Chapter

Micrometrics and Morphological Properties of Starch

Omolola Temitope Fatokun

Abstract

Starch occurs in form of granules and constitutes a primary manner in which of carbohydrates are stored chiefly in seeds and underground organs and sparingly in other morphological parts such as leaf and bark parts of plants. Grains of transitional starch can be found in the stroma of chloroplast and cytoplasm in leaf parts when exposed to the sun and transferred to organs for storage at dark times. The shape and size, ratio of amylose and amylopectin content of starch grains are peculiar to different biological sources. A literature survey was carried out using various search engines. Journals were searched for using keywords such as microscopy, amylopectin, starch granules etc. The relative qualitative and quantitative properties of starches from various morphological parts of 35 species from 15 families were studied. The qualitative features of shape and size as observed from microscopy were not specific or peculiar to each genus and family as similar shapes and sizes cut across different species. Amylopectin and amylose contents varied considerably among all the species and can be used as one of the means of identification for medicinal plants and the delineation of plant species along with other genetic and physicochemical properties.

Keywords: starch, botanical source, morphology, microscopy, amylose, amylopectin

1. Introduction

1.1 Starch and formation of starch granules

Starch, a polymer of glucose which is a metabolite from photosynthesis constitutes a major stored form of carbohydrate found in seeds, roots, rhizomes and tubers. Amylopectin (α-amylose) and amylose (β-amylose) constitute over 80% of many starches. Amylopectin (α-amylose) has a branched structure while β-amylose consists of linear chains. β-amylose has a helical arrangement comprising of six glucosyl units and a diameter of 1.3 mm. The differences in the structure and proportion or amounts of amylopectin and amylose give starch grains different properties and add immensely to the distinctive properties of starch from various sources [1–9].

The ubiquitous nature of starch granules to makes the presence or absence it a less important parameter in the identifying and classifying or re-classifying species however, each starch granule has some properties that are peculiar enough to a species and can thus be used to identify such specie. Research toward identify marker patterns in morphology and physicochemical properties are ongoing to identify morphotypes that could possibly be of use taxonomically.

2. Botanical sources of starch

Starch is essentially sourced from plants with many species having from 2 to 12% starch content. The tuberic part houses most of the starch being a storage organ as in the tuber of *Ipomoea batatas* (Convolvulaceae) with 5–9% starch. Other morphological parts such as the wood and stem bark of *Rauvolfia serpentina* (Apocynaceae); unscraped rhizome of *Zingiber officinale* Roscoe (Zingibereceae) containing 5–8% of starch; bark of *Cinnamomum zeylanicum* Blume; flower bud of the *Syzygium aromaticum* (L.) Merr. & L.M. Perry (Myrtaceae); *Musa paradisiaca* L. (Musaceae) fruits; *Sorghum bicolor* seeds among others. Starch grains have been found in most plant families. The most widely exploited botanical source of starch in which various cultivars have been developed to give varieties with different starch characteristics range from seeds of *Zea mays* (Corn starch, amylomaize, waxy maize, etc.), seeds of *Oryza sativa* (rice starch), tubers from *Ipomoea* species and root of *Manihot esculentum* (cassava starch). Other common families are Euphorbiaceae; Zingiberaceae; Cycadaceae, Taccaceae, Bombacaceae, Lamiaceae, Menispemaceae, Combreaceae, Leguminosae and Curcubitaceae (**Table 1**).

2.1 Microscopy of starches

Starch grains are either simple or compound and the number of components present in each compound granule is usually described as 2-, 3-, 4- or 5- etc. Compound granules such as in rice and cardamom are in many cases formed by simple granules clumping together. Granules are formed in from the amyloplast and marked by the hilum. The hilum might be eccentric, mostly longer than being broad, central, open or closed. When starch grains are dry, fissures as seen to begin from the hilum (**Figure 1**). Under a microscope, the position and various forms of the hilum can be described as a round dot, simple, curved, punctate, stellate or multiple cleft. Sizes of grains of starch have been observed to range from small (2–10 μm), medium (10–60 μm) and large (extending to 200 μm usually from rhizomes and tubers) however small to medium sized grains are most common [1, 2]. Starch grains come in a wide range of shapes e.g. Regular disc, oval, elongated, rounded, kidney/bean shaped, spherical (e.g. as starch grains from roots of *Cassia sieberiana*; tapioca starch), polyhedral (e.g. starch grains from maize, wheat, rice, etc.) and irregular forms. Starches high in amylose content are many times more elongated and irregular [3]. Surfaces of starch grain also vary in ornamentation, smoothness, roughness, etc. Many layers built around the hilum, lead to the formation of the starch grain. Different types of fissures such as radial, asymmetric, transverse and reverse fissures are more conspicuous in larger granules (**Figure 1**) e.g. starch from *Ipomoea* species, faintly visible in medium sized granules e.g. wheat starch or not visible at all as observed with much smaller starch grains. The striations usually due to the daytime deposition of the starch give rise to differences in some properties such as the starch density, crystallinity and refractive index of the granules. In describing and characterizing starches from different sources, the absence or presence of hilum, form and position of hilum, singular/multiple features in texture, absence or presence of striations which are well defined, fissures, vacuoles, faceting, depressions are all important characteristics [4].

2.2 Properties of starch and the delineation of species

The qualitative and quantitative morphological, chemical and genetic properties are peculiar to the source of the starch some of these characteristics include size,

		Plant Part	Starch granules (µm)		Content (%w/w)	
Genus	**Species**		**Granular shape**	**Granular size**	**Amylose**	**Amylopectin**
FAMILY: **Zingiberaceae**						
Zingiber	*Z. officinale*	Rhizome	Oval to elliptical	4–50	22.2	77
	Z. montanum	Rhizomes	Round to oval	5–20	22.9	78
Curcuma	*C. longa*	Rhizomes	Oval, flat and triangular	20–30	22	77
	C. amada	Rhizomes	Oval to elliptical	10–30	23.5	75–77
	C. caesia	Rhizomes	Round to Oval	8–30	27.7	71–74
FAMILY: **Dioscoreaceae**						
Dioscorea	*D. rotundata*	Root tuber	Oval, round, polyhedral	18.5–45	29–30 [19]	69–72
	D. alata	Root tuber	Ovoid, oblong, round	21–39	23–24 [19]	66–68 [19]
	D. bulbifera	Root tuber	Triangular	33–49	16–19 [19]	83–85 [19]
	D. dumetorum	Root tuber	Polygonal	7	15–25 [19]	75–85 [19]
	D. esculenta	Root tuber	Polygonal	1–5	14.1–17.1	82–86
FAMILY: **Convulvulaceae**						
Ipomoea	*I. batatas*	Root tuber	Polygonal	1–100	28–30%	68–70%
FAMILY: **Euphorbiaceae**						
Manihot	*M. esculenta*	Root tuber	Round with a truncated end	5–35	29.5	70
	M. utilissima	Root tuber	Polygonal	3–28	26.2	73
	M. palmata	Root tuber	Round	5–13	22	78
FAMILY: **Poaceae**						
Hordeum	*H. vulgare*	Seed kernel	Round, oval	9–32	22–27	78–73
	H. spontaneum	Seed kernel	Polygonal	10–26	24–28	76–72
	H. bulbosum	Seed kernel	Round to oval	8–23	17–19	83–81

		Plant Part	Starch granules (µm)		Content (%w/w)	
Genus	Species		Granular shape	Granular size	Amylose	Amylopectin
FAMILY: **Musaceae**						
Musa	*M. balbisiana*	Fruit	Oblong shape	10–50	37.8 [20]	62.2 [20]
	M. paradisiaca	Fruit	Oval	9–25 [20]	24.85 [20]	75.15 [20]
	M. sapientum	Fruit	Elongated oval	15–55	22.89 [20]	77.11 [20]
FAMILY: **Liliaceae**						
Fritillaria	*F. thunbergii*	Bulb	Round [21]	5–30	26.4 [21]	73.6 [21]
	F. ussuriensis	Bulb	Round to elliptical	5–30	26.3 [21]	73.7 [21]
	F. pallidiflora	Bulb	Irregular [21]	5–40	29.8	70.2 [21]
	F. cirrhosa	Bulb	Irregular/polygonal	5–25	21.7	78.3 [21]
	F. hupehensis	Bulb	Oval	5–45	30.2	69.8 [21]
FAMILY: **Typhaceae**						
Typha	*T. latifolia*	rhizomes	Special /lenticular shape[7]	9 [22]	31.69 [22]	68.31 [22]
FAMILY: **Fabaceae/Leguminosae**						
Vigna	*V. unguiculate*	Seed	Oval to spherical [23]	7.91–15.5	39.09–42.78 [23]	58–62 [23]
	V. umbellate	Seed	Oval, round and elongated	7.50–13.2	32.8 [23]	67 [23]
	V. radiata	Seed	Oval, round to bean shaped	7–26	45.3 [23]	55 [23]
Pisum	*P. sativum*	Seed	Oval or spherical	2–40	33–48.8 [24]	50–67 [24]
FAMILY: **Nelumboleaceae**						
Nelumbo	*N. nucifera*	Root	Oval, round, elongated [25]	10.2–50.7 [25]	18.75–20.84 [25]	78–82 [25]
FAMILY: **Araceae**						
Colocasia	*C. esculenta*	Root	Angular and elongated	2	7.91%	82

Table 1.
Properties of starch across different genera.

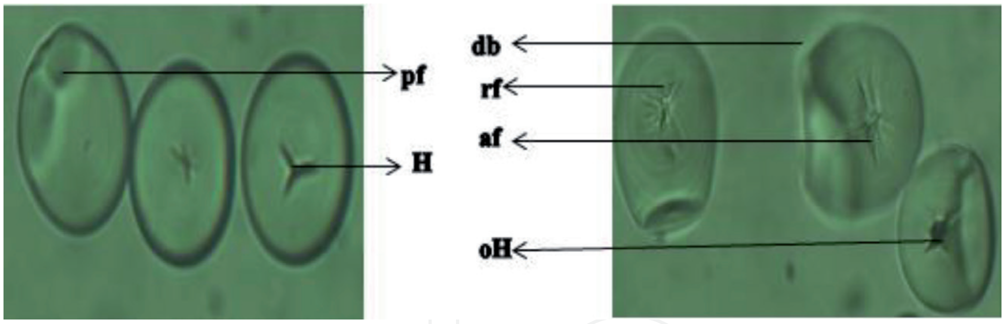

Figure 1.
Microscopy of starch grains from Cassia species (Leguminosae). H: hilum; oH: open hilum; af: asymmetric fissure; rf: reverse fissure; pf: pressure facet; db: double border.

shape, surface characteristics, gene expression, reaction with iodine, X-ray diffraction pattern and gelatinization.

2.2.1 Morphological and micrometric properties of starch granules

These properties as described earlier from the qualitative and quantitative microscopic shape and size of starch grains. Studies carried out from four (4) *Curcuma* species (*C. amada* Roxb., *C. aromatica* Salisb., *C. caesia* Roxb and *C. xanthorrhiza*) showed great variability in shape and size (**Table 1**). Granules from *C. aromatica* were the largest in size, showed surface ornamentation and varied with the rest of the species [5]. Earlier Scanning electron microscope (SEM) studies in different Curcuma species also report wide difference in the shape and size of starch grains. The rhizomes of some *Dioscorea* species viz.: *D. opposite* Thumb, *D. alata* Linn, *D. nipponica* Makino, *D. bulbifera* Linn, and *D. septemloba* Thumb showed some defining properties along the lines of morphological, crystalline and physicochemical properties [6].

The physiology of the chloroplast and amyloplast of a plant greatly influences the morphology of starch granules thus causing the size and shape of a granule vary considerably with the morphological source of starch e.g. from root or tuber or endosperm of seed or from stem bark; geographical distribution or differences in climatic conditions wherein the plant was grown [7–9]. An extensive study centered on the classification of 23,100 granules and morphological features from 22 orders and 31 families drew out marker morphometric properties based on size, psilate texture, faceting and other quantitative microscopic properties, that could possibly identify species within each family. Examples of such morphotypes are Conoid—cuneiforms or Obiculars, Pear Shaped—irregulars, Parabolic—Prism, Prism and Lobate Shell, Prismatic—Polygonal, Globular—Orbicular, Globular Trapeziform, Hemisphere—Orbicular, etc. Granules from various species from families such as Zamiaceae, Araceae, Nymphaeaceae, Taccaceae, Orchidaceae, Fabaceae, Dioscoreacea, Iridaceae, Fabaceae, Sapotaceae, Apocynaceae, Arecaceae among others were screened. Major observations were the absence direct morphometric markers within 14 of the 31 screened families. The study concluded that morphological parameters were not concrete enough to establish taxonomic identification [4]. Properties of starch grains such as size, structure and shape extracted from various plant sources differ only to a certain extent, such that starches from some different biological sources can be identified. However, the range of shapes and sizes of starch grains are often wide and cut across different granules from even the same source (**Figure 1** and **Table 1**). The variability is often as a result of differences in conditions such as climatic and/or geographic conditions, thus, features are not unique enough across all species in a family or genus. The degradative nature of starch within the tissues and storage organs at the point of seed germination, rhizome or tuber maturation, ripening of fruit or starch breakdown due to exposure to heat or chemical agents which causes it to loose textural, volumetric, and their morphometric properties, is another major factor that deters the use of micrometric parameters to classify species.

2.2.2 Physicochemical properties of starch granules

Starch grains vary in physicochemical properties. The variation in proportion of amylopectin and β-amylose present in starch granules contributes toward the slightly distinctive physical and chemical characters of starches from various biological sources. These characters often vary from species to species. In some species the amylose content increases as the granule develops or within different stages of granule formation for example the larger barley grains have higher amylose content than the smaller grains [3, 10, 11]. Pasting properties, reactions to stains, Thermal properties such as gelatinization temperatures and time and retrogradation differ between types of starch based on the amylopectin and amylose content. Increased amounts of amylose in starch, tends to raise gelatinization temperature of the starch [12, 13]. The length and degree of branching of amylopectin, lipid and amylose content of the starch grossly affects pasting properties. The swelling and pasting properties of starch are enhanced by greater amylopectin content while swelling is inhibited by a higher lipid and amylose content [14]. The viscosity of pastes from starch is also determined by the chain length of amylopectin and molecular size of amylose [15]. There are complex interactions that result in the pasting properties of starches due to the differences in structural features. An increase in pasting temperature, resistance to shear thinning of starch pastes from sources such as *Zea mays*, *Oryza sativa*, *Triticum aestivum* and *Hordeum vulgare* was observed to be due to amylose lipid complexes [16]. Some starch grains react to iodine potassium iodide differently. For example, potato starch stains purple, indicating a relatively high amount of amylose, whereas starch with very high amylopectin content, such as waxy maize and the tubers of Australian terrestrial orchids, turn to more red color when stained with iodine.

2.2.3 X-ray diffraction pattern

Native starches show three main patterns of diffraction when exposed to X-rays called type A, type B and type C, which are caused by differences in the crystalline regions of the amylopectin molecules [17] and which relate to botanical differences [3]. In general, cereal starches usually give the A-type diffraction, while tuber starches generally show the B-type pattern (although some tropical tubers have A-type starches) and some root and seed starches give the C patterns [18]. According to a study [6] on different starches also from Dioscorea species, *D. nipponica* starches displayed A-type of diffraction while starches from *D. opposite*, *D. alata*, *D. septemloba* and *D. bulbifera* exhibited the C-type of diffraction. The following degrees of crystallinity viz.: 33.90, 37.63, 43.11, 32.06 and 53.35% were obtained from the five species, respectively. The pattern of X-ray diffraction along with other physicochemical properties can serve as a distinguishing factor for starches from different sources.

3. Conclusions

It is pertinent to involve data from morphological, physicochemical, chemical and genetic features of starch granules to classify and delinate species to avoid discrepancies. In the identification of some species, some morphometric features are specific enough and marker worthy to identify these species however this will be specie specific and might not cut across the genus or family of the botanical source. The qualitative and quantitative morphological and physicochemical properties can be harnessed in the selection of starches from different botanical sources for different uses.

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Author details

Omolola Temitope Fatokun
Department of Medicinal Plant Research and Traditional Medicine, National Institute for Pharmaceutical Research and Development, Idu, Indsutrial layout, F.C.T., Abuja, Nigeria

*Address all correspondence to: omololafatokun@gmail.com

References

[1] Jane J, Kasemsuwan T, Leas S, Zobel H, Robyt JF. Anthology of starch granule morphology by scanning electron microscopy. Starch. 1994;**46**:121-129

[2] Sivak MN, Preiss J. Industrial applications of starch. In: Sivak MN, Preiss J, editors. Advances in Food Nutrition Research. Starch: Basic Science to Biotechnology. Cambridge, Massachusetts: Academic Press; 1998. pp. 163-170

[3] Buléon A, Colonna P, Planchot V, Ball S. Starch granules: Structure and biosynthesis. International Journal of Biological Macromolecules. 1998;**23**(2):85-112. DOI: 10.1016/S0141-8130(98)00040-3

[4] Mercader J, Akeju T, Brown M, Bundala M, Collins MJ, Copeland L, et al. Exaggerated expectations in ancient starch research and the need for new taphonomic and authenticity criteria. FACETS. 2018;**3**:777-798

[5] Sajitha PK, Sasikumar B. Qualitative and quantitative variation in starch from four species of *Curcuma*. Cytologia. 2014;**80**(1):45-50

[6] Jiang Q, Gao W, Shi Y, Lia X, Wang H, Huang L, et al. Physicochemical properties and in vitro digestion of starches from different *Dioscorea* plants. Food Hydrocolloids. 2013;**32**(2):432-439

[7] Singh J, McCarthy O, Singh H. Physico-chemical and morphological characteristics of new Zealand Taewa (*Maori potato*) starches. Carbohydrate Polymers. 2006;**64**:569-581

[8] Braga MEM, Moreschi SRM, Meireles MAA. Effects of supercritical fluid extraction on *Curcuma longa* L. and *Zingiber officinale* R. starches. Carbohydrate Polymers. 2006;**63**(3):340-346. DOI: 10.1016/j.carbpol.2005.08.055

[9] Zhang H, Zhang W, Xu C, Zhou X. Morphological features and physicochemical properties of waxy wheat starch. International Journal of Biological Macromolecules. 2013;**62**:304-309. DOI: 10.1016/j.ijbiomac.2013.09.030

[10] Kang MY, Sugimoto Y, Kato I, Sakamoto S, Fuwa H. Some properties of large and small starch granules of barley (*Hordeum julgare* L.) ends sperm. Agricultural and Biological Chemistry. 1985;**49**:1291-1297

[11] Tester RF. Starch: The polysaccharide fractions. In: Frazier PJ, Donald AM, Richmond P, editors. Starch: Structure and Functionality. London, UK: The Royal Society of Chemistry; 1997. pp. 163-171

[12] Galliard T, Bowler P. Morphology and composition of starch. In: Galliard T, editor. Starch: Properties and Potential. New York: John Wiley & Sons; 1987. p. 281

[13] Fredriksson H, Silverio J, Andersson R, Eliasson AC, Aman P. The influence of amylose and amylopectin characteristics on gelatinization and retrogradation properties of different starches. Carbohydrate Polymers. 1998;**35**:119-134

[14] Tester RF, Morrison WR. Swelling and gelatinization of cereal starches. Effects of amylopectins, amylose, and lipids. Cereal Chemistry. 1990;**67**:551-557

[15] Jane J, Chen JF. Effect of amylose molecular size and amylopectin branch chain length on paste properties of starch. Cereal Chemistry. 1992;**69**:60-65

[16] Jane J, Chen YY, Lee LF, McPherson AE, Wong KS, Radosavljevic M, et al. Effects of amylopectin branch chain length and amylose content on the gelatinization and pasting properties of starch. Cereal Chemistry. 1999;**76**:629-637

[17] Perez S, Imberty A. Structural features of starch. Carbohydrates in Europe. 1996;**15**:17-21

[18] Zobel HF. Starch crystal transformation and their industrial importance. Starch/Staerke. 1998;**40**:1-5

[19] Bolanle O, Mpoko B, Robert A. Physicochemical properties of yam starch: Effect on textural quality of yam food product (pounded yam). Journal of Food, Agriculture and Environment. 2011;**9**(1):145-150

[20] Otegbayo B, Lana O, Ibitoye W. Isolation and physicochemical characterization of starch isolated from plantain (*Musa paradisiaca*) and cooking banana (*Musa sapientum*). Journal of Food Biochemistry. 2009;**34**:1303-1318

[21] Shajun W, Jinglin Y, Wenyuan G, Jiping P, Yiugao Y, Peigen X. Characterization of starch isolated from *Fritillaria* in traditional Chinese medicine. Journal of Food Engineering. 2007;**80**:727-734. DOI: 10.1016/j.jfoodeng.2006.01.086

[22] Kurzawska1 A, Gorecka D, Błaszczak W, Szwengiel A, Paukszta D, Lewandowicz D. The molecular and supermolecular structure of common cattail (*Typha latifolia*) starch. Starch/Stärke. 2014;**66**:1-8. DOI: 10.1002/star.201300283

[23] Chavan U, Momin A, Chavan JK, Ryszard A. Characteristics of starch from rice bean (*Vigna umbellata* L.) seeds—A short report. Polish Journal of Food and Nutrition Sciences. 2009;**59**:25-27

[24] Stute R. Properties and application of pea starches. Part 1: Properties. Starch-Starke. 1990;**42**:178-184

[25] Syed A, Singh S. Physicochemical, thermal, rheological and morphologhical characteristics of starch from three Indian Lotus root (*Nelumbo nucifera* Gaertn) cultivars. Journal of Food Processing & Technology. 2013;**S1**:003. DOI: 10.4172/2157-7110.S1-00