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Changes in the characteristics of indica rice on the process of flaking

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Abstract
Flaked rice is flattened precooked whole rice ready to use edible food product. The present study aimed to investigate the changes in the characteristics of rice kernel undergoing the process of soaking and roasting of paddy followed by flaking process. The results obtained showed the significant differences in the physical, textural, chemical, optical and functional characteristics of representative samples drawn at every processing stages as brown, roasted and flaked rice. Color characteristics improved subsequently on roasting and flaking as the L-value significantly increased. A non-significant trend was observed in a-value from either brown rice to roasted rice or roasted rice to flaked rice. The pasting characteristics supported the fact of provided hydro-thermal treatment as final viscosity decreased for the flaked rice (2685 cP) in comparison to brown rice (7139 cP). Water absorption index was found to be increased significantly ($p \leq 0.05$) in flaked rice (7.44±0.06) and found approximately three times higher than brown rice (2.29±0.13). Scanning Electron Micro graphs depicted and supported the visible differences in starch granules at different stages of applied processing in the development of flaked rice.

Keywords: Paddy, flaked rice, resistant starch, FTIR, morphology, oryzanol

Introduction

Paddy (*Oryza sativa* L.) is major cereal crop in the world next to wheat with the world production of 741.47 MMT. India contributes about one fifth of the total world production in year 2014-2015 from the crop area of 43.40 million hectare (FAOSTAT, 2017) [7]. More than 90% paddy production is contributed by the Asian countries in the world (Kumar and Prasad, 2017) [20]. Importance of data on physical properties is well recognized in the design of various food processing equipment. Our researches on various characteristics of paddy to rice are reported elsewhere but those research data are basically relevant up to milling stage in rice processing (Ghadge and Prasad, 2012 [11]; Haq *et al.* 2015 [14]; Singh and Prasad, 2013 [35]; Singh and Prasad, 2014) [36]. Still the characterization of materials applied for the mass level of rice based products manufacturing are lacking and not readily available. Rice consumption is on the declining trend and is of great concern mainly due to changing taste preference, increased income, and price of cereal in comparison with the non-cereal rice substitutes. The studied aspects reveal the associated facts and adoption of the developed process not only improve the traditional rice food products but may further also provide greater employment opportunity in rural areas.

Flaked rice also is known in India as *Avalakki, Atakulu, Poha, Chirwa* is a whole flattened rice grain product prepared from pre-roasted paddy. It is used in different forms of convenient foods. It is an Indian traditional food product commonly consumed with or without the addition of milk or curd as a breakfast item and as a snacks food after adopting different processing methods (Kumar and Prasad, 2013) [19]. Flaked rice possesses relatively higher amounts of nutrients as compared to white or polished rice (Bhattacharya, 2011) [2]. It also contains beneficial nutrients including dietary fiber and phytochemicals, which have been linked to minimize the risk of various chronic diseases (Maisont and Kasetsart, 2009) [24]. The bran is a good source of oil (19-23%) rich in natural antioxidants, particularly γ-oryzanol known to lower down the total cholesterol and low-density lipoprotein cholesterol levels within the blood thereby lowering the risk of heart diseases (Srisaipet and Nuddagul, 2014) [38]. During the process of roasting and flaking starch gets damaged, gelatinized followed by retrograded to some extent leading to the development of 'resistant starch'. This changed portion is nutritionally important and acts as dietary fiber creating bulk and roughage, and escapes unaffected during digestion and absorption in the small intestine.

The resistant starch also promotes the formation of short-chain fatty acids (SCFA), especially butyrate, in the gut which is used as a nutritional supplement by the microbes and prevents colorectal diseases (Fuentes-Zaragoza *et al.* 2011) [8]. It reduces blood cholesterol level, glycemic index (GI) and finally assists in the control of diabetes (Fuentes *et al.* 2010) [9].
Flaked rice is a partially cooked low moisture shelf stable ready to use food product. The pasting properties are an important parameter for checking the characteristics of developed starchy food products. Amylose and amylopectin content with former in higher amounts responsible for lower viscosity and vice versa (Mervyn and Morris, 1985) [25]. The starch granules get partially gelatinized and ruptured during roasting and flaking resulting in reducing the swelling power than native intact starch granules (Ghiasi *et al.* 1982) [13]. Thus the lower viscosity in paste form was found in flaked rice as compared to milled white rice.
Eating habits in present days are gradually changing from healthier and nutritious forms of foods to unhealthier and fast or junk food products. The demand for junk food has increased in recent years. Thus, the primary aim of this study was to investigate the changes in the characteristics of rice kernel undergoing the process of soaking and roasting of paddy followed by flaking process in order to manufacture a flaked rice, traditional snack.

Materials and Methods

Sample preparation The "Gurjari" paddy variety was used in present research work was procured from Anand Agriculture University (Gujarat). The dehusking of paddy was done using Paddy de-husker (Indosaw Industries (P) Ltd. Ambala, India) and obtained brown and roasted paddy was also dehusked by the same instrument used for dehusking of the paddy. The milled rice was subjected to rice grading (Indosaw Industries Pvt. Ltd. Ambala, India) for separation of head rice from broken rice. The process flow diagram of rice flaking as depicted in Fig. 1. The paddy to flaked rice process was done at Shree Shakti Mamra Pauva Factory, Ahmedabad, Gujarat. The flaked rice was thoroughly cleaned after flaking process and a portion of bran was removed with the husk. The husk and bran got crushed and passed through the flaking machine sieve and were separated. The flaked rice was cleaned with the help of flaked rice cleaning machine to enable separation of whole flaked rice from broken flaked rice. The linear dimensions i. e. length (L), breadth (B) and thickness (T) of samples were measured by a vernier caliper (Dial type, Mitutoyo Corporation, Japan) as per the method of (Sahay and Singh, 2007 [32]; Kumar and Prasad, 2017) [20].
Preparation of rice and flaked rice flour was using dry grinding method (Prasad *et al.* 2013) [19] for analysis of viscosity and Fourier Transform Infra-red Spectroscopy (FTIR).
Physical properties the estimation of dimensional parameters of physical properties such as length, breadth, and thickness was determined using vernier caliper (Mitutoyo Corporation, Japan) having the least count of 0.01mm (Sahay and Singh, 2007 [32]; Kumar *et al.* 2016) [18]. Gravimetric properties such as thousand kernel weight of rice samples were estimated by using a digital weighing balance with an accuracy of 0.001g (Ishida Co. Ltd. Japan). The true density, bulk density, and porosity were calculated (Mohsenin, 1970 [27]; Ghadge *et al.* 2008) [12]. The frictional property such as angle of repose was determined (Prasad *et al.* 2010 [31]; Mohsenin, 1970) [27].
Optical properties the colors of brown, roasted and flaked rice were measured using Hunter Lab Chroma meter (Konica Minolta Sensing, Inc, Model No.CR-400, Japan). The values of $L^*a^*b^*$ were recorded directly from the colorimeter. The terms indicate Hunter L^* (lightness, ranging 0-100 indicating black to white) a^* [red (+)-green (-)] and b^* [yellow (+)-blue (-)] (Singh and Prasad, 2013) [35].
Proximate and chemical composition the moisture, fat, ash, protein and crude fiber contents were estimated by using standard procedure (AOAC, 2002) [1]. The total starch, resistant starch, and amylose contents were estimated using anthrone reagent (Thimmaiah, 1999) [40], alkaline steeping method (Wang and Wang, 2004) [41], and AOAC method (AOAC, 2002) [1], respectively. The temperature of the process was measured by infrared thermometer MEXTECH DT-8811 (-50 to-550 °C).
Mineral analysis Mineral content was determined by wet digestion method (AOAC 2002) [1] One g flour was weighed and dispersed in a 150 ml conical flask and 25-30 ml di acid mixture (HNO_3:$HClO_4$) in ratio 5:1 was added in a flask and kept for overnight. The digestion of contents was continued by heating until the clear white precipitates of the solution settled down at the bottom of the flask. The crystals left were dissolved by adding double distilled water followed by filtration. The contents were filtered through what man paper No.42 filter paper. The volume of filtrate was made up to 50 ml using double distilled water and the obtained samples were used for determination of trace minerals using Atomic Absorption Spectrophotometer (Shimadzu, Tokyo, Japan) (Lindsey and Norwell, 1969) [22].
Estimation of oryzanol the extracted rice bran oil was used for the estimation of oryzanol content by UV-spectrophotometric method (Srisaipet and Nuddagul, 2014) [38]. A weighed amount of oil sample was taken in 25 ml volumetric flask and made up to final volume 25 ml with HPLC grade n-heptane. The sample was well shaken before taking the readings. The instrument employed was calibrated with a solution blank and absorbance readings were taken against blank by UV-spectrophotometer-700 (Shimadzu, Tokyo, Japan) at 315 nm. The total quantity of oryzanol (mg/100g) was estimated using the formula.

$$\text{Oryzanol (mg/100g)} = \frac{Absorbance \times 25(Volume)}{359 \times Weight\ of\ sample\ in\ gram} \times 100 \quad (1)$$

Functional properties approximation Water absorption capacity (WAC) was determined by taking 1 g sample flour along with 10 ml distilled water in centrifuge tube centrifuged at 3000 rpm for 25 min. The supernatant was decanted into an evaporating dish of known weight. The left out residue was weighed and calculated for WAC by Eq. (2). The supernatant evaporated at 103 ºC was used for estimating Water solubility index (WSI) of the samples was determined using Eq. (3) (Stojceska *et al.* 2008) [39]:

$$WAI\ (g/g) = \frac{Weight\ of\ gel}{Dry\ weight\ of\ sample} \quad (2)$$

$$WSI\ (\%) = \frac{Weight\ of\ dry\ solid\ in\ supernatent}{Dry\ weight\ of\ sample} \times 100 \quad (3)$$

Pasting characteristics the pasting properties of the rice flours were evaluated using the Rapid Visco Analyzer (RVA, Newport Scientific, Australia). 25 g of distilled water was weighed into the canister and 3.5 g sample was transferred into it. Dispersion of the sample was achieved by jogging action of the paddle. The paddle was placed into the canister and jogged to disperse the sample. All the parameters recorded were shown in the form of different peaks. A programmed heating and cooling cycles were set which were held at 70 °C for 1.0 min, heated to 95 °C for 2.0 min and then held for another 2.0 min at 50 °C. All parameters recorded were different peak viz. peak viscosity (PV), trough viscosity (TV) (minimum viscosity at 95 °C), break down viscosity (BDV), final viscosity (FV), and set back viscosity (SBV), peak time (PT) and pasting temperature (PT) (Prasad *et al.* 2012) [11]. All properties were recorded in triplicates.

Textural properties Hardness of the rice samples (paddy, soaked paddy, roasted paddy, roasted rice and flaked rice) were determined using a TA-XT2 Texture Analyzer (Stable Microsystems, Surrey, UK) equipped with a 50kg load cell. A stainless steel probe P5 (5 mm diameter) and a single compression force time program was employed for compressing single rice grains along the thickness, at a test speed of 2 mm/sec, post speed 10 mm/sec, 80% strain and 5 g of trigger force. The maximum peak value was recorded as indicated the first crack of grain at one point and this value of force was taken as a measurement for hardness (Stojceska *et al.* 2008) [39].

Fourier Transform Infra-red Spectroscopy (FTIR) 2 mg of each flour sample (brown, roasted and flaked rice) was thoroughly mixed with desiccated potassium bromide (50 mg) in a mortar and pestle. The pellet was prepared from this mixture and further used to observe infra-red absorption spectra using FTIR, Spectrometer (Shimadzu, Tokyo, Japan). The calibration of the instrument was done with potassium bromide (KBr) and deuterated triglycine sulfate (DTGS) detector. The spectra of the samples were recorded at a resolution of 2 cm^{-1} and in intensity range of 4000-400 cm^{-1}.

X-ray powder diffraction (XRD) The analysis of crystalline and amorphous properties of raw, roasted and flaked rice by using the diffraction patterned. All samples were separately ground using dry grinder mixer (Sujata, Mixer) and ground floor was passed through 100 mesh sieve for uniformity. The obtained raw, roasted and flaked rice flours moisture content was found in the range of 11.12-12.13%. The powdered diffraction technique was pertain to obtain the X-ray diffraction (XRD) pattern using an X-ray diffract meter (Rigaku Denki Co. Ltd., Japan) with specification of 40 kV, 30 mA using Cu-Kα X-rays of wavelength (λ)=1.54056 Å and data was in use for the 2 Ø range of 10-60° with a resolution of 0.01°for all step. Relative crystallinity (RC) of raw, roasted and flaked rice flour was calculated using equation RC (%) = (Ac/ (Ac+ Aa)*100, where Ac is the crystalline area and Aa is the amorphous area on the X-ray diffractograms (Shujun *et al.* 2005) [33].

Scanning electron microscopy (SEM) Morphological properties of rice samples were examined using Scanning Electron Microscopy at 15 kV accelerated voltage (SEM) (Jeol JSM-6510LV, Tokyo, Japan). A double-sided tape adhered to aluminum stubs and the samples were mounted on adhesive surfaces of tape followed by its gold coating under vacuum and scanning the coated samples under different magnifications to get a clear micrograph (Kumar *et al.* 2016) [18].

Statistical analysis One-way analysis of variance (ANOVA) was used to assess data by using SPSS 16.0 software. Values are expressed as means± standard deviation and differences were considered significant at level of $p \leq 0.05$.

Result and Discussion

The process of flaking has resulted in the yield of flaked rice as 68.74%. Out of which, 63.61% was obtained as flaked rice and 5.13% as broken of flaked rice. The remaining 31.01% was obtained in form of dust of mainly the mixture of husk and bran components.

Physical properties the variation in sample dimensions parameters are as presented in Table 1. The dimensional data shows a significant increase in each dimensional parameter during processing of paddy into conversion to flaked rice. Length and breadth were varied from 6.27±0.08 to 11.60±0.48 mm, 2.20±0.15 to 4.19±0.28 mm. Length and breadth of flaked rice were found larger than brown rice whereas thickness was found to be decreased from 1.73±0.07 to 1.03±0.17 mm (Kumar *et al.* 2016) [18]. Flaking process compresses the hydro-thermally treated paddy between the rollers of edge runner leading to the increased length and breadth but the compressive force reduces the thickness on another end of flaked rice. Thousand kernel weight (TKW) of flaked rice was found to be reduced to 24.26±0.24 g from 26.41±0.26g, the rice kernel of paddy. The reason may be the combined effect of some portions of material chipping during the flaking process and the reduction in the minor level of moisture. The moisture content also reduced from roasted rice (17.40±0.49%) to flaked rice (10.22±0.39%). A significant decrease in the bulk density (528.66±3.58 kg/cm^3) and true density (1062.16±8.53 kg/cm^3) of flaked rice was observed mainly due to the enhancement if the porosity level which is almost doubled (Mohapatra and Bal, 2012) [26]. The frictional properties are an important concern and found to be affected significantly by processing and a higher level of angle of repose was found mainly due to higher surface to surface contact created with the flattened faces of flaked rice. The hardness levels have found to be reduced on flaking due to change in the alignment of the starch-protein arrangement have been disrupted on providing the hydrothermal treatment and further compression of roasted kernels have resulted in a compressed products having surface cracks as evident in the micrograph (Fig. 4).

Proximate and chemical composition proximate composition of brown, roasted and flaked rice are shown in Table 2. Moisture content was higher in roasted rice as compared to brown due to initial soaking step. Water absorption by paddy was approximately two times (Fig. 1). The moistened paddy was roasted. Roasting of paddy has reduced the moisture content to 17.40±0.49, which further reduced on milling to 10.22±0.39. The fat, protein, and total ash in brown, roasted rice, and flaked rice were varied per variation in the moisture content, whereas they are found almost similar on dry weight basis. Crude fiber content increased significantly ($p \leq 0.05$) during the process of flaking, which might be due to some portion of native starch transforming into resistant starch during the flaking process thereby acting as a dietary fiber (Table 3). It is evident that brown rice was possessed with maximum starch content as compared to flaked rice and roasted rice, whereas resistant starch content was found highest in roasted rice (0.98±0.04%). However, amylose content of brown rice was significantly ($p \leq 0.05$) higher than roasted and flaked rice. The reason might be partially gelatinized and retrograded starch formed at high temperature and mechanical expression resulting in conversion of amylose into resistant starch. The similar results were also reported elsewhere (Ibukun, 2008) [15].

Mineral composition and oryzanol content Minerals are important micro-nutrients necessary for human health due to their role in the effective functioning of the body and muscle movements. The concentration of calcium (Ca), potassium (K) and sodium (Na) were slightly higher in brown rice than roasted and flaked rice (Table 2). The processing technique involved soaking and heating, due to which the minerals were either leached out or removed from the grain (De and Chow, 1991). While, in roasted and flaked rice, the mineral content (Ca, K, Na) was found almost similar. A slight increase in iron (Fe) content was observed in flaked rice (Table 2), which might be due to the fact of absorbing the iron from the water used for soaking. Oryzanol content of brown rice was observed maximum as compared to roasted and flaked rice (Table 3). The obvious reason can be the presence or absence of bran layer which is more intact to the brown grain whereas during processing some portion of the layer gets removed resulting in decreased oryzanol content (Butsat and Siriamornpun, 2010) [3].

Water absorption index (WAI) and Water solubility index (WSI) The WAI and WSI of brown, roasted and flaked rice are shown in Table 3. Both WAI and WSI of flaked rice were significantly ($p \leq 0.05$) greater than brown rice. The WAI was found highest for flaked rice with values exceeding approximately three times as compared to brown rice and roasted rice. During the process of roasting and flaking, a portion of starch granules get mechanically damaged, surface area has increased with the removal of a portion of bran layer. This alteration causes starch granules to absorb more water and become more hygroscopic than brown rice which is having the compact structure. Lower values of WAI and WSI in brown rice can also be due to the native form of starch granules with integrated bran layer.

Optical characteristics the optical properties as observed in form of L, a & b data are presented (Table 3). L, a, and b values of brown, roasted and flaked rice ranged from 56.83 to 67.22, 2.48 to 0.40 and 9.38 to 12.18, respectively. The significant ($p \leq 0.05$) increase was observed in L value (Table 3). Increase in L value revealed that flaked rice had more brightness as compared to brown rice. A significant decrease in b value was observed from brown rice to flaked rice. Expansion during the roasting process and subsequent compression during the flaking process may have disrupted the bran layer have resulted in the change in the optical parameters.

Pasting properties pasting properties depends on the swelling power of starch granules in the presence of heat and water. During this process, the intra molecular structure of the amylose and amylopectin chain breakdown, due to which little amount of amylose leached out from the starch molecule and the similar result was reported by (Morris, 1990) [28]. In this study, the increased trend in viscosity for all types of flour was observed after cooling at 50 °C whereas, the final viscosity was found highest for brown rice flour (7139 cP) and lowest for roasted rice flour (1534 cP) (Table 4). This increase in final viscosity during cooling may be due to the amalgamation of amylose and amylopectin molecules. This phenomenon may increasing water absorption and water holding capacity during gelatinization process. The similar result was also described by (Mervyn and Morris, 1985) [25], 1985. Peak viscosity was found higher in brown rice (3289 cP) while lower in flaked (1873 cP) and roasted rice (1072 cP). In pasting property analysis the samples were at first passed through heating zone followed by the cooling zone resulting in the re-association of starch molecules and they try to convert into native form. The roasting process is the key role for development of flaked rice when the starch granules are partially gelatinized and after gelatinization the retro gradation takes place. The cycle of pasting properties was repeated so that flaked rice starch granules are not absorbed sufficient amount of water as compared to brown rice starch granules. This might be due to starch granules of flaked rice was earlier gelatinized. The similar result was also found by (Lee *et al.* 2012) [21]. The trough viscosity of roasted rice flour and flaked rice flour was found lower than the brown rice flour, while as setback viscosity was found highest for brown rice flour (4789 cP) and lowest for roasted rice flour (532 cP). The highest pasting temperature was found in roasted rice (81.50 °C) and lowest in flaked rice (75 °C).

Textural properties Hardness is one of the important textural parameters which relates to the mechanical property of foods such as firmness, resistance, toughness, stiffness, and rigidity. Hardness increases the milling yield of rice due to the production of a higher percentage of head rice. The compression force (N) significantly differs in different samples starting from brown rice to flaked rice (Table 1). The highest degree of hardness was observed in roasted rice (273.07 N) followed by brown rice (244. 03 N) and lowest degree of hardness was observed in flaked rice (213.27 N). This difference in hardness of products is due to the different arrangement of starch granules in different products as clearly seen in the SEM micrographs (Fig. 3). The flaked rice was found lowest hardness than, brown and roasted rice. During flaking process breakdown in protein-starch matrix takes place resulting in lower hardness of flaked rice as reported by (Corre *et al.* 2007) [4].

Fourier Transform Infra-red Spectroscopy (FTIR) FTIR, spectroscopy finds its use in identifying the presence of certain functional groups within molecules and to confirm the purity of a compound. The reason for FTIR analysis was to detect any changes occurring in functional groups during processing of paddy to flaked rice. The infrared (IR) absorption spectra gave different peaks corresponding to different functional groups viz. alcohol, aldehyde, esters, ketones etc. present within the sample. The stretching band of 1018 cm^{-1} and 1658 cm^{-1} corresponds to -C-O and -C=O stretching groups respectively. The FTIR spectra of brown, roasted and flaked rice are shown (Fig. 2). A visible change in the spectra is eminent at 1658 $cm^{-1}$and 3387 cm^{-1} band. The band ranges 1750-1743 cm-1 show the presence of free fatty acids. The flaked rice and roasted rice was observed and in brown rice minor peak was noted. The similar result was also described (Gangidi *et al.* 2002) [10]. The observed peak at 2854-2926 cm-1 represented the symmetrical and asymmetrical -CH2- bond stretching, whereas the band at 3387 cm-1 wave number related to the -O-H bond stretching (Fig. 2) (Dogan *et al.* 2007) [6]. The bands (931-850 cm^{-1}) in fingerprint region of brown, roasted and flaked rice indicated the α-linkage in starch. Similar results were also observed (Singh and Kumari, 2014) [34]. The shift from 1658 cm^{-1} wave number during the processing showed 7 cm^{-1} and 17 cm^{-1} shift towards lower wave number in roasted and flaked rice samples, respectively. The 3387 cm^{-1} band showed antagonistic behavior with respect to the above-mentioned band and the increase towards the higher wave number for roasted and flaked rice is 13 cm^{-1} and 27 cm^{-1} wave numbers, respectively. All the characteristic bands in comparison to brown rice showed that some degree of modification in chemical structure occurred during processing but no major difference was obtained in peaks as shown in IR spectrum (Dutta and Mahanta, 2012) [7]. The transmittance of the brown rice was lower than the values obtained from roasted and flaked samples with the former showing a slight difference and the latter depicting a dramatic increase in the transmittance (Fig. 2). The increase in the transmittance values upon processing can be attributed to the formation of crystalline structures from the amorphous one (Jeroen *et al.* 1995) [17].

X-ray powder diffraction (XRD) it is a quick diagnostic technique which is used for phase identification of crystalline materials and gives information of unit cell dimensions. X-ray diffract to gram and relative crystallinity of raw, roasted, and flaked rice was analyzed. The crystalline and amorphous regions are varied in the raw rice and processed rice. The starch molecules are categorized on the basis of a crystalline arrangement such as A, B, and C which is found in various foods. Cereals starches such as rice, maize, and wheat are found A- type is common and B-type is typical for tubers and amylose rich rice starches (Kumar and Prasad, 2017) [20]. While, C-type is a mixture of A and B patterns, which is usually present in leguminous starches (Shujun *et al.* 2005) [33]. Analyzing the X-ray diffraction pattern of raw, roasted and flaked rice (Fig. 3) exposed that the major peak angle (2θ) for the raw rice was observed at 15°, 17°, 18°, and 23° showed the comparison with the A-type pattern. The shifting of peak towards right side and broadening of peak after heat treatment (roasting) of paddy changes of crystalline structure of rice starch to the amorphous structure. Flaking process compresses the roasted paddy between the rollers of edge runner leading to the further conversion to some extent the native starch molecule in the resistant starch (Kumar *et al.* 2016) [18]. The starch molecules are down their crystallinity with gelatinization and retro gradation (Sittipod and Shi, 2016) [37]. The relative crystallinity of raw rice, parboiled rice and flaked rice was found to be 56.41, 22.22 and 15.65%. The highest relative crystallinity was found in raw rice and lowest in flaked rice. The amorphous region represents the crystallinity of starch molecule so that higher the amorphous region lower will be the crystallinity area and vice-versa (Itoh *et al.* 1985) [16].

Scanning electron microscopy (SEM) Scanning electron microscopy is a technique which gives information about the sample's external morphology and structure (Xiao *et al.* 2009) [42]. The results of micro-structural changes occur during the flaking process in the starch matrix (Kumar *et al.* 2016) [18]. The morphological features of brown, roasted, and flaked rice show difference from each other. Some irregular and hexagonal starch granules of brown rice, which have a smooth surface, globular and polygonal shape (Fig. 4). The paddy was soaked in water at room temperature and absorption of water by the starch granules takes place and ultimately starch granules were swelled up to the effect of water on the swelling of starch granules shown (Fig. 4). During roasting of paddy, the starch granules get swollen due to synergistic effect of moisture content and high temperature as depicted (Fig. 4) and the formation of high pressured steam within the granules takes place which results in the size enlargement and the partially gelatinized starch granules makes the composite structure with amorphous characteristics (Mahadevamma and Tharanathan, 2007) [23]. The morphological characteristics of roasted rice as illustrated (Fig. 4), which showed damaged starch granules forming a disbranched and compact structure making the distinction of individual starch granules very difficult. The granular fragments are clearly visible in flaked rice and simultaneous application of high temperature and pressure cause disintegration of the starch granules compact composite structure. The starch granules at first get gelatinized followed by the retro gradation of amylose chains and reformation of the starch structure into a helical complex, thereby increasing density of the amorphous structure and it is behaving like resistant starch in the flaked rice (Zhang and Jin, 2011) [43].

Table 1: Variation in Physical and textural properties during transformation of paddy to flaked rice

Parameters		Paddy		Rice		
	Raw	Soaked	Roasted	Brown	Roasted	Flaked
L (mm)	9.19 ± 0.18^{b}	9.29 ± 0.27^{b}	9.41 ± 0.15^{b}	6.27 ± 0.08^{d}	8.19 ± 0.17^{c}	11.60 ± 0.48^{a}
B (mm)	2.88 ± 0.33^{bc}	3.11 ± 0.02^{b}	2.93 ± 0.06^{bc}	2.20 ± 0.15^{d}	2.63 ± 0.04^{c}	4.19 ± 0.28^{a}
T (mm)	2.14 ± 0.07^{bc}	2.23 ± 0.02^{ab}	2.32 ± 0.04^{a}	1.73 ± 0.07^{d}	2.02 ± 0.08^{c}	1.03 ± 0.17^{e}
TKW (g)	35.80 ± 0.63^{c}	38.14 ± 0.20^{a}	37.13 ± 0.49^{b}	26.41 ± 0.26^{a}	27.75 ± 0.54^{d}	24.26 ± 0.24^{f}
BD (Kg/m^3)	610.16 ± 40.77^{b}	638.19 ± 31.84^{b}	626.34 ± 25.82^{b}	751.15 ± 7.27^{b}	783.14 ± 26.47^{a}	528.66 ± 3.58^{c}
TD (Kg/m^3)	1084.73 ± 47.93^{b}	1220.00 ± 69.40^{a}	1101.17 ± 25.70^{b}	1088.95 ± 57.24^{c}	1086.57 ± 7.04^{b}	1062.16 ± 8.53^{b}
POR (%)	43.79 ± 1.29^{b}	47.48 ± 5.62^{ab}	43.10 ± 2.64^{b}	29.28 ± 0.61^{c}	27.92 ± 2.43^{c}	51.36 ± 2.76^{a}
AOR, (degree)	39.62 ± 1.20^{b}	43.50 ± 1.07^{a}	38.93 ± 1.20^{b}	35.24 ± 1.12^{c}	36.09 ± 1.04^{c}	40.97 ± 1.13^{b}
	Textural					
Hardness (N)	313.14 ± 26.06^{a}	185.79 ± 29.48^{d}	236.66 ± 22.33^{bc}	244.03 ± 12.82^{bc}	273.07 ± 7.38^{b}	213.27 ± 24.41^{cd}

Values are represented as Mean ± Standard deviation and different superscript along each row within denote significant difference at the $p\leq0.05$.

Table 2: Nutritional evaluation of flaked rice as compared to brown and roasted rice

Parameters	Brown rice	Roasted rice	Flaked rice
Moisture (%)	10.43 ± 0.07^{b}	17.40 ± 0.49^{a}	10.22 ± 0.39^{b}
Fat (%)	3.66 ± 0.15^{a}	3.33 ± 0.19^{b}	3.01 ± 0.09^{c}
Protein (g/100g)	6.06 ± 0.05^{a}	5.96 ± 0.18^{a}	5.82 ± 0.27^{a}
Ash (%)	1.40 ± 0.05^{b}	1.33 ± 0.09^{b}	1.65 ± 0.01^{a}
Crude fiber (g/100g)	0.87 ± 0.11^{b}	1.35 ± 0.28^{a}	1.54 ± 0.05^{a}
Carbohydrate (%)	77.57 ± 0.22^{a}	70.69 ± 0.69^{b}	77.75 ± 0.60^{a}
Ca	19.53 ± 0.25^{a}	$18.43\pm.20^{b}$	18.4 ± 0.26^{b}
K	175.66 ± 7.76^{a}	119.0 ± 1.73^{b}	154.0 ± 6.24^{b}
Na	5.57 ± 0.40^{a}	5.40 ± 0.36^{a}	5.37 ± 0.11^{a}
Fe	1.33 ± 0.12^{a}	1.60 ± 0.26^{a}	$1.67\pm.15^{a}$

Values are represented as Mean± Standard deviation and different superscript along each row within denote significant difference at the $p\leq0.05$.

Table 3: Chemical, Functional and Optical properties of different products obtained during development of flaked rice

Parameters	Paddy		Flaked rice
	Brown rice	Roasted rice	
Starch (%)	82.23±0.23[a]	78.11±0.62[c]	79.20±0.46[b]
Resistant starch (%)	0.81±0.02[b]	0.98±0.04[a]	0.92±0.03[a]
Amylose (%)	20.52±0.30[a]	19.14±0.43[b]	20.05±0.40[a]
Oryzanol (mg/100g)	173.34±1.57[a]	162.78±0.31[b]	160.30±1.42[c]
WAI (g/g)	2.29±0.13[b]	7.23±0.179[a]	7.44±0.06[a]
WSI (%)	5.0±0.12[b]	7.28±0.18[a]	7.32±0.28[a]
L	56.83±1.20[b]	66.01±0.65[a]	67.22±3.37[a]
a	2.48±0.36[a]	2.05±0.85[ab]	0.40±0.19[b]
b	12.18±0.26[b]	17.54±0.34[a]	9.38±0.21[c]

Values are represented as Mean± Standard deviation and different superscript along each row within denote significant difference at the $p \leq 0.05$.

Table 4: Changes in pasting properties of flaked rice during processing of paddy to flaked rice

Parameters	Paddy		Flaked rice
	Brown rice	Roasted rice	
Peak viscosity (cP)	3289±5.57[a]	1072±28.93[c]	1873±15.39[b]
Trough viscosity (cP)	2339±10.15[a]	1001±10.40[c]	1624±4.50[b]
Break down viscosity (cP)	950.33±5.03[a]	67±4.93[c]	245±3.05[b]
Final viscosity (cP)	7139±13.45[a]	1534±16.46[c]	2685±5.57[b]
Set back Viscosity (cP)	4789±5.57[a]	532±1.15[c]	1060±7.0[b]
Peak time (cP)	6.27±0.05[b]	7.00±0.017[a]	5.53±0.065[c]
Pasting Temperature (°C)	79.80±0.52[b]	81.50±0.29[a]	75.4±0.79[c]

Values are represented as Mean± Standard deviation and different superscript along each row within denote significant difference at the $p \leq 0.05$.

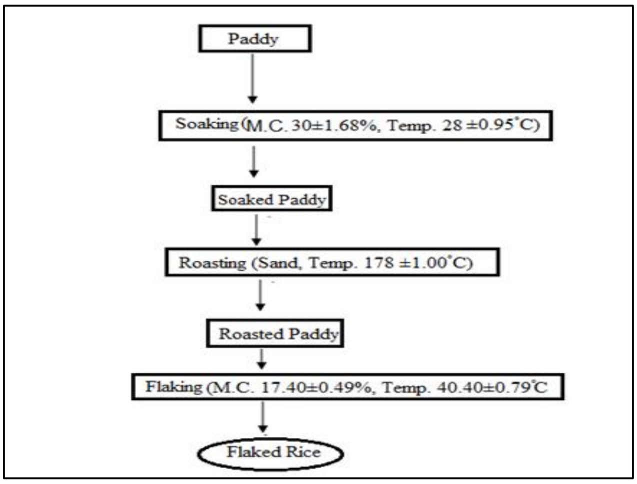


Fig 1: Process flow diagram depicting production of flaked rice

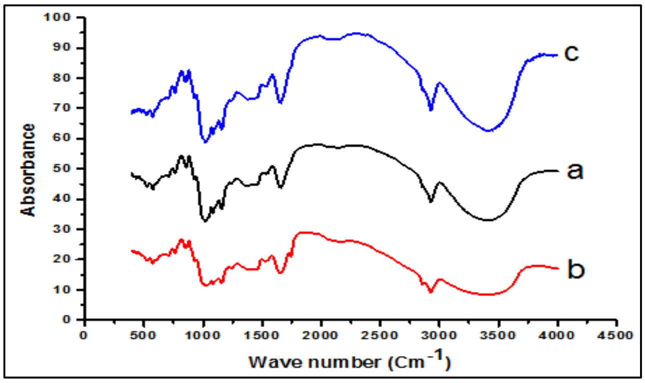


Fig 2: FTIR spectrum: (a) Brown rice (b) Roasted rice (c) Flaked rice

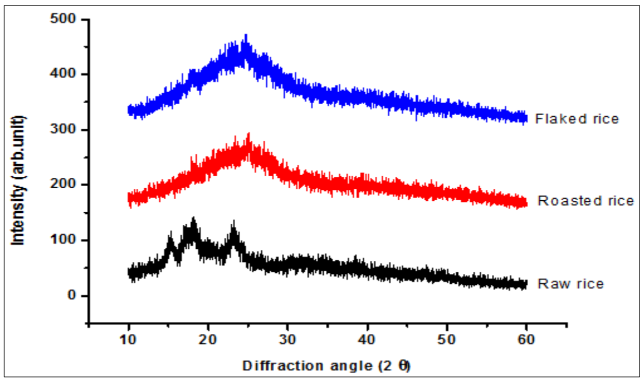
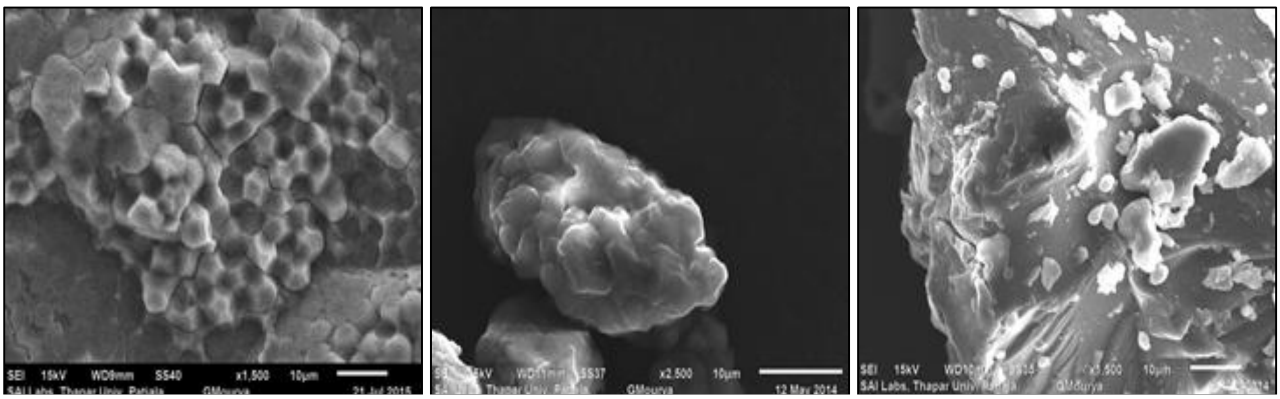


Fig 3: X ray diffraction pattern for brown rice, roasted rice and flaked rice



(i) **(ii)** **(iii)**

Fig. 4. Scanning electron micrographs at1500X and 2500X: (i) Brown rice (ii) Roasted rice (iii) Flaked rice

Conclusion

Flaked rice manufacturing process significantly affected the properties of flaked rice with respect to different intermediate products obtained during the process. The physical properties varied at each level of processing from paddy to flaked rice. The dimensional characteristics such as length and breadth of flaked rice were found to be greater than brown and roasted rice and increased approximately by two times. On the basis of optical characterization, the flaked rice was found more acceptable due to increase brightness. The increase in the resistant starch in flaked rice as compared to brown has improved the functionality of the developed ready to use food material.

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