Emirates Journal of Food and Agriculture. 2015. 27(12): 903-910
doi: 10.9755/ejfa.2015-04-172
http://www.ejfa.me/

REGULAR ARTICLE

Stability analysis for seed yield in vetch cultivars

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ABSTRACT

During the period 2012 -2014 was conducted a field trial with seven vetch cultivars: Six Moldavian cultivars Liya, Lorina, Vilena, Moldovskaya (belonging to *Vicia sativa* L.), Violeta and Viola (belonging to *Vicia villosa* Roth.) and one Bulgarian cultivar Obrazets 666 (belonging to *Vicia sativa* L.). The performance, adaptability and stability of the tested cultivars were determined in relation to some quantitative traits). Traits such as plant height, pods per plant, seeds per plant, 1000 seed weight and seed yield showed a significant genotype × environment interaction which shows the participation of different gene systems in their control. In regard of these traits were calculated parameters of phenotypic stability and selection-valuable genotypes were determined. The cultivar Moldovskaya could be revolved as close to the excellent type (bi ≈ 1.0), propitious for growing a vast environment. Liya and Obrazets 666 were determined as unstable (bi > 1) but with good responsiveness, providing them high yields at moderate environmental conditions. Cultivars Liya and Obrazets 666 could be defined as stable and with good responsiveness (bi = 1.07 - 1.11), but because of lower yields they do not have priority over others. From viewpoint of selection, cultivars Moldovskaya, Liya and Obrazets 666 are suitable for including in breeding programmes and developing new vetch lines with steady yields.

Keywords: Adaptability; Breeding; Grain yield; Traits; Vetch

INTRODUCTION

Species from genus *Vicia* L. (vetches) are multi-purpose crops and allow usage as grain, hay, fodder conservation, and at the same time provide options for green manure and grazing. In regard of their end use, they are different in some degree from food legumes. Several species could be determined as alternative crops including *Vicia sativa* L. and *Vicia villosa* Roth. (Francis et al., 1999). Pod shattering, a typical wild habit characteristic, is a main limitation in the use of many grain crops, but *V. sativa* and *V. villosa* possess non-shaterring pods and excellent agronomic characteristics (Abd et al., 1995).

Common vetch (*Vicia sativa*) is widely distributed all over the world of the vetches due to its high and stable yields and reliable seed production (Mihailović et al., 2005; Abbasi et al., 2014). Second place in the area of vetch cultivation in the world occupies hairy (winter) vetch (*Vicia villosa*). It is high prized because of huge and qualitative herbage, hay yields, resistance to pests and diseases. In addition, hairy vetch is tolerant to the biotic stresses and abiotic stress (especially frost) and this ensures reliable production. In comparison with the other *Vicia* spp, the seed yields are low, but it could be improved by using pollinators because this species is with a substantial degree of outcrossing (Zhang and Mosjidis, 1995).

Developing high yielding cultivars was usually the main purpose of breeding programs in past. Now, Now, they are aimed creating cultivars with stable and sustainable yields under various environmental conditions, not only high-productive cultivars (Fikere et al., 2009). The high yield is often associated with decreased yield stability (Padi, 2007).

Expression of a gene can be modified (to be increased or decreased) through regulatory cell mechanisms in response to change of environmental factors. Genotype can express a number of phenotypes known as reaction rate. Genotype-environment interaction leads to rearrange of varieties in change of environmental conditions. It complicates the breeding process. In farm production are preferred varieties, possessing high yields, phenotypic stability and other valuable traits (Rédei, 1998; Dechev, 2004).

The environmental factors that affect the performance of genotypes change depends on regions and years. Interaction between genotype and environment reduces

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Received: 05 May 2015; **Revised:** 26 October 2015; **Accepted:** 28 October 2015; **Published Online:** 28 October 2015

the relationship between phenotypic and genotypic values. It could resulted to weak performance of the genotypes in different environmental conditions (Bilgin and Korkut, 2000; Toker, 2004). Productivity is a phenotypic expression of the variety's genotype (G) in interaction with the environment (E). It should be not only high but also stable by years and environments (Genchev, 2011).

The response of genotypes to different environments is defined as genotype × environment interaction which is important in determining adaptation and stability of new genotypes (Beyene et al., 2011). Increasing feed supply for livestock is related to development of stable vetch cultivars which distinguished high adaptability and productivity. Genotype × environment interaction was studied by several researchers in some vetch species (Firincioglu et al., 2009; Orak and Nizam, 2009; Yucel et al., 2009).

For assessment of adaptability and stability are known different methods: Methods related to analysis of variance (Plaisted and Peterson, 1959; Wricke, 1965; Annicchiarico, 1992), simple linear regression analysis (Theil, 1950; Finlay and Wikinson, 1963; Eberhart and Russel, 1966; Tai, 1971), nonparametric analysis (Lin et al., 1988; Becker and Leon, 1988), bi-segmented regression (Cruz et al., 1989), quadratic regression (Brasil and Chaves, 1994) and etc.

The object of this study was to evaluate genotype × environment interactions of seven vetch cultivars in regard of seed yield and its components and to establish their stability as primary material for future breeding programmes.

MATERIALS AND METHODS

A field trial was carried out from 2012 to 2014 at the Second Experimental Field of the Institute of Forage Crops, Pleven (43.41ºN, 24.61ºE), situated in the central part of the Danube hilly plain. Six Moldavian vetch cultivars were included in the trial namely Liya, Lorina, Vilena, Moldovskaya (belonging to *Vicia sativa* L.), Violeta and Viola (belonging to *Vicia villosa* Roth.) and one Bulgarian cultivar namely Obrazets 666 (belonging to *Vicia sativa* L.). Moldavian cultivars are newly created and highly productive. There are only two vetch cultivars presented in the Official catalogue of Bulgaria, one of which is Obrazets 666. The trial was set up as a randomised block design method with three replications and with a plot size of 4 m^2 (1.0 m × 4.0 m). The sowing was done by hand, at the end of March, at a depth of 4 cm and with a rate of 220 viable seeds m^{-2}. The chemical composition of a haplic loamy chernozem soil is given in Table 1. The data show that the soil is slightly acidic, poor hydrolysable nitrogen, moderate

Table 1: Chemical composition of the chernozem soil during the trial in Pleven (2012-2014)

Humus (%)	Nitrogen (mg 10^{-3} soil)	Phosphorus (mg 10^{-2} soil)	Potassium (mg 10^{-2} soil)	pH in KCl	pH in H_2O
2.48	0.225	4.29	31.1	5.87	6.54

phosphorus and rich total potassium. The plants were cultivated in conditions of organic farming (without use of any fertilizers and pesticides). Weeds were controlled mechanically during growth period. Ten randomly selected plants from each unit were marked and used to estimate yield components – plant height (cm); pods per plant, stem (mm) and length (cm) of the pod,; number of seeds and pods per plant, seed weight per plant (g), and 1000 seed weight (g). For seed yield (kg da^{-1}) data for each cultivar was recorded on the basis of seed yield per plot at the end of growing season. The obtained data were processed by two-factor analysis of variance for each trait for determine of effects of genotypes (G), (E) environments and genotype environment interaction (G × E). The estimation of the ecological stability of the tested cultivars was done through the application of following methods: Regression analysis - according to Eberhart and Russell (1966), in which the regression coefficient (bi) and the variance of the deviations from regression (Si^2) were calculated; Tai (1979), (ai; λi); Theil (1950), (T); analysis of variance – mean variance component (PP) according to Plasteid and Peterson (1959); ecovalence (W^2), Wricke (1965). Plaisted and Peterson's (1959) mean variance component (PP) was a measure of a variety's contribution to the GE interaction and was computed from a total of pair-wise analysis. Annicchiarico's method proposed a reliability index (W_i) which estimates the probability of a particular genotype (cultivar) to present a performance bellow the environmental average or below any standard used. GGE biplot model was done, which uses singular value decomposition of first two principal components (Yan, 2002).

The experimental data were processed statistically with using the computer software GENES 2009.7.0 for Windows XP (Cruz, 2009). With the help of the software – Plant breeding tools 1.2 were performed principal component analysis (PCA) and GGE biplot analysis.

RESULTS AND DISCUSSION

The new varieties must be distinguished with high and stable yields over a wide range of ecological conditions. Dispersion and regression analyses were used for estimating the ecological stability and adaptability of the tested cultivars. For quantitative estimation of the ecological stability and adaptability of cultivars were used dispersion and regression analyses. Dispersion analysis (ANOVA) mainly reflects additive effects of the trait and regression analysis provides information on the additive effects as well as for one part of its interaction with the environment (Zobel et al., 1988).

The digression of empirical data on the average reaction of the genotypes in each condition of environment is determined as ecological stability by Pakudin and Lopatina (1984). Single trial years were used as the factor of environmental conditions. Some monthly meteorological data during the growth period are presented in Fig. 1. The meteorological conditions during experimental period are differed considerably. The average daily air temperature in 2012 (March-April) was by 1.2 and 1.5 ^{0}C higher as compared to those in 2013 and 2014, respectively. The high temperature in 2012 coupled with lower sum (with 172.9 and 226.9 mm as compared to 2013 and 2014, respectively) of vegetation rainfalls determined this year as drier and unfavorable for plant development. Considerably greater amount of rainfalls in 2014, their even distribution, as well as lower temperature (not exceeding 24 ^{0}C) created favorable conditions for plant growth and development. The intermediate position had 2013.

Dispersion analysis was used to assess the genotype-environment interaction. If the gradations of the factor conditions are not untrustworthy, the experiment is considered not incorrect, that is, the conditions are equal. If, on the other hand, the genotype-environment interaction is untrustworthy, there is no point for the ecological constancy to be analysed, meaning that a whole mutability of a trait is genetically determinate. The analysis of the ecological stability is applicable at an actual influence of conditions and at the interaction genotype-environment.

The genotype × environment interaction was statistically highly significant (P < 0.01) for plant height, pods per plant, seeds per plant, seeds per plant, 1000 seed weight and seed yield (Table 2).

In regard to these traits the studied cultivars significantly were distinguished in their genetic nature with considerable share of influence in the total variation (Fig. 2) – 1000 seed weight (95.31%); plant height (86.98%); seed yield (86.61%) and (pods per plant 66.10%). The exception was trait seeds per plant in which the relative share of cultivar influence was smaller (38.33%). The participation of factor genotype x environment interaction in formation of this trait was greater (40.55%). The factor of environment was

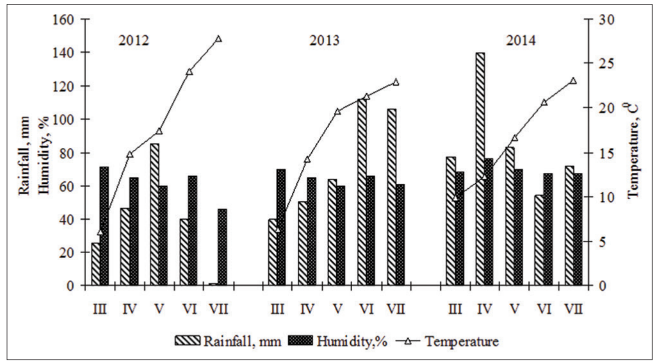

Fig 1. Climatic characterization of the experimental period.

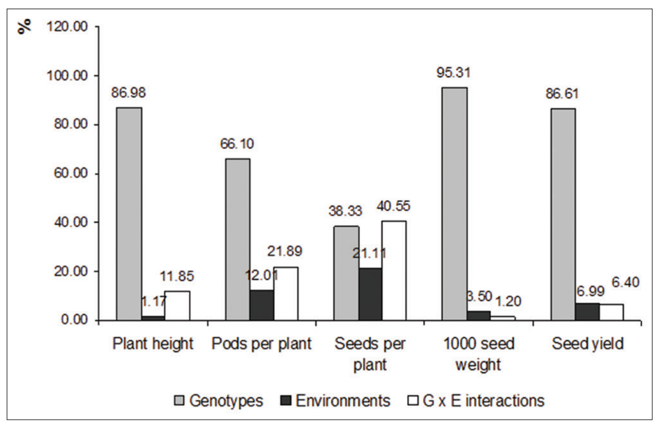

Fig 2. Influence of factors – genotype, environment and genotype × environment interaction in the total variation.

Table 2: Analysis of variance for stability for seed yield and yield components in vetch cultivars for the period 2012-2014

Source of variation	Df	Mean sum of squares for the traits studied								
		Plant height	Pods per plant	Pod stem	Pod length	Seeds per pod	Seeds per plant	Seed weight per plant	1000 seed weight	Seed yield
Environments (E)	2	238.62**	28.41**	0.08	1.05	0.53	536.88**	1.55	164.68**	4345.03**
Genotypes (G)	6	5890.90**	52.12**	0.03	15.25**	17.26**	324.91**	4.99*	1496.62**	17950.57**
G×E interactions	12	401.29**	8.63**	0.02	0.25	1.02	171.86**	0.16	9.39**	663.70**
Env/Gen	14	378.05**	6.52**	0.07	0.54	1.33	33.76**	0.11	52.33**	2242.04**
Env/Lia	2	547.96**	1.56	0.01	0.61	0.40	5.23*	0.46	38.09**	804.94**
Env/Lorina	2	403.36**	3.43	0.01	1.02	0.52	59.71**	0.17	22.59**	656.34**
Env/Vilena	2	123.37**	1.92	0.09	0.27	0.34	53.56**	0.50	10.55**	458.84**
Env/Moldovskaya	2	462.72**	0.91	0.02	0.05	0.05	32.67**	0.01	38.13**	1267.52**
Env/Obrazets 666	2	0.36	34.39**	0.01	0.03	2.48	743.47**	0.94	16.79**	1399.94**
Env/Violeta	2	84.99**	31.48**	0.00	0.05	1.54	639.64**	0.35	42.56**	1497.61**
Env/Viola	2	1023.61**	6.52**	0.07	0.54	1.33	33.76**	0.11	52.33**	2242.04**
Total	20									

Significant at *P*=0.05 (*), ***P*=0.01(**)

characterized by the smallest share of influence which showed that the formation of traits depended to a very small extent on the changing conditions of cultivation.

The relatively small magnitude of factor genotype x environment interaction with respect to the studied traits supposed a greater stability of the cultivars. This entailed the need to be estimated the ecological stability of seed yield in the tested vetch cultivars.

Plant height: The highest evaluation of stability according to the criteria of both analysis methods in regard of this trait have shown Vilena and Obrazets 666, followed by Violeta and Moldovskaya.

Pods per plant: The values of parameters of phenotypic stability according to the regression analysis of Eberhart and Russell (1966), Tai (1979) and Theil (1950) define as most valuable cultivar Viola (bi = 1.18), followed by Liya (bi = 1.27). Liya and Violeta (bi = 2.83) are more responsive under favorable conditions of the year. Moldovskaya and Vilena also represent an interest from a breeding viewpoint. According to the criteria of dispersion analysis these cultivars could be characterized as stable. Their mutual combination can be recommended due to their different responsiveness to the changing conditions.

Seeds per plant: According to parameters of Plasteid and Peterson (1959) and Wricle (1965) the genotypes Lorina and Vilena showed the highest stability because their values were the lowest. In regard of this trait and the parameters of Eberhart and Russell (1966), Tai (1979) and Theil (1950) cultivar Vilena was highly evaluated.

1000 seed weight: Vilena (bi = 0.88) and Moldovskaya (bi = 1.21) are marked out as valuable for the selection on this trait. Essential differences were established among the cultivars with respect to their responsiveness to favorable conditions. Viola (bi = 1.26) and Liya (bi = 1.48) were assessed as ecologically unstable but they were responsive to improvement of the environmental conditions in a greatest extent. The rest of cultivars were unstable under unfavorable conditions but at the same time they were insensitive to intensive cultivation. For improvement of parameters of stability and expression of the trait was recommended applying methods of combined selection.

Seed yield: The assessment of the stability of cultivars (by means of regression coefficient) determined as the most stable the genotypes Violeta (bi = 1.07) and Viola (bi = 1.11), followed by Moldovskaya. The cultivars Liya and Obrazets 666 possessed high positive values of bi (bI > 1.0) which indicates that seed yield increased as environmental index increased. Whereas, Lorina and Vilena had low values of bi that shows that seed yield did not increase as environmental index increased (Table 3).

Fig. 3 reveals the distribution of tested cultivars according to the average level of seed yield trait depending on the regression coefficient (bi). The vetch cultivars could be classified into four groups: High-yielding cultivars, with stable type of reaction; high-yielding and unstable, but with good adaptability; low-yielding with stable type of reaction; and stable cultivars, but with low yield.

High-yielding, with a coefficient of regression bi > 1.0: These cultivars have strongly predictable reaction to environmental conditions and respond well to environmental improvements. They are proper for cultivation under favorable conditions. Their yield can decrease slightly at worsening environmental conditions. This group includes Liya and Obrazets 666.

High-yielding, with a coefficient of regression bi≈1.0: These cultivars are close to ideal genotype, react well to environmental improvements and could be adopted as controls for high adaptability, as they would provide high enough and predictable yield under all conditions. Moldovskaya can be assigned to that group.

Low-yielding, with a coefficient of regression bi=1.0: In this group are included such cultivars as Violeta and Viola. According to Eberhart and Russel (1966) these are stable genotypes but during different years and especially in unfavorable conditions they stronger interact with the environmental conditions. The received yield is under the average level of trial.

Low-yielding, with a coefficient of regression bi < 1.0: Lorina and Vilena belong to this group. These are stable cultivars but with low adaptive ability since they do not react to improvements in environmental conditions by increasing

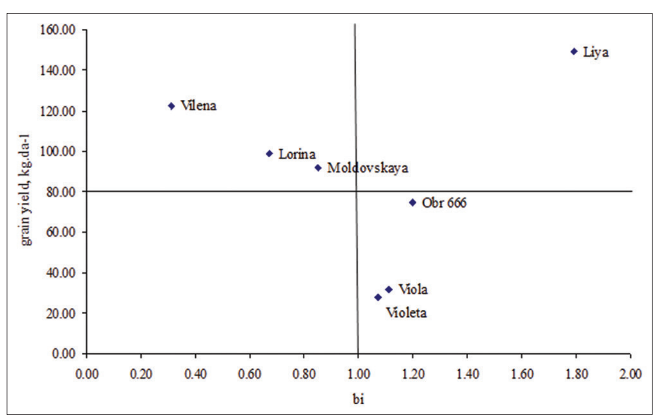

Fig 3. Determination of the varieties breeding significance according to regression coefficient (bi) and grain yield (kg.da^{-1}).

the yield. They are not appropriate to be cultivated under favorable conditions (around and above the average) but they are appropriate at worsening environmental conditions.

From viewpoint of the selection, vetch cultivars from the first three groups are suitable for including in breeding programmes, since could be expected that their progeny will combine high and stable yields.

According some authors (Yan, 2001; Yan and Rajcan, 2002) the GGE biplot presents the mean performance and stability, which give us an essential visualization of the data. According to results of GGE biplot analysis, the more productive cultivars correlate with higher values of PC1 (Fig. 4) and values of PC2 which are closely situated to zero. The two principal components determine 99.60% of the dispersion (Table 4). The polygon passes through the cultivars that are furthest away from the beginning of coordinate system. On top of the polygon are situated cultivars with high yield as well as with low yield. With respect to seed yield the cultivars are arranged in the following order: Liya, Vilena, Lorina, Moldovskaya, Obrazets 666, Viola, Violeta. The high productiveness

Table 3: Estimates of the adaptability and stability parameters for the seed yield and yield components in investigated varieties

Cultivar	Eberhart and Russell		Tai		Theil	Plaisted and Peterson	Wricke
	bi	S_i^2	ai	λ_i	T	PP	W^2
Plant height							
Liya	3.07	151.06**	3.08	264.23	3.18	139.05	745.76
Lorina	2.33	145.43**	2.33	254.79	2.43	120.75	557.50
Vilena	1.87	2.37**	1.87	4.60	1.89	72.36	59.81
Moldovskaya	3.67	2.62**	3.68	3.98	3.68	114.54	493.66
Obrazets 666	0.06	−0.16^{ns}	0.05	0.16	0.05	72.51	61.32
Violeta	−1.22	22.53**	−1.23	39.18	−1.26	105.87	404.45
Viola	−2.77	507.77**	−2.79	886.81	−2.97	308.93	2493.02
Pods per plant							
Liya	1.27	−0.3192^{ns}	1.27	0.01	1.29	1.165	0.61
Lorina	0.24	0.556^{ns}	0.21	1.46	0.46	1.825	7.41
Vilena	0.78	0.3239^{ns}	0.77	1.14	0.97	1.337	2.38
Moldovskaya	0.64	−0.161^{ns}	0.63	0.28	0.74	1.258	1.57
Obrazets 666	0.07	0.2585^{ns}	0.04	0.89	0.25	1.961	8.80
Violeta	2.83	0.8607^{ns}	2.90	1.51	3.10	4.108	30.88
Viola	1.18	16.8867**	1.19	30.13	0.18	6.153	51.92
Seeds per plant							
Liya	0.29	17.87**	0.29	31.77	−0.045	41.133	131.90
Lorina	0.04	3.06**	0.04	5.78	−0.102	42.965	150.74
Vilena	0.86	1.66*	0.86	3.49	0.749	29.185	9.00
Moldovskaya	0.36	28.86**	0.36	51.03	−0.068	42.993	151.03
Obrazets 666	−0.01	21.44**	−0.01	37.94	−0.374	49.796	221.00
Violeta	2.92	59.81**	2.92	104.64	3.528	100.739	744.98
Viola	2.54	96.42**	2.54	168.91	3.313	91.862	653.67
1000 seed weight							
Liya	1.48	0.004^{ns}	1.49	0.55	1.495	2.403	12.04
Lorina	1.21	2.22*	1.21	4.46	1.178	2.172	9.67
Vilena	0.88	2.63**	0.88	5.19	0.909	2.165	9.60
Moldovskaya	0.64	0.34^{ns}	0.63	1.15	0.652	2.031	8.22
Obrazets 666	0.71	17.10**	0.71	30.49	0.638	6.690	56.14
Violeta	0.82	0.26^{ns}	0.82	1.03	0.836	1.549	3.27
Viola	1.26	3.20**	1.26	6.17	1.292	2.568	13.74
Seed yield							
Liya	1.79	167.54**	1.78	293.63	2.117	234.69	1279.62
Lorina	0.67	351.13**	0.68	615.05	0.197	226.02	1190.48
Vilena	0.31	397.80**	0.30	696.61	−0.194	284.09	1787.70
Moldovskaya	0.85	3.96**	0.86	7.51	0.802	114.12	39.43
Obrazets 666	1.20	248.43**	1.21	435.33	0.803	187.68	796.13
Violeta	1.07	457.17**	1.07	800.62	1.611	244.35	1378.98
Viola	1.11	492.42**	1.10	862.32	1.665	255.34	1492.06

Significant at *P*=0.05 (*), ***P*=0.01(**)

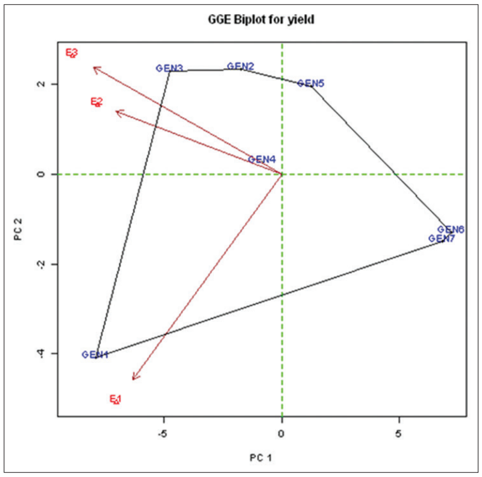

Fig 4. The GGE biplot based on seed yield (2012-2014). The cultivars are designated with the symbol GEN and the respective number from 1 to 7, as follow GGE1 – Liya; GGE2- Lorina; GGE3-Vilena; GGE4- Moldovskaya; GGE5- Obrazets 666; GGE6- Violeta; GGE7- Viola. The years are designated with the letter E and number 1; 2; and 3 for 2012, 2013 and 2014, respectively.

Table 4: Principal components analysis

	Percent	Df	Mean.Sq	F value	Pr.F
PC1	96.3	7	15504.41	115.92	0
PC2	3.3	5	745.3541	5.57	0.0007
PC3	0.4	3	136.853	1.02	0.3952

of cultivars, belonging to *V.sativa*, is also due to the fact that they are presented better in rainfall conditions while the cultivars belonging to *V. villosa* – in drier conditions. Growing the cultivars with different reaction to environmental conditions will provide a more stable yield by years and by regions.

For plant breeders and agronomists, the stability analysis is an important and efficient method for estimation. By it we can choose the most stable and high-productive genotypes which are suitable for certain environmental conditions (Ahmadi et al., 2012).

Many researchers have established that genotype–environment interaction is highly significant not only for yield components but also for seed yield. For example, Yucel et al. (2009), Nizam et al. (2011) and Sayar et al. (2013) reported for significant genotype–environment interactions in regard of dry matter yield in some vetches. This fact was confirmed for different forage crops by Aremu et al. (2009), Acikgoz et al. (2009), Nizam et al. (2012) and Al-Aysh et al. (2013).

Lin et al. (1988) determined the stability of quantitative traits that formed the productivity as dynamic where there was a predictable reaction of the genotype to changing ecological conditions.

Moll and Stuber (1974) have noted that cultivars with high stability show mainly low or average yield and react weakly on improvements in growing conditions.

The ideal genotype according to Eberhart and Russell (1966) is that which posses: The highest yield over a wide range of environments, a regression coefficient of 1.0, and a deviation mean square (Si^2) of near zero. Similar results were obtained by Acikgöz et al. (2009), Orak and Nizam (2009). Significant differences regarding to the seed yield in common vetch genotypes between genotype × environment were established also by Albayrak et al. (2005) and Nizam et al. (2011).

Kiliç and Yağbasanlar (2010) reported that most of cultivars were stable for one trait and unstable for another, suggesting that the genetic factors involved in the GEI differed between traits. Olayiwola et al., (2015) concluded that simultaneous selection of genotypes for high yield and stability was more useful in multi-environment trial.

CONCLUSION

The results of study showed a highly significant influence of the genotype, environment and the interaction between them on the formation and variability of seed yield and its components (plant height, pods per plant, seeds per plant, 1000 seed weight) in vetch *(Vicia sativa, Vicia villosa)*. The influence of genotype was considerable. The cultivar Moldovskaya could be revolved as close to the excellent type (bi ≈ 1.0), propitious for growing a vast environment. Liya and Obrazets 666 were determined as unstable (bi > 1) but with good responsiveness, providing them high yields at moderate environmental conditions. Cultivars Liya and Obrazets 666 could be defined as stable and with good responsiveness (bi = 1.07 - 1.11), but because of lower yields they do not have priority over others. From viewpoint of selection, cultivars Moldovskaya, Liya and Obrazets 666 are suitable for including in breeding programmes and developing new vetch lines with steady yields.

Author's contributions

Natalia Georgieva, Ivelina Nikolova, Valentin Kosev wrote the manuscript. Valentin Kosev conceived carried out of the statisticall analysis. Natalia Georgieva and Ivelina Nikolova revised and approved the manuscript. All authors read and approved the final manuscript.

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