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GENOTYPE-ENVIRONMENT INTERACTION IN EVALUATING YIELDING OF SELECTED EDIBLE POTATO (*SOLANUM TUBEROSUM* L.) CULTIVARS

ABSTRACT

In the research carried out in the years 1999-2001 the following characteristics of three edible potato cultivars were determined: tuber yield, starch content, dry matter content, vitamin C content and starch yield. Genotype-environment interaction for the above characteristics was evaluated on the basis of main effects (genotypes and years) and interaction effects by means of the variance analysis for repeated experiments and according to the linear model for the design which confounds the type 3^3 interaction. Moreover, there were calculated the variance of genotype stability describing the environmental variation of the genotypes, and the ecovalence coefficient which describes the genotype x environment interaction. All the analysed characteristics were influenced by the cultivars (genotypes) and the environment. The genotype-environment interaction reflecting different response of the cultivars to changeable environmental conditions proved to be significant for all the examined characteristics. The analysis of results does not allow to unambiguously indicate the stabile genotype because the Muza cultivar was most stable for vitamin C and dry matter contents, and starch yield whereas Aster and Ania proved to be most stable as far as tuber yield and starch content, respectively, were concerned.

Key words: edible potato, genotype-environment interaction, genotype stability, potato tuber quality characteristics, tuber yield

INTRODUCTION

As a result of increasing costs of edible potato production in Poland, the cultivars characterized by high stable yields and good consumption qualities have been searched for. Starch, dry matter and vitamin C contents are most often taken into account in the quality evaluation of potato tubers. The content of the aforementioned components is mainly a cultivar-specific characteristic, however, it is to a large extent modified by agronomic factors and climatic conditions of the growing season (Roztropowicz 1989; Bombik and Boligłowa 1994). Cultivars, climatic conditions and edafic conditions (soil, its mineral composition, moisture) may enter reciprocal interactions which

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contribute to differences in potato quality (Teodorczyk 1998). The genotype-environment interaction is a phenomenon which is defined in terms of its mechanisms or, what is more usual, its phenotypic effects for a given characteristic (Hill *et al.* 1998; Annicchiarico 2002; Baker 2002; Kang 2002; Yan and Kang 2003). The knowledge of genotype-environment interaction, defined as a different response of the genotype to certain environmental factors, provides valuable information on the genotype properties, their stability in particular.

Biologically-defined stability, that is maintaining the constant value of a characteristic irrespective of environmental conditions, is not desirable in agricultural production (as far as yield is concerned) as improved agronomic conditions would not produce increased yields (Gałek *et al.* 2000). As a result, stability in cultivars is considered from the standpoint of agriculture. Such stability is present when the average value of the observed cultivar characteristic (yield in this case) changes proportionally to the average response determined on the basis of the environmental mean for this characteristic (Becker and Leon 1988).

Many statistical methods have been developed to evaluate and interpret genotype-environment interaction. They are mostly based on fixed or mixed models of one-variable variance analysis suitable for two-way cross classification which includes an interaction effect (Aastveit and Mejza 1992; Czajka 1995; Pietrzykowski *et al.* 1996).

The present work aims to analyse and interpret the genotype-environment interaction for the yield (tuber yield, starch yield) and selected tuber quality characteristics (starch content, dry matter content, vitamin C content) of three potato cultivars.

MATERIAL AND METHODS

Three potato cultivars, Aster, Muza and Ania, constituted the research material. The tubers were harvested over three years (1999-2001) of conducting a field experiment. The experimental site was located at the Experimental Station in Zawady, eastern Poland, owned by the University of Podlasie in Siedlce. The soil belonged to the rye good complex, quality class IVb. The experiment was set up in a design which confounded the higher-order 3^3 type interaction with three replications. The design plan was based on the work by Przybysz (1993).

Weather conditions over the period of research are presented in Table 1. It can be noticed that average temperatures in individual growing seasons were higher than the multi-year mean value, and precipitation sums were lower compared with the multi-year precipitation.

Table 1

Distribution of temperature and precipitation

Temperature [°C]					Precipitation [mm]				
Month	Year			Pluri-annual	Month	Year			Pluri-annual
	1999	2000	2001			1999	2000	2001	
IV	9.9	12.9	8.7	7.2	IV	87.3	47.5	69.8	34.6
V	12.9	16.5	15.5	15.4	V	26.4	24.6	28.0	48.3
VI	20.5	19.5	17.1	16.7	VI	121.7	17.0	36.0	98.5
VII	21.8	19.0	23.8	18.1	VII	21.9	155.7	55.4	71.4
VIII	18.7	19.1	20.6	17.4	VIII	77.4	43.6	24.0	60.8
IX	16.1	11.8	12.1	12.7	IX	27.8	61.1	108.0	47.3
Mean	16.6	16.5	16.3	14.6	Total	362.5	349.5	321.2	360.9

Potato forecrops were winter catch crops which were sown in the third decade of August each year. In the spring the catch crop plants were incorporated (deep ploughing) to constitute green manures. Tubers of the examined cultivars were planted in the third decade of April in an amount of 2.5 t × ha^{-1}, at the spacing of 62.5 × 25 cm. After planting the successive cultivation operations were performed as needed for plant establishment.

Following harvest, the yield per plot was recorded. The starch content in potato tubers was determined by means of a Reimann's specific gravity balance. Dry matter content and vitamin C content were determined by the oven-drying gravimetric and Tillmans' methods, respectively.

The results were statistically analysed with the analysis of variance for type 3^3 confounded designs.

Genotype-environment interaction, defined as sensitivity of a genotype to certain environment factors, was evaluated on the basis of main effects (genotypes and years) and interaction effects. The method applied in the evaluation was the analysis of variance for the type 33 confounded designs in repeated experiments, and the Tukey test (Oktaba 2000). Also, for the examined characteristics which were characterised by a significant genotype-environment interaction, there were calculated the variance of genotype stability describing environmental variation, and the ecovalence coefficient reflecting an interaction between the i-th genotype and the environment (Wricke 1965; Shukla 1972; Pietrzykowski *et al*. 1996).

The variance of genotype stability was calculated according to the following formula:

$$s_i^2 = \frac{\sum_j \left(\bar{y}_{ij} - \bar{y}_{i.}\right)^2}{s-1}$$

whereas the ecovalence coefficient was computed as follows:

$$W_i = \sum_j \left(\bar{y}_{ij} - \bar{y}_{i.} - \bar{y}_{.j} + \bar{\bar{y}}_{..}\right)^2$$

in the above formulae:

y_{ij} – is the mean for a characteristic calculated across n replications for the i-th genotype in the j-th environment,

$y_{i.}$ – is a border mean calculated across sn observations for the i-th genotype (s – number of environments),

$y_{.j}$ – is a border mean calculated across gn observations for the j-th environment (g – number of genotypes),

$\bar{\bar{y}}_{..}$ – is an overall mean computed across sgn observations for the whole series of experiments.

RESULTS AND DISCUSSION

Potato tuber yield significantly depended on the cultivars and conditions of the growing seasons (Table 2). The Aster cultivar yielded significantly lower than Muza and Ania. The respective yields amounted to: 30.9, 33.7 and 35.0 t·ha-1. The most favourable conditions for potato growth and development were in the year 2000 when the highest yields were recorded. The year 2000 was characterised by the precipitation sum which was close to the multi-year sum, and the average temperature which was by 1.9°C higher than the multi-year mean.

Table 2

Potato tuber yield in successive research years [t × ha^{-1}]

Cultivar	Year			Mean
	1999	2000	2001	
Aster	32.6	31.9	28.3	30.9
Muza	28.9	36.3	35.9	33.7
Ania	35.2	41.9	28.0	35.0
Mean	32.2	36.7	30.7	33.2

Least significant difference (α = 0.05): between years = 1.7, between cultivars = 1.7, years × cultivars interaction = 2.9

Potatoes of the examined cultivars yielded differently in the studied years. The yields recorded for the Aster and Ania cultivars were the lowest in the year 2001 when the precipitation was the lowest over the whole examined period, and amounted to 321.2 mm. The most adverse growing conditions for the yielding of Muza were in the year 2000 when the recorded yields were the worst.

The highest values and the highest diversity of stability parameters were obtained for tuber yield (Table 7). The stability variance for Aster was the lowest so this genotype was the most stable under the examined environmental conditions. The Ania cultivar turned out to be least stable as far as its yield was concerned (s^2_i=48.32). The genotype-environment variance obtained for this cultivar was ninefold higher than the variance for Aster (s^2_i=5.32). a genotype-by-environment interaction proved to vary, too, the finding being reflected in the ecovalence coefficient values which ranged from 13.6 for Aster to 37.3 for Muza. It indicates that the tuber yield of Aster was to the lowest extent influenced by the conditions of plant growth and development.

Table 3

Starch content in the tubers of examined potato cultivars [%]

Cultivar	Year			Mean
	1999	2000	2001	
Aster	14.8	14.2	12.7	13.9
Muza	15.0	14.6	13.5	14.4
Ania	14.5	14.9	13.4	14.3
Mean	14.8	14.6	13.2	14.2

Least significant difference (α = 0.05): between years = 0.3, between cultivars = 0.3, years × cultivars interaction = 0.5

Starch content was modified by both the cultivars and environmental conditions (Table 3), which was also confirmed in the studies by Bombik *et al.* (2003). The value of this characteristic was significantly lower for Ania and Muza than for Aster. Aster, which is an early cultivar, accumulated by 0.45% more starch than the other two cultivars, which in general are better in this respect. The conditions favouring an accumulation of starch in potato tubers occurred in the years 1999 and 2000 when the weather was warm and sunny (especially in the former year), the conditions necessary for potato to accumulate starch in tubers. In contrast, the year 2001 was the least beneficial with respect to starch accumulation. Initially the weather was rainy and cold, and high temperatures combined with low precipitation in the second half of July and at the beginning of August could not compensate for the adverse conditions observed in the preceding months.

There was observed a different response of cultivars to changeable weather conditions of the successive research years (Table 3). The Aster cultivar was most stable for starch content which decreased significantly in successive growing seasons. It is also reflected in the highest variance of genotype stability calculated for this cultivar and the lowest ecovalence coefficient. As far as Ania and Muza were concerned, the drop in starch content was recorded only in the year 2001. Low environmental variation of these cultivars is reflected in small values of stability parameters (Table 7).

Starch yield is conditioned by tuber weight and percentage starch content in the tubers. The starch yield depended mainly on the cultivar properties of potato and the growing season conditions. There was also found a significant years × cultivars interaction for this characteristic (Table 4).

Table 4.

Starch yield of individual potato varieties [t × ha-1]

Cultivar	Year			Mean
	1999	2000	2001	
Aster	4.82	4.50	3.59	4.30
Muza	4.15	5.26	4.82	4.74
Ania	5.08	6.27	3.76	5.04
Mean	4.68	5.34	4.06	4.69

Least significant difference ($\alpha = 0.05$): between years = 0.25, between cultivars = 0.25 years × cultivars interaction = 0.44

The highest starch yield was recorded for the Ania cultivar, a significantly lower value was observed for Muza and the lowest was the value for Aster. Such findings predominantly resulted form the weather conditions of the year 2000 when the starch yield was highest for all the cultivars. There was observed a different response of cultivars to changing environmental conditions, which is reflected in the significance of years x cultivars (genotypes) interaction. Ania was an exception as in each year it produced the lowest starch yield which also differed significantly. The highest was the yield in the year 2000, it was significantly lower in the year 1999, and the lowest in the year 2001. Aster and Muza produced comparable starch yields in the years 1999 and 2000, and 2000 and 2001, respectively.

Stability parameters calculated for starch yield indicated that Ania was the least stable cultivar whereas Muza was the most stable cultivar. The respective values of variance s^2i equalled 1.576 and 0.312. Ecovalence coefficients, which describe genotype-environment interaction, slightly differed and ranged form 0.489 for Aster to 0.857 for Muza (Table 7).

Table 5.

Dry matter content in the tubers of examined potato cultivars [%]

Cultivar	Year			Mean
	1999	2000	2001	
Aster	21.3	22.5	19.3	21.0
Muza	22.9	21.2	20.9	21.7
Ania	21.4	22.4	19.3	21.0
Mean	21.9	22.0	19.8	21.2

Least significant difference ($\alpha = 0.05$): between years = 0.6, between cultivars = 0.6, years × cultivars interaction 1.0

Genetic properties and growing conditions determined the ability of the investigated cultivars to accumulate dry matter in tubers (Table 5). The lowest amount of dry matter was accumulated by potatoes in the cold and wet year 2001, whereas in the remaining years, that is 1999 and 2000, the dry matter content was much higher.

An accumulation of dry matter was higher in the tubers of Muza compared with the remaining two cultivars. The ability of genotypes to accumulate dry matter fluctuated as a result of an impact of the growing seasons, which is confirmed by the significance of the years x cultivars interaction. In the years 1999 and 2001, which were not characterised by favourable conditions for potatoes to accumulate dry matter, its content in Muza tubers was higher that in Aster and Ania tubers. In the year 2000, when the average value of dry matter reached the highest level, Muza differed significantly from the remaining cultivars with respect to dry matter content.

Table 7 shows that the lowest value of variance of genotype stability, and so the highest stability for dry matter content, was characteristic of Muza. However, the interaction of this cultivar with the environment was the strongest, which can be concluded on the basis of the highest value of ecovalence coefficient.

A cultivar factor significantly influenced the accumulation of vitamin C. Ania was characterised by a higher vitamin C than Aster and Muza. Moreover, the ascorbic acid content in the tubers of the investigated cultivars depended on meteorological conditions, as it was indicated by the significance of years x cultivars interaction. Over the whole period of research, Muza accumulated a comparable amount of vitamin C in tubers. However, there was observed a different response of vitamin C content to changing conditions of the growing seasons, as far as the remaining two cultivars were concerned. The early Aster cultivar accumulated far more vitamin C in the year 2000, when in July moderate temperatures were accompanied by relatively high rainfall. Ascorbic acid accumulation by Ania was most probably slowed down by high temperatures in July and August 2001 as it was only then that the vitamin C content in potato tubers was much lower than in the preceding seasons (Table 6).

Table 6.

Vitamin C content in the tubers of examined potato cultivars [mg%]

Cultivar	Year			Mean
	1999	2000	2001	
Aster	21.4	23.9	20.2	21.8
Muza	22.2	22.1	22.0	22.1
Ania	24.5	24.2	21.9	23.5
Mean	22.7	23.4	21.4	22.5

Least significant difference (α = 0.05): between years = 0.7, between cultivars = 0.7, years × cultivars interaction = 1.3

On the basis of the evaluation of stability parameters for vitamin C content, it can be concluded that there existed pronounced differences between both the values of the variance of genotype stability and the ecovalence coefficients calculated for the examined cultivars (Table 7). The highest and the lowest values of variance were for Aster and Muza, respectively. a similar pattern was observed with respect to the ecovalence coefficient, however, the lowest value of the coefficient was obtained only for Ania.

Table 7.

Stability parameters for selected potato quality characteristics

Quality characteristic	Stability parameters	Cultivar		
		Aster	Muza	Ania
Tuber yield	s^2_i [1]	5.320	17.320	48.320
	W_i [2]	13.600	37.300	33.200
Starch content	s^2_i	1.170	0.605	0.605
	W_i	0.140	0.050	0.210
Starch field	s^2_i	0.407	0.312	1.576
	W_i	0.489	0.857	0.761
Dry matter content	s^2_i	2.620	1.160	2.500
	W_i	0.740	2.300	0.540
Vitamin C content	s^2_i	3.650	0.010	2.025
	W_i	2.050	1.820	0.930

[1] s^2_i - Variance of genotype stability, [2] W_i - Ecovalence coefficient

The research showed that tuber yield and quality characteristics of edible potato depended on the main effects. Also, the interaction of weather conditions with cultivars proved to be significant.

Tuber yields of the examined cultivars differed significantly in the individual years of studies, which was undoubtedly influenced by the distribution and amount of monthly precipitation and temperatures recorded over the growing seasons. Heavy rainfall in July and the first decade of August contributed to an increase in yields mainly of late cultivars. It was demonstrated that, among the examined cultivars, the highest yields were obtained for the Ania cultivar, compared with the remaining two cultivars. Such a situation resulted from an impact of the conditions of the 2000 growing season when the tuber yield of Ania was the highest. In the remaining years, Muza was the highest-yielding cultivar. As a result, it is difficult to decide on which cultivar could be genetically stable under all kinds of the conditions of a growing season.

Starch and dry matter contents are genetically-conditioned but modified by environment conditions, in particular temperature and precipitation over the potato growing season. The years when warm and sunny weather prevails (just like it was in the year 1999), stimulate an accumulation by plants of the two components. The year 2001 proved to be least favourable for starch and dry matter accumulation because the initially wet and cold weather was followed by high temperatures at the end of July and the beginning of August which did not compensate for the negative conditions at the beginning of potato vegetation. In the discussed experiment Ania and Muza accumulated more starch and dry matter than Aster.

The cultivar factor influences vitamin C synthesis in potato tubers. However, weather and environment conditions contribute to this process, too. The examined cultivars accumulated more ascorbic acid when the temperatures were moderate. High temperature in July and August 2001 slowed down the process of vitamin C synthesis in the tubers of Ania and, as a result, the vitamin C content in the tubers of this cultivar in the year 2001 was the lowest.

Stability parameters indicated that the examined cultivars reacted differently to the changing environmental conditions, as far as all the characteristics were concerned. The highest difference in the stability of genotypes was recorded for tuber yield. Ania and Aster tended to be, respectively, the least and the most stable as far as tuber yield was concerned. However, Aster was characterised by the highest environmental variation with respect to starch, dry matter and vitamin C contents. An analysis of stability variance indicated that, among the investigated cultivars, the highest stability was characteristic of Muza because the values of stability variance calculated on the basis of the results for dry matter content, vitamin C content and starch yield were the lowest. The environmental variation of this genotype was high for tuber yield and starch content, yet it was not the highest. An interaction of genotypes with the environment was different (marked differences between the ecovalence coefficients). The highest values of this parameter and the highest differences between them were observed for tuber yield as its ecovalence coefficient ranged from 13.6 to 37.3 for Aster and Muza cultivars, respectively.

CONCLUSIONS

1. The genotype modified all the analysed potato quality characteristics and potato yield. The lowest average values of the examined characteristics were recorded for Aster. In general, Muza and Ania did not differ significantly.

2. The quality characteristics and tuber yield of the examined potato cultivars depended on the environment. There was also significant genotype-environment interaction for the investigated characteristics. The above-mentioned interaction reflects a different response of cultivars to changing environmental conditions. An analysis of the interaction did not make it possible to unambiguously choose the most stabile genotype. For most characteristics (starch yield, dry matter content, vitamin C content) Muza was most stable. Aster and Ania were most

stable with respect to tuber yield and starch content, respectively.

3. The knowledge of cultivar reaction to environmental conditions allows breeders to focus their work on the cultivars which assure stable tuber yields and tuber quality characteristics. It will also make it possible to choose such genotypes which, under given environmental conditions, perform best with respect to the examined characteristics. An evaluation of genotype-environment interaction should be included in reparations of agronomic recommendations for new cultivars introduced into cultivation.

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