Tropical Sources of Starches

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1 Introduction

The tropical belt which covers around 40% of the total land area encompassing five continents and many countries harbour a number of starch bearing crops which include cereals, tree, fruit and vegetable crops and most important the root crops [1-8]. However commercial use of these for starch extraction has been limited to a few of these crops. Most important of them are sago starch from sago palm, potato, cassava and sweet potato starches from the corresponding tubers. Minor quantities of starch are extracted from other crops such as Palmyra fruits, and the tuber crops like colocasia, amorphophallus, yams, arrowroot, Canna and Curcuma sp. but they have no commercial importance. Among these different starches, only cassava and sweet potato starches have been studied in detail and this chapter tries to bring out the available information on the tropical starches and also possible avenues of utilisation based on their physicochemical and functional characteristics. The starches and their properties are dealt with under different sections

1.1 Tree Crops.

Among the starch bearing tree crops, the most important ones are sago palm, mango, Plantain, jackfruit, breadfruit and Pandanus. The starch is found either in the stem, fruit or seed.

1.1.1 Sago palm (Metroxylon sagu) is a nonbranching palm cultivated in SE Asia. It grows to 9-12 metres high and flowers after 10-15 years and then dies. At the time of flowering, the palms are felled, the stems are sliced the pith is rasped, sieved and the starch granules are allowed to settle. The starch is collected, dried and used to make sago pearls by granulation. Originally all the sago pearls were obtained exclusively from sago starch, but now the sago pearls are obtained from cassava starch, which is more abundantly available.

1.1.2 Mango. (Mangifera indica) is widely grown in the tropics for its delicious fruits. The trees grow up to 40m metres in height. The seeds which form around 20-40% of the fruit contains up to 30% starch. The starch can be extracted by crushing the seeds, filtering and allowing to settle. No work has been carried out on this starch.

1.1.3 Jackfruit (Artocarpus indica) is a large tropical fruit tree with a dense crown and reaching up to 50 metres in height. The large fruits contain a fleshy portion covering


oval shaped seeds. The seeds form around 5% of the fruit and contains nearly 30% starch. Often the seeds are roasted and eaten. Very little study has been carried out on the starch properties.

1.1.4. Breadfruit (*Artocarpus altilis*) a tall tree 30 metres high and branching. It yields about 600-700 medium size round fruits per year. They are consumed as vegetable and have a very delicious taste. The fruits contain around 20% starch. Only very little work has been carried out on the starch of breadfruit.

1.1.5 Screw pine (*Pandanus lerum*) is a tall slender palm, 12-18 metre in height found in various tropical countries and Andaman and Nicobar islands of the Indian Ocean where it is very common. Its fruit (10-18Kg) is fleshy and contains nearly 20% starch. The local population consume the tubers after cooking and also extract starch, by crushing the fruits, sieving and drying. The starch has not been studied in detail.

1.2. Cereal starches.

Maize, sorghum and a number of millets are cultivated in the tropics and form important crops in many areas. They serve as a cheap source of food. Most of them contain good quantity of starch, the most important being maize.

1.2.1. Maize (*Zea Maize*) Maize is grown in large areas of tropical and subtropical belt and form a staple food. The yield of the crop is and the starch content as high as 70% in the dry cob. The extraction of starch from maize has been well standardised and is carried out extensively. The starch is commercially extracted and used in various food and industries.

1.2.2. Sorghum *Sorghum bicolor* is grown widely in tropics and is considered as poor mans cereal. The starch content is quite high, but very little work has been carried out on the starch properties.

1.2.3. Tef (*Eragostis tef*) is a major cereal staple in Ethiopia and its flour is used for making various products. The starch content in the grains is similar to other cereals and can be easily extracted using water.

1.3. Herbs/ shrubs.

There are a number of herbs/shrubs which produce starch in their grains, fruits or seeds. But these have not been exploited as starch source. Among them a few important ones are outlined below.

1.3.1 Amaranthus.

The amaranth plant family include more than 60 species that grow in many tropical regions. Although most of them produce edible leaves a few species are cultivated for their grains. The chief ones are *A. hypochondriacus, A. caudatus, and A. edulis*. They are perennial herbs widely differing in height and appearance. The grains contain 40-50% starch mainly waxy starch. The small size of the granules and low amylose
content in the starch make them very valuable as a type of starch with special food applications.

1.3.2 **Plantain/banana** Banana (*Musa* sp.) is grown extensively in most parts of the tropic for its fleshy fruits and there are a number of species having widely varying taste and texture. It is a straight annual yielding up to t/ha of fruits. The unripe fruits contain nearly 35% starch which has been rarely extracted.

1.3.3 **Okenia** (*Okenia hypogaeae*) is a perennial herbaceous crop distributed in central and south America. And the seeds contain nearly 35% starch.

1.3.4 **Quinoa** (*Chenopodium quinoa*) the anciedt andes crop is widely grown in S. America produce grains which serve as important food source. These are perennial herbs producing a grain yield of t/ha which contain approximately % starch.

1.4. Pulses The pulses also contain starch to a good extent. (20-30%). However they are never obtained pure due to presence of lipids and proteins accompanying the starch. Extraction of starches from the pulses are rarely reported except for some isolated reports on the study of their starches. A few of these are given below.

1.5. Tropical root crops

Tropical root and tuber crops are important food crops serving either as subsidiary or subsistence food in different parts of the tropical belt. They are rich sources of starch [9-12] besides many vitamins, minerals etc. Although there has been some decline in their use as food, their industrial application, especially that of cassava, is making rapid advances. Cassava and to a small extent, sweet potato (*Ipomoea batatas* Lam.) are used for starch extraction in countries like India, Brazil, Thailand, Indonesia, Philippines and China. Studies at different laboratories have brought to light the wide diversity in the starch characteristics of tuber crops and the possibility of using these native starches instead of chemically modified starches [12,13].

1.4.1. **Cassava** (*Manihot esculenta* Crantz) is a sturdy perennial crop grown in many parts of Asia, Africa and South America. The yield of the crop is normally around 20t/ha and the starch yield forms nearly one fourth of the total yield. The starch has been studied in detail and finds use in a large range of industries.

1.4.2. **Sweet potato** (*Ipomoea batatas* Lam.) is a herbaceous perennial vine and is grown extensively over the tropics and also in some parts of the USA for its tubers. The tubers have different sizes, shapes and colour. The yield varies anywhere from 8-30t/ha and it has been possible to have three crops in a year thus giving a very high annual starch yield. The starch content in the tubers vary from 12-30%.(fresh weight basis)

1.4.3 **Taro** (*Colocasia esculenta*) is a small herbaceous plant with large leaves found in most parts of the tropics, but are very important in the pacific regions. The crop is harvested at 8-10 month stage and produces a number of cormels around a corm. The yield is 5-10t/ha and starch content is 10-18%.
1.4.4. **Tannia** (*Xanthosoma sagittifolium*) is a large herbaceous plant grown widely for its cormels which are much larger than taro cormels. The yield is around 10-25 t/ha and starch content in the tubers nearly 20%.

1.4.5. **Elephant Foot Yam** (*Amorphophallus paeoniiifolius*) grown extensively for its huge corms. It is a big perennial herb harvested after one year and the corms can weigh over 15 Kg. The yield is over 20 t/ha and starch content in the tubers nearly 20%.

1.4.4. **Yams** is a large genus with over 600 species out of which a few are more commonly cultivated. Most of them are trailers. The tubers are harvested at 8-12 months after planting and the tubers especially those of *D. alata* are very large. Some of the species produce aerial tubers also. The starch yield also varies considerably and *D. rotundata* tubers have the highest starch content.

In addition, there are a number of other minor tuber and root crops which contain starch, but their utilisation is limited.

1.4.5. **African yam bean** (*Sphenostylis stenocarpa*) belongs to Luguminosae a vigorous herbaceous climbing vine reaching 1.5 -2 m in height producing pods as well as small spindle shaped tubers about 5-8 cm long similar to sweet potato. The crop is found mainly in Africa yielding up to 4 t/ha. The tubers are rich in starch (25%) but there are no studies on this starch.

1.4.6. **Arracacha**, Peruvian carrot(*Arracacia xanthorrhiza*). A stout semi-caulescent herb, resembling celery grown in south America and parts of Africa grown mainly at high altitudes. The edible secondary tubers are usually 6-10 in number with a yield of 3-18 t/ha. The tubers which contain nearly 20% starch are used as a source of edible starch.

1.4.7. **Chinese water chest nut** (*Eleocharis dulcis*) a variable annual stout aquatic plant and producing corms found in Asian region. The yield is 20-40 t/ha and starch content around 7%. In China the starch is extracted by rasping and settling.

1.4.8. **East Indian arrowroot** (*Tacca leontopetaloides*) is a perennial herb with a tuberous rhizome producing large/small sized tubers, found in tropical areas.. The tubers are similar to potato and harvested after 8-10 months. They are used in Tahiti to make ‘ poi’ a traditional food. The tubers are rich in starch (20-30 %) and starch extracted and used widely.

1.4.9. **Giant taro** (*Alocasia macrorrhiza*) is a tall succulent herbaceous plant up to 4.5 metres in height producing big corms up to 18 Kg. It is grown in Asia and South America and harvested 10-12 months after planting. The tubers contain 17-25% starch.

1.4.10. **Coleus** (*Plectranthes rotundifolius*) is a small herbaceous annual 15-30 cm high found in Africa and Asia. At maturity (6 months) they yield round to oval tubers very priced for delicate flavour. The yield 7-15 t/ha and the starch content is nearly 15%.

1.4.11. **Kudzu** (*Pueraria lobata*) known as arrowroot vine is a small perennial twining herb or shrub with elongated tuberous roots often weighing up to 40 Kg. Root are starchy 30-60 cm long used as a source of edible starch used instead of
arrowroot starch or gelatine in many foods. The starch content is over 20% and is extracted in small scale in Japan.

1.4.12. Lotus root (*Nelumbo nucifera*) is a perennial aquatic herb, rooting in mud found in S and SE Asia, Africa and Australia. The white globulous rhizomes which are harvested at 6-9 months measure 60-120 cm in length. The yield is 5 t/ha and starch content is nearly 18%. In China, a fine starch is isolated from the rhizomes.

1.4.13. Oca (*Oxalis tuberosa*) is a small compact annual tuberous herb 20-30 cm high. Oca is a ancient food plant of the Andes and found in many parts of South America. The rhizomatous tubers are harvested at 8 months maturity and are similar to potato (5-8 cm in length). The tuber yield is 4-5 t/ha while starch content is 12%.

1.4.14. Queensland arrowroot (*Canna sp*). A perennial herbaceous monocotyledon found in many parts of Asia, Africa, and S. America. The shape of the rhizomes vary from cylindrical to tapering with 5-9 cm in size. The tuber yield is 15-40 t/ha and the starch content varies from 24-30%.

1.4.15. Shoti (*Curcuma zeodoaria*) known as Indian arrowroot is a robust perennial with a fleshy branching rhizomes cultivated in Asia. The starchy finger rhizomes are greyish in colour, grow to 15 cm in length and have a musky odour. The tuber yield is 8-12 t/ha and starch content is 2-15%. The starch is extracted by rasping the tubers, sieving and settling and serves as a source of easily digested starch.

1.4.16. Swamp taro (*Cyrtosperma chamissonis*) is a giant herbaceous perennial 3-4 m in height with huge leaves. It is cultivated in many parts in Asia, Africa, and Pacific islands. The yield of corms is 7-10 t/ha and the starch content 28-30%.

1.4.17. Winged bean (*Psophocarpus tetragonolobus*) is a leguminous, climbing perennial found in Asia and Africa. Tubers are obtained 5-8 months after planting with a yield of 20%. Root tubers are 5-12 cm in length and contain nearly 20% starch.

1.5. Other minor sources.

In addition there are a few other sources of starch which have not been exploited. They are

1.5.1. Bamboo (*Guadua flabellate*) is a perennial crop grown largely as a source of wood. However, the culm of the crop has nearly 20% starch which can be easily extracted and can serve as a source of starch.

1.5.2. Black pepper (*Piper nigrum*), termed king of spices grown in Asia and Africa is a branching climbing perennial shrub. The annual yield of dry pepper is 100-300 kg/ha and the seeds contain over 40% starch but has not found any application.

1.5.3. Buffalo Gourd (*Cucurbita foetidissima*) produces roots which can be very large even up to 75 kg. The roots contain 15% starch and can be used as a source of starch.

2. Cassava starch characteristics
Among the vast sources of starch outlined above only cassava and maize starches have been commercially exploited since long and continue to be major source of starch. The extraction of maize starch is slightly complicated due to the need for steeping the dried cobs and using some whitening agents. On the other hand, cassava starch is easily extractable since the tubers contain very low quantity of proteins, fats etc. Hence the extraction process is simple and the starch obtained is pure white in colour if extraction is carried out properly. Since the lipid content in the starch is very little (<0.1%), the starch and its derivatives have a non-cereal taste very desirable in many food products.

Cassava starch granules are mostly round [14-16] with a flat surface on one side containing a conical pit, which extends to a well-defined eccentric hilum. Some granules appear to be compound. Under polarised light, a well defined cross is observed. The granules exhibit wide variation in size ranging from 5-40μm and variation in granular size distribution among varieties and during growth period and during different seasons has been reported [17, 18, 19]. Cassava starch has been assigned ‘A’ and ‘C’ XRD patterns by various workers[18]

The starch has very little lipid and phosphorus content. The amylose content in the starch is in the range of 20-27% similar to most other starches. The amylose content shows difference among varieties, but age of the crop and environmental factors do not affect the amylose content to any large extent. GPC analysis of debranched starch of different varieties did not reveal much variation among the varieties [18,20]. The soluble amylose content forms approximately 40% of the total amylose.

Thermal characteristics of cassava starch have been studied in detail using Differential Scanning Calorimetry which has become very important in characterisation of starch gelatinisation. DSC analysis of starch extracted from five varieties of cassava possessing different organoleptic quality showed that varietal differences manifest themselves in the DSC patterns Fig 1. The characteristic peak shape could be traced to structural differences among the varieties. The values reported for $T_{\text{onset}}$ and $T_{\text{end}}$ exhibited wide variation showing that varietal differences, environmental conditions, experimental conditions used for DSC measurement all influence these factors. Asaoka et al. [21] have examined the gelatinisation characteristics of four cultivars harvested at different seasons and their results indicated that both genetic constitution and environmental conditions affected the DSC parameters. Starch of one cultivar consistently displayed highest gelatinisation temperature through all the harvesting seasons (Tab. 2). Defloor et al. [19] studied the DSC characteristics of five varieties harvested during dry and rainy seasons and found that although within each planting season for each genotype and for each harvest time, significant differences in gelatinisation temperatures were noticed, no systematic changes as a function of genotype or harvest time was noticed. Starch samples harvested at six months stage in dry season had higher onset, peak and conclusion temperatures compared to that from rainy season, but the reverse was true for the tubers harvested at 12, 15 and 18 months. Even the temperature of drying affected the DSC gelatinisation temperatures. The gelatinisation parameters of cassava starch extracted using SO$_2$ incorporated water were enhanced from 59.6 to 62.0 for $T_{\text{onset}}$ and 84.7 to 87.2°C for $T_{\text{end}}$ [22].
Gelatinisation enthalpy depends on a number of factors like crystallinity, intermolecular bonding, rate of heating of the starch suspension, presence of other chemicals etc. For cassava starch, the values reported in the literature range all the way from 4.8 [23] to 16 J g\(^{-1}\) [24], Tab. 1. Genetic and environmental factors also affect the gelatinisation enthalpy as illustrated by Asaoka et al. [21] and Defloor et al. [19] from studies using different varieties, time of harvest and seasonal variations. SO\(_2\) treatment slightly enhanced the gelatinisation enthalpy of cassava starch from 18.1 to 19.1 J g\(^{-1}\) [22].

Among different tuber starches, cassava starch possesses the lowest gelatinisation temperatures. Varietal difference is also evident for the reported data from various sources. Correlation between granule size and gelatinization temperature was not obtained [19]. The gelatinisation temperatures of cassava starch determined microscopically by various workers ranged from 49-64°C [25] to 62-73°C [15]. In a Brabender Viscographic study involving starch of different varieties, pasting temperature of H 165 starch was slightly lower than those for most of the other varieties, and M4 starch had the highest range of pasting temperature [18]. The values were quite close to DSC values of 66 and 78°C for \(T_{\text{onset}}\) and \(T_{\text{peak}}\) respectively. SO\(_2\) treatment lowered the pasting temperature of cassava starch from 92 to 89°C. Gelatinization temperature of starch was enhanced tremendously in glycerol and ethanediol, while in DMSO and formalin, only slight increase was noticed. The high values observed in the first two solvents can be attributed to steric factors [26].

Viscosity is an important starch property on which many applications are based. Studies on viscosity of cassava starch have been carried out extensively and almost all their studies indicate high viscosity level for cassava starch compared most other tuber starches and the cereal starches. The viscosity characteristics are influenced by varietal differences, environmental factors, rate of heating, other ingredients present in the system etc.]. The Brabender Viscographs of starch of different varieties showed three main peak patterns viz. single stage gelatinisation with high peak viscosity and high viscosity breakdown, two-stage gelatinization with high peak viscosity and breakdown and broad two-stage gelatinization with medium viscosity and medium breakdown. These patterns seem to be genetically controlled as the patterns were maintained by these starches irrespective of the environmental factors, though there was variation in the viscosity values[12. In a comparative study of five cassava varieties having different cooking quality, it was observed that H-1687 starch had a medium peak viscosity and low viscosity breakdown but high set-back viscosity. M4 starch had slightly lower peak viscosity and setback viscosity. On the other hand, H-165 starch had a very high peak viscosity and the breakdown was also quite large. The viscochronographs clearly indicated that for H-165 starch, the set-back viscosity was much lower compared to peak viscosity, whereas for H-1687 starch, the reverse was true (Fig. 2). The result indicates a possible relationship between cooking quality and starch rheology, as tubers of variety H-1687 have reasonably good cooking quality, while H-165 is poor in its culinary quality. Tubers of variety M4 starch, whose starch behaves somewhat similar to H 1687 starch in its
rheology, has excellent organoleptic quality [18]. Olorunda et al. [27] found that mealier cassava varieties had slightly higher peak viscosity for their starches.

Rickard et al. [15] reported wide variation among the viscosity data for cassava starch from various sources [28-30] (Tab. 1). However, Rosenthal et al. [31] reported only minor variations among a few Brazilian varieties. Asaoka et al. [21] has compared the viscosity data of cassava starch using Brabender Viscograph and Rapid Visco Analyser (RVA) and the results are presented in Table 2. Breakdown of viscosity is another important factor which has a bearing on starch application in food. When the starch granules swell and they are subjected to heat and shear, the starch undergoes fragmentation and the resulting reduction in viscosity indicates the breakdown for the starch. Breakdown is not desirable since it leads to uneven viscosity and also leads to a cohesive nature for the starch paste. Cassava starch has a higher breakdown compared to most other starches, especially the cereal starches and hence is a major drawback attributed to the starch in some food applications.

Padmanabhan and Lonsane [32] observed a slight reduction in peak viscosity and breakdown in cassava starch extracted by an enzymatic method. The viscosity of cassava starch extracted from inoculum provided fermentation was lowered due to presence of fibrous matter [33]. However, the breakdown was also correspondingly reduced due to the cementing of the granules by fibrous materials and its rheology was similar to cassava flour.

Another factor related to viscosity is Setback which is attributed to the retrogradation of starch during cooling. Cassava starch has relatively low setback and this may be due to lower amylose content and also the structure of the amylopectin.

Swelling power and solubility of starch provide evidence of non-covalent bonding between starch molecules. Factors like amylose-amylopectin ratio, chain length and molecular weight distribution, degree / length of branching and conformation decide the swelling and solubility. Cassava starch has medium swelling power compared to potato and cereal starches - a property in conformity with its observed viscosity. The reported values for the swelling power of cassava starch vary considerably from 42-71 (Tab. 1) [15]. The swelling volume of different varieties of cassava varied from 25.5 to 41.8 ml g⁻¹ of starch. It was observed that during the growth period, starch of two varieties H-2304 and M4 maintained their swelling volumes within small ranges, while that for some varieties such as H-165 expressed wide variations which indicate that these varieties are very much susceptible to environmental influences [34] and also point to possible relationship between cooking quality and swelling volumes. Soni et al. [35] have reported a two stage swelling for cassava starch and attributed it to the two types of forces, which require different energy input to cause relaxation of the starch molecules. Asaoka et al. [21] have determined the swelling volume of four varieties of cassava harvested during two seasons and observed that swelling power was higher in samples harvested in November compared to those harvested in August.

Cassava starch has a higher solubility compared to the other tuber crop starches and the higher solubility can be attributed partly to the high swelling it undergoes during gelatinisation and the reported values ranged from 25 to 48% (Tab. 1) [15]. The solubility of starch of different cassava varieties varied from 17.2 to 27.2%. However no direct correlation between swelling and solubility could be observed. The values for solubility
of starch from different varieties during the growth period also indicated that starch of varieties H.2304 and M4 had good stability in their solubility, whereas the others had medium or poor stability [34]. Among a few non-aqueous solvents studied for solubility of starch, maximum solubility was obtained in DMSO and formalin, while in glycerol it was moderate. Starch was insoluble in anisole and methyl cellosolve. The solubility data indicate that starch is more soluble in polar solvents or solvents with affinity towards water [26].

The high clarity of starch has much relevance in food and textile applications and depends on the associative bonds between the starch molecules in the granules. Cassava starch having weaker associative forces compared to cereal starches has better clarity.

Another starch property which has relevance in food applications is sol stability which is decided by the retrogradation of starch molecules. During cooling and storage, the starch molecules associate leading to settling of the starch gel. This settling is not desirable in food products especially those canned and subjected to freezing and thawing. In this respect cassava starch has fair sol stability compared to the cereal starches.

The digestibility of cassava starch in native and gelatinised forms are quite high both in vivo and in vitro studies. It was over 60% in in vivo studies on small animals.

The properties of cassava starch reveal that the starch can find use in various food products. First, the bland taste of the starch is an advantage over the cereal starches which have a cereal flavour due to the lipids present in the starch. Sago pearls of best quality are obtained using cassava starch in view of its white colour, bland taste and easy gelatinisation. The starch has a very low gelatinisation temperature- lower than most other root starches and the cereal starches and hence cooking is easier. In addition the low gelatinisation temperature can be useful if some of the ingredients added to the product is heat-labile at high temperature. The high viscosity of the starch paste is also very useful in many food products which require body. This is exemplified by the preference for this starch in puddings and in fact in USA, tapioca pudding is an important food item. Though the stability of the viscosity is poor, some food products do require a cohesive texture like some gravies used in the orient and here cassava starch finds preference. Another important property which is very desirable in food products is the relatively good sol stability of the starch paste. This is of utmost importance in starch based products which are stored for long periods. The starch contains relatively lower content of amylose compared to cereal starches and its retrogradation is very low. The clarity of the cassava starch paste is excellent and hence finds favour in pie fillings where the products appear more appealing when the fruits are clearly visible. Thus the starch has a lot of desirable qualities which makes it widely used in food products. However, the starch is not used in some products due to the cohesive nature brought about by the breakdown of starch under heat and shear and poor freeze thaw stability. But with a number of modification techniques available, the undesirable properties can be rectified while maintaining the desired ones. [35-37]

3. Other starches
3.1. Sweet Potato starch
Unlike cassava, extraction of starch from sweet potato tubers is not easy. The presence of fibrous material and latex prevents easy settling of starch and this leads to extended residence time for the starch in the mother liquor. Since the mother liquor contains lot of sugars, fermentation sets in leading to deterioration of starch properties. Starch often possesses an off-colour if not processed properly due to the phenolics present in the tubers. Kallabinski and Balagopalan et al. (38) have used an enzymatic technique to extract starch from sweet potato tubers. The use of cellulase and pectinase resulted in increased yield of starch without affecting the properties of the extracted starch.

Sweet potato starch also is similar to cassava starch in its lipid and phosphorus content and hence its properties are quite similar to cassava starch.

Sweet potato starch is polygonal or almost round in shape [18,39] and has a centric distinct hilum. Polarisation crosses are less distinct compared to cassava starch. Granule size of sweet potato is in the same range as that of cassava starch. Bowkamp [40] reported negative correlation between particle size and susceptibility to amylase and acid degradation in sweet potato cultivars. Noda et al. [41] found no effect of fertilisation on starch granule size. The same authors found that the average granule size increased during early stage of development and then remained steady in two varieties. XRD pattern of sweet potato is reported as ‘A’ pattern, ‘C’ or intermediate between ‘A’ and ‘C’ [42-44]. Takeda et al. [42] observed ‘A’ pattern for two varieties while it was ‘Cα’ for another variety. The absolute crystallinity for this starch was 38% .

The molecular properties of sweet potato starch has been examined in detail. Takeda et al. [42] found a trimodal pattern for the sweet potato amylepectin while Hizukuri [45] reported a bimodal distribution. They concluded that sweet potato has a higher proportion of ‘A’ chains and short ‘B’ chains compared to potato. Seog et al. [46] reported alkali number values between 7.66 and 12.13 for six Korean sweet potato varieties compared to 5.33 for cassava starch. Noda et al. [41] used HPAEC-PAD on sweet potato starch and found the amylepectin to have peaks at DP=12 and DP=8. The concentrations of the peaks at DP=6 and DP=7 were 7.1-7.5% and 6.7-7.0% respectively.

For sweet potato starch also, considerable variation in amylose content has been reported, Tab. 3. Madamba et al. [47] found only very little variation in amylose content among six varieties of sweet potato from Philippines. Garcia and Walter [48] obtained values ranging from 20-25% by potentiometric titration for some Peruvian cultivars and location did not have any effect. Noda et al. [41] did not observe any effect of fertilisation or growth period on amylose content. Ishiguro et al [49] studied the retrogradation tendencies of starch isolated from 10 sweet potato cultivars having different amylose contents and chain length distribution. Starches having fewer amylose molecules and amylepectin molecules with higher content of short chains (DP 10) retrograded slower compared to others.
Collado et al. [50] have examined the DSC characteristics of 44 sweet potato genotypes from Philippines and obtained considerable variation in all the parameters. The mean $T_{\text{onset}}$ was 64.6°C and range 61.3-70°C, mean $T_{\text{peak}}$ 73.9°C (range 70.2-77°C) and mean $T_{\text{end}}$ 84.6°C, range being 80.7-88.5°C and the mean gelatinisation range was 20.1° with a range of 16.1 to 23°C. Garcia and Walter [48] have examined two varieties cultivated at different locations and found the range to be between 58-64°C for $T_{\text{onset}}$, 63-74°C for $T_{\text{peak}}$ and 78-83°C for $T_{\text{end}}$. While selection index did not affect the values, location influenced the parameters. Noda et al. [41] found varietal difference but no effect of fertilisation on the DSC characteristics of two sweet potato varieties. It was also found that during growth period, the $T_{\text{onset}}$ was the lowest at the latest stage of development. The starch from fresh tubers and freeze dried sweet potato tubers gave nearly equal values (67 – 73°), but the small granules gelatinised between 75 and 88°C. The pasting temperature of sweet potato starch (Tab. 3) varied between 66.0 and 86.3°C by viscosography while microscopic determination gave values between 57-70 to 70-90°C. Sweet potato starch behaves almost similar to cassava starch in its viscosity characters, viz., peak viscosity, viscosity breakdown and setback viscosity. The viscosity properties of sweet potato starch measured by various methods have been reviewed by Tian et al. [39] Tab. 3. Collado et al [50] studied 44 different sweet potato genotypes at 7 and 11% concentrations using Rapid Visco Analyser and have worked out the correlations among the RVA parameters. They observed wide variation not only in the Peak Viscosity but also the broadness of the peaks. A significant negative correlation between Peak Viscosity and amylose content was noticed. The rheological properties of sweet potato starch extracted using an enzymatic process did not vary among the different concentrations of enzyme up to 0.1% [51]. Guraya et al. [52] reported the apparent viscosity of a large number of sweet potato varieties to vary considerably from 71-442 cPs and storage led to reduction in viscosity. The rheological properties of sweet potato starch have been examined using a Bohlin rheometer [48]. Storage modulus, $G'$, Loss modulus, $G''$ and $\tan \delta$ summed over different starch samples were determined. During heating, the $G'$ and $G''$ increased while phase angle decreased indicating change from sol to gel. The initial increase has been attributed to progressive swelling of starch granules leading
to close packing. When the starch granules became very soft, deformable and compressible, decrease in $G'$ and $G''$ were observed. Elastic nature prevailed over the viscous nature of the paste.

Data on the swelling power has been compared by Tian et al. [39] and the values vary considerably not only among varieties, but also at different temperatures (Tab. 3). Delpeuch and Favier [53] have reported a two stage swelling while Rasper [54] and Madamba et al. [47] found a single stage swelling for the same starch. The comparatively lower swelling volume of sweet potato starch has been attributed to a higher degree of intermolecular association compared to cassava or potato starch. Collado et al. [50] have examined the swelling volume of starch of a number of Phillipino accessions and found the range to be between 24.5 to 32.7 ml g$^{-1}$ with a mean value of 29.9 ml g$^{-1}$ showing weaker associative forces compared to legume starches. There was no significant correlation between amylose content and swelling volumes.

The solubility of starch extracted from seven sweet potato collections from Peru indicated that solubility increased with temperature and reached nearly 10%, while for commercial starch, it was 28% [48]. The authors found that Selection Index did not have noticeable effect, but location had significant influence at temperatures above 60ºC. Collado et al. [50] found the solubility to be in the range 12 to 24% (average 16.9%). It was presumed that the bonding forces might be tenuous but comparatively extensive, immobilising the starch within the granules even at high levels of swelling.

In vitro and in vivo digestibility study of the native and gelatinised starch indicated that the starch possesses very good digestibility even in its native state. However sweet potato has been associated with flatulence and the starch has been implicated in contributing to flatulence, but the digestibility studies do not prove the role of starch in contributing to flatulence.

3.3. Yam and Aroid Starches.

The extraction of starch from yams and aroids is difficult due to presence of mucilage in the tubers. This is especially true for Colocasia which contains large quantity of mucilage. However use of dilute ammonia was found to facilitate extraction of starch from these tubers. The yield was enhanced and the quality of the resultant starch was equal or superior to the starch extracted using water [55].

These starches also have low lipid content. However the yam starches have higher phosphorus contents which contribute to their viscosity and gel properties. Yam starches have a large variability in shape viz., round, triangular, oval and elliptical. In fact, the species exhibit dramatic variability in granular size ranging from very tiny granules of *D. esculenta* (1-5um) to the very large ones observed for *D. alata* (16-110um). Farhat et al. [56] have examined the distribution in size of different yam species. *D. rotundata* and *D. cayensis* starches showed similar patterns with a single symmetrical distribution centred at 32 and 35 μm respectively while *D. alata* starch exhibited a non symmetrical wider particle distribution around 31μm and *D. dumetorum* starch had uneven distribution. Use polarised light microscopy confirmed the findings and corroborated the results of Rasper and Coursey [57] on granule sizes. Variation in granule size could not be observed among the three yam species viz *D. rotundata*, *D. alata* and *D. esculenta*. The edible *Dioscorea* starches (viz. *D. alata*, *D. esculenta* and *D. rotundata*), *D. abysinica* and *D. cayensis* starch possessed ‘B’ XRD
patterns. However ‘A’ and ‘C’ patterns has been reported for D. dumetorum starch. It was found that the XRD pattern of extracted starch is the same throughout the growth period of D. rotundata (Fig. 3). The macromolecular characteristics of 10 yam species have been studied in detail using HSEC-MAILS-DRI and it was found that the physicochemical and functional properties could be related to the macromolecular characteristics [58].

Amylose content in yam starches also varied considerably according to various reports. Farhat et al. [56] have obtained the following values for amylose content in starches of different Dioscorea species – D. alata – 25%, D. rotundata and D. cayensis – 23.8% and D. dumetorum -12.6%. A value of 29.7% was reported for the amylose content of D. abyssinica starch from Ethiopia, while Soni et al. [15] obtained 24.1% for D. balophylla starch. Only very little variation in the amylose content was observed with age of the crop for D. esculenta, D. alata and D. rotundata starches. Yam starches gelatinised over a temperature range of around 20°C and gelatinisation continued even after 95°C showing strong intermolecular linkages. The RVA results on pasting of different yam species indicate the values to range between 75 and 83°C, the highest being for D dumetorum and lowest for D. cayensis starch [56]. D. abyssinica starch had a gelatinisation temperature of 73°C. Nkala et al. [59] examined the starch of D. dumetorum from dry and wet seasons and found the values to be similar, i.e. 83°C. The large range for yam starches may be attributed to the presence of phosphate linkages in these starches (similar to potato starch).

All the yam starches showed a characteristic pattern of slow rise in viscosity and even after 95°C, an increase in viscosity was noticed. This implies that all the granules do not gelatinise at 95°C and some of them gelatinise only during the holding period. In this respect the yam starches resemble potato starch. The viscosities of starch of four varieties of D. esculenta extracted using water and ammonia solution showed only minor difference between the varieties (800-950 BU), but the viscosities of starch extracted using ammonia solution were much higher than those obtained by water extraction. For D. alata starch, there were no clear peak viscosity values. As observed for the D. esculenta starch, there was no noticeable breakdown in viscosity on heating and stirring. For most yam starches, the viscosity breakdown was quite low in spite of the high viscosity levels. The yam starches contain three to four times more phosphorus than that in cassava and aroid starches. It has been reported that the phosphate linkages in potato starch are responsible for its high viscosity and such effects may also be important in the yam starches. Gebre-Mariam and Schmidt [60] have obtained 781, 756, 1282 BU for peak viscosity, hot paste viscosity and cold viscosity respectively for D. cayensis starch showing low breakdown, but high setback for this starch. Farhat et al. [56] have examined the viscosity properties of four yam species (Fig. 4). The peak viscosities ranged from 2028 mPas for D dumetorum to 3893 mPas for D. cayensis compared to 8900 mPas for potato and 3134 mPas for cassava starches. The breakdown in viscosity was much lower compared to cassava and potato starches and in conformity with the results obtained with the Brabender Viscograph. The final viscosity was slightly higher than peak viscosity indicating a tendency to retrograde. Among these species, D. dumetorum had all the viscometric parameters lower than the other three and in support of earlier results [60]. Nkala et al. [59] did not observe much difference in the viscosity parameters of D. dumetorum starch during the dry and wet seasons. The RVA profiles
of starch of some varieties of *D. alata*, *D. esculenta* and *D. rotundata* harvested at different maturity have revealed that maturity did not affect the rheological properties to any major extent.

Swelling volume values of starch of six clonal selections of *D. rotundata* showed only slight differences among them. The swelling volume of *D. abyssinica* starch increased from 10 to 23 ml g⁻¹ as temperature was increased from 65 to 85°C. The relatively lower swelling of *Dioscorea* starch compared to potato starch has been attributed to the higher lipid content in the starch and also higher inter-associative forces compared to potato starch.

The solubility of *D. abyssinica* starch was found to be enhanced with temperature and the values resembled those of maize starch [60]. The solubility of starch of yams pretreated with various chemicals was affected to different extent by the chemicals used and also the concentration. The values were between 18-32%.

*Dioscorea* starches have almost equal clarity as cassava starch, indicating that their associative forces are similar. Variation was not observed among different varieties of *Dioscorea alata*, *D. esculenta* and *D. rotundata* starches.

The Dioscorea starches have relatively poor digestibility in the native state (20%) similar to potato starch. However gelatinisation leads to much higher digestibility.

Colocasia granules are among the smallest of starches observed in the plant kingdom making them useful in various applications eg. as a filler in biodegradable plastics, in toilet formulations, aerosol etc [61]. *Strauss* and *Griffin* [62] have examined a large number of taro cultivars and found maximum granules having size of 5.10 μm and least in the size 1.79 μm with a mean value of 3.34 μm. Unlike other tuber crop starches, which do not exhibit any significant variability in size with varietal differences, *Colocasia* starch was found to exhibit varietal difference. Studies on 10 varieties revealed a significant difference in average granule size (Fig 5)[63]. The average granule size and the distribution of the granule sizes showed only minor difference between the corms and cormels of four cultivars of *Colocasia*. Although variation existed among the cultivars, no significant variability was noticed within a cultivar during the growth period.

*Colocasia* starch has an ‘A’XRD pattern similar to cassava and sweet potato starches.

*Colocasia esculenta* starch showed a wide range in the amylose content and noticeable relationship between the amylose content and granule size was observed. The variety C-9 having the largest granule size possessed the highest amylose content among 10 varieties examined [63]. *Strauss* and *Griffin* [62] found that the maximum value for amylose content was 43% and minimum 3% and a mean value of 24.04%. They could not obtain correlation between amylose content and granule size. DSC studies indicated that *Colocasia* starch has *T*_onset values over 80°C and *T*_end values above 85.0°C, these being the highest among the starches [18]. *Strauss* and *Griffin* [87] found the gelatinisation temperature of different varieties of *Colocasia* starch to range from 69 to 74°C. Pasting temperatures by Brabender visco-graphy of different cultivars of *Colocasia esculenta* showed only very slight difference between the varieties, but were distinctly higher than
those of cassava and sweet potato starches. Considerable difference in peak viscosity values among the accessions was observed. It was also interesting to observe that starch from the C9 variety having the highest granule size and amylose content had the highest peak viscosity. There was only nominal breakdown in viscosity even at the highest concentrations pointing to the possibility of using this starch in various applications, which require paste stability.

Considerable variation in swelling volume of different varieties of *Colocasia* has also been reported. The values ranged from 26.5 to 60 ml g⁻¹ – which indicates a high degree of variability. Inverse relationship was noticed between the granule size and swelling volume of ten accessions of taro. The clarity of colocasia starch is, as expected, poor and the values are closer to that of cereal starches. *In vivo* digestibility of colocasia starch was found to be good both in native and gelatinised forms.

Xanthosoma starch possessed granular size ranging from 10-50um (Tab.4) and the starch granules are round. The starch possesses an ‘A’ RXD pattern and the amylose content is in the range 15-25%, similar to most other tuber starches. The gelatinisation temperature of the starch ranged from 68-95 °C by RVA and 79-92°C by DSC. Valetudie et al [65] found that starch of fresh and freeze dried tubers had similar gelatinisation temperatures. The T onset and T end for the starch were between 68-90°C obtained by various workers. The gelatinisation enthalpy ranged from 9-15 J/g [18]. The Brabender viscosity values showed the starch to have medium viscosity (600 BU for a 5% paste) with low breakdown. Varietal difference was not evident. The starch has a swelling volume of 20ml/g. *In vivo* digestibility of the starch was found to be quite good both in native and gelatinised form being over 60%.

Amorphophallus starch granules are round or polygonal with a granular size of 3-30um. The starch has an ‘A’ XRD pattern and there was very little variation in the amylose content among different varieties [66] Variability in the viscosity properties of *Amorphophallus paoniiifolius* starch extracted from ten accessions was quite minor. The viscosity breakdown for the starch samples was very low, similar to other aroid starches and in the same range as the cereal starches. Soni et al. [35] observed a value of 440 BU at 5% concentration and a breakdown of 40 BU, while Wankhede and Sajjan
[67] reported peak viscosity of 1570 BU at 10% concentration with a breakdown of 270BU.

**Other minor root starches.**

**Arrowroot.**
The starch granules are round or polygonal in shape and possess ‘A’ XRD pattern. The amylose content ranges from 16-27%. The starch has a pasting temperature of 75-92°C and the DSC values are T\(_{\text{onset}}\): 68.5°C, T\(_{\text{end}}\): 85°C. Gelatinisation enthalpy is 4.4J/g [23] which appears to be too low. The reported swelling volume for the starch is 23ml/g.

**Pacchyrhizus.**
The granules are round, cupoliform or polyhedral with size range of 6-35um. The starch has ‘A’ diffraction pattern, amylose content of 17-25% [18], gelatinisation temperature of 63-76°C by DSC and \( \Delta H \) of 13.65J/g [18]. It gives a viscosity of 600 BU for 5% paste and breakdown is less than 100BU and has low set back viscosity.

**Arracacha** Arracacha, Peruvian carrot, Arracacia xanthorrhiza. The starch granules are similar to cassava starch granules, and spherical or ovoid in shape, with size range of 5-27mu. The starch contains very little amylose and hence is a source of high amylopectin starch. The starch is easily digestible and hence finds importance in food applications [69,70].

3. **Chinese water chestnut.** Starch grains round or irregular have a size upto 27um. The starch finds use in canned foods because of good digestibility.

4. **East Indian arrowroot**
The starch extracted is pure white similar to cassava and arrowroot. Grains are polyhedrons or hemisphere and 8-40 um in size.

5. **Giant taro.** The starch grains are small, irregular with 1-5 um in size. The amylose content is approximately 21%

6. **Coleus** The starch granules are round or oval with a size range of 4-46um. The amylose content is higher compared to other tuber starches viz. 33%. It has a swelling volume of 33ml/g.

7. **Lotus root** The starch grains are long and elongated and are rather big in size 65-100um.

8. **Queensland arrowroot** The starch is characterised by its high phosphorus content and hence possesses high viscosity. The granules are oval or polyhedral in shape and have size range of 5-44um. It gives ‘B’ XRD pattern. The amylose content is quite high (28%). The pasting temperature ranges from 65-95°C and
DSC values for T\textsubscript{onset} and T\textsubscript{end} are 65 and 85°C respectively. The starch has very high viscosity and can be attributed to the high P content in the starch. The starch forms a strong gel even at 3% concentration and has excellent application as food grade starch. [70]

9. **Shoti** This starch is similar to Coleus starch in view of its high P content. The granules are elliptical in shape 14-42um in size. It gives ‘B’ XRD pattern, has an amylose content of 25-28%. The swelling volume is 19-30 ml/g and solubility of 11-23%. The DSC values are 74-79°C for T\textsubscript{onset} and 82-97°C for T\textsubscript{end}. $\Delta$H is 16-17J/g. The starch possesses very high viscosity and gel strength and hence very useful in food applications. [71]

10. **Swamp taro** Starch granules are round or angular and 4-18um in size

The starch properties of non-tuber sources have also been studied, and the available data is presented below.

1. **Breadfruit.**

Tumalii and Wootton [72] have studied the starch properties of seven varieties of Breadfruit. The dry pulp contains nearly 77% starch and easily extractable. The granules had a size range of 0.5-36 um (average 3-5um) in an image analyser. The starch possesses a ‘B’ XRD pattern. The starch has a two stage swelling and the swelling power varied from 13-31 g/g at 90C. The solubility varied from 8-22% among the varieties. The 8% Brabender viscosity value was 2400 (Peak) with around 300 BU breakdown and low setback. Amylose content was 16-22%. Adewusi [73] has reported lipid content of 0.17% and similar amylase content but much lower swelling and solubility.

**Sago**

*Sim et al [74]* have examined starch properties of sago starch. The granules are ellipsoidal in shape with pits at one or both ends. The amylose content is 31% - higher compared to many other starches. The unit chain length (20-23) was similar to cereal and potato starches. The starch exhibited two stage swelling and at 95°C, the swelling was nearly 90 while solubility was 40-60% at the same temperature. The 5% starch paste had a PV of 590 BU but showed only low breakdown or setback.

**Mango** Starch yield from the seeds is around 21% and the starch has a fat content of 0.36%. The average granular size is 17um and round in shape. The unit chain length is 19. The starch has a swelling of 212% at 95°C C with a solubility of 32% at the same temperature. The viscosity was found to be 192cP, slightly lower than cassava starch. The gelatinisation temperature was similar to cassava and sweet potato starches. [75]
Amaranthus

Many reports are available on this starch. The starch content is over 60% in the dry seeds. The reported fat content varied from 0.05% to a quite high value of 1.8%. The granules are very small almost ten times as small as maize starch with angular polygonal in shape. Most of the species have very low amylose content and hence can serve as source of waxy starch. The starch possesses ‘A’ XRD pattern with strong peaks showing high crystallinity. Conflicting reports are available on swelling and solubility. Whereas Stone and Lorenz [76] found only 10% swelling, Paredez-Lopez [77] found much higher values for swelling. The solubility values reported range from 33 to 80% at 95°C. The DSC data on the starch show $T_{\text{onset}}$ of 68-71°C, $T_{\text{peak}}$ of 78°C and $T_{\text{end}}$ of 87°C and a $\Delta H$ of 12-14J/g. The starch has a pasting temperature of 67°C, PV of 400-540 BU at 8% concentration, with around 40% breakdown and a small setback. Clarity of the starch paste is not very good [78]. The in vitro digestibility of the starch is quite high > 65% [79,80]. The syneresis of the starch is lower than that of corn during storage in the cold and hence can be used in many food items. Hoover et al [79] also found that environmental and varietal effects play a part in deciding starch properties. Stone and Lorenz [76] found that bread and cake quality were not good on using this starch. Singhal and Kulkarni [78] suggest that high paste viscosity, freeze thaw stability and stability under pressure cooking indicate its use in frozen and canned foods. Similarly, the starch will be useful in salad dressing where finely divided oil-in-water emulsion is formed. On the other hand, low paste clarity and poor stability under acidic conditions limit their food applications.

Tacca

Starch granules are tiny compared to many other starches, the average size being 3.5um and possess polyhedral edges. No hilum is visible. The amylose content is similar to most other starches viz., 22.5%. The pasting temperature is 72-75°C. The swelling power is quite high similar to other tuber starches. The solubility is high compared to potato starch and may be due to weak associate forces. Clarity is lower compared to potato or maize starches. This starch may have good applicability in tablet production in view of smaller grains.

Plantain

Unripe plantain contains around 88.6% starch in its flour and the flour is used in baby foods as a source of energy. The granules have irregular shape spheroid or elongated with a size of 10-50um. Lii et al [81] studied the granule size during the growth period, but most granules were in the range 20-60um. The fat content is 0.09 to 0.33% and phosphorus content is very low. The starch possesses a B XRD pattern. DSC results showed a wide variation among the varieties but most of the starches had $T_{\text{onset}}$ around 65°C, $T_{\text{end}}$ 78°C and $\Delta H$ of 10-13J/g [82]. It has very high gel strength (182Kg/cm compared to maize 13Kg/cm. The starch has restricted swelling power and solubilities showed similar trend. The gelatinisation temperature was 75-81°C. The peak viscosity is double that of corn at similar concentration and the breakdown is almost nil. The set back is low. Mota et al [82] found variability in RVA values for the different varieties. In view of low breakdown and high gel strength, it can serve as good source of starch for food applications.

Okenia
Sanchez_Hernandez et al [83] obtained 36% starch yield from the seeds. The granules are round with a diameter of 1-3\,\mu m, showing it be another small granule source and hence useful in many special applications. The fat content in starch is 0.18\% much lower than maize starch. The swelling and solubility are in the range of 20\,g/g and 19\% respectively at 100^\circ C. The starch does not have good freeze thaw stability indicating it may not be good for frozen foods. Clarity is similar to maize starch paste.

**Quinoa**

The starch granules are polygonal and extremely small 0.4-2\,\mu m The fat content in the starch is 0.11\% and amylose content is very low 9-11 [84]. The gelatinisation temperatures is 61-68^\circ C. The swelling power is 20 at 95^\circ C while solubility is only 4\% showing it to be very strong in associative forces. The Brabender Viscosity value for 5\% paste showed high values: 980 BU for peak, and 1900 BU for cold paste indicating high setback. Lorenz [85] found that the thickening power of the starch was better than many other starches as indicated by the result that the filling prepared from the this starch had highest viscosity after 5 days. However cakes and bread made from this starch were poor in quality.

**Cereals**

1. **Enset** starch contains relatively high quantity of lipid viz. 0.25\%. The granules are angular and elliptical with an average granular size of 44\,\mu m. Gebre-Mariam and Schmidt [86] have also observed granular distribution of this starch to be similar to potato starch. The starch possesses B XRD pattern. The amylose content is 29\%, the swelling power is 80 at 85^\circ C while solubility at the same temperature is 37\%. The starch has an T\textsubscript{onset} of 61.8^\circ C, T\textsubscript{peak} of 65.2^\circ C and T\textsubscript{end} 71.7^\circ C. The \Delta H is 21.6 J/g which appears quite high compared to other starches. The Brabender Viscosity values (6\%) of this starch are PV-884, V\textsubscript{H} 6090, V\textsubscript{c} 1045BU. The breakdown and setback being higher than maize but lower than potato pr cassava starches. The low breakdown of the starch paste indicates it can be used as a food starch in products requiring low cohesiveness.

**Sorghum** The starch contains quite large quantity of lipids as can be expected for cereal starches. Wankhede [87] obtained a value of 1.2\% for one Indian variety. The granules are round or polygonal in shape with the size ranging 8-20\,\mu m thus being quite small. Stark et al [88] did not observe any difference in gelatinisation pattern between smaller and larger granules. The reported amylose content varies from 21-30\%. The starch has a swelling power of 15 at 90^\circ C while solubility is nearly 20\% at this temperature. The gelatinisation temperature ranges from 68-78^\circ C and pasting temperature is 75.5^\circ C. The 8\% starch paste has a PV of 800, V\textsubscript{H} 420 and V\textsubscript{c} of 1228 BU respectively indicating high breakdown and very high setback similar to cereal starches. Native and gelatinised starch had amylase digestibility of 55-60\% and 70\% respectively. The good digestibility and small granular size is helpful in its use in food.

**Tef.**

Bultosa et al [89] have studied starch properties of five varieties. The starch granules are polygonal in shape and have a size range of 2-6\,\mu m similar to most cereal starches. SEM revealed the granules to be smooth. The amylose content was 27-28\% for the varieties by iodimetry and Concavlin precipitation methods. The gelatinisation temperature was 67-80^\circ C. by microscopy, thus being similar to rice starch. RVA analyses showed a value of around 74^\circ C for pasting temperature, 250-190 RVU for Peak Viscosity, 170-200 for
Hot paste viscosity and 280-300 for cold viscosity. The results show very low breakdown and setback. The values are lower than those for maize starches. The starch can be useful in foods requiring long duration of storage.

**Other starches**

**Bamboo** The starch extracted from the culm of bamboo from Mexico had a fat content of 0.31% and amylose content of 24%. The granules are polygonal ranging in size from 1-12um, thus being comparatively small. The starch has a gelatinisation temperature of 63-67°C similar to cassava starch. The starch has a low viscosity and even at 12% the peak viscosity is only around 400BU. The starch has low level of breakdown and very little set back. The swelling power and solubility are very low (< 5) below 80°C. However the solubility increases at high temperatures [90]

**Black pepper** contains 28-49% starch and Malabar varieties have maximum starch content. Bhat and Tharanathan [91] have examined the starch properties. The starch granules are extremely small (2-2.5um) much smaller than rice or corn starches. SEM revealed hexagonal and polygonal shapes and smooth surfaces. The amylose content is low : 17-18%. The gelatinisation temperatures determined microscopically was 70-75°C. The 10% starch paste has a peak viscosity of 530 BU reducing to 455BU at holding and reaching 550BU on cooling indicating low viscosity, breakdown and setback for the starch. Swelling power was quite low (<15) while solubility increases at temperatures above 70C. The starch had low amylase digestibility (< 30%). Bhat and Tharanathan [91] suggest that the strength of granules under mechanical shear and low breakdown and setback can make this starch very useful in food applications.

**Buffao gourd** Starch from three varieties of the starch revealed that the starch contains upto 1.14% crude lipids [92]. The granules range in size from 2-24um, average being 9um. XRD pattern is ‘B’ for the starch. The amylose content is similar to most other starches viz. 21-23%. Gelatinisation temperatures are in the range 59-69C. The swelling power varied from 14-26% while the solubility was 8-15%. The brookfield viscosity of 4% starch paste was as follows: initial pasting temperature 66-81, maximum viscosity of 12-15 Poises and very little breakdown or setback. The low swelling power solubility and viscosity indicate strong associative forces in the molecules.

**Pulses**

**Chick Pea, Cow Pea and Horse gram.** The starches from these have been studied by El Faki et al, [93]. The starch granules had varying sizes, 8-54um for chick pea, 4-39um for cow pea and 15-85um for horsegram starches. The shape varies from large oval shape to small spherical and with smooth surfaces. Chick pea and horsegram starches had B XRD pattern while it was A for cow pea. The amylose content for the starches were in the range 32-34%. The gelatinisation temperature ranged from 60-75°C for chick and cowpea while it was 71-80°C for horse gram. The cow pea and horsegram starches had much higher viscosity compared to chick pea, the vales being around 1500 BU for horse gram and cowpea compared to 600 for chick pea at 10% level

**Winged bean.** Umadevi and Wankhede [94] have studied the starch properties of winged bean starch. The starch granules are of two types: oval (25-36um) and round (10-12um). Under polarised light, they show strong centric crosses. The lipid content is
The amylose content obtained by fractionation is 36% similar to other legume starches. The gelatinisation temperature ranged from 61-70°C. The swelling power increases with temperature reaching 18.5 at 100°C, the solubility being 15% at this temperature. The digestibility of the native starch by alpha amylase was very low (15%), but increased to 40% on gelatinisation. However glucoamylase completely hydrolysed gelatinised starch.

**Baby Lima Bean** The starch granules are oval in shape and size ranging from 10-52um, average being 18um. The starch has a fat content of 0.54% while amylose content is 32.7% similar to other bean starches. The gelatinisation temperature using DSC was 75-87°C which can be considered high. The gel strength of the starch paste is quite high. The swelling power increased above 70°C and reached 19.9g/g at 90°C, while the solubility was 12% at 90°C. The Brabender viscosity values were as follows: Peak Viscosity 668, \( V_t \) 612, \( V_c \) 850 indicating only low breakdown and setback. The starch showed high syneresis explained on basis of high amylose content in the starch. The starch properties show that it can be incorporated into baked and canned foods due to higher gelatinisation temperature and water absorption capacity, but use as thickening and gelling agent in frozen or refrigerated foods is limited due to high syneresis.[95]

**Velvet bean.**

The starch granules are oval having size range of 15-30um. The fat content is 0.4% while amylose content is quite high at 39%. Gelatinisation temperature is 70-80°C microscopically. DSC data indicate the \( T_{peak} \) at 75°C. The gel strength is good. The swelling power is 17g/g at 90C while solubility is 15%. The Brabender viscosity did not show any maximum and viscosity values are lower compared to lima bean. Bentancur et al [96] conclude that the starch is good for products that require cooking at high temperatures during manufacture since it maintains good consistency during processing.

### 4. Modification of starches.

It is obvious that different starches have different physicochemical and functional characteristics. Some of these may be desirable whereas others make them unsuitable for specific applications. So attempts have been made to modify the starches so that the undesirable properties are eliminated while the desirable ones are retained. The modifications can be achieved by different techniques which include physical and chemical treatments and biotechnological techniques. Among the physical treatments thermal treatments are most common, but radiation has also been tried. In view of the availability of a large number of hydroxyl groups in the starch molecules, it is possible to prepare a large number of derivatives. The most common chemical derivatisation include esterification, etherification and crosslinking. These alter the starch properties significantly depending on the level of modification and the nature of the derivative. Use of microorganisms to alter the properties is a simple method, but with advent of gene technology it has been possible to completely alter the starch structure.
Cassava starch. The physical methods tried to modify the starch include heat-moisture treatment, steam pressure treatment and gamma radiation. Heat-moisture treatment under low levels of moisture improved the product quality as observed by Raja [97]. When the flour was sieved and heat moisture treated, the stickiness associated with untreated flour during production of various food items could be drastically brought down. Treatment with dilute phosphoric acid improved the textural quality of cassava flour and suitable for food products. [98] Steam pressure treatment of starch was attempted at various pressures and period of treatment. It was found that the viscosity came down considerably depending on the severity of treatment [99]. Along with reduction of viscosity, the breakdown was lowered. Reduction in breakdown is very desirable since it will be useful in reducing the cohesiveness of the starch paste. Heat-moisture and steam pressure treatments bring about reduction on viscosity and breakdown by strengthening the associate bonds among the starch molecules in the granules. This leads to lower swelling of the granules and less breakdown under heat and shear. The food products prepared from heat-moisture or steam pressure treated starches were actually found to be superior in texture and acceptability. Another important effect of heat-moisture treatment has been to impart fat-like characteristic to the starch and hence can find use as fat-substitute in dietary foods. Radiation modifies viscosity properties by bringing about partial breakdown of starch and leading to easy handling of starch-based food product.

Chemical treatments can be either simple complexation with a chemical or chemical reaction. It is well documented that lipids and surfactants can form strong complexes with starch. Originally it was thought that only amylose complexes with the reagents, but the role of amylopectin has also been established. These chemicals can modify the starch properties considerably. The interaction of different starches with lipids and surfactants has been widely studied. Hoover and Hadziev [100] used Glyceryl Mono Stearate to reduce the stickiness of mashed potato and attributed the effect to the complexation of soluble amylose portion of the starch with GMS and preventing its leaching out. DSC studies using native lipids on tuber starches have shown that though the tuber starches do not have inherent lipids associated with them, there is no hindrance for the starches to complex with lipids. So lipids at very low levels can be used to modify starch properties for possible food applications. The effect of various type of surfactants on the rheological properties of cassava starch has been examined and it was found that different types of surfactants affected the viscosity properties differently. Sodium stearate and sodium laurate stabilised the viscosity of the starch even at 0.3M concentrations. So these surfactants can be useful in improving the texture of the cassava paste in food applications. It was also observed that when cetyl trimethyl ammonium bromide as used, the surfactant complexed with the soluble amylose portion of cassava starch and thus this surfactant can be used to suppress the cohesive nature of the starch paste [101].
Chemical Derivatisation. Various ester and ether derivatives have been prepared from cassava starch. Among the esters, the most common one is starch acetate prepared by reaction of starch with acetic anhydride in dilute alkali or pyridine. Whereas use of pyridine results in high DS, alkali gives only low levels of DS. However, use of pyridine is not desirable in production of derivatives for food application. Starch acetate has a lower gelatinisation compared to native starch and this has advantage in food products in which heat-labile components are to be incorporated. Another advantage of the starch esters is the slowing down of retrogradation. Esterification tends to weaken the associative forces by reducing the available hydroxyl groups [102]. The bulky ester groups prevent parallel association of the starch molecules thus reducing the tendency of the starch to settle. This phenomenon helps in improving the freeze thaw stability of the starch paste, useful in canned and stored food products. When derivatives of cassava starch were compared, acetylated and propylated derivatives had better clarity, though only to a small extent. The clarity was best when pyridine-acetic anhydride was used for acetylation, probably due to the high D.S. achieved. Similarly starch propionate and starch succinate derivatives have been prepared which also have applications in food products. Cassava starch phosphate prepared by dry heating of starch-phosphate mixture has very high viscosity and finds use in instant puddings and similar products.

Crosslinking is a very useful modification technique to improve starch properties. Cassava starch paste tends to undergo breakdown when subjected to heat and shear. By use of crosslinking the starch molecules are strengthened preventing easy disintegration of starch. Some of the common crosslinking reagents used include phosphorus oxychloride, sodium tri polyphosphate and epichlorohydrin. Knight[103] has found that crosslinking improved the viscosity stability of cassava starch and can be incorporated into bread products. The freeze thaw stability could be improved by esterification of the crosslinked starch. Starches with multiple modifications are available for specific applications. These products have improved viscosity stability and better freeze thaw stability. Heat moisture treatment of starch derivatives can also yield products useful as fat substitutes.

Use of microorganisms to modify cassava starch has been practised since long. Sour starch obtained by natural fermentation has been used for preparation of bread in Brazil and Colombia and the fermented starch has better raising properties compared to native starch. Attempts have been made to reduce the fermentation time by using better and more efficient cultures [104]. Use of inoculum provided fermentation also improved the baking potential of cassava starch [33]

Modification of other starches.

Unlike cassava starch, derivatives of other starches have not been commonly reported. Acetylated, succoinylated and hydroxypropylated amaranthus starch have improved freeze thaw stability [105,106]. Steam pressure treatment of the D. alata and D. rotundata starch reduced the viscosity depending on the pressure and time of treatment. The peak viscosity came down to nil value at 15 psi for 60 minutes for both the starches [107] and hence steam pressure treatment can be attempted for the modification of yam starch. Cold water solubility has been incorporated into banana starch by alcohol-alkali
treatment [109]. There is scope for modification of the lesser known starches which possess some inherent properties like high gel strength, viscosity and digestibility so that they can replace the chemically modified starches for specific applications.

5. New Trends

Though there is a wide range of starch available with different properties, the demand for tailor made starches for specific applications is always rising. In spite of the fact that chemical methods are available for modification of starches is available, these are facing opposition from the health-conscious consumer in view of the hazards of using chemicals especially in food uses. So attempts are being made to modify starch at molecular level by using modern biotechnological tools. In addition to conventional methods by hybridisation of varieties, use of modern biotechnological tools can bring about starch modifications. Production of high amylose or high amylopectin starch by gene modification has been achieved in many crops, but very little progress has been made in the case of tropical tuber crops. Though commercial production of high-amylose or high amylopectin cassava varieties have not started, Visser and his group have made considerable progress in developing high amylose and high amylopectin cassava starch. It is hoped that this will be extended to other crops and soon they will also be available for exploitation.

It is also feasible to bring about other types of modification such as high phytoglycogen starches, changing the granule sizes, altering chain lengths and branching patterns and introduction of $\beta$-linkages in starch. These modifications are possible with the emerging new knowledge on the genes responsible for deciding these factors and new techniques available for gene modification. By applying these techniques it may be possible to produce starch with all desirable characteristics in the near future.
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