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Valorization of Basmati-370 rice brokens into pregelatinized basmati rice flour and its characterization studies

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Abstract

Among various rice cultivars, *Basmati rice* is recognized as a small but unique group owing to its distinctive aroma, delightful flavor, and texture. During milling, 20-30% of *Basmati* rice becomes broken grains, which are typically sold at low prices. Due to limited awareness about transforming these broken pieces into value-added products, they are commonly utilized as flour or animal feed. To enhance the utilization of *Basmati*-370 brokens, converting them into pre-gelatinized rice flour presents a promising approach. Pre-gelatinized rice flour has significant potential for producing high-quality noodles and pasta. This study focused on hydrothermal pre-gelatinization and its impact on the quality of *Basmati*-370 broken rice flour. The color parameters (L^* , a^* , and b^*) of the pre-gelatinized flour exhibited notable differences based on various treatment conditions. Specifically, increasing steeping time, temperature, and steam cooking resulted in a decrease in lightness (L^*), while redness (a^*) and yellowness (b^*) values increased with higher treatment intensity. The pre-gelatinization process also elevated the flour's water activity. Furthermore, treatments influenced the bulk density, which was affected accordingly. Microstructural analysis revealed that treated flour had significantly altered structures compared to untreated samples, with starch granules appearing expanded and partially gelatinized. Correlation analysis highlighted interactions between physical properties and pre-gelatinization; notably, the L^* value negatively correlated with a^* and b^* values, positively correlated with bulk density, and negatively correlated with water activity. Storage studies showed a significant decline in color parameters over time, while water activity increased due to moisture absorption, accompanied by a decrease in bulk density likely due to rising moisture content. With the advancement of storage period, significant changes in water absorption index and swelling power was observed.

Keywords: *Basmati*-370, brokens, rice, hydrothermal treatment, pregelatinization and functional properties

Introduction

Rice (*Oryza sativa* L.) is a globally significant food crop grown in various countries. *Basmati*, a unique and aromatic variety amongst all rice cultivars that has been nurtured over many years in the Himalayan foothills of India. Generally, known for its long-grain aromatic properties, distinctive flavor, and delightful soft and smooth fluffy surface. Aroma is the most highly valued characteristic then taste and post-cooking elongation (Bhattacharjee *et al.*, 2002) ^[11].

India stands as the foremost global supplier of *Basmati* rice. In the fiscal year (2023-24), India exported 5242048.39 Metric tons (Export volume FY24) and generated revenue of 587.12 (USD Mil) from the sales of *Basmati* rice worldwide (APEDA, 2025) ^[7]. Commonly, the production of *Basmati* occurs in the Union Territory of J&K, along with other states of India like Punjab, Haryana, Himachal Pradesh, Uttarakhand, Delhi and western Uttar Pradesh (<http://apeda.gov.in>) ^[9].

It plays a significant role in the life of the people living in the alpine and sub-mountainous Union Territory of Jammu and Kashmir. The different *Basmati* types cultivated are *Basmati*-370, *Basmati*-564, *Ranbir Basmati*, *Saanwal*, *Basmati*, *PRH-10* (*Basmati* hybrid) and *Pusa 1121* (Parihar, *et al.*, 2021) ^[32]. *Basmati*-370, one of the traditional varieties, is valuable both in native and foreign marketplaces. It is a highly flavoured variety grown in the UT's subtropical areas, specifically R.S. Pura, Bishnah, Jammu, Akhnour, Samba, Hiranagar, and

Kathua Tehsils in Jammu Division. In Jammu and Kashmir, the total *Basmati* area is 68,450 ha (Mushtaq *et al.*, 2024) [28].

Broken rice or rice brokens refers to remains of the rice grains usually broken down during milling process. Numerous reasons behind, such as inherited features of different rice types, the growing favourable conditions (elevated temperature and other environmental stresses), as well as management practices during cultivation and after harvest.

These brokens are parted from the intact (head) rice and classified into various categories (Phillips *et al.*, 2024) [33]. Broken means fragments of rice grains usually smaller than three-quarters of complete grain (<https://consumeraffairs.nic.in>) [8]. It is essentially white or polished rice and has composition values very similar to polished rice. Broken rice is available at most times of the year and is sometimes economic (Aftab and Creswell, 2012) [4].

In comparison to whole rice, broken rice possesses a lower profitable cost. In the year 2023, the USDA's loan rate for long-grain whole kernels was \$245.8 per metric ton and for broken kernels was \$148.6 per metric ton (USDA, 2023) [42]. Furthermore, during the period from 2018 to 2022, India's average exported rate was \$297.9 per metric ton for 100 percent broken elongated grain, reflecting a decrease of 22.5 percent less than the price of elongated grain milled rice with 5 percent broken, priced at \$384.6 per metric ton (FAOSTAT, 2022) [13].

Due to non-availability of technology for its conversion to value added products, it is mostly used in flour form or used as animal feed. Rice is a vital starchy cereal that has a wide range of innovative food items including gluten free breads, snacks, beverages, desserts like puddings, processed meats and salad dressings (Kadan *et al.*, 2008) [18]. Moreover, rice flour has tremendous usage in various extruded food products like noodles and pasta owing to gluten-free desires. A great demand of gluten-free desires creates surplus market for the tremendous usage of rice flour in extruded products. However, raw rice can't be used to process noodles and pasta etc. due to absence of gluten. Owing to its inadequate resistance to shear force; lesser elastic gel production; low viscosity and thickening power while cooking, numerous hydrothermal methods have been effectively employed to improve the physical, chemical and functional characteristics of rice powder/ flour and starch.

Pre-gelatinization is a notable physical technique used to alter starch through various combinations of heat treatments. Significantly, this method not only affects the physico-chemical but also the functional properties (Lai, 2001) [24]. Notably, pregelatinized flour as a major ingredient is extensively utilized in numerous food products as a bulking or thickening agent. Also, useful in soups and sauces because of its lower tendency to retrogradation (Adebawale and Lawal, 2003) [3]. Novel foods generally require rice flours with well-defined functional attributes, known to affect the physical characteristics of food structures (Kaur M, Singh, 2005) [21].

Although pregelatinized *Basmati* rice flour holds significant economic value, comprehensive research on its characterization remains inadequate. This research study seeks to address this paucity by illustrating a thorough analysis that is highly relevant to the utilization of *Basmati* - 370 brokens in the production of pre-gelatinized *Basmati*

rice flour.

Materials and Methods

Polished *Basmati*-370 brokens provided by Sher-e-Kashmir University of Agricultural Sciences and Technology of Jammu was used in this study. For pre-gelatinization, polished broken grains were soaked in water in ratio 1:1 at 30 °C continuously for three hours. Then steeped into hot water bath at altered temperature (60 °C, 70 °C and 80 °C) for completely 30 minutes, later, steam cooking at different timings (5, 10 and 15 minutes). After pre-gelatinization, pre-gelatinized *Basmati* brokens were dried in a tray drier (60 °C) up to expected moisture content. Finally, the pre-gelatinized brokens were ground and converted into rice powder/flour with the help of laboratory scale grinder. The rice flour samples were stored in airtight containers and analyzed for various physical parameters and functional parameters for 3 months storage studies (30 days intervals). Furthermore, microstructure analysis and correlation studies were also observed.

Characterization of pre-gelatinized *Basmati* rice flour

Physical parameters

Color Profile: The Color value (L*, a* and b*) analysis of pregelatinized rice flour was performed by using a Hunter Lab colorimeter (Color Flex Reston VA, USA). The calibration of equipment was done with white and black standard ceramic tiles. In the Hunter's lab colorimeter, sample color is denoted by the three dimensions as L*, a* and b*. L* value represents brightness of the color in the range of values from "0" means black to "100" means white; the higher the values, the brighter will be the color. The value of a* indicates the redness of sample namely "-" means green to "+" means red. The b* value indicates the yellowness of the sample namely "-" means blue to "+" means yellow (Xiaojing *et al.*, 2018) [48].

Water activity (a_w): water activity meter (Aqua Lab) was used to measure water activity of the flours at room temperature (25 °C). The device was equipped with a container that was half-filled with ground sample and positioned into it. Within 3 to 5 minutes, water activity was measured.

Bulk density (g/ml): Bulk density was determined by loading five grams of flour into graduated cylinder (10ml) and the occupied volume was recorded to compute the bulk density.

Bulk density (g/ml) = Mass of powder (g)/Volume (ml)

Functional properties

Swelling power: The swelling power of the flour samples was determined according to Tester and Morrison (1990) method (Tester and Morrison, 1990) [40]. 0.2 gram of sample was taken into a centrifugal tube with 10 mL distilled H₂O into it. After that, sample was equilibrated at 25 °C for completely 5 minutes and then placed in a hot-water bath at 95 °C for at least 30 minutes. Then cooled at 20 °C for 1 minute and centrifuged in laboratory centrifuges (SIGMA, Laborzentrifugen, Model 3K30) at 3,500 rpm for 15 minutes for the separation of gel and supernatant. Finally, the gel was weighed up to calculate swelling power and expressed in gram per gram as per formula:

$$\text{Swelling power (g/g)} = \frac{\text{Weight of the wet sediment}}{\text{Initial weight of dried sample}}$$

Water absorption index: The Water absorption index of the sample was determined as per literature (Mir and Bosco, 2013) [27]. About 2.5 gram of sample was placed into 30 ml distilled water in pre-weighed 50 ml centrifuge tube, followed by stirring continuously for 30 minutes at 30 °C, later centrifuged in laboratory centrifuges (SIGMA, Laborzentrifugen, Model 3K30) at 3000 rpm for 10 minutes. At last, the supernatant placed into a tarred evaporating dish that was weighed.

$$\text{Water absorption index (g/g)} = \frac{\text{Wet sediment weight}}{\text{Dry sediment weight}}$$

Microstructural analysis

The microstructure of rice flour particle was examined by means of scanning electron microscope (SEM) (JEOL, JSM-IT300, Japan) functioned at 10.0 kV. Rice flour sample was mounted on an SEM stub with the help of carbon tape. The disc holding samples was positioned in vacuum sublimator sputter coater, sprayed with platinum. The stub was located on a Scanning electron microscope specimen holder, already pre-frozen by liquid nitrogen and experiential at acceleration voltage 10.0 kV. Later, the images were taken at various magnifications (50x and 250x).

Statistical analysis

All the experimental analysis was carried out in triplicate form then data was evaluated statistically via suitable tests wherever required. Standard deviation and two-way ANOVA tests were used. The physical and functional properties were subjected to ANOVA while Tukey's tests to calculate the statistically significant differences among them. All the pairwise comparisons were carried out with Fisher-LSD at 5 percent level of significance. The Statistical Package used was R software (R version 4.1.3) Moreover, Pearson correlation coefficient analysis was used to investigate the relationship between the physical properties of pregelatinized rice flours.

Results

Colour Profile (L*, a* and b*)

L* value: A perusal of data in Table 1 showed significant difference in L* value of pregelatinized *Basmati* rice flour with respect to different treatments and storage interval. The L* value of pregelatinized *Basmati* rice flour decreased significantly as compared to control. At zero day of storage, the maximum L* value of 72.80 was recorded in T₁ (control) and minimum L* value of 66.16 was recorded in T₁₀ (steeping at 80 °C and steam cooking for 15 minutes). After 90 days storage, L* value decreased significantly from 72.80 to 70.45 in treatment T₁ (control) and 66.16 to 63.48 in treatment T₁₀ (steeping at 80 °C and steam cooking for 15 minutes). The influence of treatment, storage period as well as their interaction were found to have significant value.

a* value: A review of data in Table 1 showed significant variation in a* value of pregelatinized *Basmati* rice flour with respect to different treatments and storage time. The a*

value increased significantly as compared to control. At zero day of storage, the maximum a* value of 1.14 was recorded in treatment T₁₀ (steeping at 80 °C and steam cooking for 15 minutes) while minimum L* value of 0.57 was recorded in T₁ (control). After 90 days storage, a* value decreased significantly from 1.14 to 0.92 in treatment T₁₀ (steeping at 80 °C and steam cooking for 15 minutes) and from 0.57 to 0.28 in treatment T₁ (control). It has been observed that the effect of all treatments, storage period and interaction were found to be non-significant.

b* value: Statistical results regarding b* value presented in Table 1 revealed that b* value increased significantly among all the different treatments. The findings revealed that interaction between treatments and storage displayed significant variation in b* value. At zero day of storage, the highest b* value 7.21 was found in T₁₀ (steeping at 80 °C and steam cooking for 15 minutes) while lowest b* value of 5.58 was found in T₁ (control). After 30 days storage, b* value decreased significantly from 7.21 to 7.01 in T₁₀ (steeping at 80 °C and steam cooking for 15 minutes) and from 5.58 to 5.32 in treatment T₁ (control), which further decreased to 4.91 and 6.65 after 90 days storage. The effect of all treatments displayed significant increase in mean b* value of pregelatinized *Basmati* rice flour from T₁ to T₁₀ respectively. Treatments, storage period and their interaction were found to have a significant impact during the 90-day storage studies.

Water activity: The data pertaining to water activity of pregelatinized *Basmati* rice flour in Table 2 displayed that water activity varied significantly with the treatments as well as storage time. In the beginning of storage, the maximum water activity was perceived as 0.61 in treatment T₁₀ (steeping at 80 °C and steam cooking for 15 minutes) and lowest water activity was observed as 0.49 in treatment T₁ (control). During the 90 days of storage period, water activity increased significantly from 0.61 to 0.64 in treatment T₁₀ (steeping at 80 °C and steam cooking for 15 minutes) while 0.49 to 0.54 in treatment T₁ (control). Results revealed the recorded mean water activity value of pregelatinized *Basmati* rice flour increased throughout 90 days of storage. Furthermore, treatments, storage period and their interaction were found to be non-significant.

Bulk density: Table 2 illustrated the effect of different treatments and storage time on bulk density of pregelatinized *Basmati* rice flour. Initially the lowest bulk density of 0.925 was recorded in treatment T₁₀ (steeping at 80 °C and steam cooking for 15 minutes) and highest bulk density 1.063 g/ml was recorded in treatment T₁ (control). After the 90 days of storage period, the bulk density decreased from 0.925 to 0.735 g/ml in treatment T₁₀ (steeping at 80 °C and steam cooking for 15 minutes) and from 1.063 to 1.046 in treatment T₁ (control). Moreover, the observed mean bulk density value of pregelatinized *Basmati* rice flour as affected with the applied treatments followed decreasing order.

It is evident from the table, significant effect of all treatments and storage interactions was observed with respect to bulk density at 5 per cent level of significance.

Functional properties

Water absorption index: Figure 1.1 showed the influence of various treatments and storage period on water absorption index of pregelatinized *Basmati* rice flour. Initially, the lowest value of water absorption index was noted as 2.61 g/g in treatment T₁ (control) and highest water absorption index was recorded as 3.89 g/g in treatment T₁₀ (steeping at 80 °C and steam cooking for 15 minutes). After 90 days of storage period, the water absorption index significantly declined from 3.89 to 3.56 g/g in treatment T₁₀ (steeping at 80 °C and steam cooking for 15 minutes) and from 2.61 to 2.32 g/g in treatment T₁ (control).

With the advancement of storage period, significant decrease in water absorption index was noticed. Moreover, it is evident from the figure that significant effect of all treatments and storage interactions was observed with respect to water absorption index at 5 per cent level of significance.

Swelling power: A review of data in figure 1.2 showed significant differences in swelling power of pregelatinized *Basmati* rice flour with respect to different treatment and storage duration. The swelling power of pregelatinized *Basmati* rice flour increased significantly as compared to control. At zero day of storage, the maximum swelling power of 7.46 g/g was recorded in treatment T₁₀ (steeping at 80 °C and steam cooking for 15 minutes) and minimum swelling power value of 3.42 g/g was recorded in treatment T₁ (control). After 30 days storage, swelling power increased significantly from 3.42 g/g to 3.94 g/g in treatment T₁ (control) and 7.46 to 7.66 g/g in treatment T₁₀ (steeping at 80 °C and steam cooking for 15 minutes). Between 60 to 90 days storage, swelling power of pregelatinized *Basmati* rice flour decreased from 3.82 to 3.26 g/g in treatment T₁ (control) as well as from 7.52 to 7.43 g/g in treatment T₁₀ (steeping at 80 °C and steam cooking for 15 minutes). Also, the impact of treatments, storage period and their interaction were noted as significant.

Microstructure analysis: Microstructure analysis using Scanning Electron microscopy (SEM) was carried out to know the influence of hydrothermal treatment on the microstructure of treated and untreated rice flour particles. Pictures displayed the accumulation of starch granules into particles having smooth cutting apparent. As shown in figures 2.1 and 2.2, the rice starch granules seemed to be densely packed in untreated flour at 50x and 250x magnification. The visible globular or uneven particles fixed to or positioned amid the starch granules, which might be the protein bodies or remains of disrupted protein matrix throughout the milling process. However, the microscopic structure (figures 3.1, 3.2, 4.1, 4.2, 5.1 and 5.2 at 50x and 250x magnification) of treated flours (60 °C, 70 °C and 80 °C) were significantly different to those from untreated flour, where the starch granules were expanded and appears to be partially gelatinized. Our findings clearly indicated the effect of hydrothermal treatment on the morphology of rice flour.

Correlation studies: Correlation studies between physical properties of pregelatinized *Basmati* rice flour presented in

Table 3. The colour L* value showed negative correlation with colour a* ($r = -0.73$) and colour b* value ($r = -0.079$). However, it had positive correlation with bulk density ($r = 0.89$) and negative correlation with water activity ($r = -0.93$).

The colour a* value had significant positive correlation with colour b* value ($r = 0.57$), negative correlation with bulk density ($r = -0.67$) and positive correlation with water activity ($r = 0.69$). The colour b* value exhibited negative correlation with bulk density ($r = -0.86$) and positively correlated with water activity ($r = 0.85$). Also, bulk density value depicted negative correlation with water activity ($r = -0.97$).

Discussion

Colour profile (L*, a* and b*)

Colour profile value in terms of L*, a* and b* values of pregelatinized *Basmati* rice flour showed significant variances during the application of different treatments. Significant effect of different steeping time, temperature and steam cooking on lightness (L*) value of pregelatinized *Basmati* rice flour was observed and the values decreased, whereas a* and b* value increased with the increase in time and temperature applied. The mean L* value of 72.80 in T₁ (control) decreased significantly to 66.16 in T₁₀ (steeping at 80 °C and steam cooking for 15 minutes) of pregelatinized *Basmati* rice flour. Study indicated that the lightness (L*) value of 60.26 for un-soaked rice got decreased to 9.56 per cent to 16.23 per cent with soaking temperature (Kale *et al.*, 2017) [19]. Lightness (L*) value is directly associated by level of gelatinization during parboiling method, besides the time period and soaking temperature, heating and drying (Islam *et al.*, 2004) [17]. Also reported that lightness value of parboiled rice declined with increase in soaking temperature (Sareepuang *et al.*, 2008) [34]. On the other side, the mean values a* (redness) and b* (yellowness) values of pregelatinized *Basmati* rice flour increased significantly among all the different treatments. The increase of a* (redness) and b* (yellowness) values might be due to the Maillard browning in between the reducing sugars from the heated starch, the amino group of the proteins upon high heat processing and due to their modification (Lorlowhakarn and Naivikul, 2006); (Takahashi *et al.*, 2005) [26, 39].

The 90 days storage studies of pregelatinized *Basmati* rice flour showed reduction in mean L*, a* and b* values. A study reported that the colour values decreased with storage time (Ojo *et al.*, 2017) [31]. Additionally, the initiation and progression of various oxidative and Maillard browning reactions all through storage might have reduced brightness of water chestnut flour during storage intervals (Beigh *et al.*, 2019) [10].

Water activity

Water activity of a food product is a measure to know how much of free water or unbound water is available to microorganisms for their survival and growth. For this underlying reason, water activity is a very important concern for food safety. Most of the microorganisms do not breed below water activity (a_w) level of 0.90 for most pathogenic bacteria, 0.70 for spoilage molds and 0.60 for all microbes. The lower the water activity of food product, the better will be the food stability (Vesterlund, 2012) [43]. The

mean water activity of T₁ (control) flour was observed to be 0.49 which is lower when compared with other treatments such as T₂ to T₁₀ values in the range of 0.53-0.61. It clearly depicted the effect of pregelatinization that increased the water activity of flour.

During storage, the mean value of water activity of pregelatinized *Basmati* rice flour increased. Due to the hygroscopic nature, water chestnut flour collected moisture which may have raised the water activity over time (Beigh *et al.*, 2019) ^[10]. Other researchers suggested the susceptibility of foodstuffs to fungal growth depends on various aspects in which water activity and the length of storage are most important (Abdullah *et al.*, 2000) ^[1]. They mentioned that ordinary rice and rice flour should be kept at a_w of 0.65 whereas glutinous rice flour sustained at a higher a_w of 0.75 ^[26]. Singh and Kaur recommended water activity value 0.423 which was most suitable for baby corn powder to maintain good shelf stability at room temperature (Singh and Kaur, 2019) ^[36].

Bulk density

Results revealed that the bulk density of pregelatinized *Basmati* rice flour was affected with the applied treatments. Similar outcomes were stated by Bhise *et al.* (2014) ^[12] who stated that bulk density decreased with the rise in moisture content of grain. The bulk density of rice varied and declined but moisture content increased (Kibar *et al.*, 2010) ^[22]. Our findings are supported by Kashaninejad who analysed that the bulk density of rice decreased from 678.19 kg/m³ to 647.10 kg/m³ at soaking temperature of 25 °C to 40 °C and increased to 702.69 kg/m³ at soaking temperature of 70 °C (Kashaninejad *et al.*, 2007) ^[20]. Similarly, they concluded that bulk density of samples (soaked) at every soaking temperatures was lesser than samples prior to soaking (773.72 kg/m³). The decline in bulk density as the soaking temperature increased up to 40 °C depicted that reduction in mass might be due to gaining of water content by the sample and fewer than associated volumetric expansion of the bulk; beyond 40 °C is vice versa.

Storage studies of pregelatinized *Basmati* rice flour revealed a significant decrease in mean bulk density values which might be due to rise in moisture content and water activity. Increased moisture content besides decline in other components like crude fat and crude protein during storage resulted in decrease in bulk density (Zeigler *et al.*, 2016) ^[49]. Similar findings were investigated that an increase in the moisture content and water activity of water chestnut flour that changed the particle size distribution which may have perhaps decreased the bulk density of flour during storage period (Beigh *et al.* 2019) ^[10]. A decline in the density values of maize flour with the advancement of time was also examined in another study (Shobha *et al.*, 2014) ^[35]. Likewise, the storage period greatly influenced the bulk density of Indian horse chestnut flour and observed decreased bulk density with storage duration (Kumar and Thakur, 2017) ^[23].

Water absorption index

The water absorption index indicates capability of a food product to grasp water (Singh, 2001) ^[37]. The water absorption index of flour performs vital role in product development, such as it specifies the amount of water needed to improve dough of optimal consistency as well as it represents the attributes and behavior of the flour once

hydrated. Similarly, the water absorption index indicates the volume that a granule or starch polymer occupies after swelling in excess water (Singh and Kaur, 2019) ^[36]. The overall mean value of water absorption index revealed a significant increase from 2.61 g/g to 3.72 g/g that might be due to the heating treatment applied. It was evaluated that after hydrothermal treatment, the water absorption index of treated pregelatinized flour TCSW 1 rice increased (3 times that of raw rice) whereas other treated TCS 10 and TCS 17 increased slightly (1.2 ± 1.8 times of raw rice). ^[12] According to literature ^[17] the effect of soaking temperature on water absorption index of raw and parboiled samples among different rice cultivars. Their results revealed that the water absorption index increased with increase in temperatures at 60, 70 and 80 degree celsius. Besides, the compositional differences in carbohydrate, protein, fat, fibre and amylose concentration of the flour also result in changes in water absorption index of flour (Nura, 2011) ^[29].

During storage period of 3 months, water absorption index declined from 3.43 to 3.12 g/g. Our outcomes coincided with the findings of Singh and Kaur (2019) who evaluated that the water absorption index of baby corn soup mix decreased significantly from 3.150 to 2.582 g/g. Similar findings were observed (Nwosu *et al.*, 2011) ^[30].

Swelling power

Swelling power is another important functional characteristic of starch that shows the ability of starch to gain moisture under a definite cooking condition of 92.5 °C for 30 minutes (Ahmed *et al.*, 2016) ^[6]. The present study observed that the overall mean value of swelling power of pregelatinized *Basmati* rice flour increased significantly as compared to control i.e. from 3.61 to 7.52 g/g. According to another literature, the swelling power of rice flour falls in the range of 5.82 to 16.23 g/g (Fari *et al.*, 2011) ^[14]. Another study, determined the swelling power of 10.54 g/g in rice starch (Hormdok and Noomhorm, 2007) ^[16]. It has been suggested that various aspects like rice-milling techniques, temperature, starch granules, protein content, amylose and amylopectin concentration might 'distress the swelling power of rice flour (Ahmed *et al.*, 2016) ^[6]. One more study investigated the effect of rice-milling methods such as dry milling and wet milling and temperature on the swelling power capacity of rice flour. They found swelling power of wet and dry milled rice flour were 3.8 g/g, 12.6 g/g at 25 °C and 4.7 g/g, 10.9 g/g at 100 °C temperature (Heo *et al.*, 2013) ^[15]. Likewise, Thiranusornkij *et al.*, 2018 ^[41] analysed swelling power of different rice flours such as *Hom Nil rice* (HN) and *Hom Mali rice* (HM) raised as temperature (55 °C to 95 °C) increased. Results revealed that HN rice had lower swelling power ranging from 4.38 ± 0.2 g/g to 15.8 ± 0.5 g/g at all temperatures. Our results are supported by another literature who stated that the swelling power of pregelatinization gayam flour increased as the pregelatinization time increased (Wijanarka *et al.*, 2017) ^[47].

While assessing the storage behaviour it was found that the mean swelling power increased from 6.31 to 6.60 g/g during 30 days, later undergoes reduction during 90 days of storage. Overall mean values showed decline in swelling power from zero day to final day. Moreover, the influence of treatments, storage duration and their relations were observed significant. Similar results were observed for the swelling power of sweet potato flour that decreased in the first two weeks of storage later, increased amid the two to

four weeks storage (Agbemafle *et al.*, 2014) [5]. While this trend continued to sixth week in ambient conditions finally a decline in week four were reported in all the storage methods.

Microstructural analysis of pregelatinized *Basmati* rice flour

Microstructure analysis using SEM was carried out to know the effect of hydrothermal treatment on the microstructure of treated and untreated rice flour particles. The SEM images represented the shape of the rice flour particles as irregular polyhedral shapes (Figure 2.1) According to literature, polyhedral types of granules are common in rice starch. Uneven polyhedral shapes and agglomeration amid starch granules and further constituents were also observed (Wani *et al.*, 2012) [45]. Usually, rice starches in tropical areas characterized polyhedral, round and irregular forms (Wani *et al.*, 2013) [44]. In addition, the photographs presented the aggregation of starch granules into particles with a smooth cutting surface (Suklaew *et al.*, 2020) [38]. The rice starch granules appeared to be closely packed in untreated flour, as seen in figures 2.1 and 2.2. Conversely, treated flours at 60 °C, 70 °C, and 80 °C had a very diverse microscopic structure (figures 3.1, 3.2, 4.1, 4.2, 5.1 & 5.2), where the starch granules were enlarged and seemed to be partially gelatinized.

According to previous results, the flours obtained from rice cooked at 90 °C for 45 minutes were significantly dissimilar

to those obtained from 50 °C for 45 minutes where a coarser and discontinuous honeycomb-like arrangement with pores designed due to gelatinization of starch and denaturation of proteins. Consequently, the cooking temperature of the rice grain had a more significant impact on the microscopic structure of flours compared to cooking time. At a microscopic level, the cooking temperature led to an increased pore size and a more substantial starch matrix within the inner layer of the endosperm (Leelayuthsoontorn and Thipayarat, 2006) [25].

Correlation studies between physical properties of pregelatinized *Basmati* rice flours

The correlation studies are beneficial in product development. In the present research work, correlation results clearly depicted the interactions of physical properties and pregelatinization. The colour L* value showed negative correlation with colour a* and b* value. However, it had significant positive correlation with bulk density while negative correlation found with water activity of pregelatinized *Basmati* rice flour. A study revealed that the correlation between gelatinization percentage and total colour changes which include all three L*, a* and b* values (Abhiram, 2018) [2]. Another study carried out Pearson's correlation coefficients of physicochemical, functional and pasting characteristics of rice and maize flour to create relationship among variables (Wani *et al.*, 2015) [46].

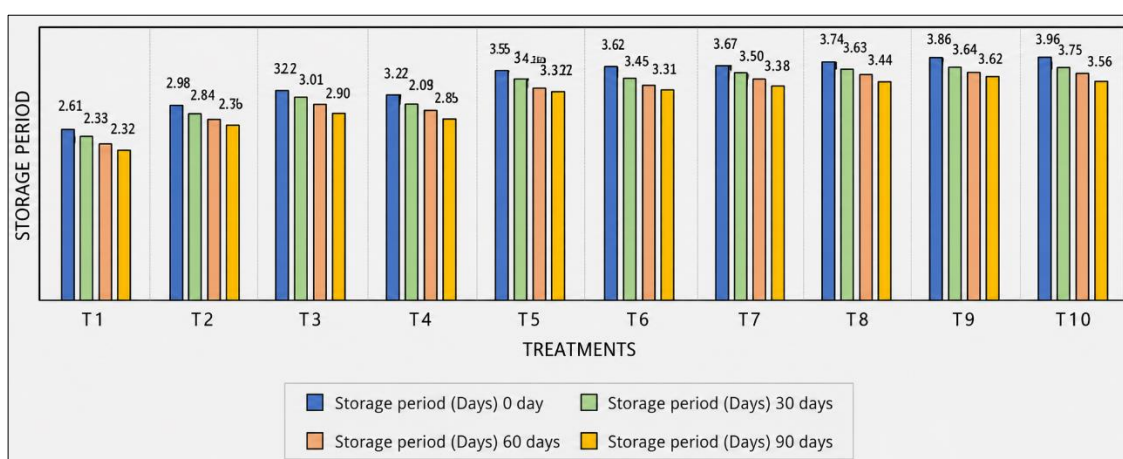


Fig 1: Effect of steeping temperature and cooking time on water absorption index (g/g) of pregelatinized basmati rice flour

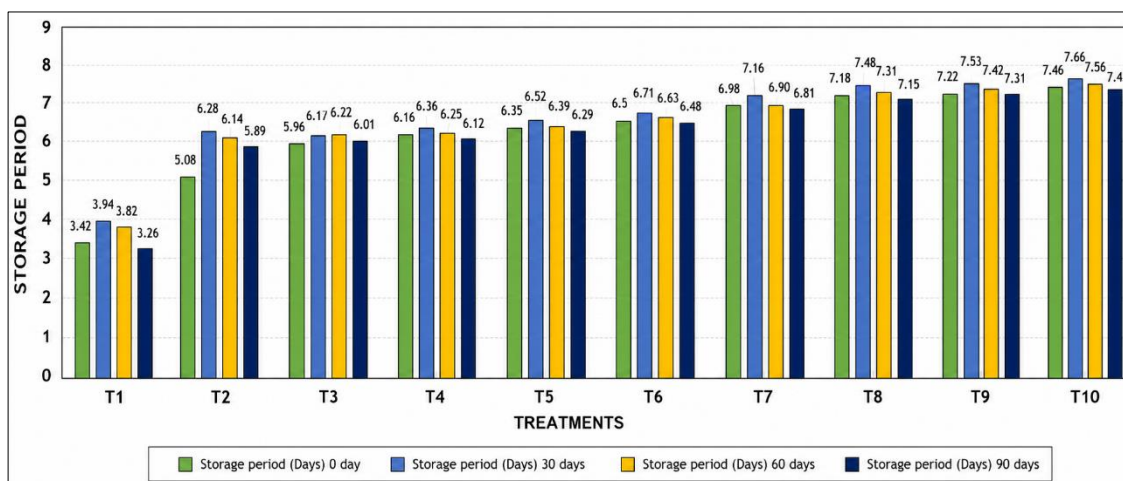


Fig 2: Effect of steeping temperature and cooking time on swelling power (g/g) of pregelatinized basmati rice flour

Table 1: Effect of steeping temperature and cooking time on colour value (L*, a* and b*) of pregelatinized *basmati* rice flour

Treatments	Lightness (L* value) Redness (a* value) Yellowness (b* value) Storage period (months) Storage period (months) Storage period (months)											
	0	1	2	3	0	1	2	3	0	1	2	3
T ₁ Control	72.80 ^a	72.32 ^b	71.09 ^c	70.45 ^d	0.57 ^{qrst}	0.46 ^{tuv}	0.39 ^{vwx}	0.28 ^x	5.58 ^{pq}	5.32 ^r	5.02 ^s	4.91 st
T ₂ (Steeping at 60 °C for 30 min. + steam cooking for 5 min.)	68.83 ^e	68.02 ^g	67.98 ^{gh}	66.87 ^l	0.66 ^{opqr}	0.53 st	0.40 ^{uvw}	0.31 ^{wx}	5.83 ^{mn}	5.69 ^{op}	5.30 ^r	4.99 st
T ₃ (Steeping at 60 °C for 30 min. + steam cooking for 10 min.)	68.78 ^e	67.89 ^h	66.66 ^m	65.09 ^x	0.96 ^{defgh}	0.89 ^{ghijk}	0.78 ^{klmn}	0.65 ^{pqr}	5.74 ^{no}	5.57 ^q	5.29 ^r	4.90 ^t
T ₄ (Steeping at 60 °C for 30 min. + steam cooking for 15 min.)	68.54 ^f	67.48 ^k	66.39 ^o	65.23 ^w	1.05 ^{abcde}	1.01 ^{bcdef}	0.97 ^{cdefg}	0.82 ^{jklm}	6.01 ^{kl}	5.92 ^{lm}	4.73 ^u	4.48 ^v
T ₅ (Steeping at 70 °C for 30 min. + steam cooking for 5 min.)	67.78 ⁱ	66.50 ⁿ	65.50 ^v	64.34 ^A	0.80 ^{klm}	0.73 ^{mno}	0.64 ^{pqrs}	0.51 ^{tu}	6.17 ^j	6.05 ^k	5.94 ^{klm}	5.76 ^{no}
T ₆ (Steeping at 70 °C for 30 min. + steam cooking for 10 min.)	67.62 ^j	66.28 ^p	65.02 ^x	64.81 ^y	0.85 ^{hijkl}	0.77 ^{lmno}	0.68 ^{nopq}	0.56 ^{rst}	6.81 ^{de}	6.68 ^f	6.44 ^g	6.21 ^{ij}
T ₇ (Steeping at 70 °C for 30 min. + steam cooking for 15 min.)	67.57 ^{jk}	66.08 ^r	64.83 ^y	64.60 ^z	1.08 ^{abc}	1.03 ^{abcde}	0.97 ^{cdefg}	0.85 ^{hijkl}	6.92 ^{bcd}	6.71 ^{ef}	6.43 ^g	6.19 ^{ij}
T ₈ (Steeping at 80 °C for 30 min. + steam cooking for 5 min.)	66.38 ^o	65.86 ^t	64.33 ^A	65.67 ^u	0.85 ^{hijkl}	0.79 ^{klmn}	0.66 ^{opqr}	0.52 ^t	6.85 ^d	6.52 ^g	6.30 ^{hi}	6.03 ^{kl}
T ₉ (Steeping at 80 °C for 30 min. + steam cooking for 10 min.)	66.24 ^{pq}	65.96 ^s	64.86 ^y	63.18 ^C	1.10 ^{ab}	0.94 ^{efghi}	0.84 ^{ijklm}	0.77 ^{lmno}	6.97 ^{bc}	6.64 ^f	6.41 ^{gh}	6.22 ^{ij}
T ₁₀ (Steeping at 80 °C for 30 min. + steam cooking for 15 min.)	66.16 ^{qr}	65.07 ^x	64.79 ^y	63.48 ^B	1.14 ^a	1.07 ^{abcd}	1.03 ^{abcde}	0.92 ^{fghij}	7.21 ^a	7.01 ^b	6.86 ^{cd}	6.65 ^f
CD (P ≤ 0.05)												
Treatments		0.05				0.06				0.03		
Storage		0.03				0.04				0.02		
Treatments × Storage		0.10				N/S				0.07		

C.D. = Critical difference

*Notes: Mean values in the column with different superscripts are significantly different at $p \leq 0.05$ **Table 2:** Effect of steeping temperature and cooking time on water activity and bulk density of pregelatinized *basmati* rice flour

Treatments	Water activity (a _w) Storage period (months) Storage period (months) Bulk density (g/ml)							
	0	1	2	3	0	1	2	3
	0.49 ^g	0.51 ^{fg}	0.52 ^{efg}	0.54 ^{cdefg}	1.063 ^a	1.060 ^a	1.055 ^a	1.046 ^{ab}
T ₁ Control	0.53 ^{defg}	0.56 ^{abcdefg}	0.58 ^{abcde}	0.60 ^{abcde}	0.989 ^{bc}	0.985 ^{bc}	0.981 ^{cd}	0.972 ^{cde}
T ₂ (Steeping at 60 °C for 30 min. + steam cooking for 5 min.)	0.54 ^{cdefg}	0.55 ^{bcdefg}	0.57 ^{abcde}	0.59 ^{abcde}	0.981 ^{cd}	0.977 ^{cd}	0.972 ^{cde}	0.960 ^{cdef}
T ₃ (Steeping at 60 °C for 30 min. + steam cooking for 10 min.)	0.54 ^{cdefg}	0.57 ^{abcde}	0.59 ^{abcde}	0.59 ^{abcde}	0.973 ^{cde}	0.967 ^{cde}	0.960 ^{cdef}	0.945 ^{cdef}
T ₄ (Steeping at 60 °C for 30 min. + steam cooking for 15 min.)	0.56 ^{abcde}	0.56 ^{abcde}	0.58 ^{abcde}	0.60 ^{abcde}	0.960 ^{cde}	0.953 ^{cde}	0.933 ^{cde}	0.917 ^{def}
T ₅ (Steeping at 70 °C for 30 min. + steam cooking for 5 min.)	0.58 ^{abcde}	0.59 ^{abcde}	0.59 ^{abcde}	0.61 ^{abcde}	0.952 ^{cde}	0.942 ^{cde}	0.928 ^{cde}	0.912 ^{ef}
T ₆ (Steeping at 70 °C for 30 min. + steam cooking for 10 min.)	0.58 ^{abcde}	0.58 ^{abcde}	0.59 ^{abcde}	0.60 ^{abcde}	0.947 ^{cde}	0.936 ^{cde}	0.920 ^{def}	0.902 ^f
T ₇ (Steeping at 70 °C for 30 min. + steam cooking for 15 min.)	0.59 ^{abcde}	0.60 ^{abcde}	0.60 ^{abcde}	0.62 ^{abc}	0.941 ^{cde}	0.929 ^{cde}	0.811 ^g	0.793 ^{gh}
T ₈ (Steeping at 80 °C for 30 min. + steam cooking for 5 min.)	0.60 ^{abcde}	0.62 ^{abc}	0.63 ^{ab}	0.63 ^{ab}	0.933 ^{cde}	0.920 ^{def}	0.762 ^{gh}	0.744 ^h
T ₉ (Steeping at 80 °C for 30 min. + steam cooking for 10 min.)	0.61 ^{abcd}	0.61 ^{abcd}	0.62 ^{abc}	0.64 ^a	0.925 ^{cde}	0.911 ^{ef}	0.754 ^{gh}	0.735 ^h
T ₁₀ (Steeping at 80 °C for 30 min. + steam cooking for 15 min.)								
CD (P ≤ 0.05)								
Treatments		0.04				0.033		
Storage		0.03				0.021		
Treatments × Storage		N/S				0.065		

C.D. = Critical difference

*Notes: Mean values in the column with different superscripts are significantly different at $p \leq 0.05$ **Table 3:** Correlation studies of physical properties of pregelatinized *basmati* rice flours

Variables	L*	a*	b*	Bulk density	Water activity
L*	1	-0.73*	-0.79**	0.89**	-0.93**
a*	-0.73*	1	0.57	-0.67*	0.69*
b*	-0.79**	0.57	1	-0.86**	0.85**
Bulk density	0.89**	-0.67*	-0.86**	1	-0.97**
Water activity	-0.93**	0.69*	0.85**	-0.97**	1

* Correlation is significant at the 0.05 level (2-tailed)

** Correlation is significant at the 0.01 level (2-tailed)

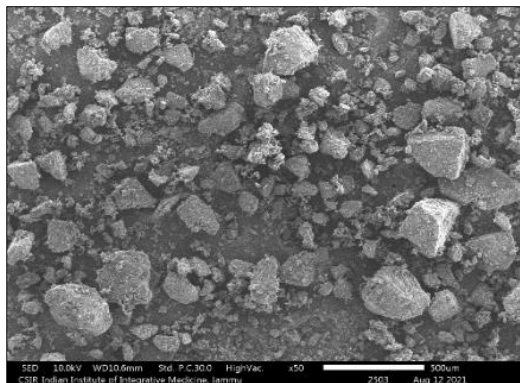


Fig 2.1: SEM images of untreated flour of 50x magnification

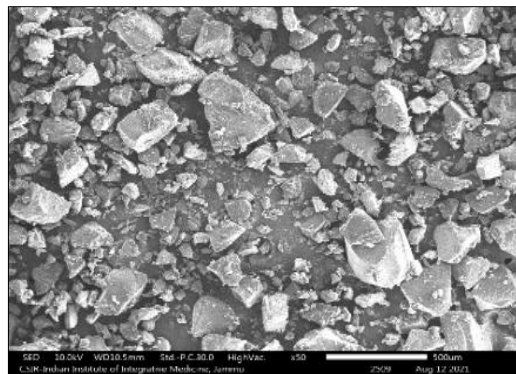


Fig 4: SEM images of treated flour (70 °C) at 50x magnification

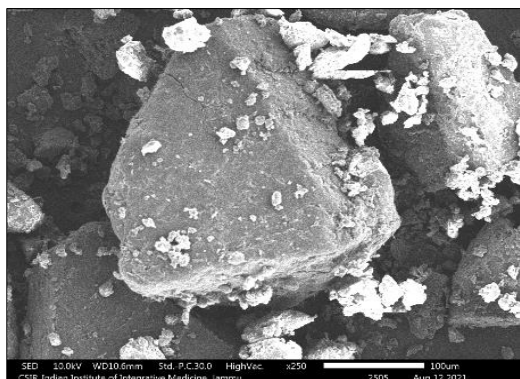


Fig 2.2: SEM images of untreated flour at 250x magnification

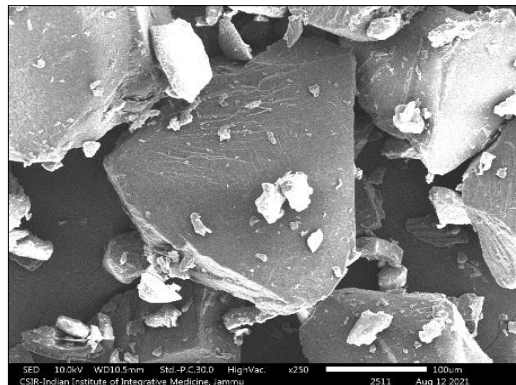


Fig 4.1: SEM images of treated flour (70 °C) at 250x magnification

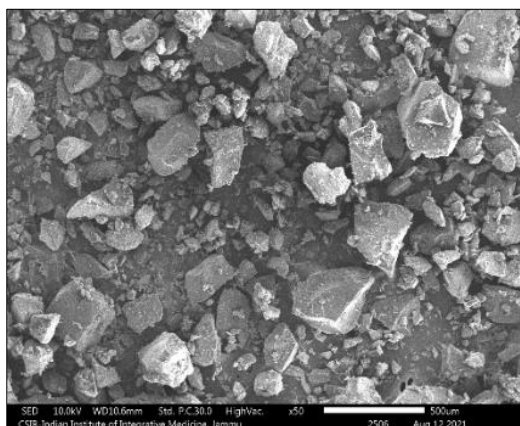


Fig 3: SEM images of treated flour (60 °C) at 50x magnification

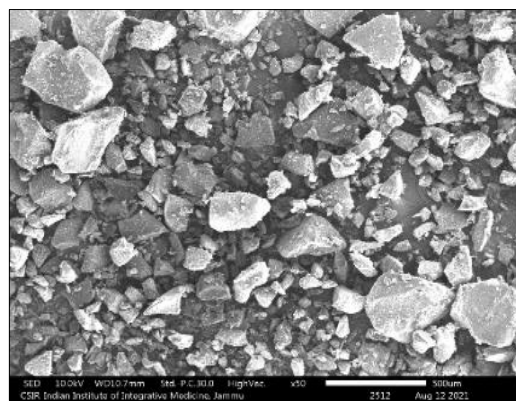


Fig 5: SEM images of treated flour (80 °C) at 50x magnification

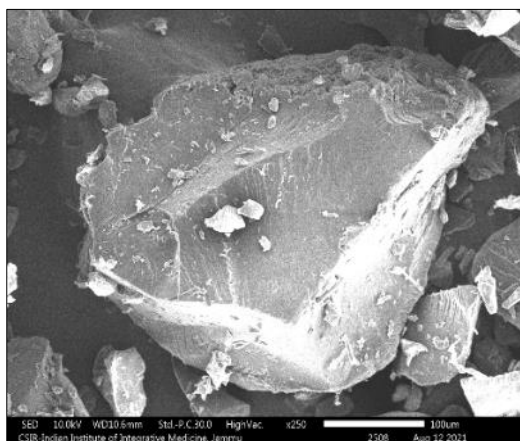


Fig 3.1: SEM images of treated flour (60 °C) at 250x magnification

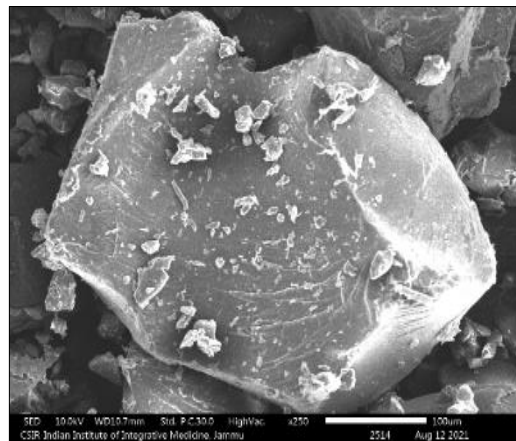


Fig 5.1: SEM images of treated flour (80 °C) at 250x magnification

Conclusion

In conclusion, it is feasible to develop pregelatinized *Basmati* rice flour from *Basmati*-370 broken. Different time and temperature for pre-gelatinization were applied in this analysis was capable to modify the physical, functional properties and morphological structure of *Basmati* rice broken flour. Accordingly, Pre-gelatinized *Basmati* rice flour would be helpful in improving the structure of batters and doughs in the absence of gluten, improves water absorption and functions as an efficient binder and thickener in gluten-free products. Furthermore, pregelatinized *Basmati* rice flour has a great possibility for making good quality noodles, pasta products and various extruded products. This research study would be very useful in intensifying the utilization and use of *Basmati*-370 broken in an effective way.

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