Kumari *et al.*
Food Production, Processing and Nutrition (2022) 4:31
https://doi.org/10.1186/s43014-022-00108-x

Food Production, Processing and Nutrition

RESEARCH

Open Access

Optimization of the iron-enriched extruded snack containing jackfruit seed flour, mung bean flour and ferrous ammonium phosphate by using response surface methodology

Aparna Kumari, Aditya Gupta and Anil Kumar Chauhan*

Abstract

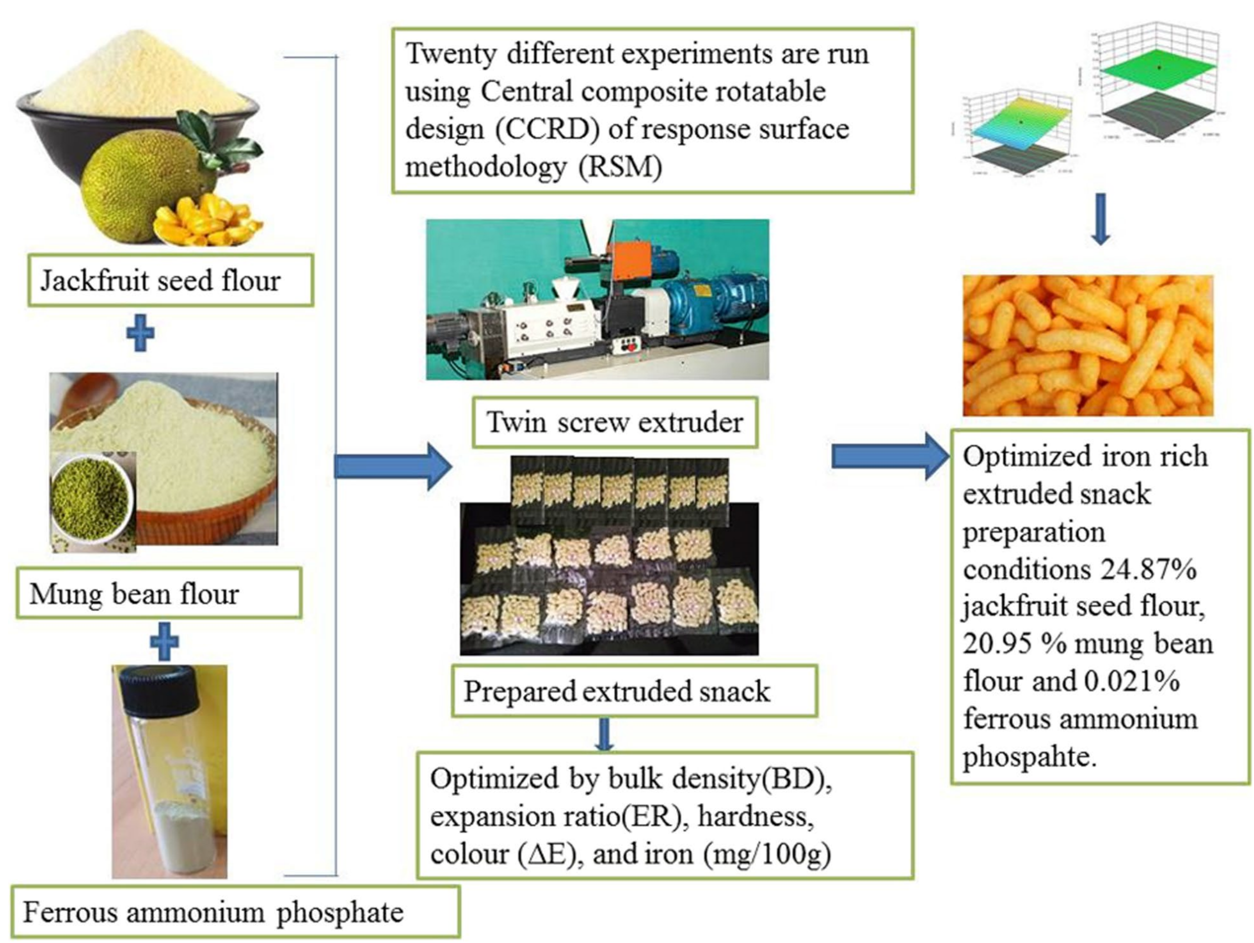
The Food and Agriculture Organization (State of food and agriculture. Moving forward on food loss and waste reduction, 2019) stated that approximately 1.3 billion tons of food wasted every year caused the emission of around 4.4 gigatons of greenhouse gas. World Health Organization highlights that iron deficiency affects billions of people worldwide and remains the leading cause of anemia. With the growth of healthy and sustainable diets and consumers' better understanding of the relationship between diet, health, and the environment, there is an opportunity to develop novel healthy extruded snacks. The present study was carried out using response surface methodology to investigate the effects of varying proportions of jackfruit seed flour, mung bean flour, and ferrous ammonium phosphate on physical and functional properties of extruded snacks. Experiments were carried out using a central composite rotatable design with three independent parameters such as jackfruit seed flour(%), mung bean flour(%), and ferrous ammonium phosphate (%), and five responses such as bulk density (BD), expansion ratio (ER), hardness, color difference (ΔE), and iron content. It was found that ferrous ammonium phosphate significantly increased the iron content. Bulk density, expansion ratio, and hardness were significantly affected by jackfruit seed flour and mung bean flour. All independent variables significantly influenced colour value. The optimized iron-enrich extruded snacks were obtained at 24.87% jackfruit seed flour, 20.95% mung bean flour, and 0.021% ferrous ammonium phosphate. The optimized extruded snack contained 15.32 g/100 g protein and 22.03 mg/100 g iron content. Results of the study indicate that the optimized extruded snack could be used as a protein and iron source to mitigate malnutrition and anemia.

Keywords: Jackfruit seed flour, Mung bean flour, Ferrous ammonium phosphate, Extruded snack, Anemia

*Correspondence: anilchauhancfst@gmail.com

Department of Dairy Science and Food Technology, Institute of Agricultural Science, Banaras Hindu University, Varanasi 221005, India

Graphical Abstract



Introduction

In 2018, the global population was more than 7.6 billion. It is predicted to be 9.2 billion in 2050 that will increase in the demand for food products by 59–102% (Pawlak & Kołodziejczak 2020). Recently, the Food and Agriculture Organization (2020) has stated that around 13% of the population living in developing countries are facing hunger. The reason behind hunger is not only insufficient food production, but the produced food is not evenly distributed hence the problem of food wastage at different stages of the agricultural supply chain (Fombang et al. 2021; Kumari et al. 2022; Wang et al. 2022). According to the literature (FAO 2019), one-third of the world's food production is spoiled or wasted before consumption, which is approximately 1.3 billion tons/year, worth US$750 billion of the global economy. From the total food waste, 413 million tons get wasted at the agriculture production stage, 148 million tons at the processing stage, 161 million tons at the distribution stage, and 280 million tons at the household consumption stage (FAO 2019; Massari et al. 2021). Considering all these facts, the utilization of fruits and vegetables by-products has recently attained much researcher and scientific attention due to worldwide efforts to combat food insecurity and world hunger.

Jackfruit (*Artocarpus heterophyllus*) is the most popular tropical fruits belonging to the family Moraceae found abundance in the rainforests of the Western Ghats. Jackfruit refers to as a source of nutrition especially during summer season as it is found plentiful during summer when food is scarce in Asia (Jagadeesh et al. 2007). A ripe jackfruit usually contains about 100–500 seeds, which is about 15–18% of the total fruit weight that is usually discarded as wastes. Nowadays researchers and scientists are giving more attention on developing food products utilizing the by-products of fruits and vegetables. Jackfruit seeds can be used as a good substitute for expensive and nutrition-dense food products in the countries where the population is high, and demands are not fulfilled by the regular seasonal vegetables (Waghmare et al. 2019). Jackfruit seed is rich in nutrients including carbohydrates (starch), proteins, vitamins, minerals, fibre and phytochemicals (Okudu 2015; Suzihaque et al. 2022; Zhang et al. 2017). Jackfruit seeds flour (JFSF) contains 60–80% starch on a dry weight basis that gives better firmness to extruded product in terms of texture which is the most important factor for extrusion. Therefore, jackfruit seed flour can be used as an alternative replacement of starch flour for extruded product (Dong et al. 2021; Suzihaque et al. 2022). Some studies (Baliga et al. 2011; Kalse & Swami 2022; Trindade et al. 2006; Waghmare et al. 2019; Yao et al. 2016) have found that jackfruit seed has anti-inflammatory, antimicrobial, anti-cariogenic, antifungal, antineoplastic, hypoglycaemic and wound healing properties against human and rabbit erythrocytes due to presence of many classes of phytochemicals such as carotenoids, flavonoids, volatile acids sterols, and tannins. Hence, during the flush season of jackfruit, there is a huge opportunity to generate value-added food products from jackfruit seeds and promote them to the general public.

Mung bean (*Vigna radiata*) comprises an excellent balance of proteins, vitamins, minerals, and dietary fibres (Gan et al. 2017). Mung bean helps in reduction of malnutrition globally because they are a good source of plant protein and have good amino acid profile (lysine, leucine, valine, isoleucine, histidine, phenylalanine, tyrosine) (Tas & Shah 2021;Yi-Shen et al. 2018). Consumption of the mung bean combined with cereals has been recommended to significantly increase the quality of protein, because cereals are rich in sulfur-containing amino acids but deficient in lysine (Boye et al. 2010). Several epidemiological and retrospective clinical studies have evinced that consumption of pulses possesses many health benefits such reduced risk of cancer (prostate, colon and breast cancers), cardiovascular disease, osteoporosis, diabetes, adrenal disease, gastrointestinal disorders, hypertension (Didinger & Thompson 2022; Hou et al. 2019; Sharma et al. 2017).

Iron deficiency anaemia (IDA) is a global public health problem, which spread in both developed and developing countries. In this study ferrous ammonium phosphate ($FeNH_4PO_4$; FAP) is used as a source of iron to fortify extruded snack. It is one of the well-known iron fortificant that is easily mixed with raw materials and produce iron-rich food products (Walczyk et al. 2013). FAP does not alter organoleptic properties of food product and shows good bioavailability due to rapid and high iron release at stomach conditions (at a pH of between 2 and 3.5) (Rekhif et al. 2002).

Extrusion cooking is promising technology that provides a convenient, inexpensive, higher shelf life, and efficient manufacturing process to obtain healthy snacks. Extrusion technology is economical, and the end product has a high rate of acceptability among all age groups of the population (Tas & Shah 2021).

In recent years, extensive work has been done to reduce food wastage and prevalence of iron deficiency that causes anemia. This study aims to optimize the production level of jackfruit seed flour, mung bean flour and ferrous ammonium phosphate with response surface methodology (RSM) for the development of iron-enriched jackfruit seed flour and mung bean flour-based extruded snacks that target all age groups, especially malnourished and anaemic population. The optimized product was then analysed on the basis of its nutritional composition.

Materials and methods

Raw materials

Jackfruits were collected from the local vegetable market of Varanasi, Uttar Pradesh, India. Other material such as mung bean, rice flour and corn flour was purchased from Tata sampan products limited, India. Flavouring of snacks such as sunflower oil (Fortune, Varanasi, India), salt (Tata, Varanasi, India), monosodium glutamate (MSG) (Haribas, Varanasi, India), onion and parsley powder (Artha Natural, Varanasi, India), for the preparations of the extruded products were procured from the local market of Varanasi, India. Ferrous sulphate, ammonium phosphate, and phosphoric acid were purchased from Sigma-aldrich.

Flour preparation

Jackfruit seeds (*Artocarpus heterophyllus* L.) were collected from ripe fruit. The fruits were washed with tap

Table 1 Independent variables and their corresponding levels for iron rich extruded snack

Independent variable	Symbol	Code Levels				
		-α	-1	0	+1	+α
Jackfruit seed flour (%)	JFSF	10	18.11	30	41.89	50
Mung bean flour (%)	MBF	5	9.05	15	20.95	25
Ferrous Ammonium Phosphate (%)	FAP	0.005	0.01	0.015	0.021	0.025

Table 2 Experimental design for iron rich extruded snack with independent variables, experimental and predicted values of responses

Run	Independent Variable			Response				
	JFSF [a] (%)	MBF [b] (%)	FAP [c] (%)	BD[d] (g/cm^3)	Expansion ratio	Hardness (N)	Colour (ΔE)	Iron (mg/100 g)
1	18.11	9.05	0.009	0.131	3.358	17.32	10.61	12.26
2	30	15	0.015	0.162	2.974	20.23	12.88	17.47
3	30	15	0.015	0.164	2.97	20.34	12.87	17.31
4	10	15	0.015	0.112	3.591	14.69	10.24	15.93
5	30	15	0.015	0.166	2.965	20.31	12.86	17.41
6	41.89	9.05	0.021	0.205	2.731	22.33	14.33	22.57
7	30	15	0.015	0.161	2.979	20.25	12.88	17.49
8	18.11	20.95	0.009	0.128	3.365	17.24	10.51	11.09
9	41.89	20.95	0.009	0.216	2.687	25.61	14.29	12.11
10	30	15	0.025	0.161	2.976	20.15	12.87	24.45
11	41.89	20.95	0.021	0.217	2.685	25.42	14.24	21.17
12	18.11	20.95	0.021	0.135	3.35	17.38	10.48	22.36
13	30	25	0.015	0.171	2.963	21.31	12.16	17.74
14	30	15	0.015	0.164	2.971	20.34	12.86	17.41
15	30	5	0.015	0.153	3.233	18.62	12.91	15.89
16	41.89	9.05	0.009	0.207	2.726	22.45	14.38	10.97
17	30	15	0.005	0.162	2.975	20.25	12.91	6.03
18	30	15	0.015	0.162	2.974	20.23	12.88	17.48
19	18.11	9.05	0.021	0.13	3.362	17.29	10.57	21.52
20	50	15	0.015	0.229	2.615	26.15	14.57	17.08

[a] *JFSF* Jackfruit seed flour

[b] *MBF* Mung bean flour

[c] *FAP* Ferrous Ammonium Phosphate

[d] *BD* Bulk density

water, peeled off, and the seeds were manually separated from the pulp. The mucilage peel of the seeds was removed manually and washed with tap water to removed dirt and dust. Then seeds were placed at room temperature (25 ± 2 °C) for 2 hr. to drain the excess water. After that, the cleaned jackfruit seeds were cut into small pieces and dried in a tray drier (Khera instrument, Noida, India) at 45° ± 2 °C for 48 hr. The dried seeds were then grounded and sieved to get fine powder of jackfruit seed flour (JFSF).

Mung beans were procured from Tata sampan Group Co., Ltd. (Varanasi, India), and grounded to obtain mung bean flour (MBF) then passed through a 200 μm-sieve to obtain uniform particle size.

Synthesis of ferrous ammonium phosphate (FAP)

Ferrous ammonium phosphate was synthesised from ferrous sulphate, ammonium hydroxide and phosphoric acid at stoichiometric ratio of 1:1:1 by the method proposed by Rekhif et al. (2002).

Experimental design

Central composite rotatable design (CCRD) of response surface methodology (RSM) (Design expert software version 13.0.11.0, Stat-Ease, Inc., Minneapolis, USA) was implemented to optimize and examine the effect of three independent variable levels, such as jackfruit seed flour (10–50%), mung bean flour (5–25%) and ferrous ammonium phosphate (0.005–0.025%) on the following dependent variables; bulk density (BD), expansion ratio (ER), hardness, colour difference (ΔE), and iron content (mg/100 g) of the extrudate. Table 1 shows the coded levels for independent variables. Twenty experiments, including six axial points, six central points, and eight fractional factorial points were planned based on different levels of process variables (Table 2).

Extruder

Twin-screw extruder (Basic Technology Pvt. Ltd., Kolkata, India) laboratory scale model was employed for the preparation of extruded snack. The diameter of die was

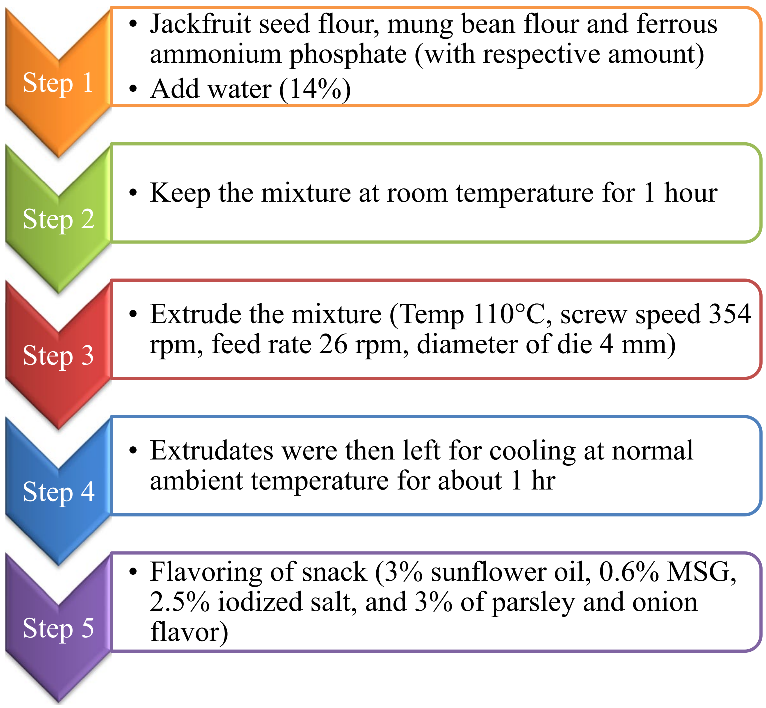


Fig. 1 **a** Flow diagram of the preparation of the extruded product

selected 4 mm as recommended by the manufacturer. In this study moisture of the feed material and the temperature of the extruder barrel were maintained at 14% wet basis and 110 °C, respectively.

Preparation of extruded snack product

Composite flour (corn flour and rice flour in the ratio of 20:80) was used as the base material for preparation of extruded snack according to literature and preliminary tests. In the present study composite flour was replaced by JFSF, MBF, and FAP. For the preparation of extruded snack, weighing the 20 experimental formulations of jackfruit seed flour, mung bean flour and ferrous ammonium phosphate, and water was added to maintain moisture content of 14% (Table 2). The laboratory scale twin-screw extruder (Basic Technology Pvt. Ltd., Kolkata, India) with temp 110 °C, screw speed 354 rpm, feed rate 26 rpm, and the diameter of die 4 mm was used to produce extruded snack. Sharp knife was used to cut the extrudates (approx. 10–15 cm long) as they come out from the die. The extrudates were dried in rotary dryer at 60 °C until their moisture was reduced below 5% and packaged in aluminium laminated bag till further analyses.

Composite flour (rice and corn flour) at ratio 80:20 was used for preparation of control extruded snack. Figure 1 shows the flow diagram of the preparation of the extruded snack.

Flavouring of snacks

Snacks were seasoned in a pan by spraying 3% sunflower oil using pneumatic spray. Afterward, a mixture of 0.6% monosodium glutamate (MSG), 2.5% iodized salt, and 3% of parsley and onion powder was added to the extrudates. The snacks were mixed properly to obtain flavoured surface. The extrudates were packed in aluminium laminated pouches and stored at 25 °C till further analyses.

Product responses

Bulk density

The bulk density of extrudates was determined by a seed displacement method as given by Nakhon et al. (2018) with some modification. The 250 mL measuring cylinder was filled with 200 ml of rapeseed and gently tapped 15 times. The volume and weight of 10 extrudates were recorded to calculate the bulk density by unit mass per unit volume (g/cm^3).

$$Density = \frac{Weight\ of\ Extrudates}{Volume\ displaced\ by\ extrudates}$$

Expansion ratio

The expansion ratio was measured as the mean of 10 samples using digital vernier calipers. The diameter of the extrudates and the die diameter were utilized to express the extrudate's expansion (Day & Swanson, 2013). The following equation was used to calculate the expansion ratio of extrudate.

$$\textit{Expansion Ratio} = \frac{\textit{Extrudate Diameter}}{\textit{Die Diameter}}$$

Texture (hardness)

Hardness in the extrudates was determined by using a stable micro system TA-XT2 texture analyzer (Texture Technology corp., UK). Extrudate of about 15 cm long was compressed with a probe three point bend ring with a target mode distance of 2.5 mm and load cell of 50 kg. Hardness value was measured as mean peak compression force and expressed in Newton (N).

Color difference

Color characteristics of extruded snacks were measured by colorimeter hunter lab (ColorFlex EZ Spectrophotometer, Virginia, U.S.A). The following parameters were defined: L∗ (white (100) to lightness; black (0)), a∗ (red saturation index; +a∗ = red, −a∗ = green) and b∗ (yellow saturation index; +b∗ = yellow, −b∗ = blue) were recorded. The total color differences (ΔE) calculated by using the following formula (Suri et al. 2020).

$$\Delta E = \sqrt{(L1*-L0*)2-(a1*-a0*)2-(b1*-b0*)2}$$

Iron

The iron content in extruded sample was determined using AOAC method number 944.02 (AOAC International 2007). The Fe content was estimated by thiocyanate colorimetry method by measuring the intensity of colour formed by the formation of Fe (III)-thiocyanate in the sample and comparing it with the color formed from the standard iron solution.

Physicochemical analysis of JFSF, MBF, control and optimized extruded snack

A digital moisture analyzer was used to estimate the moisture content of the extruded sample. The protein content present in the optimized extruded product was analyzed by the Kjeldahl method (KEL PLUS - Elite EX (VA), Pelican Equipment). To estimate protein content, nitrogen content was multiplied by a factor 6.25. The fat content was determined by the Soxhlet extraction method using SOCS PLUS SCS4 (Pelican Equipment) apparatus. Ash content in optimized extruded product was determined as per the method recommended by AOAC International (2007) in Bulletin No.70 by charring samples overnight at 500 °C. Crude fibre was determined by AOAC 2007.01. The carbohydrate content of the optimized extruded product was determined by the difference method that is, by subtracting the measured percentage of protein, ash, fat, and moisture from 100.

Statistical analysis

Design expert software version 13.0.11.0, Stat-Ease, Inc., Minneapolis, (USA) was employed to analyse the

Table 3 Regression coefficients values for iron rich extruded snack

Regression Coefficient	Bulk density	Expansion ratio	Hardness	Colour) (ΔE)	Iron
Intercept	0.163	2.97	20.27	12.88	17.41
A-JFSF[a]	0.0379***	−0.3110***	3.36***	1.64***	0.1116
B-MBF[b]	0.0039***	−0.0398**	0.7896***	−0.1195	0.1846
C-FAP[c]	0.0002*	−0.0005	−0.027	− 0.0174	5.28***
AB	0.0024	−0.01	0.7800***	0.0012	0.0087
AC	−0.0009	0.0017	−0.0525	−0.0037	0.0163
BC	0.0014	−0.0032	0.0125	0.0012	−0.0663
A^2	0.0039*	0.0397*	0.1412*	−0.2004	−0.1904
B^2	0.0009	0.0379*	−0.0196	−0.1545	− 0.0808
C^2	0.0008	−0.0054	0.0635	−0.0289	−0.6376*
R^2	0.9057	0.8754	0.9706	0.7327	0.8727

***Significant at $p < 0.001$; **Significant at $p < 0.01$; *Significant at $p < 0.05$; ns-non-significant at $p > 0.05$

[a] *JFSF* Jack fruit seed flour

[b] *MBF* Mung bean flour

[c] *FAP* Ferrous Ammonium Phosphate

experimental data statistically. Numerous statistical parameters (coefficient of variation, adjusted, predicted multiple correlation coefficients and lack-of-fit) of different polynomial models were compared to choose the best fitting polynomial model. Significant difference was determined through analysis of variance by calculating F-value at the probability of 0.01, 0.1 and 0.5. The second-order mathematical regression equation (Eqs.1) was used to calculate the effect of each independent parameter on each dependent response.

$$\begin{aligned} Yi =& \beta 0 \pm \beta 1X1 \pm \beta 2X2 \pm \beta 3X3 \\ & \pm \beta 12X1X2 \pm \beta 13X1X3 \pm \beta 23X2X3 \\ & \pm \beta 11X12 \pm \beta 22X22 \pm \beta 33X32 \end{aligned} \tag{1}$$

Model validation

The accuracy of the developed models showing the effects of JFSF, MBF and FAP on the responses (bulk density, expansion ratio, hardeness, colour (ΔE) and iron content of the extrudate) were validated with the optimum conditions predicted through design expert software. The percentages of the error were calculated to determine the "fit of the model" (Eq. 2):

$$Error\% = \frac{1}{Ne}\sum_{i=1}^{n}\frac{Ve - Vp}{Ve}x\,100 \tag{2}$$

Results and discussions

Fitting the model

Response surface methodology (RSM) is widely used statistical and mathematical technique that explores the relationships between dependent and independent variables (Guo et al. 2021; Li et al. 2021; Mehmood et al. 2018; Zhuang et al. 2021). The effect of independent variables (jackfruit seed flour, mung bean flour and ferrous ammonium phosphate) on dependent variable such bulk density (BD), expansion ratio (ER), hardness, colour (ΔE), and iron (mg/100 g) have been reported in Table 2. Coefficients of the polynomial equation were computed from experimental data to predict the values of the dependent variable. Regression equations for each dependent variable, obtained from RSM are mentioned in Eqs. (3), (4), (5), (6), and (7):

$$\begin{aligned} \text{Bulk density} =& 0.1630 + 0.0379^{*}A + 0.0039^{*}B + 0.00024^{*}C \\ & + 0.0024^{*}AB - 0.0009^{*}AC + 0.0014^{*}BC \\ & + 0.0039^{*}A^{2} + 0.0009^{*}B^{2} + 0.0008^{*}C^{2} \end{aligned} \tag{3}$$

$$\begin{aligned} \text{Expansion ratio} =& 2.9732 - 0.3110^{*}A - 0.0400^{*}B - 0.0005^{*}C \\ & - 0.0010^{*}AB + 0.0017^{*}AC - 0.0033^{*}BC \\ & + 0.0397^{*}A^{2} + 0.0379^{*}B^{2} - 0.0054^{*}C^{2} \end{aligned} \tag{4}$$

$$\begin{aligned} \text{Hardness} =& 20.2691 + 3.3575^{*}A + 0.7896^{*}B - 0.0270^{*}C \\ & + 0.7800^{*}AB - 0.0525^{*}AC + 0.0125^{*}BC \\ & + 0.1413^{*}A^{2} + -0.0196^{*}B^{2} + 0.0635^{*}C^{2} \end{aligned} \tag{5}$$

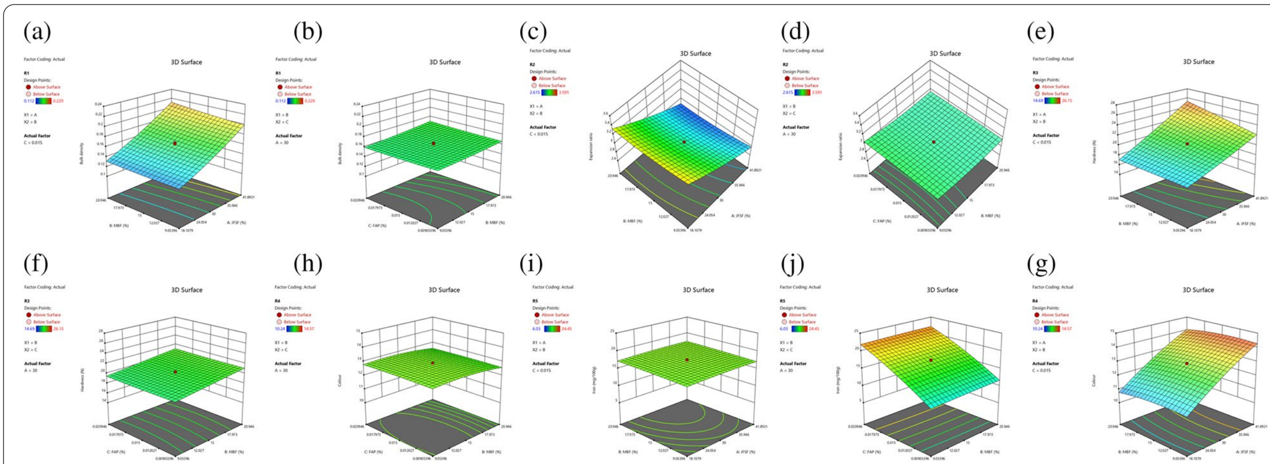


Fig. 2 Effects of process parameters on the bulk density, expansion ratio, hardness, colour, iron and overall acceptability of extruded snacks. **a** Effects of Jackfruit seed flour (JFSF) and Mung bean flour (MBF) on the bulk density of extruded snacks. **b** Effects of Ferrous ammonium phosphate (FAP) and Mung bean flour (MBF) on the bulk density of extruded snacks. **c** Effects of Jackfruit seed flour (JFSF) and Mung bean flour (MBF) on the expansion ratio of extruded snacks. **d** Effects of Ferrous ammonium phosphate (FAP) and Mung bean flour (MBF) on the expansion ratio of extruded snacks. **e** Effects of Jackfruit seed flour (JFSF) and Mung bean flour (MBF) on the hardness of extruded snacks. **f** Effects of Ferrous ammonium phosphate (FAP) and Mung bean flour (MBF) on the hardness of extruded snacks. **g** Effects of Jackfruit seed flour (JFSF) and Mung bean flour (MBF) on the colour (ΔE) of extruded snacks. **h** Effects of Ferrous ammonium phosphate (FAP) and Mung bean flour (MBF) on the colour (ΔE) of extruded snacks. **i** Effects of Jackfruit seed flour (JFSF) and Mung bean flour (MBF) on the iron content of extruded snacks. **j** Effects of Ferrous ammonium phosphate (FAP) and Mung bean flour (MBF) on the iron content of extruded snacks

$$\begin{aligned}\text{Colour} = &12.8771 + 1.6367^{*}A - 0.1195^{*}B - 0.0174^{*}C \\ &+ 0.0013^{*}AB - 0.0038^{*}AC + 0.0013^{*}BC \\ &- 0.2004^{*}A^{2} - 0.1545^{*}B^{2} - 0.0290^{*}C^{2}\end{aligned} \quad (6)$$

$$\begin{aligned}\text{Iron} = &17.4075 + 0.1116^{*}A + 0.1846^{*}B + 5.2844^{*}C \\ &+ 0.0087^{*}AB + 0.01626^{*}AC - 0.0663^{*}BC \\ &- 0.1904^{*}A^{2} - 0.0808^{*}B^{2} - 0.6376^{*}C^{2}\end{aligned} \quad (7)$$

Statistical analysis (ANOVA) results revealed that the experimental data could be represented well with a quadratic polynomial model with coefficient of determination (R^2) values for bulk density (BD), expansion ratio (ER), hardness, colour (ΔE), and iron (mg/100 g) being 0.9057, 0.8754, 0.9706, 0.7327, and 0.8727 respectively (Table 3).

Lack of fit was non-significant ($p \leq 0.05$) relative to pure error for all variables, which represent that the model are adequate and fitted for all the process variables. If the value of R^2 is close to 1 it is an indication of better model fitting to the real data. On the other hand, low values of R^2 indicate that the response variables were not suitable to explain the variation in behavior (Mehmood et al. 2018). In this study, proximity to unity R^2 demonstrates that the influence of jack fruit seed flour (X1), mung bean flour (X2), and ferrous ammonium phosphate (X3) on dependent variables could be adequately described through a quadratic polynomial model. Larger F-value and smaller *P*-value is the indication of a highly significant effect of any term on the response variable (Sullivan & Feinn 2012).

Product responses

Bulk density and expansion ratio

Bulk density and expansion ratio are closely related. Bulk density has been reported to be linked with the expansion ratio in describing the degree of puffing in extrudates. In general, bulk density decreases with the increase in the expansion ratio of extruded product (Singh et al. 2014). The value of bulk density and expansion ratio obtained from different trails from RSM software came in the range from 0.112 to 0.229 g/cm^3 and 2.615 to 3.591 respectively (Table 2). The bulk density and expansion ratio of extruded snack significantly affected by linear term of jackfruit seed flour ($p < 0.001$) and mung bean flour ($p < 0.001$). The influence of jackfruit seed flour and mung bean flour concentration on bulk density and expansion ratio of extruded snack is illustrated in Fig. 2a, b and Fig. 2c, d. In this study it was observed that BD increased with increase in the content of JFSF and MBF to extruded mixture. It was possible due that high fibre content of both jackfruit seed and mung bean flours, because fibre dilutes the starch of jackfruit seed flour and microstructure of fibres also reduced the number and size of internal air cells so that premature rupture of air cells and inhibit starch matrix puffing during the extrusion process. Aydogdu et al. (2018) stated that increase in fibre content decrease the internal air cell. Protein of MBF also affects the water holding capacity in the matrix. Protein will interact with water by various types of interactions such as hydrophilic, hydrogen bonding and polar interactions, which resulted in decreased expansion ratio and increased bulk density. Similar observation was also reported by Yagci et al. (2022) for the fortification of tomato pomace powder in extruded snacks where fibre content decrease the expansion ratio.

Hardness

Hardness of the products plays very major role for deciding the ideal combination of JFSF, MBF and FAP for the extruded product. The range of hardness of the extrudates obtained from present investigation was found to be 14.69–26.15 N (Table 2). Hardness value of extruded snack dependent on jackfruit seed flour and mung bean flour content due to its significant effect on hardness at a quadratic ($p < 0.001$) and linear level ($p < 0.001$). The combined effects of jack fruit seed and mung bean flour on hardness value are illustrated in Fig. 2e, f. Hardness was found to be constant, irrespective of increase in ferrous ammonium phosphate content but hardness value was more affected due to presence of jack fruit seed flour and mung bean flour. High amount of fibre in JFSF and MBF reduced aeration in the extruded mixture which was found to have compact and less porous structure. Proteins of JFSF and MBF coagulate during extrusion heating and subsequently led to a dense structure. The combined effect of protein and fibre of JFSF and MBF resulted in decreased volume and an increased in hardness requiring maximum force for compression of extruded snack. In agreement, Korkerd et al. (2016) also found that fibre and protein affect the hardness of extruded snacks enriched

Table 4 Optimum conditions, experimental and predicted value of response at optimized conditions

Optimum Condition	Coded levels	Actual levels
Jack fruit seed flour (JFSF)	−0.09	24.87
Mung bean flour (MBF)	−1.00	20.95
Ferrous ammonium phosphate (FAP)	−1.00	0.021
Response	**Predicted value**	**Experimental value**
Bulk density	0.15	0.16 ± 0.001
Expansion ratio	3.10	3.55 ± 0.12
Hardness	19.35	18.99 ± 0.31
Color	11.82	12.15 ± 0.23
Iron	21.99	22.36 ± 0.52

Table 5 Proximate composition (g/100 g) of jack fruit seed flour (JFSF), mung bean flour (MBF), optimized extruded snack and regular rich and corn snack

Parameter	Jackfruit seed flour (JFSF)	Mung bean flour (MBF)	Control snack	Optimized extruded snack
Moisture (%)	10.02 ± 0.53	9.15 ± 0.14	3.63 ± 0.03	2.87 ± 0.05***
Protein (%)	12.81 ± 0.14	23.78 ± 0.07	6.7 ± 0.03	15.32 ± 0.02***
Fat (%)	1.24 ± 0.22	1.56 ± 0.13	3.18 ± 0.13	3.17 ± 0.16**
Ash (%)	3.01 ± 0.09	4.95 ± 0.04	2.13 ± 0.01	3.78 ± 0.03
Carbohydrate	72.92 ± 0.71	60.56 ± 0.58	84.36 ± 0.61	77.86 ± 0.64
Crude Fibre (%)	2.57 ± 0.03	1.67 ± 0.01	1.47 ± 0.02	3.32 ± 0.05***
Iron (mg/100 g)	1.72 ± 0.36	1.03 ± .0.09	3.51 ± 0.39	22.359 ± .044**

*** Significant at $p < 0.001$; ** Significant at $p < 0.01$; * Significant at $p < 0.05$; ns-non significant at $p > 0.05$

with germinated brown rice meal, defatted soybean meal, and mango peel fibre.

Colour

Consumer acceptability is majorly affected by color of product so it can be considered as quality parameters for any product development. Colour change could be linked with the processing parameters and chemical changes occurred in food during extrusion process. The color of the extrudates made from the jackfruit seed flour and mung bean flour was white-yellowish. Colour (ΔE) value of the extruded product in the range from 10.24 to 14.57. The color was significantly affected all independent variables such JFSF, MBF, FAP (Table 2). Figure 2g, h shows effect of JFSF, MBF and FAP on colour of extruded snack. Color changes during extrusion was mainly due reaction between amino acid and sugar. However, JFSF seed contains several oligosaccharides such as stachyose and raffinose, which creates a darker color during flour processing (Setiawan, 2016).

Iron (mg/100 g)

Iron is a vital part of red blood cells (RBCs) which transports oxygen from the lungs to different organs of the body. Iron is a key constituent in various enzyme systems such as those involved in vitamin D activation, neurotransmitter metabolism, cholesterol catabolism, collagen metabolism (Kumari & Chauhan 2021). The obtained values of the iron in extruded snacks ranged from 12.11 to 24.45 mg/100 g, the highest value was recorded at 30% JFSF, 15% MBF and FAP 0.025% of the total flour (Table 2). Jackfruit seed flour and ferrous ammonium phosphate had a pronounced effect on the iron of extruded snack due to its significantly effect on iron content at a linear ($p < 0.001$) and quadratic level ($p < 0.001$). The combined effects of jack fruit seed and ferrous ammonium phosphate on iron content are illustrated in Fig. 2i, j. Iron content increased by increasing the level ferrous ammonium phosphate which is novel iron fortificant and does not changes the organoleptic properties of extruded snacks and more bioavailable due to rapid and high iron release at stomach conditions. Similar result of increasing iron content was reported by Suri et al. (2020) in defatted soy flour, barnyard millet, amla (*Indian gooseberry*) rice flour extruded snack.

Optimization of independent variables

Response surface graphs were drawn using design expert software to demonstrate the effects of jackfruit seed flour, mung bean flour and ferrous ammonium phosphate on response variables. These graphs were generated by keeping one independent variable at the central point and varying other two independent variables within experimental ranges. Figure 2a, c, e, g, and i were generated by varying the jackfruit seed flour and mung bean flour at 0.015% ferrous ammonium phosphate, while Fig. 2b, d, f, h, j and l were drawn by changing the concentration of MBF and ferrous ammonium phosphate at a central value of JFSF (30%). These graphs illustrated complex interaction among independent variables.

After that, numerical optimization was performed by desirability function using Design Expert software. The goals selected for the optimization of extruded snack were maximum level of jack fruit seed flour, mung bean flour and ferrous ammonium phosphate in order to obtain minimum bulk density and hardness to obtain maximum expansion ratio, and iron content. Twenty-six different solutions were found involving different levels of the independent variable. Maximum desirability value was selected for the optimization of extruded snack. Combined optimized preparation conditions for extruded snack were 24.865% jackfruit seed flour, 20.946% mung bean flour and 0.021% ferrous ammonium phospahte. The response values at optimized preparation conditions were 0.15 bulk density, 3.11expansion ratio, 19.35 hardness, 11.82 colour value, and 21.99 mg/100 g iron content (Table 4).

Proximate analysis and iron content in optimized product

The proximate composition of the raw materials, control and optimized extruded snack are presented in Table 5. The jackfruit seed flour (JFSF) has a good quantity of protein (12.81%), fat (1.24%), the ash (3.01%), and the crude fibre 2.57% whereas mung bean flour (MBF) contains 23.78% protein, 1.56% fat and 4.95% ash. Addition of Jackfruit seed flour and mung bean flour significantly increase proximate composition of extruded snack except fat content. Moisture content in food has a significant impact on product's quality and shelf life. The optimized extruded product has 2.87% moisture content which makes them shelf-stable. Optimized extruded snacks processed good quantity of protein (15.32%). Protein content of optimized snack shows that it is effective in reducing malnutrition. There was no significant difference between fat content of optimized extruded snack (3.17%) and control snack (3.18%). In case of crude fibre, the highest amount was seen in optimized extruded snack with 3.32% in comparison to control snack (1.47%). Crude fibre is effective in lowering the blood glucose and lipid levels. Optimized extruded snack contains good amount of mineral (3.78 g/100 g). Meethal et al. (2017) found similar results that are increasing in protein and ash content in snack bar incorporated jackfruit seed flour. The obtained value of the iron content of optimized extruded snacks is 22.359 mg/100 g that indicate it meets the recommended daily allowance (RDA) made by ICMR (2019) which is consumed minimum 30 mg iron per day iron.

Conclusion

Malnutrition and anemia continues to be a major public health problem throughout the world. The research reports stated that people now search for healthy and functional food products that are rich in protein, fibre and iron. The functional characteristics of jackfruit seed flour and mung bean flours can be used in manufacturing of healthier extruded snacks in which conventional flours that are used in preparation of extruded snack can be partially or entirely substituted. This study also gives an opportunity to utilize the jack fruit seeds, which are considered as waste and thrown away in bulk quantity. Further research is needed for the clinical and other mandatory investigation before getting approval from the regulatory bodies. Extruded snack could be trial with other agro waste and various food products other than extruded snack can be developed by incorporation of jackfruit seed flour, mung bean flour and ferrous ammonium phosphate.

Abbreviations

AOAC: Association of official analytical chemists; BD: Bulk density; CAGR : Compound annual growth rate; CCRD: Central composite rotatable design; ER: Expansion ratio; FAP: Ferrous ammonium phosphate; IDA: Iron deficiency anemia; JFSF: Jackfruit seeds flour; MBF: Mung bean flour; MSG: Monosodium glutamate; RSM: Response surface methodology.

Acknowledgements

The work described has not been published before, it is not under consideration for publication elsewhere, its submission to Food Production, Processing and Nutrition publication has been approved by all authors as well as the responsible authorities—tacitly or explicitly—at the institute where the work has been carried out, if accepted, it will not be published elsewhere in the same form, in English or in any other language, including electronically without the written consent of the copyright holder, Food Production, Processing and Nutrition journal and will not be held legally responsible should there be any claims for compensation or dispute on authorship.

Authors' contributions

This work was designed by Aparna Kumari, Aditya Gupta, Anil Kumar Chauhan. The experiments were carried out by Aparna Kumari and Aditya Gupta under the supervision of Anil Kumar Chauhan. All authors contributed to the results and discussion. The first draft of the manuscript was prepared by Aparna and Aditya Gupta, and all authors contributed to the final version. All authors have read and agreed to the published version of the manuscript.

Funding

Not Applicable.

Availability of data and materials

The authors confirm that the data supporting the findings of this study are available within the article.

Declarations

Ethics approval and consent to participate

Not Applicable.

Consent for publication

Not Applicable.

Competing interests

The authors declare that they have no conflict of interest.

Received: 25 June 2022 Accepted: 12 October 2022
Published online: 28 November 2022

References

AOAC International (2007). *Official methods of analysis of AOAC international*, (18th ed.,). Association of Analytical Chemists.

Aydogdu, A., Sumnu, G., & Sahin, S. (2018). Effects of addition of different fibres on rheological characteristics of cake batter and quality of cakes. *Journal of Food Science and Technology*, *55*(2), 667–677. https://doi.org/10.1007/s13197-017-2976-y.

Baliga, M. S., Shivashankara, A. R., Haniadka, R., Dsouza, J., & Bhat, H. P. (2011). Phytochemistry, nutritional and pharmacological properties of Artocarpus heterophyllus Lam (jackfruit): A review. *Food Research International*, *44*(7), 1800–1811. https://doi.org/10.1016/j.foodres.2011.02.035.

Boye, J., Zare, F., & Pletch, A. (2010). Pulse proteins: Processing, characterization, functional prop erties and applications in food and feed. *Food Research International*, *43*(2), 414–431. https://doi.org/10.1016/j.foodres.2009.09.003.

Day, L., & Swanson, B. G. (2013). Functionality of protein-fortified extrudates. *Comprehensive Reviews in Food Science and Food Safety*, *12*(5), 546–564. https://doi.org/10.1111/1541-4337.12023.

Didinger, C., & Thompson, H. J. (2022). The role of pulses in improving human health: A review. Legume. *Science*, e147. https://doi.org/10.1002/leg3.147.

Dong, S., Fang, G., Luo, Z., & Gao, Q. (2021). Effect of granule size on the structure and digestibility of jackfruit seed starch. *Food Hydrocolloids*, *120*, 106964. https://doi.org/10.1016/j.foodhyd.2021.106964.

FAO (2019). State of food and agriculture. Moving forward on food loss and waste reduction. https://www.fao.org/3/ca6030en/ca6030en.pdf

FAO (2020). Hunger and food insecurity. https://www.fao.org/hunger/en/

Fombang, E. N., Nobossé, P., Mbofung, C. M., & Singh, D. (2021). Impact of post harvest treatment on antioxidant activity and phenolic profile of Moringa oleifera lam leaves. *Food Production, Processing and Nutrition*, *3*(1), 1–16. https://doi.org/10.1186/s43014-021-00067-9.

Gan, R. Y., Lui, W. Y., Wu, K., Chan, C. L., Dai, S. H., Sui, Z. Q., & Corke, H. (2017). Bioactive compounds and bioactivities of germinated edible seeds and sprouts: An updated review. *Trends in Food Science & Technology*, *59*, 1–14. https://doi.org/10.1016/j.tifs.2016.11.010.

Guo, W. Y., Wang, S. Y., Ren, J., & Zhang, B. (2021). Optimized preparation of quassinoid-rich Eurycoma longifolia Jack phospholipid complex and its effects on oral bioavailability. *Journal of Food Bioactives*, *15*. https://doi.org/10.31665/JFB.2021.15285.

Hou, D., Yousaf, L., Xue, Y., Hu, J., Wu, J., Hu, X., & Shen, Q. (2019). Mung bean (Vigna radiata L.): Bioactive polyphenols, polysaccharides, peptides, and health benefits. *Nutrients*, *11*(6), 1238. https://doi.org/10.3390/nu11061238.

ICMR. (2019). Recommended dietary allowance. http://www.nin.res.in.

Jagadeesh, S. L., Reddy, B. S., Basavaraj, N., Swamy, G. S. K., Gorbal, K., Hegde, L., … Kajjidoni, S. T. (2007). Inter tree variability for fruit quality in jackfruit selections of Western Ghats of India. *Scientia Horticulturae*, *112*(4), 382–387. https://doi.org/10.1016/j.scienta.2007.01.016.

Kalse, S. B., & Swami, S. B. (2022). Recent application of jackfruit waste in food and material engineering: A review. *Food Bioscience*, *101740*. https://doi.org/10.1016/j.fbio.2022.101740.

Korkerd, S., Wanlapa, S., Puttanlek, C., Uttapap, D., & Rungsardthong, V. (2016). Expansion and functional properties of extruded snacks enriched with nutrition sources from food processing by-products. *Journal of Food Science and Technology*, *53*(1), 561–570. https://doi.org/10.1007/s13197-015-2039-1.

Kumari, A., & Chauhan, A. K. (2021). Iron nanoparticles as a promising compound for food fortification in iron deficiency anemia: A review. *Journal of Food Science and Technology*, 1–17. https://doi.org/10.1007/s13197-021-05184-4.

Kumari, A., Chauhan, A. K., & Tyagi, P. (2022). Isochoric freezing: An innovative and emerging technology for retention of food quality characteristics. *Journal of Food Processing and Preservation*, e16704. https://doi.org/10.1111/jfpp.16704.

Li, Q., Li, X., Zheng, B., & Zhao, C. (2021). The optimization of ultrasonic-microwave assisted synergistic extraction of Lotus plumule extract rich in flavonoids and its hypoglycemic activity. *Food Production, Processing and Nutrition*, *3*(1), 1–11. https://doi.org/10.1186/s43014-021-00063-z.

Massari, S., Principato, L., Antonelli, M., & Pratesi, C. A. (2021). Learning from and designing after pandemics. CEASE: A design thinking approach to maintaining food consumer behaviour and achieving zero waste. *Socio-Economic Planning Sciences*, *101143*. https://doi.org/10.1016/j.seps.2021.101143.

Meethal, S. M., Kaur, N., Singh, J., & Gat, Y. (2017). Effect of addition of jackfruit seed flour on nutrimental, phytochemical and sensory properties of snack bar. *Current Research in Nutrition and Food Science Journal*, *5*(2), 154–158. https://doi.org/10.12944/CRNFSJ.5.2.12.

Mehmood, T., Ahmed, A., Ahmad, A., Ahmad, M. S., & Sandhu, M. A. (2018). Optimization of mixed surfactants-based β-carotene nanoemulsions using response surface methodology: An ultrasonic homogenization approach. *Food Chemistry*, *253*, 179–184. https://doi.org/10.1016/j.foodchem.2018.01.136.

Nakhon, P. P. N. S., Jangchud, K., Jangchud, A., & Charunuch, C. (2018). Optimization of pumpkin and feed moisture content to produce healthy pumpkin-germinated brown rice extruded snacks. *Agriculture and Natural Resources*, *52*(6), 550–556. https://doi.org/10.1016/j.anres.2018.11.018.

Okudu, H. O. (2015). The evaluation of the nutrient composition and anti-nutritional factors of jackfruit (Artocapus heterophyllus). *Journal of Sustainable Agriculture and the Environment*, *16*(1), 1-6.

Pawlak, K., & Kołodziejczak, M. (2020). The role of agriculture in ensuring food security in developing countries: Considerations in the context of the problem of sustainable food production. *Sustainability*, *12*(13), 5488. https://doi.org/10.3390/su12135488.

Rekhif, N., Sher, A., Vadehra, D. V., & Wedral, E. R. (2002). *Food fortified with iron. U.S. patent application no. 6,344,223 B1*.

Setiawan, D. (2016). Physical and chemical characteristics of jackfruit (Artocarpus heterophyllus Lamk.) seeds flour produced under fermentation process by lactobacillus plantarum. *Agriculture and Agricultural Science Procedia*, *9*, 342–347. https://doi.org/10.1016/j.aaspro.2016.02.148.

Sharma, C., Singh, B., Hussain, S. Z., & Sharma, S. (2017). Investigation of process and product parameters for physicochemical properties of rice and mung bean (Vigna radiata) flour based extruded snacks. *Journal of Food Science and Technology*, *54*(6), 1711–1720. https://doi.org/10.1007/s13197-017-2606-8.

Singh, R. K., Majumdar, R. K., & Venkateshwarlu, G. (2014). Optimum extrusion-cooking conditions for improving physical properties of fish-cereal based snacks by response surface methodology. *Journal of Food Science and Technology*, *51*(9), 1827–1836. https://doi.org/10.1007/s13197-012-0725-9.

Sullivan, G. M., & Feinn, R. (2012). Using effect size—or why the P value is not enough. *Journal of Graduate Medical Education*, *4*(3), 279–282. https://doi.org/10.4300/JGME-D-12-00156.1.

Suri, S., Dutta, A., Shahi, N. C., Raghuvanshi, R. S., Singh, A., & Chopra, C. S. (2020). Numerical optimization of process parameters of ready-to-eat (RTE) iron rich extruded snacks for anemic population. *LWT*, *134*, 110164. https://doi.org/10.1016/j.lwt.2020.110164.

Suzihaque, M. U. H., Zaki, N. A. M., Alwi, H., Ibrahim, U. K., Abd Karim, S. F., & Anuar, N. K. (2022). *Jackfruit seed as an alternative replacement for starch flour. Materials today: Proceedings*. https://doi.org/10.1016/j.matpr.2022.04.117.

Tas, A. A., & Shah, A. U. (2021). The replacement of cereals by legumes in extruded snack foods: Science, technology and challenges. *Trends in Food Science & Technology*, *116*, 701–711. https://doi.org/10.1016/j.tifs.2021.08.016.

Trindade, M. B., Lopes, J. L., Soares-Costa, A., Monteiro-Moreira, A. C., Moreira, R. A., Oliva, M. L. V., & Beltramini, L. M. (2006). Structural characterization of novel chitin-binding lectins from the genus Artocarpus and their antifungal activity. *Biochimica et Biophysica Acta (BBA)-Proteins and Proteomics*, *1764*(1), 146–152. https://doi.org/10.1016/j.bbapap.2005.09.011.

Waghmare, R., Memon, N., Gat, Y., Gandhi, S., Kumar, V., & Panghal, A. (2019). Jackfruit seed: An accompaniment to functional foods. *Brazilian Journal of Food Technology*, *22*. https://doi.org/10.1590/1981-6723.20718.

Walczyk, T., Kastenmayer, P., Storcksdieck Genannt Bonsmann, S., Zeder, C., Grathwohl, D., & Hurrell, R. F. (2013). Ferrous ammonium phosphate (FeNH4PO4) as a new food fortificant: iron bioavailability compared to ferrous sulfate and ferric pyrophosphate from an instant milk drink. *European Journal of Nutrition*, *52*(4), 1361–1368. https://doi.org/10.1007/s00394-012-0445-y.

Wang, J., Hu, X., Huang, Y., Zou, Y., Han, L., Wang, D., & Shahidi, F. (2022). Mono- and dioleyl p-coumarate phenolipids and their antioxidant activity in a muscle food model system. *Food Production, Processing and Nutrition*, *4*(1), 1–13. https://doi.org/10.1186/s43014-022-00087-z.

Yagci, S., Calıskan, R., Gunes, Z. S., Capanoglu, E., & Tomas, M. (2022). Impact of tomato pomace powder added to extruded snacks on the in vitro gastrointestinal behaviour and stability of bioactive compounds. *Food Chemistry*, *368*, 130847. https://doi.org/10.1016/j.foodchem.2021.130847.

Yao, X., Wu, D., Dong, N., Ouyang, P., Pu, J., Hu, Q., … Huang, J. (2016). Moracin C, a phenolic compound isolated from Artocarpus heterophyllus, suppresses lipopolysaccharide-activated inflammatory responses in murine raw264. 7 macrophages. *International Journal of Molecular Sciences*, *17*(8), 1199. https://doi.org/10.3390/ijms17081199.

Yi-Shen, Z., Shuai, S., & FitzGerald, R. (2018). Mung bean proteins and peptides: Nutritional, functional and bioactive properties. *Food & Nutrition Research*, *62*. https://doi.org/10.29219/fnr.v62.1290.

Zhang, L., Tu, Z. C., Xie, X., Wang, H., Wang, H., Wang, Z. X., … Lu, Y. (2017). Jackfruit (Artocarpus heterophyllus Lam.) peel: A better source of antioxidants and a-glucosidase inhibitors than pulp, flake and seed, and phytochemical profile by HPLC-QTOF-MS/MS. *Food Chemistry*, *234*, 303–313. https://doi.org/10.1016/j.foodchem.2017.05.003.

Zhuang, C. C., Liu, C. R., Shan, C. B., Liu, Z., Liu, L., & Ma, C. M. (2021). High-yield production of secoisolariciresinol diglucoside from flaxseed hull by extraction with alcoholic ammonium hydroxide and chromatography on microporous resin. *Food Production, Processing and Nutrition*, *3*(1), 1–10. https://doi.org/10.1186/s43014-021-00079-5.

Publisher's Note