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Physicochemical and functional properties of *Curcuma angustifolia* (Tikhur) - An underutilized starch

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Abstract

Starch from *Curcuma angustifolia* rhizome was characterized for its proximate composition, physicochemical and functional properties. This starch contains 32.30 ± 0.44% amylose, 2.72 ± 0.36% moisture, 0.30 ± 0.04% ash, 97.43 ± 0.52% carbohydrates as starch and negligible amount of fat and protein. The starch granules are polyhedral, with a diameter of 9.75 to 20.43 µm and 3.409 to 5.272 µm in width. Clarity and solubility of tikhur starch are comparable with those of corn and cassava starch. Tikhur starch display higher pasting temperature (76.25 °C), suggesting the tendency to form faster paste and stability under high cooking conditions. These properties demonstrate the untapped potential of tikhur starch for use in food and non-food applications previously dominated by costlier cereal starches.

Keywords: *Curcuma angustifolia,* underutilized starch, macromolecule

1. Introduction

Starch is the most important macromolecule being used diversely to meet technological needs of today due to its low-cost, abundance, edibility, biodegradability and good film forming properties (Gao *et al*., 2014) [22]. Recently, the potential nutraceutical characteristics of starchy products have raised the interest on this biopolymer (Béllo-Perez and Paredes-López, 2009) [7] which is now considered a strategic material of the future (Saikia and Konwar, 2012) [43]. Its physicochemical, thermal, and functional properties are extensively explored in commercial cereal and tuberous starches to newer starch sources like mango ginger rhizome (Policegoudra and Aradhya, 2008) [39], harms tuber starch (Malumba *et al*., 2016) [33], lotus rhizome (Sukhija *et al*., 2016 and Zhu, 2017) [57], kiwifruit starch (Li and Zhu, 2017) [31, 63], kudzu root (Chen *et al*., 2017) [11], and parota starch (Estrada-Leon *et al*., 2016) [17]. Reasons for exploring such non-conventional starch could be the valorization of underutilized starch for example banana starch (González-Soto *et al*., 2007) [23], Jackfruit seed flour (Chowdhury *et al*., 2012) [12] or the limitations of native starch such as poor solubility, low mechanical properties and instability at high temperature, pH and shear during processing (Lawal *et al*., 2008; Abbas *et al*., 2010 and Sharma *et al*., 2015) [30, 1, 49].

Curcuma angustifolia (Tikhur) is a fast growing rhizomatous herb of Zingiberaceae family, commonly known as East Indian arrowroot or white turmeric (Paikra *et al*., 2013) [36]. The plant occurs as a wild growth in hilly tracts of Madhya Pradesh, Chhattisgarh, West Bengal, Maharashtra, Tamil Nadu and some of the lower Himalayan ranges. It is a perennial flowering plant, with modest and small spiked inflorescences of three or four yellow, funnel shaped flowers within tufts of pink terminal bracts. It is processed by cutting, peeling, rubbing fresh rhizome bulbs on rough surface of stone or on sieves of rough surface, soaking with water, decanting and drying (Patel *et al*., 2015) [38]. The yield of tikhur starch is 125-140 g from 1 kg rhizomes implying huge loss of starch together with time and labour requirement (Das *et al*., 2015; Tiwari and Patel, 2013) [15, 36, 58].

The rhizome of tikhur have great medicinal value (Jain, 1995 and Sarkar *et al*., 2015) [25, 45]. It is well known for its use in ethnomedicine as demulcent, antipyretic and blood coagulant (Tushar *et al*., 2010) [59]. The rhizome of *C. angustifolia Roxb*. can be used to heal peptic ulcers, is used in treatments of dysentery, diarrhoea, and colitis and is often employed as a herbal tonic for patients suffering from tuberculosis. Its use for the treatment cough and bronchitis is very popular in the areas where it grows (Doble *et al*., 2011) [16]. The leaves of the plant also yield volatile oil, possessing antimicrobial properties (Rani and Chawhaan, 2012) [41]. It is also reported that the boiled water extract of rhizome is used for treatment of diabetes (Sheikh *et al*., 2015) [51]. The starch of this herb is used for the preparation of several foods such as *barfi* (Shankar *et al*., 2014) [47], *halwa* (Banik *et al*., 2014) [6], *khoa-jalebi* (Kumari *et al*., 2012) [29], and *sarbat* (Singh and Palta, 2004) [52].

Because of its medicinal properties, the starchy flour is used as a weaning food called *shotti* (Sharma, 2012) [50]. The versatility of tikhur starch as a base for many food products emphasizes the need for a better understanding of its functional characteristics and attempted in this study.

2. Materials and Methods

Tikhur rhizome was procured from the local market of Kharagpur, West Bengal and extracted for starch as mentioned by the procedure of Patel *et al*. (2015) [38]. Extracted starch was used for evaluation of physico-chemical and functional properties

2.1 Physicochemical properties

2.1.1 Chemical composition

Moisture, crude protein, crude fat and ash content were determined using AACC (2000) [5] standard methods. Starch content in tikhur was determined using IS 4706-2 (BIS, 1978) method. Amylose content in tikhur was measured by the procedure reported by and amylopectin content was calculated using Eq. (1).

$$\text{Amylopectin\%} = 100 - \text{amylose\%} \qquad (1)$$

2.1.2 Calorific value

The calorific value of tikhur starch was determined using bomb calorie meter. Bomb calorie meter determines the gross heat value of a food product. For this, 1 g sample was loaded in a closed ignition vessel/bomb and combusted with oxygen at a pressure of 3 MPa. The heat released was absorbed by the surrounding water, which represented the calorific value per gram of the sample and was directly displayed on the display board of the machine (IKA® c200 bomb calorimeter).

2.1.3 True and bulk density

True volume of tikhur (V_s) was estimated using a helium pycnometer at 25 °C and 18 psi pressure (Model: 1200 e, Ultrapyc M/s Quantachrome Instruments) with an accuracy of 0.001 cm^3. True density was calculated using equation (2):

$$\rho_{ts} = \frac{m_s}{V_s} \qquad (2)$$

Bulk density was calculated by measuring the weight of 100 cc of tikhur and reported as g/cc. Porosity (%) was further calculated using formula given by Mohsenin (1996) [34]:

$$Porosity\ (\%) = \left(1 - \left[\frac{Bulk\ desnsity}{True\ density}\right]\right) \times 100 \qquad (3)$$

2.1.4 Color

Color measurement of tikhur starch and paste was carried out using Konica Minolta spectrophotometer Model CM-5. Samples were scanned in triplicate to determine L*, a*, b*, C* and h values.

2.1.5 Size and shape

To determine the starch granule size, scanning electron microscopy (SEM) of the starch was done using JOEL model no. JSM-6390LV (Oxford Instrumentation Ltd., Tokyo, Japan). For the analysis, the dried starch powder was sprinkled on the carbon tape and then coated with 30 nm gold coating using JOEL auto fine coater (model no. JFC-1600; Oxford Instrumentation Ltd.). The SEM was operated at 15–20 kV and under 1 Pascal pressure with the spot size fixed at 34.

2.2 Functional properties

2.2.1 Solubility and swelling index

The solubility and swelling index of starch were determined using the method reported by Sharlina *et al*. (2017) [48], with slight modifications. 0.2 g of dry starch was transferred into a vial containing 10 mL of distilled water and stirred using a magnetic stirrer for 30 min before being heated at 55, 65, 75, 85 and 95 °C for 30 min. Then, the starch slurry was cooled to room temperature, transferred to a centrifuge tube and centrifuged at 3000 rpm for 15 min. Different starch slurries were used for each of the temperatures. The supernatant from the centrifuge tube was carefully decanted into another vial, and wet starch precipitate was weighed after it was drained for 10 min. The supernatant was dried in an oven at 105 °C until a constant weight was reached. The analysis was performed in triplicate. The solubility and swelling power were calculated using Eqs. (4) and (5).

$$\text{Solubility (\%)} = \frac{dry\ supernatant\ (g)}{dry\ starch\ (g)} \times 100 \qquad (4)$$

$$\text{Swelling power (g/g)} = \frac{Wet\ starch\ (g)}{dry\ starch\ (g) - dry\ supernatant\ (g)} \qquad (5)$$

2.2.2 Water and oil absorption capacity

Water absorption capacity (WAC) and oil absorption capacity (OAC) were determined according to the method adopted by Julianti *et al.* (2011) [28] of Subrahmanyam and Hoseney (1995) [56]. Starch samples (1 g, moisture free) were mixed with 5 ml of distilled water/ vegetable oil stirred on vortex shaker in centrifuge tube at room temperature. After 20 min of shaking the suspension was centrifuged at 4000 rpm for 30 min at room temperature. The freed water / oil was decanted into a 10 ml graduated cylinder and the volume was recorded. WAC and OAC are represented as: Weight of wet sediment / Weight of initial sample taken (g/g).

2.2.3 Paste clarity

Paste clarity (% Transmittance at 640 nm) of starch paste was measured using the procedure of Craig *et al.* (1989) [14]. Starch suspension (2%) was heated and stirred in water bath for 30 min at 95 °C. Samples were cooled and stored for 4 d at 4 °C and percent transmittance was measured everyday at 640 nm against water blank using UV – VIS Spectrophotometer.

2.3 Thermal properties

The thermal properties viz., the onset (T_o), peak (T_p) and conclusion (T_c) temperatures, and gelatinization enthalpy (ΔH) of tikhur flour were determined in a TA DSC Q100 Instrument (Model Q100V 8.1). Deionized water (10 µl) was added to 8 mg of sample in an aluminum pan (BO160932). The sample was kept overnight at room temperature before analysis. It was heated from 20 to 100 °C with 10 °C/min heating rate. An empty aluminum pan was used as a reference (Ratnayake *et al*., 2001) [42].

2.4 Pasting properties

Pasting properties of tikhur flour were measured using Rapid Visco-Analyser 4D (RVA) manufactured by M/s Newport Scientific Pvt Ltd., Australia, according to the method described by Yadav *et al.* (2010) [60]. 3.5 g of flour sample with an initial moisture content of 2.63% (wet basis) was dispersed in 25 ml of distilled water and fitted into RVA as per manufacturer's instructions. The rotating speed of paddle was 160 rev/min except for first 10 sec (960 rev/min). The suspension was equilibrated at 50 °C for 1 min and heated at the rate of 12 °C/min to 95 °C and then held at 95 °C for 2.5 min. The sample was then cooled to 50 °C at the rate of 12 °C/min and then held for 3 min at 50 °C. Peak viscosity, trough viscosity, breakdown viscosity, final viscosity and setback viscosity were recorded in rapid viscosity units (RVU). Pasting temperature (°C) was also recorded and test was replicated thrice.

2.5 Gel strength

Tikhur starch suspension (prepared with a concentration of 8% starch solids, (db)) was heated to 95 °C and held for 30 min and cooled to 4-6 °C for gel formation; Gel strength was determined using Texture Analyzer (TA XT CT 3 Model). The following conditions were used for measurement of gel strength of tikhur starch: pre-test speed: 3.0 mm/s; test speed: 2.0 mm/s; post-test speed: 10.0 mm/s; distance: 15 mm; trigger type: Auto – 15 g; data acquisition rate: 400 pps. For gel strength measurement, when a trigger force of 15 g was attained the probe then proceeded to penetrate into the gel at a speed of 2.0 mm/s to a depth of 15 mm. During this penetration, the force was seen to drop at the point where the gel broke. Thereafter, the resulting forces were due to continuing penetration up to the required depth. Hardness or gel strength, deformation at target and adhesiveness were obtained through this measurement.

2.6 Fourier transform-infrared spectroscopy

Fourier transform infrared spectroscopy (Nicolet-6700, ThermoFisher, United States) was used to determine the functional groups in the wave length range of 4000–400 cm^{-1} of starch samples. Before taking FT-IR, the sample was blended with KBr.

2.7 Statistical data analysis

Experiments were performed three times, and data were analyzed by one sample *t*-test analysis to determine significant differences at $p < 0.05$ using SPSS 16.0 statistical software (SPSS, Inc., Chicago, IL, USA).

3 Results and Discussion

3.1 Physical and chemical characteristics

Physicochemical properties of tikhur starch are presented in Table 1. The major constituent of tikhur was starch (97.43%) and it was low in crude fat, protein and ash content. Starch was made up of 32.30% amylose and 67.70% amylopectin. The amylose content of starches is important because amylose largely determines the gelling ability of starches. Tikhur starch has high calorific value and this attribute can be utilized in gluten- free and infant food products to aid people with celiac disease.

Table 1: Physicochemical composition of tikhur starch (g/100g)

Constituents	Tikhur
Moisture (db)	2.72 ± 0.36
Crude fat	0.62 ± 0.31
Crude protein	1.02 ± 0.14
Ash	0.3 ± 0.04
Starch (db)	97.43 ± 0.52
Amylose (%)	32.30 ± 0.44
Amylopectin (%)	67.70 ± 0.38
Calorific value (cal/g)	3499 ± 1.06
True density (g/cc)	1.59 ± 0.03
Bulk density (g/cc)	0.51 ± 0.27
Porosity (%)	68 ± 1.10

3.2 Bulk density: Bulk density is a measure of heaviness of solid samples, which is important for determining packaging requirements, material handling and application in the food industry (Singh *et al*., 2011) [53]. Bulk density of tikhur starch is quite lesser than Wheat flour (0.73g/cc) and jackfruit seed flour (0.80 g/cc) as reported by Chowdhury *et al*. (2012) [12]. Tikhur starch is not suitable as thickener in food products as it is recommended that flours with high bulk densities (> 0.7 g/mL) are used as thickeners in food products (Akubor and Badifu 2004; Falade and Okafor, 2015) [3, 18].

3.3 Color: Pure starch is usually white, odorless, tasteless and insoluble in cold water and organic solvents (Radley, 1953) [40]. High value of lightness (87.73) indicated tikhur starch to be of bright white colour as evident from Fig: 1. A high value of lightness (L* value) and a low value of chroma is desired in *C. angustifolia* starch (Franklin *et al*., 2017) [20].

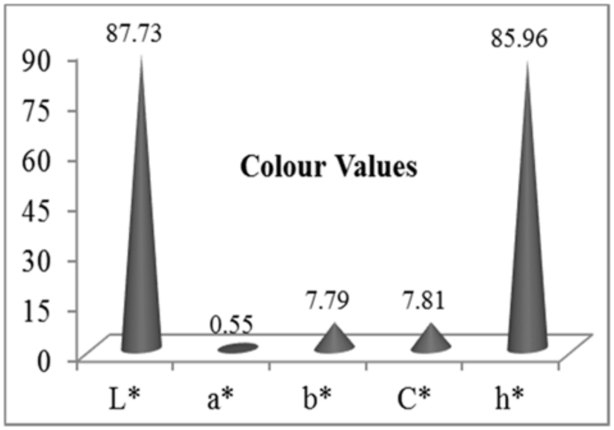

Fig 1: Colour of tikhur starch

3.4 Scanning electron microscopy: Scanning Electron Microscopy (SEM) is generally used to characterize starch at microstructure level. The results obtained by SEM showed variation in size and shape of starch granules from small to large and oval to polyhedral with the size ranging from 9.75 to 20.43 µm in length and 3.409 to 5.272 µm in width (Fig. 2 b, c and d).

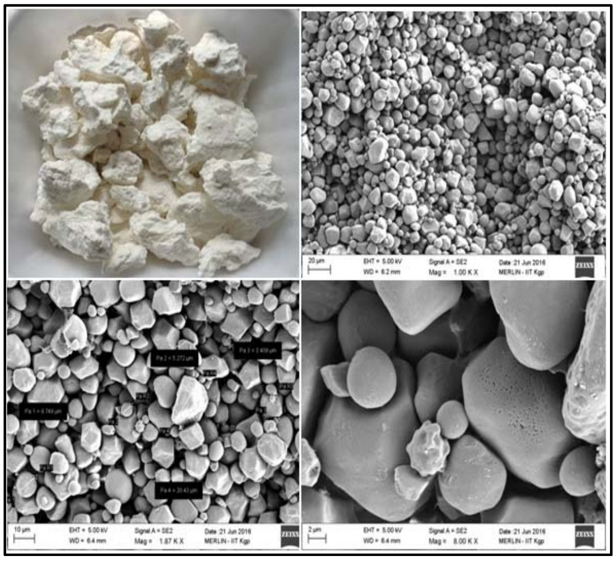

Fig 2: (a) Tikhur (b), (c) and (d) Scanning electron micrograph and size of tikhur starch

3.5 Solubility and swelling index: Heating starch in the presence of excessive amount of water leads to the granule swelling, amylose leaching, and water adsorption (Zhu, 2017) [31, 63]. Solubility (SOL) and Swelling index (SI) were directly correlated to increase in temperature (Fig. 3). Tikhur starch has acceptable solubility and swelling power of 14.61 g/g and 17.26 g/g respectively at 95 °C for use in broad range of processing temperature. Food eating quality is often connected with retention of water in the swollen starch granules (Falade and Okafor, 2015) [18].

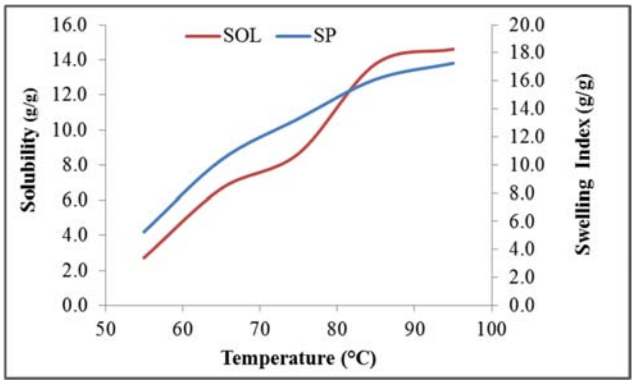

Fig 3: Solubility and swelling behaviour of tikhur starch at different temperature

3.6 Water and oil absorption capacity: Water absorption characteristics represent the ability of a product to associate with water under conditions where water is limiting (Singh, 2001) [55]. The water and oil absorption capacity of tikhur starch was 2.32 ± 0.18 g/g and 1.92 ± 0.04 g/g respectively. The maximum water absorption was about 40% for starches. Higher water absorption of starch helps to maintain the freshness of bread, cakes and sausages (Falade and Okafor, 2015) [18].

Oil absorption capacity reflects the emulsifying capacity and the amount of oil that can be picked up by a sample during frying, a highly desirable characteristic in products such as mayonnaise.

The correlation coefficient between water and oil absorption capacity was 0.29 stipulating that amylose can form complexes with lipids also.

3.7 Paste clarity: Clarity is a key parameter in starch paste quality because it gives shine and opacity to product colour. Percent transmission of tikhur starch decreased gradually from 54.6 to 50.4% on 4th day. Decrease in light transmittance of starch pastes with the increase in storage time is attributed to recrystallization of starch (Shah *et al*., 2016) [46]. But it is generally higher than percent transmittance of cassava (50.6%) and potato starch (42.2%) as outlined by Nuwamanya *et al*. (2011) [35].

3.8 Thermal properties of starch: Gelatinization of starch is a process that involves decoiling of the double helix and melting of the crystalline regions of starch granules (Han *et al*., 2013) [24]. The onset temperature (T_o), peak temperature (T_p) and conclusion temperature (T_c) of tikhur starch were 98, 105 and 114 °C respectively with single endothermic peak unlike rice and potato starch. Higher amylose content corresponded to increased gelatinization onset (T_o) and peak temperatures (T_p), pasting onset and peak temperatures, and decreased peak and trough viscosity (Park *et al*., 2007) [37].

3.9 Rapid Visco Analyser: The rapid visco analyser (RVA) is worldwide used to measure the pasting properties particularly to detect major viscosity changes, owing to starch gelatinization and liquefaction processes, and minor viscosity changes, such as proteolytic and saccharification activity of starch in grains and starchy foods (Juhasz and Salgo, 2008; Fox *et al*., 2014; Cozzolino *et al*., 2016) [26, 19, 13]. Viscosity and pasting behaviour of starch slurries are important quality traits in starchy tubers, for their processing in food and non-food industries (Malumba *et al*., 2016) [33]. The pasting characteristics of tikhur starch are depicted in Fig. 4:

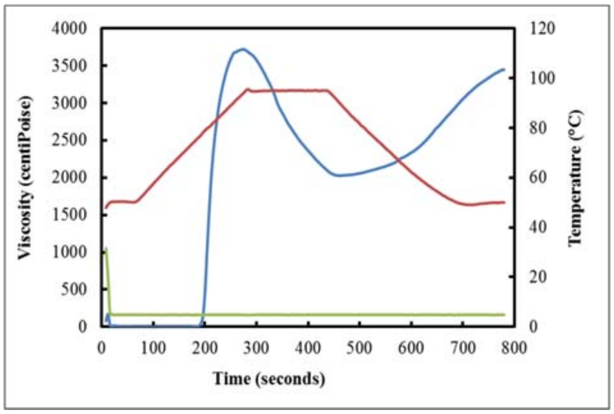

Fig 4: RVA viscosity profile of tikhur starch

Pasting temperature of tikhur starch was 76.25 °C. Pasting temperature depends on the size of the starch granules in the flour; small starch granules are more resistant to rupture and loss of molecular order (Zeng *et al*., 2013) [62]. Peak viscosity of tikhur starch was 3704.3 cP or 308.69 RVU, which showed the maximum swelling of starch granule prior to disintegration, reached in 4.53 min i.e., peak time. It has also been described as the equilibrium point between swelling and breakdown of the granules (Liu *et al*., 2006) [32]. It is generally accepted that starch with a high swelling power also yields a high peak viscosity during pasting (Chaisawang and Suphantharika, 2006) [9]. Breakdown and setback viscosity of tikhur starch were 140.30 RVU and 116.95 RVU respectively. High values of breakdown viscosity and low values of setback viscosity were indicative of good cooking quality (Gani *et al*., 2017) [21]. Pasting properties indicated the tendency to form paste, higher the pasting temperature, faster the tendency for paste to be formed, Hence it formed smooth paste in Khoa-jalebi batter.

3.10 Gel Strength

A number of factors have been suggested to be responsible for the strength of starch paste. Intrinsic interaction of the starches which is governed by their relative hydrophilicity/ hydrophobicity, ability to form complex, relative content of amylose/amylopectin, rearrangement of the amylose chains which led to increase in the porosity of the matrix and presence of nonstarch polysaccharides which may hinder hydrogen bond formation could affect the paste strength (Charoenkul *et al*., 2011; Yadav *et al*., 2013 and Alimi *et al*., 2017) [10, 61, 4].

4. Conclusions

Tikhur is a unique starch with therapeutic benefits suitable for use in different sweets as it imparts no after taste. The medium amylose content, clarity and good solubility in water imparts it soft and clear gel properties. The ΔH of gelatinization of tikhur starch were higher than common starches. It can be concluded that Tikhur starch can be utilized for wider food and non-food applications and based on these findings, FSSAI can lay down quality standards like those for Tapioca Sago (IS: 899-1971) thereby increasing the market value of tikhur starch.

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