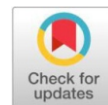


Original Research Article

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Sustainable valorization of broken basmati rice flour for functional pancake production using natural sweeteners



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ABSTRACT

In the current study, pancakes were made using broken rice flour, sugar, honey, and their mixtures, as well as popped amaranthus seeds. The quality assessment of pancakes depicted that the maximum mean a^* value (6.88), b^* value (21.95), oil absorption index (2.71g/g), water absorption capacity (2.66g/g), phosphorus content (361.53 mg/100g) and calcium content (91.39 mg/100g) were recorded in pancakes formulated using jaggery (T_3) as a sweetening agent whereas pancakes containing sugar (T_1) recorded lowest a^* value (1.18), b^* value (15.19), water absorption capacity (2.32g/g), phosphorus content (341.34 mg/100g) and calcium content (74.92 mg/100g), respectively. On evaluating the bioactive components of the pancakes it was observed that the pancakes comprising of honey recorded the highest total phenolic content and antioxidant activity which decreased significantly during refrigerated storage upto 90 days. Sensory evaluation of developed pancakes revealed that treatment T_2 (Honey) was found most acceptable and in case of crackers, treatment T_5 (86:10:4::BRF:SS:GLP) reflected highest acceptable scoring a mean value of 7.94 whereas pancakes containing jaggery scored lowest overall acceptability score of 7.14. The study encountered challenges in optimizing texture and storage stability due to the decline in bioactive compounds during prolonged storage; however, it contributes to sustainable food product development by valorizing broken rice into nutrient-rich functional foods with enhanced consumer acceptability. Hence, broken basmati rice, a rice milling by-product, can be effectively utilized for the development of pancakes using honey as a sweetener.

Keywords: Basmati broken rice, jaggery, honey, bioactive components, sensory characteristics, functional foods, storage stability, rice-based products.

Introduction

A staple food for nearly half the population of the world, rice (*Oryza sativa*) plays an integral role in the diet. The Asian region accounts for over 90 per cent of total global rice production, with China and India each contributing 28.7 per cent and 19.5 per cent of total production, respectively. India is presently self-sufficient in rice production and is also one of the world's biggest rice exporters. Rice (*Oryza sativa*) is the world's second most popular cereal grain, supplying carbohydrates, proteins, lipids, fibres, minerals, vitamins, etc. [1]. Basmati Rice is exported by India to many countries around the world. During the year 2020-21, a total of 46,30,463.14 MT of Basmati rice was exported to the world for a value of Rs. 29,849.89 crores, out of which the majority was exported to Saudi Arab, Iran, Iraq, Yemen Republic, United Arab Emirates [2]. In Indian culture, aromatic rice occupies a prominent position, not just due to its high quality, but also because they have been considered as auspicious. There is an abundance of aromatic rice in India that is collectively known as 'Basmati' rice (*bas* aroma) and is popular not only throughout Asia, but also across Europe and

the United States [3]. Basmati 1121 (PB 1121) is a rice variety that has inherited Basmati quality traits from traditional Basmati varieties such as Basmati 370 and Type 3. It has extra-long thin milled grains (9.00 mm), a nice aroma, and a cooked kernel elongation ratio of 2.5, with cooked kernel lengths of up to 22 mm, volume expansion of more than four times, attractive taste, good tongue feel, and easy digesting. It has set new norms in the Basmati rice market due to its remarkable quality attributes. Since 2008, the export of PB 1121 has generated US\$20.8 billion in foreign exchange revenues, bringing prosperity to millions of Basmati growers [4].

In India, the proportion of broken rice is considerably high, particularly in Jammu and Kashmir, where a majority of rice millers continue to employ traditional hullers rather than modern shellers for paddy milling. In the case of raw rice, the proportion of broken kernels has been reported to range between 20–30%. The miller loses 45 to 50 percent of his profit due to broken rice, which sells for roughly for Rs. 900 per quintal compared to Rs. 2500 for white rice. Broken rice is commonly sold for use in infant meals, rice flour, and extruded rice. Crispies, cereals, snacks, and coatings are just a few examples. Traditionally, broken rice has been utilized in making common Indian foods such as idlis [5]. Because of its bland taste, appealing white colour, hypoallergenicity and ease of digestion, rice flour made from broken rice has become a popular ingredient in many ready-to-eat morning cereals and snacks [6]. Rice is an essential food choice for individuals following a

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gluten-free diet, and it is particularly beneficial for those suffering from hypertension. It also serves as a good source of protein and contains all eight essential amino acids [7].

A pancake is a flat, thin, circular delicacy made by combining flour, milk, butter, and additional ingredients. The batter is also mixed with a leavening agent, like baking powder or soda, which works as a leavening agent and releases carbon dioxide, which aids in pancake rising and gives the finished product more chewability. After that, the batter is placed onto a skillet and fried [8]. Pancakes are made at home in Algeria and are typically eaten on holidays and special occasions. Because lifestyle changes contribute to obesity and overweight, food product development is currently focusing on lowering sugar and calorie content to raise consumer health awareness [9]. Sweeteners have been utilized to make meals more enticing and flavorful in order to draw in customers [10]. Due to their safety, usefulness, and potential as low-calorie sugar substitutes, natural sweetening agents are becoming more and more popular. The majority of commonly used synthetic sweeteners are non-nutritive and carcinogenic [11]. This study was conducted in order to offer consumers gluten-free and nutrient-dense pancakes. This study's second goal was to make use of rice brokens, which are regarded as a by-product of rice milling.

Material and Methods

Preparation of pancakes

Pancakes were formulated following the procedure described by [12] with slight modifications. The batter comprised rice flour (150 g), salt (2.0 g), baking powder (4.2 g), non-fat dried milk (15.0 g), melted butter (25 g), and popped amaranthus seeds (20 g). Control pancakes (T1) were sweetened with sugar (20 g), whereas the experimental treatments were prepared using honey (20 g), jaggery (20 g), and a combination of honey, sugar, and jaggery, as depicted in Figure 1.

All ingredients for each treatment were accurately weighed using an analytical balance. Water was added in optimized quantities to achieve a uniform batter, with the required volume varying across treatments. The batter was mixed manually with a spatula for one minute to obtain a homogenous slurry. A 90 mL portion of the batter was poured onto a preheated non-stick flat pan lightly greased with unsalted butter. Pancakes were cooked at 175 ± 5 °C for 2.5 minutes over medium gas flame until bubbles appeared on the surface. The flame was then reduced, and the pancakes were flipped to cook the opposite side for an additional 2–3 minutes until lightly browned. Pancakes prepared using various ratios of sweetening agents and rice flour were cooled to room temperature, individually wrapped in butter paper, and packed in laminated pouches for storage at -20 °C for three weeks. Frozen pancakes were reheated in a microwave oven for 30 seconds prior to physicochemical and sensory analyses, which were conducted in the same manner as for freshly prepared samples.

Storage of pancakes

The different pancakes were packed in aluminum laminate pouches (150 gauge) and stored for a period of 90 days under refrigerated conditions. The fresh as well as stored samples were analyzed periodically at an interval of 0, 30, 60, and 90 days of storage for physico-chemical, microbiological, and organoleptic characteristics.

Colour values

The colour of pancakes and crackers was measured using a Hunter's lab colouranalyser (Hunter Lab Color Flex Reston, VA, USA S.No. CX 1013). The equipment was calibrated using white and black standard ceramic tiles. In the Hunter's lab colorimeter, the colour of the sample is denoted by the three dimensions L^* , a^* , and b^* . L^* refers to the lightness of the colour of the sample and ranges from black = 0 to white = 100. A negative value of a^* indicates a green colour, where the positive value indicates red-purple colour. A positive value of b^* indicates a yellow colour and a negative value a blue colour.

Minerals [13]

The mineral contents were determined after the ash determination. The ash residue of each formulation was digested with perchloric acid and nitric acid (1:4) solution. The samples were left to cool, and the contents were filtered through Whatman filter paper 42. Each sample solution was made upto a final volume of 25 ml with distilled water. The aliquot was used separately to determine the mineral contents of calcium, phosphorus, and magnesium by using an Atomic Absorption Spectrophotometer (Spectra AA 220, USA Varian).

Functional Properties

Water absorption capacity and Water solubility index

The determination of water absorption capacity and water solubility index was carried out according to the method of [14]. A 2.5 g sample was dispersed in 25 g of distilled water, using a glass rod to break up any lumps. After stirring for 30 minutes, the dispersions were rinsed into centrifuge tubes, made up to 32.5 g, and centrifuged at 5000 rpm for 10 minutes. The water absorption capacity (WAC) is the weight of gel obtained per gram of dry ground sample. The water solubility index (WSI) is the percentage of dry matter recovered after the supernatant is evaporated from the water absorption determination. WAC and WSI were calculated as:

WAC = Weight of Sediment / Weight of Dry Solids

WSI = Weight of dissolved solids in supernatant / weight of dry solids $\times 100$

Oil absorption index (OAI)

Oil absorption index was determined according to the method of [15]. 3 ml of refined soybean oil was added to 1 g of ground sample in a centrifuge tube. The slurry in the tube was stirred and left for 30 minutes, followed by centrifugation at 3000 rpm for 10 minutes. The supernatant was decanted, and oil absorption index was calculated as:

$$\text{Oil absorption index (g/g)} = \frac{\text{Weight of sediment (g)}}{\text{Weight of raw material (g)}}$$

Bioactive components

Total phenol content

Total phenolic content of known samples was determined by the Folin-Ciocalteu method [16]. About two hundred microlitres of sample extract was mixed with 1 ml of 1:10 diluted Folin-Ciocalteu reagent. The prepared mixture was allowed to equilibrate for 5 minutes. Later, the sample was neutralized by using 800 μ L of saturated sodium carbonate followed by incubation at room temperature for 2 hours. Lastly, the absorbance was measured at 725 nm. The obtained results were expressed as milligrams of gallic acid equivalents per 100 grams of sample (mg GAE/100g) by reference to the gallic acid

calibration curve using the following equation:

$$Y=0.0158+0.0917Xr^2=0.99$$

Antioxidant activity

Free radical scavenging activity of samples was determined using a stable DPPH (1, 1, diphenyl-2 picrylhydrazyl) [17]. 0.1 ml of the extract solution was well mixed with 3.9 ml of methanol and 1.0 ml of DPPH solution. The mixture was kept at ambient temperature for 30 minutes prior to measurement of the absorbance at 517 nm.

The scavenging effect was derived using following equation:

$$\text{DPPH scavenging \%} = [1/(A_{517 \text{ nm, sample}} - A_{517 \text{ nm, control}})] \times 100$$

Where, a control is the absorbance of the control reaction (containing all reagents except the test sample).

Sensory evaluation

The pancakes were evaluated for overall acceptability by a semi-trained panel of 7-8 judges using 9-point hedonic scale assigning scores 9-like extremely to 1-dislike extremely. A score of 5.5 and above was considered acceptable [18].

Statistical analysis

The data obtained were analyzed statistically [19] using Factorial randomized design (CRD) for interpretation of results through analysis of variance at $p=0.05$.

Results and Discussion

Functional Properties of Pancakes

Water Absorption Capacity: For the development of ready-to-eat food products using cereal grains, water absorption capacity is the important functional property that assures the product cohesiveness. The Treatment T_3 (Jaggery) exhibited a higher water absorption capacity of 2.66g/g (Table 1). The reason might be that the high water absorption properties of fibre interfered with the degradation of starch granules resulting in a high water absorption index due to the fibre absorbing water. Our results are in agreement with [20] who reported increase in water absorption index with the increase in the level of beetroot leaf powder in extruded products. Similar finding were reported by [21] in amaranth blended snacks. [22] also reported an increase in water absorption index of nuggets prepared from chickpea and green leaf powder.

Oil Absorption: The oil absorption capacity enhances the palatability of food and is considered critical for the retention of flavor [23]. The addition of jaggery in pancakes resulted in an increase in oil absorption capacity of pancakes as compared to sugar and honey based pancakes (Table 1). This might be attributed to the increased moisture content of jaggery based pancakes. Foods with high moisture content of plant origin absorb more oil content than those of animal foods [24]. According to [25] the rate of oil absorption is also associated with high protein content. The ability of flours to bind with oil makes them useful in food applications where optimal oil absorption is desired, making flours have potential functional applications like enhancement in flavor and mouth feel. Upto certain extent oil absorption capacity is desirable for the improvement of palatability, extension of shelf life and flavor retention particularly in bakery products where fat absorption is desirable [26].

Hunter Colour Values (L^* , a^* and b^*): The colour value L^* , a^* and b^* values varied in broken basmati rice pancakes with the incorporation of different sweetening agents (Table 2). The mean L^* value decreased significantly from 65.68 in treatment T_1 (100:00:00::PRF:CP:GM) to 52.99 in treatment T_6 (85:5:10::PRF:CP:GM). Our findings are supported by [27] in muffins, wherein the findings reflected that the jaggery muffins showed lower values for lightness, higher values for redness and yellowness than sugar muffins. Our results are in agreement with [28] who reported that there was a slight decrease in lightness (L^*), an increase in a value (a^*) and yellowness (b^*) value of cookies incorporated with honey. While assessing the mean a^* value, it was found that a^* value increased significantly from 3.47 to 4.99 during 90-day storage duration. The observed variations in color parameters (L^* , a^* , and b^*) are likely due to non-enzymatic Maillard reactions and acrylamide formation, which enhance the generation of brown chromophores, thereby contributing to the darkening of the product [29]. These findings are supported by [30] and [31], who reported that the lightness.

Minerals: Among all the pancakes formulated using different proportions of sugar, honey, jaggery and their combinations, treatment T_3 (Jaggery) exhibited highest mean calcium content of 91.39 mg/100 gm and phosphorus content of 361.53 mg/100gm while the least mean calcium content of 74.92 mg/100gm and phosphorus content of 341.34 mg/100gm was recorded in treatment T_1 (Sugar) which can be seen in table 3. Our findings are supported by [32] who reported an increase in mineral content of cakes after the replacement of sugar with jaggery due to the higher mineral content in jaggery. Similar results have been reported by [33] in cassava-based pancake (*kabalagala*) formulae composed of orange-fleshed sweet potato, iron-rich beans, cassava and sweet banana. The increase in the mineral content might be due to the higher amount of mineral content present in the raw materials utilized for the preparation of pancakes. There was a significant decrease in phosphorus and calcium content with the advancement of storage time. The mean phosphorus and calcium content reduced from the initial value of 352.70 to 351.46 mg/100g and 82.40 to 81.77mg/100g, respectively. The decrease in mineral content during storage might be attributed to the interaction between minerals and other compounds like carbohydrates and proteins (Maillard reaction products), reducing bioavailability [34].

Bioactive Components of Broken Basmati Rice Flour Pancakes

Total Phenolic Content: Phenolic compounds are known to have antioxidant properties such as reactive oxygen scavenging and inhibition, metal chelation and electrophile scavenging [35]. In this study, all treatments significantly influenced the total phenolic content of broken basmati rice flour-based pancakes prepared using sugar, jaggery, honey and their combinations. On assessing the mean total phenolic content of broken basmati rice flour pancakes, the maximum mean value of 157.86 mg GAE/100g was observed in treatment T_2 (Honey) and 104.73 mg GAE/100g as the minimum mean value in treatment T_1 (Sugar). Results revealed that it might have increased due to the addition of honey. Similar results of increased total phenolic content were reported by [28] in cookies incorporated with honey. [36] also reported an increase in total phenolic content of pancakes blended with unripe papaya powder.

During 90 days of storage, there was a significant decrease in the mean total phenolic content of broken basmati rice flour pancakes from 145.70 to 118.91 mg GAE/100g (Table 4). This may be attributed to degradation by the heating effect which increased with increase in storage temperature [37]. [38] also reported a decrease in total phenolic content of fibre-enriched tortilla chips and [39] in pasta formulated using pregelatinized broken basmati rice flour, carrot pomace powder and groundnut meal.

Antioxidant Activity: Phenolic compounds are a class of antioxidant agents that acts as free radical terminators. The mean antioxidant activity of pan cakes increased with the incorporation of honey and jaggery (Table 4). This might be attributed to the increased antioxidant activity of sweetening agents. [40] reported an increase in antioxidant activity of pomegranate-enriched pancake. [36] also reported an increase in total antioxidant content of pancakes blended with unripe papaya powder. It is suggested that phytochemical compounds are partly responsible for the antioxidant activity [41]. With the advancement of time, a significant decrease in antioxidant activity was noticed (Table 4). The reason might be due to the oxidation of antioxidant components during storage [42].

Sensory Evaluation of Pancakes: The treatment and storage had a significant impact on the sensory attributes of broken basmati rice flour pancakes. The overall acceptability scores are adjudged on the basis of sensory scores obtained from evaluation of colour, texture, taste and flavor. Highest overall acceptability scores were obtained for broken basmati rice flour pancakes prepared using 20 g honey, followed by those prepared using a combination of sugar and honey in the ratio of 10:10:sugar:Honey. Lowest sensory scores were obtained for broken basmati rice flour pancakes formulated using 20g sugar

(Fig 1). Similar results have been reported by [43] in muffins prepared by replacing sugar with natural sweeteners. They stated that jaggery can be substituted upto 100 percent in terms of overall acceptability and honey can be substituted in muffins upto the levels of 20 percent. The best combination for muffins was jaggery: honey: stevia at 15:10:75 levels. Our findings agree with those of [44] in ash gourd candy, wherein ash gourd candy prepared using 72^o Brix Honey scored maximum value for colour, appearance, flavour, taste and overall acceptability score. Significant decrease in sensory characteristics was observed during the storage period of 90 days. The mean overall scores for sensory parameters of pancakes decreased during storage might be attributed to non-enzymatic browning reaction (Maillard reaction), auto oxidation of fats [45] or might be due to changes in objective characteristics. It is clear from the above findings that basmati rice can be transformed into flour to create ready-to-eat items with added value. Throughout the 90-day storage period (in the refrigerator), the created pancakes maintained their quality, with the microbiological count staying within the recommended ranges. Treatment T₂ (Honey) was determined to be the best of all the treatments based on sensory evaluation. In order to improve the nutritional and financial status of farmers, by-products from rice milling, such as broken rice, can be utilized to make nutritious, ready-to-eat food products.

Table 1: Effect of sweetening agents on water absorption capacity and Oil absorption index of broken basmati rice flour pancakes

Treatments	Water absorption capacity (g/g)	Oil absorption index(g/g)
T ₁ (Sugar)	2.32	2.25
T ₂ (Honey)	2.57	2.36
T ₃ (Jaggery)	2.66	2.71
T ₄ (Sugar + Honey)	2.39	2.11
T ₅ (Sugar + Jaggery)	2.43	2.52
T ₆ (Honey + Jaggery)	2.47	2.33
Mean	2.48	2.37
CD (p=0.05)	0.05	0.05

Table 2: Effect of sweetening agents on colour values of broken basmati rice flour pancakes

Treatments	Colour values	0 Day	30 Day	60 Day	90 Day	Mean
T ₁ (Sugar)	L* Value	72.16	70.78	67.62	63.17	68.43
	a* Value	0.95	1.12	1.27	1.40	1.18
	b* Value	14.96	15.12	15.29	15.42	15.19
T ₂ (Honey)	L* Value	64.23	62.11	58.98	55.06	60.09
	a* Value	1.31	1.52	1.71	1.93	1.61
	b* Value	17.53	17.69	17.82	17.98	17.75
T ₃ (Jaggery)	L* Value	52.83	49.92	46.88	43.12	48.18
	a* Value	6.58	6.80	7.01	7.14	6.88
	b* Value	21.74	21.87	22.03	22.16	21.95
T ₄ (Sugar + Honey)	L* Value	68.13	65.71	62.00	59.18	63.75
	a* Value	1.02	1.15	1.28	1.42	1.21
	b* Value	15.68	15.81	15.97	16.12	15.89
T ₅ (Sugar + Jaggery)	L* Value	60.27	57.82	54.39	50.16	55.66
	a* Value	3.18	3.32	3.50	3.65	3.41
	b* Value	18.10	18.23	18.39	18.52	18.31
T ₆ (Honey + Jaggery)	L* Value	55.93	52.26	49.62	45.62	50.85
	a* Value	4.92	5.08	5.21	5.35	5.14
	b* Value	20.34	20.49	20.61	20.78	20.55
Mean	L* Value	62.25	59.76	56.58	52.71	
	a* Value	2.99	3.16	3.33	3.48	
	b* Value	18.05	18.20	18.35	18.49	
CD (p=0.05)	L* Value Treatment (T) : 0.03 Storage (S) : 0.02 (T) × (S) : 0.05 0.06	a* Value Treatment (T) : 0.02 Storage (S) : 0.02 (T) × (S) : 0.05 0.06		b* Value Treatment (T) : 0.23 Storage (S) : 0.02 (T) × (S) : 0.05 0.06 0.03		

Table 3: Effect of sweetening agents on mineral content of broken basmati rice flour pancakes

Treatments	Treatment	0 Day	30 Day	60 Day	90 Day	Mean
Phosphorus content (mg/100g)	T ₁	342.06	341.52	341.08	340.73	341.34
	T ₂	350.93	350.46	350.02	349.75	350.29
	T ₃	362.16	361.79	361.26	360.91	361.53
	T ₄	348.45	348.07	347.68	347.23	347.85
	T ₅	355.13	354.72	354.19	353.88	354.48
	T ₆	357.52	357.14	356.83	356.29	356.94
	Mean	352.70	352.28	351.84	351.46	
C.D _(p=0.05)	Treatment (T) : 0.02; Storage (S) : 0.01; (T) X (S) : 0.03					
Calcium content (mg/100g)	T ₁	75.25	75.02	74.85	74.59	74.92
	T ₂	80.73	80.55	80.32	80.17	80.44
	T ₃	91.73	91.52	91.28	91.03	91.39
	T ₄	77.60	77.48	77.23	76.98	77.32
	T ₅	83.92	83.76	83.54	83.27	83.62
	T ₆	85.18	85.03	84.86	84.58	84.91
	Mean	82.40	82.22	82.01	81.77	
C.D _(p=0.05)	Treatment (T) : 0.03; Storage (S) : 0.03; (T) X (S) : 0.07					

Table 4: Effect of sweetening agents on bioactive components of broken basmati rice flour pancakes

Treatments	Treatment	0 Day	30 Day	60 Day	90 Day	Mean
Total phenolic content (mg GAE/100g)	T ₁	112.18	110.51	102.53	93.72	104.73
	T ₂	173.16	165.43	153.19	139.67	157.86
	T ₃	148.28	140.73	131.37	120.13	135.12
	T ₄	146.18	138.60	131.68	122.18	134.66
	T ₅	134.20	126.43	117.37	105.67	120.91
	T ₆	160.20	151.21	143.13	132.11	146.66
	Mean	145.70	138.81	129.87	118.91	
C.D _(p=0.05)	Treatment (T) : 1.03; Storage (S) : 0.02; (T) X (S) : 0.05					
Antioxidant activity (%)	T ₁	35.48	33.54	24.10	15.07	27.04
	T ₂	45.36	43.67	35.29	28.79	38.27
	T ₃	42.29	40.69	34.12	25.31	35.60
	T ₄	41.80	38.23	30.59	23.85	33.61
	T ₅	40.73	36.16	32.68	23.12	33.17
	T ₆	44.12	42.35	35.21	26.42	37.02
	Mean	41.63	39.10	31.99	23.76	
C.D _(p=0.05)	Treatment (T) : 0.03; Storage (S) : 0.02; (T) X (S) : 0.05					

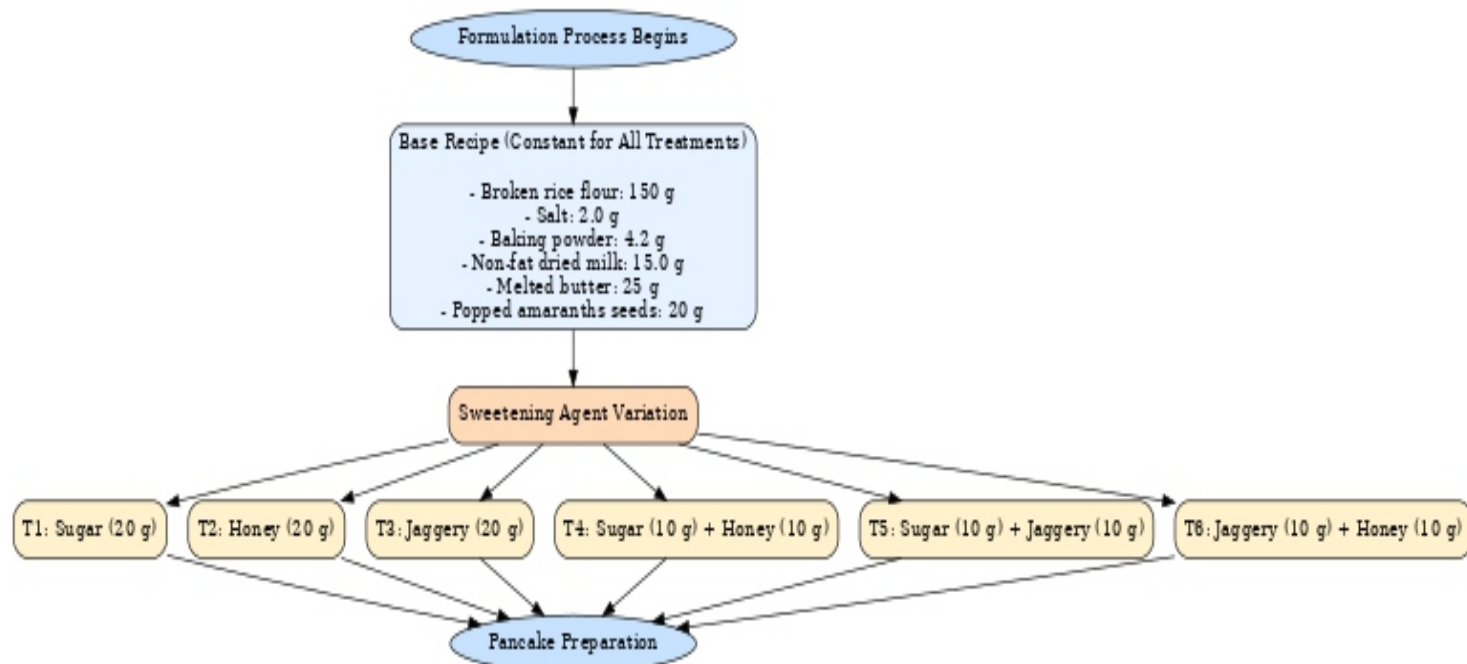


Figure 1: Flow chart for the preparation of broken basmati rice flour pancakes

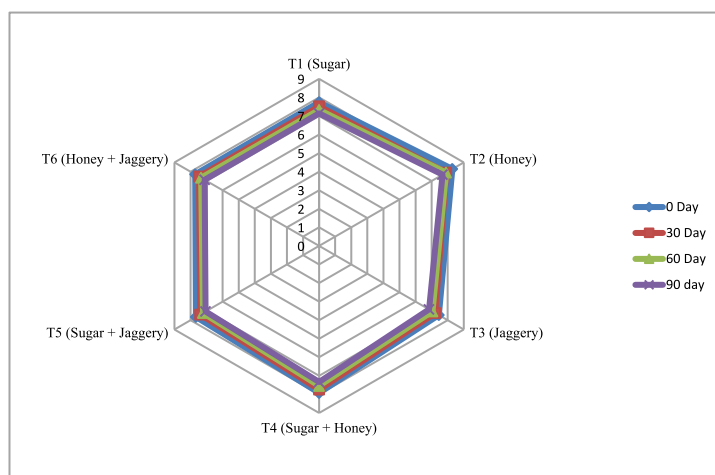


Figure 2: Effect of sweetening agents on overall acceptability scores (Hedonic scale) of broken basmati rice flour pancakes

Conclusion

The present study demonstrated that broken basmati rice, a by-product of rice milling, can be effectively valorized into nutrient-dense, gluten-free pancakes using natural sweeteners such as honey and jaggery. Among the treatments, pancakes prepared with honey (T_2) exhibited superior sensory acceptability, higher total phenolic content, and enhanced antioxidant activity, while jaggery-based pancakes (T_3) showed improved mineral content and functional properties such as water and oil absorption capacities. The incorporation of natural sweeteners contributed not only to the nutritional enhancement but also to the development of functional food products with potential health benefits. During storage, a gradual decline in bioactive compounds, mineral content, and sensory scores was observed, highlighting the need for optimized storage conditions and formulation strategies to maintain product quality. Overall, the study underscores the potential of utilizing broken rice for the production of functional, ready-to-eat foods, contributing to sustainable food systems and minimizing post-milling losses.

Future Scope: Future research can focus on enhancing the shelf-life and storage stability of broken rice-based pancakes through natural preservatives, optimized packaging, or stabilizing agents. Nutritional fortification with fruit, vegetable, or protein powders could further improve their functional properties. Additionally, exploring other rice-based functional products, such as snacks, cookies, and extruded cereals, can expand the utilization of broken rice. Economic and consumer acceptance studies will help evaluate the commercial feasibility and potential market adoption of these sustainable, nutrient-rich products.

Declaration

The authors declare that there is no conflict of interest.

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