Starch Content and Properties of 106 Sweetpotato Clones from the World Germplasm Collection Held at CIP, Peru

C. Brabet[1], D. Reynoso[1], D. Dufour[2], C. Mestres[2], J. Arredondo[3], and G. Scott[1]

Poverty alleviation through increased postharvest crop use is the major thrust of CIP's research on sweetpotato (*Ipomoea batatas*) in Asia. Much of the effort has focused on China, which produces roughly 85% of the world's sweetpotato (CIP, 1998). A series of collaborative diagnostic studies, and technology and market assessments identified sweetpotato starch production, especially for noodle processing, as an important income-generating activity in poorer areas of China (Scott and Wheatley, 1997; Scott et al., 1992).

Realizing the full income-generating potential of this activity depends on an integrated approach that includes better raw material and improved procurement, processing, and packaging (Wheatley et al., 1997; Zhang, 1999). From a varietal perspective, increasing starch content in fresh roots, extraction rate, and quality are critical components. A better knowledge and understanding of sweetpotato starch properties, and how they compare with those of other starch sources, is necessary to enhance the potential value of sweetpotato starch in existing and novel uses. Latex, the resin produced by sweetpotato latificers, is another important trait to be considered by the starch industry as the latex may contaminate the starch and adhere to equipment (Woolfe, 1992).

There is significant cultivar difference in the content and properties of sweetpotato starch (Tian et al., 1991; Woolfe, 1992), which suggests that genetic improvement of these traits may be achieved. However, the variability of starch content and properties in accessions from the sweetpotato gene bank held at CIP has not been comprehensively evaluated. The gene bank maintains a collection of about 5,500 cultivated accessions from 57 countries.

The objectives of this study were to (1) evaluate the variability of starch content and properties (amylose content and pasting properties) in advanced sweetpotato clones selected from the gene bank held at CIP, (2) estimate the most relevant correlation between the evaluated variables, (3) identify clones with potential for incorporation into CIP's breeding programs for starch production and use, and (4) provide recommendations for future evaluation and use of the sweetpotato gene bank.

Materials and Methods

Plant material

One hundred and six sweetpotato clones were evaluated in this study (Table 1). The set was chosen to represent diverse geographical origin, high variation in predominant root flesh color, and high dry matter (DM) content (> 25% for orange-fleshed clones and > 30% for others). Clones were also selected for adaptation to the agroecological conditions at the trial site based on CIP's root yield data. In addition, performance (high root yields) and relative importance of the clones in CIP's regions (widely grown) were considered.

1 CIP, Lima, Peru.
2 Centre de Coopération Internationale en Recherche Agronomique pour le Développement (CIRAD), Montpellier, France.
3 Universidad Nacional Agraria, La Molina, Lima, Peru.

Table 1. Origin and predominant root flesh color of 106 sweetpotato clones selected from the gene bank held at CIP, Lima, Peru.

Origin	Clones (Nº)	Predominant root flesh color[a]		
		White/cream	Yellow	Orange[b]
North America	**(10)**	**(1)**	**-**	**(9)**
Mexico[c]	1	-	-	1
United States	9	1	-	8
Central America and Caribbean	**(8)**	**(7)**	**(1)**	**-**
Cuba	1	1	-	-
Puerto Rico	7	6	1	-
South America	**(18)**	**(6)**	**(4)**	**(8)**
Brazil	3	1	2	-
Peru	15	5[d]	2	8
Sub-Saharan Africa	**(11)**	**(5)**	**(3)**	**(3)**
Burundi	1	1	-	-
Kenya	1	-	1	-
Nigeria	7	3	1	3
Rwanda	1	1	-	-
Uganda	1	-	1	-
Middle East and North Africa	**-**	**-**	**-**	**-**
East and Southeast Asia and the Pacific	**(57)**	**(27)**	**(11)**	**(19)**
China	5	4	-	1
Japan	5	1	4	-
Korea	2	1	-	1
Papua New Guinea	9	7	1	1
Philippines	5	1	1	3
Taiwan, China	15	2	3	10
Thailand	15	10	2	3
Tonga	1	1	-	-
South and West Asia	**(2)**	**-**	**(1)**	**(1)**
Bangladesh	1	-	-	1
Sri Lanka	1	-	1	-
Oceania	**-**	**-**	**-**	**-**
Total	**106**	**46[d]**	**20**	**40**

[a] Assessed visually after cross sectioning fresh roots according to the method described by Huaman (1991).

[b] Including yellow/orange- to orange-fleshed clones.

[C] Including bred lines developed at CIP.

[d] One clone was strongly pigmented with anthocyanins.

Sweetpotato clones were grown under standard cultural practices during the dry season (av temperature range 18.9-32.5°C, total rainfall 437 mm) at CIP's experiment station in San Ramon, Peru (tropical midland located at lat. 11°06' S, long. 75°18' W, and 800 m above sea level). Nitrogen fertilizer was applied at the rate of 80 kg/ha and sprinkler irrigation was supplied as needed. Clones were planted on 26 May 1997 and harvested after 164 d. Two-row plots were used with 10 plants per row spaced 0.25 m within rows and 0.90 m between rows. Plots were separated by one unplanted row and not replicated. Ten to 20 healthy roots (> 125 g each) per clone were sampled and immediately placed in paper bags under shade. They were then taken to CIP-Lima and stored at 13°C until processing. Because of the large number of clones and the long distance between field and laboratory, the time between harvest and processing was about 15 d.

Sample preparation

Washed and unpeeled sweetpotato roots were cut longitudinally in one half and two quarters after removing the extremities. One half was used for starch extraction, one quarter for flour preparation, and the other quarter for determining DM content.

Starch. Root halves were sliced and thoroughly mixed. A subsample of approximately 1 kg was macerated in a kitchen blender with tap water (1:1 v/v) for 2 min at maximum speed and filtered through a muslin cloth. The residue was resuspended in tap water (1:2 v/v), macerated, and filtered in the same way. The two filtrates were pooled, passed through a 250 µm sieve and adjusted to 4 L with tap water. Starch was allowed to settle for 3 h at room temperature (20-24°C) and the supernatant was discarded. The starch was resuspended in 2 L of tap water, filtered through a 75 µm sieve and left to settle in a tray for 2 h. This last step was repeated three times without the sieving step, and using deionized water instead of tap water for the last two washings. The recovered starch was dried in a forced-air oven at 40-45°C for 24 h, ground with a mortar and pestle to pass through a 250 µm sieve, and stored in sealed polyethylene bags at 6°C.

Flour. Root quarters were cut into 1 mm thick slices and mixed. A subsample of approximately 400 g was freeze-dried, then ground in a mill to pass through a 425 µm sieve. The resulting flour was stored in sealed polyethylene bags at -20°C.

Root analysis

Dry matter. Root quarters were cut into about 0.5 cm^2 cubes and mixed. Three subsamples of approximately 200 g were dried in a forced-air oven at 90°C for 48 h (i.e., until constant weight).

Extractable starch. Extractable starch was calculated as the ratio of g starch at standard 14% moisture content (MC)/100 g fresh roots.

Total starch. Total starch in flour was determined using a Total Starch Assay Kit (Cat. No. K-TSTA, Megazyme, Ireland). The method consisted of hydrolyzing starch to glucose by an enzymic procedure. Glucose was measured colorimetrically with glucose oxidase-peroxidase reagent. Flour MC was determined using the AOAC Official Method 925.10 (AOAC, 1995). Both analyses were done in duplicate.

Latex. Latex production was assessed visually after cross sectioning five fresh roots using the ratings 0 = latex not discernible, 3 = little latex, 5 = some latex, and 7 = abundant latex.

Starch properties

Moisture. MC was determined by oven drying two representative starch samples of about 4 g each at 105°C for 24 h.

pH. 5 g of starch on a dry weight basis (dwb) were dispersed and stirred in 50 ml of distilled water at room temperature for 30 min. After filtering, the pH of the

solution was measured. The analysis was done in duplicate.

Amylose. Amylose content was determined using the differential scanning calorimetry method described by Mestres et al. (1996).

Pasting properties. Viscosity profiles of starch suspensions of 9% (dwb/w) in distilled water through a heating and cooling cycle were obtained using a Rapid Visco-Analyzer (RVA) model 3D (Newport Scientific, Australia) as described by Collado and Corke (1997). Pasting temperature (Tp) at which viscosity started to increase, maximum or peak viscosity (PV), viscosity at the end of the hold time at 95°C or hot-paste viscosity (HPV), and viscosity at the end of the hold time at 50°C or cool-paste viscosity (CPV) were recorded (Figure 1). The stability (HPV/PV) and setback ratios (CPV/HPV) were calculated.

Statistical analysis

PROC MEAN and PROC CORR procedures (SAS, 1992) were used to calculate the descriptive statistics and Pearson's correlation coefficients between variables.

Results and Discussion

Root dry matter and starch content

Root DM and total starch content of the 106 sweetpotato clones varied widely. Root DM ranged from 19.9 to 45.4% and starch content from 11.1 to 33.5% on a fresh weight basis (fwb), with an average total starch content of 21.6% (Table 2) or 61.5% dwb. These values are within the ranges reported in the literature (Woolfe, 1992). The 106 clones were initially selected for high DM content based on CIP data, which explains the high average of 34.9% (Table 2). Most of the white/cream- (58%) and yellow-fleshed clones (85%) had a DM content > 35% (Figure 2). Sixty percent of the orange-fleshed clones (including yellow

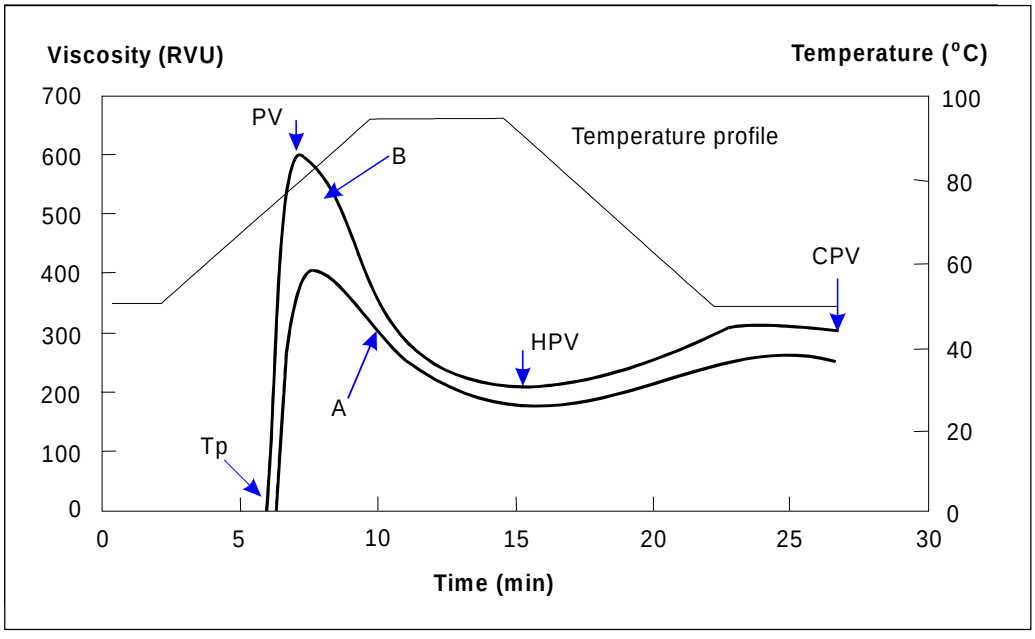

Figure 1. Typical RVA viscosity profiles of sweetpotato starch suspension of 9% (dwb/w) in distilled water observed in 106 clones selected from the gene bank held at CIP, Lima, Peru. Position of pasting temperature (Tp), peak viscosity (PV), hot-paste viscosity (HPV), and cool-paste viscosity (CPV) is indicated. Profiles A (CIP440029, Feng Shou Bai, China, white/cream-fleshed clone) and B (CIP440068, IITA-TIS 5081, Nigeria, yellow/orange-fleshed clone) correspond to the lowest and highest PV values.

Table 2. Variability of root dry matter and total starch content, extractable starch, and starch physicochemical properties[a] among 106 sweetpotato clones selected from the gene bank held at CIP, Lima, Peru.

Variables[a]	Range	Mean	Standard Deviation	Coefficient of variation (%)	Literature range[b]
Dry matter (%)	19.9 - 45.4	34.9	4.5	13	13.6 - 48.2
Total starch (%, fwb[c])	11.1 - 33.5	21.6	4.5	21	5.3 - 28.4
Extractable starch[d] (%, fwb)	6.5 - 25.7	17.3	3.6	21	/ - /
Starch pH	5.1 - 7.0	6.1	0.5	9	5.9 - 6.8
Amylose (%)	18.6 - 27.1	21.8	1.3	6	8.5 - 38
Tp[e] (°C)	70.2 - 76.6	73.8	1.4	2	66.5 - 86.3
PV[e] (RVA)	410 - 600	494.0	38.0	8	329 - 428
HPV[e] (RVA)	161 - 243	204.0	16.0	8	127 - 203
CPV[e] (RVA)	242 - 342	285.0	23.0	8	208 - 284
Stability ratio (HPV/PV)	0.31 - 0.52	0.41	0.04	10	0.35 - 0.55
Setback ratio (CPV/HPV)	1.22 - 1.62	1.4	0.08	6	1.40 - 1.67

[a] Analyses were done at least in duplicate, except for extractable starch, and starch amylose content and pasting properties.
[b] Dry matter and total starch (Woolfe, 1992); Amylose and Tp (Tian et al., 1991); Starch pH and pasting properties, except Tp (Collado and Corke, 1997).
[c] Fresh weight basis.
[d] 14% moisture content.
[e] Starch pasting properties: Tp = Pasting temperature, PV = Peak viscosity, HPV = Hot-paste viscosity, CPV = Cool-paste viscosity, RVA = Rapid Visco-Analyzer unit.

orange) had a DM content > 30%, with 10 clones > 35%. The Peruvian clone (CIP420053, Capadito), which is strongly pigmented with anthocyanins, had a DM content of 39.1%. These results suggest the potential for increasing DM content in sweetpotato roots by using these clones in breeding programs. Many varieties now cultivated have a DM content too low (25-30%) to be used in the processing industry (Mok et al., 1997), which prefers a DM content > 30-35%.

Extractable starch ranged from 6.5 to 25.7% fwb, with an average of 17.3% (Table 2). That represents an average recovery rate of 80.3% (ratio of starch at standard 14% MC to total starch content in roots), with values ranging from 54.6 to 91.4%. Wheatley (1996) found a highly significant positive correlation ($r = 0.90$, $P < 0.01$) between laboratory and industrial extraction rates. That demonstrates the usefulness of the laboratory method used in this study for screening clones for the starch industry. White/cream- and yellow-fleshed clones averaged higher extractable starch (18.3% and 19.1%, respectively) than orange-fleshed clones (15.2%). Sixty-two percent of the white/cream-fleshed clones and 70% of the yellow-fleshed clones had extractable starch values between 15 and 20%, whereas about half of the orange-fleshed clones had values < 15% (Figure 2). Approximately 29% of the white/cream-fleshed clones, 30% of the yellow, and 18% of the orange were in the highest extractable starch range of 20-26%.

A small amount of latex (3 rating) was produced in fresh roots of approximately 40% of the 106 clones; 12% produced abundant latex (7 rating) (Figure 2). Compared to the orange-fleshed clones of which 28% produced little latex and 20% abundant latex, a higher proportion of white/

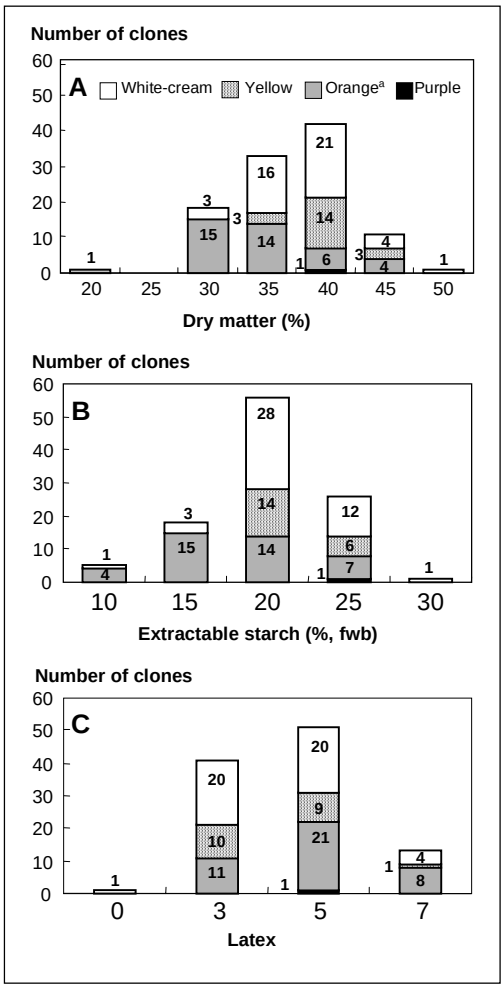

Figure 2. Frequency distribution of (A) dry matter content, (B) extractable starch at 14% MC, and (C) latex production in fresh roots for 106 sweetpotato clones selected from the gene bank held at CIP, Lima, Peru. Latex (C) was assessed visually using the scale 0 = latex not discernible, 3 = little latex, 5 = some latex, and 7 = abundant latex. Analyses were done at least in duplicate, except for extractable starch. (a. Including yellow/orange- to orange-fleshed clones.)

cream- (47%) and yellow-fleshed clones (50%) produced a small amount of latex, and a lower proportion of these clones (9% and 5%, respectively) produced an abundant amount.

Carotenoid pigment responsible for the orange flesh color of sweetpotato roots and anthocyanin pigment, which is responsible for purple flesh color, make the production of a white starch difficult. Hence white/cream- and yellow-fleshed clones are the most suitable for the starch industry. Seven light-fleshed clones with high extractable starch and low latex production in fresh roots have been identified from the 106 sweetpotato clones (Table 3).

A highly significant positive correlation was found between extractable starch and both root DM and total starch content ($r = 0.92$, $P < 0.001$ for both). A similar result was reported by Mok et al. (1997). Thus, root DM content, which is simple, fast, and cheap to determine, can be used to select sweetpotato clones with high extractable starch. That would be particularly useful in breeding programs in the first or second generation when a large number of clones are evaluated. Extractable starch in advanced clones could then be measured in the laboratory and confirmed in the field.

Starch properties

Amylose content and pasting properties are among the most important quality traits of starch. When an aqueous suspension of starch is heated above a critical temperature, granules swell irreversibly and amylose leaches out into the aqueous phase, resulting in increased viscosity (pasting). At this stage the granules are highly susceptible to thermal or mechanical breakdown, which leads to a decrease in starch paste viscosity. Upon cooling, the starch paste forms a gel (gelification) along with increased viscosity. Pasting and gelification are important properties in determining starch behavior in various food and industrial applications. They affect starch-based product quality such as texture, stability, and digestibility. The RVA provides as good a method for measuring these functional properties and describing starch potential end-uses as the Brabender viscoamylograph, which is usually used but consumes more time and sample.

Table 3. Sweetpotato clones selected for high extractable starch and low latex production[a] in fresh roots from the gene bank held at CIP, Lima, Peru.

CIP Number	Name	Origin	Predominant root flesh color	Latex[a,b]	Dry matter[a] (%)	Total starch[a] (%, fwb[c])	Extractable starch[a] (%, fwb)
187016.1	Caplina	Peru	White/cream	3	41.0	27.3	21.4
187016.3	TN89.315	Peru	White/cream	3	39.8	25.6	20.0
188004.3	LM88.113	Peru	Yellow	3	39.4	24.8	22.6
440041	Papota	Puerto Rico	White/cream	3	39.3	25.9	23.3
440046	Viola	Puerto Rico	White/cream	3	38.9	25.5	21.0
440341	I01273	Thailand	Yellow	3	38.4	24.4	20.2
440376	Woksaken	Papua New Guinea	White/cream	3	39.2	26.8	21.7

[a] Analyses were done at least in duplicate, except for extractable starch.
[b] Assessed visually using the scale 0=latex not discernible, 3=little latex, 5=some latex, and 7=abundant latex.
[c] Fresh weight basis.

Amylose content. Amylose content varied from 18.6% in the yellow-fleshed clone CIP187001.2 to 27.1% in the orange-fleshed clone CIP420012, with an average of 21.8% in all clones (Table 2). These values are within the ranges reported in the literature (Tian et al., 1991). Over 50% of the 106 clones had an amylose content of between 20 and 23%.

Pasting properties. Pasting properties also varied among the 106 sweetpotato clones (Table 2). The RVA viscosity profiles were all of the A type (using the starch classification of Schoch and Maywald, 1968) normally observed for root and tuber starch. They were characterized by moderate to high PV with a major breakdown and low CPV with respect to PV (Figure 1). Starch pH typically fell between 5.1 and 7 (Table 2), within the range where it usually does not affect pasting properties, as revealed by nonsignificant Pearson's correlation coefficients (not shown). Collado and Corke (1997) obtained a similar RVA pattern for 14 Philippine sweetpotato clones using the same operating conditions, but with a lower range of variation in pasting parameters, especially in PV (Table 2).

Although the importance of amylose has been established, viscoamylography was found to be a more practical and reliable method for predicting starch noodle quality (Collado and Corke, 1997). These authors found a high and positive correlation between the firmness of sweetpotato starch noodles and the RVA pasting parameters of stability ratio ($r = 0.95$), CPV ($r = 0.83$), and HPV ($r = 0.73$), $P < 0.01$. Twenty clones with the lowest and highest starch paste stability and amylose content, as well as 40 additional clones selected at random from the 106, are being evaluated for starch noodle production in Asia at Hong Kong University, to gain better information on the relationship between sweetpotato starch properties and noodle quality, and to identify suitable clones for this purpose.

Conclusions

This study is the first evaluation of starch content and properties of a large sample from the sweetpotato gene bank. These studied traits can also be affected by environmental factors such as site, season, and year, as well as root storage time (Tian et al., 1991). Results reported in this study, therefore, cannot be considered as absolute

values for each clone. Nevertheless, they are useful for general comparison and preliminary screening of sweetpotato germplasm collections for suitable root quality traits. The second phase study, already being initiated at CIP, aims to evaluate the stability of starch content and properties across different environments in Peru.

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