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Adaptive capabilities and productive potential of initial material from peas (*Pisum sativum*)

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ABSTRACT

The productivity of crops is related to their adaptive potential to the soil and climatic conditions of the environment. In this work the adaptive properties of seven pea (*Pisum sativum* L.) varieties were studied on the root length, dry root mass weight, number of nodules and number of leaves/plant. The study was conducted in 2014-2016 in the experimental field of the Institute of Forage Crops, Pleven, Bulgaria. Peas varieties in the complex of proanalyzed characteristics can be distributed as follows: Wt6803 combines high stability (bi = 1.04, 0.54), homeostaticity (Hom = 9.43, 40.96) and productivity (54.11, 73.42) by number of nodules and number of leaves/plant. The variety Mir has high values of the studied traits and was characterized by the same high degree of both, plasticity and stability. X07P54, X06PWY, NDPO80138-B-2 and CA1P were stable (bi <1) and showed high homeostasis for most signs but are low productive. L020140 had a mean expression of the signs and was sensitive to changes in environmental conditions (bi> 1) by number of leaves per plant and dry root mass weight. The varieties Wt6803, Mir and L020140 represent a specific selective value by number of nodules (43.34, 7.51, 15.81) and number of leaves/plant (57.87, 62.57, 27.54) and can be used to create new genetic diversity, and the selection should be not only aimed at increasing the upper productivity threshold but also at the lower.

Key words: Adaptability, Peas, Productivity, Stability

Legumes are the main source of food protein in many densely populated countries. Peas (*Pisum sativum* L.) occupy a leading position from the legumes spread in the temperate climate. It is one of the main crops suitable for growing in different soil and climatic conditions. Due to its high plasticity, cold resistance and early ripening, peas have a wide distribution range (Zotikov and Borovlev 2008).

The use of peas is multifaceted and varied, i.e. as food in the form of mature seeds, such as green peas in the canning industry, as feed for cereal fodder, green fodder, silage, hay in fodder production (Ashiev 2014).

Peas serve as an important factor in biological intensification as a culture enriching the soil with biological nitrogen. The use of the nitrogen fixation potential of legumes, including peas, allows to save mineral nitrogen (Zubov and Katyuk 2007).

However, in recent years there has been a fluctuation in the area planted with peas. The reasons for this are poor accessibility to mechanized harvesting, lodging, uneven ripening, low adaptability of newly created varieties to extreme environmental conditions. In connection with rising energy resource prices, there is a need for varieties that do not require intensive agro-technology and can produce stable yields in natural soil fertility (Katyuk *et al.* 2014).

The expansion of pea production is limited by the significant differences in yields in individual years. Stabilizing the potential of crops at a high level requires the complex application of selection and agro technological methods, among which great importance is attached to the creation of varieties with high stable and productive potential. The knowledge of the adaptive features and the change in the structure of plants under different conditions for growing are of practical interest in this direction (Medvedev 2011, Fadeev 2014).

Genetic analysis methods based on genotyping testing in different environments allow identifying their general and specific adaptability as well as their stability (Kilchevsky and Khotyleva 1985a, b). They allow to determine the selective value of the genotype and to make a successful selection by adaptability depending on the selection task. These methods are widely used in assessing the adaptability and selection value of promising selection materials and varieties in the selection programs of many crops (Sandukhadze and Zhuravleva 2008).

The aim of the study was to select competitive, high-yield pea genotypes, adapted to the soil and climatic conditions of central northern Bulgaria, using appropriate

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statistical methods.

MATERIALS AND METHODS

The study was conducted in 2014-2016 in the experimental field of the Institute of Forage Crops, Pleven, Bulgaria. Plant material from aboveground and root biomass of 7 peas varieties originating in the country and abroad, i.e X07P54, X06PWY, NDPO80138-B-2, CA1P, L020140, Wt6803 and Mir was analyzed. Sowing was carried out manually in optimal time, according to the technology of cultivation of pea.

The following characteristics have been assessing in the beginning of flowering stage after soil monoliths taking and washing the roots of the plants with water: root mass length (cm), dry root mass weight (g), number of nodules/plant and for the aboveground mass - number of leaves/plant. Biometric measurements were made to 10 plants of each variety.

From the methods for the quantitative assessment of the parameters of plasticity and stability, the Kilchevsky and Khotyleva method (1985a, b) was used in the present study. This method is based on variety testing in different environments (years) and allows to reveal general adaptive ability (GAA) and specific adaptive ability (SAA) and their stability (Sgi), criterion for the estimation of genotype ability to enter into interaction with the environment (G×E) gi, as well as the selective value of genotype and stable forms. According to the presented method, the general adaptive ability (GAA) characterizes the mean value of the sign under different environmental conditions and the specific adaptive ability (SAA) as a deviation from the general adaptive ability (GAA) in a particular environment.

The stress resistance (Y) of varieties by Rossielle and Hamblin (1981) method was determined. Homeostaticity (Hom) was calculated by the method of Khangildin (1984), the variety stability (VS) by Nettevich (2001).

The analysis of adaptability were performed according to the methods proposed by Nascimento *et al*. (2009), stability parameter Finlay and Wilkinson (1963) and Francis and Kannenberg (1978).

All experimental data were processed statistically with using the computer software GENES 2009.7.0 and Excel for Windows XP (Cruz 2009).

RESULTS AND DISCUSSION

The study period covers three consecutive years differing in climatic terms. Table 1 presents the data on average monthly temperatures and the amount of precipitated rainfall by months during vegetation. The vegetation 2014 is the most favorable with average monthly air temperatures for April 12.3 °C, May 16.7 °C and June 20.6 °C, and rainfall 139.8 l/m^2, 83.0 l/m^2 and 54.3 l/m^2, respectively. As a result of the balanced combination of air temperature and optimum rainfall it has been favorable for plant development. The second year (2015) has relatively higher temperatures in May of 18.8 °C and uneven precipitation distribution, characterized by a certain drought in April (43.6 l/m^2) and May (30.6 l/m^2), and a larger quantity in June (95.7 l/m^2). The third year (2016) occupies an intermediate position over the other two years with temperatures in the months of April and May, close to normal (15.3-16.4 °C) and rainfall between 73.1 and 76.5 l/m^2.

The response of the individual variety to the specific conditions of the vegetation period can be determined by the ratio of productivity (yield) to the average productivity (yield) for the studied group of varieties. At the same time, the value of a given parameter may be expressed as a percentage or as a coefficient of adaptability. The value of the parameter can be judged whether the variety is adaptive or productive. Under unfavorable conditions, the potential productivity is poor, and adaptability, on the contrary, is more pronounced (Chirko 2009).

Coefficient of regression (bi) of Finlay and Wilkinson (1963) in variety NDPO80138-B-2 and especially in the Mir the number of nodules per plant exceeds one (bi> 1), which places them in a group of ecologically unstable varieties but responsive to growing conditions (Table 2). The calculated value of the ecological stability parameter (bi) determines the Wt6803 as close to the ideal type (bi = 1.04), suitable for growing in a wide range of environment. X06PWY is also stable (bi = 1.01) and with good responsiveness, but has no advantage over Wt6803 due to the lower expression of the traits value.

The Wt6803 showed the highest general adaptive ability (GAA = 24.19), relative stability (Sgi=20.62) and selective value of genotype (SVG = 43.34). The control variety Mir in this indicator occupies a second position (GAA =

Table 1 Climatic characterization of the experimental period

Months	2014			2015			2016		
	t (°C)	Rainfall (l/m^2)	Humidity (%)	t (°C)	Rainfall (l/m^2)	Humidity (%)	t (°C)	Rainfall (l/m^2)	Humidity (%)
I	0.8	41.8	82.0	1.9	12.4	80.0	-0.5	98.0	78.0
II	2.3	3.4	82.0	2.3	39.2	80.0	8.7	46.0	75.0
III	9.7	76.9	68.0	6.7	68.4	71.0	8.5	76.6	73.0
IV	12.3	139.8	76.0	12.2	43.6	54.0	15.3	73.1	66.0
V	16.7	83.0	70.0	18.8	30.6	66.0	16.4	76.5	71.0
VI	20.6	54.3	67.0	20.7	95.7	64.0	23.0	45.8	67.0
VII	23.1	71.8	67.0	25.8	21.5	54.0	24.6	7.8	57.0

Table 2 Parameters of adaptability and stability in peas varieties

Varietiys	bi	GxEgi	SAA	Sgi (%)	GAA	SVG
			Number of nodules/plant			
X07P54	0.51**	9.34	2.72	25.75	-19.36	7.93
X06PWY	1.01	-28.51	10.85	73.23	-15.10	4.35
NDPO80138-B-2	1.16	24.17	14.66	59.70	-5.36	10.41
CA1P	0.01	261.92	10.17	40.65	-4.89	15.21
L020140	0.02**	526.22	19.41	56.20	4.62	15.81
Wt6803	1.04	-32.84	11.16	20.62	24.19	43.34
Mir	3.27**	752.29	39.70	86.66	15.90	7.51
			Number of leaves/plant			
X07P54	1.82**	54.80	17.49	55.94	-25.15	-3.61
X06PWY	0.09	340.88	8.43	20.18	-14.65	24.96
NDPO80138-B-2	1.62**	94.07	17.51	32.20	-2.02	19.48
CA1P	0.51**	24.91	4.99	12.84	-17.55	28.91
L020140	2.20**	128.81	21.28	30.41	13.56	27.54
Wt6803	0.54**	54.70	7.80	10.62	17.00	57.87
Mir	1.20**	-2.11	11.37	13.34	28.82	62.57
			Length of root mass (cm)			
X07P54	0.38**	6.28	0.87	8.30	-4.66	8.82
X06PWY	0.44**	4.74	1.30	10.01	-2.10	10.55
NDPO80138-B-2	0.51**	5.24	2.30	19.50	-3.33	7.43
CA1P	0.06	25.40	1.15	8.90	-2.19	10.75
L020140	1.06	7.54	5.57	36.61	0.08	4.64
Wt6803	2.31**	35.08	10.55	45.42	8.09	3.20
Mir	2.36**	36.22	10.69	55.62	4.10	-1.07
			Dry root mass weight (g)			
X07P54	0.47	0.0005	0.017	15.746	-0.08	0.08
X06PWY	1.21	0.0010	0.072	40.833	-0.02	0.07
NDPO80138-B-2	0.73	0.0002	0.039	21.626	-0.01	0.12
CA1P	0.03	0.0069	0.064	43.490	-0.05	0.05
L020140	1.34	0.0001	0.071	31.875	0.03	0.12
Wt6803	1.57	0.0017	0.090	34.771	0.06	0.12
Mir	1.64	0.0091	0.126	47.452	0.07	0.08

b_i -FW- Regression coefficient Finlay and Wilkinson's regression model; GAA - general adaptive ability; SAA - specific adaptive ability; Sgi - relative stability of the genotypes; σ^2CACi - variance of specific adaptability; Igi - organism's reaction to the cultivation place, σ(GxE)gi - criterion for estimation of the genotype ability to enter into interaction with environment; SVG - selective value of genotype.

24.19) but has a higher specific adaptive ability (SAA = 39.70) with a good response to changing environmental conditions ((G×E) gi = 752.29) and selective value below the average for the group varieties, indicating that this variety in separate years will retreat on the selection value compared to other varieties.

According to the values of the linear regression coefficient with respect to number of leaves/plant, interest is Wt6803 with bi = 0.54. The varieties X06PWY (bi = 0.09) and CA1P (bi = 0.51) are also stable in this pattern but fail to form more than 40 leaves/plant (Table 2) and have a very low general adaptive ability (GAA = 14.65; -17.55). They are not suitable for growing in conditions around and above the average, but they can be relied upon in case of environmental worsening.

The Mir standard, as well as L020140, X07P54 and NDPO80138-B-2 can be attributed to varieties with a highly predictable response to environmental conditions that are very well suited to improvements. They can be grown under favorable conditions, but in case of worsening, they may slightly retreat to others. According to the values of the parameters obtained by the Kilchevsky and Khotyleva method (1985a, b) by the number of leaves/plant, the Mir and Wt6803, which are the most productive, exceed the remaining varieties by relative stability of the genotypes (Sgi = 13.34; 10.62), general adaptive ability (GAA = 28.82; 17.00) and selective value of genotype (SVG = 62.57; 57.87). This allows success they to be used in the combinative selection to create a new genetic variety of hybrid forms with a greater number of leaves/plant.

According to the indicated stability level of the root mass length indicator, the low-productive varieties X07P54, X06PWY, NDPO80138-B-2 and CA1P can be assessed as stable with a linear regression coefficient significantly smaller than one (bi <1) CA1P. L020140 by trait value occupies a third position with a root length of about 22 cm. It has very good stability (bi = 1.06) and interacts better with environmental conditions than previous varieties. The Wt6803 and Mir varieties based on the bi and (G×E) gi parameters respond very strongly to changes in the environment. They meet the requirement to combine high productivity (root mass length) with high general adaptive ability (GAA = 8.09; 4.10) and good specific adaptive ability (SAA = 10.55; 10.69). Among the varieties tested, X06PWY and CA1P are distinguished by the relative stability of the genotype (Sgi) and the selective value of the genotype (SVG), although they do not exceed the Mir variety in terms of the quantitative expression of the trait.

The coefficient of linear regression on dry root mass weight was statistically insignificant and therefore pea varieties were evaluated by other parameters. On this basis, Mir and Wt6803 are very close to each other and exceed the rest, both in terms of its value and general adaptive capacity (0.06; 0.07) as well. By parameter selective value of genotype which unites general and specific adaptive ability the NDPO80138-B-2, L020140 and Mir have the advantage over the other varieties and are characterized by higher values (SVG = 0.12).

Homeostatistics and stress resistance

According to Kurkova *et al*. (2015) in the process of adapting the organism to sharper and longer-lasting changes in the external environment, the homeostasis may be insufficient, as a result of which a steady state passes into another, possibly less appropriate for the organism.

The homeostaticity parameter determines the varieties' ability to exhibit low variability of traits in different environments. Homeostasis is closely interrelated with the coefficient of variation and characterizes the stability of the trait in a changing environment. The largest homeostasis (Table 3) was found at Wt6803 (9.43) and CA1P (2.24), by number of nodules/plant and by the stress resistance at X07P54 and X06PWY, and by the number of leaves/plant at Wt6803 (40.96), Mir (26.20) and CA1P (17.80).

Relatively high homeostaticity and stress resistance with little difference in each other, exhibit CA1P (18.96; -4.20) and X06PWY (17.79; -4.38) by root length, and the lowest for Wt6803 and Mir varieties. The X07P54 and NDPO80138-B-2 are characterized by the highest stress resistance and homeostaticity in regard to the dry root mass weight.

The VS parameter (variety stability) is a complex parameter that allows simultaneous account to be taken of the level of productivity of the trait and its stability level. In the analyzed varieties, VS values show that Wt6803 and Mir occupy the first positions on almost all signs. Along the root mass length, X06PWY and CA1P are also evaluated as highly stable, confirming the assessment obtained from previous statistical methods.

The stability of the quantitative traits of the pea varieties is determined by different genetic bases. Combining them into one genotype is a good prerequisite for success in the selection process. The distribution of varieties of peas by the respective variation coefficient by the Francis and Kannenberg method (1978) is graphically represented in Fig 1.

Based on the proposed method varieties L020140 and Wt6803 can be identified as favorites, being stable and at the same time forming a large number of leaves and higher dry root mass weight as well.

Variety Wt6803 is the most stable and definitely stands better than others by the number of nodules/plant. X07P54, X06PWY, NDPO80138-B-2 and CA1P are relatively high variable with low expression of the trait and can not be assigned to varieties forming a large number of nodules.

By the root length trait, X07P54, X06PWY, NDPO80138-B-2 and CA1P are the closest to the beginning of the coordinate system and are poorly variable and low productive. In the opposite quadrant are Wt6803 and Mir,

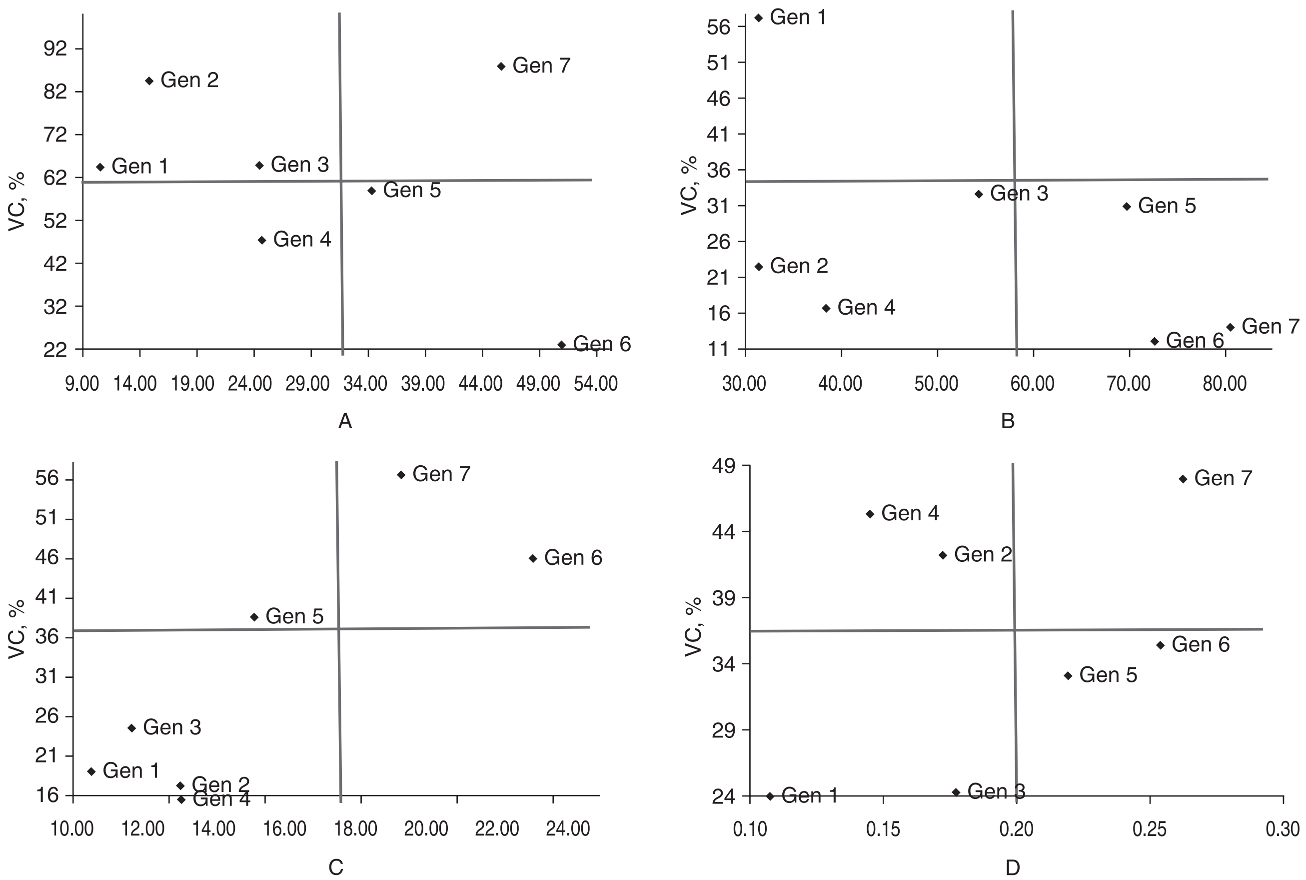

Fig 1 Stability (according to Francis and Kannenberg 1978) and distribution of varieties by the parameters studied in peas. A - Number of nodules/plant, B - Number of leaves/plant, C - Length of root mass, D - Dry root mass weight. Gen1 - X07P54, Gen 2 - X06PWY; Gen 3 - NDPO80138-B-2, Gen 4 - CA1P, Gen 5 - L020140, Gen 6 - Wt6803, Gen 7 - Mir.

Table 3 Parameters of homeostaticity (Hom) of peas varieties

Varietiys	Parameters				
	VS	X_{opt}	X_{lim}	Y- Stress resistance	Hom
Number of nodules/plant					
X07P54	1.734	18.25	5.42	-12.83	1.28
X06PWY	2.601	29.25	7.20	-22.05	0.46
NDPO80138-B-2	9.295	42.25	11.40	-30.85	1.23
CA1P	13.143	35.40	12.00	-23.40	2.24
L020140	20.213	56.80	16.80	-40.00	1.46
Wt6803	125.618	68.52	44.20	-24.32	9.43
Mir	23.931	90.24	12.00	-78.24	0.67
Number of leaves/plant					
X07P54	16.993	52.00	19.80	-32.20	1.69
X06PWY	42.892	50.80	32.00	-18.80	5.46
NDPO80138-B-2	89.380	72.00	36.00	-36.00	4.56
CA1P	89.918	45.00	32.00	-13.00	17.80
L020140	158.005	95.00	56.52	-38.48	5.87
Wt6803	446.605	78.05	63.20	-14.85	40.96
Mir	510.985	99.00	76.12	-22.88	26.20
Length of root mass (cm)					
X07P54	5.849	12.3	8.4	-3.90	14.33
X06PWY	10.097	15.175	10.8	-4.38	17.79
NDPO80138-B-2	5.668	14.78	9.00	-5.78	8.33
CA1P	10.300	15.00	10.8	-4.20	18.96
L020140	6.026	20.22	8.8	-11.42	3.47
Wt6803	11.708	35.55	16.6	-18.95	2.66
Mir	6.557	31.56	11.3	-20.26	1.68
Dry root mass weight (g)					
X07P54	0.0005	0.14	0.09	-0.05	12.10
X06PWY	0.0007	0.25	0.10	-0.15	2.80
NDPO80138-B-2	0.0013	0.23	0.14	-0.09	8.25
CA1P	0.0005	0.22	0.08	-0.14	2.33
L020140	0.0015	0.31	0.16	-0.15	4.51
Wt6803	0.0019	0.36	0.18	-0.18	4.05
Mir	0.0015	0.38	0.13	-0.25	2.30

X_{opt} – the average value on the sign with an optimal background on the growing, X_{lim}- the average value on the sign at limiting conditions of growing, Y- Stress resistance, VS - variety stability, Hom – homeostaticity.

whose plants have the longest roots but are also very variable, especially the Mir variety.

Rank analysis

The results of the rank analysis obtained by the centroid method proposed by Nascimento *et al*. (2009) to determine the adaptability of the varieties during the period of study indicate that there is a reassessment of genetic control over the signs tested when changing the limits of the environment (varieties change their rank) (Table 4). X07P54 is unsatisfactory with poor adaptation (rank IV) for all signs.

The same level of adaptation also shows NDPO80138-B-2 CA1P, except for the number of nodules/plant (rank IV). As such, along with the dry root mass weight, the Wt6803 occupies a stable first position (rank I) on the rank list, which defines it as a variety with the best general adaptation. The control variety Mir is rated I rank by number of leaves/plant and dry root mass weight. It has good adaptability under favorable conditions (rank VI) on the number of nodules and root mass length.

On average for the period of study the principal components analyses (PCA) graphically presented (Fig 2) shows that the varieties used differ significantly in their adaptive capability. The results of the rank analysis are confirmed and it is clear that with the best general adaptive ability of the number of nodules/plant and the length and weight of the root mass is Wt6803, by the number of leaves/plant and by the dry root mass weight is variety Mir.

According to Kadermas (2014), the adaptive selection should be directed not to the potential, but to the actual plant productivity. The author points out that usually in the selection programs the main task is to obtain genotypes with high potential productivity, its manifestation necessitates the creation of an increased agrophon, which, however, would be atypical for many areas of cultivation.

Zolotaryova (2012) found that adaptive ability depends primarily on the level of stability and effectiveness of the interaction of genotype in various limiting environments. The genes determining the productivity in individual varieties are distinguished from the stability control genes. For the purpose of combinative selection, genotypes with high general adaptive ability and productivity can be selected, and hybrid combinations can be selected by combining both parameters, i.e. high stability and productivity.

Abrosimova and Fadeeva (2015) expressed the view that selection work with only high-yielding genotypes would lead to a loss of their ecological stability. Since the average value of the trait and response to changes in environmental conditions are relatively independent and genetically determined, the selection process for enhancing environmental stability must be constantly monitored.

Türk *et al*. (2011) and Zelenov *et al*. (2014) in pea research reported that the selection of this crop should take into account features related to the morphology (type) of the leaves. The authors consider that in the grain direction, the semi-molded peas are of interest, and for forage is suitable the playophile type, which is characterized by a

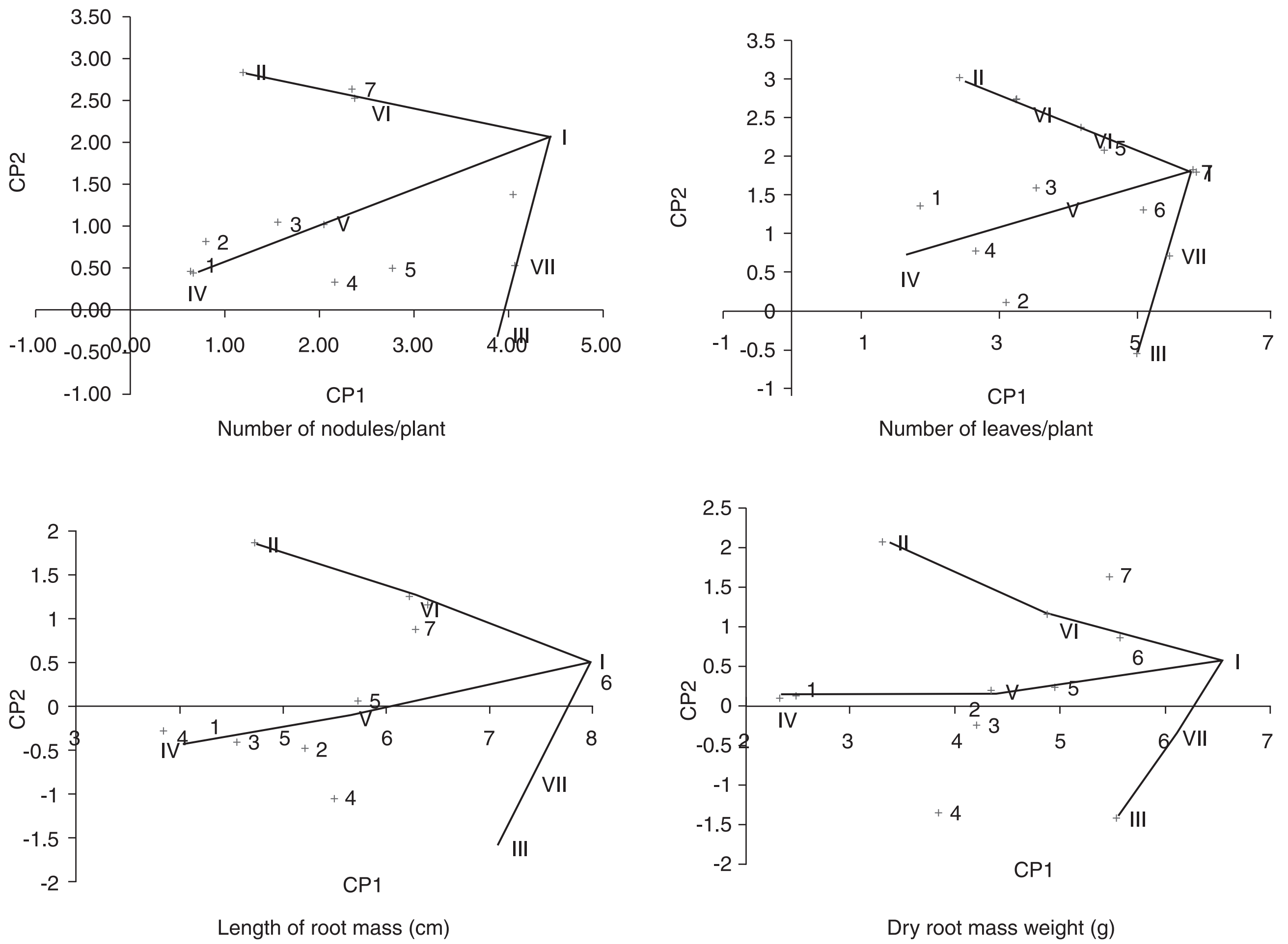

Fig 2 Graphical dispersion – Principal Components. I - high general adaptability; II/VI - specific adaptability to favorable environments; III/VII - specific adaptability to adverse environments; IV - Weak adaptability; V - Average adaptability. 1 - X07P54, 2 - X06PWY; 3 - NDPO80138-B-2, 4 - CA1P, 5 - L020140, 6 - Wt6803, 7 – Mir.

high intensity of photosynthesis and a balanced amino acid composition. The same authors find that peas with this type of leaves usually have low homeostaticity and instability of seed productivity.

Productivity and general adaptive ability show a strong positive relationship. In this way, the selection of new varieties adapted to a wide range of environmental conditions contributes to an increase in average productivity and yield when grown in different soil and climatic conditions.

When testing the varieties for a more objective and complete characterization as well as for the evaluation of a selection material, it is necessary to use a combination

Table 4 Estimation of parameters of adaptability of peas varieties for some parameters, based on the methodologies of centroid (Nascimento *et al.* 2009)

Variety	Number of nodules/plant	Rank	Number of leaves/plant	Rank	Length of root mass (cm)	Rank	Dry root mass weight (g)	Rank
X07P54	10.56^{a}	IV	31.27^{a}	IV	10.47^{a}	IV	0.11^{a}	IV
X06PWY	14.82^{a}	IV	31.10^{ab}	IV	13.03^{ab}	V	0.18^{abc}	V
NDPO80138-B-2	24.55^{ab}	V	54.40^{bc}	V	11.79^{ab}	IV	0.18^{abc}	V
CA1P	25.02^{ab}	V	38.87^{ab}	IV	12.93^{ab}	IV	0.15^{ab}	IV
L020140	34.54^{ab}	III	69.98^{cd}	VI	15.21^{abc}	V	0.22^{bc}	V
Wt6803	54.11^{b}	I	73.42^{cd}	VII	23.22^{c}	I	0.26^{c}	I
Mir	45.81^{b}	VI	85.24^{d}	I	19.22^{bc}	VI	0.27^{c}	I

Rank I: High general adaptability; Rank II: Specific adaptability to favorable environments; Rank III: Specific adaptability to adverse environments; Rank IV: Partially adapted; Rank V: Adaptability overall average; Rank VI: Specific adaptability to favorable environments; Rank VII: Adaptability specific to unfavorable environments. a, b, c, - statistically proven differences in P=0.05.

of different statistical models and parameters and the adaptability of the variety should be considered in terms of plasticity, stability and homeostaticity. The most adaptive in number of nodules, root mass length, and root mass weight were the plants of Wt6803, and in the number of leaves and dry root mass weight was Mir. These varieties are capable of forming relatively high and stable productivity not only in favorable but also under contrast conditions of the environment.

Thus, the assessment of adaptive capacity and stability by Kilchevsky and Khotyleva (1985a, b) methods increases the efficiency of the final stages of the selection process and reduces the possibility of making erroneous judgments in the choice of suitable varieties for growing in different environmental domains.

Conclusions

In the complex of proanalyzed characteristics the studied peas varieties can be distributed as follows: Wt6803 combines high stability (bi = 1.04, 0.54), homeostaticity (Hom = 9.43, 40.96) and productivity (54.11, 73.42) by number of nodules and number of leaves/plant, respectively. Variety Mir has high values of the studied features and is characterized by the same high degree of plasticity and stability. X07P54, X06PWY, NDPO80138-B-2 and CA1P are stable (bi <1) and have high homeostasis for most signs but are low productive. L020140 has a mean expression of the signs and is sensitive to changes in environmental conditions (bi> 1) by number of leaves/plant and dry root mass weight. The varieties Wt6803, Mir and L020140 represent a specific selective value by number of nodules (43.34, 7.51, 15.81) and number of leaves/plant (57.87, 62.57, 27.54) and can be used to create new genetic diversity, and the selection should be not only aimed at increasing the upper productivity threshold but also at the lower.

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