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Research Article

MULTI-TRAIT EVALUATION OF VALUE FOR CULTIVATION AND USE OF EARLY MATURING EDIBLE POTATO CULTIVARS REGISTERED IN POLAND

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ABSTRACT
The work presents an analysis of diversity and comparison of value for cultivation and use of early maturing potato cultivars registered with the Polish National Register of Cultivars. The comparison was based on 17 yield and appearance traits and quality attributes of tubers as well as their resistance to diseases. The analysis employed the following multi-dimensional statistical methods: principal component analysis and cluster analysis. The principal component analysis revealed that over 70% of the total variation was associated with the first 6 principal components. Cluster analysis yielded 4 groups of genotypes. The first group consisted of the cultivars which produced tubers with the most shallow eyes, the best flavour and the least severe darkening of raw flesh. The cultivars in the second group produced high yields and were low in starch, dry matter and glycoalkaloids. The tubers of cultivars which were classified into the third group had the highest starch, dry matter and vitamin C contents. However, they produced the lowest yields and were quite susceptible to most diseases. The fourth group was made up of high-yielding cultivars which tended to accumulate glycoalkaloids but were most resistant to hollow heart in tubers.

Keywords: edible potato, potato cultivar, principal component analysis, cluster analysis

INTRODUCTION

Potato (*Solanum tuberosum*) is one of the major crop plants cultivated worldwide due to its versatility as it is consumed fresh, in processed forms and also used for industrial processing purposes [Oruna-Concha et al. 2002, Zgórska and Grudzińska 2012]. The plant's popularity is obvious when one considers the number of potato cultivars grown worldwide (over 4000) [Hamouz et al. 2010]. The most valuable cultivars produce high and stable yields of tubers which have attractive appearance and are of good quality. Apart from sensory traits, potato quality is also influenced by dry matter, starch and vitamin C contents [Hamouz et al. 2006, Murnice et al. 2011, Arvanitoyannis et al. 2012]. Moreover, good quality tubers should contain no or low levels of harmful substances, glycoalkaloids in particular [Trawczyński and Wierzbicka 2011].

In Poland, like in other EU countries, cultivation of early maturing potatoes is gaining popularity [Dwořák et al. 2006, Hamouz at.al. 2006, Wierzbicka 2012. As a result, the number of such genotypes registered is also increasing Rykaczewska 2007]. Cultivars registered (in variety-testing experiments and post-registration testing) are evaluated with respect to many traits which are then used to prepare a cultivar description. A great number of traits makes it difficult to select a suitable cultivar. When this is the case, multi-dimensional statistical analyses may be employed and they are increasingly popular in natural sciences [Madlaina et al. 2008, Grużewska et al. 2009, Rakonjac et al. 2010, Mohamed et al. 2011, Rymuza et al. 2012]. The methods make it possible to evaluate variation of objects with respect to many traits and to separate them into groups which share similar characteristics. Principal component analysis (PCA) and cluster analysis are most frequently used to this end [Veronesi and Falcinelli 1988, Charmet et al. 1994, Ahmadizadeh and Felenji 2011, Arvanitoyannis et al. 2012], because, according to Pluta et al. [2012], they are most effective.

Bearing the above in mind, an attempt was made to evaluate the multi-trait diversity of value for cultivation and use of early maturing edible potato cultivars registered in Poland in 2012 and classify them, by means of cluster analysis, into groups sharing similar characteristics.

MATERIALS AND METHODS

The analysis was based on the data describing potato cultivars registered in the Register of Cultivars (National List). Research centers all over Poland conduct studies to assess the registered cultivars in terms of characteristics associated with agrotechnology and use. The results of these studies are further analysed synthetically to produce a final description of potato cultivars. The data were also used in the present work.

The following groups of traits describing a cultivar's value for cultivation and use were considered in this analysis:

- tuber yield (t/ha);
- tuber morphological characteristics: tuber size (9-point scale), tuber shape regularity (9-point scale where 9 – perfect regularity, 1 – deformed), eye depth (9-point scale where 9 – very shallow eyes, 1 – very deep eyes);
- usable and technological value: starch content (%), dry matter content (%); vitamin C content (mg%) glycoalkaloid content (mg×kg^{-1}), flavour (9-point scale where 9 – delicious flavour, 1 – bad flavour, tuber unsuitable for consumption), darkening of raw and cooked (by boiling) tuber flesh (9-point scale where 9 – no darkening, a 1 – the most severe darkening), resistance to mechanical injury;
- plant resistance to diseases and pests: resistance to potato virus Y (PVY) (9-point scale where 9 – very high resistance, 1 – very low resistance), resistance to potato leafroll virus (PLRV) (9-point scale where 9 – very high resistance, 1 – very low resistance), resistance to potato blight (9-point scale where 9 – very high resistance, 1 – very low resistance), resistance to hollow heart (5-point scale where 1 – very low resistance, 5 – very high resistance), and resistance to internal rust spot (5-point scale where 1 – very low resistance, 5 – very high resistance).

The analysis was based on two multi-dimensional statistical analyses: principal component analysis and cluster analysis [Badenes et al. 2000, Lotti et al. 2008]. As the variables used in the analysis had different units, they were standardised. Principal component analysis (PCA) was used to determine multi-dimensional associations between the traits studied. PCA made it possible to reduce a relatively high number of diagnostic variables to only several formal variables called principal components [Mohammadi and Prasanna 2003, Kreutzmann et al. 2011, Arvanitoyannis et al. 2012]. The number of components for consideration was selected based on the Kaiser's criterion according to which only the variables with the value of more than 1 are analysed [Iezzoni and Pritts 1991, Lotti et al. 2008]. Such components carry only the most significant information which reflects variation of the objects so they were used in the second part of the analysis – cluster analysis. The purpose of this analysis is to group objects which are similar with respect to many characteristics (variables) [Mądry et al. 2010, Pluta et al. 2012]. Euclidean distance was used as a measure of distance between objects and Ward's procedure as an agglomeration method [Nikolic et al., 2010]. The intersection point was determined applying the Mojena's rule [Rymuza and Bombik 2012].

All the calculations were performed using Statistica 10.0 PL.

RESULTS AND DISCUSSION

Following works by Arslanoglu et al. [2011 and Haydar [2007], principal component analysis and cluster analysis were used in order to examine multi-dimensional relationships between characteristics describing *Solanum tuberosum* L genotypes. The methods yielded groups of cultivars with similar parameters reflecting potato value for cultivation and use.

Principal component analysis demonstrated that early maturing potato quality was associated with the first six components: PC1, PC2, PC3, PC4, PC5 and PC6. The components explained over 78.34% of the total variance – that is overall multi-dimensional variation of traits (Table 1).

The first principal component, explaining over 21% of total variation, was most closely correlated with dry matter content (r = 0.858) and starch content (r = 0.754). Similar relations were

Table 1. Factor loads, eigenvalues and proportion of the total variance in potato cultivars, as explained by the first five principal components

Traits	PC 1	PC 2	PC 3	PC 4	PC 5	PC 6
Tuber field	-0.172	-0.095	0.016	0.157	-0.827	-0.062
Tuber size	-0.154	0.232	-0.107	-0.071	-0.817	-0.037
Tuber shape regularity	0.364	0.336	0.663	-0.240	0.074	0.086
Eye depth	0.008	0.302	0.772	-0.030	0.430	-0.091
Delicious flavour	-0.550	0.045	0.209	0.711	-0.076	0.045
Darkening of raw tuber flesh	0.063	0.739	0.369	0.187	-0.296	-0.240
Darkening of cooked tuber flesh	-0.532	-0.358	0.453	0.004	0.140	0.437
Starch content	0.754	-0.058	-0.041	0.061	0.484	0.102
Dry matter content	0.858	0.038	0.210	-0.129	0.064	-0.194
Vitamin C content	0.164	-0.008	0.060	-0.056	-0.059	-0.890
Glycoalkaloid content	0.302	-0.731	0.176	0.393	-0.126	0.045
Resistance to internal rust spot	0.105	-0.010	-0.021	0.895	-0.074	-0.057
Resistance to hollow heart	0.200	-0.069	-0.317	0.435	-0.533	0.322
Resistance to mechanical injury	-0.306	0.082	-0.368	0.666	0.072	0.183
Resistance to potato virus Y (PVY)	0.045	0.096	-0.766	-0.092	0.199	0.068
Resistance to potato leafroll virus (PLRV)	-0.241	0.491	0.041	0.082	0.189	-0.510
Resistance to potato blight	-0.234	-0.814	-0.163	-0.117	0.020	-0.125
Eigenvalue principal components	3.66	2.74	2.16	1.87	1.67	1.22
Explained proportion of tatal variance(%)	21.52	16.13	12.69	11.01	9.8	7.19
Comulative proportion of total vaiance %	21.52	37.65	50.34	61.35	71.15	78.34

reported by Ahmadizadeh and Felenja [2011]. The values of correlation coefficients indicated that cultivars rich in starch and dry matter have got worse flavour and tend to darken after cooking (Table 2). Also, Thybo et al. [2000], Thygensen et al. [2001] and Kreutzmann et al. [2011] reported similar finding and concluded that dry matter and starch contents are the main factors determining the culinary value of potato tubers. Moreover, Murnice et al. [2011] as well as Zgórska and Grudzińska [2012] have pointed to the relationship of tuber texture and flavour with starch and dry matter content.

The second principal component, strongly associated with plant resistance to potato blight (r = -0.814), after-cooking darkening (r = 0.739) and glycoalkaloid content (-0.731 mg), explained over 16% of total variation. Potato tubers whose raw flesh tended to darken were also less resistant to potato blight and had higher glycoalkaloid contents. Negative correlation of raw tuber darkening and resistance to potato blight with PC2 can be explained by the fact that pathogen-resistant tubers contain more phenolic compounds, in particular chlorogenic acid and tyrosine [Styszko, 2001, 2004].

The third principal component is mainly the carrier of information about tuber morphological characteristics (eye depth and regularity of shape) which are very important from consumer's point of view [Styszko et al., 2003]. What is more, the component is quite strongly correlated with resistance to potato virus Y (-0.766). Cultivars which have tubers more regular in shape are usually more shallow-eyed but less resistant to PVY.

The fourth principal component, accounting for 11% of total variation, was predominantly correlated with resistance to internal rust spot (r = 0.895), flavour (r = 0.711) and resistance to mechanical injury (r = 0.666). Potato tubers with better flavour are more susceptible to internal rust spot and mechanical injury. PC5 explained only under 10% of the total variation of genotypes studied and is strongly correlated with yield (r = 0.827) and tuber size (r = 0.817). The last component, which explained only 7% variability, carried information about vitamin C content (r = -0.890) and resistance to PVY (r = -0.510).

The cluster analysis, based on the above-discussed principal components, yielded a dendrogram presented in Figure 1.

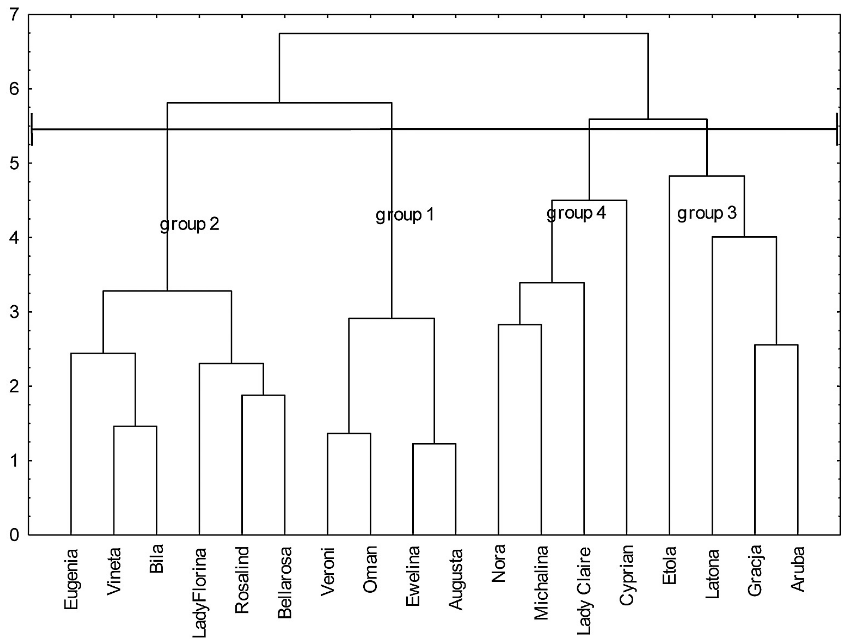


Figure 1. Dendrogram for the 18 cultivars obtained for the first six principal components

The cultivars were divided into 4 groups with different properties. Mean values of traits for each group are compiled in Table 2. Figure 2 shows spatial variation of the cultivars as influenced by the first three components, which explained over 50% of the total variation. The first group was made up of two German cultivars (Augusta, Ewelina), one Polish cultivar (Oman) and one Dutch cultivar (Veroni) (Table 3). The cultivars were slightly (positively or negatively) associated with PC1, PC2 and PC3. They had the most shallow eyes (7.55, on average), the best flavour (7.20 on average) and their raw flesh darkened least (7.95), which indicates that they are the best cultivars for consumption when fresh and for processing [Tarant, 2005, Chotkowski and Rembeza, 2005]. Other characteristics of this cultivar included the highest resistance of tubers to internal rust spot (4.75) and mechanical injury (7.0), and the highest susceptibility to potato virus Y (4.35).

Table 2. Means of the observed traits for the potato cultivars for the four groups distinguished by the cluster analysis

	Group 1	Group 2	Group 3	Group 4
Tuber field	37.10	38.67	35.95	41.13
Tuber size	7.75	8.42	7.63	8.25
Tuber shape regularity	7.30	7.22	7.33	7.15
Eye depth	7.55	7.18	7.15	7.03
Delicious flavour	7.20	7.02	6.55	6.95
Darkening of raw tuber flesh	7.95	7.93	7.03	6.73
Darkening of cooked tuber flesh	8.43	8.17	7.88	8.68
starch content	12.95	12.58	14.28	13.15
Dry matter content	20.60	19.78	22.58	20.48
Vitamin C content	20.80	18.78	22.20	16.78
Glycoalkaloid content	74.25	38.17	71.50	90.25
Resistance to internal rust spot	4.75	3.83	3.50	3.75
Resistance to hollow heart	3.75	4.17	3.75	4.50
Resistance to mechanical injury	7.00	6.83	5.00	5.75
Resistance to potato virus Y (PVY)	4.35	6.42	6.38	5.50
Resistance to potato leafroll virus (PLRV)	6.50	6.58	5.88	4.50
Resistance to potato blight	3.00	2.67	3.50	3.50

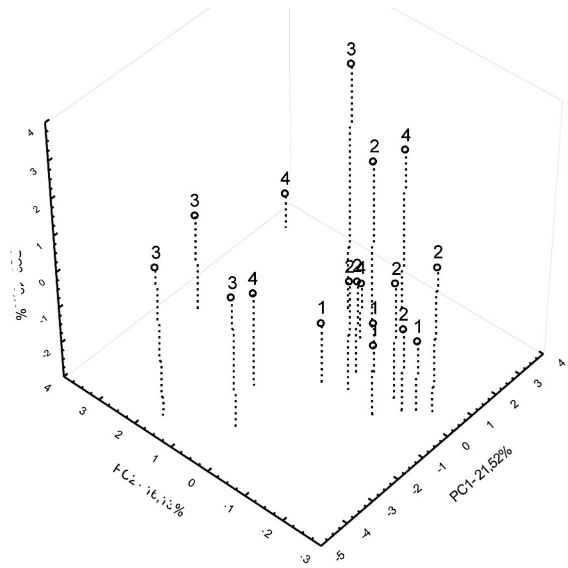
Table 3. List of the potato cultivars, their geographic origins and their assigment to homogenous group, as by cluster analysis

Cultivar	Year	Country of origin	Group number	Cultivar	Year	Country of orgin	Group number
Aruba	2007	Poland	3	Lady Claire	2001	Holand	4
Augusta	2003	German	1	LadyFlorina	2004	Holand	2
Bellarosa	2006	German	2	Latona	1997	Holand	3
Bila	1994	Poland	2	Michalina	2010	Poland	4
Cyprian	2007	Poland	4	Nora	2003	Greman	4
Etola	2009	Poland	3	Oman	2005	Poland	1
Eugenia	2006	Poland	2	Rosalind	2001	German	2
Ewelina	2006	German	1	Veroni	2005	Holand	1
Gracja	2002	Poland	3	Vineta	1999	German	2

The second group consisted of cultivars which were only slightly correlated with PC1 and PC2, and moderately and positively associated with the third principal component. The group included three German cultivars: Bellarosa, Rosalind and Vinieta, two Polish cultivars: Bila and Eugenia, and Lady Florina – a Dutch cultivar. They are high-yielding varieties (38.67 t/ha) which produce large tubers (8.42) with low starch, dry matter and glycoalkaloid contents (12.58%, 19.78% and 38.17mg/kg, respectively). It is assumed that the levels of glycoalkaloids in tubers should not exceed 200 mg/kg [Friedman and Mc Donald 1997 Hall 1992]. A low tendency for these cultivars to accumulate TGA indicates that it is unlikely that dangerous concentrations of glycoalkaloids could be exceeded in potato under field conditions of production [Trawczyński and Wierzbicka 2011]. The cultivars in this group are quite resistant to potato virus Y, potato leafroll virus and mechanical injury but, at the same time, susceptible to potato blight (2.67) (table 2,3, fig.1)

As shown in Figure 2, most cultivars in the third group are highly and negatively correlated with PC1 and positively correlated with PC2. Tubers of these cultivars are quite tasty 6.55), tend to darken after cooking (7.88) and accumulate most starch (14.28%), dry matter (22.58%) and vitamin C (22.20 mg%). However, their yields are the lowest and they are most susceptible to internal rust spot, hollow heart and mechanic injury.

Cultivars in the fourth group were positively correlated with PC1 and PC2 and negatively associated with PC3. The group was made up of the following cultivars: Nora, Michalina, Lady Clarine and Cyprian. They produced the highest yields (41.13 t/ha) of tubers with the least after-cooking discolouration (8.68) and low resistance to potato leafroll virus (4,50) which tended to accumulate most glycoalkaloids (90.25) and were most resistant to hollow heart (4.50). The considerably high yield potential is clear a evidence of the fact that breeding progress makes it possible to create genotypes which give stable crops under favourable conditions irrespective of geographical location: Michalina and Cyprian are Polish cultivars, Lady Clarine is a Dutch cultivar and Nora is a German cultivar (Table 2, 3 and Figure 1, 2).



1, 2, 3, 4 – espective signs denote cultivars assigned to particular groups identified by cluster analysis

Figure 2. Dystrybution of 18 potato cultivars terms of 17 traits in the system of the three components

CONCLUSION

The analytical tools presented here are useful when one wants to conduct a complex and detailed analysis of trait diversity among cultivars.

These tool make it possible to classify genotypes simultaneously in terms of many characteristics and describe them (typology). Cultivar classification makes it easier to choose the best cultivars depending on their use, e.g.: to produce chips, crisps or to grow organic potatoes.

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