1.000	–	–	–	–
Plant height	0.076	0.291*	–0.337*	0.139	0.035	0.422**	–0.277**	–0.643**	0.043	0.138	–0.152	0.198	1.000	–	–	–
Leaf length	–0.109	–0.134	0.265*	0.078	–0.364*	–0.573**	0.108	0.738**	0.034	0.249*	–0.171	–0.066	–0.728**	1.000	–	–
Leaf width	–0.152	–0.281*	0.395**	–0.001	–0.323*	–0.557**	0.118	0.728**	0.077	0.194	–0.125	–0.179	–0.756**	0.956**	1.000	–
Yield	–0.09	0.024	–0.310*	–0.126	–0.314*	–0.270*	–0.197	0.184	–0.225*	0.376**	–0.006	0.923**	0.392**	0.310*	0.185	1.000

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

Cultivars and genotypes that can preserve their mean optimal yields in different climatic conditions and undergo less fluctuation are more valuable and stable, so various cultivars and landraces are evaluated in various locations and years [Hakim et al. 2021]. Weather variations and annual fluctuations of variables like precipitation, moisture, and temperature, and even the occurrence of environmental stresses influence plant yields remarkably. The cultivation of plants, especially new genotypes, in regions that are characterized by climatic and environmental variations can change their growth patterns and yields. Therefore, producers focus on developing cultivars and genotypes with optimal traits for new geographical regions with diverse weather conditions, hoping these genotypes can preserve their economic and yield advantages for many years [Owuor et al. 2011].

The eggplant is a vegetable with low carbohydrate content suitable for diabetics [Gurbuz et al. 2018]. The carbohydrate content has been reported at various levels in different eggplant cultivars. For example, it was recorded at 2.80–6.82% in 20 genotypes by Bidaramali et al. [2020] while at 4.27–6.63% in 10 genotypes by Quamruzzaman et al. [2020]. The highest level of carbohydrates in the present research was 3.43%, as recorded by genotype 13521 in the second year. In total, the present and past research results show that eggplant cultivars and genotypes differ in carbohydrates considerably.

Eggplant fruits contain little protein, and cultivars with purple fruits have higher protein content than those with green or white fruits [Bidaramali et al. 2020]. Sharma and Kaushik [2021] estimated the protein content of fresh eggplants at 0.98% and Rosa-Martínez et al. [2021] reported it in 10 eggplant varieties at 8.1–20.8 g kg^{-1} FW. Likewise, Guillermo et al. [2014] showed that the protein content of five eggplant cultivars was 0.65–0.9%, whereas Rodriquez-Jimenz et al. [2018] demonstrated it in a range of 12.55–12.77%. A protein content of 0.85–1.54% in 10 eggplant cultivars [Quamruzzaman et al. 2020] and 13.85–16.98% in 20 genotypes [Bidaramali et al. 2020] are other results, showing that the protein content of eggplant fruit depends on cultivar and genotype, as well as the environmental and growth conditions.

The eggplant is poor in fat [Agoreyo et al. 2012]. Previous researchers have recorded the fat content at 0.02–0.4% in 10 eggplant cultivars [Quamruzzaman et al. 2020] and 0.24–0.42% in four eggplant cultivars [Ossamulu et al. 2014]. The fat content of *Solanum melongena*, *S. torvum*, and *S. melongena* Insanum was estimated at 0.23%, 0.82%, and 0.7%, respectively [Nadeeshani et al. 2021], showing that our studied genotypes were analogous to *S. melongena* in fat content, but had lower fat than *S. torvum* and *S. melongena* Insanum. So, these genotypes are suitable for people suffering from diabetes and obesity [Nadeeshani et al. 2021].

The fiber content of eggplant fruits greatly contributes to better food digestion and the disposal of toxins and wastes. It also reduces the risk of colon and gastric cancers [Gurbuz et al. 2018]. Nadeeshani et al. (2021) reported the amount of crude fiber in *S. melongena*, *S. melongena* Insanum, and *S. torvum* were 4.85%, 3.91%, and 3.81%, respectively. Ossamulu et al. [2014] found that four eggplant species e.g. *Solanum macrocarpon* (round), *Solanum atheopicum*, *Solanum gilo*, and *S. macrocapon* (oval) had 2.21–3.07% of crude fiber. In another study, the crude fiber content of 10 eggplant cultivars varied from 1.01 to 2.48% [Quameuzzanan et al. 2020]. So, the genotypes we studied outperformed the cultivars reported in this literature regarding crude fiber.

The eggplant is a good source of antioxidants, including vitamin C. Research have reported various ranges for the vitamin C content of different eggplant genotypes. For example, Sharma and Kaushik [2021] reported it at 1.8–2.2 mg 100 g^{-1} FW, which is consistent with the vitamin C content of genotypes 13411 (1.94 mg 100 g^{-1} FW) and 13511 (1.86 mg 100 g^{-1} FW) in our study. In Nadeeshani et al.'s [2021] research, it was found to be lower than 20 mg 100 g^{-1} FW for the *S. melongena*, *S. melongena* Insanum, and *S. torvum*, among which the latter had the highest amount. Other researchers have reported values like 0.66–3.53 mg 100 g^{-1} FW [Bidaramali et al. 2020], 3.9–1.4 mg 100 g^{-1} FW [Shabetya et al. 2020], 6.57–17.21 mg 100 g^{-1} FW [Quamruzzaman et al. 2020], and 0.3–1 g kg^{-1} FW [Rosa-Martínez et al. 2020]. Thus, different eggplant species and cultivars can meet a part of the human body's daily need for vitamin C [Rosa-Martínez et al. 2020].

The eggplant is a good source of minerals (K, Fe, Ca, P, Zn, and Mg), which is more economical as a cheaper source of food than the other mineral-rich nutrients in addition to its availability throughout the year [Yarmohammdi et al. 2021]. Nadeeshani et al. [2021] reported the amount of Mg, K, Ca, Fe, and Zn in three eggplant species at 23.8–49.6, 427–632, 60.5–329, 1.07–1.85, and 0.34–1 mg kg^{-1}, respectively. This means that the genotypes studied in our research were almost similar to *S. melongena* Insanum in terms of Fe (1.07 mg kg^{-1}) and Zn (0.34 mg kg^{-1}). In terms of Mg, genotype 13411 (22.10 mg kg^{-1}) was similar to *S. melongena* (23.8 mg kg^{-1}) [Nadeeshani et al. 2021]. Since the recommended level of daily intake of Ca, K, P, Fe, Mg, and Zn is 1000 mg, 100 mg, 4000 mg, 18 mg, 400 mg, and 15 mg [Arivalagan et al. 2012], the daily consumption of 100 g of the studied white eggplant genotypes can only provide a small fraction of the body requirements.

A positive correlation between the studied traits is a helpful index to select a genotype with more desirable characteristics for the development of its cultivation and consumption [Kameli et al. 2020].

CONCLUSION

Based on the results, most genotypes exhibited higher yield, leaf length, and width but lower plant height in the second year. Aretussa was in the first rank in protein, crude fiber, and vitamin C and was one of the best in plant height, leaf length, plant yield, dry matter, Fe, and Zn. Genotype 11121 outperformed the other genotypes in P, K, and Fe content, and was one of the best in Ca, Zn, and Mg. Genotype 13421 produced the highest yield (53.4 t ha^{-1}) in the first year, but its yield sharply declined in the second year. Aretussa showed a decline in yield in the second year versus the first year, but its yield was the highest in the second year and it was among the best genotypes in terms of vitamin C in both years. Genotype 11121 was the best in P and K in both years and in Ca and Mg in the first year. The best crude fiber and dry matter genotype in both years was 11111. The studied genotypes differed in quantitative and qualitative traits, but their differences had no specific pattern. However, the summary of the results for the two years shows that the three genotypes of 13421, 51311, and Aretussa were the best in terms of the economical trait (fruit yield per ha) and performed acceptably in the qualitative traits, so this research recommends them as the best genotypes for mass production to meet the consumer needs.

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