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*Full Length Research Paper*

# Stability of head weight in cabbage accessions (*Brassica oleracea* var. *capitata* L.)

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**An understanding of the causes of genotype x environment interaction can help in identifying traits and environments for better cultivar evaluation. The fact that head formation depends on other factors besides the cabbage accessions involved, makes it necessary to investigate accessions responses to agroecological growing conditions. Studied in the present paper was the stability of 21 cabbage accessions (10 cultivars and 11 F1-hybrids) with regard to head weight over three growing seasons. Joint analysis of variance revealed highly significant differences among the cabbage accessions, study years and accessions x year interactions. The parameter stability test showed that seven of the accessions (Kopenhaski and Elisa-F1 as early type; Tucana-F1 as summer type; Srpski melez, SG-3014, Ljubljanski and Rodeo-F1 as late type) significantly deviated from the regression line. Four of the seven accessions are cultivars and three F1-hybrids. These accessions had quite different regression coefficients around or above the value of one. Analysis of stability parameters for head weight showed the following accessions to be very stable: Copenhagen market (an early variety), Grenadier-F1 (a summer cabbage) and Ljubljanski (a late variety).**

**Key words:** Stability, variety, cabbage, interaction, growing.

## INTRODUCTION

Identification of high yielding and stable accession across variable environments has been a continued challenge to plant breeders worldwide. The basic and ultimate goal behind these experiments is to select stable accession or cultivars. The characterization of stable accession is often complicated by the frequent occurrence of genotype-byenvironment interactions. Plant breeders, to address the accessions-byenvironment interactions issue, evaluate accessions in multi-environment trials inclusive of favorable as well as unfavorable conditions. This concept of stability has been defined in several ways, and several biometrical methods including univariate and multivariate ones, have been developed to assess stability.

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Several stability analyses have been proposed to handle genotype-byenvironment interactions so as to recommend the accessions that perform consistently better and yield higher across different locations. Stability indices are either based on regression analysis or principal component analysis (Bernardo, 2002). Some of the most commonly used stability parameters are Finlay and Wilkinson (1963) regression coefficient, Eberhart and Russell (1966) deviation from regression, Shukla (1972) stability variance and Kang (1993) yield stability parameter and the additive main effects and multiplicative interaction model (Gauch, 1992).

The Eberhart and Russell (1966) regression model has been widely used in the past few decades mainly because variability in performance of any genotype could be subdivided into predictable (regression) and unpredictable (var-dev) components. The method is based on simple regression analysis and is widely used because of its simplicity and efficiency, as shown by several authors working with various crops (Oliveira, 1976; Gama and Hallauer, 1980; Miranda, 1993; Gonçalves, 1997;

**Table 1.** Varieties and F1-hybrids included maturity type and origin.

| S/N | Cabbage accession | Parameter | Type | Origin |
|---|---|---|---|---|
| 1 | Marcanata-F1 | F1-hybrid | early | Vikima Seed |
| 2 | Copenhagen market | Variety | early | Domesticated |
| 3 | Kopenhaski | Variety | early | Domesticated |
| 4 | Resistor-F1 | F1-hybrid | early | Syngenta Seed |
| 5 | Balbro-F1 | F1-hybrid | early | Nickerson Zwaan |
| 6 | Elisa-F1 | F1-hybrid | early | Sakata Seed |
| 7 | Nosomi-F1 | F1-hybrid | early | Sakata Seed |
| 8 | Ditmar | Variety | early | Domesticated |
| 9 | Prva zetva | Variety | early | Domesticated |
| 10 | Grenadier-F1 | F1-hybrid | summer | Syngenta Seed |
| 11 | Pruktor-F1 | F1-hybrid | summer | L.Daehnfeldt |
| 12 | Tucana-F1 | F1-hybrid | summer | Royal Sluis |
| 13 | Futoski | Variety | late | Local variety |
| 14 | Srpski melez | Variety | late | Local variety |
| 15 | SG-3014 | Variety | late | Sluis groot |
| 16 | Late flat dutch | Variety | late | Domesticated |
| 17 | Slava | Variety | late | Domesticated |
| 18 | Quisto-F1 | F1-hybrid | late | Syngenta Seed |
| 19 | Castelo-F1 | F1-hybrid | late | Nickerson Zwan |
| 20 | Ljubljanski | Variety | late | Domesticated |
| 21 | Rodeo-F1 | F1-hybrid | late | Nickerson Zwan |

Vendruscolo, 1997).

Similar research was done on the other vegetable crops-autumn garlic (Gvozdanovic et al., 2002). When breeding for a particular set of growing conditions, it is highly important to know and use the local populations, since in them the relationships among yield components are balanced and in harmony with the effects of the specific climatic and edaphic factors (Vasic et al., 2008).

From the breeders' point of view, location is fixed factor, and yield consistency over time is the only relevant component of genotypes yield stability (Annicchiarico, 2002). But yield is a complex character which is controlled by association of various characters. Thus, information on association of yield attributes and their direct and indirect effects on grain yield are of paramount significance (Immanuel et al., 2011).

Therefore, it is always attempted to test the stability or consistency of each genotypes in a wide range of different environments. The obtained data is very useful in selection of the cultivar with most stable head weight, making this kind of research quite important for breeders and growers alike (Tuck et al., 2006).

The objective of this study was to assess the reaction of cabbages from different growth types to variable environmental conditions, that is, to assess their reaction to the weather conditions during the growing season, and to identify stable cabbage accession for head weight.

## MATERIALS AND METHODS

The studied material consisted of 21 cabbage accessions (10 varieties and 11 F1 hybrids) from three maturity groups. Among the varieties, there were two domestic ones, Futoski and Srpski melez, which are suitable for fresh use late in the season as well as for pickling, and which have a history of being grown in the country for more than 30 years now. The other eight varieties are from the list of cabbage varieties domesticated in Serbia (www.sorte.minpolj.gov.rs) and are well adapted to the climate and growing conditions under which the study was carried out. The trial also included the late experimental variety SG-3014, which is suitable for both pickling and fresh use (Table 1).

The trial was carried out on chernozem at the Rimski Sancevi Experiment Field of the Institute of Field and Vegetable Crops in Novi Sad, Serbia, 45°19'N latitude and 19°50'E longitude, at altitude 79 m above mean sea level. The horizons in which most of the root system of cabbage develops are neutral in reaction and slightly calcareous. The soil has a medium supply of total nitrogen, an optimum supply of readily available phosphorus, and a high readily available potassium content (Vasin et al., 2002).

The trial was carried out over a three-year period (2000, 2001 and 2002) using a randomized block design with three replications. The experimental units for the early cabbage accessions were plots 6.0 $m^2$ in size. Each plot had three rows with 36 plants in total (60 × 50 cm; 33300 plants per hectare). In the case of the summer and late accessions, the size of the experimental unit was 10.5 $m^2$ with

**Table 2.** Average monthly temperatures (°C) and sum of precipitation (mm) in the years were the genotypes were grown.

| Month | Year | | | | | |
|---|---|---|---|---|---|---|
| | 2000 | | 2001 | | 2002 | |
| | °C | mm | °C | mm | °C | mm |
| January | -1.7 | 17.0 | 3.5 | 38 | 0.2 | 7.5 |
| February | 4.3 | 7.0 | 4.6 | 27 | 6.7 | 28.4 |
| March | 7.3 | 27.0 | 11.0 | 73 | 8.6 | 10.1 |
| April | 14.9 | 24 | 11.2 | 127 | 11.1 | 30.4 |
| May | 18.5 | 39 | 17.7 | 77 | 19.1 | 84.7 |
| June | 21.3 | 28 | 19.8 | 233 | 22.0 | 27.5 |
| July | 22.1 | 29 | 22.5 | 56 | 23.5 | 35.0 |
| August | 24.1 | 5 | 22.7 | 30 | 21.5 | 53.8 |
| September | 17.8 | 13 | 16.1 | 162 | 16.4 | 47.5 |
| October | 15.3 | 6 | 14.1 | 14.7 | 12.1 | 91.7 |
| November | 11.7 | 22 | 3.6 | 71.4 | 9.5 | 23.7 |
| December | 4.0 | 53 | -3.4 | 27.6 | 0.5 | 41.6 |

three rows per plot (70 × 50 cm; 28500 plants per hectare) and 30 plants per plot in total. The varieties and hybrids were grown from transplants, which were started in the greenhouse on either March 20 (early accessions), April 18 (summer accessions) or May 20 (late accessions). Throughout the entire period of growing the transplants in the greenhouse, the plants were provided with optimal temperature and moisture conditions. The transplants were transferred into the open field on May 4 (early accessions), May 31 (summer ones) or July 9 (late cabbages).

Before planting, the plots were fertilized prior to primary tillage using NPK (8:16:24) at 600 kg per hectare. During the season, the crops were top-dressed on two occasions, and they were protected from diseases and pests as well. After the transplantation, irrigation was applied. The crops were also irrigated in the course of the growing season on several occasions depending on the soil moisture status and plant water requirements.

The stability of cabbage accessions from different maturity groups was determined via head weight. The time and degree of head maturity were determined based on visual observation and head compactness. Thirty plants were analyzed per replicate and cabbage accessions.

The experimental field has a temperate continental climate with some specific characteristics, such as a wide interval between the highest and lowest mean monthly temperature (21.4°C in July and -1.3°C in January, respectively). In the Vojvodina province (where the experimental field is located), the precipitation regime in general and the distribution of precipitation in particular are in part typical of those found in Central Europe/ the Danube region, that is, there are extremely rainy periods in early summer (June) and periods with little or no precipitation (October and March), (www.hidmet.gov.rs). A brief description of the climatic conditions of each year is shown in Table 2.

### Statistical analysis

Consequently, when trying to identify the desirable genotypes by means of the regression approach, one is left with the three parameters: The regression coefficients, the means and the deviation mean square. The two latter are the most important (Davik, 1989).

Statistical analysis of head weight was done using variance analysis of a two-factorial trial according to Hadzivukovic (1989), while genotype stability for the trait in question was analyzed by the regression analysis method (Eberhart and Russell, 1966):

$$Y_{ij} = \mu_i + b_i I_j + \delta_{ij} \qquad (i = 1, 2,....t, \text{ a } j = 1, 2,.....s)$$

Where, $Y_{ij}$ is the average of i-th genotype in j-th environment; $\mu_i$ is the average of all variants in all environments; $b_i$ is the regression coefficient of i-th genotype for location index which tests genotype response to different locations; $\delta_{ij}$ is the deviation from regression of i-th genotype in j-th environment; $I_j$ is the ecological index of location.

We calculated the following stability parameters:

Regression coefficient:

$$b_i = \Sigma Y_{ij} I_j / \Sigma I^2_j$$

j j

Deviation from linear regression:

$$S^2_d = \Sigma dij /(n-2) - S^2_e /r$$

$S^2_e /r$ = assessment of pooled error.

This method enables us to calculate the trait's coefficient of linear regression (bi) for each accessions relative to the genotype mean in each environment. Standard deviation from regression is also calculated for each accessions. Theoretically, stable accessions have bi = 1.00 and a regression deviation of $Sd^2i = 0.00$. Parameter stability was assessed by the F test (Singh and Chaudary, 1979).

## RESULTS

Our analysis of variance of the cabbage accessions indicates the presence of statistically significant differences among the cabbage accessions as well as the presence of the genotype x year interaction.

The results of our study are in agreement with those of Prasad et al. (1989), who reported highly significant differences and interactions between the years and cabbage accessions in their study. This leads to the conclusion that the year effects can often present a limiting factor in the formation of head weight.

**Table 3.** Types, head weight (kg), stability parameters and F-values of cabbage accessions.

| S/N | Cabbage accesson | Year | | | Average | $b_i$ | $Sd^2i$ | F-value | Yield tons/ha |
|---|---|---|---|---|---|---|---|---|---|
| | | 2000 | 2001 | 2002 | | | | | |
| 1 | Marcanata-F1 | 1.72 | 1.82 | 1.79 | 1.74 | 0.349 | 0.001 | 2.44 | 57.9 |
| 2 | Copenhagen market | 1.63 | 1.79 | 1.84 | 1.73 | 0.929 | 0.001 | 1.58 | 57.6 |
| 3 | Kopenhaski | 1.53 | 1.66 | 2.01 | 1.73 | 2.052 | 0.010 | 10.9** | 57.6 |
| 4 | Resistor-F1 | 1.58 | 1.61 | 1.70 | 1.61 | 0.485 | 0.001 | 1.26 | 53.6 |
| 5 | Balbro-F1 | 1.52 | 1.61 | 1.66 | 1.56 | 0.629 | -0.001 | 0.10 | 51.9 |
| 6 | Ditmar | 1.37 | 1.36 | 1.43 | 1.36 | 0.238 | 0.001 | 1.05 | 45.3 |
| 7 | Prva zetva | 1.32 | 1.38 | 1.38 | 1.34 | 0.265 | -0.001 | 0.48 | 44.6 |
| 8 | Nosomi-F1 | 0.82 | 0.87 | 1.03 | 0.91 | 0.902 | 0.002 | 2.84 | 30.3 |
| 9 | Elisa-F1 | 0.83 | 0.87 | 1.09 | 0.91 | 1.098 | 0.005 | 6.19* | 30.3 |
| 10 | Grenadier-F1 | 1.83 | 1.91 | 2.04 | 1.91 | 0.938 | 0.001 | 0.87 | 54.4 |
| 11 | Pructor-F1 | 0.91 | 1.11 | 1.18 | 1.03 | 1.221 | 0.001 | 1.63 | 29.4 |
| 12 | Tucana-F1 | 0.86 | 0.93 | 1.19 | 0.97 | 1.402 | 0.006 | 7.22** | 27.6 |
| 13 | Futoski | 2.18 | 2.46 | 2.61 | 2.41 | 1.875 | 0.001 | 1.36 | 68.6 |
| 14 | Srpski melez | 1.98 | 2.36 | 2.53 | 2.26 | 2.422 | 0.003 | 4.02* | 64.4 |
| 15 | SG-3014 | 1.95 | 2.27 | 2.28 | 2.17 | 1.459 | 0.011 | 11.92** | 61.8 |
| 16 | Late flat dutch | 1.97 | 2.03 | 2.15 | 2.03 | 0.792 | 0.001 | 0.97 | 57.8 |
| 17 | Slava | 1.63 | 1.91 | 2.08 | 1.86 | 1.975 | 0.001 | 0.87 | 53.1 |
| 18 | Quisto-F1 | 1.58 | 1.66 | 1.64 | 1.61 | 0.287 | 0.001 | 1.33 | 45.8 |
| 19 | Castelo-F1 | 1.51 | 1.58 | 1.61 | 1.53 | 0.415 | 0.001 | 0.56 | 43.6 |
| 20 | Ljubljanski | 1.24 | 1.44 | 1.45 | 1.36 | 0.924 | 0.004 | 4.97* | 38.7 |
| 21 | Rodeo-F1 | 0.81 | 0.74 | 0.88 | 0.81 | 0.340 | 0.006 | 6.58* | 23.1 |
| | Average years | 1.46 | 1.59 | 1.69 | 1.58 | | | | |

Gvozdanovic et al. (2004) conducted a three-year study on autumn garlic and found that climatic factors had a significant influence on the formation of bulb mass and yield during the period analyzed.

Most of the accessions responded the same to changes in environmental factors over the growing season (precipitation, temperature), that is, their head weight dropped in the extremely dry year 2000. However, it must be stressed that there was sufficient soil moisture, that is, the cabbage heads suffered only from low humidity (such as high daily temperatures), as confirmed by the fact that 2000 had the smallest overall mean for head weight of all three study years (Table 2).

The average head weight across the cabbage accessions over the three growing seasons was 1.58 kg. In the first year of study, the average head weight across the accessions was 1.46 kg, although, it has to be noted that this was the year with the lowest average of the three study years (Table 3). The average head weight was the lowest in 2000 because of the negative influence of high daily temperatures and small amounts of rainfall throughout the growing season.

The head weight mean in the second year was 1.59 kg and was almost the same as the overall value of this trait across the cabbage accessions. The third year had the largest average head weight value of all three study years of 1.69 kg. This was a result of optimal temperatures and evenly distributed rainfall during the growing season. The results show that the climatic conditions (temperature and precipitation) differed during the three years of the study. The variations in climatic factors led to significant differences in head weight variation not only among the different types of cabbage but also within each type itself. The variability obtained in the study is another confirmation of the significant influence of climatic factors (temperature and precipitation) on head weight formation, which has a direct effect on yield. The largest average head weight across the study years was found in the Futoski population (2.41 kg), and the Srpski melez, SG-3014 and late flat dutch accessions also had very large heads. The lowest value of this trait was recorded in Rodeo-F1 (0.74 kg), while the largest differences between the minimum and maximum values were observed in Futoski, Kopenhaski, Slava and Srpski melez, where the differences between the first and second year ranged from 0.43 to 0.55 kg. We can also see that many of F1-hybrids had a more uniform performance over varying environmental conditions than the varieties with which it was compared (Table 3).

Figure 1 provides the real picture of how the means rank changed across the years as well as of the interaction involved. At the bottom of the figure, we can see that a particular group of genotypes stands apart

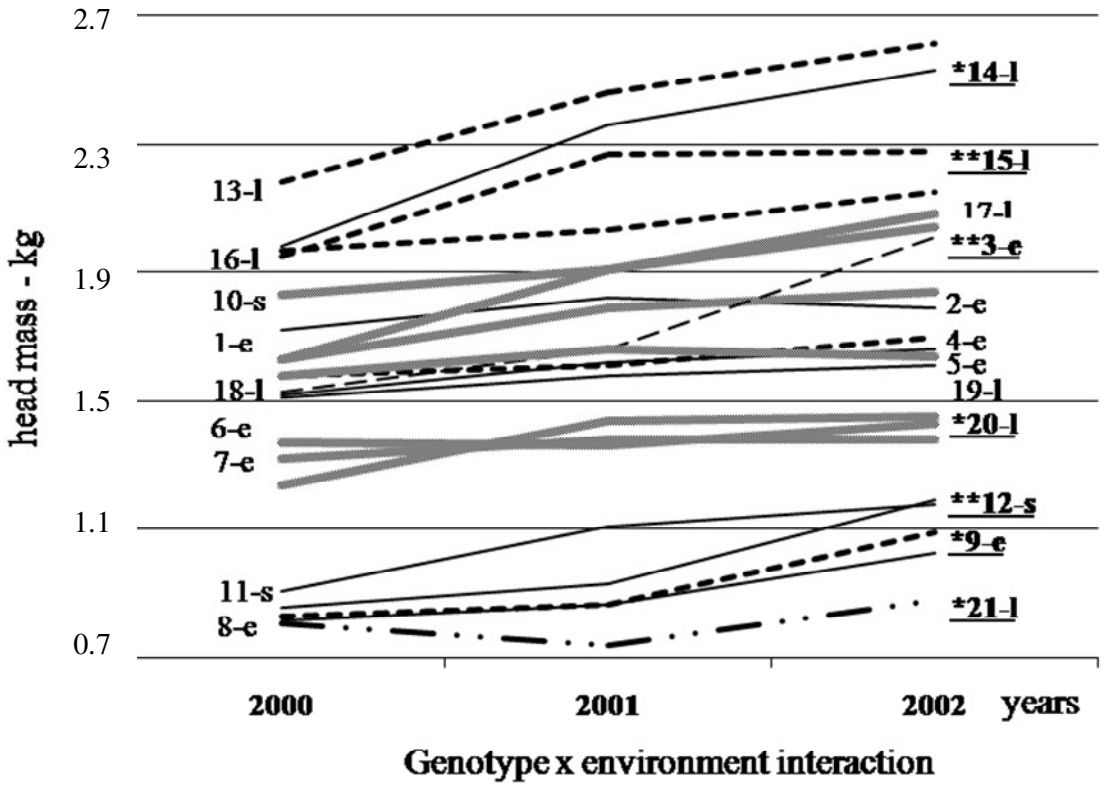


**Figure 1.** Changes in the ranking of cabbages accessins over three growing seasons (names of cabbage accessions are the same as numbers in Table 1).

from the others. These are the cabbage accessions with a short growing season and a smaller head weight.

The figure also shows what type of interaction was involved and in which of the genotypes (Kang, 1993). Looking at the data, we can see that Prva zetva, Ditmar and Quisto-F1 had the smallest variation of head weight across the years. The difference between the smallest and largest average heads ranged between 0.06 and 0.08 kg. A similar level of difference was found in Marcanta-F1, Resistor-F1 and Castelo-F1, as well (Table 3).

Analysis of stability parameters for head weight showed the following cabbage accessions to be very stable: Grenadier-F1 ($b_i$-0.94; $Sd^2i$-0.001), Copenhagen market and Ljubljanski. Grenadier-F1 and Copenhagen market had a larger average head weight than the overall average and Ljubljanski had a lower one (Table 3).

Pructor-F1, Futoski and Slava had a coefficient of regression larger than 1.1 and belong to cabbage accessions that are better adapted to more favorable conditions (optimal temperature and evenly distributed rainfall during the growing season) that is, their response consists in the production of a larger head weight and maximum yields.

The stability parameters were assessed using the F test. Statistically highly significant deviations from the regression line were found in Kopenhaski, Srpski melez, Ljubljanski, Sg-3014, Rodeo-F1, Tucana-F1 and Elisa-F1 (Table 3, Figure 2).

The F1-hybrids Grenadier-F1, Nosomi-F1 and Balbro-F1 and the cultivars Copenhagen market and Late flat dutch had regression coefficients below the value of 1 and should therefore be better adapted to somewhat poorer environmental conditions (high daily temperatures, small amounts of rainfall) than to more favorable ones. This means that they are better adapted to agroecological environments with a lower potential. Kopenhaski, Sg-3014 and Tucana-F1 were shown to be fairly stable; however, we can see that their head weights differed considerably. This difference is noticeable with the three-year average as well. Also, it needs to be said that these three cabbage accessions belong in three different maturity groups and, hence, have different head weights as a result (Table 3).

## DISCUSSION

Our results are in agreement with those of Davik (1989), who reported that the regression method is difficult to apply when identification of desirable cabbage accessions is the objective. The results of the method depend too much on the samples of both cabbage accessions and environments, leading to low reliability and stability

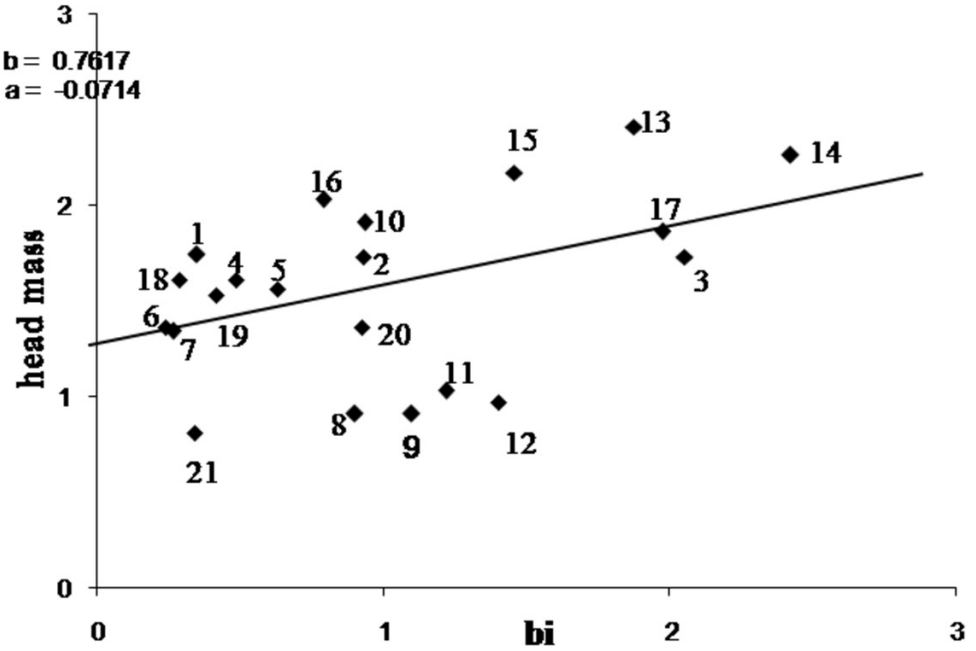


**Figure 2.** The relation of head mass and stability of 21 cabbage accessions in the year 2000 to 2002 (names of cabbage accesssions are the same as numbers in Table 1).

of the estimated parameters. Making a decision about identification of desirable cabbage accessions thus, becomes very difficult.

Cabbage accessions may have a low or a high coefficient of regression and still perform above the average in the chosen environment. Thus, these coefficients should be regarded as additional information on the average response of accessions to a set of environmental conditions (Davik, 1989). The deviation mean squares should, however, be low (Becker and Leon, 1988).

Process of breeding involves a comparison of experimental F1-hybrids against commercial cultivars and F1-hybrids. According to Gowers (2000), emphasis should be placed in the breeding of cole crops on the uniformity of the desirable characters. Results of Tanaka et al. (2009) suggested that useful criterion for the selection of parents for early-head-forming F1-hybrid cultivars is the leaf position at which head formation start. They concluded that this trait is inherited additively with high narrow-sense heritability. The earliness of head formation is defined as the number of days after transplanting required for the head to attain the target commercial weight.

In practicing crop production aimed at obtaining as high and stable yields as possible in an economical way, it is essential to know how accessions will behave in different agroecological conditions of growing. That is why the goal of all scientists involved in crop production is to develop cultivars and F1-hybrids that will produce high and stable yields provided optimum cultural practice and proper regional distribution are applied (Bocanski et al., 2000). Based on the results of Cravero et al., (2010), farmers are most interested in varieties that produce consistent yields under their growing conditions and breeders also want to fulfill these needs. For intensive cabbage production, it is necessary to have appropriate cultivars. Although, the available domestic cultivars are suitable for fresh con-sumption and sauerkraut making, local growers prefer to grow foreign cultivars (Cervenski et al., 2010).

Head weight is a variable trait that is influenced by environmental factors. This is especially pronounced if head weight is regarded as yield that is a function of growing period length and plant density. Among the early cabbage accessions, the highest-yielding ones were Marcanta-F1, Copenhagen market, Kopenhaski, Resistor-F1 and Balbro-F1. Grenadier-F1 was the highest-yielding summer cabbage, while Futoski, Srpski melez, SG-3014, Late flat dutch, Slava, and Qusto-F1 were the highest-yielding late ones (Table 3).

In conclusion, the domestic and domesticated varieties proved to be reliable and useful materials under the investigated conditions as they were shown to have a wide range of adaptability in the growing environment concerned. From the standpoint of breeding, they can be used as a source of stability when it comes to the adaptive response to a growing environment, yield stability or even resistance to certain diseases or pests. The studied F1-hybrids, on the other hand are a product of breeding aimed at satisfying a pre-defined set of requirements specified by crop growers. As a result, they

do not necessarily always meet to the full extent of a particular set of growing conditions. For this reason, some F1-hybrids will sometimes be grown in a given area for fewer years and will not be embraced by the growers.

The following cabbage accessions proved stable over the three-year period analyzed in our study: Copenhagen market (an early variety), Grenadier-F1 (a summer cabbage) and Ljubljanski (a late variety). These cabbage accessions are good materials for breeding purposes, because in addition to having good head weight stability they also have other good qualitative traits. In the present study, stable cabbage accessions were distributed equally among the different maturity groups investigated. Still, the major climatic factors were very variable over the three study years (including the occurrence of above-average temperatures in the second year), the early F1-hybrids exhibited high levels of head weight stability. This means that cabbage accessions with a shorter growing season will be better able to withstand less favorable growing conditions, as they are exposed to stress conditions for a shorter period of time. When growing cabbage in the summer, the F1-hybrid Grenadier is a reliable choice. If cabbages are grown in more intensive conditions, the most suitable cabbage accessions are the late varieties Futoski and Slava and the summer F1-hybrid Pructor.

For obtaining a satisfactory head weight, in addition to the agroecological conditions present and agronomic practices used, the choice of the right F1-hybrid or cultivar for a particular area is of great importance as well. The correct choice of F1-hybrid or cultivar for a given area should allow genes that control head weight to fully express themselves, that is, to minimize the effects of limiting environmental factors. Therefore, identification of desirable cabbage accessions depends not only on the environments included in the study, but also on the particular set of cabbage accessions tested.

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