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Genotype x year interaction for agronomical traits and proximate composition in yam beans (*Pachyrhizus* spp., Fabaceae) in the Brazilian Amazon

E.S. Silva[1], A.L. Atroch[2], R.S. de Jesus[3], M.A.F. Bitencourt[3] and C.A. Ticona-Benavente[4]

[1] Universidade Federal do Amazonas, Programa de Pós-Graduação em Agronomia Tropical, Manaus, Brasil
[2] Embrapa Amazônia Ocidental, Manaus, Brasil
[3] Instituto Nacional de Pesquisas da Amazônia, Laboratório de Tecnologia de Alimentos, Manaus, Brasil
[4] Instituto Nacional de Pesquisas da Amazônia, Laboratório de Melhoramento de Plantas, Manaus, Brasil

Corresponding author: C.A. Ticona-Benavente
E-mail: cesar.benavente@gmail.com

Genet. Mol. Res. 21 (1): gmr18981
Received October 11, 2021
Accepted January 12, 2022
Published February 27, 2022
DOI http://dx.doi.org/10.4238/gmr18981

ABSTRACT. The yam bean (*Pachyrhizus* spp.) is an underutilized leguminous tuber that is well adapted to the Amazonian climate. This bean has 5 to 20% protein in its tuberous roots (dry weight), though it is little known even in Brazil. No improved varieties have been recommended for the Amazon region. We examine the Genotype x Year (GxY) interaction in 20 selected yam bean stocks and selected genotypes based on their performance. These materials were obtained from among a selection of 64 genotypes with natural outcrossing of *P. erosus* x *P. tuberosus*. The experiments were carried out in the Central Amazon during a low water period, from April to September in 2017 and 2018, in a completely randomized block design with 20 genotypes, three replicates, and eight plants per plot, 1 x 0.5 m apart between and within rows. Pods and roots were harvested after having been cultivated for six months. Pod and root yield, as well as the latter's proximate composition, were evaluated. We found no significant GxY interaction, for pod and root yield. However, the carbohydrate, protein, lipid, fiber, and ash content in roots showed significant GxY interaction. These results indicate that selection of genotypes with high pod and root yield can be carried out in a single year in the dry period for cultivation during that season. However, selection to increase its nutritional value must be carried out over several years. The selected genotypes for presenting high root yield (> 3 t ha^{-1}) were P7, P11, P15, P19, P37 and P57. The genotypes selected for high protein content in the roots (> 10% dry weight) were P13, P14, P37 and P62.

Key words: Jacatupé; Jicama; Underutilized species; Breeding

INTRODUCTION

Yam bean (*Pachyrhizus* spp.) is an annual plant that develops edible tuberous roots. It tastes slightly sweet and is crunchy-textured when fresh. This species is considered an underutilized food species, though it has an enormous agronomic and nutritional potential (National Research Council, 1979).

The yam bean is originated from the Americas. *P. erosus* from México, *P. ahipa* from the Peruvian – Bolivian Andes, and *P. tuberosus* from the Amazon. Perhaps its oldest record is the images of roots in Paracas fabrics and Nazca ceramics in pre-Incan civilizations (1000 AD) (Yacovleff, 1933). This bean has various common names, including 'jacatupé' (Brazil), 'jícama', 'frijol camote' or 'nabo mexicano' (Mexico and Central America) (Santayana et al., 2014), 'jíquima' or 'asipa' or 'chicama' (Peru), 'ahipa' or 'ajipa' (Bolivia) (Yacovleff, 1933).

The species' botanical classification is confusing since the genus has been classified as *Dolicos* and then *Cacara* and, from these to the current *Pachyrhizus*. Sorensen (1988 and 1989) has distinguished three cultivated and two wild species by the morphology of their seeds, leaves, roots, and pollen. He concluded the cultivated species to be: *P. erosus*, *P. ahipa* and *P. tuberosus;* and the wild ones: *P. ferrrugineus* and *P. panamensis*. Additional studies indicated a other species, including *P. tuberosus* and *P. ahipa* cultivated in the Andean region (Silva et al., 2016; Zanklan et al., 2018).

Yam bean roots are edible, both fresh and cooked. When raw, they are juicy, so they are suitable to be eaten directly or in salads. When cooked, they serve for preparing cakes and sweets (Silva et al., 2016). Root yield in research ranges from 14 - 108 t ha^{-1} (Nielsen et al., 2000; Belford et al., 2001; Silva et al., 2016; Jean et al., 2017) and at a commercial level 40 - 80; 25-65; 24 and 7-17 t ha^{-1} in Mexico, Thailand, Hawaii, and the Far East, respectively (Phillips-Mora et al., 1993). Its composition ranges from 78 to 94% moisture, 1.0 to 2.2% proteins, 0.0 to 0.8% lipids, 4.6 to 14.9% carbohydrates, 0.5 to 1.4% fibers, and 0.3 to 0.8% ash (Sorensen, 1996).

On the other hand, the seeds are toxic due to rotenone, rotenoids, and pachyrhizine (Estrella-Parra et al., 2014; Lautié et al., 2013; Leuner et al., 2013). Consequently, farmers and traditional populations have used the seeds as pesticides (Catteau et al., 2013). The proximate composition was determined for lipids (20-28%), proteins (23-34%), carbohydrates (20.0%), fiber (7.0%), and ash (3.6%), (Duke, 1981; Grüneberg et al., 1999).

To increase root yield, flower pruning is recommended. The pruning beneficial effect was observed in cultivar AC-102 (*P. ahipa*). It produced 40 t ha^{-1} and 5 t ha^{-1} (Castellanos et al., 1997) when pruned and not pruned, respectively. This same study showed cultivar San Miguelito (*P. erosus*) to produce 105 t ha^{-1} when pruned and, 25 t ha^{-1} when not pruned. Pruning can increase yield up to 4 or 5-fold, however, it seems to be unfeasible on a large scale. For this reason, one aim of the yam bean breeding program is to develop varieties with high-yield without the need of the flower pruning.

In Africa, breeding studies with 33 yam bean accessions have shown genotype x environment interaction effects to be significant for roots yield, but not for some physicochemical traits of roots (Zanklan et al., 2007). Breeding in the Amazon region is incipient, though the National Research Institute of Amazonia (INPA) has collected material (*P. erosus* and *P. tuberosus*) since 1976, and it currently maintains 64 genotypes with natural outcrossing (Silva et al., 2016). This material was agronomically characterized (Silva et al., 2016), and 20 genotypes with high root and pod yield have been selected. This selection was carried out with no flower pruning. Under these conditions, root yield of up to 33 t ha^{-1} was obtained (Vasconcelos et al., 2018). However, the nutritional potential of the genotypes selected was not evaluated.

To help bridge this knowledge gap, we assessed the genotype x year (GxY) interaction of 20 selected yam bean genotypes along two years, both in agronomic traits and proximate composition values, under Central Amazon conditions.

MATERIAL AND METHODS

Location

The experiments were conducted at the National Research Institute of Amazonia (INPA), Experimental Vegetable Station, located in Manaus-AM (02º 59 '48.2' 'S and 60º 01' 22.4 " O) from April to September in 2017 and 2018. The station’s soil is classified as Yellow, sandy-textured dystrophic Argisol. The climate is characterized as hot and humid equatorial “Af” according to the Köppen classification (Alvares et al., 2013), with a mean annual temperature of 26.5°C varying between 22.5 and 38.0 ºC and precipitation of 2700 mm (Inmet, 2018). The experiments' precipitation and temperature data are shown in Table 1.

Table 1. Monthly accumulated precipitation and temperature ranges in 2017 and 2018. Manaus-AM. (Inmet, 2018).

Month	Precipitation (mm)		Mean temperature (ºC)		Maximum temperature (ºC)	
	2017	2018	2017	2018	2017	2018
April	325	280	30.0	28.0	34.5	33.0
May	135	180	28.2	28.5	35.0	34.0
June	120	190	30.0	28.7	34.2	34.0
July	80	50	30.0	30.2	36.0	36.0
August	27	20	32.0	32.0	37.0	37.0
September	180	75	31.0	32.0	37.2	36.0

Plant Material

Twenty genotypes of yam bean (*Pachyrhizus* spp.) from this bean's breeding program at INPA, which exhibited high root yield, were evaluated. These genotypes were selected from 64 genotypes with natural outcrossing between *P. erosus* (México) and *P tuberosus* (Mato Grosso, Brazil). The selected genotypes displayed root and pod yield stability both in lowland floodplain and non-flooded land (unpublished data). Their names are shown in Table 3.

Methodology

The soil was prepared and rows were raised where pits were dug. Then, 2 kg of organic compost (8:2 of soil and chicken manure per pit), were placed into them. Sowing was carried out directly following a completely randomized block design with 20 treatments, three replicates, and eight plants per plot, 1 x 0.5 m apart between and within rows.

Agronomic performance was evaluated through pod and root yield. The pods were harvested at maturity when they appeared dry with the seeds dried and loose in the capsules. These pods were harvested and weighed plot by plot to estimate plant yield. Similarly, tuberous roots were harvested at plot level in the sixth month and the yield per plant was estimated. The roots were also evaluated as to their specific gravity, with the aid of a hydrostatic balance.

The proximate composition assessments were made from peeled, sliced, and dehydrated roots in a forced air oven at 65ºC for 72h. Then, the samples were crushed in a mechanical mill and sieved in 30 mesh. Samples in triplicate were taken from this dry flour to estimate proximate composition.

Protein content was determined using the Kjeldahl method (IAL-Instituto Adolfo Lutz, 2008). Zero.02 g of the sample, 0.02 g of a catalytic solution composed of sodium chloride + potassium chloride, and 5 ml of sulfuric acid were placed in a Kjeldahl microtube. Then they were taken to digestion at 350°C for 4 hours and then distilled and titrated with 0.1N sulfuric acid.

The lipid content was determined from 0.5 g of a sample, which was diluted in 200 ml of hexane. This solution was placed in glass balloons, which were attached to the Soxhlet device. After 6 hours, the ether extract was weighed (IAL-Instituto Adolfo Lutz, 2008). Lipid percentage was estimated as follows: LM / SM * 100, where LM = lipid mass and SM = sample mass.

The ash content was obtained from a 0.5 g sample, which was charred in a bench oven. Then, the coal was placed in a muffle furnace at 550ºC for 4.5 hours or until the ashes became light and uniform. The ashes were wei,ghed and their percentage was estimated as follows: AM / SM * 100, where AM = ash mass and SM = sample mass.

Fiber content was determined by weighing sachets with and without samples. The sachets holding 2 g of samples were subjected to the following steps: the first one, consisting of 200 ml of the 0.255N sulfuric acid solution (H_2SO_4) at 100°C, was taken to the digestive device for 30 minutes. The second one, consisting of, 200 ml of the 0.313N NaOH solution, at 100°C, is taken to the digestive device for 30 minutes. Fiber content was estimated as follows: FM / SM * 100, where FM = fiber mass and SM = sample mass.

Carbohydrate content was calculated by the difference [100 - ash - lipids - proteins - fibers].

Statistical analyses

Agronomic and proximate composition data were subjected to the individual analysis of variance and Duncan's test. These analyses were performed to detect significant genotype effect and test the difference between all genotype mean levels. The significant effect of GxY interaction was detected by the joint analysis of variance considering the two years, which was performed following the Box criteria: bigger mean square error / smaller mean square error < 4 (Box, 1954). To determine the adaptability and stability of the genotypes, the GxY interaction was decomposed into year nested within each genotype. All analyses were performed using the SAS 9.1.3 program (SAS Institute Inc., Cary, NC). Finally, a biplot based on principal components was built to show the distribution of genotypes in terms of the significant characteristics of *Pachyrhizus* spp. This analysis was performed using JMP 10 software (SAS Institute Inc., Cary, NC).

RESULTS AND DISCUSSION

Pachyrhizus spp. is well adapted to the humid tropical climate, species. However, its breeding in the Brazilian Amazon has shown to be a great challenge, since there is very collected germplasm and few varieties with some commercial value. However, there is an increasing demand for novel healthy foods.

This species is characterized due to presenting roots holding protein content of about 10% on a dry weight basis. Its cultivation does not demand a lot of cultural treatments and, its root yield is around 50 tons per hectare. Here, we evaluated the genotype x year (GxY) interaction for root yield and physicochemical composition in 2017 and 2018.

Agronomic traits

GxY interaction effect was not significant for root yield (Table 2). This shows that selection may be able to be carried out in a single crop as long as it comes about at the same planting time. Root yield ranged from 1.60 - 3.51 t ha^{-1} and 1.59 - 3.53 t ha^{-1} in the 2017 and 2018 crops, respectively. Genotypes P7, P11, P15, P19, P37, and P57 stood out on account of having produced over 3.0 t ha^{-1} in both years (Table 3).

Vasconcelos et al. (2018) reported that these same genotypes gave yields ranging 19.64 - 33.16 t ha^{-1} in the 2016 crop. The planting season may account for these higher values. The present work and that of Vasconcelos et al. (2018) were carried out in the receding and rising water periods (June-October) and (November-May), respectively, in the Central Amazon. Therefore, all results of our study are only valid for the receding water period. Further work should be undertaken addressing the genotype x period interaction.

Previous studies in yam bean reported that root yield ranges from 14 – 108 t ha^{-1} (Nielsen et al., 2000; Belford et al., 2001; Silva et al., 2016; Jean et al., 2017; Vasconcelos et al. 2018). In contrast, we found up to 3.53 t ha^{-1}. Silva et al. (2016) carried out a similar experiment at the same site and found root yield ranging from 29.6 – 108 t ha^{-1}. These authors used techniques to prompt tuberization, i.e., planting seedlings, pruning flowers and harvest after eight months. The low root yield of our study can be mainly explained by two factors. First, we harvested early (six months after sowing), and second, we used no methods to increase tuberization.

Table 2. Analyses of variance for yam bean (*Pachyrhizus* spp.) physicochemical composition and agronomical traits when cultivated during low water period in 2017 e 2018. Manaus-AM.

		Mean Square							
Source of variation	**DF**	**Pod yield (t ha^{-1})**	**Root yield (t/ha^{-1})**	**Root specific gravity**	**Protein (%)**	**Lipid (%)**	**Fiber (%)**	**Ash (%)**	**Carbohydrates (%)**
Year (Y)	1	0.63**	0.01^{ns}	<0.01^{ns}	1.27**	0.01*	27.38**	0.12*	44.50**
Genotype (G)	19	0.13**	1.80^{ns}	<0.01**	15.73**	0.05**	106.13**	1.16**	143.83**
GxY	19	0.03^{ns}	0.01^{ns}	<0.01^{ns}	3.30**	0.02**	30.30**	0.09**	33.55**
Error	80	0.07	1.04	<0.01	0.01	0.01	0.01	0.01	0.04
Total	119								
General average		0.73	2.72	1.01	8.13	0.55	16.70	2.44	72.15
2017 average		0.66	2.72	1.01	8.23	0.55	17.18	2.48	71.54
2018 average		0.80	2.72	1.01	8.02	0.56	16.22	2.41	72.76
CV (%)		37.33	37.45	0.56	0.88	4.56	0.79	3.84	0.29

*, ** = P<0,05 and P<0,01 respectively; ns= not-significant.

Table 3. Averages of agronomic traits of 20 genotypes of yam bean (*Pachyrhizus* spp.) in 2017 and 2018 crops. Manaus-AM.

Genotype	**Pod yield t ha^{-1}**		**Root yield t ha^{-1}**		**Root specific gravity**	
	2017	**8**	**2017**		**2017**	**2018**
P7	0.81 ab[1]	0.79 ab	3.54	3.53	1.0126 ab	1.0127 ab
P9	0.74 ab	0.87 ab	2.50	2.50	1.0176 ab	1.0176 ab
P11	0.98 a	1.03 ab	3.52	3.51	1.0136 ab	1.0137 ab
P13	0.66 ab	1.05 ab	2.90	2.90	1.0126 ab	1.0126 ab
P14	0.52 b	0.52 b	2.77	2.76	1.0126 ab	1.0127 ab
P15	0.59 ab	0.66 ab	3.05	3.04	1.0101 b	1.0102 b
P17	0.70 ab	0.70 ab	2.21	2.22	1.0177 ab	1.0177 ab
P19	0.51 b	0.64 ab	3.30	3.31	1.0181 ab	1.0183 ab
P28	0.81 ab	0.80 ab	1.69	1.68	1.0226 a	1.0226 a
P35	0.48 b	0.81 ab	2.93	2.92	1.0177 ab	1.0177 ab
P37	0.57 ab	0.58 ab	3.29	3.29	1.0119 ab	1.0120 ab
P41	0.76 ab	0.89 ab	2.35	2.34	1.0169 ab	1.0170 ab
P48	0.52 b	0.47 b	2.95	2.95	1.0102 b	1.0103 b
P49	0.55 ab	0.84 ab	2.93	2.92	1.0181 ab	1.0182 ab
P51	0.57 ab	0.72 ab	2.37	2.38	1.0140 ab	1.0140 ab
P53	0.88 ab	1.16 a	2.47	2.46	1.0182 ab	1.0183 ab
P55	0.64 ab	1.03 ab	2.90	2.90	1.0184 ab	1.0184 ab
P57	0.77 ab	0.90 ab	3.13	3.13	1.0150 ab	1.0150 ab
P62	0.62 ab	0.97 ab	2.18	2.17	1.0172 ab	1.0170 ab
P64	0.49 b	0.66 ab	1.60	1.59	1.0183 ab	1.0185 ab
Averages	0.66	0.80	2.72	2.72	1.0157	1.0157
CV(%)	34.18	39.02	37.5	37.45	0.56	0.56

Averages with the same letters in the column indicate no significant difference (P=0.05) by the Duncan test. CV= coefficient of variation.

Pod yield showed there to be no significant GxY interaction but to be a significant Years and Genotypes effect. Indicating the selection of genotypes, which would yield the largest amount of grains, could be undertaken in a single crop during the receding water period, aiming to obtain varieties to be used in the Central Amazon at that time. Pod yield ranged 0.49 - 0.98 t ha^{-1} in the 2017 crop and 0.47 - 1.16 t ha^{-1} in that of 2018 (Table 3). Genotypes P11 and P53, which produced about 1 t ha^{-1} both in 2017 and 2018, stood out. Consequently, these genotypes should be tested for grain yield, through competitiveness assays, in the receding water period.

Seed mass represents 35 to 50% of the pods mass in *P. erosus*, *P. tuberosus,* and *P. ahipa* (Zanklan et al., 2007). Therefore, the present work shows that seed yield would be able to reach up to 580 kg ha^{-1}. This value is below that found by Zanklan et al. (2007), who reported 1.1-5.7 t ha^{-1}. They tutored *P. erosus* and *P. tuberosus* plants so the flowers would be more exposed to pollinating insects. Thus, tests aiming at selecting high-grain yield varieties will have to be conducted, using some tutoring method.

The seeds contain a toxic substance called rotenone (Catteau et al., 2013). Extracts containing this substance have shown to be toxic to insects (Roark, 1942), fish (Estrella-Parra et al., 2014), and humans (Narongchai et al., 2005). Therefore, genotypes P11 and P53 should be studied for their rotenone content and genotype x environment interaction.

Root specific gravity (Table 3) helps to quantify the dry matter content. It was only significantly affected by the genotype effect, with no GxY interaction. This shows, there to be genetic variability for this trait, and its selection able to be done in a receding water season aiming to sow during that time. Its specific gravity ranged 1.0101 - 1.0226 considering both crops. When this value tends to 1, it indicates the moisture value to be high. Therefore, the juiciest roots showed to be P15 (1.0102) and P48 (1.0103). Conversely, genotype P28 bore the highest specific gravity value (1.0226), which suggests it bears higher dry matter value and, may be recommended for obtaining flour or chips.

Using Schippers equation (1976) where Dry matter = −217.2 + 221.2 (specific gravity), it was found that the dry matter of *Pachyrhizus* spp. ranged from 6.5 to 9.2%. In *P. ahipa* it showed to be 10 - 18% (Mussury et al., 2013; Leonel et al., 2002). A group of *P. tuberosus* genotypes with dry matter around 30% has only been found in the Peruvian Amazon (Zanklan et al., 2003). It is locally called Chuin, and would be suitable for making flour. Consequently, the evaluated genotype are more suitable for being consumed fresh. Nevertheless, P28 genotype selection can be performed to make processed products, such as chips or flours.

Physicochemical traits

Protein, lipids, fibers, ash, and carbohydrates contents showed that the Years, Genotypes, and the GxY interaction effects, were significant (Table 2). The Years and GxY interaction significance indicate these characteristics to be sensitive to environmental changes, despite the planting having been carried out at the same time. The genotype effect significance indicates there to be genetic variability on these nutrients contents.

GxY interaction decomposition (Table 4) and genotypes means helped to identify the most stable genotypes, which held the largest amount of nutrients.

As to protein content, the only stable genotype was P28 (Table 4), which put forth 7.64 and 7.73% in the 2017 and 2018 crops, respectively (Table 5). Nevertheless, P13, P14, P37, and P62 bore high content levels ranging 10.0 - 11.8% on the dry base in both crops. Consequently, these genotypes may be selected for feeding humans or animals. Leonel and Cereda (2002) found 1% in *P. ahipa*; Zanklan et al. (2003) 8 - 12% in *Pachyrhizus* spp.;

Mussury et al. (2013) 15.3% in *P. ahipa*; López et al. (2010) 6.5% in *P. ahipa*. More recently, Vasconcelos et al. (2018) found 12.51% in genotype P47.

Table 4. GxY interaction mean square decomposition of 20 genotypes of yam bean (*Pachyrhizus* spp.). Manaus 2017 and 2018.

Source of variation	GL	Mean Square: Protein $(\%)^2$	Fat $(\%)^2$	Carbohydrate $(\%)^2$	Ash $(\%)^2$	Fiber $(\%)^2$
Year (Y)	1	1.27^{*}	0.002^{**}	44.50^{*}	0.12^{*}	27.38^{*}
Genotype (G)	19	15.73^{*}	0.053^{*}	143.83^{*}	1.16^{*}	6.13^{*}
GxY	19	3.30^{*}	0.028^{*}	33.55^{*}	0.09^{*}	30.30^{*}
Year/P7	1	4.72^{**}	0.104^{**}	1.60^{**}	0.07^{**}	8.03^{**}
Year/P9	1	6.34^{**}	0.002^{*}	26.21^{**}	0.09^{**}	8.18^{**}
Year/P11	1	1.54^{**}	0.001^{ns}	12.85^{**}	0.01^{ns}	5.27^{**}
Year/P13	1	0.38^{**}	0.002^{*}	87.37^{**}	0.12^{**}	83.26^{**}
Year/P14	1	0.18^{**}	0.006^{*}	60.07^{**}	0.09^{**}	57.12^{*}
Year/P15	1	2.09^{**}	0.158^{**}	164.97^{**}	0.15^{**}	129.92^{**}
Year/P17	1	3.10^{**}	0.025^{**}	126.59^{**}	0.04^{*}	97.18^{**}
Year/P19	1	0.31^{**}	0.079^{**}	0.003^{ns}	0.02^{ns}	0.13^{*}
Year/P28	1	0.01^{ns}	0.003^{*}	2.12^{**}	0.37^{**}	4.03^{**}
Year/P35	1	0.21^{**}	0.001^{ns}	6.33^{**}	0.01^{ns}	8.56^{**}
Year/P37	1	0.32^{**}	0.005^{*}	11.17^{**}	0.20^{**}	12.44^{**}
Year/P41	1	1.24^{**}	0.009^{**}	96.05^{**}	0.04^{*}	125.94^{**}
Year/P48	1	1.52^{**}	0.072^{**}	31.70^{**}	0.01^{ns}	22.08^{**}
Year/P49	1	1.55^{**}	0.001^{ns}	3.92^{**}	0.07^{*}	0.94^{**}
Year/P51	1	3.57^{**}	0.008^{*}	0.13^{ns}	0.01^{ns}	6.08^{**}
Year/P53	1	18.70^{**}	0.056^{**}	6.15^{**}	0.07^{*}	3.55^{**}
Year/P55	1	2.47^{**}	0.001^{ns}	9.52^{**}	0.03^{*}	23.03^{**}
Year/P57	1	3.59^{**}	0.001^{ns}	10.19^{**}	0.41^{**}	3.64^{**}
Year/P62	1	4.69^{**}	0.001^{ns}	10.20^{**}	0.02^{ns}	1.39^{**}
Year/P64	1	7.55^{**}	0.001^{ns}	14.79^{**}	0.13^{**}	2.24^{**}
Error	80	0.003	0.0005	0.037	0.007	0.017
Total	119					

*, ** = P < 0,05 and P < 0,01 respectively; ns= non-significant.

Table 5. Physicochemical composition averages of 20 genotypes of yam bean (*Pachyrhizus* spp.) in 2017 and 2018 crops. Manaus-AM.

	Protein (%)		Lipid (%)		Fiber (%)		Ash (%)		Carbohydrates (%)	
Genotype	2017	2018	2017	2018	2017	2018	2017	2018	2017	2018
P7	5.83 m	7.60 j	0.69 a	0.42 h	14.54 h	12.22 q	2.25 efgh	2.02 h	76.67 cd	77.71 c
P9	8.97 f	6.92 l	0.67 ab	0.63 d	23.50 c	21.17 d	2.84 bc	3.10 b	63.98 n	68.16 o
P11	6.92 k	5.91 p	0.61 cd	0.64 d	12.36 k	10.48 s	2.85 bc	2.78 c	77.24 b	80.17 a
P13	10.25 d	10.75 b	0.47 h	0.43 h	11.83 e	19.28 f	2.47 de	2.18 g	74.97 f	67.33 q
P14	10.54 c	10.19 d	0.66 ab	0.60 de	16.66 g	10.48 s	2.23 fgh	2.49 de	69.89 h	76.22 e
P15	7.79 h	6.61 n	0.52 fgh	0.84 a	24.33 b	15.02 l	2.14 h	1.81 i	65.21 m	75.69 g
P17	7.74 h	6.30 o	0.40 i	0.53 f	22.41 d	14.36 m	2.31 efgh	2.48 de	67.12 j	76.30 e
P19	10.10 d	9.64 f	0.40 i	0.63 d	12.80 j	13.09 p	2.64 cd	2.51 d	74.04 g	74.09 i
P28	7.64 h	7.73 i	0.48 gh	0.44 h	12.45 k	14.09 n	2.26 efgh	1.76 i	77.14 bc	75.95 f
P35	7.11 j	6.74 m	0.40 i	0.36 i	13.66 i	16.05 h	3.71 a	3.78 a	75.09 f	73.04 k
P37	10.57 b	11.22 a	0.63 bc	0.69 c	19.21 f	16.33 g	2.20 fgh	1.83 i	67.18 j	69.91 n
P41	6.70 l	5.79 q	0.70 a	0.62 de	14.54 h	23.70 b	2.35 efgh	2.17 g	75.68 e	67.68 p
P48	7.62 h	6.62 n	0.53 efg	0.75 b	23.73 c	19.90 e	2.40 efg	2.43 de	65.69 l	70.29 m
P49	5.74 m	6.76 m	0.60 cd	0.62 de	14.37 h	15.17 k	2.27 efgh	2.05 h	77.00 bcd	75.38 h
P51	7.38 i	5.84 q	0.57 de	0.50 fg	11.75 l	13.76 o	2.43 def	2.33 f	77.85 a	77.55 d
P53	6.95 kj	10.49 c	0.71 a	0.52 fg	23.50 c	21.96 c	2.18 gh	2.40 ef	66.63 k	64.61 r
P55	8.06 g	9.34 g	0.52 fg	0.49 g	19.62 e	15.70 i	2.92 b	3.07 b	68.85 i	71.37 l
P57	6.95 kj	8.50 h	0.57 def	0.59 e	13.77 i	15.33 j	2.17 gh	1.64 j	76.51 d	73.91 j
P62	11.82 a	10.05 e	0.51 gh	0.50 fg	26.66 a	25.69 a	2.71 bc	2.84 c	58.29 o	60.89 s
P64	9.72 e	7.48 k	0.36 i	0.38 i	11.91 l	10.68 r	2.21 fgh	2.52 d	75.78 e	78.92 b
Average	8.23	8.02	0.55	0.56	17.18	16.22	2.48	2.41	71.54	72.76
CV(%)	1.15	0.44	5.17	3.86	1.08	0.17	4.95	2.13	0.40	0.10

Averages with same letters in the column indicate there to be no significant difference (P=0.05) by the Duncan test. CV= coefficient of variation.

Cassava, the flour of which only bears 1.6% protein, is another much-cultivated root in the Amazon (Nepa, 2011). The protein content in the most consumed beans in Brazil (carioca type) is 20% (Nepa, 2011). Therefore, *Pachyrhizus* spp., roots bear half the carioca beans' protein content. These results confirm this root's high nutritional value. For this reason, efforts should be made to encourage their cultivation and consumption.

Lipid content's squares sum decomposition showed P15 genotype to be the most unstable one, among the years (0.52-0.84%) (Table 5). Although it had presented greater instability, its mean lipid content percentage was higher than that of the others (0.68%) (Table5). Conversely, the most stable genotypes were: P11, P35, P49, P55, P57, P62, and P64 (Table 5). If one wishes to select stable genotypes bearing high mean values, the chosen ones would be P11 and P49. If stable genotypes bearing low means are desired, the recommended ones would be P35 and P64. Dorporto et al. (2011) found 0.65% lipids for *P. ahipa* in the dry base. More recent studies by Buckman et al. (2018) found 0.54% in *P. erosus*.

Carbohydrate content was influenced by GxY interaction (Table 4). In general, genotypes presented instability between 2017 and 2018 (Table 4). However, genotypes P19 and P51 showed to be stable (Table 5). P19 had contents of 74.04% in 2017 and 74.09% in 2018. P51 had contents of 77.85% in 2017 and 77.55% in 2018. Yet, genotype P11 obtained higher content levels in both years: 77.24 and 80.17%, respectively (Table 5), and genotype P62 the lowest content levels: 58.29 and 60.89%, respectively.

In *P. ahipa* (Wedd) Parodi, Mussury et al. (2013) found 84 % of de carbohydrates. In *P. tuberosus* (Lam.) Spreng, Ascheri et al. (2014) found 30 - 74%. Zanklan et al. (2007) have observed, in the three cultivated species of *Pachyrhizus* that the starch content varies from 43 to 57% in the dry base. This indicates that most carbohydrates found in this work would be starches. These authors also detected other carbohydrates, such as glucose (1.5 - 5.8%), fructose (1.4 - 6.75%), and sucrose (3.1 - 5.4%). As *Pachyrhizus* starch has similar properties to those of cassava (Ascheri et al., 2014) it would be desirable for its content to be high. Thus, genotype P11 may be recommended. Genotype P62 may be recommended if low carbohydrate content roots are to be desired.

Fiber content showed GxY interaction significance (Table 4). Interaction decomposition in years within each genotype showed there to be significant for all genotypes. This indicates they all present fiber content instability. Based on the GxY interaction decomposition, genotypes P15 and P41 contributed 42% to the interaction. P15 had 24.33 and 15.02 % fiber in 2017 and 2018 respectively, and P41 had 14.5 and 23.7% fiber in the same years. Even though all genotypes showed to be unstable, P62 presented the highest mean levels (26.66-25.69%) both years.

Flours usually consumed in Brazil have low fiber contents. For instance, cassava, corn, and wheat flour present 6.4, 5.5, and 2.3% fibers, respectively (Nepa, 2011). This shows that, *Pachyrhizus* spp. flour can be considered a functional food that aids digestion. Therefore, the P62 genotype flour should be incorporated into the bakery recipes.

Ash content showed GxY interaction significance (Table 4). When unfolding this interaction, it was observed that most genotypes showed to be unstable, among years. Considering the GxY interaction's unfolding mean squares, genotypes P28, P37, and P57 accounted for 50% of the total square sum (Table 4). These genotypes ash contents showed to be 2.20 - 2.26% in 2017 and 1.64 - 1.83% in 2018. P11, P19, P35, P48, P51, and P62 were the stable genotypes (Table 5). However, P35 was the stable genotype bearing a high mean level: 3.71% and 3.78%, in 2017 and 2018, respectively (Table 5).

Several works have also evaluated this trait on genus *Pachyrhizus*. Leonel and Cereda (2002) found 0.4% ashes in *P. ahipa* tuberous roots. Mussury et al. (2013) 6.3% ashes in *P. ahipa*. Vasconcelos et al. (2018) 1.0 - 5.2% ashes in *Pachyrhizus* spp.

The cassava, corn and, wheat flour ash contents are 0.9, 0.5, and 0.8% respectively (Nepa, 2011). Ashes are associated with gross mineral content. Thus, the genotype P35 should be selected due to its great nutritional value.

The principal component-based biplot chart was built with physicochemical data (Figure 1). It accounted for 70.3% of the total variation, therefore, geometric interpretations are highly reliable.

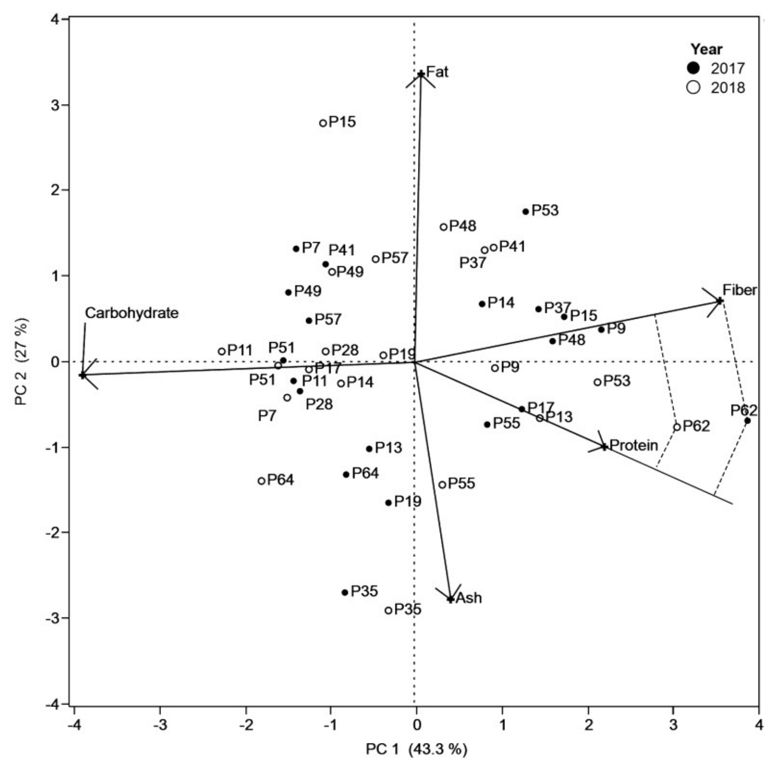

Figure 1. Principal component-based biplot shows the distribution of genotypes in terms of *Pachyrhizus* spp roots physicochemical composition. The experiments were conducted in Manaus during the receding water period in 2017 and 2018.

P62 genotype orthogonal projections, either in 2017 or 2018, resulted in the highest norm of the fiber and protein vectors and the lowest ones for the carbohydrate vector. This suggests this genotype has the highest protein and fiber content, and the lowest carbohydrate content. As the P62 orthogonal projections on the fat and ash vectors form small norms, one may conclude the fat and ash contents to be within their mean level. As root yield had no significant difference between the genotypes, the P62 genotype, should be selected as food with high nutritional functional value.

CONCLUSIONS

The agronomic characteristics of *Pachyrhizus* spp., such as root and grain yield as well the former's dry matter content may be selected in a single year during the receding water period, aiming to cultivate it within this same period. Conversely, the roots' nutritional components selection must be carried out throughout several years.

Among the evaluated materials, the P62 genotype should be tested in experiments of cultivar recommendation as well as, fresh and processed acceptability.

ACKNOWLEDGMENTS

The first author thanks the Coordination for the Improvement of Higher Education Personnel (CAPES) for having granted his doctoral scholarship. The authors thank Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) for financial support, process 424815/2016-8.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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