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Review article

STARCH: AN OVERVIEW OF ITS CONVENTIONAL AND UNCONVENTIONAL SOURCES, PHARMACEUTICAL AND INDUSTRIAL APPLICATIONS

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Abstract

Starch is a naturally producing powder or polymer which has broad range of application in the field of pharmacy, food and beverages industry, cosmetic industry, etc. It works as an energy store for the both plants and animals. Starch is the main storage polysaccharide deposited in the seeds, tubers, roots, stem pith of plants which occurs as tiny granules of size ranging from 1 to 100 microns and shape of the granules are plant species specific. Industrially, starch is obtained from cereal grains such as wheat and maize (corn), or from tubers, such as potatoes, tapioca, and arrowroot, or from the pith of the sago plant. Different procedures are used to extract starch from different sources primarily determined by the source of the starch and its intended usage. Starch extracted from different sources has different properties according to their sources because of which they have different functionality properties so rather than using only conventional sources studies are going on to use unconventional sources, so new botanical sources like mango, jackfruit, litchi, longan, loquat, banana, rhizomes of turmeric (Curcuma longa), African arrowroot (Canna edulis), Canna indica), Tiger lily (Lilium lancifolium) bulb gaining momentum as unconventional sources of starch, raising their commercial importance. Starch is having the internal properties that are appropriate for pharmaceutical use. It is also used in a wide range of specialty drug delivery applications, such as delivering of complex molecules and targeting specific areas of the body. This article is aiming to explain about sources, origin, modern applications and worldwide industrialization of starch.

Keywords: Starch, Conventional Sources, Non Conventional Sources, Applications, Industrialization

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Introduction

Starch is a powder or polymer which is produce by plants or animals naturally. It works as an energy store for the both plants and animals. The starch present in the animal is known as glycogen. Actually starch is the main storage polysaccharides deposited in the seeds, tubers, roots, stem pith of plants which occurs as tiny granules of size ranging from 1 to 100 microns and shape of the granules are plant species specific [1]. Starch is made up of two polymers, namely amylose and amylopectin. Amylose is a chain structure where glucose molecules joined by α-1, 4-glycosidic bonds which composed of open chains of 100 or more glucose members. Amylopectin is a branched structure where glucose molecules joined by β-1, 4-glycosidic bonds which composed of unit chain of about 20 glucose residues.

In the field of pharmaceutical starch is becoming more valuable substance because of its many advantages, such as it is versatile and inexpensive polysaccharide which has received great attention in drug delivery applications as they are hydrophilic, biodegradable, and biocompatible with tissue and cells [2]. In pharmacy starches are used as binding agent, diluents, disintegrating agent etc. and with its advantageous nature they are now used in the field of nano drug delivery system. Starches are extracted from different sources. Conventional sources of starch include sources like cereal corps and legume seeds, tuber crops, and some root tubers [3- 6]. Due to unbelievable increasing demand for starch some nonconventional starch resources have been investigated in recent Years. Testing and experiments are going on to characterize the property of the starches extracted from unconventional sources or from new different sources. Normally starch from maize, potato, wheat, rice, sorghum is used in large amount in the field of pharmacy.

Conventional sources of starch

Industrially, starch is obtained from cereal grains such as wheat and maize (corn), or from tubers, such as potatoes, tapioca, and arrowroot, or from the pith of the sago plant. By far, the larger part of the starch is obtained from maize, wheat, potato, and tapioca. Starches from the different sources have different properties that affect their functionality (Table1) and, therefore, it is in their end-of-use. In India only starches from maize and tapioca are produced in a significant amount [1]. Starch is the polysaccharide which is the second most important renewable resource in terms of availability after cellulose; worldwide production of starch is more than 50 million ton per year [8]. Starch is present in almost all the tissue such as leaves, roots, tubers, seeds, stems, flowers, etc. of green plants however there are some plants which are grown commercially for the starch which includes cereal such as wheat, corn, sorghum, and rice, tuber mainly potato, root like tapioca and arrowroot, stem of sago, and legume crops mainly pea. Worldwide production of starch is depending on the use of cereals as the raw materials. Corn or maize is the main crop which supplies around 80% of the global starch market conquering the title of world largest industry situated in U.S. [7].

Different procedures are used to extract starch from different sources primarily determined by the source of the starch and its intended usage. In addition to the commonly employed wet milling method, the use of several solutions and the enzymatic treatment method is used for protein removal and recovery of starch. A lower degree of starch degradation is associated with the enzymatic treatment method, while, the addition of several alkalis like sodium hydroxide and sodium dodecyl-sulfate in the steeping medium increases the starch damage. Ultimately, each approach has benefits and drawbacks; therefore, it is critical to select an accurate method with high starch yield and purity.

Origin of starch

Starch extraction was first described in the natural history of Pliny the Elder, around AD77-79. [9]. Around 30,000 years ago Starch grains from the rhizomes of *Typhus cattails*, *Bulrushes cattails*, was used as flour in certain grinding stones, in Europe as early as 30,000 years ago [1]. Starchy grain sorghum has been discovered, in the Ngalueh Cave, Mozambique dating back up to 100,000 years ago. Ancient Egypt Pure extracted wheat starch paste was used may be to glue papyrus [9]. The Romans also used it in cosmetic creams, to powder the hair and to thicken the sauces. Persians and Indians used it to make dishes similar to gothumi wheat halva. Rice starch as a paper surface coating has been used in paper production in China since 700 CE [12].

Corn or maize starch

Corn or maize was 1st grown in Central Mexico and they have been cultivated for more than 5000 to 7000 years. Modern varieties of corn are different from the earlier one or the first corn which were produce through mutation, hybridization, and random and conscious selection. Among the corn varieties existing today like popcorn, sweet corn, dent corn, flint corn, and flour, dent corn is mostly used in production of starch because of their availability at law price, their storability and their high starch content (70-73% per weight). In 1884 commercial productions of maize started and a small plant was established in Jersey City, N.J., U.S.A., and in Columbus, Ohio, U.S.A. A larger plant was built in Oswego, N.Y., U.S.A. in 1888 and since then the manufacturing technology of starch from maize was steadily improved representing the dominant raw material for starch manufacture. U.S.A. is the largest producer of maize starch worldwide hence most of the development took place here. There are different kinds of process for the manufacturing of starch from maize but most commonly used and most preferable process is wet milling which has been used since then.

Sorghum starch

Another major cereal crop is sorghum (*Sorghum bicolor*) which is also known as Milo. It was probably cultivated 5000-7000 years ago in eastern Africa. It is a major cereal crop contains 71.2% of starch and same as corn in general composition but sometimes it is considered as inferior as corn starch in case of food, feed and industrial uses. In comparison to corn, sorghum can be effectively grown in more arid region and it can be milled in similar process. Sorghum starch has many properties which are same as corn starch and extraction process of sorghum starch is similar with the extraction process of corn starch i.e. wet milling.

Wheat starch

Wheat cultivation was probably started in the Middle East and it has been grown by man for 8000-9000 years. In 1500s Commercial production of wheat starch Started in England .Wheat is mainly harvested by mechanical means, starch is isolated by using several processes such as the Martin process, the Batter process, the Fesca process, the ammonia process, the acid process, wet wheat milling, whole wheat fractionation, the Rasio process, or the Hydroclone process. The first two of these processes are use more often. Wheat has 60%-70% starch on a whole seed basis. In 1835 the martin process was used first and uses wheat flour as its raw material. Starch extracted from the wheat is the co product of vital gluten (the main protein of wheat) present in the wheat. Due to change in the agriculture market of Europe in seventies wheat emerged as significant sources of starch in Europe. Terrified made the import of maize and hard wheat (containing 17% gluten) too expensive so to make European soft wheat (containing 8-9% gluten) and to fortified with vital gluten, the demand for availability of vital gluten was increased which leads to the increased availability of the wheat starch in the Europe and made Europe largest producer of vital gluten as well as wheat starch in the world.

Rice starch

Rice *(Orziya sativa)* has been used in the Asian country since ancient time. It is the main food of Asian countries. There is different variety of rice available so depending upon the variety of rice the quality of rice starch changes according to the character or properties of the rice. Rice is a small grain consisting of an edible grain (caryopsis). The outer fibrous layer of rice grain is covered with starchy endosperm and the germ. The outer layer that is endosperm contains mainly the starch granules around 60-65%and protein bodies. For isolation of starch generally rice powder (after dehulled and blending) are treated with 0.1-0.5% sodium hydroxide for 24-48 hrs to remove protein part. The rice starch slurry after removing protein part are further isolated by centrifugation washing and dried. Generally rice starch is used in a little amount because of their high cost of production in comparison to other commercial starches.

Potato starch

Potato starch is extracted from the tubers of *Solanum tuberosum*, which was first cultivated around ad 200 in Peru. And it is mainly produced in Europe especially in the Netherlands and Germany [1, 8]. Potato starch manufacture is regulated by subsidy system and around 25% of starches produced in Europe are produces from potato. About 1.7 million ton of potato starch spread over several Europeans countries which are offered by regulation to the subsidiaries. Potato starch is isolated from cull potatoes, surplus potatoes and waste streams from potato processing. However, there are special cultivators developed for starch production. The tubers generally contains 65–80% starch. A large amount of potato starch is used to compress commercial soup, and pre-gelatinized starch is useful in instant pudding. Other use of starch contains pie fillings, sweets, chewing gums and extrusion cooking etc.

Tapioca starch

Tapioca starch is produced from the large tuberous root of cassava plat (*Manihot utilissima*, *Manihot esculenta)* grows in many equatorial regions. Cassava roots are may be sweet or bitter depending upon the presence of hydrogen cyanide per kilogram of fresh root. Sweet root vanities are used for food purposes while bitter varieties are used for industrial uses and in both cases hydrogen cyanide level is lowered to acceptable ranges during processing. In some Asian countries a commercial product of tapioca starch is available which is known as ‘sago’ and this product has no relation with the original sago starch. Sago produced from tapioca contains 24% of starch and this starch contains 0.5-1.00 mm diameter long starch pearls which are made from the extracted tapioca starch cake. Tapioca starch is mainly produced in southern Asia, Brazil, and India and in India 50,000 million ton of the tapioca starch produced is converted in to “sago” pearls [1]. In India most of this starch is produced in Salem district of Tamil Nadu. Manufacturing process of potato and tapioca starch is almost similar though there is difference in the details.

Sago starch

Sago starch is derived from the stem of palms (principally *Metroxylon spp., Arenga spp.,* and *Maurilia spp)* which are eight or more years old. In regard to sago production, currently Malaysia is the third largest sago producer in the world after Indonesia and Papua New Guinea which combined produce approximately 94.6 % of the world production. Indonesia, the biggest producer of sago starch in the world, produces 585,093 tons per year [13]. One palm trunk can yield 90–180 kg of sago starch; the granules of sago starch are large containing 20-60mm diameter. Sago starch is used in foodstuffs or in textile sizing and adhesives. They are produced manually in home and commercially production of this starch is almost same as household method though they used machines in some steps.

Arrowroot starch

Arrowroot starch is produced from the square root of a tropical perennial plant *Maranta arundinacea*. The roots are harvested after 6 to 12 months of cultivation, and able to contain more than 20% of the starch, the majority of which has been extracted in the same manner as the tapioca starch. The difference in processing between the two roots is that arrowroot requires more washing than cassava. This starch of the arrowroot is mainly produce in China, Brazil, India and Saint Vincent in the West Indies. It is a thickening agent used to add texture and structure in cooking and baking application.

Pea starch

Pea starch is extracted from the genus *Pisum sativum*. It is produced by all over the world with many other names such as field pea, garden pea, green pea, yellow pea, smooth pea, wrinkled peas, etc. Canada is the world's largest producer by producing 25% of the total pea and it exports 40% of the total number of peas. France produces approximately 17% of the total pea starch production. Pea starch is the cheap source of starch as compared to the corn, wheat, potato starch as they are by product of protein extraction. Due to its poor functional properties their use in food is limited but they are used effectively in industrial application. Starch extraction from green peas is very difficult due to the presence of a non-soluble flocculent proteins, and fine fibers. Pea starch is isolated with the aid of water-based methods, as well as the dry methods (pin milling and air classification) and most commonly used commercial method of pea starch isolation is air classification.

Non-conventional sources of starch

Starch derived from different sources exhibits different physicochemical properties. And, these physicochemical properties determine the application of starch in a different field. So, there is a growing interest for novel and unique starch sources [14]. New botanical materials are gaining momentum as unconventional sources of starch, raising their commercial importance and, as a result, providing a higher demand for starch with novel and unique characteristics to replace traditional starch sources. With the development of food and other industries, these non-conventional sources of starch have been investigated deeply in recent years. Some of the unconventional starch sources are shown in Table 2.Because of their high level of starch, mango, jackfruit, litchi, longan, and loquat fruits starch has been explored as a source for starch production among the starches acquired from fruits. Guo K. [15] in their study, isolated starch from kernels of mango, jackfruit, litchi, longan, and loquat fruits and investigated the structural and functional properties (Table 2). Availability of 64, 56, 53, 59, and 71 % starch, respectively, in the five fruit kernels, indicates that they are good sources of starch. The starches were spherical, elliptical, and irregularly shaped with varying sizes containing approximately 25% amylose. Mango, jackfruit, and longan starches displayed A-type crystallinity whereas litchi and loquat starches showed C-type crystallinity. Significant differences were also observed in enthalpy, gelatinization temperature, viscosity, crystalline lamellar intensity, and susceptibility to enzyme hydrolysis [15].

Banana starch has been suggested as a promising source of starch, because of its high content of starch, approximately 69.5% and 22.6% in dry flesh and peel, respectively. The starch had irregular and oval-shaped granules with eccentric hila. Both flesh and peel exhibited B-type crystallinity with similar lamellar structures and relative crystallinity. Banana starch is also renowned for being a good source of indigestible carbohydrates. For native starch, the contents of rapidly digestible starch, slowly digestible starch, and resistant starch of flesh and peel were 1.7 %, 4.3 %, 94.1 %, and 1.4 %, 3.4 %, 95.2 %, respectively, and 73.0 %, 5.1 %, 21.9 %, and 72.3 %, 4.5 %, 23.2 %, respectively for gelatinized starch [17]. Banana starch isolation typically generates 70% starch with 94% purity. However, as starch purity is linked to the development of the fruit, it is more closely linked to the degree of ripeness than to the process of starch extraction[18].

Huang J. [16] isolated starch from the rhizomes of *Curcuma longa*, *Canna edulis*), *Canna indica* and *Lilium lancifolium* bulb and compared the structural properties (Table 3). They observed variations in the structural and functional properties of the isolated starch. The isolated starches were different in morphology and size. *C. edulis* starch with the largest granule size had the highest breakdown viscosity, pasting peak, and swelling power. While *C. longa* starch with the smallest granule size possessed very high resistance to hydrolysis and digestion. A high content of amylopectin long branch chain and low content of amylopectin short branch chain was observed in *C. longa*.. The *L. lancifolium* starch possesses low resistance to gelatinization, digestion, and hydrolysis. X-ray diffraction pattern revealed the B type crystallinity of all the isolated starches [16].

The non-conventional sources of starch have been less utilized. So, it's critical to make use of these underutilized starch sources for a variety of food and non-food uses. Also, it will be beneficial to improve the economic worth of underutilized starch sources by isolating starch from non- conventional sources. Because starch has a longer shelf life, post-harvest losses are avoided, and these starches can be used to generate a variety of innovative products [19].

Application of starch

Starch has the internal properties that are appropriate for pharmaceutical use. It is also used in a wide range of specialty drug delivery applications, such as delivering of complex molecules and targeting specific areas of the body. While there are several official native starch carriers with different identities, new sources are available that will continue to grow with the political, economic, and scientific interest in starch and starch-based products. The size of the starch granules on the functional application is important for starches. Taking for example the rice starch grain is among the smallest in size which make it a desirable candidate to be used in both medicated powders and cosmetic powders for topical use. Due to the small size of starch, it can be used as an absorbent of oil from the skin; hence it is suitable as excipients in dry shampoo and also as a lubricant in some diagnostic and surgical materials. Starch or starch-based as excipients have been revealed to offer several advantages in drug formulation and production in terms of the product safety lower in cost, and quality of product. The starch has been used as binder, diluents, disintegrant, lubricant and glidant in granules, capsules, and in tablet formulation [21].

Diluents

As a diluent, the starch provides mass to solid formulations that contain a small dose of the active ingredient and are added to become a fundamental part of the formulations like granules, tablets, and capsules. They have been utilized for the planning of normalized pulverizes of colorants and strong medications, and to work with blending and taking care of. Local starches are insoluble diluents and have certain attractive characteristic properties like the shortfall of hazardous collaborations with most normal APIs and excipients, the shortfall of physiological and pharmacological exercises just as reliable physicochemical and utilitarian properties. Local starch is modest, but arediluents that will rely upon such factors as the relative focus, plan strategy and the properties of the APIs, and other excipients that will be utilized [21].

Disintegrant

The most popularly used disintegrating agent in the formulation of tablets and capsules of branded and generic medicine is starch. Since starch is a hydrophilic substance which absorb water and leads to swelling and hence break the tablet into smaller fragments for drug release. As a disintegrant, local starch is utilized inside the scope of 3–25% w/w of the granules' or tablets' weight, an ordinary fixation is 15% w/w. During the formulation of granule, ideal disintegrant action is obtained when a part of the starch is used for the mixture of granules as endo-disintegrant while the other half is joined straightforwardly into the dried granules as exo disintegrant[22].

Binders

Starch is dispersed in water and when heat is applied to it, starch gel is formed which can be used in tablets and capsules as a binding agent to the other excipients holding them together to form granules by using the wet granulation technique. The major contributions of wet granulation using starch as binder is by providing ingredient homogeneity, compaction enhancing, powder density and flow enhancement, dust reduction, drug release adjusting, and provides required tablets and granules form[23]. From all the known approved starches, corn starch is the most commonly used in the formulation technology of granules and tablets but new studies have shown that the novel or modified starches are potential binders and may possibly be used as a replacement for corn starch[21]

Glidant

Starch a hydrophilic glidant can be used in the conventional capsules and tablets formulation with a concentration of 2-10 % w/w to reduce the inter-particulate abrasion and provides a better powder and granules flow. Different types of starch like Maize starch are mainly used as a glidant in capsules and tablets formulation, and starch from yam, cassava, and fonio have shown to be a potential glidants in the formulation of tablets. The flow rate, angle of repose, and flow factor are the properties of starch as a glidant that is evaluated in pharmaceutical powders and granules [24].

Lubricant

Lubricants are excipients that are added typically in little amounts to powders and granules during tablets and capsules formulation to decrease the interfacial friction between the die walls and the tablet's surface needed in ejection, prevent sticking of the granules and tablets to the punch. The concentration of starch is 2-10 % of the granules and powder weight. When starch is to be used as a lubricant in tablets and capsules formulation, enough trials need to be done to acquire an optimized concentration as starch can cause alteration in the flow and compaction of the mixed powder. Maize starch BP is commonly used as a lubricant, having dual mechanism like increasing the powder flow, prevents sticking of the tablets and granules to the die walls and punches[25].

Novel applications

As a novel application, starch has been used as a drug carrier for controlled drug delivery. As starch is composed of amylose and amylopectin, it can be used as a coating or film forming polymer which makes it compatible for target delivery and control the release of drug from the system due to its mucoadhesive properties. Studies on maize starch has been evaluated as an effective film coat for tablets which retards or slow down the dissolution rate and confer controlled drug release and the starch coating can also be used in the matrix system and nanoparticles to carry the drug to the specific sites like the lungs, colon, and to target cancer cells [26,27]. To improve the starch in film-forming, it can be combined with other polymers such as chitosan, sodium alginate, and PVP.
The use of starch as a coating polymer has made it to be used in delivering of drugs through microspheres system. The properties for starch as microspheres in the effect of cross-linking are the particle size increase with the increase in the time of cross-linking which will increase the concentration of drug loading, the particles swelling ratio was a function of the type of cross linker and not of the cross linking time [28]. The cross-linking of starch can also be used in the targeting drug delivery system of protein drug matrix that is used in the targeting of drug to the colon. This is done by double modification of cross-linking the pregelatinized maize starch along with POCl3 which will decrease the enzymatic degradation and can be used as a potential drug carrier to target the colon. The resistant starch shows similar release of drug and it is envisaged to be resistant to the amylase enzyme in the intestinal wall, without the formed nanoparticles fast release of drug is shown when compared to the conventional or native starch. When the branch is reduced, it implies an idyllic precursor for directing ligand conjugation in design of oral colon-specific nano-particulate drug carrier [29].

The starch nanoparticles can be prepared by different methods like cross-linking microemulsion, ultra-sonication, nanoprecipitation, acid hydrolysis, recrystallization, and enzymolysis [30]. Starch-based nanoparticles have been utilized for the transdermal drug delivery of the medications like testosterone, flufenamic acidand caffeine. The skin penetration information for the three medications recommends that starch nanoparticles have the potential for transdermal medication delivery applications. Exemplification and delivery properties of these nanoparticles were considered, showing high epitome effectiveness for these three tried medications (testosterone, flufenamic acid, and caffeine); likewise, a near straight delivery profile was noticed for hydrophobic medications with an invalid starting burst impact [31-37].

Conclusion

Starch is a naturally producing powder which has broad range of application in the field of pharmacy, food and beverages industry, cosmetic industry etc. it extracted from different kind of sources where cereal crops like maize, tapioca, rice, wheat plays an important role. It also extracted from tubers like potato, roots like arrowroot, stem like palm stem. Starch extracted from different sources has different properties according to their sources because of which they have different functional properties so rather than using only conventional sources study are going on to use unconventional sources. New botanical materials are gaining momentum as unconventional sources of starch, raising their commercial importance and, as a result, providing a higher demand for starch with novel and unique characteristics to replace traditional or conventional starch sources. With growing demand of starch in different industries the production of starch also increases globally. Largest producer of starch is China and U.S. who shares 30% of total world market. European Union shares 14% of total market. In case of starch production, India has lowest value in production as compared to China, US, EU, Thailand, although India produces a larger amount of corn starch. India holds second position in production of rice but production of rice starch is very little in India because of its hard extraction process and poor yield of starch. In pharmacy starches are conventionally used as diluent, disintegrant, lubricant, binders, and glidants. But now a day they are also used in drug delivery system. With emerging properties they are now entered to the field of nanotechnology. They are wildly using for controlled release of drug and targeted release of drug.

Table 1: Proximate physicochemical and functional property of starch extracted from conventional Sources.

Avg*- Average

Property	Corn starch	Sorghum starch	Wheat starch	Rice starch	Potato starch	Tapioca starch	Sago starch	Arrowroot starch	Pea starch
Morphology	Polyhedral, A-type crysta	Oval or semi spherical, A type	Spherical, A type	Polyhedral C-Type	Oval, B-type crysta	Small round, C-type crystani	Oval, C-type crysta	Irregular or predominant oval	Oval, C-typ

	nility	crystanility	or B type crystanility	crystanility	nility	lity	nility	shape C-type crystanility	e crystanility
Starch Content (per weight)	70-73%	71.2%	60-70%	60-65%	65-80%	15-33%	>80%	>99%	53.61-57.23%
Amylose Content	24-28%	25.5%	24-28%	<5% to >24%	20-23%	17-20%	21.4-30.0%	>40%	35-39%
Granule mean diameter in µm	2-32, 13.5 Avg*	5.5-30, 15.5 Avg*	2-45, 20 Avg*	2-20, 5 Avg*	10-100, 46 Avg*	5-35, 13 Avg*	10-15,	29-126, 57 Avg*	5-90, 30 Avg*
Gelatinization Temperature (^{0}c)	62-72	68-78	51-60	68-78	60-65	67-70	69-71	63.94	62
Moisture Content	12%	25%	13%	14%	18%	10-13%	3-14%	12-13%	14%
Swelling Temperature (^{0}c)	64	60	55	72	63	60-90	18-22	60	60
Reference	[56]	[57]	[56]	[56]	[56]	[58, 59]	[60]	[61]	[56]

Table 2: Proximate physicochemical and functional property of starch extracted from Mango, Jackfruit, Litchi, L0ngan, loquat, banana.

Property	Mango starch	jackfruit starch	Litchi starch	Longan starch	Loquat starch	Banana starch

Granule Shape	elliptical, spherical or dome-shaped, A-type crystallinity	irregular, truncated, spherical, A-type crystallinity	Round to oval, C-type crystallinity	oval or irregular, polygonal, A-type crystallinity	irregular, truncated, spherical, C-type crystallinity	rod shape, irregular oval, B-type crystallinity
Starch Content (per weight)	64%	56%	40.7%	59%	71%	81.71-89.62%
Amylose Content	32.14%	24.1-26.4%	24.1-26.4%	24.1-26.4%	10.53-45.69%	23.10-32.05%
Granule size mean diameter in µm	7.98-36.48, 15 Avg	7-11%, 10 Avg	3-10, 6.5 Avg	<20	29.05-43.66Avg	21-24
Gelatinization Temperature (^{0}c)	77.9-88.8	84.2-92.0	73.3-82.6	71.9-83.5	59.4-75.9	62.08-87.99
Moisture Content	9.95%	6.28-9.02%	0.48-1.62%	72.3-83%	7.36-8.29%	9.53-11.8%
Swelling Temperature (^{0}c)	80-95	85	60-90	70-85	65	85-95

Reference	[62]	[63]	[64]	[65]	[66]	[67,68]

Avg*- Average

Table 3: Proximate physicochemical and functional property of starch extracted from *Curcuma longa* *(C. longa)*, *Canna edulis* *(C. edulis)*, *Canna indica (C. indica)*, and *Lilium lancifolium* (*L. lancifolium)*.

Property	***C. longa* starch**	***C. indica* starch**	***C. edulis* starch**	***Lilium lancifolium* starch**
Starch Morphology	flaky triangular shape, B-type crystallinity	elliptical shape with different sizes, B-type crystallinity	rounded and oval-shaped, B-type crystallinity	Triangular, elliptical or nearly round, B-type crystallinity
Starch Content (per weight)	45.24-48.48%	24%	70-80%	69.07%
Amylose Content	29%	25.0%	25.2%	28.17%
Granule size, mean diameter in µm	18.6	31.8	41.4	24.4
Gelatinization temperature (^{0}c)	12.1-72.9	15.0-60.6	13.9-60.0	8.8-60.2
Moisture Content	15.02%	10.08%	18.17-27%	-
Swelling Temperature (^{0}c)	75-95	65-80	65-85	65-70
Reference	[16]	[16]	[16]	[16]

Conflict of Interest

The authors declare no conflicting interests.

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