New Starches are the Trend for Industry Applications: A Review

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Abstract  Starch is widely consumed by humans as an inexpensive and stable available carbohydrate source, and much work has been performed on the structure, functionality and applicability of starches. Although conventional sources of starch, such as corn and potato, other sources with improved properties are becoming significant to allow simpler and more robust processes. The feasibility of the use of new starches, i.e., legume, seed and palm, as renewable materials for commercial application may provide cost reduction of raw material in industries. Little information is available on the structure, properties and practical applicability of non-conventional sources of starch. Thus, it is necessary that these starches be studied to obtain and report their structural parameters, information that is required to gain competitiveness in an international-scale industry. A review of properties, applications, future trends and perspectives of some new starches is presented in this review.

Keywords  New starches, Non-conventional starches, Turmeric, Annatto

1. Introduction  Most foods are multi-component systems that contain complex mixtures of water, carbohydrates, proteins, lipids and numerous minor constituents. Starch is a macro-constituent of many foods, and its properties and interactions with other constituents are of interest to the food industry and for human nutrition.

Sales of starches and derivatives were $51.2 billion in 2012 and are expected to reach $77.4 billion by 2018, a compound annual growth rate (CAGR) of 7.1% between 2012 and 2018 [1]. Indeed, the starch derivative market is expected to grow extensively at a rate of 6.2% from 2014 to 2019 because of the technological advancements occurring in the industry [2].

Starch application in industrial-related products dates back to ancient times [3]. For industrial uses, the selection of a starch is made by considering its availability and also its physicochemical characteristics, which vary depending on the source [4].

The inherent functional diversity of materials extracted from different biological sources adds to the range of applications. Currently, some uses of starch include the following: as a food additive to control the consistency and texture of sauces and soups, to resist the breakdown of gel during processing and to increase shelf life of an end product in the food industry; in the laundry sizing of fine fabrics and skin cosmetics in the textile and cosmetic industry; for enhancing paper strength and printing properties in the paper industry; as drug fillers in the pharmaceutical industry; as binders in the packaging industry [3].

Globally, intensive efforts have been channeled toward producing polysaccharide derivatives of different types of starch for diverse applications in different industries [5]. The widespread use of starch is justified because it is inexpensive and available in large quantities. In addition, it is relatively pure and does not require intense purification, as is often the case with other natural polymers such as cellulose and gums [6].

Commercial starches are obtained from cereals, such as corn, wheat and various types of rice, and from tubers or roots, such as potato and cassava (or tapioca) [7]. The main botanical source of starch is maize, accounting for about 80% of the world market. Maize starch is an important ingredient in the production of foodstuffs, and has been widely used as a thickener, stabiliser, colloidal gelling agent, water retention agent and as an adhesive [8].

The use of new starches, i.e., starches from non-conventional sources such as those isolated from roots and tubers could provide options for extending the spectrum of desired functional properties, which are needed for added-value food product development [7].

With the industry demand for new technological properties, several non-conventional starch sources, with different properties have been studied due to interest in using native starches for food production instead of using chemically modified starches [9]. Currently, these native...
starches are usually ignored and wasted during the isolation and separation of small molecule bioactive ingredients [10].

A large number of scientific investigations concerned with the use of starch have been published to date. Table 1 shows the literature searched in the “Scopus” and “Web of Knowledge” databases using the keywords “starch”, “food” and “processing”.

Table 1. Number and type of documents published in the Scopus and Web of Knowledge databases between 2010 and 2014

| Year | Scopus | Web of Science |
|------|--------|----------------|
| 2014 | 85     | 112            |
| 2013 | 153    | 185            |
| 2012 | 154    | 189            |
| 2011 | 154    | 205            |
| 2010 | 147    | 183            |

A comprehensive study on the relationship between the structural characteristics and functional properties of starches from different sources could provide important information for optimizing industrial applications.

Much work was done for a better understanding of the new starches characteristics. This review summarises some of several non-conventional sources of starch, in terms of properties, applications, future trends and perspectives, to provide a greater range of options for increasing the use of these new starches.

2. Classification

Starch can be divided into three categories based on its nutritional classification: rapidly digestible starch, slowly digestible starch and resistant starch. Resistant starch is not digested in the small intestine and enters the colon for fermentation [11].

The starch molecule can be extracted and sold as such (native starch), but it can also undergo several processing operations to improve its properties and enlarge the range of its uses (modified and hydrolyzed starches).

Native starch is the starch chain extracted from raw material in its original form. Modified starches are starches that are modified by a chemical, physical or enzymatic process. Hydrolyzed starch is the starch chain broken into smaller glucose chains via a hydrolysis reaction.

Native starches has limited application in industry because it exhibits some disadvantages such as a low shear resistance, high retrogradation and syneresis, and it is often modified by physical, chemical or enzymatic processes or a combination thereof to provide desirable functional properties for determined uses.

Physically modified starch can be considered as a natural material and a highly safe ingredient [12]. Nevertheless, the commonly used ways of obtaining modified starch are complex, expensive and time consuming [13, 14] and frequently employ treatments with hazardous chemicals.

Many industrial applications require the modification of native starches, including oxidation, esterification, hydro-xymethylation, dextrinization and cross-linking. These modifications overcome the limitations of native starch properties (e.g., stabilizing the polymers against severe heating, shear, freezing or storage).

Such modified starches have innumerable applications in the food industry, particularly in confectionery and bakery processes for thickening and emulsification, and in non-food sectors as adhesive gums, biodegradable materials and sizing agents in the textile and paper industries [15].

3. Properties of Starch

Starch is composed of two different glucan chains, amylose (a linear polymer of α-D-glucose units linked by α-1,4 glycosidic linkages) and amylopectin (a branched polymer of α-D-glucose units linked by α-1,4 and α-1,6 glycosidic linkages), representing approximately 98–99% of the dry weight [16]. These polymers have the same basic structure but differ in their length and degree of branching, which ultimately affects their physicochemical properties [13].
Starch varies greatly in form and functionality between and within botanical species and even from the same plant cultivar grown under different conditions. This variability provides starches of different properties, but it can also cause problems in processing due to inconsistency of the raw materials [19].

Figures 2 and 3 deal with structure and whole raw material between two plants that represent common and uncommon sources of starch, respectively.

Physicochemical (e.g., gelatinization and retrogradation) and functional (e.g., solubility, swelling, water absorption, syneresis and rheological behavior of pastes and gels) properties determine the potential uses of starches in food systems and other industrial applications.

These properties depend on the molecular structural composition of amylose and amylopectin; how they are arranged in starch granules plays an important role in formulations. In food products, the functional roles of starch could be as a thickener, binding agent, emulsifier, clouding agent or gelling agent.

Another important material property of starch is its glass transition, in which the molecules in the amorphous fraction of starch transform from a frozen to a mobile state. Glass transitions of starch have been measured using, e.g., differential scanning calorimetry (DSC) [21]. DSC is one of the most suitable techniques that enable accurate determination of the temperature at which state changes occur in biopolymer systems [22].

The most important physical changes that occur during the industrial processing of native starches are the swelling of the granules upon heating in an excess of water and the subsequent solubilization of amylose and amylopectin (‘gelatinization’). Amylose diffuses out of the swollen granule and, upon cooling, forms a continuous gel phase. Swollen amylopectin-enriched granules aggregate into gel particles, generating a viscous solution. This two-phase structure, called starch paste, is desirable for many applications in which processed starches are used as thickeners or binders. Native starches have few other uses because the polymers are relatively inert [15].

Starch hydrolysis has been used in the food industry to convert starches, starch derivatives and starch saccharification products, which have several applications in food processing. The products from starch hydrolysis are certainly highly versatile ingredients used in the food industry and are used in a wide range of food products due to both their functional and nutritional properties [23].

4. Applicability

With wide applications in the food, textile, pharmaceutical, paper and, recently, synthetic polymer industries, starch plays prominent a role even in technological developments [24]. In addition, it is purified in the shape of micro-granules and widely used as a solid matrix for the encapsulation of food ingredients [25].

Starch has been investigated widely for its use in the
potential manufacture of products, including water-soluble pouches for detergents and insecticides, flushable liners and bags and medical delivery systems and devices [26]. In ceramic technology, starch is a frequently used as pore-forming agent [27].

Novel approaches in polymer manufacture imply the use of composites; for example, polypropylene carbonate (PPC) is being doped with starch to create ecofriendly, naturally degrading materials, thus reducing the negative effect of polymeric waste production. Starch also shows very interesting optical properties; for example, the second-harmonic generation of light can be achieved on starch granules [28].

The use of edible films in the food industry has been constantly increasing, and starch-based films play a key role in the food industry because starch is abundant, inexpensive, naturally renewable, biodegradable polysaccharide industries especially food products and more readily available worldwide than other natural resources, in applicability part [29].

One way of increasing the usefulness of starch for industrial applications is by treating it with acid at elevated temperature. It is mainly the amorphous part of the native starch that is subjected to acid hydrolysis, and this method is used as a pretreatment in various industrial applications (e.g., for gums, pastilles, jellies) to decrease viscosity and increase gel strength. Acid hydrolysis is also used to determine the degree of crystallinity of native starches and to prepare starch nanocrystals [21].

In addition to physical modifications, blending different native starches is another way to obtain new starch properties. It may also offer an economic advantage when a more expensive starch can be partially replaced by a cheaper alternative without affecting product quality [30]. Jackfruit, a source of new starch; the structure of its starch in formulation with sodium alginate is illustrated in Figure 4. Table 2 lists some general applications of starch.

![Figure 4. Whole jackfruit (A) [31], jackfruit seed powder (B) [32] and Scanning electron microscopy (SEM) of jackfruit seed starch-sodium alginate optimized formulation (C) [33]](image)

| Table 2. Applications of starches |
|----------------------------------|
| Type of starch | Applications | References |
| Native starches | Paper, Textile food, cardboard and potable alcohol production (FI) industry | [34] |
| Hydrolyzed starches | | |
| Malto-dextrins: | - Food preparation (bulking agent) | [35] |
| | - Pharmaceutical (excipient) | [6] |
| | - Ingredient in ice cream industry | [36] |
| Glucose syrup: | - Dextrose Equivalent of between 40 and 60: food industry | [37] |
| | - Beverage and confectionary industry | [38] |
| | - Used directly as a substrate for the manufacture of fermentation products (such as citric acid, lysine or ethanol or glutamic acid) | [39] |
| | - Processed into other major starch derivatives, such as isoglucose, fructose syrup | [37] |
| Modified starches | | |
| Substituted starches (starch esters, ethers, cross-linked starch): | - Textiles | [40] |
| | - Paper | [41] |
| | - Water treatment (flocculation) | [42] |
| | - Oil industry (fluid loss reducer) | [43] |
| Degraded/Converted starches: | - Dextrins: Adhesives (gummed paper, bag adhesives, bottle labeling); | [35] |
| | - Textiles (textile fabric finishing, printing); | [44] |
| Roast dextrin, oxidized starch, thin-boiled starch: | - Acid-modified starches: Food industry (sweets) and Pharmaceuticals | [45] |
| | - Oxidized starches: Food and paper industry (surface sizing, coating); | [46] |
| | - Textile industry (fabric finishing, warp sizing) | [47] |
| | - Enzymatically converted starch: paper industry and fermentation industry | [48] |
| Cross-linked starches: | - Food industry (desserts, bakery products, soups, sauces) | [49] |
| | - Textile industry (printing) | [50] |
| | - Adhesives | [51] |
| | - Pharmaceuticals | [6] |

Source: Adapted from [52].
5. Non-Conventional Sources

Starch accounts for a significant fraction of a large range of crops. Cereals (e.g., corn, wheat, rice, oat, barley) contain from 60% to 80% of this carbohydrate, legumes (e.g., chickpea, bean, pea) from 25% to 50%, tubers (e.g., potato, cassava, cocoyam, arrowroot) from 60% to 90% and some green or immature fruit (e.g., banana, mango) as much as 70% of the dry weight [53]. Table 3 shows the starch content of some conventional and non-conventional sources.

Starch is frequently isolated and is used in food industries to impart the desirable functional properties, and modify food texture and consistency [54].

New starch preparation is done for each raw material before further analyses and application. There is a huge variety of methods to isolate, or prepare, starch and to evaluate its total content in products.

Among these methods authors take the liberty of using validated methods available in literature [55, 56], or their own method [13], or modified methodologies [7, 57] to isolate the starches from their studied raw materials.

To quantify starch some references use a total starch quantification kit according to the American Association of Cereal Chemists (AACC) [58], or the methodology of Association of Official Agricultural Chemists (AOAC) [59], or those validated and available in literature [60].

The source used for starch production varies worldwide depending on local traditions and climatic conditions, but more or less only starch and starch derivatives of maize and potato are of commercial interest [24].

Starches from different botanical sources vary in size, composition and the fine structure of amylpectin, and these factors influence the physical properties and end-uses for different natural starches [15]. The development of products and characterization of native starches from different botanical sources has been widely studied by several authors [99, 104, 114, 90].

The physicochemical and morphological characteristics of pine nut starch demonstrated its applicability as a pharmaceutical excipient due to the presence of phenolic compounds [6].

Sugar cane provides starches with very attractive properties that are completely different from those of cassava [115].

The addition of cellulose and cellulose nanoparticles to chayote tuber starch films was found to improve some of the mechanical, barrier and functional properties, solving the problems of plastic waste to obtain environmentally friendly materials [26].

The understanding of the gelling behavior of lentil starch and protein in composite gel is helpful for the structure formation of these two biopolymers in mixtures and will help their application in new product development [116].

After minor physical or chemical modification, chickpea starch from different cultivars is suitable for incorporation into foods subjected to high temperature processing, high shear and frozen storage due to its higher crystallinity, higher thermal stability and lower set-back [78].

Native chestnut starch presents a pasting profile similar to corn starch, making it a potential technological alternative to corn starch [76].

Velvet bean appears to be suitable in its native state for incorporation into thermally processed and frozen foods due to its higher thermal stability, higher resistance to shear and lower extent of set-back [90].

The properties of breadfruit starch indicate that it would require modification to reduce retrogradation [71].

A starch-rich fraction from the pulp of cupuassu fruit is described as being rheologically similar to the starches of tapioca (cassava) and corn [79]. The properties of sweetsop starch indicate that it has a potential for application as a thickener in frozen foods [56], Kamo Kamo (Cucurbita pepo) starch exhibits behavior similar to that of potato starch [88].

Mango ginger (Curcuma amada Roxb.), a unique species with rhizomes that have a mango flavor, has high medicinal importance and occupies a position between turmeric and ginger starch [97].

Jack fruit seed starch is considered a useful stabilizer in a high-acid sauce [87] and could be used as an alternative for modified starches in a system needing starch with a high thermal and/or mechanical shear stability [117].

Pyrodextrinized lima bean starch is potentially useful in the manufacture of dressings and instant beverages, juices, jelly and soft candy, and it can be used as a stabilizer in sausages [118].

Table 4 briefly shows some of the application of these new starches.

The main benefit of starch addition to dairy products is cost reduction; however, starch does contribute important attributes that can improve the product functionality and performance. Starches are now readily added to yoghurts, cheese, custards etc. and thus, understanding their role within a specific product is extremely important. For example, syneresis can be inhibited or greatly reduced by starch addition; the counter effect could be a grainy texture. Thus, by manipulation the formulation and/or the processing conditions the desired outcome can be achieved [121].

There is strong interest in biologically based and/or biodegradable polymers. The reasons for this include the reduced cost, the abundance of the biomass and biodegradability of the materials, combined to the reduced disposal of non-degradable waste into the environment [122].

Although conventional sources of starch, such as corn, potato, other sources with improved properties are becoming significant to allow simpler and more robust processes. The feasibility of new starches as a renewable material for commercial application may provide cost reduction of raw material.

Industry continually aims to improve on existing products and/or explore solutions for cost reduction. Moreover, finding applications for new or existing ingredients continues to be at the forefront of their research [121].
| Source          | Popular name                      | Specie                        | Type       | Method of obtaining | Content of starch (%) | Reference |
|-----------------|-----------------------------------|-------------------------------|------------|--------------------|-----------------------|-----------|
| **Non-conventional** |                                   |                               |            |                    |                       |           |
| Amaranth        | Amaranthus cruentus               | Cereal                        | [61]       | 57,5               | [62]                  |           |
| Anatto          | Bibra orellana L.                 | Seed                          | NI *       | 40                 | [63]                  |           |
| Apple           | Malus domestica Borkh             | Fruit                         | [64]       | 45,8               | [65]                  |           |
| Babassu         | Orbigyna phalerata Mart.          | Palm                          | [66]       | 60,05              | [67]                  |           |
| Baby lima bean  | Phaseolus lunatus                 | Legume                        | [68]       | 63                 | [68]                  |           |
| Borassus aethiopum | Borassus aethiopum            | Palm                          | [69]       | 24,73              | [70]                  |           |
| Breadfruit      | Arlocarpus altilis               | Fruit                         | [69]       | 64,5               | [71]                  |           |
| Broad bean      | Vicia faba L.                    | Legume                        | [72]       | 35                 | [14]                  |           |
| Buckwheat       | Fagopyrum tataricum Gaertn.       | Pseudocereal                  | [73]       | 80,5               | [29]                  |           |
| Chayote         | Sechium edule Sw                  | Tuber                          | [74]       | 60                 | [26]                  |           |
| Cherimoya       | Annona cherimola                 | Fruit                         | [75]       | 27,7               | [60]                  |           |
| Chestnut        | Castanea sativa                  | Nut                            | [76]       | 93,2               | [76]                  |           |
| Chickpea        | Cicer arietinum L.                | Legume                        | [77]       | 34,75              | [78]                  |           |
| Cocoyam         | Colocasia esculenta               | Root                           | NI *       | 11,91              | [3]                   |           |
| Horse chestnut  | Aesculus indica                  | Nut                            | [72]       | 38,3               | [13]                  |           |
| Jack bean       | Canavalia ensiformis              | Legume                        | [24]       | 18,42              | [24]                  |           |
| Jackfruit seed  | Arctocarpus heterophyllas L.      | Fruit                         | [86]       | 32,14              | [87]                  |           |
| Kamo Kamo       | Cucurbita pepo                    | Fruit                         | [72]       | 23,2               | [88]                  |           |
| Kudzu           | Pueraria lobata                   | Root                           | [89]       | 99,5               | [58]                  |           |
| Lablab bean     | Lablab purpureus                  | Legume                         | [80]       | 29,9               | [90]                  |           |
| Lentil          | Lens culinaris                    | Legume                         | [91]       | 51,7               | [92]                  |           |
| Lima beans      | Phaseolus lunatus                 | Legume                         | [93]       | 37,5               | [94]                  |           |
| Maca            | Lepidium meyenii Walpers          | Root                           | [95]       | 23,17              | [96]                  |           |
| Mango ginger    | Curcuma amada Roxb.               | Rhizome                        | [77]       | 43                 | [97]                  |           |
| Millet          | Panicum sumatrense                | Cereal                         | [98]       | 70                 | [99]                  |           |
| Navy bean       | Phaseolus vulgaris                | Legume                         | [80]       | 24,3               | [90]                  |           |
| Palmarah        | Borassus flabelifer L.            | Palm                           | [72]       | 38,34              | [100]                 |           |
| Pea             | Pisma sativum L.                  | Legume                         | NI *       | 40                 | [101]                 |           |
| Pehuen seeds    | Araucaria araucana (Mol) K. Koch) | Pine                           | [72]       | 84                 | [102]                 |           |
| Peruvian carrot  | Arracacia xanthorrhiza, Bancroft  | Root                           | [80]       | 80                 | [9]                   |           |
| Pine nut        | Araucaria angustifolia            | Pine                           | [6]        | 72                 | [6]                   |           |
| Ramon           | Brosimum alicamstrum Swartz       | Fruit                          | [77]       | 92,57              | [7]                   |           |
| Soursop         | Annona muricata                   | Fruit                          | [103]      | 27,3               | [56]                  |           |
| Sugar cane      | Saccharum officinarum L.          | Grass                          | [104]      | 99,1               | [104]                 |           |
| Sweet sorghum   | Sorghum bicolor                   | Grass                          | [104]      | 98,9               | [104]                 |           |
| Sweetstrop      | Annona squamosal                  | Fruit                          | [103]      | 25,6               | [56]                  |           |
| Tef             | Ergagostris tef (Zucc.) Trotter   | Grain                          | [105]      | 75                 | [106]                 |           |
| Tepary bean     | Phaseolus acutifolius             | Legume                         | [80]       | 27,6               | [90]                  |           |
| Turmeric        | Curcuma longa L.                  | Rhizome                        | [72]       | 76                 | [82]                  |           |
| Wolf Apple      | Solanum lycocarpum               | Fruit                          | [80]       | 51                 | [4]                   |           |
| White Yam       | Dioscorea spp.                    | Tuber                           | NI *       | 83,93              | [108]                 |           |
| Velvet bean     | Mucuna pruriens                  | Legume                         | [109]      | 25,2               | [90]                  |           |
| **Conventional** |                                   |                               |            |                    |                       |           |
| Banana          | Musa paradisiaca                  | Fruit                          | [110]      | 26,3               | [111]                 |           |
| Barley          | Hordeum vulgare                   | Cereal                         | [112]      | 60                 | [112]                 |           |
| Corn            | Zea mays                          | Cereal                         | [110]      | 31,3               | [111]                 |           |
| Potato          | Solanum tuberosum                 | Tuber                          | [110]      | 23,65              | [111]                 |           |
| Rice            | Oryza sativa                      | Grain                          | [105]      | 87,7               | [106]                 |           |
| Cassava         | Manihot esculenta                 | Root                           | [72]       | 84                 | [113]                 |           |
| Wheat           | Triticum aestivum L.              | Cereal                         | [110]      | 25,03              | [111]                 |           |

* NI – Not Identified
6. Future Trends and Perspectives: The Uses of Annatto and Turmeric Starches

Commercial extracts of annatto seeds and turmeric rhizomes are rich sources of the natural pigments bixin and curcumin, respectively, which are largely used for the coloring of various food products and for cosmetics and pharmaceutical applications [123, 82]. This has resulted in the increased demand for these compounds and consequently the number of studies published on obtaining these compounds. Nevertheless, there is a lack of research reporting the use of starch from these raw materials (usually contained in the residue).

Turmeric (Curcuma longa) and annatto (Bixa orellana L.), which are already used in industry to obtain food coloring and pharmaceutical products, may become commercially interesting as starch raw materials (Figures 5 and 6).

Figure 5. Whole form (A) [124], seeds (B) [125] and powder (C) [126] of annatto (Bixa orellana L.)

Figure 6. Rhizomes (A) [127] and powder (B) [128] of turmeric (Curcuma longa L.)

The main reserve carbohydrate on annatto seeds is starch [129]. Isolated starch from turmeric rhizomes after the extraction of its oil using supercritical fluid extraction (SFE) contains about 40% (w/w) starch [82].

Information on the unique characteristics of uncommon starches would be helpful for practical applications in food and non-food processing to improve the functionality of end-use products.

6.1. Methods of Value Addition to Turmeric and Annatto

6.1.1. New Product Development

The extraction of curcuminoids (pigments) from turmeric rhizomes generates a waste predominantly consisting of starch. This agroindustrial residue is considered to be a potential renewable material for ethanol and lactic acid production when subjected to acid hydrolysis [120].

Curcumin has been encapsulated in baker’s yeast (Saccharomyces cerevisiae) cells, b-cyclodextrin (b-CD) and modified starch (MS) by various methods [130].
6.1.2. Extraction of Curcuminoids, Turmerones and Bixin Using Supercritical Technology

The starch from turmeric was analyzed before and after supercritical fluid extraction, showed in Figure 7, to obtain oleoresin and essential oil, revealing characteristics similar to commercial starches, indicating the potential for industrial applications [82].

Pressurized liquid extraction is a versatile technique that allows the extraction of natural bioactive compounds such as curcuminoids [131]. Supercritical technology has been employed for optimizing ar-turmerone extraction from turmeric volatile oil [132].

Figure 7. SEM images of turmeric starches before (A) and after (B) SFE [82]

Supercritical CO2 extraction for the defatting of annatto seeds was studied as a pretreatment for the production of bixin [133]. Pressurized liquid extraction (PLE) and low-pressure solvent extraction (LPSE) methods have been used for the extraction of bixin from defatted annatto seeds [134].

The encapsulation of bixin in poly(3-hydroxybutirate-co-hydroxyvalerate) (PHBV) with dichloromethane as an organic solvent using the SEDS (solution-enhanced dispersion by supercritical fluids) technique was studied to evaluate the behavior of bixin release in different solvent media [135].

6.1.3. Spray-dried Turmeric Oleoresin

Turmeric extract have a commercial potential for obtaining spray-dried microparticles of poorly water-soluble phytochemicals [136].

6.1.4. Microwave and Ultrasound-assisted Extraction Technique for Curcuminoids and Bixin

A microwave-assisted extraction technique was more efficient in curcumin extraction from powdered C. longa rhizome in comparison with soxhlet, microwave, ultra-sonic and supercritical carbon dioxide-assisted extraction in terms of percent yield and the required extraction time [137].

Ultrasound-assisted extraction is an effective technique for annatto color extraction in comparison with conventional extraction methods, such as microwave-assisted extraction and supercritical fluid extraction [138].

Ultrasound-assisted curcumin emulsification was successfully used for the preparation of starch-stabilized nanoemulsions at lower temperatures (40–45 °C) with reduced energy consumption [139].

7. Conclusions

Starch, a renewable biopolymer, is a versatile agricultural raw material for industrial purposes because it is inexpensive, relatively easy to handle, completely biodegradable and widely available in nature from sources such as cereals, roots, tubers, palms and seeds.

Developments in the industrial sector have increased interest in the identification of new starches with distinct properties and their potential for processing at large scales. However, little information is available on the structure, properties and practical applicability of non-conventional sources of starch. Thus, it is necessary that these starches be studied to obtain and report their structural parameters, information that is required to gain competitiveness in an international-scale industry.

These starches show similarity or advantages with respect to some conventional sources, such as corn, potato and tapioca, making them attractive additives for food formulations in which the retrogradation process is undesirable; in addition, their aqueous suspension gelatinization requires less time and energy.

Legume, rhizome, grass, seed and palm starches can be used as ingredients in the same way as starches from cereals and tubers because of their similarity in physicochemical and functional attributes. These properties will allow the use of new starches with improved functionality, which can be employed to develop new processes and consequently new products.

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