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Original scientific paper

A NEW EXPERIMENTAL HYBRID OF CABBAGE SUITABLE FOR EARLY PRODUCTION

Janko ČERVENSKI, Jelica GVOZDANOVIĆ-VARGA, Dušanka BUGARSKI, Adam TAKAČ, Svetlana GLOGOVAC

Institute of Field and Vegetable Crops in Novi Sad, Serbia

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The paper analyzes experimental hybrids of early cabbage developed at the Institute of Field and Vegetable Crops in the previous period. The hybrids were tested together for two years and then one (H17) was chosen and submitted to the Variety Commission of the Republic of Serbia. In 2011, the experimental hybrid H17 was officially released as an early cabbage hybrid and registered under the name of NS Mendo F1. The hybrid had been developed by crossing two early lines, one of which was sterile. It is characterized by a short growing season - 65 days from transplanting to harvest. The head weight ranges from 2.5 to 3.5 kg depending on the cultural practice applied. The head is light green in color, sweet-tasting, and

Corresponding author: Janko Červenski, Institute of Field and Vegetable Crops in Novi Sad, M.Gorkog 30, 21000 Novi Sad, Serbia, phone + 381 21 4898356, e-mail: jankic@ifvcns.ns.ac.rs, web: www.nsseme.com

suitable for fresh consumption. The hybrid's traits that contributed significantly to the formation of the first principal component were in fact those that the breeders attach most importance to in their breeding programs. These are the traits that directly influence the market value of a new hybrid and make a given hybrid recognizable on the market. Most notable among such traits are head weight and the weight of the useful part of the head.

Key words: biplot, cabbage, grouping, principal components

INTRODUCTION

Cabbage is a vegetable species in which the head is the part that is consumed. A cabbage head should be tightly-packed, sweet-tasting, and healthy. The leaves should preferably be softer, and the heads should vary in weight from one cultivar or hybrid to the next. It is all these traits that determine whether a cabbage will be used for fresh consumption or processed in some way before use (ČERVENSKI *et al*., 2010).

According to GOWERS S. (2000), the main emphasis in crucifers should be placed on a high degree of uniformity of the traits being studied. For this reason, testing in these plant species lasts for a number of years and evaluates both the qualitative and quantitative aspects of traits. Such studies also involve the assessment of various lines for the purposes of hybridization and selecting the most suitable hybrid combinations.

Cabbage accounts for a significant proportion of all the areas planted to vegetables. One of the factors in advancing cabbage production is the existence of an appropriate range of cultivars. The cabbage genotypes grown in Serbia are mostly those suitable for fresh use and pickling. For the most part, the growers make use of foreign cultivars (ČERVENSKI *et al*., 2006).

Old varieties and populations are grown alongside an increasing number of foreign cultivars, which are slowly supplanting the former, resulting in genetic erosion. These evaluations could assist breeders to select and identify genotypes with desirable characteristics for inclusions in variety breeding programs. (ČERVENSKI *et al*., 2011a). Early cabbage hybrids play a significant role in early vegetable production and contribute significantly to the inflow of money on the vegetable market. In Serbia, however, only foreign hybrids of cabbage are grown for the most part, since no competitive domestic hybrids have been developed so far (ČERVENSKI *et al.*, 2011b).

Because of that, we at the Institute of Field and Vegetable Crops in Novi Sad have developed over the previous period several experimental hybrids of this crop that are suitable for early production. The objective was to develop early cabbage hybrids that meet the early spring market requirements. These are the hybrids that are light green in color, sweet-tasting, and intended for fresh consumption.

MATERIALS AND METHODS

Crosses among select cabbage lines were carried out in an indoor space in 2006, after which eight early experimental hybrids intended for fresh use were selected for the purposes of testing. Subsequently, in 2007 and 2008, a trial with five replications was conducted at the Experiment Field of the Institute of Field and Vegetable Crops in Novi Sad to test those eight hybrids.

A total of 14 cabbage traits were analyzed, namely plant height, rosette diameter, number of leaves in the rosette, total plant weight, head weight, usable part of the head, outer stem length, inner stem length, head height, head diameter, total plant to head weight ratio, head index, ratio of inner stem length to head height, and ratio of usable part of head to head weight.

The results were processed by multivariate analysis. Principal component analysis was used to determine total variability and traits the studied materials were most variable for. For determining the genetic divergence of the genotypes under study, we used the hierarchical clustering method as well as the method of Euclidean distance as the parameter that best reflects differences among the different groups (GVOZDANOVIĆ-VARGA, 2004).

The data were processed using the SYSTAT statistics package, Modules CLUSTER and FACTOR (1986).

Because the cabbage genotypes tested belonged to the same maturity group, our objectives were to determine if there were any differences among them with respect to trait variability, to describe the structure of their variability, to perform a grouping of traits with the greatest proportion of variability, and to select a promising hybrid for early fresh consumption.

RESULTS

Principal component analysis focuses the variability on the first principal component. The first principal component explains as much of the variability of all the traits under study as possible. The second principal component is independent of the first and explains the largest variability of what remains after the subtraction of the first component, and so forth.

The first two principal components helped explain 60.0% of the variance, which was not enough, so quartimax rotation was made use of and the percentage of variance explained slowly increased with an increase in the number of principal components being taken into consideration (Tab.1).

The relationships among the studied traits were analyzed based on communality (% contribution of variance) for the four rotated principal components. The cumulative communality of the four components was 87.2%, i.e. it was those components that defined most of the trait variability.

The first principal component explained 45.3% of the variance. The first group of traits defined by this component comprised plant height (Y1= 0.920), rosette diameter (Y1= 0.717), total plant weight (Y1= 0.956), head weight (Y1= 0.950), usable portion of head (Y1= 0.952), head height (Y1= 0.950), and head diameter (Y1= 0.873). These traits contributed the most to the diversity of the

hybrids under study and were responsible for the bulk of their variability. Looking at the traits included in this principal component, it can be concluded that larger-sized plants of greater height and larger rosette diameter will produce heavier plants with larger heads and a greater proportion of the usable part of the head. This is based on the fact that that some of the traits were highly positively correlated with this principal component.

Table 1. Principal component analysis of variability of the analyzed characteristics of cabbage hybrids by the quartimax rotation method

Characteristic	Y1	Y2	Y3	Y4
Plant height	**0.920**	0.055	-0.135	-0.053
Rosette diameter	**0.717**	0.291	0.228	-0.065
No. of leaves in the rosette	0.008	**0.881**	0.175	0.074
Total plant weight	**0.956**	-0.031	0.253	0.089
Head weight (HW)	**0.950**	-0.025	0.251	-0.121
Usable part of the head (UPH)	**0.952**	0.020	0.245	-0.120
Length of outer stem (LOS)	-0.289	0.468	**-0.621**	0.001
Length of inner stem	0.005	-0.254	**-0.930**	0.067
Head height (HH)	**0.950**	-0.164	0.155	0.003
Head diameter	**0.873**	0.127	0.136	-0.421
Total plant to head weight ratio	-0.284	0.016	-0.152	**0.873**
Head index	0.291	**-0.587**	0.192	0.564
LIS/HH ratio	-0.381	-0.131	**-0.892**	0.065
UPH/HW ratio	0.447	**0.705**	0.144	-0.163
Latent roots	6.341	2.052	2.458	1.342
% of total variance explained	45.3	14.7	17.6	9.6
Cumulative communality	45.3	60.0	77.6	87.2

A high degree of correlation with the second principal component was observed in the number of rosette leaves (Y1= 0.881), head index (Y1= -0.587), and the UPH/HW ratio (Y1= 0.705).

The third principal component explained 17.6% of the variance and was comprised of outer stem length (Y1= -0.621), inner stem length (Y1= -0.930), and the LIS/HH ratio (Y1= -0.892). These traits were negatively correlated with this principal component.

The fourth principal component explained 9.6% of the total variance. Total plant to head weight ratio was highly correlated with the fourth principal component (Y1= 0.873). This trait was dominant in the fourth component and contributed to hybrid differentiation with about 9% of the total variance (Tab.1).

Due to the high volume of the results obtained in the study, only the first two principal components have been presented in tabular form (tab.2).

In order to be better able to see the similarities and differences among the experimental hybrids, the hierarchical clustering method was used. In the

dendrogram shown in Graph 1, the clustering was performed based on all of the traits investigated in the study. The genotypes were divided into three groups. The first and largest one contained the hybrids H11, H7, H4, H3, and H14. The second group was smaller and included the hybrids H10 and H1. The third group was comprised of a single genotype, H17.

Table 2. Characteristics of early cabbage hybrids associated with the first two principal components

Hybrids/ Year[d)]	Head height (in cm)	Width of leaf rosette (in cm)	Number of leaves in the rosette	Total plant weight (in gr.)	Head weight (in gr.)	Mass of usable part of head[c)]	Head height (in cm)	Head width (in cm)	Head index[a)] HH/HW	UPH/HM (In %)[b)]
H1-2007	23.9	58.8	14	2371.0	1750.0	1461.7	16.2	17.5	0.9	83.1
H3-2007	24.2	67.7	11	3215.3	2347.7	1938.3	17.7	18.7	0.9	81.6
H4-2007	22.8	65.7	12	3296.7	2500.0	2022.3	18.3	18.8	1.0	80.8
H7-2007	23.5	62.6	12	2594.7	1933.3	1601.3	16.4	18.4	0.9	82.6
H10-2007	23.0	63.9	14	2716.0	1968.7	1686.7	16.6	17.9	0.9	85.5
H11-2007	24.9	79.9	13	3861.3	2877.3	2363.7	17.9	20.4	0.9	82.5
H14-2007	25.0	73.9	12	3112.7	2406.0	2036.3	17.7	20.0	0.9	84.5
H17-2007	27.0	74.5	12	4888.7	3854.3	3276.3	20.5	21.6	1.0	85.1
H1-2008	24.4	70.8	12	3302.4	1827.0	1486.0	17.0	16.7	1.0	81.2
H3-2008	24.7	76.4	14	3657.3	2705.7	2290.7	18.4	19.8	0.9	84.6
H4-2008	23.9	74.9	13	3637.0	2730.0	2245.7	18.7	19.1	1.0	82.1
H7-2008	25.4	79.8	15	4354.3	3303.3	2806.0	19.2	21.2	0.9	84.8
H10-2008	22.7	74.7	15	3036.0	2186.3	1865.0	16.9	18.1	0.9	85.3
H11-2008	25.8	88.7	14	4198.0	3097.3	2620.3	18.6	21.2	0.9	84.6
H14-2008	26.1	83.9	13	3467.7	2594.8	2182.7	17.7	21.0	0.8	84.3
H17-2008	27.7	82.4	13	5202.0	4087.7	3506.3	21.2	21.9	1.0	85.8

[a)] HH/HW = Head height to head width ratio

[b)] UPH/HM = Usable part of the head to head weight ratio

[c)] in grams

[d)] hybrid title and test year

As seen in the dendrogram, H17 was the hybrid that stood out among all the genotypes studied, as its characteristics set it apart from the other hybrids in the study. However, some of the parent lines in the hybrids had a common origin. Thus, the hybrids H7 and H17 had the same lines as parents, the only difference being that they had been used reciprocally. This resulted in the maximum distance being observed in this particular case, as the shortest distance was recorded in H7 and the largest in H17.

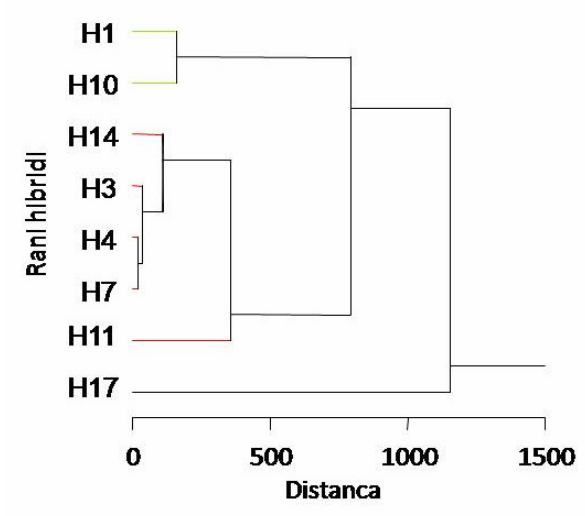
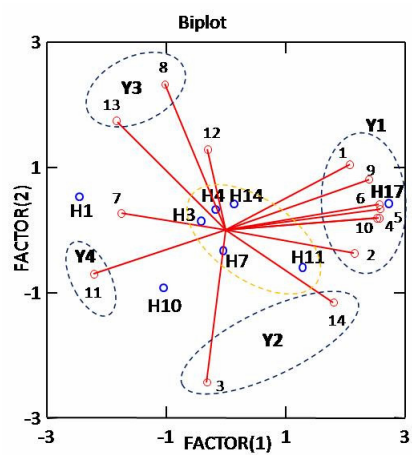


Figure 1. Dendrogram showing the clustering of the experimental cabbage hybrids.

Biplot analysis was used to represent the graphic distribution of the relations among the principal components (Y1, Y2, Y3, Y4), traits (1-14), and experimental hybrids (H1, H3, H4, H7, H10, H11, H14, H17) analyzed (Graph 2).



Legend:

nr	Plant characteristic
1	Plant height
2	Rosette diameter
3	No. of leaves in the rosette
4	Total plant weight
5	Head weight (HW)
6	Usable part of the head (UPH)
7	Length of outer stem (LOS)
8	Length of inner stem
9	Head height (HH)
10	Head diameter
11	Total plant to head weight ratio
12	Head index
13	LIS/HH ratio
14	UPH/HW ratio

Figure 2. Biplot analysis and graphic representation of principal components, analyzed traits, and experimental cabbage hybrids

Especially prominent was the hybrid H17, which was closely connected to the following traits: plant height, rosette diameter, total plant weight, head weight, usable part of head, head height, and head diameter. These traits were included in the first principal component, which explained the largest proportion of the variance. None of the other hybrids were connected with the traits in a similar way.

DISCUSSION

Principal component analysis (PCA) is a multivariate method used for reducing the dimensions of a data set while trying to retain as much of the variability as possible in order to be able to represent the data more easily and gain better insight into the structure of the hybrids and the relationships among the variables being used.

PCA is a method of data reduction that transforms the original variables into a limited number of uncorrelated new variables. The techniques is thus a useful device for representing a set of variables by u much smaller set of composite variables that account for much of the variance among the set of original variables. It allows visualization of the differences among the individuals, identification of possible groups and relationships among individuals and variables (RAKONJAC *et al.*, 2010).

The principle component method focuses the variability on the first two principal components. The first principal component explains as much of the variability as possible of all the traits being analyzed. The second principal component, independent of the first one, explains as much variability as possible in what remains when the first component is removed, and so on. In the present paper, we chose four components based on the percentage of the total variance explained (87.1%). An analysis was made of the 14 traits having the highest levels of communality with the first principal component, namely plant height, rosette diameter, total plant weight, head weight, usable portion of the head, head height, and head diameter. All the traits were positively correlated with the first principal component. Those were the traits that explained 45.3% of the variability of the hybrids being investigated. Increasing the value of any of these seven traits increases the values of the other six.

TANAKA *et al.* (2003) analyzed the characteristics of early hybrids and grouped them based on PCA analysis. They obtained four main groups as well, with the variance percentage contributions being PC1-52.3%, PC2-13.0%, PC3-9.1%, and PC4-7.0% of the total variance, amounting to cumulative variance of 81.4%. In our study, there were also four principal components, and the percentage variance was similar as well. The largest variance percentage was also found in the first group, just like in the case of the study above, and the cumulative variance was 87.2% in our study and 81.4% in TANAKA *et al.* (2003), which show that our results and theirs were very similar.

Taking a closer look at the first principal component, we can see that this is where the traits that form the yields of early hybrids are. Our findings are in

agreement with those of a study by VASIC *et al.* (2008), in which the first principal component was termed „the yield component".

Traits found in the first principal component are in actual fact the main objectives of breeding programs on early cabbage hybrids. In a cabbage breeding program, it is difficult to make the decision on selecting a particular hybrid solely on the basis of data presented in this paper. For obtaining satisfactory head weight, in addition to the prevailing growing conditions and agronomic practices used, the choice of hybrid or cultivar suitable for a particular area is of great importance as well. The correct choice of hybrid or cultivar allows the genes that control head weight to be fully expressed, i.e. it minimizes the effects of limiting environmental factors (ČERVENSKI *et al.*, 2007).

Early and medium-early varieties can be successfully grown as a stubble crop after an early preceding crop such as pea or barley. Hybrids from the present paper had been tested in such conditions too. When grown as a stubble crop, they produced ample yields ranging from 39 to 68 tons per hectare (MAKSIMOVIĆ *et al.*, 2008).

Experimental lines that were used in the development of the hybrid H17 had been by tested NIKOLIĆ *et al.* (2007). It was determined in that study that the lines had a high level of uniformity and that they could be used for crosses in the process of hybrid development. Results obtained in this study can be used for practical purposes in the process of breeding, i.e. they can be used in the selection of parental combinations when developing cabbage hybrids.

One of the experimental hybrids used in the present study, NS-H17, was released in 2011 under the name of NS Mendo F1. It is a hybrid suitable for early fresh use that has a head which is light green in color. The time from emergence to harvesting is 95-97 days and that from transplantation to harvesting around 60. NS-H17 has a leaf rosette that is 80-85 in diameter. The rosette consists of 13 true leaves that are light green in color and have inconspicuous venation. The average weight of the whole plant including the leaf rosette, head, and the outer stem is 3,255 grams, while the average head weight is 2,540 grams. Such great weight of the head reduces the total plant to head weight ratio down to 1.3, indicating that the weight of the head is positively large relative to the weight of the whole plant. The head is white-yellow in cross section. The useful part of the head in NS-H17 weighs 2,180 grams, accounting for over 85% of the overall head weight. This indicates that the inner stem in this hybrid is short and that the base of the leaf is finely formed. Looking at the head in cross section, the following observations can be made. The average length of the inner stem is 6.9 cm. Head height in cross section is 21.2 cm, while the diameter of the head is 21.9 cm. The ratio of head height to head diameter is called the head index. In NS-H17, the head index is 1.0, indicating that the hybrid has a round head. Another thing worth noting is the ratio of inner stem length to head height. In NS-H17, this ratio is 32.7% on average. This value is fairly low, which is indicative of a higher proportion of the useful portion of the head.

CONCLUSION

The results of the present paper have contributed to a better understanding of the grouping of variability among the traits being studied. Traits that contributed significantly to the formation of the first principal component were in fact those that the breeders attach most importance to in their breeding programs. These are the traits that directly influence the market value of a new hybrid and make a given hybrid recognizable on the market. Most notable among such traits are head weight and the weight of the useful part of the head. Because of this, care must be taken when interpreting study results to make the correct selection of the hybrid. Analysis of findings using statistical methods is the first part of the answer when making the choice of the hybrid. The second part of the answer lies in environmental factors, i.e. growing conditions.

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NOVI EKPERIMENTALNI HIBRID KUPUSA POGODAN ZA RANU PROIZVODNJU

Janko ČERVENSKI, Jelica GVOZDANOVIĆ-VARGA, Dušanka BUGARSKI, Adam TAKAČ, Svetlana GLOGOVAC

Institut za ratarstvo i povrtarstvo, Novi Sad, Srbija

U radu su analizirani eksperimentalni hibridi ranog kupusa stvoreni u prethodnom periodu u Institutu za ratarstvo i povrtarstvo. Hibridi su međusobno dve godine testirani, iz čega je jedan hibrid (H17) izabran i prijavljen Republičkoj sortnoj komisiji. 2011 godine je eksperimentalni hibrid H17 i zvanično priznat kao rani hibrid kupusa, te registrovan pod imenom NS Mendo F1. Navedeni rani hibrid je nastao ukrštanjem dve linije kupusa, od kojih je jedna sterilna linija. Karakteriše se kratkom dužinom vegetacije, tj. 65 dana od rasadjivanja do berbe. Masa glavice se kreće od 2,5 kg do 3,5 kg u zavisnosti od agrotehnike. Glavica je svetlo zelene boje, slatkog ukusa pogodna za svežu potrošnju. Osobine koje su pokazale značajan udeo na formiranje varijabilnosti prve glavne komponente, su u stvari i osobine na koje selekcioneri daju i najveći značaj u oplemenjivačkim programima. To su svojstva koja direktno utiču na formiranje tržišne vrednosti novi hibrida, i čine pojedine hibride prepoznatljive na tržištu. To se odnosi pre svega na masu glavice i masu korisnog dela glavice.

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