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Full Length Research Paper

Variability of characteristics in new experimental hybrids of early cabbage (*Brassica oleracea* var. *capitata* L.)

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Early hybrids take a significant share of the Serbian fresh vegetables market; however, all early hybrids are foreign. New domestic experimental hybrids of early cabbage have been analyzed and results are presented in this paper. In order to get a better insight in the variability among the tested hybrids, we have analyzed them for 14 characteristics by the principal component analysis (PCA) method. This paper deals with four principal components that explain 87.2% of the total variance. Out of the 14 traits analyzed, only seven traits had the highest communality with the first principal component and these were plant height, rosette diameter, the weight of the whole plant, head weight, the usable part of the head, head height and head diameter. All characteristics were positively correlated with the first principal component. Cabbage characteristics that constitute the first principal component are in fact the main objectives in programs of breeding early maturing cabbage. These characteristics explained 45.3% of the variability of the tested hybrids. If value of any of these seven characteristics is increased, the values of the other six characteristics increased proportionally. The results of this work have therefore contributed to a better understanding of the clustering of variability of the studied characteristics. These characteristics directly impact the formation of market value of new hybrids, and make them recognizable on the market.

Key words: Cabbage, head weight, principal component analysis, useful portion.

INTRODUCTION

Several experimental early cabbage hybrids have been developed at Institute of Field and Vegetable Crops, Novi Sad, in recent years. The objective was to develop cabbage hybrids for production in early spring. These hybrids are light green, sweet taste and intended for fresh consumption. It is known that heterosis is applicable in the development of early cabbage hybrids. Early maturity, head forming and their correlations have been investigated by Tanaka and Niikura, (2006). They concluded that head shape, size and density must go together with the earliness of head formation to answer market demand. In Serbia, cabbage is grown at about 21,000 ha (http://faostat.fao.org). This acreage includes both hybrids and varieties, early, mid-season or late, for the fresh market, pickling or long storage. Early cabbage hybrids play an important role in the early vegetables production. They are also an important cash crop. However, foreign hybrids are exclusively grown in the country since no competitive domestic hybrids have been developed so far (Cervenski et al., 2006, 2011).

Principal component analysis (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 a 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

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(Rakonjac et al., 2010). Results obtained from such analyses are very important for developing and recommending best cultivar for production in a specific area, as a selection criteria for further genetic improvements and can enable objective estimation of experimental genotypes, hence, developing best possible varieties for official testing by national registration authorities (Marjanović-Jeromela et al., 2008).

The objective of this study was to analyze the structure of principal components of variability of characteristics of experimental early cabbage hybrids in order to assess the contribution of individual characteristics to the total variability, and to establish similarities and differences among the studied hybrids. Such analysis would help us decide which of the experimental hybrids to register in the Varietal Commission.

MATERIALS AND METHODS

The latest cycle of cabbage breeding at the Institute produced a set of cabbage lines, some of which were used to develop experimental lines suitable for fresh consumption after early field or greenhouse production. It included eight early cabbage hybrids intended for fresh consumption. The selected material was crossed in the course of 2005 and 2006. Regardless of the fact that the hybrids belonged to the same maturity group, it was our intention to see if there exist differences in the variability of characteristics of the hybrids, to show the structure of the variability and to group the characteristics possessing the highest level of variability.

Experimental site and data collection

Experiments were established at the experiment field Rimski Šancevi in the Institute of Field and Vegetable Crops, Novi Sad. Experimental materials were planted manually in well prepared soil in the half of April. A randomized block design with five replications was used in the trial, with space between rows 60 cm and between plants in row 50 cm. Conventional cultural practics were applied during growing season. The area has a continental semiarid to semihumid climate, a mean annual air temperature of 11.0°C, an annual precipitation sum of 617 mm and an uneven distribution of precipitation. The experiment was established in a loamy soil with pH 7.0, organic matter content of 2.82%, N-NO_3 of 10.7 ppm, P2O5 of 30.8 ppm and K2O of 26.6 ppm. The previous crop was winter wheat, whose straw was baled and removed after harvest.

The analyses involved a total of fourteen characteristics during two year period (2007 to 2008), which were measured and described as: plant height (PH) in cm, rosette diameter (RD) in cm, number of rosette leaves (NRL), total plant weight (TPW) in g, head weight (HW) in g, weight of useful part of the head (WUPH) in g, outer stem length (OSL) in cm, inner stem length (ISL) in cm, head height (HH) in cm, head diameter (HD) in cm, total plant to head weight ratio (PHR), head index (HI), inner stem length to head height ratio (ISHHR) in %, useful part of the head to head weight ratio (UPHR) in %.

Statistical analysis

In order to determine the contribution of individual characteristics of the total variability, the analysis of principal components was applied, or more precisely the varimax rotation method from the group of multivariate analyses. The statistical package “Statistica” 9.1 (Statsoft, Inc., 2011) was used. The same method was used to analyze the divergence and similarity of the tested cabbage hybrids. The choice of principal components was based on the percent of explained variability calculated by the scree test. To determine which of the four principal components (PC) accounted for the greatest amount of variation, the Eigenvalues of the four PCs were compared for each trait.

RESULTS AND DISCUSSION

The principal components analysis places focus on the variability of the first principal component. The first principal component explains as much as possible, the variability of all traits, while the second principal component independent of the first, explains the highest variability of what remains after the first component is subtracted, etc. As the first two principal components explained 60.0% of the total variability, which was not high enough, we applied the quadrimax rotation and the percentage of explained variability increased slowly as we increased the number of principal components taken into consideration (Table 1).

Relations between characteristics of the tested cabbage hybrids were analyzed based on the communality (% share of the variance) of the four rotated principal components. The sum communality of the four principal components was 87.2%, that is most of the variability of the characteristics was explained by them. Our result is similar with Tucak et al. (2009). The objectives of their research were to explore the extent and pattern of phenotypic variability in the alfalfa collections, to classify the germplasm into similar groups and to identify the main traits contributing to the overall variability. They found that the first four PCs contributed 89,02% of the entire variability among the populations and cultivars.

The first principal component however explained 45.3% of the variance. The first group of hybrid cabbage characteristics that were defined by this component included: plant height (PH),PC1 = 0.920; rosette diameter (RD), PC1 = 0.717; total plant weight (TPW), PC1 = 0.956; head weight (HW), PC1 = 0.950; usable part of the head (WUPH), PC1 = 0.952; head height (HH), PC1 = 0.950 and head diameter (HD), PC1 = 0.873. These characteristics account for the largest part of divergence and variability among the tested hybrids. Considering the characteristics associated with the first principal component, we concluded that large plants with greater height and rosette diameter are bound to form plants with greater weight, larger heads and a larger usable part of the head. This conclusion was drawn on the basis of the fact that some of the above characteristics were highly positively correlated with the first principal component. The following characteristics were highly correlated with the second principal component: number of rosette

Table 1. Eigenvalues, proportion of total variability and correlation between the original variables and the first four principal components (PCs).

Characteristic[a]	PC1	PC2	PC3	PC4
PH	0.920	0.055	-0.135	-0.053
RD	0.717	0.291	0.228	-0.065
NRL	0.008	0.881	0.175	0.074
TPW	0.956	-0.031	0.253	0.089
HW	0.950	-0.025	0.251	-0.121
WUPH	0.952	0.020	0.245	-0.120
OSL	-0.289	0.468	-0.621	0.001
ISL	0.005	-0.254	-0.930	0.067
HH	0.950	-0.164	0.155	0.003
HD	0.873	0.127	0.136	-0.421
PHR	-0.284	0.016	-0.152	0.873
HI	0.291	-0.587	0.192	0.564
ISHHR	-0.381	-0.131	-0.892	0.065
UPHR	0.447	0.705	0.144	-0.163
Eigenvalue	6.341	2.052	2.458	1.342
% Var.	45.3	14.7	17.6	9.6
% Cum.	45.3	60.0	77.6	87.2

[a]For explanation of character symbols, see materials and method, under experimental data collection.

leaves (NRL)(PC2 = 0.881), head index (HI)(PC2 = -0.587) and the usable part of the head to head weight ratio (UPHR)(PC2 = 0.705).

More also, the third principal component explained 17.6% of the variance and it included the outer stem length (OSL)(PC3 = -0.621), the internal stem length (ISL)(PC3 = -0.930) and the inner stem length to head height ratio (ISHHR)(PC3 = -0.892). These characteristics were negatively correlated with this principal component. The fourth principal component explained 9.6% of the total variance. Total plant weight to head weight ratio (PHR) was highly correlated with the fourth principal component (PC4 = 0.873). That characteristic was dominant in this component, contributing to hybrids' differentiation with about 9% of the total variability (Table 1). Based on the size of the obtained results, only the characteristics associated with the first two principal components are presented (Table 2).

The number of principal components to be included in the analysis was determined by the significance test of characteristic roots. For this purpose, we chose a graphic representation of the values of the characteristic roots according to their ordinal numbers. This diagram is called the scree test, and it was proposed by Cattell (1966) (Figure 1). Using this test, we selected principal components whose values of characteristic roots were above the unity. When the variance of the principal component is less than unity, the characteristic root too is less than one, which means that this component explains less than the originally observed characteristic. Eliminating from the system all components having the characteristic roots less than one is a way to choose for observation, a requisite number of principal components. In some instances it is necessary to choose the number of principal components that is required to explain satisfactorily the variability percentage of a set (Kovacevic, 1994).

PCA is a multivariate analytical method, which is used to downsize the dimensions of a data set, while maximally retaining its variability. All of it aimed at facilitating the presentation of data and the understanding of data structure and relationships among variables used. The method of principal component focuses on the variability of the first few principal components. The first principal component explains as much as possible, the variability of all traits, while the second principal component, independent of the first, explains the greatest part of the variance that remains after the first and so on. For this study, we selected four components that explained 87.1% of the total variance. We analyzed fourteen traits, but only seven traits had the highest communality with the first principal component: plant height, rosette diameter, whole plant weight, head weight, usable part of the head, head height and head diameter. All these characteristics were positively correlated with the first principal component and they explained 45.3% of the variability of the tested hybrids. If value of any of these seven characteristics is increased, the values of the other six characteristics increase proportionally. Tanaka and Niikura, (2003) analyzed the characteristics of early

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

Hybrids/Year[a]	PH[b]	RD	NRL	TPW	HW	WUPH	HH	HW	HI	UPHR
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] Hybrid title and test year; [b]For explanation of character symbols, see experimetal data collection under materials and method.

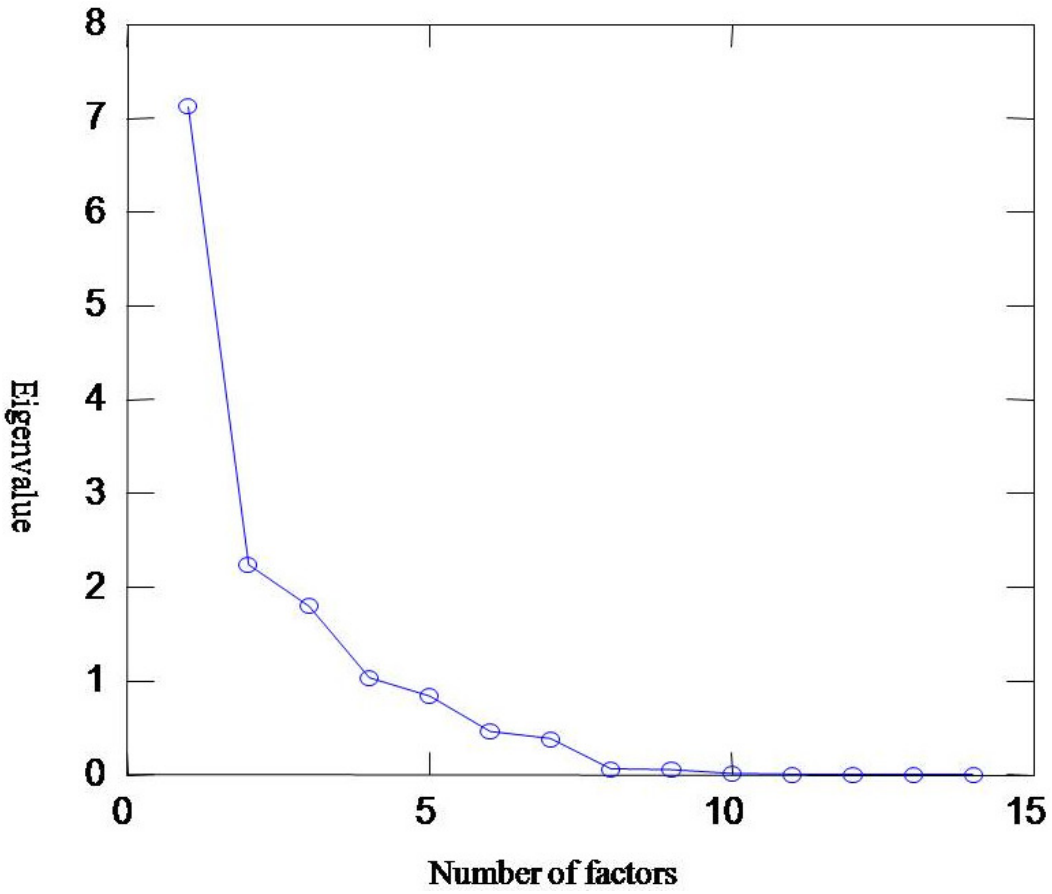

Figure 1. Scree test of the principal components for the tested characteristics of cabbage hybrids.

hybrids and grouped them on the basis of the PCA. These authors also obtained 4 major groups which shared the variance in the following way: PC1 - 52.3, PC2 - 13.0, PC3 - 9.1 and PC4 - 7.0% of the total variance, and their cumulative variance amounted to 81.4%. Our results also show a group of four principal components, with similar percentages of variance. The highest percentage of variance is also in the first group, as in the case of the above authors, and the cumulative variance of 87.2% again shows high similarity. After rotation, a selected group of principal components retained some part of communality of the original variables observed in communality of a single original variable and the participation of variance explained by selected principal components, but the values for some of the main components change. Orthogonal rotation facilitates the interpretation of principal components and it clarifies the relationships among the original variables.

A closer look at the first principal component reveals that this component contains the characteristics that form the yield of early maturing hybrids. Our results are in agreement with those of Vasic et al. (2008), who named the first principal component the yield component. Cabbage characteristics that constitute the first principal component are in fact the main objectives in programs of breeding early maturing cabbage. When engaged in breeding, it is difficult to bring a decision and select a hybrid only on the basis of the data discussed in this paper. To obtain a satisfactory head weight, in addition to the prevailing agro ecological conditions and agronomic practices used, choice of a hybrid or cultivar suitable for a particular area is of great importance. Correct choice of hybrid or cultivar allows the genes that control head weight to be fully expressed, thus minimizing the effects of limiting environmental factors (Červenski et al., 2007).

Multivariate analysis is a very useful method because it reveals the relationships and correlation among variables studies. This type of analysis applied to studies of germplasm collection allows a better understanding of the structure of the collection, identification of more relevant variables, detection of the relationships among accession, as well as identification of possible groups (Martines-Calvo et al., 2008). Rotation of principal components makes it easier to see the location of each studied characteristic within the system of principal components. Mutual relationships between individual characteristics remain unchanged, but changes take place in their correlations with the principal components, their proportion in certain principal components and their load factor. Some characteristics become more firmly attached to one of the principal components, and less firmly attached to others. In that way, we maximize the variance or the proportion of a set of principal components and individual characteristics that comprise them within the total variability.

The analysis of genetic divergence therefore plays an important role in breeding programs for determining new sources of variability that could be included in a desired plant model (Gvozdanovic-Varga et al., 2002). For a successful breeding program, genetic diversity and variability play a vital role. Population genetic diversity is a prerequisite for an effective plant–breeding program. It is a useful and essential tool for parents' choice in hybridization to develop high yield potential cultivars and to meet the diversified goals of plant breeding (Arslanoglu et al., 2011).

Conclusion

The results of this work have contributed to a better understanding of the clustering of variability of the studied characteristics. Positive traits for breeding were found in all clusters. The characteristics that take a significant role in the formation of variability of the first principal component are in fact the characteristics considered by breeders to be of greatest importance in breeding programs. These characteristics directly impact the formation of market value of new hybrids, and make them recognizable on the market. When cabbage is concerned, this applies in the first place to head weight and the weight of the usable part of the head. Therefore, when choosing hybrids for a market, care should be taken to 1) correctly interpret the statistical data derived from the available experimental results and 2) to carefully consider the available range of environmental factors (growing conditions). The latest cycle of cabbage breeding at the Institute produced a set of cabbage lines, some of which were used to develop experimental lines suitable for fresh consumption after early field or greenhouse production. This effort has produced the experimental hybrid H17, which in terms of quality, is capable of competing with the cabbage cultivars currently present on the Serbian market. The hybrid takes up to 65 days to mature from transplanting, its head is light green and its flavor is sweet and pleasant.

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