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Nonparametric indexes in selecting advanced potato clones

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ABSTRACT

This study aimed to test nonparametric selection indexes for selection of advanced potato clones and identification of those that are likely to become cultivars. The experiments were carried out in 2016 and 2017 crop seasons, from May to August, in the experimental field of Embrapa Vegetables. Seventeen advanced potato clones and two check cultivars (Agata and Asterix) were evaluated. A randomized complete block design with four replications was used. Experimental plots consisted of a 3 m row, with 10 tubers spaced 30 cm apart within and 80 cm between rows. At 115 days after planting, tubers of each plot were harvested, classified, counted and weighed. Analysis of variance was performed and the following nonparametric selection indexes were applied: weight-free index, sum of ranks index and distance of the genotype-ideotype index. The three selection indexes coincided with the choice of the best genotypes, with the first two being superior, because the weight-free index was more restrictive than the other indexes. Among the selected clones, F97-07-08 and F183-08-01 stood out for being coincident in the three indexes. In addition to these, clones F158-08-01 and F18-09-03 were also selected by the indexes of the genotype-ideotype and sum of ranks.

Keywords: *Solanum tuberosum*, breeding, weight-free index, sum of ranks index, genotype-ideotype index.

RESUMO

Índices não paramétricos na seleção de clones avançados de batata

Este trabalho teve como objetivos testar índices não paramétricos na seleção de clones avançados de batata e identificar clones promissores para poderem ser lançados como cultivares. Os experimentos foram conduzidos nos meses de maio a agosto dos anos 2016 e 2017, no setor de campos experimentais da Embrapa Hortaliças. Foram avaliados 17 clones avançados de batata e duas cultivares testemunha (Agata e Asterix). O delineamento experimental foi blocos casualizados com quatro repetições. As parcelas experimentais foram constituídas por uma linha de 3 m de comprimento, com 10 tubérculos espaçados de 30 cm entre si, e distância de 80 cm entre sulcos. Aos 115 dias após o plantio, foi realizada a colheita e os tubérculos foram classificados, contados e pesados. Após análise de variância, foram aplicados os seguintes índices de seleção não paramétricos: livre de pesos e parâmetros, soma de *ranks* e distância do genótipo-ideótipo. Os três índices de seleção foram coincidentes na escolha dos melhores genótipos, mas os dois primeiros foram superiores, pois o índice livre de pesos e parâmetros foi mais restritivo que os demais. Entre os clones selecionados, F97-07-08 e F183-08-01 se destacaram por serem coincidentes nos três índices. Além desses, os clones F158-08-01 e F18-09-03 também foram selecionados pelos índices da menor distância do genótipo-ideótipo e soma dos *ranks*.

Palavras-chave: *Solanum tuberosum*, melhoramento, livre de pesos e de parâmetros, soma de *ranks*, genótipo-ideótipo.

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In potato breeding programs, a large number of clones is usually evaluated in early generations due to the tetraploid nature of the potato, which provides great variability in crosses. In the first phases of selection, generations 1 and 2, many clones are eliminated based on qualitative characters, while in more advanced stages, generations 3 and 4, in addition to qualitative characters, a series of quantitative characters is evaluated in multi-local and repeating tests (Silva & Pereira, 2011).

Selecting advanced clones based on only one character is simple; however, as it is necessary to match several characters to reach a new cultivar, it is important to use techniques that allow the selection of these characters simultaneously. This is possible with the use of selection indexes, which are based on the constitution of an additional character, established by the optimal linear combination of the various characters evaluated (Cruz *et al*., 2012).

There are two groups of selection indices: parametric and nonparametric. The first requires parameter estimates and usually the assignment of weights based on the importance of the character. In addition, they are suitable when the set of genotypes forms a random sample (Vittorazzi *et al*., 2013). Nonparametric indices do not require parameter estimates or weight assignment, and therefore are less subjective. Also as an advantage, non-parametric indices can be applied, both together with genotypes forming a random sample, as well as to pre-selected genotypes (Garcia & Souza Junior, 1999). In the case of potato breeding, they can be used in a set of advanced potato clones, pre-selected for non-quantitative characters.

Among non-parametric indices, the weight-free index (Elston, 1963) has as characteristic the possibility of eliminating the creation of 'economic' weights (genotypic standard deviation, heritability genotypic variation coefficient or weights attributed by attempts) relative to the set of characters under evaluation. In addition, estimates of genotypic and phenotypic variances and covariances that can cause distortions as in the classical selection index (Smith, 1936) are not necessary. In potatoes, the weight-free index proved to be less efficient than other indices such as multiplicative and sum of ranks index (Terres *et al*., 2015).

Another nonparametric index is known as the sum of ranks (Mulamba & Mock, 1978). It is characterized by the ranking of genotypes based on each of their characters in an order favorable to genetic breeding. When classified, the orders of each genotype referring to each character are added, resulting in an additional measure that is used as a selection criterion (Cruz *et al*., 2012). This index was used in potatoes (Terres *et al*., 2015; Silva *et al*., 2018), being very efficient in the selection of potato clones for multiple characters.

Still in the nonparametric group, there is the *genotype-ideotype distance* index (Schwarzbach, 1972). This index is based on assigning an optimal value for each character, based on the data itself. Thus, an idealized genotype is composed, the ideotype, that is, the genotype with the best values of that set of genotypes evaluated for each character. The genotypes to be selected are those that present the shortest Euclidean distance in relation to the ideal genotype. In potatoes this index was considered ideal for the selection of advanced clones based on tuber yield characters and frying quality (Silva *et al*., 2014).

Although these indices have already been evaluated for the selection of potato genotypes in some studies, the use of all these indices in the selection of the same set of clones would provide a better comparison among them, especially for a more extensive set of characters and, therefore, with a more complete characterization of the clones under evaluation.

Thus, the objective of this study was to test the nonparametric genotype-ideotype, weight-free and sum of ranks indices in the selection of advanced potato clones, and to identify the promising ones, based on the set of characters.

MATERIAL AND METHODS

The experiments were carried out in the 2016 and 2017 crop seasons in the experimental field of Embrapa Vegetables (15º55'44"S; 48º08'35"W; Altitude 1,000 m), located in Brasília-DF. The climate of the region is type Aw, tropical with dry season in winter, according to Köppen-Geiger. The soil of the experimental area is classified as a dystrophic red latosol of clayey texture. The average temperature for 2016 was 21.4ºC (minimum 9.6ºC and maximum 32.4ºC) and total precipitation of 17.4 mm (May 9.2 mm, June 0.2 mm, July 0.0 mm, and August 8.4 mm) and 2017 average temperature of 20.4ºC (minimum 7.6ºC and maximum 32.1ºC) and total precipitation of 35.5 mm, only in May.

A total of 16 advanced potato clones (F13-09-03, F18-09-03, F21-09-07, F22-08-01, F31-08-05, F37-08-01, F63-10-07, F82-08-10, F97-07-03, F102-07-22, F102-08-04, F117-08-06, F150-08-03, F158-08-01, F158-08-02 and F183-08-01), from Embrapa's Potato Genetic Breeding Program; one advanced clone (CL 308) from the Epagri's Potato Genetic Breeding Program, and two cultivars widely cultivated in Brazil (Agata and Asterix), used as checks.

The experimental design was randomized complete blocks with four replications in the two experiments. The experimental plots consisted of a 3 m long row, with 10 tubers spaced 30 cm within rows, and 80 cm between rows (Pereira *et al*., 2017).

The seed tubers were planted in an area under fallow with summer grasses (millet and napier grass), which were desiccated with non-selective herbicide, fragmented with straw chopper and incorporated in the first plowing operation 60 days before planting. No limestone was added, because the chemical analysis of the soil did not show the need for correction. One week before planting, the soil was prepared with disking and with rotary tiller. The planting furrows were opened using a tractor-operated furrower/fertilizer.

Planting fertilization in the two years was performed with 90 kg ha^{-1} urea (41 kg ha^{-1} N), 1,450 kg ha^{-1} triple superphosphate (661 kg ha^{-1} P_2O_5) and 90 kg ha^{-1} potassium chloride (54 kg ha^{-1} K_2O).

The experiments were planted at the beginning of the third week of May of each year, using type II seed tubers after four months of cold storage at 4.0°C. The tuber seeds of all genotypes were sprouted and were taken out from the cold chamber two weeks before planting. Irrigation was provided by conventional sprinkler with a 28 mm slide per shift, twice a week. Hilling was performed using a hilling machine 25 days after planting, and the topdressing was performed at the time of the hilling at the dosage of 120 kg ha^{-1} ammonium nitrate (41 kg ha^{-1} N). The other cultural treatments were the ones commonly used for the potato crop in the Brazilian Savannah region (Filgueira, 2008).

At 15 days after planting, plant emergence was evaluated by counting the number of plants emerged in relation to the total number of tubers planted. At 60 days after planting, the plant vigor was evaluated with the assignment of grades from 1 to 5, with 1 being the lowest vigor and 5 the highest vigor (Sadawarti *et al*., 2018), and incidence of bacterial wilt observed by counting plants that presented wilting symptoms in relation to the total number of plants in the plot.

From 90 to 110 days after planting, the vegetative cycle was evaluated by assigning grades to plots that presented more than 80% of plants with senescent leaves, with grade 1 for 90 days, grade

2 for 100, grade 3 for 110 and grade 4 for those ones that presented a cycle greater than 110 days after planting, respectively.

At 110 days after planting, desiccation was performed with paraquat herbicide at a dose of 2 L ha^{-1} (0.4 kg a.i. ha^{-1}). The harvest was carried out at 115 days after planting using the semi-mechanized system, with exposure of tubers with tractor ted harvester and manual collection.

In the laboratory, the following characteristics were evaluated: total tuber mass (kg $plot^{-1}$, TTM), obtained by weighing all tubers collected in each plot; commercial tuber mass (kg $plot^{-1}$, CTM), obtained by weighing the tubers without external defect and with a diameter above 45 mm; noncommercial tuber mass (kg $plot^{-1}$, NTM), calculated by the difference between TTM and CTM; commercial tubers number (CTN), obtained by counting the tubers without defect and with a diameter greater than 45 mm; total tuber number (TTN), obtained by counting all tubers harvested in each plot; noncommercial tubers number (NTN), calculated by the difference between TTN and CTN; proportion of the commercial tuber mass (PCTM), calculated by dividing the CTM by TTM; and average tuber mass (g, ATM), calculated by dividing TTM by TTN.

The characters measured by weighing were transformed into tons per hectare (TTM, CTM, and NTM) or /1000 tubers per hectare (TTN, CTN, and NTN).

The analysis of variance was performed jointly according to the model: Yijk = m + bj(k) + gi + ak + (ga)ik + εij (k), in which: i = 1, 2, ..., I Genotypes; j = 1, 2, ..., J blocks; k = 1, 2, ..., K experiments, considering genotypes and experiments as fixed effects and assuming significance of 5% probability by f test. Estimates of nonparametric indices were obtained with the computational application Genes VS 2013.5.1. (Cruz, 2013). Those variables that did not meet the assumptions of variance analysis were transformed into $\sqrt{x+0.5}$.

The weight-free index is calculated by the following estimator:

$$I_{Ei} = log\prod_{j=1}^{m}(x_{ij}-k_j) = \log[(x_{i1}-k_1)(x_{i2}-k_2 \ldots (x_{in}-k_n)]$$

where, IE_i represents the weight- free index, X_{ij} refers to the mean of character j, measured in genotype i and, k_j, the lowest value that can be determined by

$$\left(k_j = \frac{n\left(min.x_{ij} - max.x_{ij}\right)}{n-1}\right)$$

n is the number of genotypes evaluated, and $min.x_{ij}$ and $max.x_{ij}$ are, the lowest and highest means of the character j, respectively.

The sum of ranks index is provided by the estimator:

$$\left(I_{MMi} = \sum_{j=1}^{m} n_{ij},\right)$$

where, IMM_i is the sum of rank index, and n_{ij} is the classification number of genotype i in relation to character j, being used the genetic standard deviation as 'economic' weight.

To calculate the base index of the shortest distance of the genotype-ideotype (genotype-ideotype index), the expression presented by Cruz (2006) is used:

$$I_{DGI} = \sqrt{\frac{1}{n}\sum_{j=1}^{n}\left(y_{ij} - VO_j\right)^2}$$

where, I_{GDI} = distance between genotype j and ideotype I (j = 1, ..., 19); y_{ij} = measure of character i in genotype j (i = 1, ..., 12); VO_j = value defined for ideotype I, referring to character i. By this expression, the best clones were those that presented the shortest Euclidean distance in relation to the ideotype. First, these characters were standardized and then, the ideal genotype was defined as the one with the highest values for plant emergence, plant vigor, TTM, CTM, TTN, CTN, PCTM, and ATM and lowest value for vegetative cycle, bacterial wilt index, NTM, and NTN.

RESULTS AND DISCUSSION

The source of variation year influenced the manifestation of the characters plant vigor, vegetative cycle, total tuber mass (TTM), commercial tuber mass (CTM), and commercial tuber number (CTN) (Table 1). Regarding the difference among genotypes, for the set of clones evaluated in the two years, there were significant differences for plant vigor, noncommercial tuber mass (NTM), total tuber number (TTN), CTN, proportion of commercial tuber mass to the total tuber mass (PCTM), and average tuber mass (ATM). The year x genotype interaction was significant for the plant vigor, bacterial wilt incidence, TTN, CTN, PCTM, and ATM.

The only character that did not present differences between years, genotypes or in the interaction between these two factors was plant emergence, which ensured the good final stand of the experiment, and the need not to adjust the plot data for this covariate. The experimental coefficients of variation (CVe %) ranged from 5.40% for plant emergence to 63.87% for bacterial wilt incidence, with most characters with values below 20%. These estimates demonstrate the good precision of the experiments. The incidence of bacterial wilt is a character greatly influenced by the environment, especially in field-level experiments.

The genotypic determination coefficient (GDC) was higher than 80% for most of the evaluated characters, showing a situation very favorable to selection due to the high inheritable variation based on the mean of the evaluated experiments. The rate between genotypic and environmental coefficients of variation (CVg/CVe) presented values between 0.03 and 1.02. The literature reports that favorable values for selection would be those equal to or greater than 1 (Cruz *et al.*, 2012). Thus, it is observed that greater responses to the selection would be obtained for plant vigor, vegetative cycle, TTM, CTM, TTN, and CTN. It is noteworthy that the most important characters that are TTM and CTM did not present differences among potato genotypes. This fact can be ascribed to previous selections carried out in the set of equivalent clones in which the performance of the clones was leveled in levels to the checks Agata and Asterix. Thus, other characters were responsible for defining the best clones.

By the methodologies of sum of ranks index and the genotype-ideotype index, four (F158-08-01, F183-08-01, F97-07-08 and F18-09-03) of the five clones selected by these methodologies are coincident (Table 2). By the weight-free index, using the mean as k_j value, only the two selected (F183-08-01 and F97-07-08) are coincident with two other methodologies. The latter, therefore, is more restrictive for the set of genotypes evaluated in the present study. Non-parametric indices should be used with caution in breeding programs aimed at the selection of cultivars, especially the weight-free index, because the restriction of genotypes can limit the choice of any cultivar if any selected character is outside the minimum standard susceptible to cultivation. Thus, broader indexes allowed greater alternatives, either in the choice of cultivars, or in the selection of genotypes in recurrent selection programs (Garcia & Souza Júnior, 1999).

The coincidence between the sum of rank index and genotype-ideotype index is reported in the literature. In cassava, in the evaluation of eight genotypes for

Table 1. Summary of the analysis of joint variance for the characters plant emergency (EME, %), plant vigor (VIG, notes 1 to 5), bacterial wilt index (BWI, plants per plot), vegetative cycle (CIC, notes 1 to 4), total tuber mass (TTM, t ha^{-1}), commercial tubers mass (CTM, t ha^{-1}), noncommercial tuber mass (NTM, t ha^{-1}), total tubers number (TTN, /1000 ha^{-1}), commercial tubers number (CTN, /1000 ha^{-1}), noncommercial tuber number (NTN, /1000 ha^{-1}), proportion between CTM/TTM (PCTM) and average tuber mass (ATM, g) in potato clones in 2016 and 2017. Brasilia, Embrapa Hortaliças, 2019.

Character	Mean square				Mean	CV (%)	CDG	CVg/CVe
	Years (A)	Genotypes (G)	A x G	Error				
EME	0.47^{ns}/1	0.14 ^{ns}	0.47 ^{ns}	0.28	94.57	5.40	40.40	0.03
VIG	0.20**	3.74**	0.06**	0.03	3.01	8.61	86.79	0.94
BWI	5.20 ^{ns}	9.68 ^{ns}	4.31**	0.99	1.93	63.87	81.05	0.39
CIC	0.29**	0.19 ^{ns}	0.05 ^{ns}	0.04	2.04	12.70	86.09	0.99
TTM	5.87**	1.44 ^{ns}	1.13 ^{ns}	0.80	32.10	15.68	86.35	0.99
CTM	4.77**	5.05 ^{ns}	0.69 ^{ns}	0.83	24.01	18.44	88.51	0.90
NTM	1.36 ^{ns}	14.69*	1.13**	0.46	8.45	22.61	66.51	0.29
TTN	35.19 ^{ns}	317.37**	16.62**	4.89	209.11	15.27	86.11	0.80
CTN	24.53**	8.40 ^{ns}	5.12 ^{ns}	3.09	110.08	16.71	87.42	1.02
NTN	20.75 ^{ns}	502.73**	12.46**	3.14	95.22	18.12	84.86	0.66
PCTM	0.001 ^{ns}	0.034*	0.086**	0.004	0.70	5.55	65.23	0.31
ATM	12.70 ^{ns}	264.70**	12.44**	2.87	164.36	13.18	77.44	0.12

[1] ** and * Significant at 1 and 5% by the F test, respectively; ^{ns}=not significant. CDG: Genotypic coefficient of determination; CVg/CVe: coefficient of genetic variation over the environment.

Table 2. Means of clones selected by different nonparametric indices for the plant emergency (EME, %), plant vigor (VIG, notes 1 to 5), bacterial wilt index (BWI, plants per plot), vegetative cycle (CIC, notes 1 to 4), total tuber mass (TTM, t ha^{-1}), commercial tubers mass (CTM, t ha^{-1}), noncommercial tuber mass (NTM, t ha^{-1}), total tubers number (TTN, /1000 ha^{-1}), commercial tubers number (CTN, /1000 ha^{-1}), noncommercial tuber number (NTN, /1000 ha^{-1}), proportion between CTM/TTM (PCTM) and average tuber mass (ATM, g) in potato clones in 2016 and 2017. Brasilia, Embrapa Hortaliças, 2019.

Character	Sum of ranks index	Sum of ranks and genotype-ideotype indices				Genotype-ideotype index	Ideotype mean
			Weight-free index				
	F21-09-07	F158-08-01	F183-08-01	F97-07-08	F18-09-03	F150-08-03	
EME	99.70	98.10	94.76	95.54	100.00	93.98	100.00
VIG	2.96	4.30	3.62	3.74	2.92	3.62	4.30
BWI	1.04	3.11	0.08	0.31	0.78	0.00	0.00
CIC	1.93	2.81	2.81	2.63	2.00	3.83	2.00
TTM	39.95	52.50	49.06	42.01	38.69	47.52	52.50
CTM	27.06	34.43	40.08	32.79	29.75	40.59	40.59
NTM	12.89	18.07	8.98	9.22	8.94	6.92	11.91
TTN	322.06	301.91	257.74	256.14	260.97	236.35	301.91
CTN	149.56	207.72	154.50	135.22	146.88	162.06	207.72
NTN	172.50	94.19	103.24	120.92	114.09	74.29	94.19
PCTM	0.73	0.71	0.80	0.69	0.78	0.80	0.80
AMT	126.29	173.74	192.15	173.74	150.79	202.85	202.85

Order of classification of potato clones	Sum of ranks index	F158-08-01> F183-08-01> F21-09-07> F18-09-03> F97-07-08
	Genotype-ideotype index	F158-08-01> F183-08-01> F150-08-03> F97-07-08> F18-09-03
	Weight-free index	F183-08-01> F97-07-08

multiple characters, the coincidence of the indices of base index in sum of ranks and genotype-ideotype index was of high magnitude (Lessa *et al*., 2017). For potatoes the results were not coincident between different selection indices. Some studies demonstrated efficiency of the sum of ranks index in the choice of the best genotypes (Terres *et al*., 2015), while others found superiority of the genotype-ideotype index (Silva *et al*., 2014).

In relation to clones closest to the ideotype, F158-08-01 and F183-08-01 were identified as the most promising. Regarding F183-08-01, the promising performance of this clone has already been reported in studies in the literature in the evaluation of the aforementioned clone in Canoinhas-SC and Pelotas-RS (Silva *et al*., 2016). In addition, this clone has already been registered in the National Register of Cultivars (RNC) of the Ministry of Agriculture Livestock and Supply (MAPA) registration number 41,671, and has fancy name BRS F183. It will be intended for potato chain agents who process tubers in the form of frozen French fry.

The fact that clone F158-08-01 was not selected by the weight-free index can be explained by the high incidence of bacterial wilt (incidence of 3.1% compared to 0.9% incidence for mean of the other genotypes). Thus, the weight-free index eliminated the clone F158-08-01, because it presented Kj values above the maximum established for cultivation and culminated in the disposal of this clone.

The means of genotypes F183-08-01 and F97-07-08, which were selected in the present study by the three selection indices, together with F158-08-01 and F18-09-03, which were also selected by the genotype-ideotype and sum of ranks indices, were higher than the overall average of the experiment for the characters plant emergence (2.58% higher), plant vigor (21.10%), TTM (41.95%), CTM (42.70%), TTN (28.73%), CTN (46.33%), PCTM (6.43%) and ATM (5.02%). In the selection of these superior genotypes for tuber yield there would also be an increase in the NTM (33.76%) and an increase in the NTN (13.54%), because there would be an increase not only in commercial tubers, but also in the total tuber yield.

There was a desirable decrease in the incidence of bacterial wilt in 44.56% (Table 2), but an increase of 25.61% in the score for the vegetative cycle character. This is due to the fact that long-cycle genotypes are generally more productive than short-cycle genotypes, probably due to the longer time to synthesize and store photoassimilates (Silva & Pinto, 2005; Rodrigues *et al*., 2009; Silva *et al*., 2020), therefore, it is expected that in the selection of more productive genotypes it is necessary to allow clones of longer cycles.

In view of these results, it was possible to verify that the three selection methodologies used in this study are efficient in potatoes, however it is considered that the genotype-ideotype and sum of ranks indices are superior to the weight-free index. Therefore, this last one is not indicated for potato breeding aiming to develop cultivars. According to the three indices, clones F97-07-08 and F183-08-01 were superior to the other genotypes. In addition to these two clones, F158-08-01 and F18-09-03 should also be considered as candidates to be released as new cultivars.

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