Crop Breeding and Applied Biotechnology 6: 242-249, 2006
Brazilian Society of Plant Breeding. Printed in Brazil

NOTE

Estimate of cross efficiency of potato parents

Roberto Fritsche Neto[1], Velci Queiroz de Souza[1*], Arione da Silva Pereira[2], Giovani Olegário da Silva[1], and Sandra Müller Garcia[1]

Received 4 February 2006

Accepted 14 April 2006

ABSTRACT - *The objective of this study was to estimate the cross efficiency of 43 genotypes frequently used as parents in the potato breeding program of Embrapa Clima Temperado. The study was conducted under greenhouse conditions in the seasons autumn and winter/spring, from 2000 to 2004, in Pelotas, RS, Brazil. For each cross, the number of pollinated flower buds, the fruit-set and the number of seeds were recorded. Each season, in which the genotype was crossed, was considered a replication. The data were analyzed using the REML/BLUE statistic model. Male parents adapted to the ecological conditions of the southern regions of Brazil presented higher efficiency in crosses than female parents. Genotypes used as male parents influenced the number of seeds per flower bud more than female parents.*

Key words: *Solanum tuberosum* L., hybridization, true seed.

INTRODUCTION

Potato is native to the Andes of southern Peru and northern Bolivia, adapted to the short day regime of the region. The introduction of the crop in Europe resulted in selection for tuberization during the period of long summer days of the northern region of the continent. From there the crop was spread to other countries of the world (Hawkes 1993).

Despite the importance of this crop in Brazil, the country has few national cultivars. Once adapted to the ecological and technological conditions of the country, brasilian cultivars are easier to grow and cost less for the same yield level when compared to imported ones (Pereira 2000).

Breeding can contribute significantly to the improvement of crop efficiency. For this purpose, it is important to be able to cross introduced genotypes with adapted ones, with a view to establish progenies that present variability for the target traits.

The choice of parents depends on the focus of the program (Tarn 1992). However, the use of any genotype is given, obviously, by its ability of flowering and producing fruits and viable seeds (Pinto and Martins 1994). It is necessary to know the ability of a genotype to transfer desirable traits to its descents, its combining ability, the fertility-restricting factors and its ability to cross as male and female parent (Pereira 2003).

The objective of this study was to estimate the efficiency of crosses of introduced genotypes with

[1] Faculdade de Agronomia "Eliseu Maciel" (FAEM), Universidade Federal de Pelotas (UFPel), C. P. 354, 96.001-970, Pelotas, RS, Brasil. *E-mail: velciq@gmail.com
[2] Embrapa Clima Temperado, Rodovia BR 392, km 78, C. P. 403, 96.001-970, Pelotas, RS, Brasil

genotypes adapted to the edaphic-climatic conditions of southern Brazil.

.

MATERIAL AND METHODS

The study was conducted in a greenhouse in the autumn and winter/spring cross seasons, from 2000 to 2004, at the headquarters of Embrapa Clima Temperado, Pelotas, RS, Brazil (lat 31° S, long 52° W). Forty-three frequently used parent genotypes in the potato breeding program of Embrapa Clima Temperado were studied. These genotypes were tested as male and female parents in at least three out of the ten crop seasons.

The adapted genotypes were the following: 2CRI-1149-1-78, 3CRI-1316-8-82, C-1485-16-87, C-1485-6-87, C-1684-7-93, C-1720-40-94, C-1730-7-94, C-1740-11-95, C-1750-15-95, C-1750-2-95, C-1786-6-96, C-1786-7-96, C-1786-9-96, C-1311-11-80, C-1226-35-80, C-1883-5-97, C-1890-1-97, C-1714-7-94, Araucária, Baronesa, Catucha, Cristal, Eliza, Macaca, Monte Bonito, and Pérola. The introduced genotypes were: Agria, Asterix, Atlantic, Bintje-Japão, BP-1, Cyklámen, Exquisa, Fabula, Monalisa, Ona, Pukara, Rioja, Shepody, Van Der Plank, Vivaldi, and White Lady.

Plants were grown in 5L pots filled with organic soil, and string-trellised by simply wrapping the plant stem around a plastic twine. To induce flowering, nights were interrupted by two-hour lighting, using 160W mercury blended tungsten filament lamps. The temperature was kept at 20 ± 5 ºC by adjusting heaters, fans and greenhouse windows.

Crossings were performed by hand-pollination using the genotypes with available pollen and genotypes with flowers in the bud stage, which were emasculated simply by cutting the petals.

Fruits were harvested about three weeks after fruit set and the seeds were extracted by a mini-processor, which softens fruits up and frees the seeds. The seeds were then placed on plastic cups in a greenhouse to dry.

For each cross, data of the number of pollinated buds, number of fruit sets and number of seeds were collected. Each season in which the genotype was crossed was considered a replication.

The data of percentage of fruit set, number of seeds per fruit and number of seeds per flower bud were obtained for each genotype and crop season, whether they were used as a parent, male or female.

Data of percentage of fruit set were transformed by the expression $\sqrt{(\chi + 0.5)}$.

The data were analyzed using the statistical software SAS Learning Edition (2002) and applying Proc Mixed. This procedure is appropriate for the analysis of unbalanced mixed models, as it clearly differentiates fixed from random effects (Littell et al. 1996). The Reml/Blue statistical model (Restricted maximum likelihood/Best linear unbiased estimators) was used. In a matrix form, the general linear mixed model described by Harville (1977) is:

$$y = X\beta + Zv + e$$

where

${}_{n}y_{1}$ is the observation vector;

${}_{n}X_{p+1}$ is the incidence matrix of fixed effects (known);

${}_{p+1}\beta_{1}$ is the vector of unknown fixed effects;

${}_{n}Z_{q}$ is the incidence matrix of random effects (known);

${}_{q}\mathbf{v}_{1}$ is the vector of unknown random effects;

${}_{n}e_{1}$ is the vector of random errors;

where

n is the number of observations;

p is the number of parameters;

q is the number of random effects.

It is assumed that the random effects and errors (residues) have a normal distribution with average zero and were not correlated with the variance and covariance matrices, respectively. By hypothesis, G and R defined matrices positively and therefore not singular, given by:

$$Var(v) = E(vv') = G \text{ and } Var(e) = E(ee') = R.$$

In a matrix this can be expressed as

$$Var\begin{bmatrix} v \\ e \end{bmatrix} = \begin{bmatrix} G & \Phi \\ \Phi & R \end{bmatrix}$$

It follows that

$$V = Var(y) = Var(X\beta) + Var(Zv) + Var(e) = ZVar(v)Z' + R = ZGZ' + R$$

It is assumed that V is not singular and $E(y) = E(X\beta + Zv + e) = X\beta$.

so, $y \sim N(X\beta; ZGZ'+R)$.

RESULTS

The observed means of fruit set, number of seeds per fruit and number of seeds per flower bud of potato genotypes for male and female parents are presented in Table 1. There were significant differences ($p < 0.05$) among the genotypes used as male and female parents for all variables.

Performance of genotypes as female parents

It was observed that the genotypes C-1786-6-96, Macaca, White Lady, Fabula, C-1226-35-80 and Exquiza had a higher fruit set than C-1740-11-94, Cristal and Vivaldi, which presented the lowest estimates of breeding value, i.e., the worst performances as female parents (Figure 1).

In relation to the number of seeds per fruit, 'Ona' had the highest estimate (best breeding value), and was significantly higher than 'Catucha', 'Araucária', 'Macaca', 'C-1311-11-82', 'Vivaldi', 'C-1786-9-96' and 'C-1720-40-94', which had the lowest estimates as female parents.

The breeding value of the genotype White Lady exceeded the majority of the genotypes with respect to number of seeds per flower bud.

'Vivaldi' and 'Araucária' had the smallest estimates for number of seeds per flower bud, but were significantly lower than 'White Lady' only.

Performance of genotypes as male parents

It was verified that in relation to fruit set, '2CRI-1149-1-78' had the highest breeding value as male parent. However, it did not differ significantly from 'C-1750-2-95', 'C-1883-5-97', 'Ona', 'Monalisa', 'Vivaldi', 'C-1787-14-96', 'C-1226-35-80', 'Baronesa', 'C-1890-1-97', 'C-1786-6-96', 'Araucária', 'Monte Bonito', 'Eliza', 'Macaca', 'Pukara', 'Exquiza', or 'Bintje-Japan' (Figure 2).

Regarding the estimate of the breeding value for the number of seeds per fruit, 2CRI-1149-1-78 was once more superior to most genotypes, except for C-1883-5-97, C-1787-14-96, C-1226-35-80, Baronesa, C-1890-1-97, C-1786-6-96, Araucária, Monte Bonito, Shepody, Eliza, Macaca, Pukara, and Ona.

In relation to the number of seeds per flower bud, '2CRI-1149-1-78' also presented a high breeding value estimate, being superior to all genotypes, except for C-1226-35-80, C-1787-14-96 and C-1786-6-96.

'Rioja', which had the smallest estimate of number of seeds per flower bud, was significantly lower than only the clones 2CRI-1149-1-78, C-1226-35-80, C-1787-14-96, C-1786-6-96, and Eliza.

DISCUSSION

The parents are chosen according to the objectives established for a breeding program. This step represents the most important phase of the process for exploiting the most of the genetic variability within families (Macedo et al. 1998, Souza et al. 2004). However, the use of a genotype as parent depends on its success in hybridizing.

The REML methodology (Patterson and Thompson 1971) generates nonbiased parameter estimates (Resende et al. 1996) and is the preferred method to estimate variance components of unbalanced data (Harville 1977, Henderson 1984, Searle et al. 1992). In general, predictions of random as well as fixed effects depend on the variance component estimates (Perri and Iemma 1998). The BLUE model appears to be the best estimator for fixed models (Henderson 1974).

In the present study, it was observed that the genotypes adapted to the ecological conditions of the southern region of Brazil, generally performed better than the introduced genotypes when used as male parents. According to Menezes (1994), the environmental conditions such as temperature and day length affect the hormonal balance, for instance the gibberelin levels, which results in high rates of parthenocarpic fruits in cucumber (Tofanelli et al. 2003) and can reduce pollen viability and ovule fertility (Thomas 1995).

Despite the superior performance of the set of genotypes for number of seeds per flower bud, a small performance variation among them was observed when used as female parents. Comparing the genotypes as male parents, the performance varied largely. This suggests that, as expected, there is a high effect of pollen fertility on the number of seeds per flower bud.

All plant breeding programs are intended to produce superior populations with a high frequency of selectable individuals in the selection cycles (Simmonds 1996). In potatoes, the production of botanic seeds from crossings is difficult due to the low fruit set, low yield of seeds per fruit in many genotype combinations, or furthermore, due to high flower bud dropping. Achat

Table 1. Means for fruit set, number of seeds per fruit and number of seeds per flower bud of potato genotypes used as male and female parents

Genotype	Fruit set (%)		Number of seeds fruit^{-1}		Number of seeds flower bud^{-1}	
	Male	Female	Male	Female	Male	Female
2CRI-1149-1-78	16.21	30.75	37.83	45.57	8.17	152.57
3CRI-1316-8-82	18.0	62.00	44.00	0.50	16.00	15.00
C-1226-35-80	23.61	23.61	110.00	29.50	27.17	119.67
C-1311-11-82	7.62	6.16	21.80	4.75	6.20	44.50
C-1485-16-87	13.86	3.55	91.33	3.00	12.78	58.44
C-1485-6-87	15.55	2.54	72.00	1.00	17.57	25.00
C-1684-7-93	4.50	0.00	94.33	0.00	3.67	0.00
C-1720-40-94	4.21	0.87	45.00	0.25	2.00	17.75
C-1730-7-94	7.71	7.18	70.80	4.50	9.40	46.33
C-1740-11-95	2.71	12.25	77.00	13.67	3.40	75.67
C-1750-15-95	12.76	10.81	92.10	10.00	12.30	70.90
C-1750-2-95	12.66	12.15	157.00	8.00	19.00	32.50
C-1786-6-94	22.72	25.08	63.67	25.50	15.67	100.50
C-1786-7-96	16.17	2.29	78.00	1.25	12.67	25.25
C-1786-9-96	6.43	20.77	30.67	5.00	3.33	37.00
C-1787-14-96	9.61	11.54	81.00	27.50	13.33	120.00
C-1883-5-97	8.75	14.58	87.50	11.00	7.50	75.50
C-1890-1-97	11.71	17.93	146.00	21.50	17.50	115.50
Agria	9.29	2.27	104.78	1.75	8.89	55.38
Araucaria	16.25	26.06	9.00	23.50	1.00	94.00
Asterix	7.67	10.05	97.00	7.10	7.80	64.00
Atlantic	14.12	7.91	103.00	12.00	16.40	74.00
Baronesa	5.49	13.93	58.67	15.50	5.67	117.00
Bintje-Japão	18.77	14.04	110.00	6.00	21.00	41.50
BP-1	16.08	3.07	85.00	0.43	13.14	18.14
Catucha	10.70	7.22	4.83	3.40	1.50	63.60
Cristal	2.56	4.47	92.63	3.14	2.75	51.86
Cyklámen	16.87	5.94	47.80	1.80	14.80	27.00
Eliza	12.22	19.83	68.89	21.11	7.33	93.33
Exquiza	23.17	6.84	91.25	2.75	29.75	42.25
Fabula	34.85	1.88	60.00	1.00	26.25	26.75
Macaca	21.47	15.56	17.50	13.00	4.00	88.80
Monalisa	7.41	15.51	24.50	8.00	1.50	50.50
Monte Bonito	14.89	12.05	72.00	13.00	7.20	105.75
Ona1	9.83	22.97	175.00	19.50	34.50	84.50
Pérola	7.40	2.56	87.67	0.50	9.00	12.50
Princesa	7.87	3.55	61.71	1.60	6.57	57.00
Pukara	18.60	11.26	117.00	12.00	24.00	93.67
Rioja	16.07	2.63	81.20	0.60	12.40	19.40
Shepody	11.17	9.151	16.75	11.00	13.25	98.50
Van Der Plank	11.54	4.85	71.75	1.00	8.50	10.00
Vivaldi	2.26	19.69	28.00	15.50	1.75	67.25
White Lady	23.72	6.44	135.44	3.00	36.89	18.00

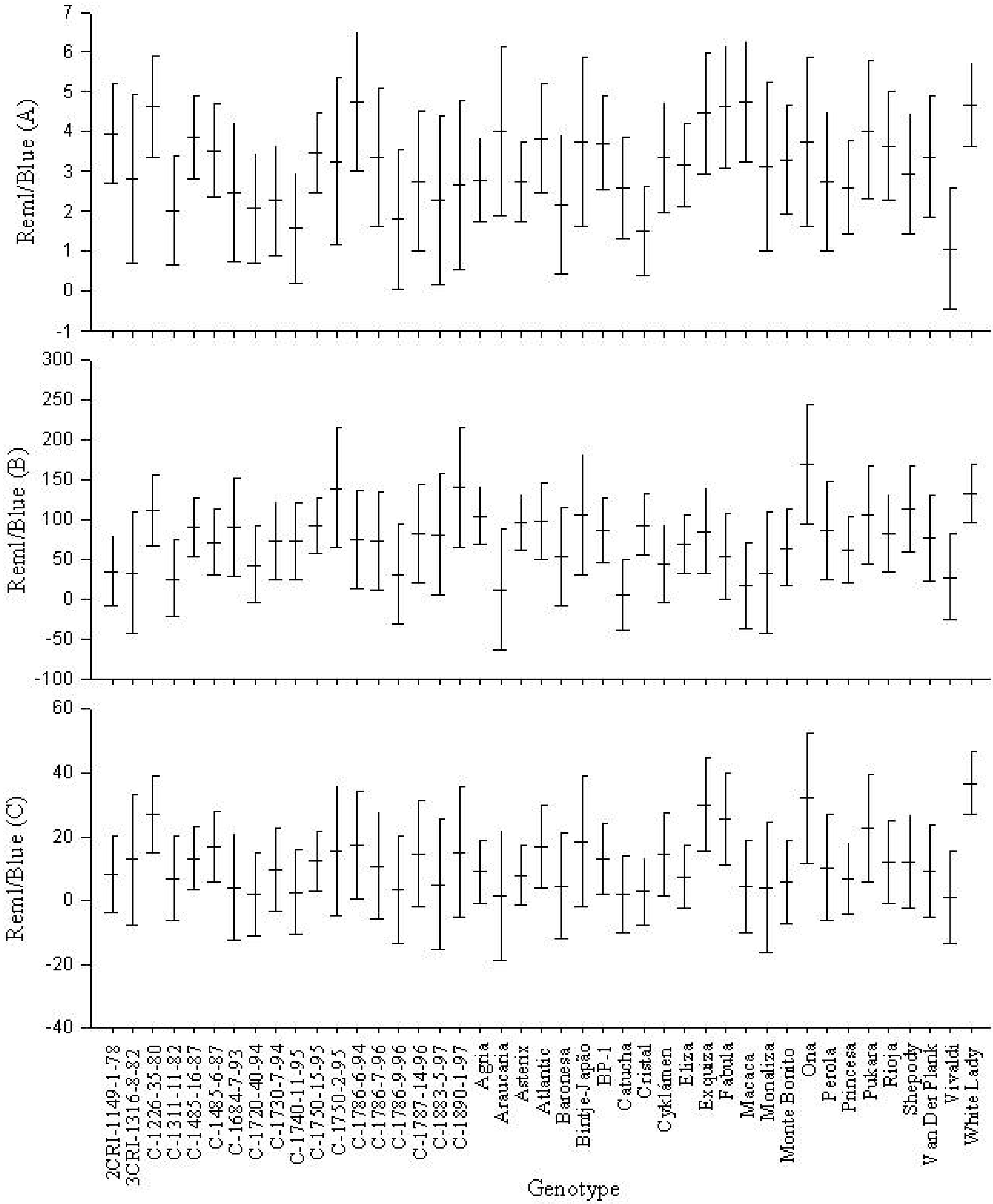

Figure 1. Breeding value estimates of potato genotypes for fruit set (A), number of seeds per fruit (B) and number of seeds per flower bud ©,when crossed as female parents, using Reml/Blue. Intermediate dashes on the lines represent estimates of average breeding values and dashes at the ends of lines represents the range of genotype variance

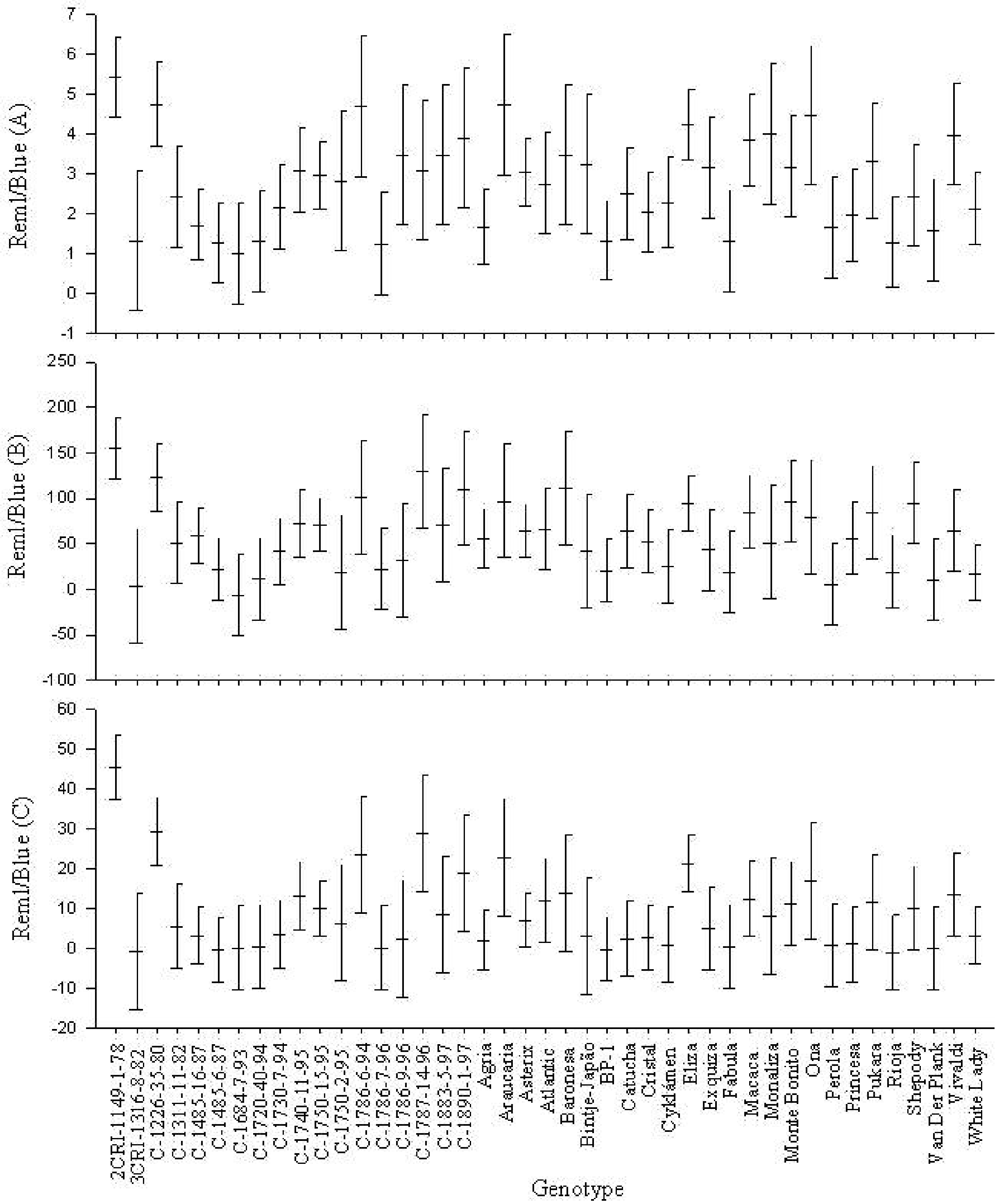

Figure 2. Breeding value estimates of potato genotypes for fruit set (A), number of seeds per fruit (B) and number of seeds per flower bud (C), when crossed as male parents, using Reml/Blue. Intermediate dashes on the lines represent estimates of average breeding values and dashes at the ends of lines represents the range of genotype variance

Cultivar for instance forms flower buds that abort even before opening (Pinto and Martins 1994). Some genotypes, such as C-1750-2-95, C-1883-5-97, Monalisa, Vivaldi, Eliza, Exquiza and Bintje-Japão have high fruit sets, but low yield of seeds per flower bud. This indicates embryo abortion, probably as a result of genetic incompatibility or abnormal chromosome number, resulting in poor gamete formation (Guerra 1988).

In relation to the performance of the genotypes as female parents, only 'Ona' was superior to the others for the number of seeds per fruit. This suggests that the number of seeds per fruit as well as the number of seeds per flower bud are strongly influenced by pollen fertility, since the performance variations for the two variables in the genotypes used as male parents were greater than in the female parents.

Considering the results of the adapted genotypes as male parents and previous observations on pollen fertility and viability, clone 2CRI-1149-1-78 was again significantly superior to other genotypes. 'Eliza' and 'Cristal' had intermediate performance, and 'Cascata' and 'C-1730-7-94' had inferior performance. This suggests that pollen fertility and viability of a genotype are good indicators of its crossing efficiency as male parent.

The variation of genotype performance as female parents was very large for fruit set. This was not true for genotypes as male parents, suggesting that for fruit setting there is a higher influence of the female parent. The variation of performance is probably, apart from other genetic factors, due to hormone levels of the genotype, mainly gibberelins, which can stimulate the fruit development even without pollination (Kohli et al. 1981).

Few of the genotypes that were taken into consideration for crossing had superior performance. Nevertheless, in potatoes, it is necessary to use genotypes with low cross efficiency to avoid a narrowing of the genetic base in the population and losses through endogamy. As it is well known, the basic determinants of potato performance are its tetraploid nature, tetrasomic inheritance and multiallelism (Van Loon 1987).

Recapitulating, the results of this study indicate that genotypes adapted to ecological conditions of the southern region of Brazil offer higher probability of success with hybridization. This is particularly true when the genotypes are used as male parents, as they have a stronger influence on the number of seeds per flower bud than female parents do.

Estimativa da eficiência de cruzamento de genitores de batata

RESUMO - *O objetivo deste trabalho foi estimar a eficiência de cruzamento de 43 genótipos freqüentemente utilizados como genitores no Programa de Melhoramento Genético de Batata da Embrapa Clima Temperado. Os trabalhos foram conduzidos em casa-de-vegetação nos períodos de outono e inverno/primavera de 2000 a 2004, em Pelotas, RS, Brasil. Em cada cruzamento, foram anotados o número de botões florais polinizados, o número de frutos pegos e o número de sementes. Cada período que o genitor foi levado ao bloco de cruzamentos foi considerado uma repetição. Os dados foram analisados pelo modelo estatístico Reml/Blue. Genitores adaptados às condições ecológicas da região apresentaram maior eficiência de cruzamento como genitor masculino do que como feminino. Genótipos usados como genitores masculinos possuem maior influência sobre o número de sementes produzidas por botão floral do que como genitores femininos.*

Palavras-chave: *Solanum tuberosum* L., hibridação, semente verdadeira.

REFERENCES

Guerra M (1988) **Introdução à citogenética geral**. Editora Guanabara, Rio de Janeiro, 142p.

Harville DA (1977) Maximum-likelihood approaches to variances component estimation and to related problems. **Journal of the American Statistical Association 72**: 320-340.

Hawkes JG (1993) Origins of cultivated potatoes and species relationship. In: Bradshaw JE and Mackay GR (eds.) **Potato genetics**. University Press, Cambridge, 552p.

Henderson CR (1974) General flexibility of linear model techniques for sire evaluation. **Journal of Dairy Sciences 57**: 963-972.

Henderson CR (1984) **Applications of linear models in animal breeding**. University of Guelph, Ontario, 462p.

Kohli UK, Dua LS and Saini SS (1981) Gibberelic acid as androecide for bell pepper. **Scientia Horticulturae 15**: 17-22.

Littell RC, Milliken GA, Stroup WW and Wolfinger RD (1996) **SAS system for mixed models**. SAS Institute Inc., Cary, 633p.

Macedo LC, Melo PE and Brune S (1998) Seleção para características de tubérculo em batata a partir da média das famílias clonais. **Horticultura Brasileira 16** (CD-ROM).

Menezes NL (1994) Fatores que afetam a expressão sexual em plantas de pepino. **Ciência Rural 24**: 209-215.

Patterson HD and Thompson R (1971) Recovery of inter-block information when blocks sizes are unequal. **Biometrika 58**: 545-554.

Pereira AS (2000) Melhoramento Genético de Batata. In: **IV Simpósio deatualização e melhoramento de plantas**, UFLA, Lavras, p. 41-50.

Pereira AS (2003) Melhoramento genético. In Pereira AS and Daniels J (eds.) **O cultivo da batata na região sul do Brasil**. Embrapa Informação Tecnológica, Brasília, p. 105-124.

Perri SHV and Iemma AF (1998) Procedimento "MIXED" do SAS para análise de modelos mistos. **Scientia Agricola 56**: 959-967.

Pinto CABP and Martins PR (1994) Indução de florescimento e pegamento de frutos em polinizações controladas em batata. **Ciência e Prática 18**: 370-377.

Resende MDV, Prates DF, Yamada CK and Jesus A (1996) Estimação de componentes de variância e predição de valores genéticos pelo método de máxima verossimilhança restrita (REML) e melhor predição linear não viciada (BLUP) em *Pinus*. **Boletim de Pesquisa Florestal 32/33**: 23-42.

SAS Learning Edition (2002) **Getting started with the SAS learning edition.** SAS Institute Inc., Cary.

Searle SR, Casella G and McCulloch C (1992) **Variance components**. John Wiley, New York, 501p.

Simmonds NW (1996) Family selection in plant breeding. **Euphytica 90**: 201-208.

Souza VQ, Pereira AS, Fritsche Neto R, Silva GO and Oliveira AC (2004) Potential of selection among and within potato clonal families. **Crop Breeding and Applied Biotechnology 5**: 47-54.

Tarn TR, Tai GCC, De Jong H, Murphy AM and Seabrook JEA (1992) Breeding potatoes for long-day, temperate climates. In: Janick J (ed). **Plant Breeding Reviews 9**. John Wiley & Sons, New York, p. 271-332.

Thomas G (1995) Natural and synthesis grown regulators and their use in horticultural and agronomic crops. In: Davies PJ (ed.) **Plants hormones, physiology, biochemistry and molecular biology**. 2nd ed., Kluwer Academic Publisher, Amsterdam, p. 751-773.

Tofanelli MBD, Amaya-Robles JE, Rodrigues JD and Ono EO (2003) Ácido giberélico na produção de frutos partenocárpicos de pimenta. **Horticultura Brasileira 21**: 116-118.

Van Loon JP (1987) Potato Breeding in the Netherlands. In: Jellis GJ and Richardson DE (eds.) **The production of new potato varieties: technological advances**. Cambridge University Press, Cambridge, p.45-54.