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Adaptability and stability of purple-fleshed sweetpotato genotypes in producing regions of Brazil using the AMMI and WAASB methodologies

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ABSTRACT

Purple-fleshed sweetpotato (*Ipomoea batatas*) have gained attention from producers and consumers for their nutritional values and high levels of anthocyanins. This study aimed to evaluate the adaptability and stability of these genotypes in producing regions of Brazil with AMMI and WAASB methodologies. The recently released purple-fleshed cultivars BRS Anembé and BRS Cotinga, along with four purple-fleshed advanced clones (BGBD0080, BGBD1399, BGBD1402, and BGBD1405), and the cultivars Brazlândia Roxa and Beauregard as controls, were evaluated in eight environments using a complete randomized blocks design with four replications. The roots were evaluated on yield, appearance, insect damage, and shape traits. The new purple-fleshed cultivars BRS Cotinga and BRS Anembé stood out in their higher root yield, good root shape and weight, expressive resistance to insect damage, and adaptability to environments with higher yield potential. Additionally, 'BRS Anembé' also showed a favorable root appearance. The cultivar Beauregard was the most susceptible to insect damage while 'Brazlândia Roxa' demonstrated the highest resistance.

Keywords: *Ipomoea batatas*, yield, breeding, genotype-by-environment interaction.

RESUMO

Adaptabilidade e estabilidade de genótipos de batata-doce de polpa roxa em regiões produtoras brasileiras usando as metodologias AMMI e WAASB

Batatas-doces (*Ipomoea batatas*) de polpa roxa têm chamado a atenção de produtores e consumidores por seu valor nutricional e altos teores de antocianinas. Este trabalho teve como objetivo avaliar a adaptabilidade e estabilidade de genótipos de batata-doce de polpa roxa em regiões produtoras do Brasil utilizando as metodologias AMMI e WAASB. As novas cultivares de polpa roxa BRS Anembé e BRS Cotinga juntamente com quatro clones avançados de polpa roxa (BGBD0080, BGBD1399, BGBD1402 e BGBD1405), e as cultivares testemunha Brazlândia Roxa e Beauregard, foram avaliados em oito ambientes usando delineamento em blocos casualizados com quatro repetições. Na colheita, as raízes foram avaliadas quanto ao rendimento, aparência, danos causados por insetos e características de formato. As novas cultivares de polpa roxa BRS Cotinga e BRS Anembé destacaram-se pela maior produtividade de raízes, bom formato e peso de raízes, expressiva resistência a danos causados por insetos, e adaptabilidade a ambientes com maior potencial produtivo. Adicionalmente, 'BRS Anembé' também apresentou aparência de raiz favorável. A cultivar Beauregard mostrou-se mais suscetível a danos causados por insetos, enquanto 'Brazlândia Roxa' apresentou a maior resistência.

Palavras-chave: *Ipomoea batatas*, produtividade, melhoramento genético, interação genótipo x ambiente.

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Sweetpotato (*Ipomoea batatas*) holds significant importance in Brazil, given its economic and cultural relevance. Over the past decade, both production and consumption have seen notable growth (IBGE, 2019), mainly attributed to the recognition of dietary benefits associated with this crop (Mello *et al*., 2022).

Storage roots are a source of energy, fiber, and minerals, and contain high levels of bioactive compounds (Frond *et al*., 2019). Anthocyanins, a class of flavonoids known for their antioxidant properties and positive effects on human health, are responsible for the purple color found in purple-fleshed sweetpotatoes (Li *et al*., 2019). As a natural edible pigment, anthocyanins have several advantages such as being safe, non-toxic, odorless, bright in color, and high yield and low cost (Li *et al*., 2019). These properties enable its broad application in the cosmetics, medicine, and food industries (Li *et al*., 2019).

Despite these recognized relevant attributes, Brazil had local varieties and just one registered purple-fleshed sweetpotato cultivar specifically recommended for the state of Santa Catarina. Only recently, Embrapa released two new cultivars, BRS Anembé (Melo *et al*., 2021) and BRS Cotinga (Vendrame *et al*., 2022).

The presence of genotype-by-environment interaction (GxE) interferes in the selection of superior, stable, and adapted genotypes across diverse environments. Therefore, it is crucial to study the adaptability and stability of advanced genotypes (Karuniawan *et al*., 2021). The assessment of these traits can be carried out with the aid of a series of methods; among them, the AMMI analysis (additive main effect and multiplicative interaction) is widely and traditionally used (Karuniawan *et al*., 2021). AMMI analysis combines univariate and multivariate methods, which can be plotted as principal components (PCs) (Zobel *et al*., 1988).

Recently, a method called WAASB (weighted average of absolute scores from the singular value decomposition of the matrix of BLUPs for the GxE effects generated by a linear mixed model) was proposed (Olivoto, 2019).This methodology combines features of AMMI and the mixed model BLUP (best linear unbiased predictor) techniques. Besides the advantage of using random effects, WAASB also provides 100% of the variation explained in a bi-dimensional plotted index (Olivoto, 2019). There are no examples in the literature of studies using the WAASB method in sweet-potato.

Thus, this study aimed to evaluate the adaptability and stability of purple-fleshed sweetpotato genotypes in producing regions of Brazil using the AMMI and WAASB methodologies.

MATERIAL AND METHODS

The evaluation trials were conducted in different cities/states (Table 1) with two purple-fleshed sweetpotato cultivars BRS Anembé (released in 2021) and BRS Cotinga (released in 2022), and four advanced genotypes from the Embrapa's breeding program: BGBD0080, BGBD1399, BGBD1402, and BGBD1405. In the absence of purple-fleshed control cultivars with known adaptability to different regions of Brazil, Brazlândia Roxa and Beauregard cultivars were used as controls, considering the abundance of research results that describe their adaptation to different Brazilian regions.

All the experiments were conducted using a complete randomized block design with four replications. Plots consisted of four rows with 15 plants each, held in six locations and two crop seasons each (Table 1). The planting dates, harvest dates, and plants and row spacing are also provided in Table 1.

Table 1. Environments (locations and crop years), dates, and row and plant spacing. Embrapa, 2023.

Code	Location-state	Coordinates and (altitude, m)	Planting date	Harvest (days after planting date)	Space between rows and plants (m)
CAN18	Canoinhas-SC	26°10'S, 50°23'W (839)	Oct 16, 2017	150	0.75x0.35
CAN19	Canoinhas-SC	26°10'S, 50°23'W, (839)	Oct 13, 2018	155	0.75x0.35
EST19	Estiva-MG	22°31'2"S, 45°59'31"W (900)	Dec 06, 2018	140	0.90x0.25
EST20	Estiva-MG	22°31'2"S, 45°59'31"W (900)	Dec 07, 2019	180	0.90x0.25
URU19	Uruana-GO	15°3'43"S, 49°43'17"W (588)	Dec 06, 2018	130	0.80x0.25
URU20	Uruana-GO	15°38'43"S, 49°43'17"W, (588)	Jan 16, 2020	133	0.80x0.25
GAM18	Gama-DF	15°55'59"S, 48°8'25"W (1003)	Apr 16, 2018	140	0.80x0.25
GAM19	Gama-DF	15°55'59"S, 48°8'25"W (1003)	Feb 07, 2019	140	0.80x0.25
PLAN18	Planaltina-GO	15°47'24"S 47°37'46"W (1000)	May 02, 2018	140	0.45x0.30
PLAN19	Planaltina-GO	15°47'24"S 47°37'46"W (1000)	Fev 27, 2019	165	0.45x0.30
PET18	Petrolina-PE	9º8'40"S, 40º18'50"W (369)	Jul 01, 2019	148	0.90x0.30
PET19	Petrolina-PE	9º8'40"S, 40º18'50"W (369)	Nov 01, 2018	132	0.90x0.30

The pre-planting fertilization was conducted following the state recommendations for soils with good or high nutrient availability, ranging from 40 to 50 kg/ha of N, 50 to 60 kg/ha of P_2O_5, and 80 to 120 kg/ha of K_20. In all experiments, slips/vines were transplanted 7.6 cm deep with 4 plant nodes underground and 2 to 3 nodes above the ground. Manual weed control was carried out, and a top-dress N fertilization (50 kg/ha) was applied about 30 days after planting (DAP). No insecticides or fungicides were applied. Irrigation was performed based on soil water tensions close to field capacity in the first 10 days, until the plants were fully established. Until 20 days after planting, weekly irrigations were carried out to maintain soil water tension between 15 and 25 kPa. After this period, irrigations occurred approximately every two weeks with water tensions between 25 and 40 kPa.

At harvest dates, the two central rows of each plot were harvested and roots were evaluated for the following storage root yield components: 1) marketable root yield [MRY, (t/ha)]; 2) average root mass [ARM (g)] calculated as the ratio of the total root mass to total root number.

The appearance of storage roots (APPE) was evaluated using visual index scores, ranging from 1 to 5 as follows: 1= non-standards, with a very irregular shape, large veins, growth cracks, and other defects; 2= very non-uniform, with the presence of large veins and growth cracks, and other defects; 3= non-uniform, with small veins, growth cracks, and other defects; 4= uniform with the eventual presence of veins or growth cracks, and other defects; and 5= regular fusiform without veins, growth cracks, and other defects (Andrade Júnior *et al*., 2012).

Ten marketable roots selected at random per plot were evaluated for insect damage (INSE) using an index score as follows: 1= free of insect damage; 2= minimal damage; 3= few marketable roots damaged; 4= most of the marketable roots damaged; and 5= roots unsuitable for both human and animal consumption (Andrade Júnior *et al*., 2012). The same samples were used for the evaluation of root diameter (DIAM, cm) and length (LENG, cm). Marketable roots were defined as those with APPE scores ranging from 4 to 5, INSE scores from 1 to 3, and weighing between 150 g and 1.5 kg (Melo *et al*., 2020).

Data were subjected to a combined analysis of variance. The Scott-Knott grouping test was used to compare the cluster means at 5% using Genes software (Cruz, 2013). The analysis of adaptability and stability was conducted using the methodologies of AMMI (additive main effect and multiplicative interaction) (Zobel *et al*., 1988) and WAASB [weighted average of absolute scores from the singular value decomposition of the matrix of the best linear unbiased predictor (BLUPs) for the genotype x environmental (GxE) effects generated by a linear mixed model], performed with R 3.5.2 package Metam (Olivoto, 2019; R Core Team, 2022).

RESULTS AND DISCUSSION

Significant differences were observed among genotypes for almost all the evaluated traits (Tables 2, 3 and 4), except for insect damage in two experiments, in which there was a low pressure resulting in minimal damage to the roots (EST19 and PLAN19) (Table 4). Furthermore, a significant interaction between environments (locations and years) and genotypes was observed for all traits (data not shown), indicating distinct responses of these genotypes across different environments.

Table 2. Grouping of means for marketable root yield and root mass for purple-fleshed sweetpotato genotypes in different locations and years. Embrapa, 2023.

Sweetpotato	Marketable root yield (t/ha)					
	Location-year					
	CAN18*	**CAN19**	**EST19**	**EST20**	**URU19**	**URU20**
BGBD0080	20.48 cC	56.19 aA	28.54 bB	37.87 bB	17.26 cC	6.86 bD
BGBD1399	15.27 cC	7.38 cC	21.72 bB	30.18 cB	21.13 bB	12.29 bC
BGBD1402	23.85 cB	18.41cB	41.96 aA	41.21 bA	7.32 cC	6.31 bC
BGBD1405	60.65 aA	19.52 cD	32.92 bC	23.80 cD	29.47 bC	19.77 aD
BRS Cotinga	43.34 bC	51.51 aB	54.07 aB	92.59 aA	43.38 aC	21.50 aD
BRS Anembé	25.23 cC	58.97 aA	36.53 bB	51.39 bA	51.63 aA	12.92 bC
Beauregard	42.98 bA	52.94 aA	43.79 aA	43.34 bA	30.32 bB	22.54 aB
Braz. Roxa	20.05 cC	38.89 bB	41.90 aB	27.59 cB	55.07 aA	2.39 bD
Mean	31.48	37.98	37.68	43.50	31.95	13.07
CV (%)	27.63	24.57	30.19	20.24	26.12	25.92
	GAM18	**GAM19**	**PLAN18**	**PLAN19**	**PETR18**	**PETR19**
BGBD0080	18.35 cC	25.03 bC	31.36 cB	24.32 cC	3.24 cD	29.34 bC
BGBD1399	9.37 cC	22.40 bB	41.09 cA	37.33 bA	0.34 cC	25.42 bB
BGBD1402	35.38 bA	16.84 bB	49.00 bA	16.23 cB	1.90 cC	25.36 bB
BGBD1405	19.49 cD	21.22 bD	35.32 cC	20.60 cD	30.79 aC	40.74 aB
BRS Cotinga	51.11 aB	18.79 bD	57.25 aB	61.47 aB	5.47 cE	45.00 aC
BRS Anembé	36.25 bB	10.79 bC	64.72 aA	40.34 bB	17.08 bC	51.29 aA
Beauregard	28.18 bB	35.68 aA	48.46 bA	40.19 bA	14.39 bB	47.81 aA
Braz. Roxa	35.46 bB	14.75 bC	36.28 cB	16.42 cC	38.88 aB	32.58 bB
Mean	29.20	20.69	45.43	32.11	14.01	37.19
CV (%)	29.65	30.79	34.84	27.36	32.05	15.85
	Average root mass (g)					
	CAN18	**CAN19**	**EST19**	**EST20**	**URU19**	**URU20**
BGBD080	95.24 cD	345.40 aA	139.40 bC	138.93 cC	109.45 bD	99.75 cD
BGBD1399	158.34 bC	101.17 cD	138.28 bC	272.81 aA	193.61 aB	144.49 bC
BGBD1402	125.07 bB	92.00 cB	159.25 bA	169.92 bA	84.90 bB	82.64 cB
BGBD1405	314.21 aA	89.74 cD	148.19 bC	90.83 cD	141.50 bC	236.40 aB
BRS Cotinga	304.79 aA	182.81 bC	228.39 aB	308.70 aA	203.20 aC	168.24 bC
BRS Anembé	60.08 cD	326.33 aA	166.55 bC	187.51 bB	139.68 bC	122.91 cC
Beauregard	286.13 aA	329.49 aA	218.73 aB	196.09 bB	122.85 bC	161.52 bC
Cont. table 2						
Braz. Roxa	129.64 bC	182.66 bB	162.81 bB	128.22 cC	186.39 aB	56.96 cD

Sweetpotato	Marketable root yield (t/ha)					
	Location-year					
	CAN18*	**CAN19**	**EST19**	**EST20**	**URU19**	**URU20**
Mean	184.19	206.20	170.20	186.62	147.70	134.11
CV (%)	14.98	19.56	21.25	19.39	25.18	22.61
	GAM18	**GAM19**	**PLAN18**	**PLAN19**	**PETR18**	**PETR19**
BGBD0080	84.64 cD	197.45 aB	151.04 bC	106.84 bD	84.76 dD	179.40 bB
BGBD1399	70.74 cD	159.76 bC	165.09 bC	141.70 bC	89.12 dD	258.38 aA
BGBD1402	121.77 bB	161.24 bA	174.77 bA	94.53 bB	79.75 dB	191.71 bA
BGBD1405	98.58 cD	149.14 bC	200.14 aB	112.77 bD	187.28 bB	175.17 bC
BRS Cotinga	258.99 aB	128.72 cD	242.56 aB	205.31 aC	141.47 cD	269.83 aB
BRS Anembé	121.91 bC	93.69 cD	209.52 aB	132.60 bC	140.70 cC	234.33 aB
Beauregard	118.73 bC	220.95 aB	182.20 bB	177.97 aB	214.91 bB	211.26 bB
Braz. Roxa	157.77 bB	105.06 cC	133.67 bC	86.42 bD	295.70 aA	189.64 bB
Mean	129.14	152.00	182.37	132.27	154.21	213.71
CV (%)	20.91	34.60	15.59	23.30	17.65	17.23

Means followed by the same lowercase letter in the column and uppercase in the two lines did not differ by Skott-Knott at 5%. CV (%)= phenotypic coefficient of variation. *Growing locations according to Table 1.

Table 3. Grouping of means for phenotypic characters (root length and root diameter) for purple-fleshed sweetpotato genotypes in different locations and years. Embrapa, 2023.

Sweetpotato	Root length (cm)							
	Location-year							
	CAN18*	**CAN19**	**EST19**	**URU19**	**PLAN19**	**GAM18**	**GAM19**	
BGBD0080	21.75 aA	14.75 aB	13.67 bB	11.99 bB	14.85 bB	22.82 aA	15.50 aB	
BGBD1399	24.75 aA	14.00 aB	16.65 bB	16.64 aB	19.43 aB	17.96 bB	15.46 aB	
BGBD1402	19.25 bA	14.00 aB	14.97 bB	11.25 bB	14.85 bB	15.11 bB	15.09 aB	
BGBD1405	21.75 aA	16.50 aB	21.19 aA	18.19 aB	16.35 bB	17.39 bB	16.01 aB	
BRS Cotinga	16.00 bA	19.50 aA	20.29 aA	18.19 aA	20.00 aA	18.16 bA	17.56 aA	
BRS Anembé	15.75 bA	15.75 aA	15.22 bA	14.56 bA	16.40 bA	16.04 bA	15.30 aA	
Beauregard	15.75 bA	15.25 aA	16.26 bA	16.55 aA	20.40 aA	15.88 bA	15.67 aA	
Braz. Roxa	22.75 aA	17.25 aB	20.26 aA	18.18 aB	15.60 bB	15.72 bB	15.05 aB	
Mean	19.72	15.88	17.31	15.69	17.23	17.38	15.70	
CV (%)	6.54	11.64	11.56	12.55	9.82	32.26	17.77	
	Root diameter (cm)							
	CAN18	**CAN19**	**EST19**	**URU19**	**PLAN19**	**GAM18**	**GAM19**	**LENG/DIAM**
BGBD0080	5.75 cA	5.75 cA	5.38 bA	6.00 aA	4.67 aA	5.19 aA	5.43 aA	3.02
BGBD1399	6.00 cA	6.50 cA	5.31 bB	4.62 bC	4.36 aC	4.06 bC	5.26 aB	3.46
BGBD1402	5.25 cA	6.25 cA	5.99 aA	6.08 aA	4.56 aB	5.36 aA	4.14 bB	2.78
BGBD1405	8.75 bA	7.50 bB	4.82 bC	4.93 bC	4.40 aC	4.15 bC	4.43 bC	3.27
BRS Cotinga	10.75 aA	9.00 aB	5.97 aC	6.01 aC	4.59 aD	5.74 aC	4.87 aD	2.76
BRS Anembé	4.25 dC	6.50 cA	5.88 aA	5.79 aA	5.14 aB	5.21 aB	4.22 bC	2.95
Beauregard	10.75 aA	8.50 aB	6.44 aC	5.28 bD	4.20 aE	2.53 cF	4.52 bE	2.74
Braz. Roxa	8.00 bA	7.75 bA	5.23 bB	5.43 bB	3.89 aC	5.84 aB	4.20 bC	3.09
Mean	7.44	7.22	5.63	5.52	4.47	4.76	4.63	3.01
CV (%)	10.32	14.47	11.70	13.36	6.33	11.69	15.61	-

Means followed by the same lowercase letter in the column and uppercase in the two lines did not differ by Skott-Knott at 5%. CV (%)= phenotypic coefficient of variation. *Growing locations according to Table 1.

Table 4. Root appearance and insect damage for purple-fleshed genotypes in different locations and years. Embrapa, 2023.

Sweetpotato	Root appearance (APPE)				
	Location-year				
	CAN18*	**CAN19**	**EST19**	**URU19**	**PLAN19**
BGBD0080	4.75 aA	1.75 cC	1.75 cC	3.75 cB	1.75 bC
BGBD1399	3.50 bA	2.25 cB	2.25 bB	3.25 cA	2.50 aB
BGBD1402	3.00 bB	2.00 cC	1.25 cD	4.00 bA	1.50 bD
BGBD1405	4.75 aA	4.50 aA	1.50 cC	4.25 bA	1.75 bC
BRS Cotinga	1.25 dB	1.00 dB	3.00 aA	3.00 cA	2.75 aA
BRS Anembé	4.00 aA	3.50 bA	2.00 bB	4.75 aA	1.75 bB
Beauregard	1.25 dC	4.50 aA	1.25 cC	2.75 cB	1.25 bC
Braz. Roxa	2.25 cD	4.75 aA	1.25 cE	5.00 aA	1.25 bE
Mean	3.09	3.03	1.78	3.84	1.81
CV (%)	17.14	18.22	24.21	23.52	26.58
	GAM18	**GAM19**	**EST20**	**PLAN18**	**-**
BGBD0080	3.00 bB	2.50 dC	1.00 bD	2.00 bC	-
BGBD1399	2.50 bB	3.25 cA	2.25 aB	2.25 bB	-
BGBD1402	3.00 bB	3.50 cA	1.00 bD	2.25 bC	-
BGBD1405	3.00 bB	4.00 bA	1.25 bC	3.00 aB	-
BRS Cotinga	3.00 bA	2.50 dA	1.50 aB	2.00 bB	-
BRS Anembé	4.00 aA	4.25 bA	1.00 bC	2.00 bB	-
Beauregard	1.00 cC	5.00 aA	1.75 aC	2.75 aB	-
Braz. Roxa	4.00 aB	3.25 cC	1.00 bE	3.00 aC	-
Mean	2.94	3.53	1.34	2.41	-
CV (%)	6.95	19.69	23.85	24.68	-
	Insect damage (INSE)				
	CAN18*	**CAN19**	**EST19**	**URU19**	**PLAN19**
BGBD0080	1.00 c	1.00 c	1.00 a	2.75 b	1.50 a
BGBD1399	1.00 c	1.00 c	1.00 a	3.00 b	1.75 a
BGBD1402	2.25 a	1.25 c	1.00 a	2.50 c	1.25 a
BGBD1405	1.75 b	3.00 b	1.00 a	4.00 a	1.50 a
BRS Cotinga	1.00 c	1.00 c	1.25 a	2.00 c	2.25 a
BRS Anembé	1.00 c	2.75 b	1.00 a	3.00 b	1.50 a
Beauregard	2.75 a	4.25 a	1.75 a	3.00 b	1.50 a
Braz. Roxa	1.00 c	1.00 c	1.00 a	3.50 a	1.50 a
Mean	1.47	1.91	1.13	2.97	1.59
CV (%)	19.12	37.37	23.76	18.24	35.98
	EST20	**-**	**-**	**-**	**-**
BGBD0080	1.00 b	-	-	-	-
BGBD1399	2.00 a	-	-	-	-
BGBD1402	2.00 a	-	-	-	-
BGBD1405	2.00 a	-	-	-	-
BRS Cotinga	2.00 a	-	-	-	-
BRS Anembé	1.50 b	-	-	-	-
Beauregard	1.75 a	-	-	-	-
Braz. Roxa	1.25 b	-	-	-	-
Mean	1.69	-	-	-	-
CV (%)	25.46	-	-	-	-

APPE: grades 1 to 10: 1= non-marketable roots, very irregular and deformed, with many veins and cracks; 10= regular fusiform shape without veins or any type of crack; INSE= grades from 1 to 5: 1= roots free from any type of holes and/or galleries caused by insects; 2= roots with small holes and galleries; 3= presence of galleries and holes in the roots in greater intensity; 4= presence of many galleries, holes, and signs of early-stage decay, making them unfit for the market; 5= root filled with galleries, holes, and more advanced rot. Means followed by the same lowercase letter in the column and uppercase in the two lines did not differ by Skott-Knott at 5%. CV (%)= phenotypic coefficient of variation. *Growing locations according to Table 1.

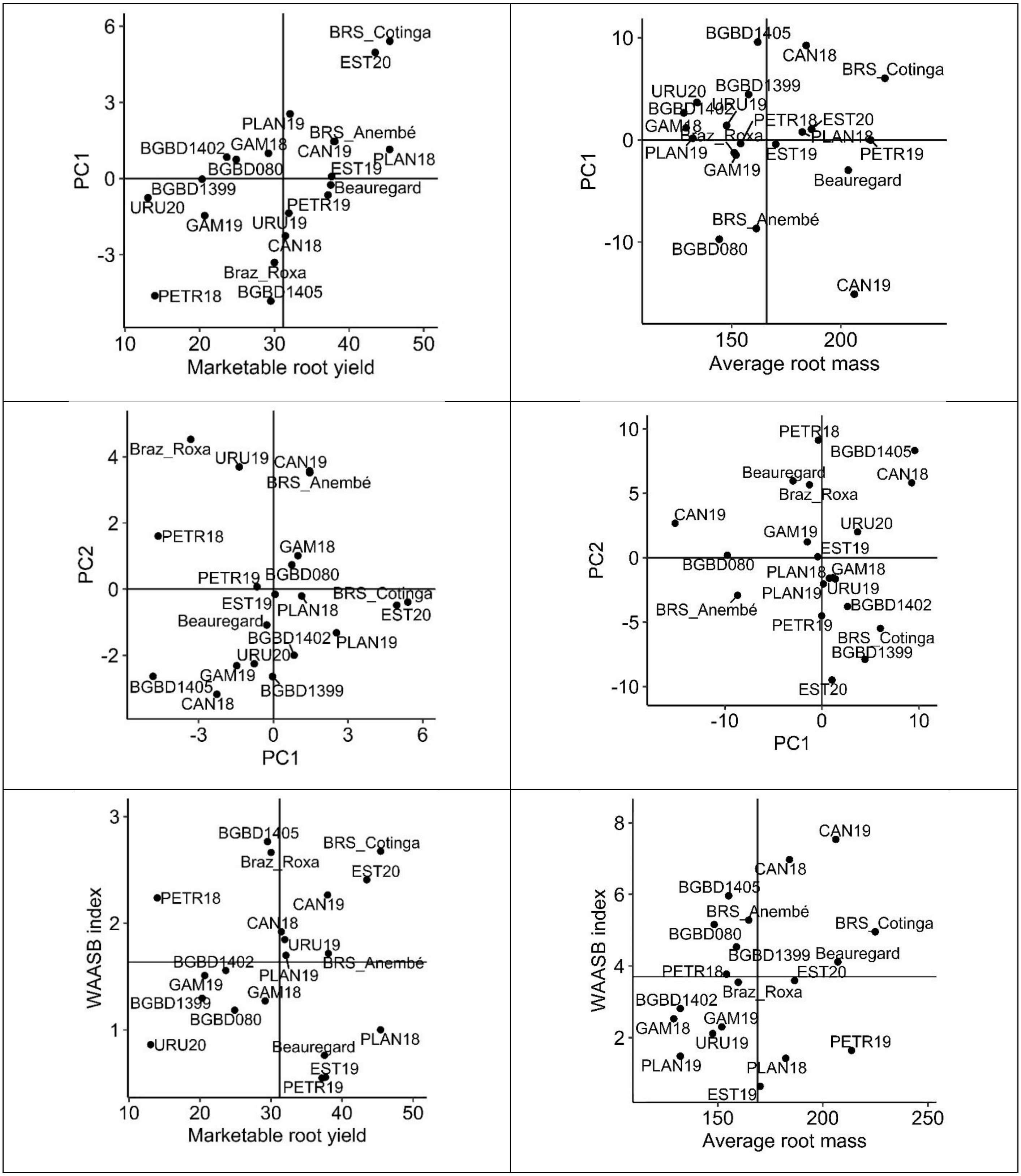

Figure 1. AMMI and WAASB adaptability and stability indexes for marketable root yield (t/ha) on the left side (40 and 64% of AMMI1 and AMMI2 explanation), and average root mass (g), in the right side (42 and 65% of AMMI1 and AMMI2 explanation). Embrapa, 2023.

Observing the AMMI-1 model, the graphical dispersion of the marketable root yield and the first principal component (PC1) (Figure 1); 'BRS Cotinga' exhibited the highest yield potential and showed the greatest adaptation to the Estiva-MG environment in 2020 (EST20). 'BRS Anembé' and 'Beauregard' also demonstrated above-average values of root yield potential, and greater stability compared to 'BRS Cotinga'. The environments PLAN18, CAN19, EST19, and PETR19 likewise enabled higher root yields similarly.

In the AMMI-2 model, the first two principal components (PCA) support the observation of the good fit of 'BRS Cotinga' to the EST20 environment, although it did not exhibit high overall stability. Another genotype that showed higher root yield was 'BRS Anembé', which demonstrated high adaptability to the CAN19 environment.

The WAASB index considers the information from all PCAs and allows the formation of four quadrants, in which the lower values of this index indicate more stable genotypes and environments with low discrimination potential (Olivoto *et al*., 2019). 'BRS Cotinga' had the highest yield potential and the greatest adaptation to EST20. 'BRS Anembé' and 'Beauregard' also exhibited a higher yield with 'Beauregard' being the most stable. The genotypes exhibited greater stability in Estiva (EST), Canoinhas (CAN), and Planaltina (PLAN) across the two crop years. The greatest genotypes' potential discrimination was observed in EST20, CAN19, and PETR18, whereas the highest yields were in EST20 and CAN19. In the PLAN18, EST19, and PETR19 locations, the genotypes showed higher root yield but low discrimination potential. Although 'Brazlândia Roxa' and the genotype BGBD1405 demonstrated a root yield potential similar to the average, they lacked stability.

The general means are shown in Table 2. Among the cultivars, BRS Cotinga produced an average of 45.46 t/ha, which was 45.75% higher than the overall average of 31.19 t/ha. Notably, in the EST20 environment, 'BRS Cotinga' achieved a significantly higher yield of 92.59 t/ha. 'BRS Anembé' yielded 38.10 t/ha, similar to 'Beauregard' with a yield of 37.55 t/ha, while 'Brazlândia Roxa' yielded 30.02 t/ha. These values expressively exceed the average Brazilian production of approximately 14 t/ha (IBGE, 2019), demonstrating their substantial yield potential.‘Beauregard’ is a cultivar recognized for being widely adapted and high-yielding, extensively adopted in numerous countries. Laurie *et al*. (2015), in their evaluation using the AMMI methodology, also reported its high PC1 (yield) and low PC2 (highly stable) across various regions in South Africa.

Regarding the average root mass, it is noteworthy that values ranging between 150 and 450 g are associated with a superior classification and higher prices in the local wholesale market (CEAGESP, 2014). The majority of the evaluated genotypes produced root mass exceeding 150 g, except BGBD1402 (128.13 g) and BGBD080 (144.36 g). Particularly, 'BRS Cotinga' (220.27 g) and 'Beauregard' (203.40 g) exhibited the highest values for this trait. The roots demonstrated greater stability in the PLAN18 and PETR19 environments while exhibiting higher discrimination potential in the CAN18 and CAN19 environments. Additionally, sweetpotatoes with heavier roots were produced in these four growing environments (Table 2 and Figure 1).

Consumer’s preferences in the Brazilian market can result in variations regarding the desired diameter and length of roots. However, it is generally preferred that the roots have a fusiform shape with a length-to-diameter ratio of approximately 3/1 (Melo *et al*., 2020).

The longest roots were observed for 'BRS Cotinga' (18.53 cm), genotypes BGBD1405 (18.20 cm) and BGBD1399 (17.84 cm), and 'Brazlândia Roxa' (15.60 cm) (Table 3). BGBD1399 and 'Brazlândia Roxa' showed higher stability, as the AMMI1 graphic and WAASB index indicated. In the CAN18 environment, sweetpotatoes showed longer roots and demonstrated a higher discrimination potential. 'Beauregard' (6.03 cm), 'BRS Cotinga' (6.70 cm), and 'Brazlândia Roxa' (5.76 cm) exhibited root diameters exceeding the average. Sweetpotatoes with a larger diameter and higher discrimination potential were produced in the CAN18 and CAN19 environments.

The genotype BGBD080 (3.02), and the cultivars Brazlândia Roxa (3.09) and BRS Anembé (2.95) exhibited a length-to-diameter ratio similar to 3/1 (Table 3), indicating a favorable root shape. Notably, the genotypes BGBD1399 (3.46) and BGBD1405 (3.27) showed longer roots, and all genotypes showed roots with a satisfactory shape compared to ‘Beauregard’ 2.74) and ‘Brazlândia Roxa’ (3.09), which are widely accepted in the local market (Table 3 and Figure 2).

Senff *et al*. (2021) reported similar root yield values for 'Beauregard' and 'Brazlândia Roxa', consistent with the findings of this study. Additionally, these authors described 'Beauregard' as having a larger diameter (6.25 cm) and slightly shorter roots (18.11 cm) compared to 'Brazlândia Roxa', which had a diameter of 4.54 cm and a length of 20.20 cm. In the present study, 'Beauregard' demonstrated a root diameter of 6.03 cm and a length of 16.54 cm, while 'Brazlândia Roxa' showed a root diameter of 5.76 cm and a length of 15.60 cm.

Appearance is a critical sensory attribute that significantly influences the product purchase decision-making process (Leksrisompong *et al*., 2012). Better root appearance and higher stability across the evaluated environments were observed in the cultivars BRS Anembé (3.03) and Brazlândia Roxa (2.86), and the genotype BGBD1405 (3.35). Sweetpotatoes produced in Canoinhas-SC (CAN), Gama-DF (GAM), and Uruana-GO (URU) showed better root appearance. Among these locations, Canoinhas-SC stood out as the one that best discriminated all the genotypes and cultivars evaluated (Table 4 and Figure 3)

Insect damage is a significant factor that adversely affects the appearance and quality of roots. Contrary to other traits, lower values in this context indicate a higher level of resistance, presenting an opposite interpretation. Most of the genotypes were grouped below the average performance of the control cultivar Brazlândia Roxa, which is well-known for its resistance to insect damage (Andrade Junior *et al*., 2012; Amaro *et al*., 2019; Melo *et al*., 2020). Additional genotypes showing notable resistance included 'BRS Cotinga', BGBD1399, BGBD1402, and BGBD080.

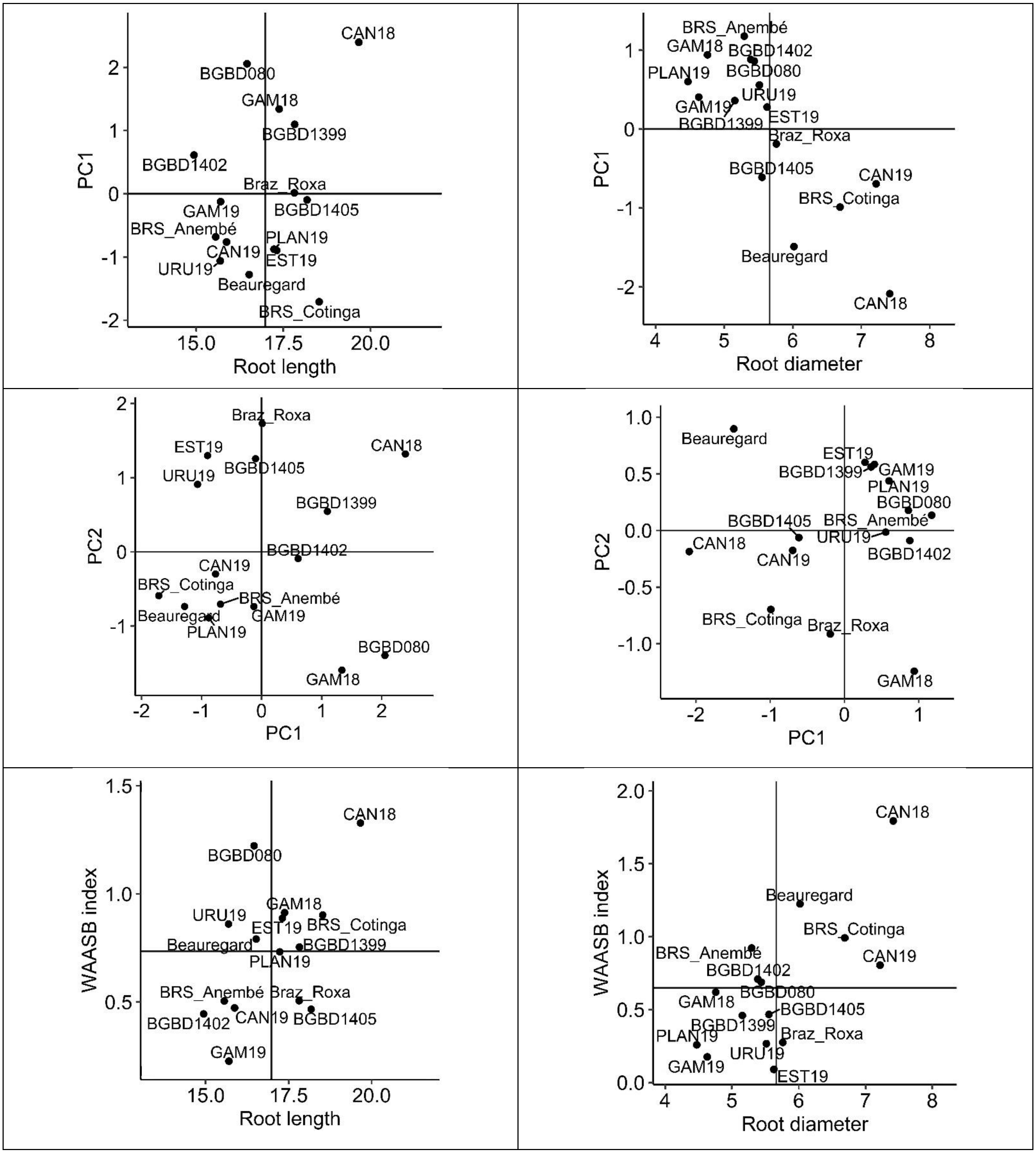

Figure 2. AMMI and WAASB adaptability and stability indexes for root length (cm), on the left side (52 and 82% of AMMI1 and AMMI2 explanation), and root diameter (cm), on the right side (81 and 92% of AMMI1 and AMMI2 explanation). Embrapa, 2023.

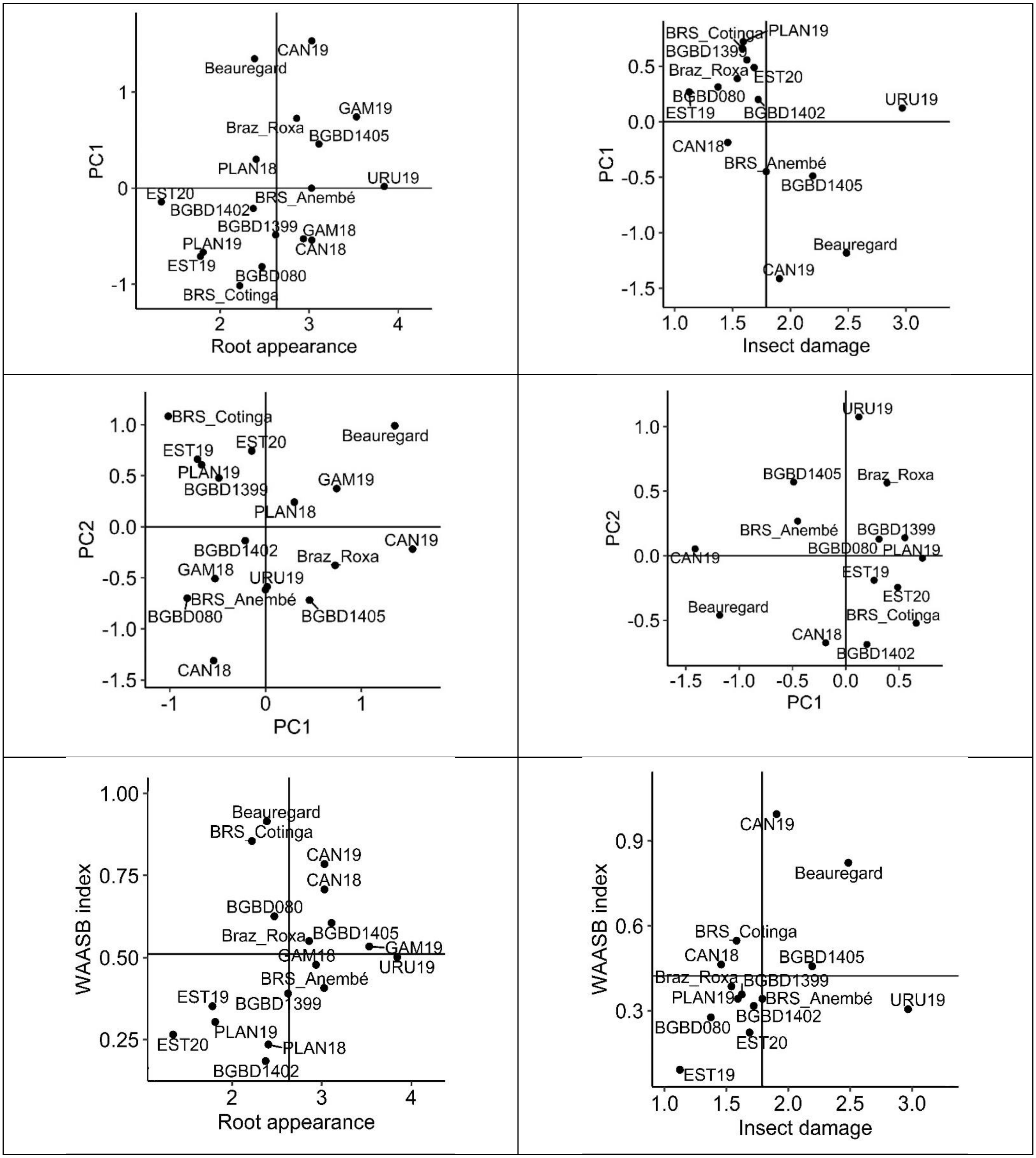

Figure 3. AMMI and WAASB adaptability and stability indexes for root appearance, on the left side (45 and 79% of AMMI1 and AMMI2 explanation), and insect damage, on the right side (62 and 83% of AMMI1 and AMMI2 explanation). Embrapa, 2023.

The cultivar BRS Anembé performed within the average. In contrast, 'Beauregard', known for having high susceptibility to insect damage (Melo *et al., 2020), along with the genotype BGBD1405, were the most susceptible.*

The environment URU19 exhibited the highest incidence of root-damaging insects, while CAN19 proved to be thebetter environment for discriminating the evaluated cultivars/genotypes (Table 4 and Figure 3)

The newly purple-fleshed cultivars, BRS Cotinga and BRS Anembé, exhibit traits that align with the desired traits for a sweetpotato breeding program. These cultivars showed higher root yield, well-formed shapes, substantial root weight, and a notable level of resistance to insect damage. Additionally, they showed adaptability to environments with higher yield potential.

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