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Development and Optimization of Jaggery Based Cold Extruded Products

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A B S T R A C T

Jaggery is the sugarcane based traditional Indian sweetener. Jaggery is among major agro processing industries in India. At present, 61.4 MT of jaggery is being produced from total sugarcane produced in the country, which is known as most nutritious agent among all sweeteners. Value addition to solid jaggery by inclusion of nutritive substances through puffed rice, gram, sesame and various kinds of nuts (cashew, almond), vitamins, iron, and taste enhancers like chocolate powder will increase demand for this kind of jaggery. In this study, value added jaggery based cold extruded products were prepared by using cold extrusion. The ingredients used were multi grain flour, maida flour, jaggery powder. The multi grain flour was prepared by mixing three flours *viz.*, wheat flour, ragi flour and corn flour. By conducting preliminary experiments, the composition of multi grain flour was decided as 50 % of wheat flour, 30 % of corn flour and 20 % of ragi flour. The physical characteristics such as colour, bulk density of jaggery based cold extruded products were measured. The bulk density of jaggery based cold extruded products ranged from 0.31 to 0.47 g/cc. The hardness of the uncooked jaggery based cold extruded products was ranged from 3871.02 to 14534.50 N. The hardness of the cooked products was ranged from 81.22 to 350.30 N. Optimization of jaggery based cold extruded products was performed by using Response Surface Methodology. The numerical optimization showed that R17 (MGF-450 g, MF-95 g, JP- 225 g, WATER-80 ml) sample was selected as best sample with desirability of 0.875.

Introduction

Jaggery is the sugarcane based traditional Indian sweetener. Jaggery is a traditional unrefined non-centrifugal sugar consumed in Asia, Africa, Latin America and the Caribbean. It is a concentrated product of date, cane juice, or palm sap without separation of the molasses and crystals, and can vary from golden brown to dark brown in colour and is considered as a special because of its inherent taste and aroma due to high molasses content. Containing all the minerals and vitamins present in sugarcane juice, it is known as healthiest sugar in the world. India is the largest producer and consumer of jaggery. Out of total world production, more than 70% is produced in India. It is consumed in almost all sections of the society as a sweetener, and as a source of energy. It is also used in animal feed mixtures (Nath *et al.,* 2015). In cement industries and coalmines jaggery is supplied to the workers in order to protect them from dust allergies (Shrivastav *et al.,* 2016).

Jaggery, a product of sugarcane, is rich in important minerals (viz., calcium-40-100 mg, magnesium-70-90 mg, potassium-1056 mg, phosphorus-20-90 mg, sodium-19-30 mg, iron-10-13 mg, manganese-0.2-0.5 mg, zinc-0.2- 0.4 mg, copper-0.1-0.9 mg, and chloride-5.3 mg per 100 g of jaggery), vitamins (viz., vitamin A-3.8 mg, vitamin B1-0.01 mg, vitamin B2-0.06 mg, vitamin B5-0.01 mg, vitamin B6-0.01 mg, vitamin C-7.00 mg, vitamin D2-6.50 mg, vitamin E-111.30 mg, vitamin PP-7.00 mg), and protein-280 mg per 100 g of jaggery, which can be made available to the masses to mitigate the problems of mal nutrition and under nutrition (Singh *et al.,* 2011).

Value addition to solid jaggery by inclusion of nutritive substances through puffed rice, gram, sesame and various kinds of nuts (cashew, almond), vitamins, iron, and taste enhancers like chocolate powder will increase demand for this kind of jaggery. Almost all food products that can be prepared with refined sugar can also be prepared with jaggery. Products like cakes, sweets, pooranpoli, chikkis and candies are mostly prevalent (Jaggery Research in India, 2015). The nutritive value and palatability can be enhanced by preparing different kinds of jaggery with the addition of puffed rice, gram and groundnut, mixing with wheat flour and mixing with gram flour. The jaggery with 10% cocoa powder yielded a product (chocolate) which was very much acceptable as a substitute for chocolate. Value added jaggery will be a cheap source of nutrition to the poor and malnourished (Prashant *et al.,* 2013). Padma *et al.,* (2015) developed a ready-to-eat nutritious ladoo mix by blending the flour of sprouted, roasted grains like wheat, ragi, jowar, bajra, green gram and horse gram with jaggery in an optimized proportion of 1:1:1.6. Other ingredients like powdered cardamom and sesame were added in small amounts to enhance the flavour. Khulve *et al.,* (2015) prepared jaggery based energy bar using jaggery powder, skimmed milk powder, and 40% of total quantity of butter.

Noodles of different combinations are prepared such as noodles exclusively made of finger millet, finger millet and wheat in the ratio of 1:1 and finger millet blended with wheat and soy flour in the ratio of 5:4:1. Generally, in the preparation of noodles, wheat flour is invariably used as an important member of blend because the presence of wheat gluten has an added advantage which not only helps in easy extrusion but also gives a smooth and fissure free texture to the noodles (Veenu *et al.,* 2012). Devraju *et al.,* (2003) developed pasta with Finger millet flour (50%), refined wheat flour (40%), defatted soy/whey protein concentrate (10%) and extruded using both cold (30°C) and hot water (75°C). Sanjarambam *et al., (2015)* developed millet fortified cold extruded pasta products and to study the quality attributes of the developed products. Khan *et al.,* (2012) developed a jaggery based extruded snack using blends of soy-flour, wheat-flour and jaggery. Shanthi *et al.,* (2005) studied the effect of incorporation of finger millet in pasta products. Archana (2001) also reported that pasta prepared from pearl millet and fenugreeks (80:20) were found to be very much acceptable. Ranganna *et al.,* (2012) used a sophisticated Brabender Single Screw Extruder to develop small millets based extruded pasta by blending cassava flour.

Nutritionally balanced extruded snacks food products using jaggery as a sweetener is not yet been developed. The incorporation of jaggery into the blend of soya flour and wheat flour increases the taste and overall acceptability. Extruded snacks prepared from wheat-soy flour and jaggery can fulfill the requirement of all nutrients up to some extent and may provide a good neutraceutical diet (Khan *et al.*, 2012). Making such value added multi grain flour and jaggery based extruded products may enhance protein and energy intake of the vulnerable group at comparatively economic cost.

Materials and Methods

Experimental site

The experiment was carried out at AICRP on PHET, Regional Agricultural Research Station.

Raw materials

The raw materials used for the development of jaggery based cold extruded products were multigrain flour (wheat flour, ragi flour and corn flour), maida and jaggery powder.

Material source

Multi grain flour

Multi grain flour was prepared by selecting, milling and mixing of flour of different grains. In present study, the multi grain flour was prepared by using three types of grains namely ragi, wheat and corn. The selection of ingredients for making multi grain flour was based on the review and the local availability of ingredients to be mixed. Readily available milled wheat flour, ragi flour and corn seeds were purchased from the local market. The corn seeds were made into corn flour by using domestic grain burr mill locally available at Anakapalle. The selected three ingredients were mixed thoroughly and uniformly to make multi grain flour. The composition of multi grain flour was optimized by conducting preliminary experiments with different ratios of ingredient flours.

Maida flour

Maida flour was purchased from the local market at Anakapalle. It is used as a binding agent that helps to produce smooth finished cold extruded products.

Jaggery powder

Fresh jaggery powder was made from sugarcane juice at jaggery manufacturing unit situated at RARS, Anakapalle

Equipment

The laboratory model *Pasta Machine* (make: La Monferrina, Italy; model: P12) was used for the experiment and was basically a medium, compact cold extruder (Plate 3.1). The unit was basically a single screw extruder with a short stainless steel screw of uniform pitch powered by a 3 hp electrical motor through a speed reduction system.

Preliminary experiments

Preliminary studies were conducted on the basis of review conducted on development of various extruded products to decide the suitable composition of multi grain flour to prepare jaggery based cold extruded products. In view of results obtained from preliminary experiments the variable and actual levels were decided.

Experimental design

The multi grain flour having composition of 50% of wheat flour, 30% of corn flour and 20% of ragi flour was found to be acceptable to prepare jaggery based cold extruded products after conducting preliminary experiments. The effect of three independent variables on the response was studied using a three-level, four-factor Central Composite Rotatable Design (CCRD) of Response Surface Methodology (RSM) (Ferreira *et al.*, 2009). The four independent variables were multigrain flour (X_1), maida flour (X_2), jaggery powder (X_3) and water (X_4) and each variable was set at three levels. The range and levels of variables investigated are given in Table 2.

A total of 30 experiments were designed with sixteen tests of factorial points (three levels for each factor), eight axial points (two for each variable) and six repetitions of central points. Regression analysis was performed for the experiment data and fitted to the empirical second order polynomial model, as shown in the following equation:

$$Y = \beta_0 + \beta_1X_1 + \beta_2X_2 + \beta_3X_3 + \beta_3X_4 + \beta_{11}X_1^2 + \beta_{22}X_2^2 + \beta_{33}X_3^2 + \beta_{44}X_4^2$$

$$\beta_{12}X_1X_2 + \beta_{13}X_1X_3 + \beta_{23}X_2X_3 + \beta_{24}X_2X_4 + \beta_{14}X_1X_4 + \beta_{34}X_3X_4$$

Development of jaggery based cold extruded products

The jaggery based cold extruded products were manufactured by the following systematic procedure advocated by the single screw extruder machine manufacturer. All the ingredients (multi grain flour, maida flour and jaggery powder) were mixed for 5 min and then kneaded for about 45 min after adding optimum quantity of water. The quantity of water was decided based on manufacturer recommendations and the preliminary experiments. When the dough characteristic was optimum, it was extruded using appropriate dies or plates (in all available shapes – shanku, ribbed tube, twisted ribbons). The cutter was operated manually according to the discharge of product and its speed could ranges from 3 to 12 rpm depending upon the shape of the final product. The extruded products were cooled to some extent by the fan provided at the bottom and were collected in trays. The collected extruded products were dried in a tray dryer for storage.

Physical parameters of jaggery based cold extruded products

Bulk density

Bulk density is the mass per unit bulk volume of the material where the volume includes the volume of voids. It was worked out by tapping method. The extrudates were filled in a measuring cylinder of capacity 100 ml and tapped. The extrudates were allowed to settle thoroughly inside the cylinder. The tapping of the cylinder was stopped when no more settling was observed. It was weighed and the mass of 100 ml sample was recorded. The bulk density was worked out using following formula:

$$\text{Bulk density, g/cc} = \frac{\text{Weight of sample}}{\text{Volume of sample}} \quad (1)$$

Hardness

The hardness of jaggery based cold extruded products was determined by using TA. XT. PLUS texture analyzer A cylindrical probe P25 was used for compression of the samples. Each sample was triplicated and the average reading was noted.

TA settings

Mode: Measure Force in Compression
Pre Text speed: 10 mm/s
Test speed: 1 mm/s
Post Test speed: 10 mm/s
Distance (compression): 3 mm
Data Acquisition Rate: 200 pps

Results and Discussions

Bulk density

The bulk density of jaggery based cold extruded products was found to be varied from 0.31 to 0.47 g/cc. The lowest bulk density was found for R29 (MGF-400 g, MF-65 g, JP- 200 g, Water-72.5 ml) and the highest run was found for R25 (MGF-350 g, MF-75 g, JP- 225 g, Water-80 ml). The bulk density values for all the samples was given in Appendix-A. The bulk density of jaggery based extruded snack from soy-wheat flour by using hand operated extruder was ranged between 1.027 to 1.496 g/cc (Khan *et al.*, 2012). The bulk density of cold extruded snacks produced from blends of breadfruit, cashew nut, and defatted coconut was ranged from 0.32 to 0.51 g/cm^3 (Gabriel *et al.*, 2014).

Hardness

The hardness of the jaggery based cold extruded products was ranged from 3871.02 to 14534.50 N (Table 6). The minimum hardness was found for R14 (MGF-300 g, MF-85 g, JP- 200 g, Water-72.5 ml) and the maximum hardness was found for R5 (MGF-450 g, MF- 75 g, JP- 175 g, Water-65 ml). The samples having optimum hardness were found to be acceptable. The hardness values for all the samples were given in Table 1.

Optimization of Jaggery based cold extruded products

Fitting the model

Three level factorial method was used to optimize the process conditions for the application of jaggery based cold extruded products. In order to study the effects of the four independent variables viz, A Multi grain flour (MGF, 350-450 g), B Maida flour (75-95 g), C Jaggery powder (JP, 175-225 g) and D Water (65- 80 ml), Central Composite Rotatable Design of Response methodology was applied. ANOVA was used to evaluate the significance of the coefficients of the models. For any of the terms in the model, a large regression coefficient and a small p-value would indicate a more significant effect on the respective response variables (Quanhong and Caili, 2005). Analysis of variance (ANOVA) showed that the resultant second order polynomial model adequately represented the experimental data with the coefficient of multiple determinations (R^2) and adjusted R^2 for the equilibrium moisture content (EMC), being 0. 9788 and 0.9785, respectively (Table 2).

The final equation for bulk density is given as

Bulk density = +3.53456 -1.24433E-003* MGF +3.97996E-003 * MF -6.43777E-003 * JP -0.071042 * Water -1.49863E-005 * MGF * MF -9.00546E-006 * MGF * JP +1.12933E-006 * MGF * Water -3.80191E-005* MF * JP +1.15619E-004 * MF * Water +4.48634E-005 * JP * Water +5.33015E-006 * MGF2 +1.65870E-005* MF2 +2.59627E-005* JP2 +3.62548E-004 * Water2 (4.1)

The final equation for hardness is given as

Hardness = +42794.58795 +345.62511 * MGF +825.42218 * MF -381.88523 * JP -2465.72921 * Water -0.60842*MGF*MF -0.019057 * MGF* JP -0.76126* MGF *Water -1.05267 * MF * JP -1.51066 * MF * Water +4.98910 * JP*Water -0.27990 * MGF2 -1.33484 * MF2 +0.26017 * JP2 +10.68963* Water2 (4.2)

Analysis of variance for selected models

The Model F-value of 0.78 implies the model was not significant. There was only a 67.60% chance that an F-value this large could occur due to noise (Table 3–5).

Table.1 Experimental setup for the production of jaggery based cold extruded products

Factor	Name	Units	Type	Minimum	Maximum	Levels
1	Multi grain flour	gm	Numeric	350	450	3
2	Maida flour	gm	Numeric	75	95	3
3	Jaggery powder	gm	Numeric	175	225	3
4	Water	ml	Numeric	65	80	3

Table.2 Hardness of jaggery based cold extruded products

Sample	Hardness N	Sample	Hardness N
1	14283.57	16	14356.86
2	7592.67	17	9536.31
3	7796.67	18	-
4	5125.28	19	5387.21
5	14534.50	20	-
6	9508.86	21	5752.96
7	6272.59	22	-
8	-	23	9293.19
9	8866.88	24	8982.04
10	-	25	7470.82
11	9291.48	26	-
12	-	27	9548.32
13	-	28	7464.37
14	3871.02	29	8197.09
15	6177.84	30	11720.92

Table.3 Analysis of variance (ANOVA)

S. No		EMC (% db.)
1	Std. Dev.	0.12
2	Mean	13.87
3	C.V. %	2.05
4	R-Squared	0.9788
5	Adj R-Squared	0.9785

Table.4 ANOVA showing the coefficient quadratic model for bulk density

Source	Sum of Squares	Df	Mean Square	F Value	p-value Prob > F
Model	0.023595	14	0.001685	0.775968	0.6760
A-MGF	3.61E-05	1	3.61E-05	0.016608	0.9011
B-MF	0.004769	1	0.004769	2.195854	0.1819
C-JP	0.00106	1	0.00106	0.488278	0.5072
D-Water	0.000433	1	0.000433	0.19938	0.6687
AB	0.000645	1	0.000645	0.296839	0.6028
AC	0.001455	1	0.001455	0.669918	0.4400
AD	2.06E-06	1	2.06E-06	0.000948	0.9763
BC	0.001127	1	0.001127	0.51881	0.4947
BD	0.000938	1	0.000938	0.431825	0.5321
CD	0.000883	1	0.000883	0.40636	0.5441
A^2	0.002984	1	0.002984	1.373773	0.2795
B^2	4.62E-05	1	4.62E-05	0.021286	0.8881
C^2	0.002911	1	0.002911	1.340447	0.2849
D^2	0.004598	1	0.004598	2.117227	0.1890
Residual	0.015203	7	0.002172		
Lack of Fit	0.013781	6	0.002297	1.614976	0.5387
Pure Error	0.001422	1	0.001422		
Cor Total	0.038798	21			

Table.5 ANOVA showing the coefficient quadratic model for hardness

Source	Sum of Squares	Df	Mean Square	F Value	p-value Prob > F
Model	1.51E+08	14	10765566	2.366385	0.1276
A-MGF	6095617	1	6095617	1.339881	0.2850
B-MF	2338726	1	2338726	0.514077	0.4966
C-JP	1380105	1	1380105	0.303362	0.5989
D-Water	87657202	1	87657202	19.26797	0.0032
AB	1062634	1	1062634	0.233578	0.6436
AC	6515.759	1	6515.759	0.001432	0.9709
AD	935746.2	1	935746.2	0.205687	0.6639
BC	863838.9	1	863838.9	0.189881	0.6761
BD	160111.4	1	160111.4	0.035194	0.8565
CD	10914713	1	10914713	2.399168	0.1653
A^2	8227652	1	8227652	1.808524	0.2206
B^2	299402.7	1	299402.7	0.065812	0.8049
C^2	292361.7	1	292361.7	0.064264	0.8072
D^2	3997633	1	3997633	0.878722	0.3798
Residual	31845612	7	4549373		
Lack of Fit	31755467	6	5292578	58.71175	0.0996
Pure Error	90145.12	1	90145.12		
Cor Total	1.83E+08	21			

Table.6 Optimization criteria for different factors and responses

Constraints name	Goal	Lower limit	Upper limit	Lower weight	Upper weight	Importance
MGF	in range	350	405	1	1	3
MF	equal to	75	95	1	1	3
JP	Target	175	225	1	1	3
Water	equal to	65	80	1	1	3
Bulk Density	Maximize	0.31	0.47	1	1	3
Hardness	Minimize	3871.03	14534.5	1	1	3

Fig.1 Single screw extruder

Fig.1 3D surface plot for the effect of MF and MGF on bulk density of jaggery based cold extruded products

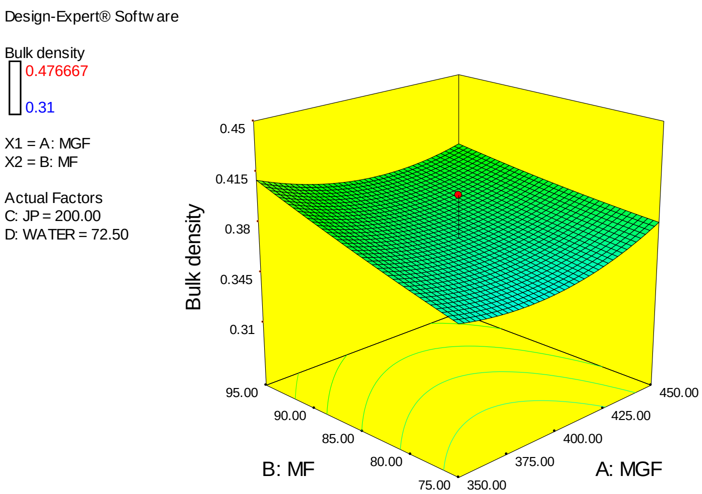


Fig.2 3D surface plot for the effect of water and JP on bulk density of jaggery based cold extruded products

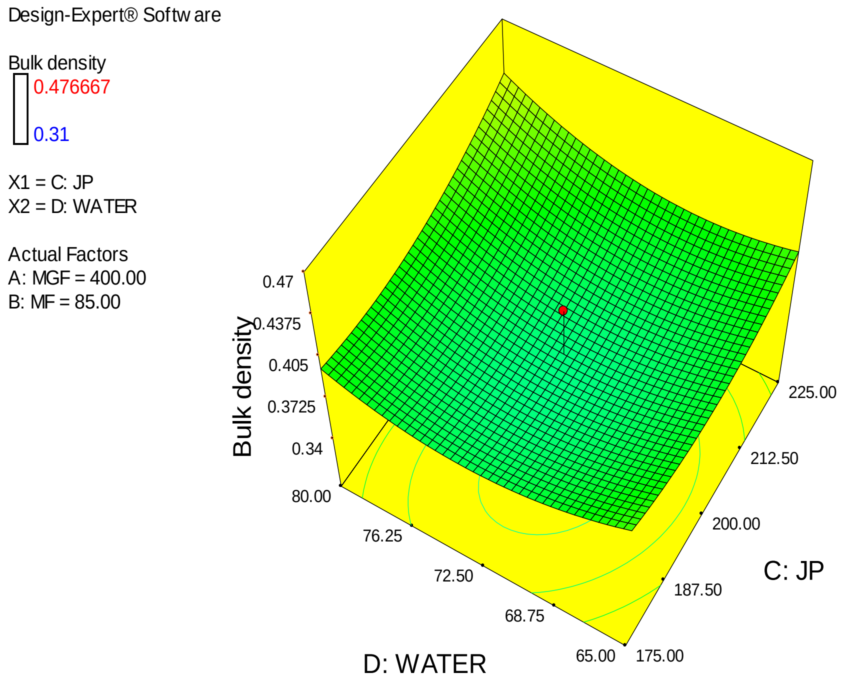


Fig.3 3D surface plot for the effect of JP and MF on bulk density of jaggery based cold extruded products

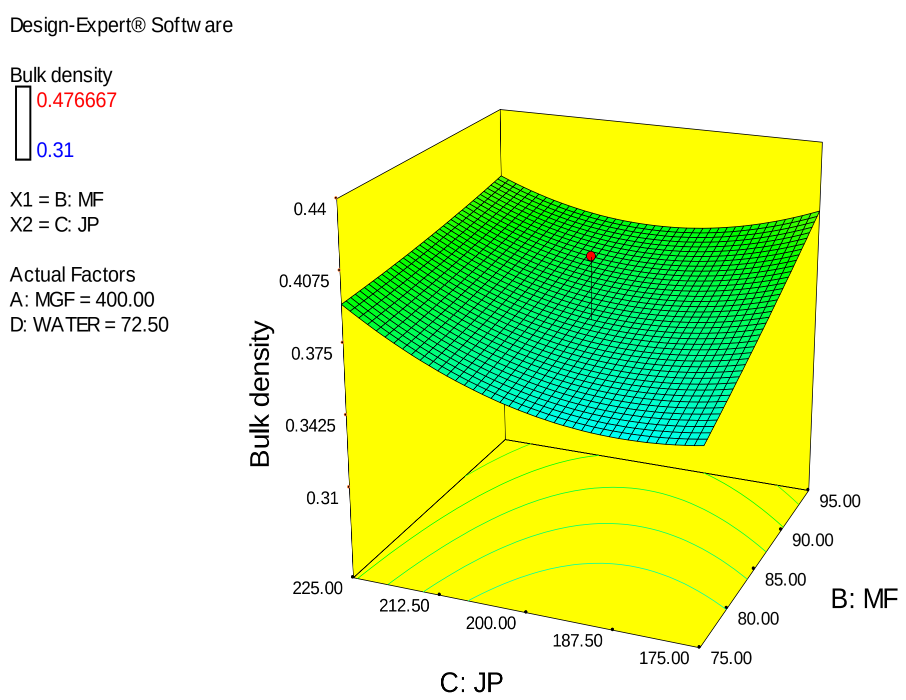


Fig.4 3D surface plot for the effect of MF and MGF on hardness of jaggery based cold extruded products

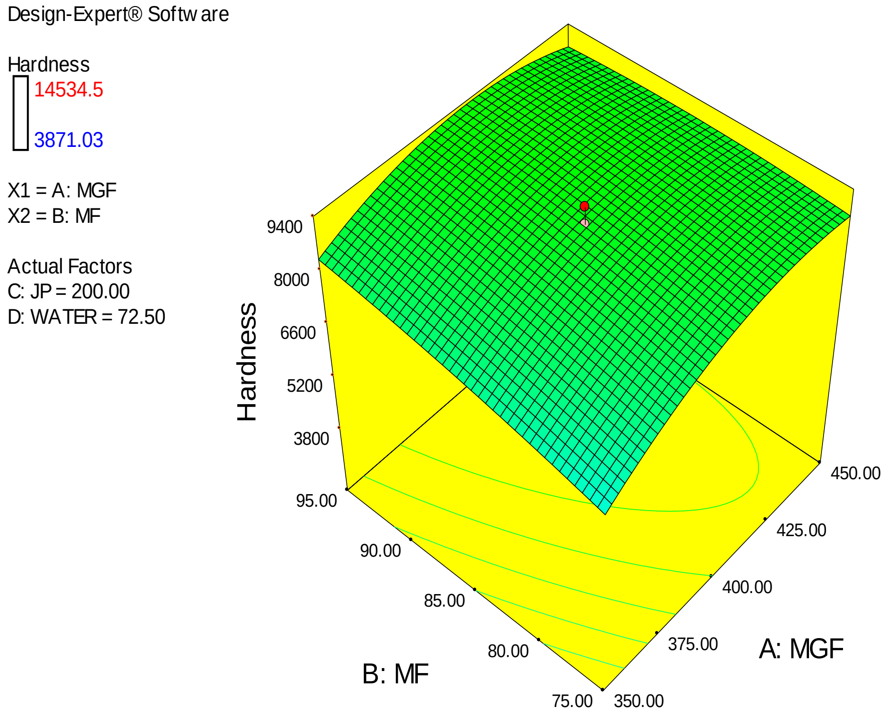


Fig.5 3D surface plot for the effect of JP and MGF on hardness of jaggery based cold extruded products

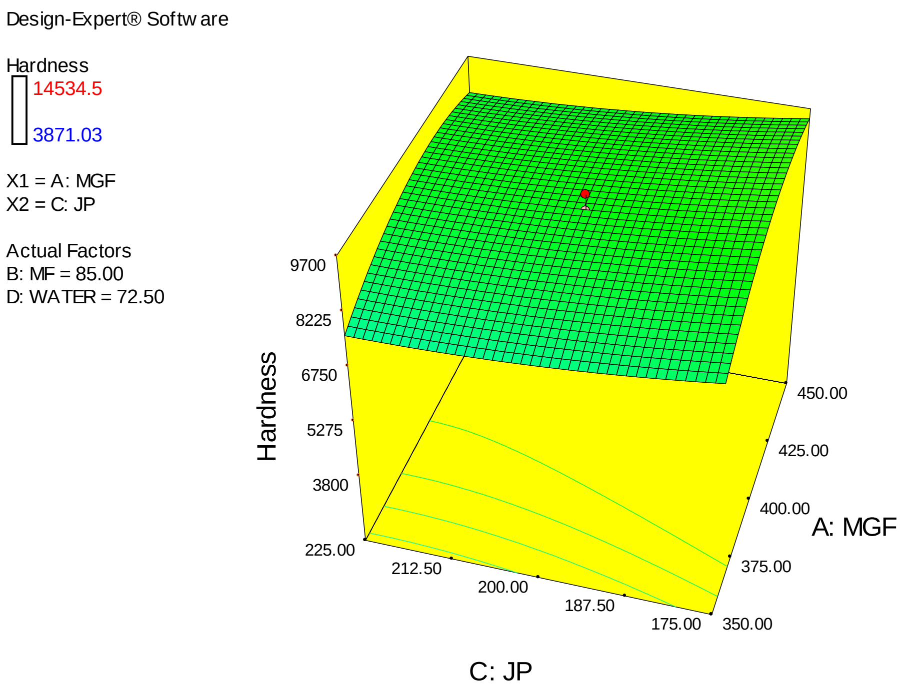
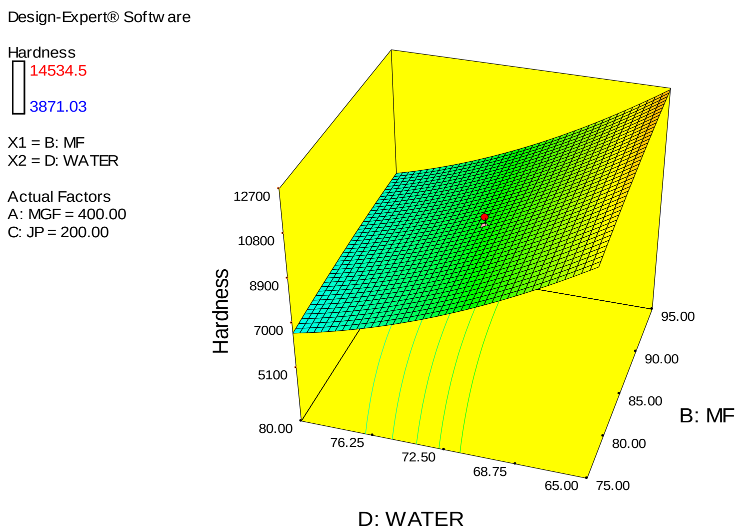


Fig.6 3D surface plot for the effect of Water and MF on hardness of jaggery based cold extruded products



Values of "Prob > F" less than 0.0500 indicate model terms were significant. In this case A, B, C, D, AB, AC, AD, BC, BD, CD were significant model terms. Values greater than 0.1000 indicate the model terms were not significant.

Analysis of response surfaces

The Figure 1 shows that the bulk density of the jaggery based cold extruded products was decreased by decreasing the amount of maida flour and it was also decreased as the amount of multi grain flour decreases.

The Figure 2 show that the bulk density of the jaggery based cold extruded samples was first decreased by decreasing the amount of water and then it was increased. As the jaggery powder was increased, the bulk density was also increased.

The Figure 3 shows that the simultaneous increase in jaggery powder and maida flour caused increase in bulk density of the jaggery based cold extruded products. Hence, the bulk density had a positive effect with both jaggery powder and multi grain flour.

The Figure 4 shows that the hardness of the jaggery based cold extruded products was decreased with simultaneous decrease in maida flour and multi grain flour. Thus, it was observed that hardness had a positive effect with the maida flour and multi grain flour.

The Figure 5 shows that the hardness of the jaggery based cold extruded products was decreased with decreasing multi grain flour, but it was slightly increased with decreasing jaggery powder. Hence, it is noted that hardness had a positive effect with multi grain flour and had a negative effect with jaggery powder.

The Figure 6 shows that the hardness of the jaggery based cold extruded products was increased with decreasing water and was decreased with decreasing maida flour. Hence, the hardness had positive effect with maida flour and negative effect with the amount of water.

Numerical optimization

Numerical optimization technique of the Design-Expert version 8.06 software was used for simultaneous optimization of the multiple responses. The desired goals for each factor and response were chosen. The goals may apply to either factors or responses. The possible goals are: maximize, minimize, target, within range, none (for responses only). The independent factors viz. MGF was kept in range, JP was kept targeted and MF and Water were kept equal to while the responses viz. Bulk density was kept maximized and hardness was kept minimized. The numerical optimization results showed that the overall optimum area was predicted to be obtained by the combination of 450g of MGF, 95 g of MF, 225 g of JP and 80 ml of Water i.e., R17 (MGF-450 g, MF-95 g, JP-225 g, Water-80 ml) with desirability of 0.875 % by response surface plots and response optimizer.

Jaggery is a traditional unrefined non-centrifugal sugar consumed in Asia, Africa, Latin America and the Caribbean. India is the largest producer and consumer of jaggery. Out of total world production, more than 70% is produced in India. It is consumed in almost all sections of the society as a sweetener, and as a source of energy. It is also used in animal feed mixtures. Jaggery is among major agro processing industries in India. Value addition to solid jaggery by inclusion of nutritive substances through puffed rice, gram, sesame and various kinds of nuts (cashew, almond), vitamins, iron, and taste enhancers like chocolate powder will increase demand for this kind of jaggery.

The bulk density of jaggery based cold extruded products was ranged from 0.31 to 0.47 g/cc. The lowest bulk density was found for R29 (MGF-400 g, MF-65 g, JP- 200 g, Water-72.5 ml) and the highest run was found for R25 (MGF-350 g, MF-75 g, JP- 225 g, Water-80 ml). The hardness of the uncooked jaggery based cold extruded products was ranged from 3871.026 to 14534.503 N. The numerical optimization showed that R17 (MGF-450 g, MF-95 g, JP- 225 g, Water-80 ml) sample was selected as best sample with desirability of 0.875.

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