Yield stability in cassava (*Manihot esculenta*, Crantz) cultivars in the north and northwest regions of Paraná State

Fabrício Rimoldi[1]; Pedro Soares Vidigal Filho[*1]; Maria Celeste Gonçalves Vidigal[1]; Antônio Teixeira do Amaral Júnior[2]; Rogério Rui Maia[3]; Marcus Vinicius Kvitschal[3] and Edvaldo Sagrilo[3]

[1] Departamento de Agronomia, Universidade Estadual de Maringá, Av. Colombo, 5790, CEP 87020-900, Maringá, PR, Brazil, bolsista do CNPq; [2] Universidade Estadual do Norte Fluminense, Av. Alberto Lamego, 2000, Horto, CEP 28015-620, Campos dos Goytacazes, RJ, Brazil, bolsista do CNPq; [3] Estudante de Pós-Graduação em Agronomia, Universidade Estadual de Maringá, Av. Colombo, 5790, CEP 87020-900, Maringá, PR, Brazil. ([*]Corresponding Author. E-mail: gvidigal@wnet.com.br)

ABSTRACT

A study was carried out to investigate the genotype x environment interaction and study the yield stability of storage roots in eight cassava cultivars, using methodologies by Plaisted and Peterson (1959), Lin and Binns (1988) and Kang (1988), in the counties of Maringá and Rolandia in 1996/97 and 1997/98. The treatments were set out in randomized complete blocks with four replications. The Branca de Santa Catararina, Fibra, IAC 41-85 and IAC 45-85 cultivars were the most stable according the the Plaisted and Peterson (1959) methodology, while the Fibra cultivar, by the Lin and Binns methodology (1988), was oustanding with the lowest possible P_i value and greatest influence of the genetic deviation component. It was the more stable cultivar defined by this methodology. According to Kang (1998) methodology, the Fibra, IAC 45-85 and IAC 163-85 cultivars were the most stable and presented good yield.

KEY WORDS: Genotype x environment interaction, breeding.

INTRODUCTION

Generally, the objective of agriculture is greater yield thus both breeding and agricultural practices should be products of scientific research. Destro and Montalván (1999) observed the importance of cassava breeding in agricultural production by assessing its multiple contributions, which are: increase in storage root yield, reduction in toxic substance content, resistance to pest and diseases, tolerance to extremes in temperature and humidity and tolerance to acidity and water shortage.

When many cassava cultivars are introduced into a determined ecosystem to be selected as the most adapted, the procedure is not expensive. Thus the existing cultivars should be assessed to select those which adapt best to the ecological conditions of each region (Bueno, 1986). Considering that the cultivar assessment phase is the main step in any breeding program, Farias et al. (1997) identified and recommended superior material.

Cultivar performance of any crop normally varies with the environment, so that one cultivar is rarely the best under all cropping conditions. The different response of cultivars to environmental variation is called genotype by environment interaction, which means that the genetic and environmental effects are not independent (Vendruscolo, 1997).

Crops are submitted to many environment variations in Brazil, and the genotype x environment interaction plays a fundamental role in the manifestation of the phenotype. Thus this interaction should be estimated, considering its importance in both the cultivar recommendation and in the genetic breeding programs (Ramalho et al., 1993). Cultivars must be identified by genotypic performance to minimize the significant effects of genotype x environment interaction in order to assess behavior more efficiently, so that behavior adaptability and stability methodologies (Vendruscolo, 1997) are used.

The adaptability of a cultivar refers to its capacity to make good use of environmental variations while stability refers to its capacity of present a highly predictable behavior in function of the quality of environmental stimuli (Borém, 1998).

This study aimed at quantifying the genotype x environment interaction in cassava cultivars, and estimating phenotypic stability parameters concerning the selection of genotypes which correspond to the needs of the cassava agriculture industry in the north and northwest regions of Paraná State.

MATERIAL AND METHODS

Experiments were carried out in 1996/97 and 1997/98 in the counties of Maringá (Iguatemi Experimental Farm – UEM) and Rolandia (Experimental Field of theRolandia Agricultural Cooperative - Corol) which are located in the northwest and north regions of Paraná State, respectively.

Distrophic Red Lattosol soil predominates in the experimental area at Maringá while Distrophic Red Nitossolo predominates at the Rolandia (Embrapa, 1999) experimental area. Chemical analysis of the soil material from the Maringá experimental area showed the following values: pH (H_2O): 6,3; pH ($CaCl_2$): 5,8; $H^+ + Al^{+3}$: 2,95 $cmol_c.dm^{-3}$; Al^{+3}: 0,00 $cmol_c.dm^{-3}$; $Ca^{+2} + Mg^{+2}$: 5,46 $cmol_c.dm^{-3}$; Ca^{+2}: 3,76 $cmol_c.dm^{-3}$; K^+: 0,46 $cmol_c.dm^{-3}$ and P: 7,00 $mg.dm^{-3}$. In the Rolândia experimental area, the chemical analysis of soil material showed the following values: pH (H_2O): 6,2; pH ($CaCl_2$): 5,5; $H^+ + Al^{+3}$: 4,28 $cmol_c/dm^3$; Al^{+3}: 0,00 $cmol_c/dm^3$; $Ca^{+2} + Mg^{+2}$: 7,88 $cmol_c/dm^3$; Ca^{+2}: 6,03 $cmol_c/dm^3$; K^+: 1,41 $cmol_c/dm^3$ and P: 3,80 mg/dm^3.

According to Köppen classification, the climate in Maringá is CWa type, that is, mesothermic wet climate with summer rains and hot autumn and summer, while in Rolândia, the climate is Cfa type, with a dry winter and occasional night frosts.

Five remaining cultivars from the last selection cycle selected by Lorenzi et al. (1996) in Campinas-SP, called IAC 41-85, IAC 45-85, IAC 78-85 IAC 163-85 and IAC 321-85 were assessed in Maringá and Rolândia, in 1996/97 and 1997/98, using the Branca and Santa Catarina, IAC 12 and Fibra cultivars as controls.

In the experiments carried out in Maringá, the experimental plots measured 4.0 m x 8.0 m, with four rows of plants, spaced at 1.0 m between rows and 0.80 m between plants. The useful plot area consisted of the two central rows, with the final 0.80 m eliminated from the ends, leaving a total of 12.80 m^2, with 16 plants. In Rolândia, the plots measured 4.80 m x 8.0 m ,with four rows of plants, with 1.20 m spacing between rows and 0.80 m between plants. The plot useful area consisted of the two central rows, with the final 0.80 m eliminated from the ends, making a total of 15.36 m^2, with 16 plants.

In both assessment periods, planting took place in the first two weeks of October, using the drill planting method, placing with the cassava cuttings horizontally, approximately 0.10 m deep ,and covered with soil. The usual crop treatments were applied according to Dias and Lorenzi (1992).

Experiments were not fertilized to conform as much as possible with the reality of the cassava farming carried out in the north and northwest of Paraná State.

Treatments were set out in randomized complete blocks with four replications, making a total of 32 experimental units in each assessment experiment.

The following characteristics were assessed: a) Mean storage root yield, expressed in $kg.ha^{-1}$, obtained by weighing the roots from all the plants harvested in the useful area of the experimental plot; b) Bacteriosis incidence (*Xanthomonas axonopodis* pv. *manihotis*, Dye et al., 1980) assessed at three, six and nine months at field level using the scale proposed by Fukuda et al. (1984).; c) Over lengthening incidence (*Spaceloma manihoticula,* Bittancourt and Jenkinns, 1950), performed on ten plants from the useful area of each plot, at four and six months after emergence, according to a scale proposed by Lozano (1978) quoted by Silva (1981).

Locations and years were considered environments, totalling four. Genotype effects were considered fixed while the other were random (Cruz and Regazzi, 1997).

Data on each trait collected from different environments were first submitted to an analysis of variance followed by a joint analysis of variance, using the residual mean squares which did not differ by more than the 7:1 ratio, according to Pimentel Gomes (1990). Concerning the cases where significance was found for the genotype x environment interaction, the Plaisted and Peterson (1959), Lin and Binns (1988) and Kang (1988) methodologies were applied, using the Genes computer program.

The incidence of bacteriosis and over lengthening characteristics were analyzed by descriptive statistics.

Phenotypic performance under environmental variations was assessed using the adaptability and stability parameter estimates by the methods proposed by Plaisted and Peterson (1959), Lin and Binns (1988) and Kang (1988).

RESULTS AND DISCUSSION

Disease assessment

The Branca de Santa Catarina and Fibra cultivars showed high susceptibility to bacteriosis. The IAC

12 and IAC 78-85 showed average resistance to bacteriosis, while the IAC 41-85, IAC 45-85, IAC 163-85 and IAC 321-85 cultivars showed high resistance (Table 1). High susceptibility to bacteriosis in the Branca de Santa Catarina and Fibra cultivars was also observed by Vidigal Filho et al. (2000) when studying the performance of cassava cultivars from Paraná State and the Campinas Agronomic Institute, in the county of Araruna, northwest Paraná State.

The behavior of the cultivars regarding bacteriosis is representative because to obtain good yield, resistance to bacteriosis must be associated with high potential yield and good adaptation ability (Fukuda et al., 1983). The Fibra cultivar, although showing high susceptibly to bacteriosis, is still one of the main cultivars exploited for flour production by cassava farmers in the northwest and north Paraná State. (Vidigal Filho et al., 2000). This cultivar, introduced in northwestern Paraná in the early 1980s, was considered not only high yielding but also resistant to bacteriosis (Lorenzi et al., 1996).

Branca de Santa Catarina, IAC 12, Fibra, IAC 45-85, IAC 7885, IAC 321-85 cultivars showed average resistance to the over lengthening pathogen, while the IAC 41-85 and IAC 163-85 cultivars were extremely susceptible (Table 1). Lorenzi et al. (1996) in research studies to select and assess the yield capacity of the same cultivars, in two locations in São Paulo State, Santa Maria da Serra and Assis, also observed high susceptibility to the *Sphaceloma manihoticula* pathogen (Bittancourt and Jenkinns, 1950) in the IAC 163-85 cultivar.

Table 1. Reaction to bacteriosis and to over lengthening of the assessed cassava cultivars.

Cultivars	Characteristics	
	Susceptibility to bacteriosis	Susceptibility to over lengthening
Branca de Santa Catarina	High	Medium
IAC 12	Medium	Medium
Fibra	High	Medium
IAC 41-85	Low	High
IAC 45-85	Low	Medium
IAC 78-85	Medium	Médium
IAC 163-85	Low	High
IAC 321-85	Low	Medium

Mean and joint analysis of variance

Table 2 shows variation among cultivar means, where the IAC 163-85 cultivar appears as the highest yielding and the IAC 12 cultivar as the least, with values of 23,257.06 and 15,214.13 $kg.ha^{-1}$, respectively. Taking into consideration the cultivar means for storage root yield trait, the top yielding cultivars were IAC 163-85, Fibra and IAC 45-85. These results are similar to those obtained by Lorenzi et al. (1996) when they assessed the same cultivars in locations in São Paulo State, Santa Maria da Serra and Assis.

Table 2 also shows variation in the storage root yield means according to environment, in Rolândia, during the agricultural years of 1996/97, showing the highest mean among all the environments tested (23,632.84 $kg.ha^{-1}$), and the lowest mean at 10,506.15 $kg.ha^{-1}$ in 1997/98. The low storage root yield observed in Rolândia in 1997/98 was probably due to the high precipitation in February, March, April and May, which promoted growth in the canopy and consequently a reduction in storage root yield.

When the four environments were analyzed separately, the IAC163-85, Fibra and IAC 45-85 cultivars had an outstanding performance in Rolândia, in both 1996/97 and in 1997/98. In 1996/97 these cultivars showed superior yield means to the mean of the environment and the general mean, while in 1997/98 the Fibra, IAC 45-85 and IAC 163-85 cultivars presented mean yields superior to the environment mean but not superior to the general mean. In the experiments carried out in Maringá in 1996/97 ,the IAC 45-85, IAC 163-85 and Fibra cultivars were superior, showing yield means superior to both the environmental mean and the general mean,while in 1997/98 the IAC 163-85, Fibra and IAC- 12 cultivars showed mean yields superior to the environmental mean and the general mean, as shown in Table 2.

Table 3 shows the results of the joint analysis of variance for storage root yield. The general analysis shows the significant effect for genotypes and for the genotype x environment interaction. This demonstrates that the genotypes presented different behavior for storage root yield from one environment to another, and contributed negatively to the assessment (Table 3).

The cultivars were then assessed for their genotypic performance to minimize the significant effects of the genotype x environment interaction.

Table 2. Mean storage root yield in kg.ha^{-1} of eight cassava cultivars assessed in four environments.

Cultivars	Environments [1/]				Mean
	1	2	3	4	
Branca de Santa Catarina	19,059.00	8,925.50	17,362.50	18,359.50	15,926.63
IAC 12	17,301.50	7,381.25	16,115.00	20,058.75	15,214.13
Fibra	29,117.75	14,558.50	20,315.00	20,097.50	21,022.19
IAC 41-85	23,226.00	7,391.75	14,822.50	15,527.50	15,241.94
IAC 45-85	25,130.25	14,453.00	23,162.50	19,980.25	20,681.50
IAC 78-85	25,049.00	6,315.00	19,042.50	16,661.50	16,767.00
IAC 163-85	32,747.50	13,110.50	22,950.00	24,220.25	23,257.06
IAC 321-85	17,431.75	11,913.75	14,042,50	19,687.50	15,768.88
Mean	23,632.84	10,506.15	18,476.56	19,324.09	17,984.91

[1/] 1: Rolândia Agricultural Cooperative (Corol), 1996/97; 2: Rolândia Agricultural Cooperative (Corol), 1997/98; 3: Iguatemi Experimental Farm (FEI) 1996/97 and 4: Iguatemi Experimental Farm (FEI) 1997/98.

Plaisted and Peterson (1959) methodology

According to Plaisted and Peterson methodology, the cultivars which show lower values for the θ_i (%) estimate are considered more stable. Table 4, shows that the most stable cultivars were IAC 41-85, Branca de Santa Catarina, IAC 45-85 and Fibra, with percentage values of 6.20; 6.82; 8.20 and 9.58 respectively.

Although Plaisted and Peterson (1959) method has the advantage of being applied to a limited number of environments, it has the disadvantage of being imprecise in assessing stability parameters , in providing information on the environments assessed and in directioning the response of cultivars under environmental variation (Cruz and Regazzi, 1997). This shows that more stable cultivars do not necessarily imply higher yields.

The comparison in Tables 2 and 4 shows that only IAC 45-85 had a good yield mean, while the other two cultivars remained among the 50% lowest yielding cultivars, thus no agreement was found between yield and stability. The IAC 163-85 cultivar was another example of this disagreement which, according to this method, is one of the least stable; however, according to Table 2 , it presented the best mean storage root yield.

Disagreement between yield and stability was also found by Monge (1981) in bean cultivars, by Veronesi (1995) in common maize genotypes, by Vendruscolo (1997) in popcorn maize genotypes and by Vilhegas et al. (2001) in hybrid maize stability analyses during the winter planting in northwest Paraná.

Lin and Binns Methodology (1988)

Table 5 shows the stability parameter estimates proposed by Lin and Binns (1988), the breakdown of the P_i parameter and the contribution to the interaction of the storage roots yield trait.

Of the four top yielding cultivars, IAC 163-85, Fibra, IAC 45-85 and IAC 78-85, only Fibra and IAC 78-85 showed components due to the genetic deviation superior to the interaction. The cultivars with the lowest P_i values were, hierarchically: IAC 163-85, Fibra and IAC 45-85 (Table 5) and, therefore, are recommended for commercial planting. However, the IAC 45-85 and IAC 163-85 cultivars should be disregarded because they show a deviation in the

Table 3. Joint analysis of variance for storage root yield of eight cassava cultivars evaluated in four environments.

S.V.	D.F.	Mean square
Blocks/Environments	12	40.5903
Environments (A)	3	958.5711
Genotypes (G)	7	160.2835[2/]
GxA	21	28.6547[1/]
Residue	84	11.6037
Mean		17.9849
C.V. (%)		18.8940

[1/], [2/] significant at levels of 1% and 5% probability for the F test, respectively.

interaction superior to the genetic deviation. Although both presented outstanding good yield mean, they did not behave regularly in the environments.

However, it should be pointed out that high P_i values do not always represent unstable cultivars. Table 5 shows that the IAC 12, IAC 321-85 and IAC 41-85 cultivars, although among the 50% with highest P_i values, had a genetic deviation superior to that of the interaction. Similar results were obtained by Daros (1999) when evaluating sweet potato accessions under environmental conditions at the Campos dos Goytacazes RJ, and by Farias et al. (1997) when evaluating herbaceous cotton yield in northeast Brazil.

Table 4. Stability parameters estimates proposed by Plaisted and Peterson (1959) for the storage root yield of eight cassava cultivars evaluated in four different environments.

Cultivars	Stability estimate	
	θ_i	θ_i (%)
Branca de Santa Catarina	2.3274	6.8247
IAC 12	5.4921	16.1048
Fibra	3.2683	9.5848
IAC 41-85	2.1163	6.2057
IAC 45-85	2.7994	8.2089
IAC 78-85	4.6900	13.7528
IAC 163-85	4.9974	14.6542
IAC 321-85	8.4113	24.6651
Mean	4.2628	

Kang Methodology (1988)

Table 6 shows that the Fibra and IAC 45-85 cultivars showed the lowest sum of ‘ranks´ and are considered more stable and productive for storage root yield.

Furthermore, the Fibra cultivar showed reasonable stability, being among the 50% most stable and the fourth among the eight cultivars assessed (Table 6). On the other hand, this cultivar showed good storage root yield (Table 2), which placed it as the second in the ‘rank´ for yield means when the stability and yield estimates were analyzed separately. The fact that both the Fibra cultivar and the IAC 45-85 (Table 6) are more stable is basically due to their storage root yield (Table 2).

The IAC 45-85 cultivar was quite stable, and was also ranked as the third among the 50% most stable ones,presenting the θ_i value below the general mean for this parameter and excellent storage root yield (Table 2), which also places it as the third position in the ‘rank´ sum presented in Table 6.

CONCLUSIONS

Plaisted and Peterson (1959) method indicated that the most stable cultivars were IAC 41-85, Branca de Santa Catarina, IAC 45-85 and Fibra, considering their storage root yield.

Lin and Binns method (1988) showed that the Fibra cultivar was outstanding for storage root yield, with the lowest possible P_i value, having a great influence from the genetic deviation component.

Considering storage root yield, the Kang method

Table 5. Stability parameters estimates proposed by Lin and Binns (1988) for storage root yield in eight cassava cultivars evaluated in four environments.

Cultivars	Mean[1/]	P_i	Deviation		Contribution to interaction (%)
			Genetic	Interaction	
Branca de Santa Catarina	15,926.63	35.8866	29.9963	5.8903	16.90
IAC 12	15,214.13	44.6347	35.7688	8.8659	25.43
Fibra	21,022.19	4.7850	3.5112	1.2738	3.65
IAC 41-85	15,241.94	35.8925	35.5341	0.3584	1.02
IAC 45-85	20,681.50	9.5014	4.4721	5.0292	14.42
IAC 78-85	16,767.00	25.1663	23.8402	1.3243	3.79
IAC 163-85	23,257.06	0.2677	0.0861	0.1816	0.52
IAC 321-85	15,768.88	43.1610	31.2310	11.9300	34.22
General mean	17,984.91				

[1/] Storage roots mean yield.

Table 6. Stability parameters estimates proposed by Kang (1988) for storage root yield in eight cassava cultivars evaluated in four environments.

Cultivars	Estimate of θ_i (%)	Classification of θ_i (%)	Mean[1/]	Classification of storage root mean	Sum[2/]
Branca de Santa Catarina	6.8247	2	15,926.63	5	7
IAC 12	16.1048	7	15,214.13	8	15
Fibra	9.5848	4	21,022.19	2	6
IAC 41-85	6.2057	1	15,241.94	7	8
IAC 45-85	8.2089	3	20,681.50	3	6
IAC 78-85	13.7528	5	16,767.00	4	9
IAC 163-85	14.6542	6	23,257.06	1	7
IAC 321-85	24.6651	8	15,768.88	6	14

[1/] Storage roots mean yield; [2/] Sum of the classifications involving the θ_i (%) classification (%) and the classification of storage root mean yield.

(1988) classified the Fibra and IAC 45-85 cultivars as the most stable and promising, showing good yield.

The outstanding cultivars for bacteriosis resistance were IAC 41-85, IAC 45-85, IAC 163-85 and IAC 321-85 while the highly susceptible cultivars were Branca de Santa Catarina and Fibra.

Cultivars with mean susceptibility for over lengthening were Branca de Santa Catarina, IAC 12, Fibra, IAC 45-85, IAC 78-85 and IAC 321-85, while the highly susceptible cultivars were IAC 41-85 and IAC 163-85.

It was observed that the IAC 45-85 cultivar was stable, highly resistant to bacteriosis, had a medium susceptibility to over lengthening and a good yield mean in the environments assessed by the methodologies used in this study.

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RESUMO

Estabilidade de produção de cultivares de mandioca (*Manihot esculenta*, Crantz) nas regiões norte e noroeste do Estado do Paraná

O trabalho teve por objetivo quantificar a interação genótipos por ambientes e estudar a estabilidade de produção de raízes tuberosas de oito cultivares de mandioca, empregando-se as metodologias de Plaisted e Peterson (1959), Lin e Binns (1988) e Kang (1988), nos municípios de Maringá e Rolândia, nos anos agrícolas de 1996/97 e 1997/98. Os tratamentos foram delineados em blocos completos, casualizados, com quatro repetições. Observou-se que as cultivares Branca de Santa Catarina, Fibra, IAC 41-85 e IAC 45-85 foram as mais estáveis pela metodologia de Plaisted e Peterson (1959), enquanto que a cultivar Fibra, com base no método de Lin e Binns (1988), destacou-se com menor valor possível de P_i e maior influência do componente de desvio genético, sendo portanto, a cultivar mais estável por esta metodologia. Pela metodologia de Kang (1988), observou-se que as cultivares Fibra, IAC 45-85 e IAC 163-85 foram as mais estáveis e apresentaram boa produtividade.

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