EFFECT OF PROCESS PARAMETERS ON PHYSICOCHEMICAL PROPERTIES AND QUALITY OF ROLLED WHOLE GRAIN CORN FLAKES - A RESPONSE SURFACE STUDY

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ABSTRACT

The commercially produced breakfast cereals are mostly prepared using refined flour, which lacks essential nutrients and contributes to nutritional deficiencies. The breakfast cereal industry in Pakistan is still under-developed, this research was aimed at optimizing and developing processing technology to produce rolled corn flakes using traditional steam rolling methods. Torque for the corn was highly significant ($P < 0.001$) and values of R^2 and R^2 adj. were 0.994 and 0.933 respectively. Torque decreased with increasing value of input variables and its mean response was 17.504±0.315 Nm and 16.81±1.184 Nm. The water absorption index (WAI) for rolled corn was 3.57725. Crude fat, crude protein, crude fiber and ash content for corn flakes were observed as 3.86±1.52, 7.57±1.65, 5.88±2.06, and 1.27±0.24, respectively. Cooking time (CT) was the most dominant factor in determining the product characteristics, followed by baking time (BT) and baking temperature (BH). It can be deduced that breakfast cereals are a good source of nutrients and have good bioavailability of minerals. Commercial processing can be performed using this data.

Keywords: Rolled corn, corn flakes, process optimization, food processing

INTRODUCTION

Cereals are prominent source of vitamins, minerals, carbohydrates, lipids and protein (Sarwar *et al.*, 2013). World production of corn is highest among cereals (FAO, 2019), while it ranks after wheat and rice in terms of production in Pakistan which stood at 5,702 thousand MT 2017-18 (GOP, 2018). It supplies substantial quantity of energy, vitamins and other micronutrients (USDA Nutrient Database, 2019). Despite having high quantities of dietary fiber and trace minerals like magnesium and phosphorous, most of it is utilized for animal feed preparation instead of being utilized for human food. Corn starch is one of the most prominent commercial product prepared form it and even is primarily used in non-food sources (Fast, 2000).

In contrast to the general perception, breakfast cereals are not a new food product and have been consumed since millennia. Traditional products like dalia, porridge, boiled and roasted cereals have been eaten in Indian Subcontinent and parts of Europe for centuries; but most of the industry is domestic scale and these are not consumed as a regular breakfast or other meal due.

Whole grain cereals contain 100% of the grain while some ready to eat (RTE) can be made with up to half of the mass from coatings and sweeteners. Majority of commercially made cereals are made from refined flour. This makes these nutritionally inferior as the elimination of bran, germ and aleurone layer results in removal of valuable nutrients like dietary fiber, minerals, antioxidants and vitamins. High glycemic index of refined flour-based breakfast cereal makes it unsuitable for consumption by diabetic patients and can also lead to obesity, metabolic disorders and cardiovascular diseases. Consumption of whole grain breakfast cereals reduces these diseases and provides nutritional benefits from naturally present bioactive compounds and dietary fiber (Smith and Tucker, 2011).

High production and reasonable nutritional profile of corn has to be utilized to make various healthy and appetizing food products. This study was primarily focused on evaluating the effects of processing parameters to produce good quality steam rolled corn flakes for human consumption with respect to the chemical composition, physicochemical properties and sensory attributes. The consumption of whole grain rolled corn flakes is non-existent in Pakistan. Traditional cereals are steamed, dried, flaked, shredded, baked, toasted, cooled, coated and packaged (Fast, 2000). Rolled cereal flakes are made by rolling cut or intact kernels along with the aforementioned processing operations. These parameters effect the quality of the breakfast cereals with respect to functional and nutritional attributes.

Process parameters involved in breakfast cereal preparation determine the physicochemical and organoleptic properties of the end products. During manufacture of traditional cereals cooking time (CT), baking time (BT) and baking temperature (BH) are the factors which have to be adjusted according to the required quality and functional attributes. Parameters like Water Absorption Index (WAI), Water Solubility Index (WSI), Color and Hardness of the flakes plays a key role in determining the overall acceptability of the flakes. This study gives an insight in to the main and interaction effects of the process parameters in relation to the end product quality. The development of breakfast cereal industry in Pakistan will lead to the availability of low-cost and nutritious products to alleviate malnutrition and associated socioeconomic impact. The primary goal of this study was to produce production models for making rolled flakes with desired characteristics to increase consumption of whole grain corn in Pakistan and pave the wave to scaling-up of the production technology.

MATERIALS AND METHODS

PROCUREMENT AND PRE-TREATMENT OF RAW MATERIALS

Corn grains (Yusafwala Hybrid) were acquired from Ayub Agriculture Research Institute (AARI) Faisalabad, Pakistan. Grains were cleaned to remove dust, dirt, straw and other foreign particles.

CEREAL MANUFACTURE PROCESS PARAMETERS

Grains were cooked in a steam cooker, followed by drying in a hot air oven and subsequently baked according to its particular baking time (BT) and baking temperature (BH) (Table 1). Parameter ranges were determined after conducting careful trials and parameters were selected with respect to the suitability for succeeding processing step and acceptability. The acceptable treatment ranges were formulated into a response surface design to prepare the following treatment plan for production of rolled whole grain corn breakfast cereals. The grains were cooked in a steam cooker at 15 psi according to the respective time mentioned in Table 1. Corn grains took 15 minutes to reach 50% moisture level in a hot air oven at 70 °C. Time and temperature were determined after conducting trials to facilitate maximum production of flakes. A machine with stainless steel, smooth surfaced pair of rolls (11.5 cm diameter) with adjustable gap was used to produce flakes from moist grains. The nip of the rolls was adjusted to ensure minimum breakage while achieving maximum compression and flaking. A convection baking oven (WF-4500RKC, Westpoint, Bordeaux, France) with temperature and time control was used to reduce moisture content of baked rolled flakes and achieve golden brown color while cooking the grains completely to make it edible. Flakes were immediately cooled after baking to avoid absorbance of moisture by the flakes. Then packed in polyethylene bags which were stored in airtight jars.

Table 1: Treatment plan for preparation of rolled whole grain corn

Cereal	**Pattern**	**Cooking time (CT)**	**Baking time (BT)**	**Baking Temp (BH)**
Maize	−−−	40	10	200
Maize	−−+	40	10	250
Maize	a00	40	20	225
Maize	−+−	40	30	200
Maize	−++	40	30	250
Maize	0a0	60	10	225
Maize	00a	60	20	200
Maize	0	60	20	225
Maize	0	60	20	225
Maize	00A	60	20	250
Maize	0A0	60	30	225
Maize	+−−	80	10	200
Maize	+−+	80	10	250
Maize	A00	80	20	225
Maize	++−	80	30	200
Maize	+++	80	30	250

CHEMICAL ANALYSIS OF GRAINS AND ROLLED FLAKES

The grains and produced corn flakes were analyzed for moisture, crude fat, crude protein, and nitrogen-free extract using methods devised by AACC (2000) using methods No. 44-15, 30-25, 46-10, 32-10 and 30-25 respectively.

COLOR OF ROLLED FLAKES

Lightness (L), redness(a), and yellowness (b) was measured using colorimeter (Color Tec-PCM^{TM}, Pittsford, New York, USA.) following method by Holguín-Acuña *et al.* (2008).

TEXTURE OF ROLLED FLAKES

Breaking strength (hardness) of the produced cereal flakes was measured using method adopted by Onwulata *et al.* (2001) using TA-XT2, Plus, Stable Microsystems, Surrey, UK, interfaced with Texture Expert program version 4.0.9.0.

BULK DENSITY OF ROLLED FLAKES

Bulk density of the flakes was determined by using the volume of 1 mm glass beads displaced by the flakes and was expressed as kg/m^3 as described by Ali *et al.,* (1996).

WAI/WSI OF ROLLED FLAKES

Centrifugation, drying of gel and evaporation of supernatant was used to measure the Water Absorption Index (WAI) and Water Solubility Index (WSI) of the flakes as described by Borah *et al.*, (2016). Flakes were ground into fine powder using a grinder and passed through a 2 mm screen. 2.5 g powder was then taken in a 50 mL centrifuge tube and 30 mL of 30 °C distilled water was added to it and gently mixed. The tubes were maintained at 30 °C in a shaking water bath for 30 minutes. The samples were then centrifuged at 6000 RPM (3K30, Sigma laboratory centrifuges, Osterode am Harz, Germany) for 10 min. The ratio of the precipitate holding water to the original weight of the sample was expressed as WAI. Supernatant was poured into pre-weighed aluminum pans and dried at 105 °C overnight in a hot air oven (Model # UFE-400, Memmert, Schwabach, Germany). The weight of the dried residue left in the pans was used as percent fraction of the original sample and expressed as WSI.

RESULTS

CHEMICAL ANALYSIS OF ROLLED FLAKES

Chemical composition of rolled corn flakes was very close to the whole grains. The moisture content of the corn was reduced to a stable (9.6±0.19%), the differences among were negligible. A similar pattern was observed with crude fat, crude protein, crude fiber and ash content. Crude fat, crude protein, ash and crude fiber for rolled corn flakes was observed as 3.86±1.52, 7.57±1.65, 5.88±2.06, and 1.27±0.24, respectively.

COLOR (L*) OF ROLLED CORN FLAKES

Consumers generally prefer a lighter color rolled cereal product, which makes it essential for consumer acceptance (Table 2). The response surface model was highly significant for determination of L* of whole grain rolled breakfast cereals ($P < 0.01$). The reliability of the model also very high, indicated by very high values of R^2 (0.98) and R^2 Adj. (0.94).

Table 2. Parameter Estimates of rolled corn flakes for Color L*, a* and b*

Term	Color L*		Color a*		Color b*	
	Estimate	Std Error	Estimate	Std Error	Estimate	Std Error
Intercept	53.0149	0.557566	5.922414	0.206101	16.10897	0.556777
Cooking time (40,80)	-5.2053	0.372425	0.559	0.137665	-5.263	0.371898
Baking time (10,30)	0.0197	0.372425	0.384	0.137665	-0.157	0.371898
Baking Temp (200,250)	1.3457	0.372425	-0.092	0.137665	0.622	0.371898
Cooking time*Baking time	-0.32963	0.416384	-0.1875	0.153914	-1.455	0.415794
Cooking time*Baking Temp	0.177875	0.416384	0.3925	0.153914	0.165	0.415794
Baking time*Baking Temp	-0.49713	0.416384	-0.28	0.153914	-0.3925	0.415794
Cooking time*Cooking time	3.250155	0.725331	0.016379	0.268115	0.661552	0.724304
Baking time*Baking time	-1.76485	0.725331	0.201379	0.268115	-0.38845	0.724304
Baking Temp*Baking Temp	0.245155	0.725331	0.201379	0.268115	0.216552	0.724304
R^2	0.975024		0.865148		0.973186	
R^2 Adj.	0.93756		0.66287		0.932965	
Root Mean Square Error	1.177712		0.435335		1.176044	
Mean of Response	54.09644		6.184375		16.415	

The main effects of cooking time were highly significant on lightness of the steam rolled corn flakes. Increase in CT (1 min) decreased the L* of the corn flakes by -5.2053. BH was significant for the L*, resulting in slight increase of 1.35 for 1 °C increase in temperature. The baking time did not have a significant effect of the lightness of the steam rolled corn flakes. The response surfaces for L* were hyperbolic paraboloid shape. Maillard reaction is the principal determinant of the color change for cooking of cereals (Rosentrater and Evers, 2018), increase in CT results in darker product with more coloration.

a* (REDNESS) OF ROLLED CORN FLAKES

The response surface model was significant for determination of redness (a*) of whole grain steam rolled corn flakes (Table 2). The reliability of the model was also acceptable. The main effects of CT and BT were highly significant ($P < 0.01$) and the BH was insignificant. The interaction effects of CT*BH were also significant for corn flakes. Increase in cooking time and baking time increased the a* of the corn flakes by 0.559 and 0.384 respectively. Mean a* for corn was 6.18±0.43. Response surfaces for CT indicated curvilinear response to a*.

b* (YELLOWNESS) OF ROLLED CORN FLAKES

The fitness of the model was highly acceptable, indicated by high values of R^2 (0.97) and R^2 Adj (0.93) (Table 2). The response surface model was also highly significant for determination of b* of rolled corn flakes. The main effects of CT were significant on b*, while BT and BH were insignificant. The interaction effects of CT*BT were significant for corn flakes. Increase in cooking time decreased the b* of the corn flakes by -5.263. Interaction effects of CT*BT for corn flakes also varied negatively with b* with unit positive change decreasing it by -1.455. Mean b* for corn was 16.415±1.17.

TEXTURE OF ROLLED FLAKES (HARDNESS)

Texture analyzer was used to determine the hardness of the rolled corn grain flakes (Fig. 1). Hardness determines the fractur ability and pulverization during storage and handling. It also influences consumer preference as flat, whole rolled groats are generally priced higher than broken or cut kernels. Hardness of the rolled flakes was determined as compressive strength; the flakes were placed in petri dish and a cylindrical probe with flat bottom was used to apply compressive force. Probe travel of 2.5 mm was measured as compression. The model was significant for determining the effect of processing variables on hardness of the rolled flakes ($P<0.01$). Fitness of model was indicated by high values of R^2 (0.97) and R^2 Adj. (0.92).

The main and interaction effects of CT, BT and BH were all significant and positively correlated to the hardness of the flakes. Mean hardness for corn was 1.71 kg and unit increase in CT, BT, and BH increased the hardness by 0.2, 0.13 and 0.2 kg respectively. This indicates that heat treatment in the form of steaming and baking is responsible for giving the characteristic hard texture to the corn flakes. The response surfaces indicate curvilinear increase in hardness with the highest value at saddle point.

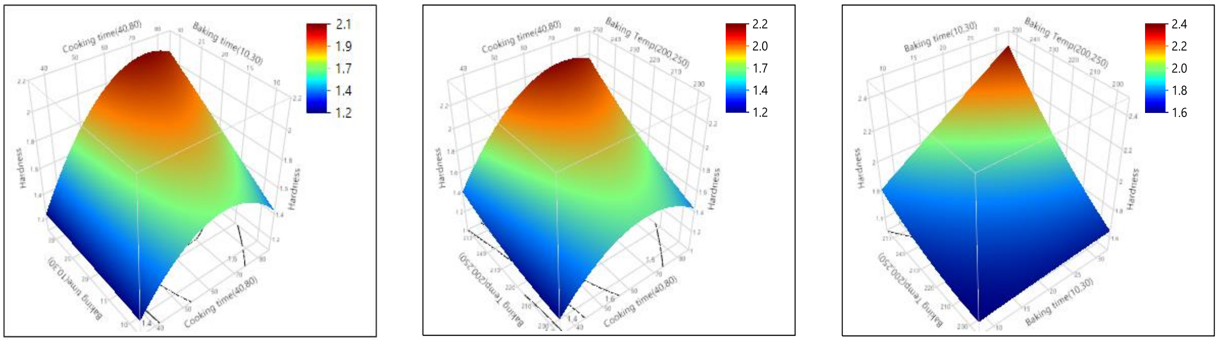

Figure 1: Effect of Cooking Time, Baking Time and Baking Temperature on the hardness of corn flake

BULK DENSITY OF ROLLED CORN

Bulk density of the rolled flakes is one of the key quality characteristics determining consumer acceptance. It is the ratio of mass over volume and determined by displacement method using 1mm glass beads in a graduated cylinder and calculated as kg/m^3. The analysis of variance for the whole grain cereals indicated that density of the rolled corn flakes was non-significant for the current response surface model. This can be explained by uniform compaction imparted by the rolling machine during flaking process. Density of rolled corn was observed 1.268 ± 0.08 kg/m^3.

WATER ABSORPTION INDEX (WAI)

Water absorption index of the steam rolled corn flakes determines the texture, taste, hardness, mouthfeel and overall acceptance before consumption by the consumer (Fig. 2). Rolled cereals are generally consumed after steeping in warm liquids like water and milk while can also be consumed as such. WAI determines the organoleptic and quality perception of whole grain rolled cereals.

The WAI of steam rolled corn grains was significantly affected by the process model. The accuracy of the model was found to be adequate for determining WAI for this study indicated by R^2 and R^2 Adj. values of 0.963 and 0.907, respectively. This indicates the reliability of results for this experiment. The main effects of cooking time were the most dominant factor ($P < 0.01$) influencing WAI for corn, resulting in 0.694 increase in WAI for every 1-minute increase in CT, followed by BT which resulted in 0.102 increase for every minute increment and unit increase in BH added 0.054 in WAI. The only significant interaction effect was Cooking Time*baking Time; this corresponds to overall heat treatment. These results indicate that the length of heat treatment in the form of steam cooking and baking are the predominant factors influencing the WAI, where moist heat plays significant part. Independent uniform inputs reaffirmed this as indicated by variable importance of 0.694 for CT, 0.8 for baking time and 0.066 for baking Temperature. The highly significant effect of steam cooking can be attributed to the phenomenon of starch gelatinization which is highly increased in the presence of moisture; the gelatinized starch absorbs more water than native starch. Highest value of WAI was 4.687 and the lowest was 3.136.

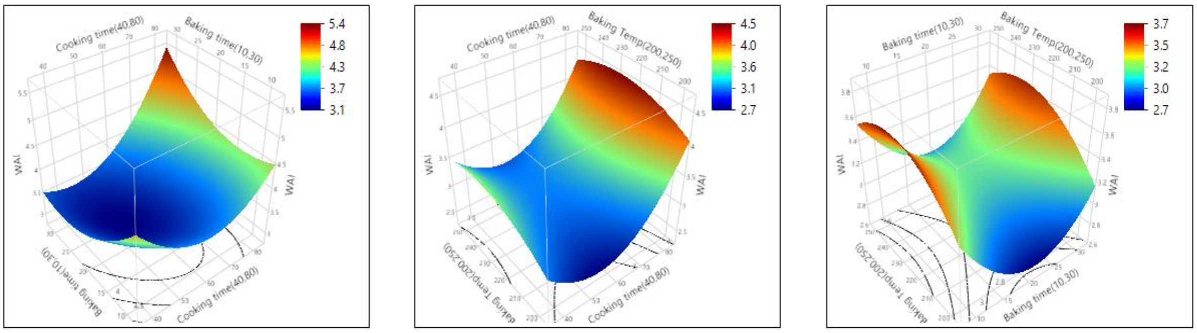

Figure 2: Effect of Cooking Time, Baking Time and Baking Temperature on the water absorption index (WAI) of corn flakes

WATER SOLUBILITY INDEX (WSI)

The amount of solids which get dissolved in liquid medium when the flakes are prepared for consumption affects the texture of the fluid part and changes the mouthfeel and taste of the breakfast cereal (Fig. 3). Response surface model applied for preparation of rolled cereals flakes was found to be non-significant steam rolled corn flakes. Mean WSI observed for corn CT, BT and BH was 2.87±0.38.

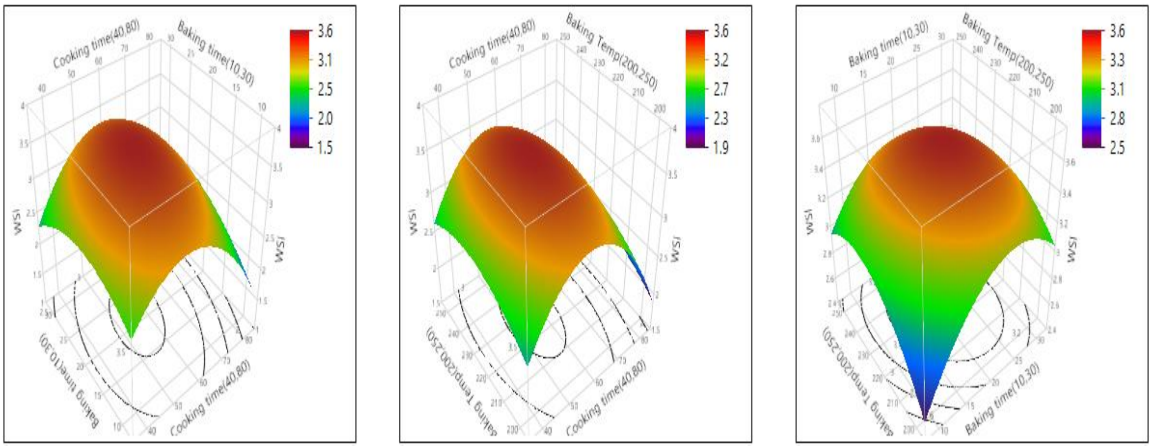

Figure 3: Effect of Cooking Time, Baking Time and Baking Temperature on the water stability index of corn flakes

SENSORY EVALUATION

Rolled breakfast cereals were evaluated on a 9-point hedonic scale by trained judges to check the acceptability and quality. Cereal flakes were soaked in warm milk for 30 seconds before being evaluated. Evaluators were positively able to distinguish between color of the flakes, while most were unable to differentiate between different treatments based on crispiness, intensity of odor, taste and flavor. Sensory perception of color was negatively influenced by CT, BT and BH. This indicates higher consumer preference towards lighter colored flakes. CT was the most dominant factor, followed by BT and BH respectively. The interaction effect of cooking and baking time was also significant and negatively correlated to the sensory perception of color. The whole grain flakes tend to be darker in color in addition to the natural reddish yellow color.

Overall acceptability had mixed results with most treatments falling in between fair to good range. For selection of best treatment sensory evaluation on its own cannot be considered a reliable criteria as other factors like the functional properties and technical quality attributes have to be considered.

DISCUSSION

The present investigation therefore attempted to optimize processing parameters for manufacturing rolled whole-grain cornflakes and determine how it would affect their physicochemical properties and quality. There were several important points that the findings made in order to assist in high-quality breakfast cereal development. It was observed from the outcomes that cooking time (CT) is the most significant parameter influencing the physicochemical properties of cornflakes followed by baking time (BT) and baking temperature (BH). The torque required for rolling, Water absorption index (WAI), and texture of the final product were significantly influenced by these parameters.

The Torque required for rolling corn was found highly significant ($P < 0.001$) with $R^2=0.994$ and R^2 adj = 0.933 values respectively. Such similar findings were reported by Yağcı & Göğüş (2008) who said that there is a significant effect of processing conditions on energy requirement for the extrusion of corn-based snacks. Optimum process conditions can reduce energy demands which are vital to industrial applications such as Yağcı & Göğüş(2008).

The WAI of the cornflakes rolling was affected by processing parameters with CT being the main factor among them. Cooking for a longer period would enhance WAI due to increasing starch gelatinization as stated by Singh *et al.*, (2000). This is important in consumer acceptance because it influences the texture and mouthfeel of the cereal when rehydrated (Singh *et al.*, 2000). The hardness, which is measured as texture, was positively associated with CT, BT, and BH. Stronger texture develops at higher temperatures and longer processing times which helps in maintaining structural integrity of flakes during storage and consumption. These results are consistent with Guy and Horne (1988) who established that hardness in extruded cereal products increased with higher processing times and temperatures (Guy & Horne, 1988).

According to chemical analysis, the nutritional composition of rolled cornflakes was comparable to whole grain with a slight reduction in moisture content at a steady state level of 9.6±0.19%. The crude fat, protein, fiber, and ash contents were maintained, ensuring that the dietary benefits of whole grains were retained in the final product. The latter finding contradicts Brennan *et al.*'s study (2012), which noted nutrient losses in extruded whole grain cereals mainly on account of high temperature during processing.

Consumer preference for cornflakes is in favor of light-colored flakes, and the response surface model indicates that the lightness (L*) of the cornflakes is significantly affected by CT. Color changes during the cooking process occur as a result of Maillard reactions whose result is darker flakes with longer CT. This finding agrees with Fasolin *et al.*'s study (2007) which showed that longer cooking times resulted in more dark shades on extruded corn-based snacks due to Maillard browning reactions (Fasolin *et al.*, 2007).

However, the sensory evaluation revealed that consumers could not discriminate different treatments using smoothness, roughness, elasticity, or hardness. Therefore, this means color is first and foremost crucial while other sensory attributes such as taste and crunchiness are also significant for overall satisfaction. The same findings were made by Almeida *et al.* (2013), who discovered that color was a key determinant of consumer acceptance of extruded cereal products; however, texture and flavor were important determinants of the overall acceptability (Almeida *et al.*, 2013).

The findings of the study provide important insights for optimizing processing parameters toward whole-grain rolled cornflake production. This research, by identifying what factors affect the physicochemical properties and quality of the flakes, creates a pathway to the commercial production of healthy and best breakfast cereals in Pakistan. This is because such foods can reduce malnutrition issues in children, hence offering nutritious alternatives to refined flour-based cereals (and thus bettering public health). These suggestions are supported by Kahlon and Chow (2000) who gave importance to whole grain cereals to improve dietary fiber intake as well as general health improvement.

CONCLUSION

In conclusion, the optimization of CT, BT, and BH is indispensable in achieving high-quality rolled cornflakes with desirable physicochemical properties and consumer acceptance. Consequently, ensuring that nutritional value is maintained while improving sensory characteristics through process parameter manipulation has significant implications for the breakfast cereal industry that encourages adoption of whole grain products and promotes better dietary habits.

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Conflict of Interest

The authors have no affiliations with or involvement in any organization or entity with any financial interest (such as honoraria; membership; consultancies; stock ownership and expert testimony or patent-licensing arrangements), or non-financial interest (such as personal or professional relationships, affiliations, knowledge or beliefs) in the subject matter or materials discussed in this manuscript.

Data Availability

This is the original data presented in this manuscript.

Author's Contribution

I, Mr. Abdullah Salik, have collected, prepared and analyzed the samples. Prof. Dr. Imran Pasha has supervised the whole research. Prof. Dr. Nuzhat Huma has provided her expertise in statistical design and data analysis and use of JMP Pro statistical software. Prof. Dr. Amer Jamil has helped in writing and critically reviewing the manuscript. The research was performed at National Institute of Food Science and Technology, University of Agriculture, Faisalabad.

Animal Research

No animals were harmed.

Consent to Publish

This journal is chosen for the possible publication of our manuscript as it is a multidisciplinary journal and publishes a quality work. All the authors are willing and have no conflict in publishing the article in this journal.

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