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ORIGINAL PAPER

EVALUATION OF SUGAR BEET (*BETA VULGARIS*) MONOGERM HYBRIDS INFECTED WITH RHIZOMANIA BASED ON SOME MORPHOPHYSIOLOGICAL TRAITS AND NUTRIENT CONTENT*

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Abstract

In order to evaluate the resistance of 16 sugar beet hybrids to rhizomania, an experiment was carried out based RCBD with four replications. The Anova showed significant differences between the assessed hybrids for most traits except yellow color, infection severity and storage root yield (RY). The Pearson correlation coefficients between sodium with potassium and nitrogen elements and potassium with nitrogen were positively significant. The correlation between white sugar yield (WSY) with impurity related traits and alkalinity was negatively significant, and its correlation with sugar content (SC), molasses, white sugar content (WSC) and extraction coefficient of sugar (ECS) was positively significant. Cluster analysis by the Ward's method classified hybrids into two main groups. Hybrids 1, 2, 3, 4, 5, 6 and 7 were placed in the first cluster and the second cluster included the other hybrids. In the first group, the content of sodium, potassium and nitrogen, RY, molasses sugar, infection severity and yellow color were above the total mean. The percentage of these elements is directly related to the amount of infection, which the results of this research confirms. Cultivars with partial resistance to rhizomania were characterized not only by a higher RY and sugar content but also by a lower sodium and potassium content. In this research, for the WSY, the second cluster hybrids also had a higher value than the total mean. Due to the low level of infection incidence in this cluster, the general recommendation is to use the second cluster hybrids, which have less infection and high white sugar yield. This indicates that developing sugar beet hybrids that are resistant to disease is the most efficient measure of controlling the disease.

Keywords: amino-nitrogen, *Polymyxa betae,* potassium, *rhizomania,* sodium, WSY.

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INTRODUCTION

Sugar beet (*Beta vulgaris* L.) as an important crop with great economic value, is one of the two major crops supplying sugar (sucrose) worldwide (Biancardi et al. 2005, Koo, Taylor 2012). In Iran, the area under cultivation, production and yield of sugar beet is 108 thousand ha, 5.6 million tons and 51 t ha^{-1}, respectively (Anonymous 2020). The main challenges are the lack of sugar factory in the main areas of sugar beet cultivation in the country, and the irregular import of sugar and its bad effect on domestic production (Abdollahian et al. 2011). In the 2018-2019 crop year, global sugar production was approximately 166.18 million metric tons. Approximately 80% of the world's sugar is produced from sugar cane in tropical and subtropical climates. The remaining 20% comes from sugar beets, which are grown mostly in the temperate zones of the northern hemisphere (FAO, 2020). Crop rotation is necessary in beet production, due to disease problems (Koo, Taylor 2012), which may also be effectively eliminated by inducing resistance through different breeding approaches. For successful production of sugar beet, it is necessary to conduct prevention against infestation by insects and disease infection (Fischer 1989). Among the viruses infecting sugar beet, rhizomania is one of the most destructive viral diseases of sugar beet worldwide (Scholten et al. 1999). This disease is caused by beet necrotic yellow vein virus or BNYVV (*Benyvirus*), which is transmitted by the soil-borne fungus *Polymyxa betae* (Fujisawa, Sugimoto 1977). The disease reduces root yield by 45 to 50% or more and sugar content by 60 to 79% (Mac Grann et al. 2009).

First attempts to select for resistance were based on differences in the appearance of symptoms, such as yellowing or crinkling of leaves, veins and/ or severity of root rot at harvest time observed in sugar beet cultivars and breeding lines grown in fields with rhizomania infection (Fujisawa, Sugimoto 1977). The most effective way to control the disease is breeding and planting rhizomania resistant cultivars (Scholten et al. 1999). Improvement for resistance started with selection by scoring disease symptoms in field experiments. The breeding of sugar beet aims at the development of cultivars with high sugar yields and resistance to pests and diseases, especially to rhizomania, which is currently the most important disease in sugar beet worldwide (Fujisawa, Sugimoto 1977). Rhizomania is a limiting factor in improvement of sugar beet, which in itself does not contain genes of resistance to the pathogen. Investigation of Wisler et al. (1999) showed that triploid varieties carrying the *Rz1* gene become more likely infected with BNYVV than diploid varieties of sugar beet. Breeding for resistance to rhizomania, either by conventional or through biotechnology methods, is critical, both to allow the continued production of sugar beets on rhizomania infested fields and to prevent further spread of the disease (Brunt, Richards 1989, Putz et al. 1990). The development of genotypes with genetic resistance to rhizomania is one of the most significant successes in sugar beet breeding (Biancardi et al. 2005).

Based on the mentioned explanations, the aim of this study was to conduct the screening and selection of cultivars resistant to this destructive virus based on important quantitative and qualitative characteristics, and finally to introduce them to cultivation in regions with infected fields, such as most area of West Azerbaijan Province.

MATERIALS AND METHODS

This study was conducted at Miandoab Agricultural Research Station (36°58′N; 46°90′E), West Azerbaijan Province, Iran, in 2014. The 30-year average temperature and an annual rainfall in the location were 13.5°C and 243 mm, respectively, and the soil of the field was clay-loam. Miandoab station is located northwest of the city, at an altitude of 1314 m. This area has the Ferric temperature regime (the average annual temperature of the soil is 8-15°C) and Xeric moisture regime (semi-arid) with the soil of the field being silty loam. In this research, 16 sugar beet hybrids (Table 1) were evaluated in a randomized complete block design (RCBD) with six replications. Hybrids 1-10 are improved to Rhizomania, hybrids 11 and 14 are internally resistant to rhizomania, hybrids 13, 15 and 16 are externally resistant

Table 1

The name and pedigree of used sugar beet hybrids

No.	Pedigree
1	(7112 * SB36) * SB33 - HSF – 1
2	(7112 * SB36) * SB33 - HSF – 2
3	(7112 * SB36) * SB33 - HSF – 3
4	(7112 * SB36) * SB33 - HSF – 4
5	(7112 * SB36) * SB33 - HSF – 5
6	(7112 * SB36) * SB33 - HSF – 6
7	(7112 * SB36) * SB33 - HSF – 7
8	(7112 * SB36) * SB33 - HSF – 8
9	(7112 * SB36) * SB33 - HSF – 9
10	(7112 * SB36) * SB33 - HSF – 10
11	Pars
12	Sharif
13	7R26
14	SBSI 031
15	Boomerang
16	Novodoro

Hybrids 1-10 are improved to rhizomania, 11 and 14 are internally resistant to rhizomania, 13, 15 and 16 are externally resistant to rhizomania, 12 is sensitive to rhizomania.

to rhizomania, hybrid 12 is sensitive. Monogerm hybrids were planted in a naturally rhizomania infected research field, where the presence of the virus, BNYVV, was visible. The BNYVV concentration was estimated by using the most probable number method (MPN) based on Tuitert (1990). Seedbed preparation practices including plowing, disking and leveling were uniformly applied. Phosphorous and potassium fertilizers (200 kg ha^{-1} ammonium phosphate, 150 kg h^{-1} potassium sulfate) were applied at the time of seedbed preparation and fertilizer of nitrogen (250 kg ha^{-1} urea) was applied as topdressing. Each plot (14.4 m^2) consisted of three rows 8 m long and the between and within row spacing was 60 and 15 cm, respectively. Cultural practices such as irrigation and control of diseases and pests were applied if necessary.

During the growing season, traits such as yellow color (based on leaf yellowing and freshness, a score was given between 1 and 5; yellow plants were given score 1 and completely green plants were given score 5), infection incidence (number of infected plants/total plant number) and infection severity (Büttner et al. 2004) were measured. Harvest was carried out in early November. The roots harvested were washed, weighed and applied to take brie (pulp) samples. The brie samples were then immediately frozen and sent to the Sugar Beet Technology Lab of Sugar Beet Seed Institute, Karaj, Iran, for determination of root related traits such as storage root yield (RY, t ha^{-1}), sugar content (SC, g sugar kg^{-1} beet), sodium (Na, mmol kg^{-1} beet), and potassium (K, mmol kg^{-1} beet). Sugar content (SC) was measured by the polarimetry method, Na and K by flame photometry and α-amino nitrogen (N, mmol kg^{-1} beet) by the blue number method using copper reagent. Molasses sugar (MS, g sugar kg^{-1} beet) was estimated by using the formula of Buchholz et al. (1995). Sugar yield (SY, t ha^{-1}), white sugar yield (WSY, t ha^{-1}), white sugar content (WSC, % in beet), extraction coefficient of sugar (ECS, % in sugar) and alkalinity coefficient (Alk, mmol kg^{-1} beet) were calculated based on the following equations (Abdollahian et al. 2011):

$$SY = RY \times SC,$$

$$WSY = RY \times WSC,$$

$$ECS = (WSC / SC) \times 100,$$

$$Alk = (K + Na)/N,$$

$$WSC = SC - (\text{molasses sugar} + \text{sugar losses in molasses}).$$

The beet analysis data was used to predict a formula for sugar losses in molasses as follows (Aref et al. 2012):

$$\text{molasses sugar} = 0.343 \times (K + Na) + 0.094 \times (N) - 0.31,$$

$$\text{sugar losses in molasses} = 0.14W(K+Na) + 0.25W(N) + 0.45,$$

where: (K+ Na) – summation of potassium and sodium and N is α-amino nitrogen, W – amount of substance in mmol 100 g^{-1} beet.

The one-way ANOVA was performed and means compared by the LSD method. Correlations between traits computed and hierarchical clustering method were used for the classification of hybrids by the Ward's algorithm and Euclidian distance measure. Principal components analysis (PCA) was used for reduce variables and determine the most important traits in total variance explanation. In PCA, the traits were selected that had a high correlation with the main components. Data were analyzed by GenStat Ver.12 and NTSYS-pc software.

In this research, we evaluated 16 sugar beet monogerm hybrids infected with rhizomania. The purpose of the study was to identify the best hybrids based on agronomic traits, the amount of elements and sugar percentage for farming.

RESULTS AND DISCUSSION

ANOVA

The results of analysis of variance showed significant differences between the assessed hybrids for most traits except yellow color, infection severity and root yield traits (Table 2). Due to high difference in the monogerm hybrids, they can be used in rhizomania resistance breeding programs. Table 3 shows means of measured traits in sugar beet hybrids. Wolf (1995) reported that sugar beet varieties showed different yield and quality levels in different regions and that the interaction between a genotype and the

Table 2

Analysis of variance of studied traits in sugar beet monogerm hybrids

Trait	MS			CV (%)
	replication	genotype	error	
Sodium	0.194	30.76**	0.155	13.3
Potassium	0.023	6.79**	0.049	4
Nitrogen	0.038	4.24**	0.021	7.8
Alkalinity coefficient (Alk)	0.211	0.966**	0.099	6.6
Yellow color	0.771	1.03^{ns}	0.977	26.8
Infection incidence	5.40	13.69**	5.92	74.7
Infection severity	119.70	129.60^{ns}	123.90	45.8
Root yield	66.80	72.74*	40.01	26
Sugar content (SC)	0.660	68.78**	0.394	3.6
Molasses sugar	0.041	8.53**	0.032	6.4
White sugar content (WSC)	0.982	124.03**	0.552	5.4
Extraction coefficient of sugar (ECS)	5.70	833.89**	2.98	2.2
Sugar yield (SY)	18943	40235^{ns}	13426	27.8
White sugar yield (WSY)	12106	64272**	9696	29.6

* and ** significant at 0.05 and 0.01 probability level, respectively.

Table 3

Mean values of traits in sugar beet monogerm hybrids

G	Sodium (mmol kg^{-1} beet)	Potassium (mmol kg^{-1} beet)	Nitrogen (mmol kg^{-1} beet)	Alkalinity coefficient (Alk) (mmol kg^{-1} beet)	Yellow color	Infection incidence (%)	Infection severity	Root yield (t ha^{-1})	Sugar content (SC) (g kg^{-1})	Molasses sugar (g kg^{-1})	White sugar content (WSC) (t ha^{-1})	Extraction coefficient of sugar (% in sugar)
1	59.6	63.10	80.08	1.53	3.62	34.25	1.16	30.00	126.6	41.6	7.89	62.30
2	55.7	62.20	81.20	1.45	4.08	24.25	1.098	25.75	128.7	40.1	8.26	64.08
3	59.4	62.30	78.96	1.54	4.00	21.83	0.86	24.41	127.5	41.3	8.01	62.82
4	61.1	69.60	85.12	1.54	3.37	55.00	2.28	25.16	130.9	44.6	8.03	61.33
5	44.9	70.04	74.76	1.54	3.54	39.16	1.60	17.16	149.1	39.0	10.41	69.80
6	50.0	68.60	74.76	1.59	3.62	49.16	2.44	27.50	141.5	40.1	9.54	67.31
7	42.5	70.50	65.52	1.72	3.95	31.66	1.41	28.25	153.3	37.9	10.94	71.33
8	25.1	59.00	52.08	1.61	3.00	43.33	1.71	26.75	189.3	27.5	15.58	82.01
9	14.9	53.80	38.36	1.79	3.87	44.16	1.46	18.16	203.6	21.7	17.59	86.34
10	13.6	53.80	35.28	1.91	3.75	34.16	1.18	27.50	199.2	21.2	17.20	86.30
11	9.80	49.10	32.76	1.80	3.16	48.33	1.91	24.33	207.3	18.2	18.31	88.31
12	8.30	45.00	31.08	1.71	3.33	40.83	19.71	23.33	204.8	16.2	18.25	89.11
13	8.00	44.20	29.68	1.76	3.29	45.00	1.07	23.50	205.6	15.8	18.38	89.36
14	6.00	43.00	26.60	1.84	3.70	27.50	0.73	21.00	205.0	14.6	18.43	89.93
15	6.50	42.50	26.88	1.82	4.00	20.83	0.43	23.83	198.5	14.6	17.79	89.59
16	7.00	44.30	27.72	1.85	4.66	4.16	0.04	22.50	194.6	15.4	17.31	88.96
Total mean	29.50	56.30	52.55	1.69	3.6875	35.2292	2.44	24.32	172.8	28.1	13.87	78.05
LSD	4.50	2.50	4.48	0.36	1.13	30.2500	12.8	7.27	7.20	2.0	0.85	1.98

environment was not significant statistically. In a study on different sugar beet cultivars, Fotouhi et al. (2016) showed that the effect of cultivar on root yield, sugar yield, white sugar yield, yellow score and infection incidence was significant. Asher et al. (2002) found that the BNYVV virus in varieties carrying the resistance gene was one-third lower than that of susceptible controls. Indeed, virus resistant varieties yielded 20% lower than non-resistant ones in uninfected soils. Based on largescale field trials on rhizomania-free sites, Asher et al. (2002) showed that resistant lines have similar sugar yields and agronomic performance to those of high yielding susceptible cultivars. Disease responses at the physiology level include reduced transpiration and CO_2 uptake, a reduced content of nitrogen, chlorophyll and carotenoid and an elevated level of amino nitrogen, sodium and potassium in the root sap (Steddom et al. 2003). Many authors suggest a large reduction in root yield especially in sensitive genotypes under rhizomania infection conditions (Kovacev et al. 2005, Pospisil et al. 2006, Radivojevic et al. 2008). Rhizomania incidence and severity can be only very moderately reduced by preventive cultural practices, such as rotation, avoidance of excessive soil moisture and early plantings. Consequently, the only substantial means to ensure a viable crop production in regions with rhizomania infection is the use of genetically resistant cultivars (Biancardi et al. 2002). Infected roots show stunting with abnormal proliferation of secondary rootlets around the tap root, necrotic rings in the root section, and chlorotic leaves. Diseased roots present higher contents of reducing sugars, K and Na, and lower content of total N with respect to healthy roots (Uchino, Kanzawa 1995). For further improvement of beet quality, it could be interesting to consider additional parameters as selection criteria. Apart from potassium, sodium and α-amino N, other quality related traits should be taken into account, which are not yet included in quality assessment. The most important among them are total soluble N, further betaine which is molassigenic, invert sugar which is a strong alkalinity consumer and forms color precursors together with amino acids, and raffinose which hampers the crystallization of sugar (Van Der Poel et al. 1998).

Correlation coefficients

The Pearson correlation coefficients (Table 4) showed that correlation between sodium with potassium (0.890**) and nitrogen (0.994**) and potassium with nitrogen (0.917**) were positively significant ($P \leq 0.01$). Correlation coefficient of alkalinity with these mentioned traits was negatively significant. Among measured traits, only yellow color and infection incidence had negatively significant relationship (-0.842**). On the other hand, the correlation between white sugar yield (WSY) with impurity related traits and alkalinity was negatively significant and the correlation with SC, Molasses, WSC and ECS was positively significant. Reports on significant negative correlations between virus concentration in tap roots of fully-grown sugar beet, and both sugar content and sugar yield (Giunchedi et al. 1987) led to the estimation of the virus concentration in sugar beet plants as an additional selection criterion for resistance breeding.

Cluster analysis

In order to define the similarities and differences among the used hybrids more clearly, a hierarchical clustering method was applied. The cluster analysis by the Ward's minimum variance method classified 16 sugar beet hybrids into two main groups (Figure 1). In both groups, there are several subgroups with similar hybrids. Hybrids 1, 2, 3, 4, 5, 6 and 7 were placed in the first cluster. The second cluster included hybrids 8, 9, 10, 11, 12, 13, 14,

Table 4

Pearson correlation coefficients between assessed traits in 16 sugar beet hybrids

	Sodium	Potassium	Nitrogen	Alkalinity coefficient (Alk)	Yellow color	Infection incidence	Infection severity	Root yield	Sugar content	Molasses sugar	White sugar content (WSC)	Extraction coefficient of sugar (ECS)	Sugar yield (SY)	White sugar yield (WSY)
Sodium	1	.89**	.99**	-.89**	.027	.15	-.19	.37	-.98**	.98**	-.99**	-.99**	-.73**	-.90**
Potassium		1	.91**	-.74**	-.084	.32	-.19	.28	-.84**	.94**	-.87**	-.88**	-.63**	-.79**
Nitrogen			1	-.91**	-.018	.19	-.17	.33	-.97**	.99**	-.98**	-.99**	-.75**	-.91**
Alkalinity coefficient (Alk)				1	.18	-.23	-.031	-.22	.87**	-.86**	.87**	.88**	.72**	.83**
Yellow color					1	-.84**	-.31	-.09	-.15	-.01	-.11	-.05	-.24	-.18
Infection severity						1	.23	.04	-.01	.21	-.06	-.13	.01	-.04
Infection severity							1	-.05	.20	-.19	.20	.19	.17	.20
Root yield								1	-.37	.35	-.36	-.36	.32	.02
Sugar content									1	-.96**	.99**	.99**	.75**	.91**
Molasses sugar										1	-.98**	-.98**	-.72**	-.89**
White sugar content (WSE)											1	.99**	.75**	.91**
Extraction coefficient of sugar (ECS)												1	.74**	.91**
Sugar yield (SY)													1	.95**
White sugar yield (WSY)														1

* and ** significant at 0.05 and 0.01 probability level, respectively.

15 and 16. This indicates that developing sugar beet genotypes that are resistant to the disease is the most efficient measure of controlling the disease. The dendrogram that follows shows the grouping of hybrids on the basis of the result obtained for root yield and sugar content.

In terms of selecting the best hybrid in each cluster, the cluster that had a higher mean than the total mean is valuable. Therefore, in order to determine the characteristics of each group in terms of the traits studied, the mean of each cluster for each trait and its deviation from the total mean were calculated and shown in Table 5. In first group, sodium content, potassium content, nitrogen content, storage root yield, molasses sugar, infection

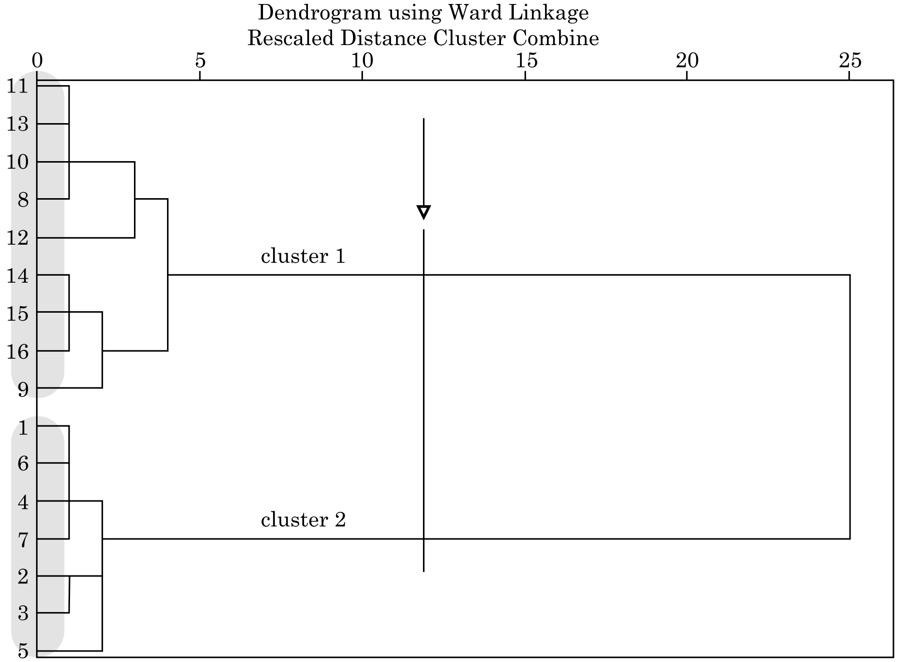

Fig. 1. Dendrogram of cluster analysis based on the Ward's minimum variance algorithm for sugar beet monogerm hybrids

Table 5

The mean and deviation percentage from total mean of three cluster for the evaluated traits in 16 sugar beet hybrids

Cluster	Mean and deviation	Sodium	Potassium	Nitrogen	Alkalinity coefficient (Alk)	Yellow color	Infection incidence	Infection severity
1	mean	5.23	6.73	2.74	4.38	3.76	36.84	1.61
	deviation (%)	76.97	19.38	45.85	-7.38	2.07	4.59	-33.84
2	mean	1.10	4.83	1.19	5.01	3.64	34.25	3.14
	deviation (%)	-62.60	-14.25	-36.40	5.95	-1.19	-2.75	28.39
Cluster		root yield	sugar content	molasses sugar	white sugar	extraction coefficient	sugar yield	white sugar yield
1	mean	24.70	13.85	4.05	9.20	66.11	341.37	226.51
	deviation (%)	1.58	-19.87	43.94	-33.68	-15.30	-18.03	-31.79
2	mean	23.43	20.093	1.84	17.65	87.77	470.56	412.98
	deviation (%)	-3.65	16.219	-34.63	27.23	12.44	12.97	24.34

severity and yellow color were above the total mean. Previous studies (Asheer 1993) have shown that the percentage of these elements is directly related to the amount of infection, which the results of this research also confirm.

In the second group, sugar content (SC), white sugar content (WSC), extraction coefficient of sugar (ECS), sugar yield (SY), white sugar yield (WSY), infection incidence and alkalinity coefficient (Alk) were higher than the total mean. Asheer (1993) reported that low levels of sugar and harmful nitrogen and, at the same time, increasing sodium impurities are symptoms of rhizomania-caused damage. Research done by Dosenovic et al. (2006) showed that rhizomania is manifested by a decrease in sugar and its content. In this research, for, the second cluster hybrids also had a higher value of the white sugar yield than the total mean. Due to the low level of infection incidence in the cluster, therefore, the general recommendation is to use the second cluster hybrids, which have less infection and high white sugar yield.

Principal components analysis (PCA)

The results of PCA showed that the first three components explained totally 90.728% of variance (Table 6). The first, second and third component

Table 6

Total variance explained in PCA

Component	Initial eigenvalues		
	total	% of variance	cumulative (%)
1	9.1	65.5	65.5
2	2.1	15.4	81.1
3	1.3	9.6	90.7

explained 65.568, 15.466 and 9.694%, respectively. In the first component, sodium (-0.994), potassium (-0.904), nitrogen (-0.996), molasses sugar (-0.990) traits had the highest negative coefficients and sugar content (0.982), white sugar content (0.991) and extraction coefficient sugar (0.993) traits had the highest positive coefficients. In second component, infection incidence (0.888) and yellow color (-0.940) had high and low coefficients, respectively (Table 7). So, the first component can be denoted as a sugar component.

To identify the hybrids with high sugar and white sugar contents, factor scores were used. Hybrids 15, 14, 12, 13, 16 and 11 were allocated high scores, respectively (Table 8).

The grouping of the hybrids with two principal components confirmed the classification with the cluster analysis and the two clusters obtained from it were placed in distinct groups in the PCA (Figure 2).

Table 7

Trait coefficients in the first three principal components obtained from the PCA

Component matrix			
Trait	component		
	1	2	3
Sodium	-.99	.02	.08
Potassium	-.90	.15	.03
Nitrogen	-.99	.06	.03
Alkalinity coefficient (Alk)	.90	-.18	.11
Yellow color	-.04	-.94	.11
Infection incidence	-.15	.88	-.21
Infection severity	.19	.47	-.24
Root yield	-.28	.25	.90
Sugar content (SC)	.98	.09	-.10
Molasses sugar (MS)	-.99	.07	.06
White sugar content (WSC)	.99	.05	-.09
Extraction coefficient sugar (ECS)	.99	-.00	-.08
Sugar yield (SY)	.79	.29	.52
White sugar yield (WSY)	.93	.18	.27

Table 8

Factor scores of monogerm hybrids in the PCA

Genotype	Factor scores		
	1	2	3
1	-1.18	0.16	1.16
2	-1.19	-0.83	0.19
3	-1.20	-0.97	-0.09
4	-1.35	0.91	-0.40
5	-0.99	-0.19	-2.26
6	-0.93	0.66	0.46
7	-0.55	-0.22	1.18
8	0.23	1.32	0.70
9	0.53	-0.31	-1.63
10	0.86	0.13	1.44
11	0.91	1.05	0.12
12	0.97	1.41	-0.88
13	0.96	0.68	-0.10
14	1.00	-0.58	-0.59
15	1.01	-0.92	0.39
16	0.93	-2.30	0.30

16	0.93	-2.30	0.30

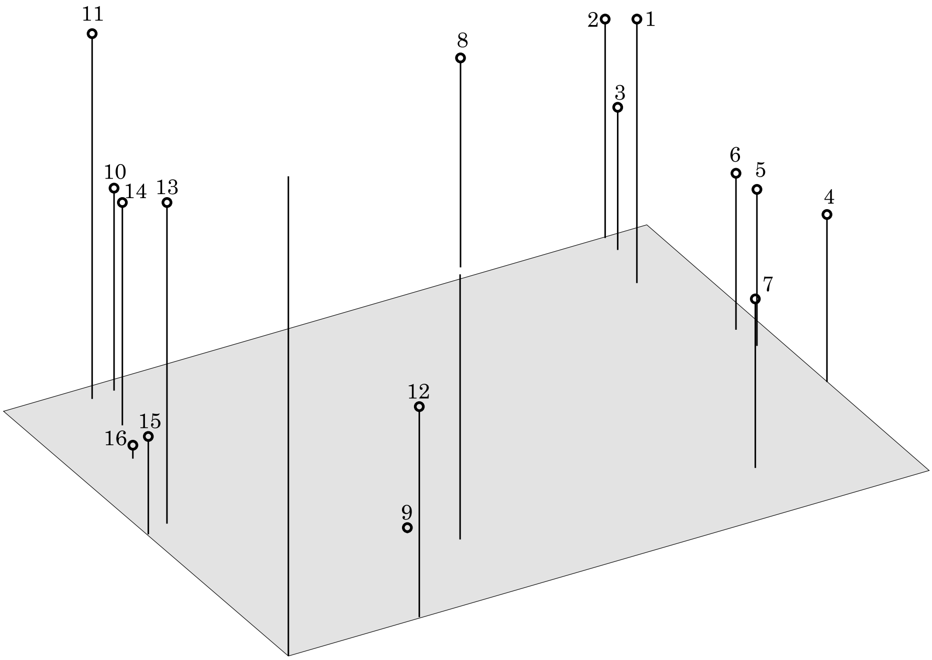

Fig. 2. The scatterplot of sugar beet monogerm hybrids in the principal components analysis

CONCLUSION

In rhizomania-infected areas, the economic production of sugar depends directly on the resistance of the cultivars to rhizomania, because severe infection leads to a yield reduction of up to 90% in susceptible cultivars. At present, the best solution is the use of resistant cultivars, which guarantees the survival of the crop and the sugar beet industry. In this study, the results of the evaluation of monogerm hybrids showed that the hybrids analyzed had good potential. By performing some breeding methods on the paternal and maternal bases of monogerm hybrids, we can hope to produce more resistant and high yielding genotypes. According to the current results, the second cluster of hybrids was distinguished by high white sugar content and low infection, hence these hybrids can serve as a good and suitable parent in the production of rhizomania-resistant cultivars.

REFERENCES

Abdollahian N.M., Radaei-Al-Amoli Z., Akbari G.A., Sadat-Nuri S.A. 2011. *Effect of severe water stress on morphological, quantitative and qualitative characteristics of 20 sugar beet genotypes*. Iran. J. Field Crop Sci., 42: 453-464.

Anonymous 2020. *Agricultural Statistics*. Vol. I. *Crops of 2018-2019*. Office of Statistics and Information Technology of the Ministry of Jihad-e-Agriculture. (in Persian)

Aref A.A., Samir Y.E.S., Mohamed M.E.T., Ibrahim A.G. 2012. *Effect of nitrogen fertilizer on the sugar beet quality and sugar recovery*. Egypt Sugar J., 5: 1-21.

Asher M.J.C., 1993. *Rhizomania*. In: *The Sugar Beet Crop. Science into Practice*. Eds Cooke D.A. & Scott R.K. Chapman and Hall, London, pp. 311-346.

Asher M.J.C., Chwarszczynska D.M., Leaman M. 2002. *The evaluation of rhizomania resistant sugar beet for the UK*. Ann Appl Biol, 141: 101-109. DOI: 10.1111/j.1744-7348. 2002.tb00201.x

Biancardi E., De Biaggi M., Campbell L.G. 2005. *Genetics and Breeding of Sugar Beet*. CRC Press.

Biancardi E., Lewellen R.T., Debiaggi M., Erichsen A.W., Stevanato P. 2002. *The origin of rhizomania resistance in sugar beet*. Euphytica, 127: 383-397. DOI: 10.1023/ A:1020310718166

Brunt A.A., Richards K.E. 1989. *Biology and molecular biology of furoviruses*. Adv Virus Res, 36: 1-32. DOI: /10.1016/s0065-3527(08)60581-3

Buchholz K., Marlander B., Puke H., Glattkowski H., Thielecke K. 1995. *Neubewertung des technischen Wertes von Zuckerruben*. Zuckerindustrie, 120: 113-121. (in German)

Büttner G., Pfähler B., Märländer B. 2004. *Greenhouse and field techniques for testing sugar beet for resistance to Rhizoctonia root and crown rot*. Plant Breeding, 123: 158-166. DOI: 10.1046/j.1439-0523.2003.00967.x

Dosenovic I.S., Radivojevic S., Kabic D.R., Pajic D.J.P, Skrbic K.Z. 2006. *Assessment of technological quality of sugar beet grown on soils with a high level of rhizomania infestation*. Rev. Serbian Matica Nat. Sci., 110: 75-83.

FAO, 2020. *FAOSTAT data*. http://www.faostat.fao.org/faostat

Fischer H.E. 1989. *Origin of the 'Weisse Schlesische RuK be' (white Silesian beet) and resynthesis of sugar beet*. Euphytica, 41: 75-80. DOI: 10.1007/BF00022414

Fotouhi K., Majidi Heravan E., Rajabi A., Azizinejad R. 2016. *The assessment of sugar beet half-sib families based on some morph physiological traits under drought stress conditions*. Ambient Sci, 3: 22-29.

Fujisawa I., Sugimoto T. 1977. *Transmission of beet necrotic yellow vein virus by Polymyxa betae*. Ann Phytopathol Soc Japan, 43: 583-586.

Giunchedi L., De Biaggi M. Poggi Pollini C. 1987. *Correlation between tolerance and beet necrotic yellow vein virus in sugar beet genotypes*. Phytopathol Mediterr, 26: 23-28.

Koo W.W., Taylor R.D. 2012. *Outlook of the U.S. and world sugar markets, 2011-2021*. Agribus Appl Econ Rep, 692: 1-2.

Kovacev L.M., Cacic N.A., Mezei S.M., Nagl N. 2005. *Productivity NS hybrid varieties resistant to rhizomania (BNYVV) in long-term trials*. Rev. Field Veg. Crops Res., 40, 379-387.

Mc Grann G.R.D., Grimmer M.K., Mutasa-Gttgens E.S., Stevens M. 2009. *Progress towards the understanding and control of sugar beet rhizomania disease*. Mol. Plant Pathol., 10: 129-141. DOI: 10.1111/j.1364-3703.2008.00514.x

Pospisil M., Pospisil A., Mustapic Z., Butorac J., Tot I., Zeravica A. 2006. *Production values of researched hybrids of sugar beet*. Agriculture, 12: 16-21.

Putz C., Merdinoglu D., Lemaire O., Stocky G., Valentin P., Wiedemann S. 1990. *Beet necrotic yellow vein virus, causal agent of sugar beet rhizomania. Disease profile*. Rev Plant Pathol, 69: 247-253.

Radivojevic S., Dosenovic I., Filipovic V., Rozic R. 2008. *Tolerance of certain sugar beet varieties to diseases*. J. Agric. Sci., 53: 173-178. DOI: 10.2298/JAS0803173R

Scholten O.E., De Bock T.S.M., Klein-Lankhorst R.M., Lange W. 1999. *Inheritance of resistance to beet necrotic yellow vein virus in Beta vulgaris conferred by a second gene for resistance*. Theor. Appl. Genet., 99: 740-746. DOI: 10.1007/s001220051292

Steddom K., Heidel G., Jones D., Rush C.M. 2003. *Remote detection of rhizomania in sugar beets*. Phytopathology, 93: 720-726. DOI: 10.1094/PHYTO.2003.93.6.720

Tuitert G. 1990. *Assessment of the inoculum potential of Polymyxabetae and beet necrotic yellow vein virus (BNYVV) in soil using themost probable number method*. Eur. J. Plant Pathol., 96: 331-341. DOI: 10.1007/BF01998782

Uchino H., Kanzawa K. 1995. *Suppression of rhizomania by controlling soil pH at low level by ferrous sulfate in infested sugar beet field*. Proc Japan Soc Sugar Beet Technol, 37: 114-121.

Van Der Poel P.W., Schiweck H., Schwartz T. 1998. *Sugar Technology Beet and Cane Sugar Manufacture*. Dr. Albert Bartens, Berlin.

Wisler G.C., Lewellen R.T., Sears J.L., Liu H.Y., Duffus J.E. 1999. *Specificity of TAS-ELISA for beet necrotic yellow vein virus and its application for determining rhizomania resistance in field-grown sugar beets*. Plant Dis., 83: 864-870. DOI: 10.1094/PDIS.1999.83.9.864

Wolf I. 1995. *Sorte und Sortenwahl bei Zuckerrüben und deren Wechselwirkung zu Umwelt und Qualitätsbezahlung*. Dissertation Göttingen, Cuvillier Verlag Göttingen. (in German)