DR-2072
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RESEARCH ARTICLE

Asian Journal of Dairy and Food Research

Formulation and Numerical Optimization of Finger Millet and Quinoa Incorporated Eggless Doughnuts

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10.18805/ajdfr.DR-2072

ABSTRACT

Background: The consumption of finger millet and quinoa can be increased by partially substituting refined wheat flour (RWF) with these grains in popular snack food item doughnuts. The present study was conducted to formulate eggless doughnuts using composite flour of RWF, finger millet flour and quinoa flour.

Methods: Response Surface Methodology was used for optimization of process parameters for which seventeen different combinations of finger millet flour: quinoa flour (X_1), butter (X_2) and curd (X_3) were taken as independent variables. The effect of independent variables on the responses (crude protein, crude fat, *in vitro* protein digestibility, springiness, flavor, appearance) was investigated.

Result: Optimized doughnuts (X_1= 3:1, X_2= 16.712% of composite flour and X_3= 25% of composite flour) were formulated, analyzed and compared with control RWF doughnuts prepared under similar conditions for nutritional quality, hardness and sensory quality. Significantly higher values were observed for total ash, crude protein, crude fibre, hardness and springiness of optimized doughnuts in comparison to control RWF doughnuts whereas sensory evaluation showed non-significant difference except for color of the doughnuts. This study showed that the formulated eggless doughnuts were nutritious and could be a good substitute for the market based doughnuts especially for vegetarian people and who are allergic to egg protein.

Key words: Finger millet, Optimization, Quinoa, Response surface methodology.

INTRODUCTION

The consumption of snack food item have witnessed a great surge in recent years in India. The most commonly consumed snack food item worldwide is doughnut. Doughnut is a kind of confectionery fried dough or dessert bread. It has gained popularity in various countries and is made in different forms as a sweet snack that can be prepared in home or bought from bakeries, food stalls, supermarkets and franchised speciality outlets (Kumar *et al*., 2018). These are generally made from refined wheat flour which lack dietary fibre and micronutrients consequently may yield lowered health benefits compared with whole grain products (Cheong, 2001). Fibre lacking diet has been associated with constipation, diverticulitis, diabetes, obesity, cardiovascular disease and cancer (Anonymous, 2001).

Millets and pseudocereals are rich in fibre and micronutrients. Incorporation of these grains such as finger millet and quinoa can enrich the nutritional quality of doughnuts**.** Finger millet (*Eleusine coracana*) commonly consumed small millet in India. It has gained importance due to its nutritional and therapeutic benefits (Pore and Magar, 1977) which consists of 18% dietary fibre, 65-75% carbohydrates and 2.5-3.5% minerals and also relatively balanced amount of essential amino acids and contains upto 15.58% protein (Singh and Srivastava, 2006 ; Chandra *et al*., 2016) and pseudocereal quinoa (*Chenopodium quiona wild*) from the Andean region has received increasing scientific and commercial attention due to the exceptional nutritional value of its seeds, combined with high protein quality and content, good amino acid composition and high polyunsaturated fatty acids in recent years (*Surjana et al*., 2017). Quinoa grains comprise of 58.3% carbohydrates, 6.5% fat and 13.52% protein (Malik, 2017) and is a rich source of dietary fibre and omega-3 fatty acids (Ando *et al*., 2002). Mineral content of quinoa is much higher than other cereals (Konishi *et al*., 2004).

In addition to refined wheat flour one of the ingredients of doughnuts is egg, which acts as leavening agent but vegetarian population and people allergic to egg protein do not find it suitable for consumption. Eggless doughnuts could be developed incorporating quinoa so that in absence of egg also the presence of quinoa in doughnuts could provide good amount of protein as it contains complete protein. Also the work related to incorporation of millets or pseudocereals in doughnuts is very scarce.

Therefore the study aimed to develop eggless doughnuts combining two super foods finger millet and

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How to cite this article: Joshi, A., Srivastava, S., Shahi, N.C., Kushwaha, A. and Acharya, R. (2023). Formulation and Numerical Optimization of Finger Millet and Quinoa Incorporated Eggless Doughnuts. Asian Journal of Dairy and Food Research. doi:10.18805/ajdfr.DR-2072.

Submitted: 28-01-2023 **Accepted:** 07-06-2023 **Online:** 22-07-2023

quinoa by partially substituting refined wheat flour. Composite flour of refined wheat flour, finger millet and quinoa flour will lead to development of nutritious eggless doughnuts as well as will add variety to the diet.

MATERIALS AND METHODS

Procurement of raw materials

Finger millet flour (FMF) was procured from Saras market of Haldwani of district Nainital, Uttarakhand. Organic quinoa flour (QF) of Organic India was purchased online. Refined wheat flour (RWF) along with other ingredients was procured from the local market of G.B. Pant University of Agriculture and Technology, Pantnagar.

Study area and period

The study was conducted in department of Foods and Nutrition, College of Homescience, GBPUAT, Pantnagar, U.S. Nagar in the period of 2018-2020.

Formulation of doughnuts

The dry ingredients like RWF, QF, FMF, skim milk powder, grounded sugar, baking powder and baking soda were mixed together. Then vanilla essence and the melted butter were added to the dry ingredients and were mixed well. On the other side curd and water were mixed together which was used for kneading and preparing soft dough. The dough was rolled to uniform thickness and cut into the shape of doughnuts using doughnut cutter. These doughnuts were then fried in low flame until the color turned to brown.

Experimental design

The Box Behnken Model of Response surface methodology (RSM) was used to lower the number of experiments, to optimize and examine the effect of three independent variables *viz*. blend ratio of FMF and QF (X_1=1:1 to 3:1), butter (X_2=12 to 16% of composite flour) and curd (X_3=15 to 25% of composite flour) on the following dependent variables crude protein (CP), crude fat (CF), *in vitro* protein digestibility (IVPD), springiness (SP), flavor and appearance. Seventeen experiments were conducted on the basis of different levels of process parameters (Table 1). The levels of independent variables were selected by conducting preliminary trials whereas level of other ingredients was kept constant.

Analytical procedures for product responses

For analysis of these parameters doughnut was crumbled and uniformly mixed which represented the whole doughnut. The CP and CF were analysed by Kjeldahl and Socs plus method, respectively using AOAC (2000). IVPD was estimated by the procedure given by Akeson and Stahman (1964) by slightly modifying the method of Degroot and Slump (1969) using the formula:

$$\%\ \text{digestibility} = \frac{\%\ \text{Nitrogen in digested sample}}{\%\ \text{Nitrogen in sample}} \times 100$$

The springiness of doughnuts were estimated using texture analyzer (TA HD plus) which were calculated and given by the TA software. Sensory quality analysis *viz*. appearance and flavor of the doughnuts was assessed using score card method (Amerine *et al.,* 2013). A jury consisting of 10 members from the Deptt. of Foods and Nutrition, College of Home Science, GBPUAT Pantnagar performed this evaluation.

Data analysis

RSM was used to test the significant difference between the variables using a one-way analysis of variance (ANOVA) procedure at p<0.01 and p<0.05 level of significance. The second-order mathematical regression equation (Equation (1) was developed to calculate the effect of each independent parameter on each response.

$$Yi = \beta 0 \pm \beta_1 X_1 \pm \beta_2 X_2 \pm \beta_3 X_3 \pm \beta_{12} X_1 X_2 \pm \beta_{13} X_1 X_3 \pm \beta_{23} X_2 X_3 \pm \beta_{11} X_1^2 \pm \beta_{22} X_2^2 \pm \beta_{33} X_3^2 \quad \text{...(Eq 1)}$$

Where,

Yi = Product responses.

X_1, X_2 and X_3 = Independent variables.

βo = Intercept.

β_1, β_2, β_3 = Linear effects.

β_{12}, β_{13}, β_{23} = Interactive effects.

β_1^2, β_2^2, β_3^2 = Quadratic effects (Cornell, 2011).

The model developed for each determination was examined for significance and lack of fit, while non-significant terms were removed for designing response surface plot.

Optimization of independent variables

The optimization was carried out on the basis of all the chosen responses of the experiment. The developed models were used for interpreting the effect of independent variables on the responses. Response surface plots were drawn with the help of software to get the range of independent variables for product development.

Quality evaluation of optimized FMF and QF incorporated doughnut and control RWF doughnut

Control RWF doughnuts and optimized FMF and QF incorporated doughnuts, both were prepared in similar way and subjected to nutritional analysis, textural analysis (hardness, cohesiveness and springiness) and sensory quality for comparison. Nutritional analysis comprised of estimation of proximate composition (moisture, total ash, crude fibre, crude protein, crude fat, carbohydrate by difference and physiological fuel value), calcium and iron content of the doughnuts using AOAC (2000).

Statistical analysis

One way ANOVA was used to find out the significant difference between the nutritional quality, textural profile and sensory quality of control RWF doughnuts and optimized FMF and QF incorporated doughnuts.

RESULTS AND DISCUSSION

Model and its validation

The effect of independent variables on the product responses has been reported in Table 1. According to the

ANOVA table from RSM, it was found that the model was well fitted for all the process variables (Table 2) as the F value was significant ($p<0.05$), lack of fit was insignificant ($p<0.05$) and the CV values were less than 7%. The values of the coefficient of the determination (R^2) for all the models was in the range of 0.91-0.99 which proves the data accuracy. The Predicted R^2 was in reasonable agreement with the adjusted R^2 in which the difference was less than 0.2 among the both. Adequate Precision which measures the signal to noise ratio was found to be high in all the responses so, this model can be used to navigate the design space.

Product responses

Crude protein (CP)

The CP of doughnuts ranged from 7.86 to 9.55% (Table 1). According to the regression model it was found that blend ratio and curd showed significant effect on CP content ($p<0.01$) at linear level whereas at quadratic level blend ratio and butter showed significant effect at ($p<0.01$) and ($p<0.05$), respectively (Table 3). The linear effect of blend ratio showed that with the increase in the blend ratio, the CP decreased (Fig 1a) whereas the positive linear effect of curd showed that CP increased with the increase in the curd content (Fig 1b). This could be because of decrease in amount of quinoa flour from 1:1to 3:1 as the protein content of quinoa (16.89%) is more than that of finger millet (8.9%) (Dhaka and Prasad, 2020) and curd is known as excellent source of protein and contains protein with high biological value (Mckinley, 2005).

Crude fat (CF)

The CF content varied from 18.68 to 26.66% (Table 1). According to the regression model it was found that at linear level butter and curd content showed positive significant

Table 1: Experimental design and values of various responses.

		Factor 1	Factor 2	Factor 3	R 1	R 2	R 3	R 4	R 5	R 6
Std	Run	X_1:Blend ratio	X_2:Butter content % of composite flour	X_3:Curd content % of composite flour	CP %	CF %	IVPD %	SP mm	Flavor	Appearance
16	1	2:1	16	20	8.46	24.89	72.65	0.265	8.20	8.30
7	2	1:1	16	25	9.45	24.22	79.47	0.415	7.80	8.60
13	3	2:1	16	20	8.62	23.54	72.9	0.25	8.50	8.20
8	4	3:1	16	25	8.24	23.82	77.57	0.365	8.80	8.20
6	5	3:1	16	15	7.86	21.8	74.35	0.396	8.80	8.00
2	6	3:1	12	20	8.31	18.68	75.75	0.349	8.75	7.80
5	7	1:1	16	15	8.98	22.12	76.92	0.375	7.75	8.60
11	8	2:1	12	25	8.65	20.84	78.57	0.326	8.00	7.75
1	9	1:1	12	20	9.55	18.88	75.34	0.357	7.40	8.50
9	10	2:1	12	15	8.31	18.56	74.60	0.36	8.20	8.00
3	11	1:1	20	20	9.28	25.62	72.34	0.256	8.20	8.80
10	12	2:1	20	15	8.45	24.86	66.67	0.265	8.50	8.00
17	13	2:1	16	20	8.42	21.04	70.56	0.289	8.00	8.20
14	14	2:1	16	20	8.57	24.25	75.20	0.259	8.40	8.00
15	15	2:1	16	20	8.40	23.36	71.54	0.251	8.30	8.20
4	16	3:1	20	20	8.24	25.20	67.67	0.298	9.00	8.00
12	17	2:1	20	25	8.75	26.66	71.42	0.262	8.60	8.40

Table 2: Analysis of variance (ANOVA) table for the fit of study data to the response surface model.

Factors	Product responses					
	Crude protein (%)	Crude fat (%)	IVPD (%)	Springiness	Flavor	Appearance
Model F value	29.79***	8.34	9.53	21.75	14.01	12.26
Lack of fit	1.7200^{ns}	0.0256^{ns}	0.3399^{ns}	1.0100^{ns}	0.0619^{ns}	0.9549^{ns}
CV (%)	1.28	4.88	2.00	5.07	1.79	1.32
R^2	0.9746	0.9147	0.9245	0.9655	0.9474	0.9404
Adjusted R^2	0.9418	0.8050	0.8275	0.9211	0.8798	0.8637
Predicted R^2	0.7534	0.8435	0.6608	0.7308	0.8841	0.5475
Model adequate precision	18.8285	9.8205	11.1997	12.2391	13.4771	11.7938

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

CP: Crude protein, IVPD: In vitro protein digestibility, TDF: Total dietary fibre, OA: Overall acceptability.

effect on CF content at ($p<0.01$) and ($p<0.05$), respectively (Table 3) whereas blend ratio showed non-significant effect. None of the parameters showed significant effect at both interactive and quadratic level. It was seen that CF increased highly with the increase in butter content (Fig 1c) and slightly increased with increase in curd content (Fig 1d). This is due to the fact that butter contains good amount of fat in which bakery fats (margarine and butter) contain about 80% fat (Mamat and Hill, 2014) and curd contains about 3-4% fat (Anonymous, 2017).

In vitro protein digestibility (IVPD)

IVPD varied from 66.67 to 79.47% (Table 1). According to the regression model it was found that at linear level butter and curd showed significant effect on IVPD ($p<0.01$) whereas blend ratio showed non-significant effect. At quadratic level all the three independent variables showed significant effect ($p<0.05$) (Table 3). It was found that with increase in butter from 12 to 20%, IVPD decreased (Fig 1e). This is because of binding ability of protein with fat (Kinsella, 1982) leading to reduced bioavailability of protein. IVPD slightly decreased and then increased with increase in curd content (Fig 1f). This is because of presence of high biological value protein in curd (Mckinley, 2005).

Springiness

Springiness refers to the height that the doughnut recovers after the end of first bite and the starting of the second bite. The obtained values varied from 0.250 to 0.415 mm (Table 1). According to the regression model it was found that at linear level only butter showed significant effect on springiness ($p<0.01$) whereas blend ratio and curd showed non-significant effect. At quadratic level, blend ratio and curd showed significant effect ($p<0.01$) (Table 3). It was observed that springiness decreased with increase in the butter from 12 to 20% (Fig 1g). This is due to the fact that more amount of butter makes the product easy to crumble and hence results in decreased springiness. Similarly Srikanlaya et al. (2017) conducted a study which showed that when butter content was increased from 10 to 30 g/100 g flour, hardness of the bread was decreased and springiness increased.

Flavor

The score varied from 7.4 to 9 (Table 1). According to the regression model it was found that at linear level, blend ratio and butter showed significant effect on flavor ($p<0.01$) whereas none of the parameters showed significant effect at quadratic and interactive level (Table 3). Both the blend ratio and butter showed positive linear effect with flavor as shown in Fig 1(h) and Fig 1(i), respectively. This was due to the reason that flavor of FMF was liked more by the panelist as compared to flavor of quinoa and butter enhances the flavor of the other ingredients and also contributes its own flavor to the product (Geetha and Narayanan, 2004).

Appearance

The score varied from 7.75 to 8.80 (Table 1). According to the regression model it was found that at linear level, blend ratio and butter showed significant effect on appearance ($p<0.01$), at interactive level butter and curd showed significant effect ($p<0.05$) and at quadratic level only blend ratio showed significant effect ($p<0.01$) (Table 3). The acceptance for appearance decreased with increase in blend ratio from 1:1 to 3:1 because of black colour of finger millet (Fig 1j) whereas increased with increase in butter from 12 to 20% (Fig 1k) due to the fact that bakery shortenings added to the product showed better surface characteristic (Manohar and Rao, 2002). Interactive effect of butter and curd content has been shown in 3-D graph (Fig 1l). It is observed in the figure that at higher level of curd content if the butter content is increasing then the score for appearance of the doughnuts is also increasing.

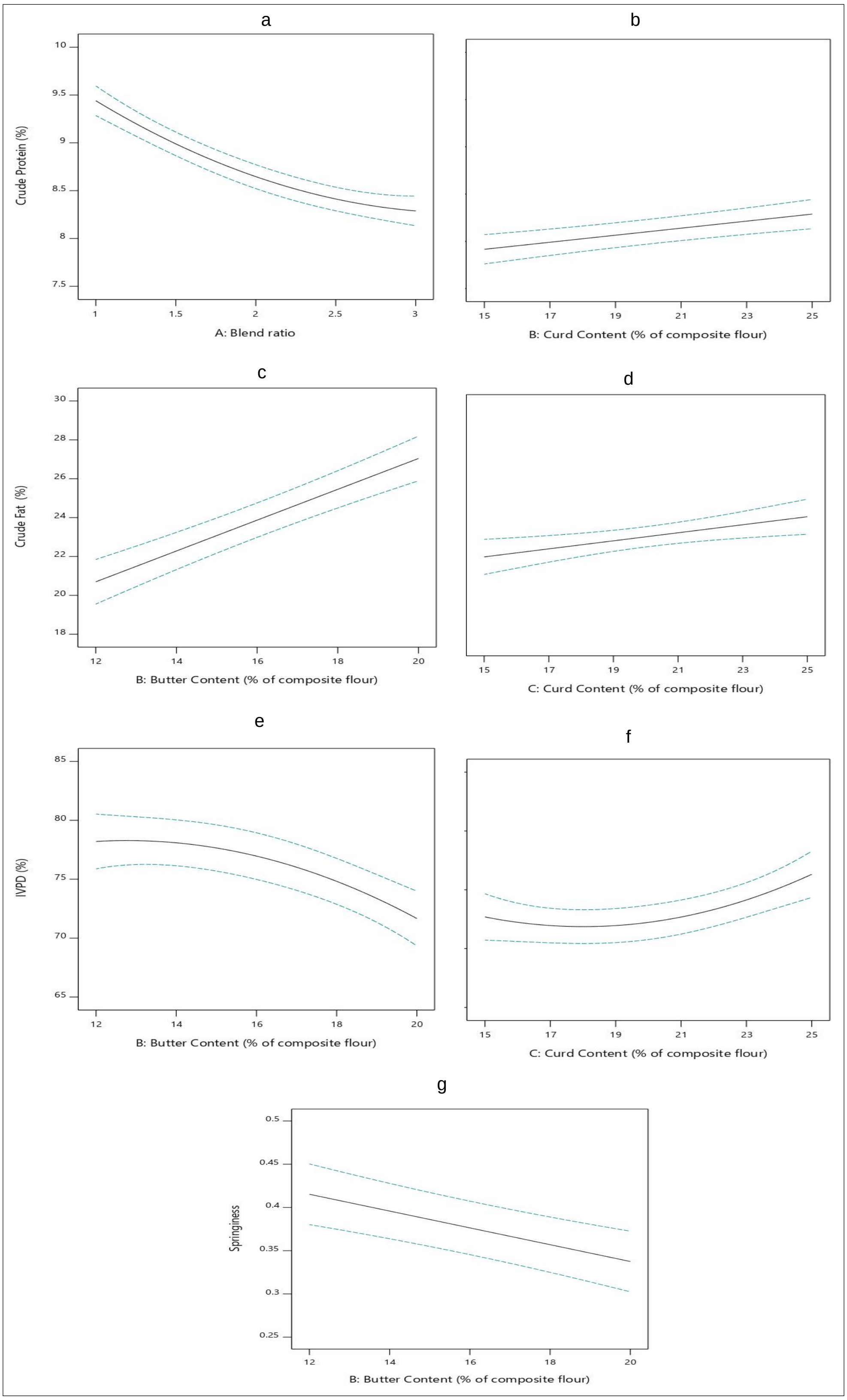
Optimization and validation of variables

Process variables were optimized using the RSM software to obtain the most acceptable doughnut. The main standard for optimization was the CP, IVPD, springiness, flavor, appearance which were maximized and CF was minimized. According to the data analysis, the process variables that gave the desired qualities for doughnuts were blend ratio 3:1, butter 16.712% of CF and curd 25% of CF. Table 4 showing the predicted and observed values of process variables indicating their mean and standard deviation.

Table 3: Regression analysis cofficients for each process parameter and responses.

	Crude protein (%)	Crude fat (%)	IVPD (%)	Springiness	Flavor	Appearance
Intercept	8.49	23.42	72.57	0.2682	8.28	8.18
X_1-Blend ratio	-0.5762***	-0.1675	-1.09	0.0006	0.5250***	-0.3125***
X_2-Butter content	-0.0125	3.17***	-3.27***	-0.0389***	0.2437**	0.1438**
X_3-Curd content	0.1862**	1.03*	1.81*	-0.0035	-0.0062	0.0437
X_1X_2	0.0500	-0.0550	-1.27	0.0125	-0.1375	-0.0250
X_1X_3	-0.0225	-0.0200	0.1675	-0.0178	-0.0125	0.0500
X_2X_3	-0.0100	-0.1200	0.1950	0.0077	0.0750	0.1625*
X_1^2	0.2217**	-0.5305	2.23*	0.0684***	0.0100	0.2037**
X_2^2	0.1292*	-0.7905	-2.03*	-0.0162	0.0475	-0.1088
X_3^2	-0.0832	0.1045	2.27*	0.0566***	-0.0025	-0.0337

***Significant at $p<0.001$; **Significant at $p<0.01$; *Significant at $p<0.05$.



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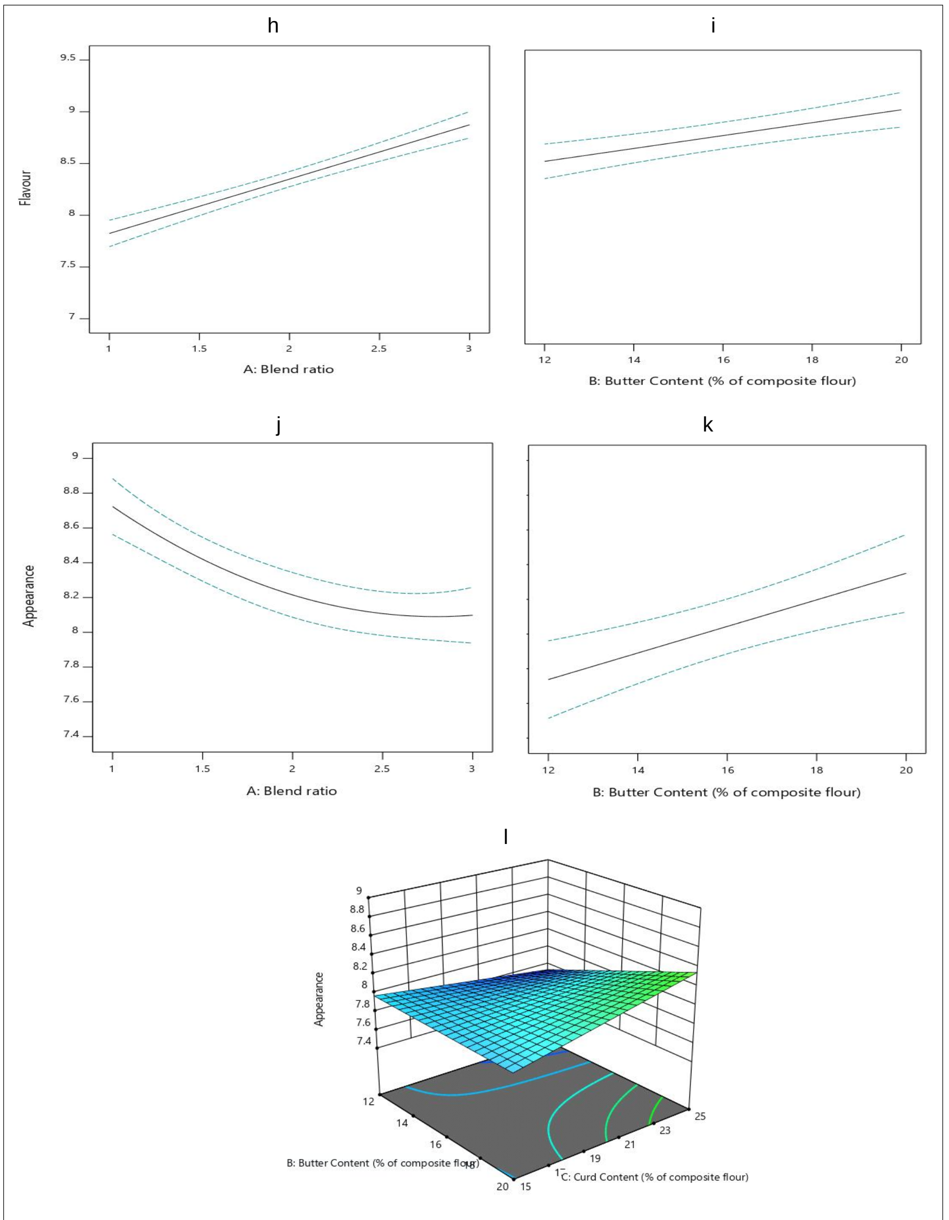

(a); Effect of blend ratio on CP, (b); Effect of curd on CP, (c); Effect of butter on crude fat, (d); Effect of curd on crude fat, (e); Effect of butter on IVPD, (f); Effect of curd on IVPD, (g); Effect of butter on springiness, (h); Effect of blend ratio on flavor, (i); Effect of butter on flavor (j); Effect of blend ratio on appearance, (k); Effect of butter on appearance, (l); Combined effect of butter and curd content on appearance.

Fig 1: Effects of process parameters on various responses of doughnuts.

Quality evaluation and comparison of control RWF doughnuts and optimized FMF and QF incorporated doughnuts

The optimized FMF and QF incorporated eggless doughnuts as well as control RWF doughnuts were analyzed for different quality parameters such as nutritional, sensory and textural quality.

In terms of nutritional quality significantly higher values were observed for total ash (1.83%), crude protein (8.98%), crude fibre (3.11%) of optimized doughnuts in comparison with for total ash (1.67%), crude protein (4.81%), crude fibre (0.63%) of control RWF doughnuts as shown in Table 5. Similarly, Kumar *et al*., (2018) reported higher crude protein content and lower total ash content in doughnuts prepared by 40% substitution of RWF with FMF in comparison to control RWF doughnuts. Similarly, calcium (114.67 mg/100 g) and iron (3.10 mg/100 g) were also found to be significantly higher in optimized doughnuts than calcium (29.33mg/100 g) and iron (1.59 mg/100 g) in control doughnuts as shown in Table 5. In contrast to this carbohydrate content (53.58%) and physiological fuel value (440 Kcal) of control doughnuts were found to be significantly higher when compared to carbohydrate content (42.49%) and physiological fuel value (397 Kcal) of optimized doughnuts.

In terms of textural quality hardness of optimized doughnuts (169.5 N) has been found to be significantly higher than that of control doughnuts (146.43 N) as shown in Table 5. It is because of presence of more dietary fibre content in optimized doughnuts because when the dietary fibre content increases the hardness of the product increases (Li *et al*., 2020). Whereas, springiness of control doughnuts (0.331 mm) has been found to be significantly higher than that of optimized doughnuts (0.241 mm) as shown in Table 5. This is because of mixing of FMF with RWF results in reduction of gas retention capacity of dough which lowers the springiness of the product and also with increase in dietary fibre the elasticity of the product decreases (Li *et al*., 2020). Sensory evaluation on the basis of Hedonic scale showed non-significant difference between control RWF doughnuts (7.95) and optimized doughnuts (8.20) as shown in Table 6. In contrast to this sensory evaluation conducted on pear millet blended doughnuts showed lowest score for sensory parameters when compared with refined wheat flour doughnuts (Kaur *et al*., 2017).

Table 4: Predicted and observed value of responses.

Particulars	Optimized value	Desirability of model	% error
Blend ratio	3:1	0.55	
Butter (% of Composite flour)	16.712		
Curd (% of Composite flour)	25		
	Mean and S.D. predicted	**Mean and S.D. observed**	
Crude protein (%)	8.23±0.11	8.98 ± 0.02	9.11
Crude fat (%)	24.34±1.11	22.97 ± 0.53	5.62
In vitro protein digestibility (%)	77.12±1.47	76.21±1.68	1.17
Springiness (mm)	0.36±0.02	0.24±0.03	33.33
Appearance	8.18±0.11	7.85±0.24	4.03
Flavor	8.82±0.15	7.95±0.55	9.86

Table 5: Proximate composition and textural parameters of control doughnuts and optimized doughnuts on fresh weight basis.

Parameters	Control doughnuts	Optimized doughnuts	S.Em.	CD at 5%
Moisture (%)	16.11 ± 0.81	21.23 ± 0.56	0.40	1.57*
Total ash (%)	1.67 ± 0.05	1.83 ± 0.06	0.03	0.13*
Crude protein (%)	4.81 ± 0.02	8.98 ± 0.02	0.01	0.04*
Crude fat (%)	23.20 ±0.40	22.97 ± 0.53	0.27	1.07
Crude fibre (%)	0.63 ± 0.15	3.11 ± 0.29	0.13	0.52*
Carbohydrate (%)	53.58 ± 0.99	42.39 ± 0.54	0.46	1.81*
Physiological energy (Kcal/100g)	440 ±2.89	397±2.89	1.66	6.52*
Hardness (N)	146.43±3.830	169.50±8.720	3.66	14.32*
Springiness (mm)	0.331± 0.037	0.241 ± 0.032	0.022	0.087*
Cohesiveness	0.355±0.039	0.319±0.034	0.027	0.107

All results are mean±standard deviation of three values.

*Significant at $p<0.05$.

Table 6: Sensory evaluation of control refined wheat flour doughnuts and optimized doughnuts by score card method.

Parameter	Control doughnuts	Optimized doughnuts	S.Em.	CD at 5%
Color	8.35±0.33	7.80±0.25	0.09	0.28*
Taste	8.30±0.48	8.05±0.59	0.17	0.51
Texture	8.05±0.28	8.25±0.42	0.11	0.33
Flavor	8.25±0.48	7.95±0.55	0.16	0.48
Overall acceptability	8.20±0.48	7.95±1.10	0.16	0.48

All results are mean±standard deviation of ten values.

*Significant at $p<0.05$.

CONCLUSION

This study concluded that nutritionally superior eggless doughnuts can be prepared using RWF, FMF, QF and curd. It may be summed up that the process variables especially blend ratio of flour and curd level showed tremendous effects on doughnuts. The optimum process conditions obtained were blend ratio 3:1, butter 16.712% of composite flour and curd 25% of composite flour. FMF and QF incorporated optimized doughnuts and their comparison with control RWF doughnuts showed that these optimized doughnuts were found to have more crude fibre, crude protein, total ash content in comparison to control RWF doughnuts and were observed to have non-significant difference with respect to sensory characteristics. These optimized eggless doughnuts were superior in nutritional quality as compared to control RWF doughnuts and being eggless add variety to the diet of vegetarian people and those who are allergic to egg protein. Moreover, the results of this study could provide the industry useful information about potential utilization of millet grains and pseudocereal in food formulations and product development for new functional foods.

Funding statement

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

ACKNOWLEDGEMENT

The authors thank the Department of Foods and Nutrition, College of Home Science, GBPUAT, Pantnagar, Uttarakhand, India for helping in conducting this research. The authors are grateful to Dr. Anil Kumar for conducting texture analysis of doughnuts, Dr. Shweta Suri, Mr. S.D. Joshi, Mr. Bhanu, Ms. Shikhangi, Mr. Deepak Pal for giving the helpful insights during writing of the draft.

Author's contribution

Ayushi Joshi: Conceptualization, Investigation, Writing-original draft. Sarita Srivastava: Supervision, Project administration, Visualization, Writing-review and editing. Navin Chandra Shahi: Methodology, Writing-review and editing. Archana Kushwaha: Editing, Visualization, Ranjana Acharya: Writing.

Conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this manuscript. No conflict of interest exits in the submission of this manuscript.

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