Functional properties of starches from perishable tropical sources: starch behaviour under different agro-industrial stress conditions

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Starches can nowadays be given stable technical and functional properties satisfying the criteria set by the agrifood industry, using varietal selection and the genetic improvement of plants in association with the chemical and physical modification of the starches themselves. Some of today's consumers want to see more "natural", "organic", "GMO-free", "healthier" industrial products manufactured "without chemical processing" on the market, and manufacturers of food ingredients and additives are searching for new "natural" compounds that satisfy the technical and economic constraints of production. The starches currently available on the world market come mainly from maize, wheat, potato and cassava. The present study was conducted to evaluate the industrial potential of native starches from a wide variety of starchy tropical plants.

The physicochemical and functional properties of the native starches of 33 clones, representative of 22 tropical plant species being grown in Colombia, were studied. Resistance to physical and chemical stresses (lengthy cooking at high temperature, refrigeration, acidic media) was evaluated and compared to that of industrial starches.

Raw materials (Table 1)

Table 1.

Botanical name	Common name	French name	Colombian name
Tropical roots and tubers (0 - 1000 m above sea level)			
Colocasia esculenta	Taro	Taro	Papa china
Dioscorea alata	Greater yam	Igname	Ñame
Dioscorea bulbifera	Potato yam	Igname	Ñame
Dioscorea rotundata	White yam	Igname	Ñame
Dioscorea esculenta	Lesser yam	Igname	Ñame
Ipomoea batatas	Sweet potato	Patate douce	Batata
Manihot esculenta Crantz	Cassava	Manioc	Yuca
Maranta arundinacea	Arrowroot	Arrowroot	Sagú
Xanthosoma sagittifolium	Tannia ; Yautia ; Cocoyam	Macabo	Mafafa
Tropical fruits, stems, palms and cycads			
Alocasia macrorrhiza	Giant Taro	Oreille d'éléphant	Bore
Artocarpus altilis	Breadfruit	Arbre à pain	Arbol del pan
Mauritia flexuosa	Mauritia	Mauritia	Moriche
Musa paradisiaca	Plantain	Plantain	Plátano
Musa sapientum	Cavendish banana	Banane	Banano
Zamia chigua	Zamia	Zamia	Chigua
Andeans roots and tubers (1000 - 4000 m above sea level)			
Arracacia xanthorrhiza	Arracacha	Arracacha	Arracacha
Canna edulis Ker-Gawler	Edible canna ; Queensland arrowroot	Canna ; Balisier ; Toloman	Achira
Pachyrrhizus erosus	Yam bean	Dolique tubéreuse	Jicama
Oxalis tuberosa	Oca	Oxalis	Ibias, Oca
Solanum tuberosum	Potato	Pomme de terre	Papa
Tropaeolum tuberosum	Añu	Cubio	Cubio
Ullucus tuberosus	Ullucu	Ulluco	Chuquas ; Ulluco

Table 2.

Common name	Cultivars	Dry matter %wb	Starch %db (1)	Ease of extraction*	Amylose DSC % (2)	Particule size µ (small ф) (3)	Clarity (4)	Vmax (BU) (5)	Vfinal (BU) (5)	Profile type
Andeans roots and tubers (1000 - 4000 m above sea level)										
Arracacha	*Amarilla*	23.6	78	2	15	—	28%	500	497	C
Arracacha	*Blanca*	28.4	80	2	2	—	74%	1180	487	A
Arracacha	*Morada*	29.3	73	2	16	8	—	717	480	C
Edible canna	*Raizuda*	26.0	76	3 (P, S)	27	25	65%	1510	1440	B
Edible canna	*Roja*	31.2	76	3 (P, S)	30	—	—	1150	1135	B
Oca	*Violeta*	18.3	82	2 (M)	—	—	—	—	—	—
Oca	*Amarilla*	16.4	62	2 (M)	19	18	—	865	440	C
Potato	*Sabanera*	22.2	77	1	19	—	—	1590	780	A
Potato	*Parda*	26.3	83	1	—	23	92%	2080	800	A
Añu	*Cubio*	11.2	68	4 (C, M)	21	10	55%	930	750	C
Ullucu	*Chuguas*	14.8	75	3 (M)	20	9	66%	816	690	C
Ullucu	*Ulluco*	13.5	80	3 (M)	17	—	—	665	392	C
Yam bean		13.0	53	4	28	6	4%	140	125	D
Tropical roots and tubers (0 - 1000 m above sea level)										
Taro	*Blanca*	30.9	83	3 (P, U, M)	13	4	2%	158	250	D
Taro	*Morada*	41.9	86	3 (P, U, M)	11	—	—	—	—	—
Greater yam	*861124*	29.0	78	3 (P, U, M)	23	—	—	34	96	D
Greater yam	*Criollo*	28.1	80	3 (P, U, M)	24	—	—	346	338	C
Greater yam	*Ceda*	28.2	70	3 (P, U, M)	25	18	8%	580	535	C
Greater yam	*Oso*	28.5	72	3 (P, U, M)	24	—	—	—	—	—
Potato yam	*Tumba*	28.7	81	—	32	—	—	—	—	—
Lesser yam	*Azucar*	38.7	78	3 (P, U, M)	—	—	—	200	197	D
White yam	*Espino*	37.3	77	2 (P, U, M)	22	—	—	385	378	C
Sweet potato		26.4	83	1	20	15	77%	520	458	C
Cassava	*CM 3306-4*	40.6	83	1	21	12	43%	330	410	C
Arrowroot		27.2	82	1	19	10	35%	570	570	C
Tannia		25.1	75	2 (P, U, M)	26	12	4%	236	220	D
Tropical fruits, stems, palms and cycads										
Breadfruit		37.8	67	3	13	—	—	—	—	—
Mauritia		27.4	47	4 (P, C)	17	—	3%	197	106	D
Plantain	*Harton*	41.5	83	4 (S)	27	—	—	439	423	C
Cavendish banana		24.8	75	4 (S)	22	—	—	595	575	C
Giant taro		13.0	56	3 (P, C)	12	2	0%	76	66	D
Zamia		62.8	74	4	26	—	—	202	198	D

*P = Phenolic compounds ; M = Mucilaginous compounds ; C = Colored compounds ; U = Urticating compounds ; S = Separation difficulty

Starch extractability

Four classes of raw material were distinguished according to ease of starch extraction and starch yield (Table 2). In Class 1, starch was easy to extract and yield was high (around 60%: potato and white yam) or very high (between 70 and 80%: cassava, sweet potato). In Class 2, starch was difficult to extract but starch yield was very high (tannia, oca) or starch yield and ease of extraction were medium (arracacha). In Class 3, starch was difficult to extract and yield was medium to high (e.g. edible canna, greater yam), and in Class 4 both ease of extraction and yield were low or very low (e.g. yam bean and banana).

Starch physicochemical characteristics

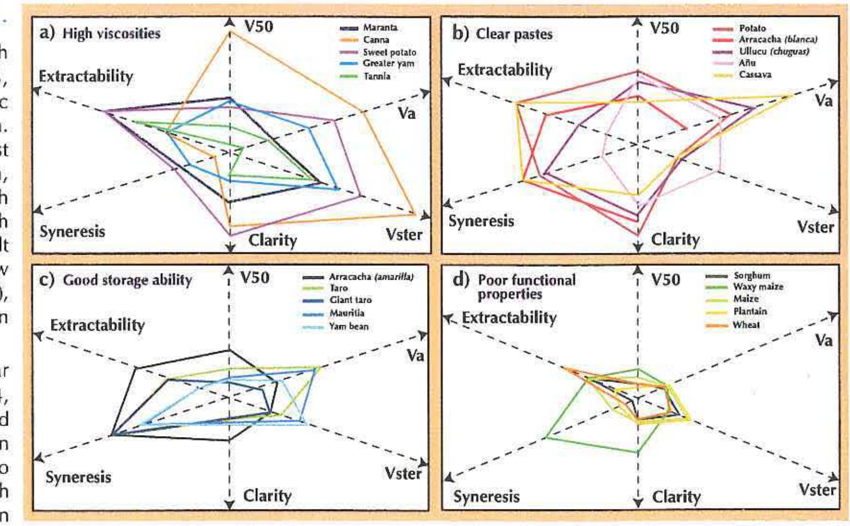
Amylose content ranged from 2 to 32% and samples were divided into four classes (table 2). The amylose-free class contained only the blanca cultivar of arracacha. The medium-low amylose content (10 to 16%) class consisted of the other cultivars of arracacha and the aroids. The medium amylose content (around 20%) class contained potato, cassava, ullucu, arrowroot and some yam cultivars. The high amylose (over 25%) class consisted of edible canna and potato yam. Granule size was small (under 10 µm) for taro, yam bean and giant taro. This may explain the relative slowness of the starch to settle or the need for centrifugation to separate the granules. Large granules were observed for potato, oca and edible canna.

Starch functional properties

Four types of pasting profile were distinguished (table 2). In Type A, the peak for viscosity during heating was high (over 1,000 Brabender units) but sharp (breakdown was half to two-thirds of peak viscosity): potato and arracacha (blanca cultivar) samples had this profile. Type B, characterized by high peak and final viscosities (zero setback), was observed only with edible canna starches. In Type D, all viscosities were very low (close to or under 200 Brabender units). The Type C profile was intermediate. Starch extracted from soft wheat, maize and sorghum had Type D pasting profiles, with the exception of waxy maize starch, which had a Type C profile.

▲ Data on good storage ability and resistance to acidity were highly cross-correlated. They were summarized in terms of two parameters: the initial viscosity of the gel prepared under acidic conditions and the degree of syneresis after 8 weeks' storage at 4°C. Resistance to heat was evaluated by paste viscosity after sterilization for 120 min at 121°C, and paste clarity was measured by light transmission. The functional and physical properties of the starches were summarized in graphs having the following 6 axes (clockwise from the top vertical): Brabender viscosity at 50°C (V50), viscosity in acidic medium (Va), viscosity after sterilization (Vster), paste clarity (Clarity), degree of syneresis in acidic medium (Syneresis) and ease of extraction (Extractability). All data were centred and reduced: the origin of each axis was placed at the centre. The scales were reversed for axes 5 and 6 so that useful properties were located towards the outside for all dimensions. Four groups of starches were distinguished (Figure 1):

Figure 1.



● 1 a- Starch pastes with high viscosities (axes 1 to 3, Figure 1a) especially in acidic medium or after sterilization. Canna starch was the most interesting in this domain, followed by sweet potato starch and yam starch. However, such starches were relatively difficult to extract (axis 6) and had low resistance to syneresis (axis 5), which would limit their use in refrigerated products.

● 1 b- Starches giving clear pastes and gels (axis 4, Figure 1b). Potato starch and cassava starch, both known to give clear pastes, belong to this class. Three other starch sources, with clarity between that of potato starch and cassava starch, could be of interest in this field: arracacha blanca, ullucu and añu. In addition, most of these starches had good storage ability but poor resistance to acidic media (except for cassava starch) or sterilization (except for añu starch). On the other hand, canna starch and ipomoea starch were both resistant to these conditions and also gave clear pastes (Figure 1a).

● 1 c- Starches with good storage ability only (Figure 1c). With two (taro and arracacha amarilla), the degree of syneresis was similar to that of waxy maize starch, which can be considered as a reference for this property. These starches also had unfavourable qualities (paste viscosity and clarity, extractability). Starches from the preceding class with resistance to syneresis should therefore be preferred if good storage ability is required.

● 1 d- Starches with poor functional properties (Figure 1d). This class included Cavendish banana starch and cereal starch. The only exception was waxy maize starch, which had good storage ability and gave clear paste. The majority of widely used starches (from cereals) came out badly in this study.

Several non-conventional root and tuber starches in Groups a and b have good potential as food industry additives or ingredients: among them edible canna, sweet potato and yam starches, due to their resistance to sterilization and acidic media, and arracacha starch because of its good storage ability. In addition, these starches generally gave clear pastes. Their only disadvantage is their difficulty of extraction, which could be resolved with appropriate technologies. Taro starch might also interest users requiring good storage ability.

(1) Batey, I. L. (1982). Starch analysis using thermostable alpha-amylases in wheat bran and germ. Starch, 34 (4): 125-128.
(2) Mestres, C. Matencio, F., Pons, B., Yajid, M. & Fliedel, G. (1996). A rapid Method for the determination of amylose content by using differential scanning calorimetry. Starch/Stärke, 48 (1), 2-6.
(3) Particule size: Small diameters, Scanning Electronic Microscopy
(4) Craig, S. A. S., Maningat, C. C., Seib, P. A. & Hoseney R. C. (1989) Starch paste clarity. Cereal Chem., 66 (3), 173-182.
(5) Tipples, K.H.(1980). Chapter III: Uses and Applications, in The Amylograph Handbook, Ed by Shuey, W. C. & Tipples, K. H., The American Association of Cereal Chemists, Minnesota, USA, pp 12-24.

Relationship between starch functional and physicochemical properties

Resistance to acidity and sterilization, syneresis and amylose content were cross-correlated. Viscosity in acidic medium and syneresis increased linearly with amylose content once the latter was above 15% (Figures 2a and 2b). This result agreed with the fact that starch polymer gelification and retrogradation, responsible for syneresis, are faster and higher for amylose. The high positive correlation between resistance to sterilization and the degree of syneresis means that it will be difficult to find a natural starch combining resistance to sterilization and good storage ability.

Figure 2.

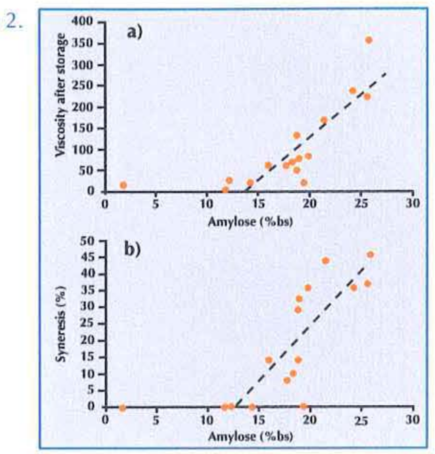


Figure 3.

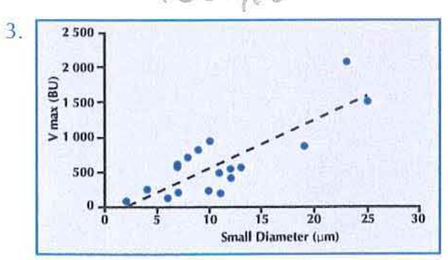
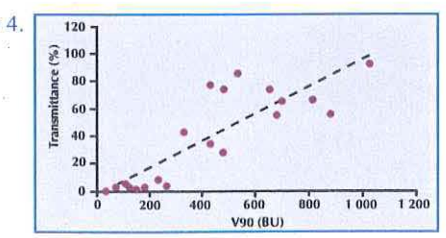


Figure 4.



Brabender viscosity increased with starch particle size (Figure 3): in particular, starches extracted from edible canna and potato with a particle size of 25 µm had a Vmax of over 1,500 RVA units.

There was a high positive correlation between paste clarity and Brabender viscosity. The correlation coefficient was 0.84 with V90 (Figure 4). On the other hand, there was no correlation between paste clarity and amylose content: the greatest clarity was observed with amylose-free starch (arracacha, blanca cultivar), medium amylose starch (potato) or high amylose starch (edible canna). Our results thus confirmed that the most important factor for paste clarity is granular remnants size rather than amylose gelation.

Conclusion

● Resistance to sterilization and syneresis increased when amylose was above 15% (db). Both can be linked to amylose gelification and retrogradation. On the other hand, paste clarity appeared to be mainly linked to light refraction on starch granule remnants: it increased with V90, which might indicate the size of starch granule remnants.

Four groups of starches were distinguished on the basis of their main functional properties. Three plants (edible canna, sweet potato and yam) appeared particularly interesting as their starches are resistant to sterilization and to acidic media, and the first two also give clear pastes: with cereal starches, these properties can be obtained only after chemical modification. Starch from arracacha (blanca cultivar), on the other hand, could be used to replace potato starch as it gives clear paste with good storage ability.

● The study showed the considerable potential of some native starches from non-cereal crops cultivated in tropical America to satisfy industrial demands for resistance to certain physicochemical stresses occurring during the manufacture of "new natural products". Research into the physical and chemical properties of native starches can be used to identify new market opportunities for certain root and tuber crops, thus promoting renewed interest in their cultivation.

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