PLANTING TIME, DEVELOPMENTAL STAGES AND CHARACTERISTICS OF ROOTS AND STARCH OF *Pachyrhizus ahipa*

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ABSTRACT: Starch characteristics generally alter with plant developmental stage. The object of this study is to evaluate the effects of planting and harvesting dates on root physical-chemical characteristics, starch granule size distribution, and viscographics properties of starches in *Pachryrhizus ahipa*. Harvesting dates influenced root and starch characteristics for the two planting dates. The best conditions for cultivating *Pachyrhizus ahipa* for starch extraction are October planting and July harvesting dates. Their flowers must be cut after three months of cultivation.
Key words: ahipa, starch, microscopy, viscosity

CARACTERÍSTICAS DAS RAÍZES E DO AMIDO DE *Pachyrhizus ahipa* EM DIFERENTES ÉPOCAS DE PLANTIO E ESTÁDIOS DE DESENVOLVIMENTO DA PLANTA

RESUMO: De forma geral, as características do amido variam não somente com a planta de origem, mas também com o estádio de desenvolvimento desta. Neste trabalho objetivou-se avaliar a influência da época de plantio e estádio de desenvolvimento da planta de ahipa sobre as características físico-químicas das raízes, tamanho de grânulos do amido e suas propriedades viscográficas. Constatou-se influência do estádio de desenvolvimento da planta nas características físico-químicas das raízes e do amido, independentemente da época de plantio. A melhor época para o plantio de *Pachyrhizus ahipa* é outubro e a colheita deve ser feita no máximo com 9 meses, adotando-se o procedimento de retirada das flores a partir dos 3 meses.
Palavras-chave: jacatupé, amido, viscosidade, microscopia

INTRODUCTION

Pachyrhizus is one of a few Fabaceae with edible roots. *Pachyrhizus erosus* is the only species widely cultivated for domestic consumption and export, and has been introduced in several regions including Brazil. However, only two of the five identified species in the gender are cultivated: *P. ahipa* and *P. tuberosus*, both originated from South America (Castellanos et al., 1997). *P. ahipa* has some very interesting properties; systemically there is no previous known primitive material; morphologically it presents genotypes with erect, short growth habits; and agronomically it presents photoperiod neutrality, short development cycle (approximately 5 months), and considerable climatic adaptability (Orting et al., 1996).

Starch consumption is in general related to a given country development level. Two main points can summarize the situation of the world's starch sector: new or derived chemical reagents will rarely be approved for feeding, and in existing starches, the permitted chemical treatment levels for modification will remain unchanged. Reasons for these restrictions are consumer protection, worker safety, environment protection, and economic production costs. Therefore, both the food industry and agricultural producers are interested in identifying and developing species that produce native starches with special physicochemical characteristics. These starches could replace chemically-modified starches or open new starch markets (Kim et al., 1995).

In recent years, there has been growing interest in the effects that cultivation conditions and tuber age have on the synthesis and properties of starches. According to Noda et al. (1995), starch properties differ according to botanical origin, and more interestingly, starches from the same botanical source may have different characteristics depending on plant development stage.

This study aimed to evaluate the influence of planting period and development stage on root physicochemical characteristics and starch properties (granule size and viscographic properties) of *Pachyrhizus ahipa* plants.

MATERIAL AND METHODS

The experiment was performed at Fazenda Experimental Lageado, Botucatu, SP. The climate in the region is classified as Csa or rainy temperate, humid, with hot summers, average annual precipitation 1,517 mm, and average annual temperature 20.6°C. The soil in the area is a Dystrophic Purple Latosol A Moderate. In each planting period, 150 *P. ahipa* seeds were sown in polystyrene trays with substrate (50% Plantmax and 50% soil), kept in a nebulizated greenhouse for 30 days, and then 120 plants were transplanted to the experimental field.

The first *P. ahipa* planting period was October, 2001, with four harvests at three, five, seven and nine months. The second planting period was February, 2002, with harvests at five, seven and nine months. At each harvest, 20 plants were removed and weighed. *Ahipa* roots were characterized for composition: humidity, ash, protein, lipids, fibers, starch, and total and reducing soluble sugars (Somogy, 1945; AOAC, 1980; Rickard & Behn, 1987).

From the fifth month on, roots were processed to obtain starch by the following steps: root washing, disintegration pulp pressing liquid separation (250 Tyler mesh sieve) to remove residue, decantation and dehydration (35°C). The isolated starch was characterized for amylose content according to Williams et al. (1970).

A KS-300 Image Analysis System was used to determine starch granule size distribution. Starch samples were collected with a platinum thread and mixed with two drops of water glycerin solution (50%) on glass slide and covered by cover slide. Ten slides were observed under optical microscope (AXIOCOP II – ZEISS) and the selected images were analyzed. Five hundred largest diameter (mm) measurements were taken, as recommended by Vigneau et al. (2000), to analyze granule size distribution in different stages and periods.

Starch paste properties were analyzed with a Series 4 Rapid Visco Analyser (RVA) from Newport Scientific, and Thermocline for Windows. Starch suspensions (2.5 g starch in 25 mL H_2O) corrected to 14% humidity base were exposed to the following time/temperature sequence: 50°C for 1 minute, heating from 50°C to 95°C at 6°C/min, maintained at 95°C for 5 minutes, and cooled from 95°C to 50°C at 6°C/min rate. The apparent viscosity was expressed in RVU. The following characteristics were evaluated from the graph obtained: pasting temperature, maximum peak viscosity, breakdown viscosity (difference between the maximum and post-peak minimum viscosity), final viscosity, and setback (difference between the final viscosity and the minimum post-peak viscosity).

Analysis of Variance for completely randomized experiments was used to compare chemical characterization parameters and amylose levels at the different plant development stages in both planting periods. Means were compared by Tukey test ($\alpha = 0.05$).

RESULTS AND DISCUSSION

Plants from the first planting (October) harvested at 90 days, flowered and developed pods with seeds, but the roots were not tuberized. According to Sorensen et al. (1997), the planting of *P. ahipa* in Bolivia happens between August and October, and flowering occurs between the fourth and seventh months; flower and pod removal improves tuberization. As flowering in this experiment occurred from the second month on, and at three months there was no root tuberization, flowers and pods were removed from this date on, and the biggest seeds collected for replanting.

At second harvest (March), the five month-old plants were flowering with very few pods, and roots were tuberized bearing pear-shaped tubers. These observations confirmed the need to remove pods and flowers for better root tuberization, as recommended by Sorensen et al. (1997). At the third harvest (May), seven months after the planting, the roots were tuberized and the aerial part was starting to wilt. At nine months (July), the roots were tuberized and the aerial part was completely dry (Figure 1).

Weight measurements taken during plant development (Figure 2) showed that in the first months of growth, the plants had marked aerial development. Flowers and pods removal every thirty days after the first three months increased root weight, which tended to stabilize after seven months. Nine months after planting in the field, aerial drying was complete and the roots were in good conditions for processing.

In the second planting period (February), measurements of plant development showed that, after only seven months in the field, plants were developed, tuberized, and the aerial part was completely dry. Therefore the cycle was reduced from nine to seven months by

Figure 1 - *P. ahipa* at 9 months of development.

planting at that time (Figures 3 and 4). Flower and pod removal every thirty days after the three first months also led to better root tuberization and weight increases. At nine months, roots lost weight due to decomposition, different to first period plants where the aerial part dried at nine months, but it was still possible to harvest roots in good condition at this stage.

The comparison of root composition between same age plants from the different planting periods, shows that period influenced root composition. *P. ahipa* roots of five months-old planted in october had less dry matter but had more starch, protein, and reduced sugars than roots from the second planting (Table 1).

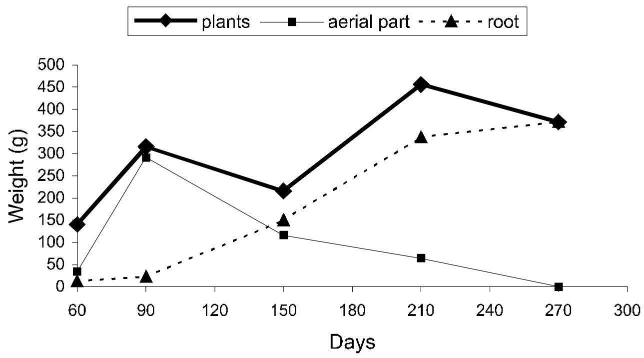

Figure 2 - Weight of plant parts during *P. ahipa* development – first planting period.

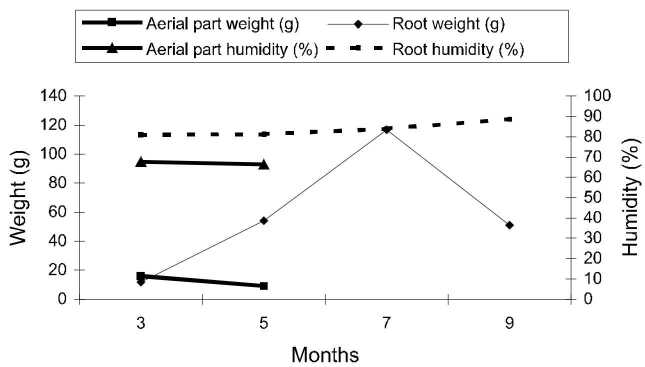

Figure 3 - Weight and humidity of *P. ahipa* in the second planting period.

Figure 4 - *P. ahipa* plant at 9 months (second planting period), showing rotten roots.

At seven months (Table 2), there was no difference in root humidity between the planting periods roots planted in February had higher amounts of total sugars and smaller amounts of starch than roots from the first planting period (October).

If *P. ahipa* is considered a potential raw material for natural starch with harvesting at seven months, theoretical starch yield - 89.6 kg t^{-1} processed root - will be better in an October planting, than the 68.5 kg t^{-1} in a February planting. Also there were no roots decomposition at nine months in the October planting allowing later harvest. As for the other root components, the high protein and fiber levels may interfere in the starch extraction process.

Table 3 shows that plant age had no impact on amylose content in the first planting, but in the second planting, younger plants had markedly higher amylose content. If harvesting time is at seven months, this pa-

Table 1 - Composition of *P. ahipa* plant roots at five months in both planting periods.

Variables	Planting in October	Planting in February	CV*
Initial humidity (%)	83.38^{A**}	81.18^{B}	0.49
%, dry basis			
Ash	2.53^{B}	2.65^{A}	2.26
Reduced sugar	13.00^{A}	9.69^{B}	0.63
Total soluble sugar	26.85^{B}	27.39^{A}	0.53
Lipids	0.41^{B}	0.83^{A}	6.51
Protein (Nx6.25)	8.23^{A}	7.18^{B}	2.13
Starch	50.72^{A}	47.28^{B}	0.75
Fibers	2.08^{B}	8.36^{A}	0.90

* CV= coefficient of variation
**Means followed by the same letter on the same line are not statistically different (P = 0.05).

Table 2 - Composition of *P. ahipa* plant roots at seven months in both planting periods.

Variables	Planting in October	Planting in February	CV*
Initial humidity	84.33^{A**}	83.91^{A}	0.56
%, dry basis			
Ash	1.99^{B}	2.70^{A}	5.74
Reduced sugar	8.99^{B}	10.42^{A}	2.27
Total soluble sugar	15.83^{B}	28.31^{A}	0.63
Lipids	0.70^{A}	0.35^{B}	6.09
Protein	6.14^{B}	8.54^{A}	3.97
Starch	57.16^{A}	42.55^{B}	0.73
Fibers	8.93^{B}	9.93^{A}	3.49

*CV= coefficient of variation
**Means followed by the same letter on the same line are not statistically different at (P = 0.05).

rameter is similar for both planting periods; however, amylose contents in both planting periods and at different plant development stages were very superior to those of Orting et al. (1996), who analyzed 19 *P. ahipa* crops and found 1 to 5% amylose content, very low values in comparison to other tubers, such as the potato (20-25%), sweet potato (19-26%) and cassava (17%) (Bermudez, 1987). The average amylose values herein recorded were close to those of Forsthy et al. (2002), who reported 11.6-16.8% for six *P. ahipa* crops.

Extracted starch granule size distribution in *P. ahipa* plant roots in the first planting period (Figure 5) increased with plant development stage (higher percentage of 10 to 20 μm granules at five months, 15 to 25 μm at seven months, and 12 to 18 μm at nine months); at seven months, granule size averaged 20.46 μm and had heterogeneous distribution. At nine months, distribution was very homorogeneous, that means, a high percentage of granules with the same size, and average large granule size - 16.54 μm - showing the end of root tuberization.

In the second planting period (Figure 6), starch granules also increased in size with plant development (13.79 μm and 15.48 μm average granule size at five and seven months, respectively). However, at the end of seven months, starch granule size distribution was not as homogeneous as for the first planting, at nine months. Granule size distribution graphs for both periods show that large starch granule size distribution has broader spectrum in the first planting than in the second; that is plant age and planting period influence this characteristic.

Sriroth et al. (1999) studied the influence of the harvest period on the starch granule size of four commercial cassava commercial crops in Thailand using an image analysis system (Carl Zeiss, KS 400 v2) connected to an optical microscope (Axiophol 2 Zeiss). They found that granule size distribution was affected by plant age and gradually changed from normal to bimodal distribution.

Noda et al. (1992) studied starch granule size from different root tissues in two sweet potato varieties. They made 1,200 size determinations using an image analysis system (Excell-II, Nippon Avionics Co.) connected to an optical microscope (Microphot-FXA, Nikon Co.). Starch granule size ranged on 2-40 mm with similar distribution curves seen for both varieties and no significant difference between layers. That means that root tuberization influences size distribution, in other words, roots whose tuberization process involves both the central and peripheral cambium tend to have more homogeneous size distribution.

Milanez (2002), studying *P. ahipa* plant development, observed that main ahipa root tuberization process

Table 3 - Amylose content in *P. ahipa* starches by planting period and at different plant development stages.

Planting period	Stage of development	
	5 months	7 months
October	13.9 Ab	13.3 Aa
February	15.8 Aa	13.7 Ba

CV=1.64%

*Means followed by equal capital letters in the same line are not different ($P > 0.05$). Means followed by equal small letters in the same column are not different ($P > 0.05$).

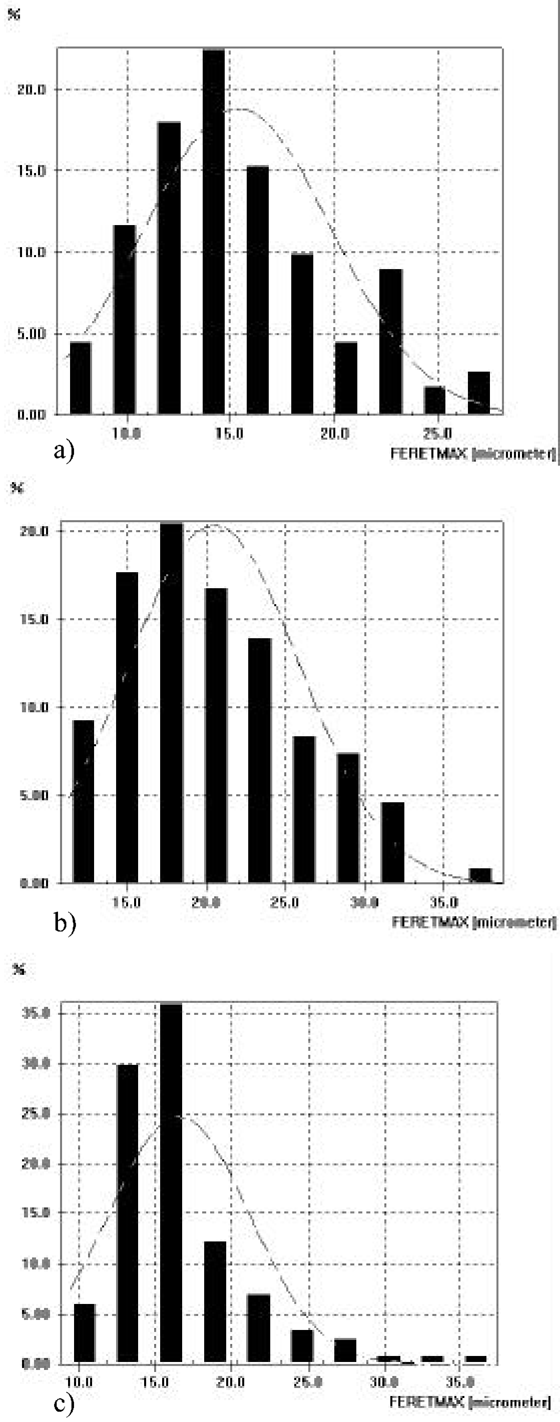

Figure 5 - Large starch granule size distribution, in the first planting period, October (a = 5 months; b = 7 months; c = 9 months).

involves not only typical vascular cambium activity but also activity from secondary cambiums distributed throughout the organ. Therefore, no tissue gradient distribution is detected, which favors a more homogeneous starch granule size distribution; this was also registered for granule size distribution of starch extracted from nine-month old plants from the first planting.

Figure 7 shows *P. ahipa* starch viscosity profile in Rapid Visco Analyser from both planting periods. The properties of starch pastes isolated from first the planting showed alterations (Table 4) during plant development. Starch viscosity profile in younger plants (five months) was different from the others requiring higher temperature to start paste formation, longer time to reach peak viscosity, and this peak was less sharp, showing non-uniform starch granule expansion and rupture in these younger plants. Later harvests had more defined pasting curves; pasting temperature had a later and sharper peak (higher homogeneity in expansion/rupture). However, maximum and final viscosities were variable. The most remarkable starch viscosity profiles alterations lied between five and seven months.

Profile and properties of *P. ahipa* starch paste at seven and nine months (1st planting) were similar to those of Leonel et al. (2002) for cassava starch under the same conditions. Plants harvested at seven months showed significantly higher peak viscosity, final viscosity, and setback value than both younger (5 months) and older (9 months) plants. Five month-old plant starch maximum and breakdown viscosities were smaller than other plants. However, starch pasting temperature was higher, showing higher resistance of associative forces within the granules, making their expansion more difficult (Table 4).

Table 5 shows starch and pasting properties from the second planting at five and seven months. The behav-

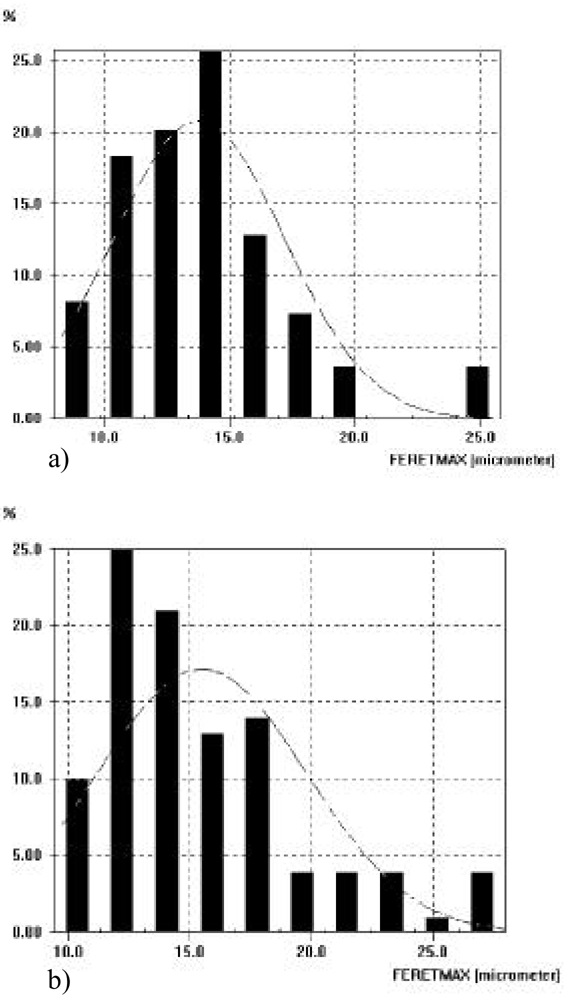

Figure 6 - Large starch granule size distribution, in the second planting period, February (a = 5 months; b = 7 months).

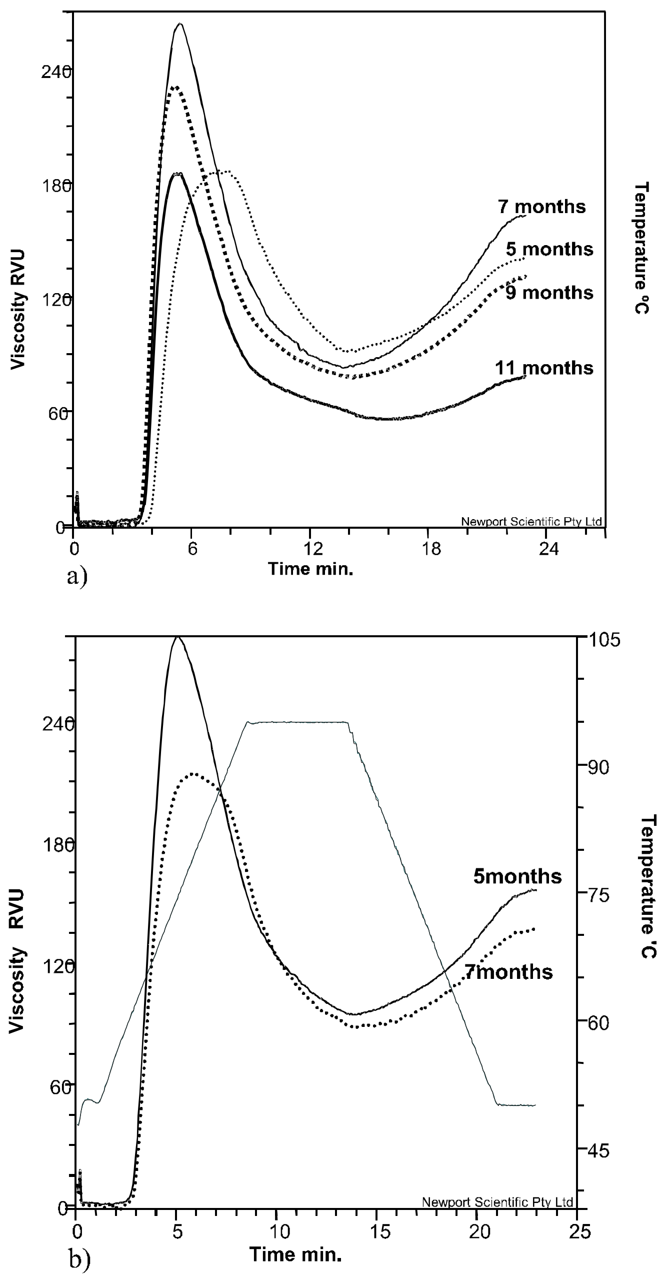

Figure 7 - Starch viscoamilographic profiles (2.5 g /25 mL) from *P. ahipa* planted in October (a) and February (b).

Table 4 - Pasting properties from the first *P. ahipa* planting (October) starch.

	Viscosity				Pasting temperature
	Peak	Breakdown	Final	Setback	
months	--------------- RVU			--------------	ºC
5	189C	96B	144B	51B	67.8A
7	265A	180A	167A	82A	65.0B
9	231B	154A	130B	54B	64.8B
C.V.* (%)	0.80	3.84	2.79	4.22	0.27

*CV= coefficient of variation
**Column values followed by the same letter are not significantly different at 5% level.

Table 5 - Pasting properties from the second *P. ahipa* planting (February) starch.

	Viscosity				Pasting temperature
	Peak	Breakdown	Final	Setback	
months	--------------- RVU			---------------	ºC
5	282A	189A	154A	61A	61.0A
7	213B	126B	135B	48B	61.6A
C.V.* (%)	0.57	0.80	1.88	0.27	0.32

*CV= coefficient of variation
**Column values followed by the same letter are not significantly different at 5% level.

ior of starch isolated from five month-old plant roots was more similar to the first planting, seven month-old plants starch. These results corroborate data registered for root characterization, demonstrating that the February planting lead to an early root harvest, but with lower starch yield.

At the second planting, five month-old plants had very different starch pasting properties than the seven month plants, except for pasting temperature. Viscosity was significantly reduced after some time. According to Madesen & Christensen (1996) the pasting properties of potato starch show differences with plant development. Pasting temperature, peak viscosity, and hot paste stability decreased with tuber growth, while peak viscosity increased.

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