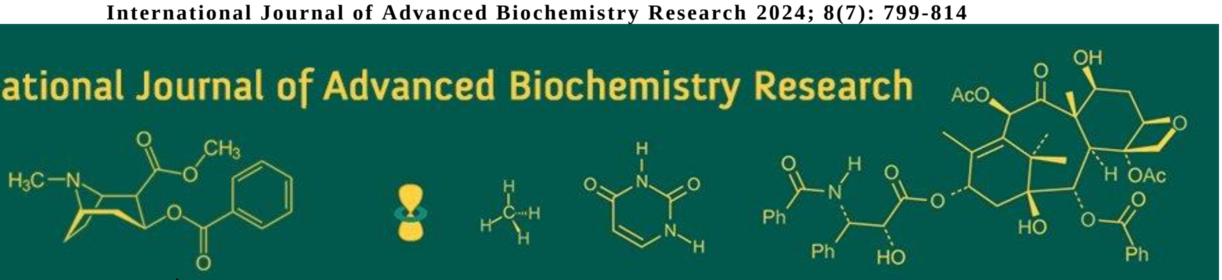
International Journal of Advanced Biochemistry Research 2024; 8(7): 799-814

International Journal of Advanced Biochemistry Research



ISSN Print: 2617-4693
ISSN Online: 2617-4707
IJABR 2024; 8(7): 799-814
www.biochemjournal.com
Received: 02-04-2024
Accepted: 08-05-2024

Physical and machine parameters of extruded products prepared from pearl millet flour blended with defatted peanut flour

Dhruv Chocha, PR Davara, VP Sangani, Vidhya V and Poornima Diwate

DOI: https://doi.org/10.33545/26174693.2024.v8.i7j.1591

Dhruv Chocha
M.Tech. Scholar, Department of Processing and Food Engineering, College of Agricultural Engineering and Technology, Junagadh Agricultural University, Gujarat, India

PR Davara
Assistant Professor, Department of Processing and Food Engineering, College of Agricultural Engineering and Technology, Junagadh Agricultural University, Gujarat, India

VP Sangani
Assistant Professor, Department of Processing and Food Engineering, College of Agricultural Engineering and Technology, Junagadh Agricultural University, Gujarat, India

Vidhya V
M.Tech. Scholar, Department of Processing and Food Engineering, College of Agricultural Engineering and Technology, Junagadh Agricultural University, Gujarat, India

Poornima Diwate
M.Tech. Scholar, Department of Processing and Food Engineering, College of Agricultural Engineering and Technology, Junagadh Agricultural University, Gujarat, India

Corresponding Author:
Dhruv Chocha
M.Tech. Scholar, Department of Processing and Food Engineering, College of Agricultural Engineering and Technology, Junagadh Agricultural University, Gujarat, India

Abstract

Extruded products were developed through blending of pearl millet flour and defatted peanut flour using a twin screw extruder. Prior to extrusion cooking, the flours underwent mixing and conditioning with water. The study aimed to investigate the combined effects of feed moisture content, screw speed and die head temperature on physical parameters (bulk density, specific length and expansion ratio) and machine parameters (machine torque and mass flow rate) of extruded snacks. Response Surface Methodology (RSM) was employed to design and analyse the experiments. Optimal conditions for production were determined as follows: 15% feed moisture content, screw speed of 267 rpm and die head temperature of 134 °C. The study underscores the significance of these processing parameters in influencing both physical and machine parameters of the extruded snacks. By systematically varying these factors within the defined ranges, the study not only optimized product quality but also provided insights into the intricate interplay between ingredients and process conditions in extrusion technology. This research contributes to the broader understanding of using pearl millet flour and defatted peanut flour in snack production, highlighting its potential in enhancing nutritional profiles while maintaining product quality and consumer acceptability.

Keywords: Extrusion cooking, pearl millet flour, defatted peanut flour, extruded product

1. Introduction

Pearl millet (*Pennisetum glaucum*), known as bajra, thrives in arid and semi-arid regions, enduring harsh conditions like drought and high temperatures (Kaur *et al.*, 2018) [18]. Nutritionally dense, it offers 67.5 g carbs, 11.6 g protein, 5 g fat, 1.2 g fiber, and 2.3 g minerals per 100 g, with significant calcium, iron, zinc, and B vitamins (Gopalan *et al.*, 2004) [15]. Providing 361 kcal/100 g, pearl millet exceeds rice, wheat, sorghum, and maize in energy content, and is gluten-free with a low glycemic index (Kaur *et al.*, 2018) [18].

Peanuts (Arachis hypogaea) rank fifth globally in vegetable oil production, with the byproduct, peanut oil cake or meal, used post-oil extraction (Kain *et al.*, 2009) [13]. Processed into partially defatted peanut flour (DPF), it retains protein richness (47-55%) and essential amino acids, making it ideal for diverse food applications (Kain *et al.*, 2009; Rehrah *et al.*, 2009; Ma *et al.*, 2010) [13, 29, 24].

Extrusion cooking, similar to thermoplastic processing, is favored for producing food analogues from cereals and legumes (Mościcki and Zuilichem, 2011) [26]. It efficiently texturizes proteins and is cost-effective for high-volume food processing (Alam *et al.*, 2016) [3]. With rising health awareness, there is a demand for nutritious snack ingredients. This study aimed to enhance the physical attributes of extruded snacks by blending pearl millet flour and defatted peanut flour via twin-screw extrusion. The objective was to explore the feasibility of incorporating defatted peanut flour into extruded snack production.

2. Materials and Methods

2.1 Raw Materials

The key ingredients utilized in developing extruded products include pearl millet flour and defatted peanut flour. Pearl millet procured from the local market in Junagadh city was meticulously cleaned to remove impurities and subsequently coarsely ground using a stone mill to obtain flour. The resulting flour underwent sieving to ensure uniform particle size before being packaged in polyethylene bags and stored in a refrigerator. Defatted peanut flour, sourced from Shreenathji Proteins, Rajkot (Gujarat, India), was obtained in vacuum-sealed bags as a fine powder.

2.2 Proximate composition of raw materials

The biochemical properties of pearl millet flour and defatted peanut flour were comprehensively analysed using standardized methods. Moisture content was determined by the AOAC (2005) [1] oven drying method. Total carbohydrate content was quantified using the Phenol Sulphuric Acid method according to Nielsen (2010) [28]. Protein content in both raw flour and extruded products was assessed using Lowry's method (Lowry *et al*., 1965) [23]. Fat content was extracted using the Soxhlet extraction method as outlined in AOAC (2005) [1]. Ash content was determined using a muffle furnace based on AOAC (2005) [1] guidelines. These methodologies ensured accurate measurement of key nutritional components essential for evaluating the quality and composition of the flours.

2.3 Experimental design

The Response Surface Methodology (RSM) is a statistical technique used for empirical modeling through multiple regression analysis, effectively handling quantitative data from well-structured experiments to solve multivariable equations simultaneously. This approach has been extensively documented in experimental design literature (Myers, 1976; Khuri and Cornell, 1987; Montgomery, 2001) [27, 19, 25]. In this study, a three-factor five-level Central Composite Rotatable Design (CCRD) with a quadratic model was employed. Independent variables were feed moisture content (A), screw speed (B), and die head temperature (C). These variables were coded at levels of -1.682, -1, 0, 1 and -1.682. This experimental design is particularly suited for exploring the combined effects of independent variables on various response variables. The levels of the independent parameters, both in coded and actual values, are detailed in Table 1. Table 2 presents the treatment combinations derived from this experimental design. These methods and designs were selected to systematically investigate and optimize the relationships between the independent variables and the responses of interest, ensuring robust and comprehensive analysis of the experimental outcomes.

The second-order polynomial coefficients were calculated using Design Expert version 13, a software package developed by STAT-EASE Inc. based in Minneapolis, MN, USA. This software is utilized for estimating the responses of dependent variables in experimental designs such as Central Composite Rotatable Designs (CCRD). By employing this tool, the study was able to derive and analyse the coefficients of the polynomial model, thereby facilitating the prediction and optimization of the responses based on the experimental data collected.

Table 1: Coded and uncoded values of independent parameters to be used for the preparation of extruded product

Parameter	**Code**	**Coded and Uncoded value**				
		-1.682	**-1**	**0**	**+1**	**+1.682**
Feed moisture content (%)	A	12	13.22	15	16.78	18
Screw speed (rpm)	B	200	220	250	280	300
Die head temperature (°C)	C	90	102	120	138	150

Table 2: Treatment combinations as per the central composite rotatable design for preparation of extruded product

Run No.	**Coded**			**Uncoded**		
	A	**B**	**C**	**Feed moisture content (%)**	**Screw speed (rpm)**	**Die head temperature (ºC)**
1	0	-1.68	0	15.00	200.00	120.00
2	1	-1	1	16.78	220.00	138.00
3	0	1.68	0	15.00	300.00	120.00
4	0	0	1.68	15.00	250.00	150.00
5	0	0	0	15.00	250.00	120.00
6	1	1	-1	16.78	280.00	102.00
7	0	0	0	15.00	250.00	120.00
8	-1	-1	-1	13.22	220.00	102.00
9	1.68	0	0	18.00	250.00	120.00
10	-1	-1	1	13.22	220.00	138.00
11	1	1	1	16.78	280.00	138.00
12	0	0	0	15.00	250.00	120.00
13	-1	1	1	13.22	280.00	138.00
14	0	0	0	15.00	250.00	120.00
15	0	0	0	15.00	250.00	120.00
16	0	0	-1.68	15.00	250.00	90.00
17	0	0	0	15.00	250.00	120.00
18	1	-1	-1	16.78	220.00	102.00
19	-1	1	-1	13.22	280.00	102.00
20	-1.68	0	0	12.00	250.00	120.00

2.4 Extruded product preparation

Extrusion trials were conducted using a co-rotating twin-screw extruder manufactured by Basic Technology Pvt. Ltd., Kolkata, India. Prior to its use, the extruder underwent a conditioning phase where it was operated without feeding any material. This step was crucial to eliminate any residual material deposited in the barrel assembly. Subsequently, the heating system of the twin-screw extruder was activated, allowing it to reach and maintain the required temperatures across its different sections. For the extrusion process, a round hole die with a diameter of 3 mm was employed to produce the extruded product. A total of 300 grams of composite flour, consisting of a blend of pearl millet flour and defatted peanut flour in a ratio of 75:25, was fed into the extruder. Extrusion was performed under varying processing conditions, with adjustments made to the cutter speed as necessary.

Following extrusion, the product was collected into a tray and subjected to drying using a laboratory tray drier set at a temperature of 60 °C for 1 hour. This step aimed to reduce the moisture content of the product to approximately 2-3% (w.b.) before further analysis. Subsequently, the dried product was packed in zip-lock plastic bags and stored at room temperature for future analysis. This procedure ensured the preservation of the extruded product's quality for subsequent nutritional and functional assessments.

2.5 Physical parameters of extruded products

2.5.1 Bulk density

The bulk density of dried extrudates was calculated by determining the volume of extrudates by filling a container of known volume and noting the sample mass (Anderson *et al.* 1969) [4]. Bulk density of extrudate product gives an idea about required space to store the product and shows the overall expansion, changes in cell structure including development of pores and voids. Minimum bulk density is desired for acceptable product. It was calculated by following formula.

$$\text{Bulk density (g/cm}^3\text{)} = \frac{\text{Weight of extrudates}}{\text{Volume of cyliner}}$$

2.5.2 Specific length

The ratio of length of specimen and the weight of specimen was used to express the specific length (Kanojia and Singh, 2016) [17]. The length of extrudate was determined as the mean of 10 random measurements made with a vernier calliper. It is a quality parameter to know the longitudinal expansion of extrudate, which shows that maximum length in per unit mass is desirable for better product quality. The extrudate specific length was calculated by following formula.

$$\text{Specific length (mm/g)} = \frac{\text{Length of specimen}}{\text{Weight of specimen}}$$

2.5.3 Expansion ratio

The ratio of diameter of extrudate and the diameter of die (3 mm) was used to express the expansion of extrudate (Fan *et al.* 1996) [10]. The diameter of extrudate was determined as the mean of 10 random measurements made with a vernier calliper. The extrudate expansion ratio was calculated by following formula. Expansion is a critical physical characteristic of snack foods, describing the degree of puffing exhibited by the sample upon exiting the extruder. The expansion process is predominantly influenced by starch content (Kokini *et al.*, 1992) [21]. It is also affected by the viscosity and elasticity of the dough, which are in turn governed by the ratio of starch, protein, and fiber. Studies indicate that higher starch content in extrudates correlates with greater expansion (Linko *et al.*, 1981) [22], whereas higher protein content tends to reduce expansion (Faubion *et al.*, 1982; Adesina *et al.*, 1998; N Lakshmi *et al.*, 2012) [11, 2, 21].

$$\text{Expansion ratio (mm/mm)} = \frac{\text{Extrudate diameter}}{\text{Die diameter}}$$

2.6 Machine parameters for extrusion cooking

2.6.1 Machine torque

The maximum torque generated in the twin – screw extruder during extrusion process was recorded from digital indicator provided in panel board of extruder. It provides a direct indication of the energy absorbed by the material due to the shear exerted by the extruder screw and die orifice.

The machine torque was measured in Nm.

2.6.2 Mass flow rate

Mass flow rate was measured by collecting the extrudates in polyethylene bags for a specific period of time, as soon as it comes out of the die its weight taken instantly after its cooling to ambient temperature (Deshpande and Poshadri, 2011) [8]. Consistently maintaining barrel temperature is crucial for controlling the production rate of extrudates. Studies by Deshpande and Poshadri (2011) [8] and Geetha *et al.* (2016) [13] emphasize that this practice effectively reduces fluctuations in the mass flow rate of extrudate samples.

$$\text{Mass flow rate (g/min)} = \frac{\text{Weight of sample collected}}{\text{Time taken to collect sample}}$$

2.7 Statistical analysis

The data were analysed on Design Expert version 13 and graphical representation, analysis of variance (ANOVA), and multiple regression were carried out. This statistical analysis of experimental data was conducted to assess how specific process parameters impact various outcomes. Three-dimensional (3D) response surface plots were generated by fixing one variable at its central value and varying the other two within their experimental ranges. From the ANOVA results, we derived the coefficients for linear, interaction, and quadratic terms to understand their effects. Significance of these terms in the polynomial equation was determined using F-values at probability (p) levels of 0.001, 0.01, and 0.05

3. Results and Discussion

3.1 Proximate composition of raw materials

Table 3. presents the proximate composition of both pearl millet flour and defatted peanut flour used in the study.

Table 3: Proximate composition of pearl millet flour and defatted peanut flour

Sr. No.	Characteristic	Value	
		PMF	**DPF**
1.	Moisture content (%w.b.)	7.05	5.30
2.	Carbohydrate (%)	67.84	26.69
3.	True protein (%)	8.78	59.15
4.	Fat (%)	2.25	5.91
5.	Ash (%)	1.64	4.67

3.2 Effect of feed moisture content, screw speed and die head temperature on response variables

The treatment-wise data regarding various physical and machine parameters of extruded products prepared by blending of pearl millet flour and defatted peanut flour is presented in the Table 4.

Table 4: Machine and Physical parameters of extruded products

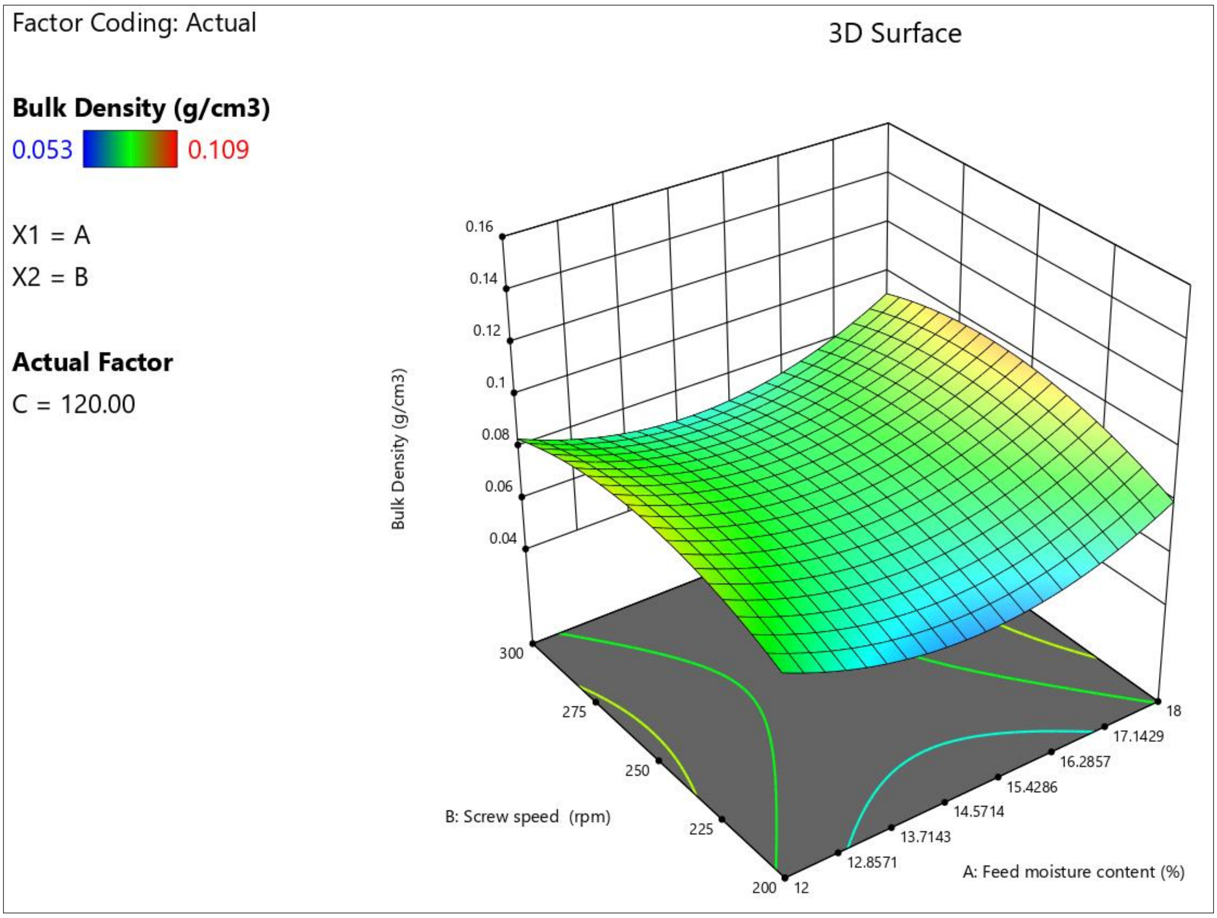
Run No.	Independent variable			Response					
	Feed Moisture content (A) (%w.b.)	**Screw speed (B) (rpm)**	**Die head temperature (C) (°C)**	**Bulk density (g/cm^3)**	**Specific length (mm/g)**	**Expansion ratio**	**Machine Torque (Nm)**	**Mass flow rate (g/min)**
1	15.00	200.00	120.00	0.056	106.23	3.04	19	178
2	16.78	220.00	138.00	0.071	109.12	2.78	19	171
3	15.00	300.00	120.00	0.071	107.68	3.16	16	177
4	15.00	250.00	150.00	0.053	120.44	3.02	17	169
5	15.00	250.00	120.00	0.081	115.49	2.85	17	178
6	16.78	280.00	102.00	0.109	96.35	2.61	16	171
7	15.00	250.00	120.00	0.081	112.18	2.92	16	174
8	13.22	220.00	102.00	0.068	93.62	2.68	20	154
9	18.00	250.00	120.00	0.096	110.22	2.25	20	162
10	13.22	220.00	138.00	0.092	108.62	2.98	19	164
11	16.78	280.00	138.00	0.063	112.61	2.98	15	159
12	15.00	250.00	120.00	0.083	116.84	2.79	17	174
13	13.22	280.00	138.00	0.078	116.53	3.01	17	166
14	15.00	250.00	120.00	0.079	111.12	2.78	17	165
15	15.00	250.00	120.00	0.073	111.65	2.90	17	169
16	15.00	250.00	90.00	0.106	80.56	2.52	17	166
17	15.00	250.00	120.00	0.069	113.32	2.91	16	170
18	16.78	220.00	102.00	0.094	90.27	2.56	18	168
19	13.22	280.00	102.00	0.085	99.58	2.71	17	160
20	12.00	250.00	120.00	0.092	106.86	2.75	22	150

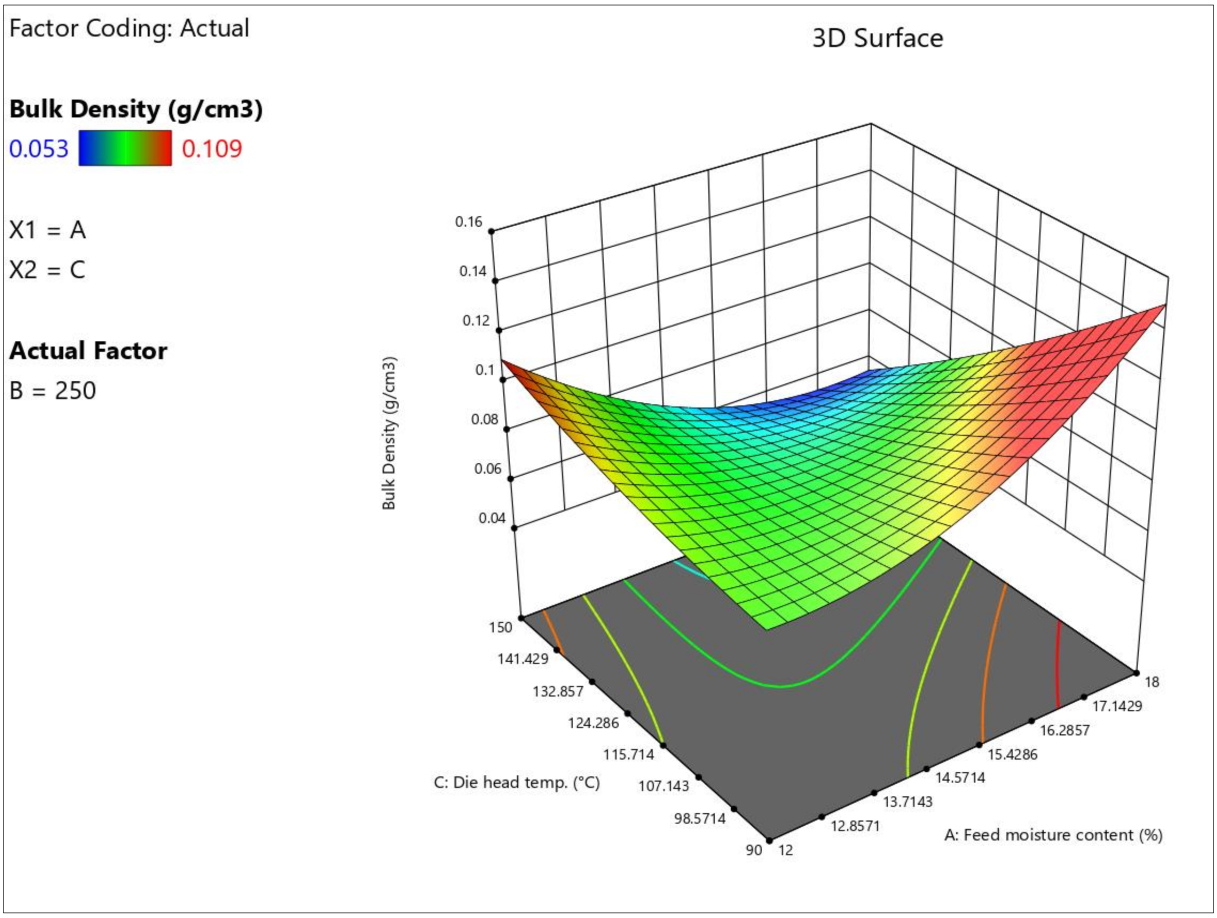
3.2.1 Bulk density

Table 4 displays experimental bulk density values obtained from various processing conditions during the production of extruded products. The bulk density ranged between 0.053 g/cm^3 to 0.109 g/cm^3. Figure 1 illustrates response surface curves depicting the bulk density variations. Increasing the feed moisture content up to 15.05% and screw speed up to 256.90 rpm generally decreased bulk density. For instance, at 15.01% moisture content and 200 rpm screw speed, bulk density was expected to decrease to 0.0612 g/cm^3. However, further increases in these parameters resulted in higher bulk densities. Similarly, bulk density increased with die head temperature up to a maximum of 150 °C. The lowest predicted bulk density of 0.0536 g/cm^3 occurred at 17.29% moisture content and 149.83 °C die head temperature. Increasing screw speed up to 297.99 rpm increased bulk density, while higher die head temperatures up to 113.45 °C decreased it. This aligns with findings from previous studies where higher die temperatures reduced bulk density, while increased feed moisture content generally increased it. These outcomes also confirmed by the other researchers (Gojiya *et al.*, 2022) [14]. Studies by Shruthi *et al.* (2017) [31] and Sapariya *et al.* (2022) [30] corroborate these trends, noting temperature's influence on bulk density and moisture content's impact on density, respectively. Baik *et al.* (2004) [5] attributed higher bulk density to increased moisture content, explaining how elevated temperatures during extrusion expelled more moisture from the product, thus reducing its density. Elasticity reduction due to increased moisture content also contributed to higher extrudate densities, as observed by Banerjee *et al.* (2003). Ding *et al.* (2004) [9] further demonstrated that higher barrel temperatures during extrusion could enhance expansion, inversely affecting density. Table 5 presents regression and ANOVA results for further insights into bulk density variations in extruded products.

3.2.2 Specific length

The study investigated the influence of various processing parameters on the specific length of extruded products, as summarized in Table 4. The specific length of the extruded products ranged from 80.56 mm/g to 120.44 mm/g. Figure 2 illustrates the response surface curves depicting the relationship with bulk density. The findings indicate that specific length increased initially with higher feed moisture content, peaking at 14.71%, and with screw speed up to 261.15 rpm. This combination yielded a maximum specific length of 113.85 mm/g. Further increases in these parameters led to a decrease in specific length. Similarly, specific length increased up to 15.03% feed moisture content and a die head temperature of 137.97 °C, reaching a peak of 118.41 mm/g. Beyond this point, higher moisture content and die head temperatures continued to enhance specific length. Additionally, specific length rose with screw speeds up to 260.39 rpm and die head temperatures of 137.86 °C, culminating in a maximum of 118.72 mm/g. Further increments in these variables resulted in further increases in specific length. These observations align with prior research indicating that specific length of extruded products made from blends of pearl millet, sorghum, and soybean flour tends to increase with higher feed moisture content (Yatin *et al.*, 2015) [32]. Similarly, Bhople and Singh (2017) [6] reported that the specific length of these blended extrudates also increases with higher barrel temperatures during the extrusion process. Table 5 presents the regression analysis and ANOVA results for the specific length of extruded product.


Factor Coding: Actual
Bulk Density (g/cm3)
0.053
0.109
X1 = A
X2 = B
Actual Factor
C = 120.00
3D Surface
Bulk Density (g/cm3)
0.16
0.14
0.12
0.1
0.08
0.06
0.04
B: Screw speed (rpm)
300
275
250
225
200
A: Feed moisture content (%)
12
12.8571
13.7143
14.5714
15.4286
16.2857
17.1429
18


Factor Coding: Actual
Bulk Density (g/cm3)
0.053
0.109
X1 = A
X2 = C
Actual Factor
B = 250
3D Surface
Bulk Density (g/cm3)
0.16
0.14
0.12
0.1
0.08
0.06
0.04
C: Die head temp. (°C)
150
141.429
132.857
124.286
115.714
107.143
98.5714
90
A: Feed moisture content (%)
12
12.8571
13.7143
14.5714
15.4286
16.2857
17.1429
18

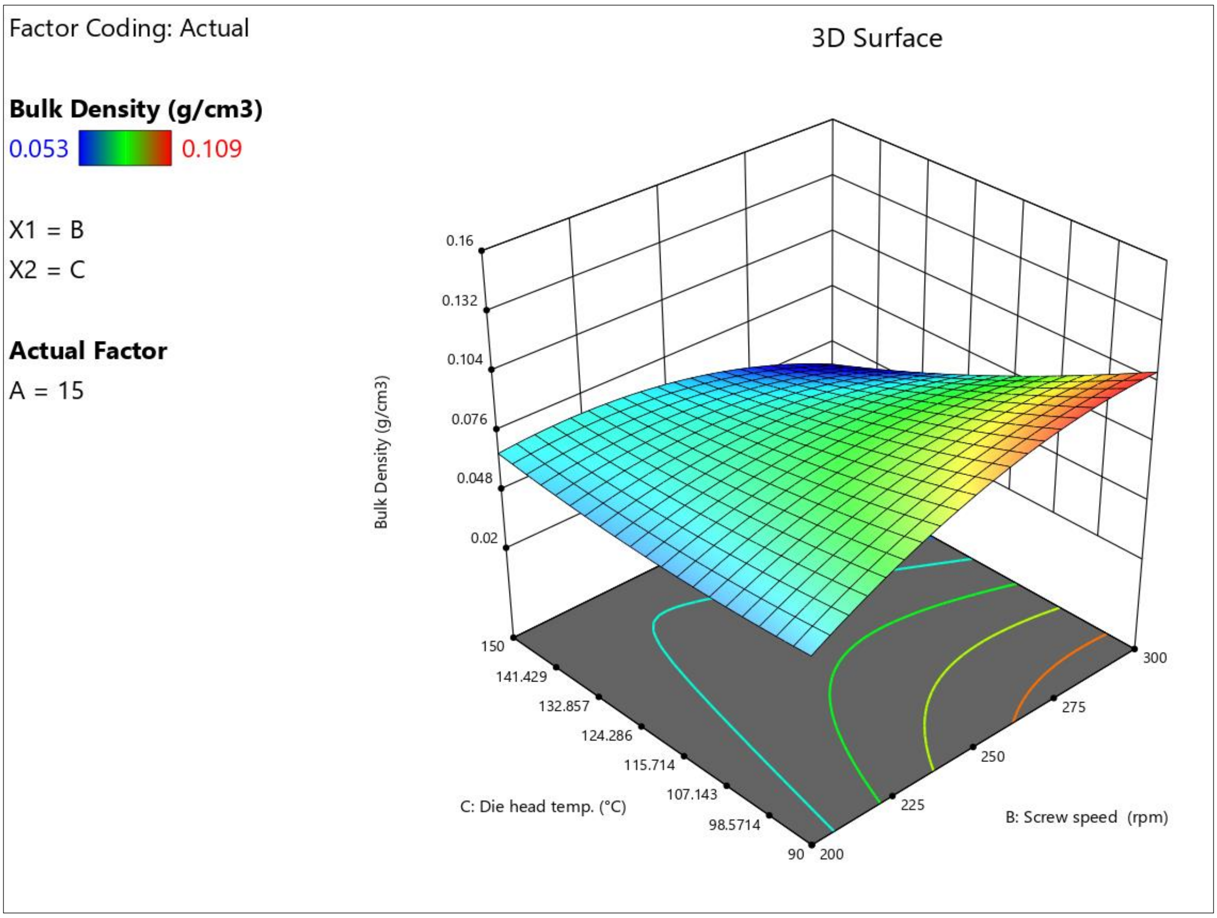
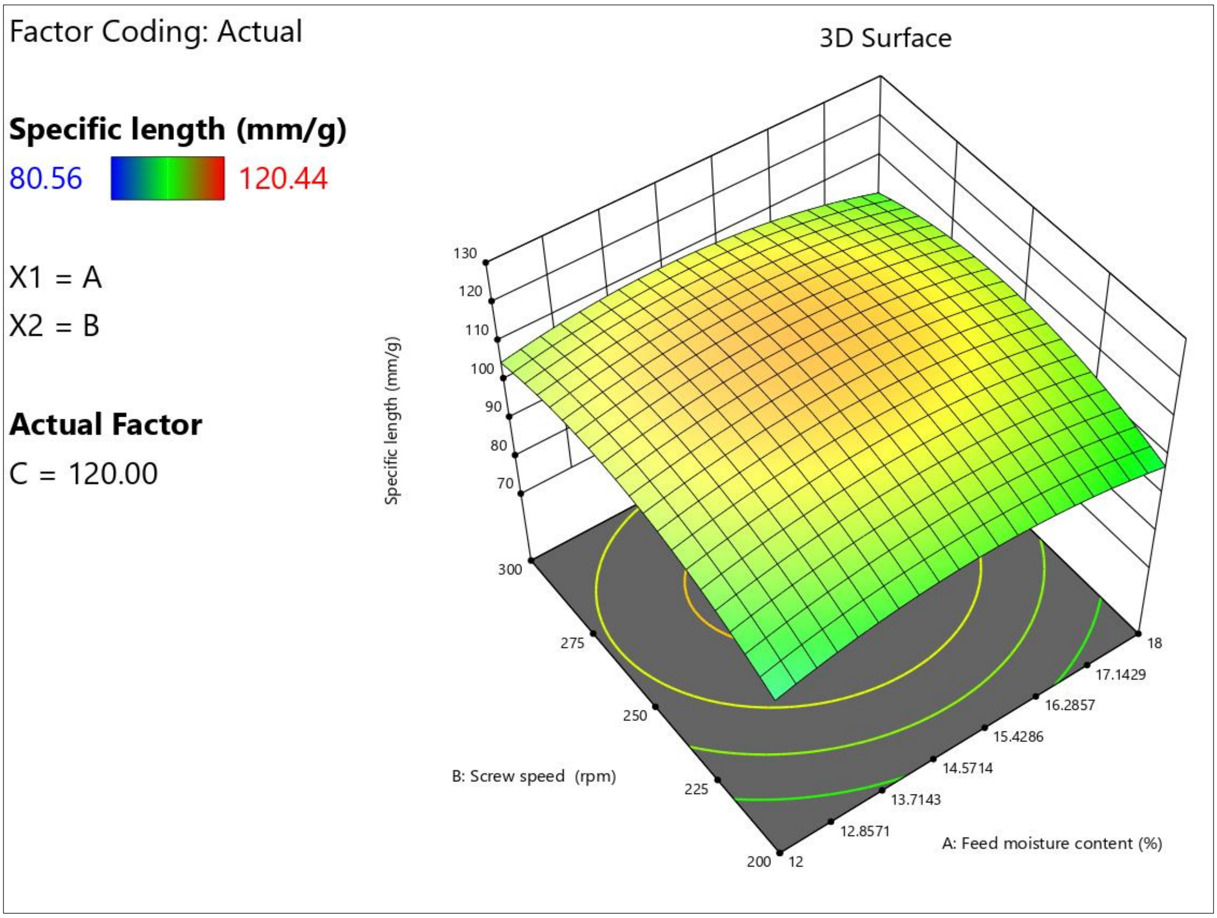


Fig 1: Effect of feed moisture content, screw speed and die head temperature on Bulk density



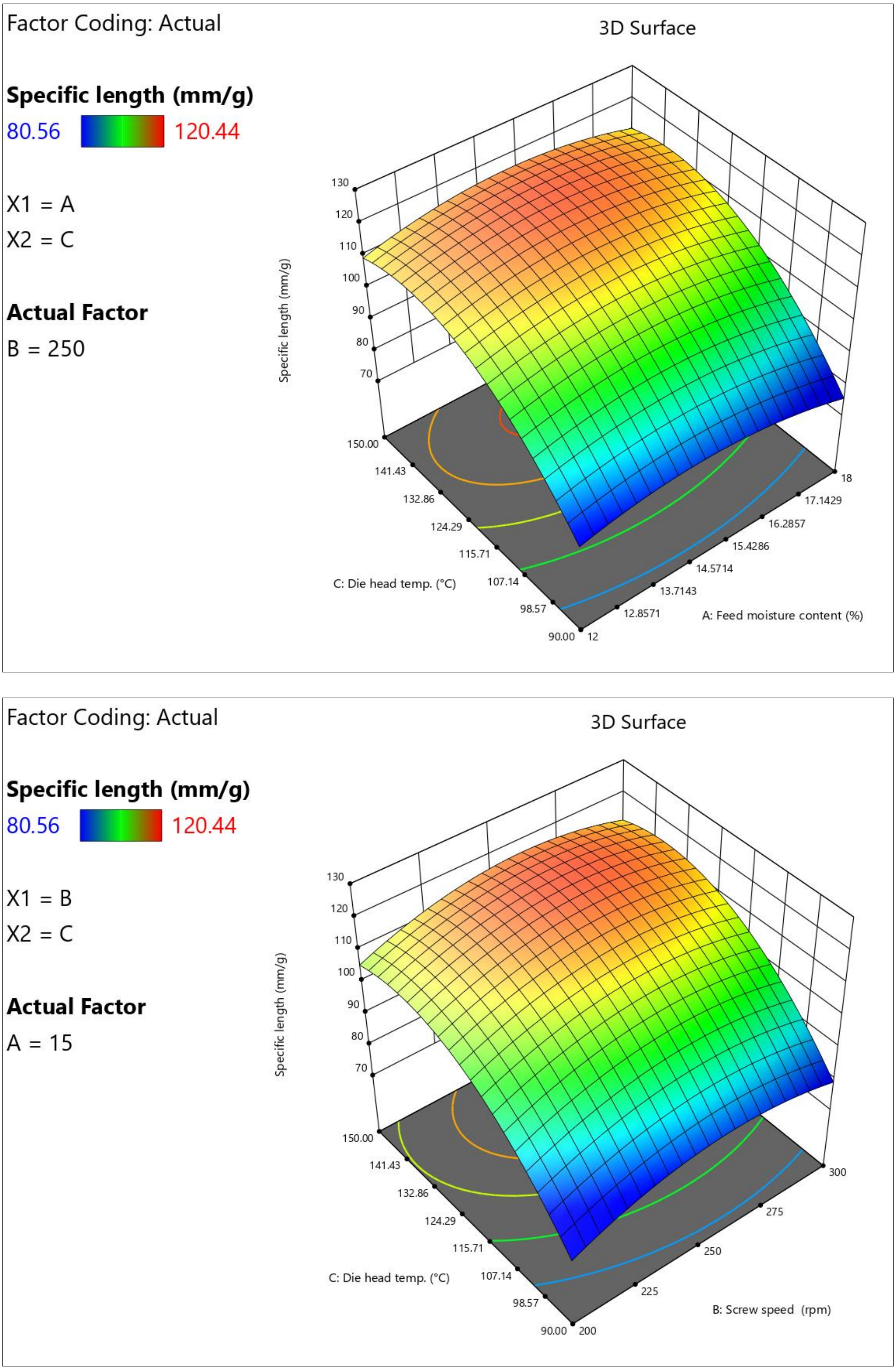
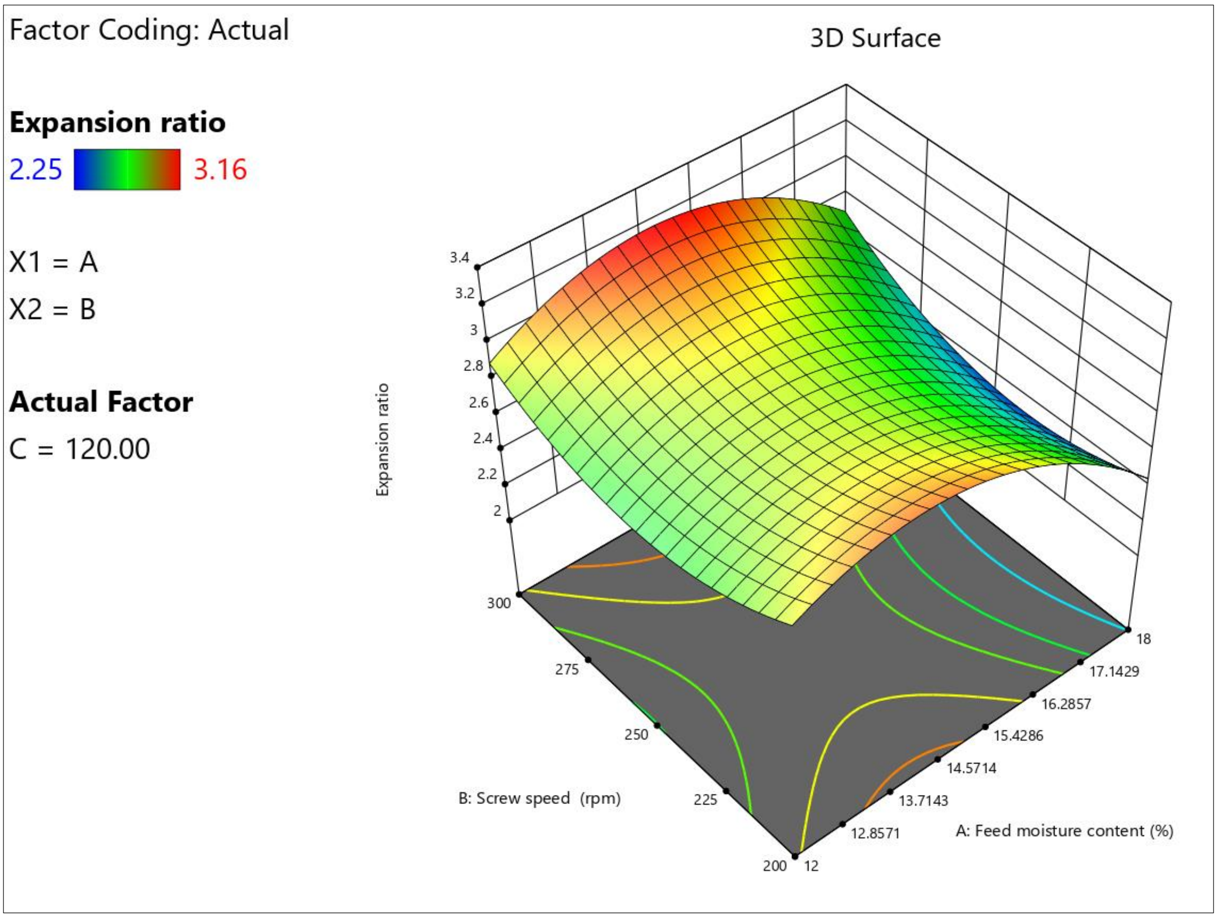


Fig 2: Effect of feed moisture content, screw speed and die head temperature on Specific length

3.2.3 Expansion ratio

Table 4 presents the expansion ratios of extruded products under varying treatment conditions, ranging from 2.25 to 3.16. Figure 3 illustrates response surface curves and contour plots depicting the expansion behaviour of the extruded product. Analysis of the contour maps reveals that the expansion ratio increases with higher feed moisture content, peaking at 14.04%, and with screw speeds up to 250.51 rpm. The combination of increased feed moisture content and screw speed is expected to enhance the expansion ratio, with optimal conditions at 14.56% feed moisture content and 300 rpm screw speed resulting in a maximum predicted ratio of 3.16. However, further increases in these factors lead to a decline in the expansion ratio. Similarly, the expansion ratio increases with higher feed moisture content up to 14.32% and with die head temperatures up to 150 °C. The optimal combination of feed moisture content and die head temperature is associated with a peak expansion ratio of 3.04. Beyond these thresholds, the expansion ratio diminishes with additional increases in feed moisture content. Conversely, the ratio decreases with screw speeds above 249.15 rpm but shows improvement with higher die head temperatures up to 150 °C. The maximum predicted expansion ratio of 3.37 is achieved with the combination of maximum screw speed and die head temperature. For detailed statistical analysis, including regression and ANOVA results, refer to Table 5. These findings underscore the critical role of feed moisture content, screw speed, and die head temperature in influencing the expansion characteristics of extruded products, offering significant insights for optimizing extrusion processes in industrial applications. These findings also have strong agreement with result mentioned by (Davara *et al*., 2022 and Gojiya *et al*., 2022) [7, 14] for extruded products. Gat and Ananthanarayan (2015) [12] discovered that higher feed moisture levels led to a reduction in the size increase of extruded products. They also observed a minor decrease in expansion when utilizing hotter die heads. Similarly, Stojceska *et al*. (2009) [34] found that higher screw speeds enhanced expansion. They attributed this phenomenon to the starch in the feed acquiring a more gel-like consistency at elevated temperatures, which facilitated increased bubble formation during extrusion.



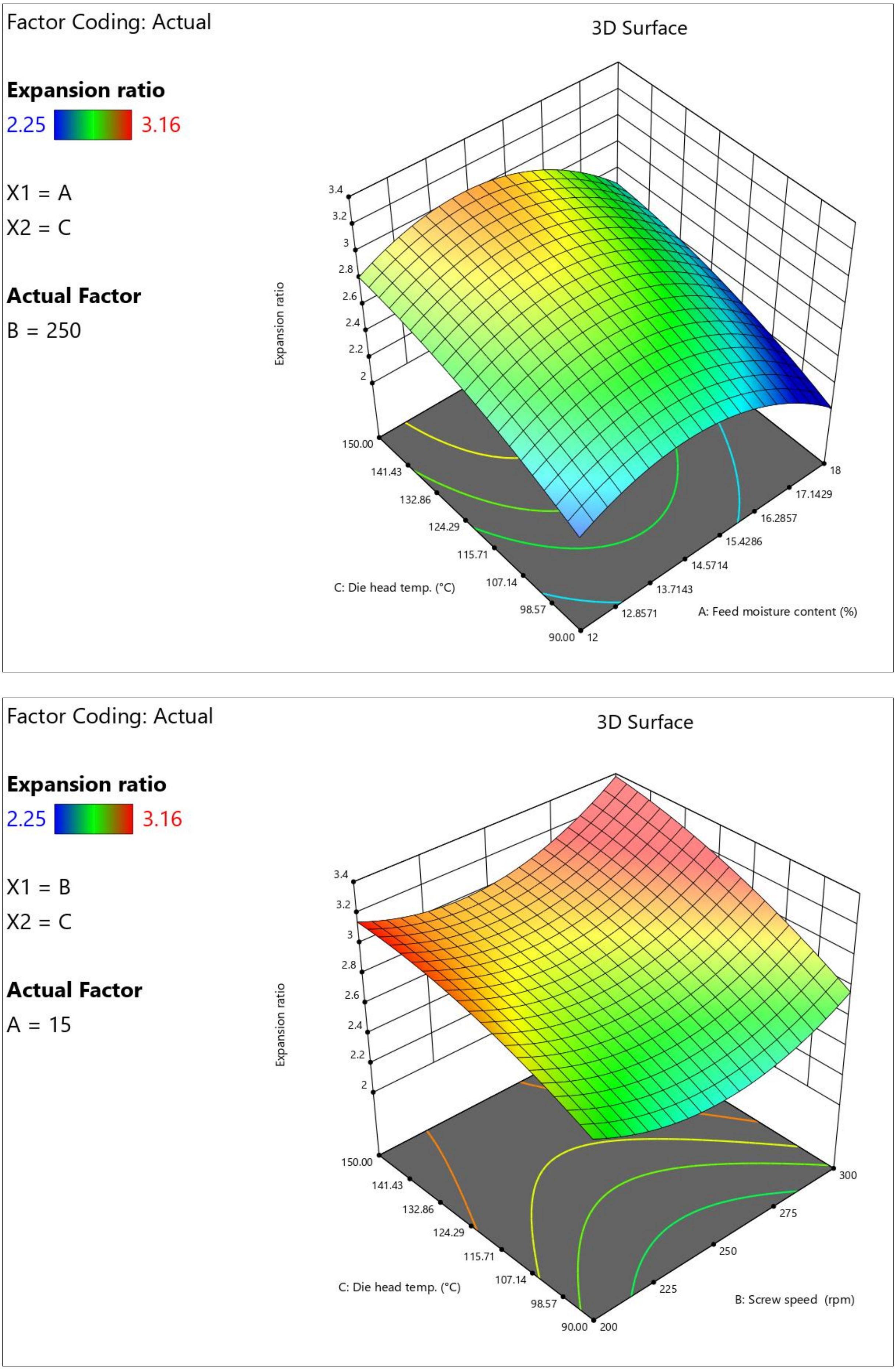
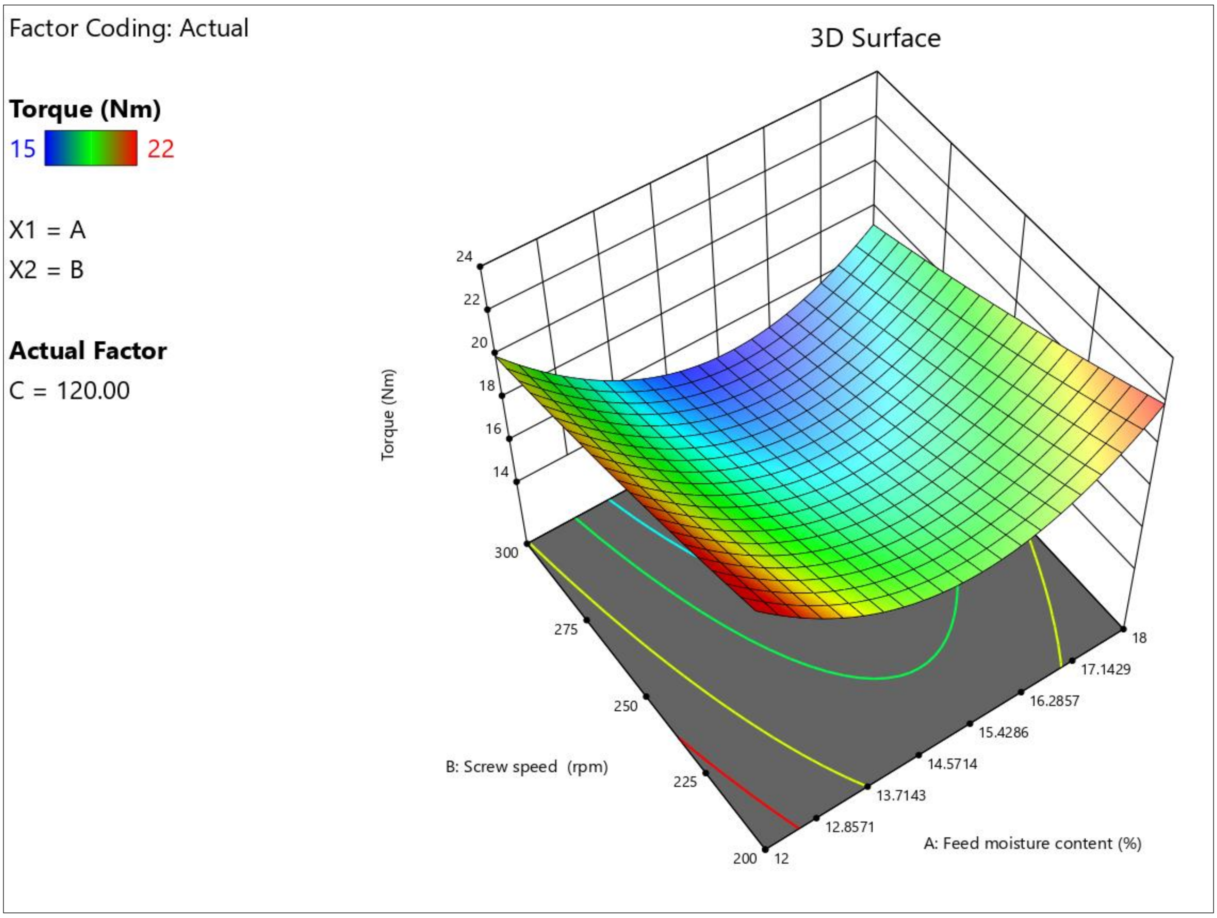


Fig 3: Effect of feed moisture content, screw speed and die head temperature on Expansion ratio

3.2.4 Machine Torque

The experimental study investigated the influence of various process parameters on machine torque in the context of twin-screw extrusion for producing extruded products. Table 4 presents the observed torque values, ranging from 15 to 22 Nm, under different treatment conditions. Response surface curves and contour plots in Fig. 4 illustrate the impact of independent parameters on machine torque. An increase in feed moisture content initially led to a decrease in machine torque, reaching its lowest point at 15%. However, further increases up to 18% resulted in higher torque levels. Similarly, escalating the screw speed up to its maximum of 300 rpm initially decreased torque, with the minimum observed at 13.94 Nm using a combination of 15.73% moisture content and 299.91 rpm screw speed. Contour maps indicated that torque decreased with higher feed moisture content until 15.5%, beyond which torque increased. Moreover, raising the die head temperature up to 150 °C initially reduced torque, with the lowest value of 16.24 Nm predicted at 15.75% moisture content and 90.08 °C die head temperature. Further analysis revealed that torque initially decreased with increasing die head temperature up to 120 °C, followed by an increase. The minimum torque of 13.35 Nm was projected for the combination of 300 rpm screw speed and 150 °C die head temperature. Consistent with prior research (Shukla *et al*., 2021) [32], the study confirms that increasing screw speed generally increases torque. Detailed regression analysis and ANOVA results are summarized in Table 5, providing comprehensive insights into the torque dynamics during twin-screw extrusion processes for extruded product preparation.



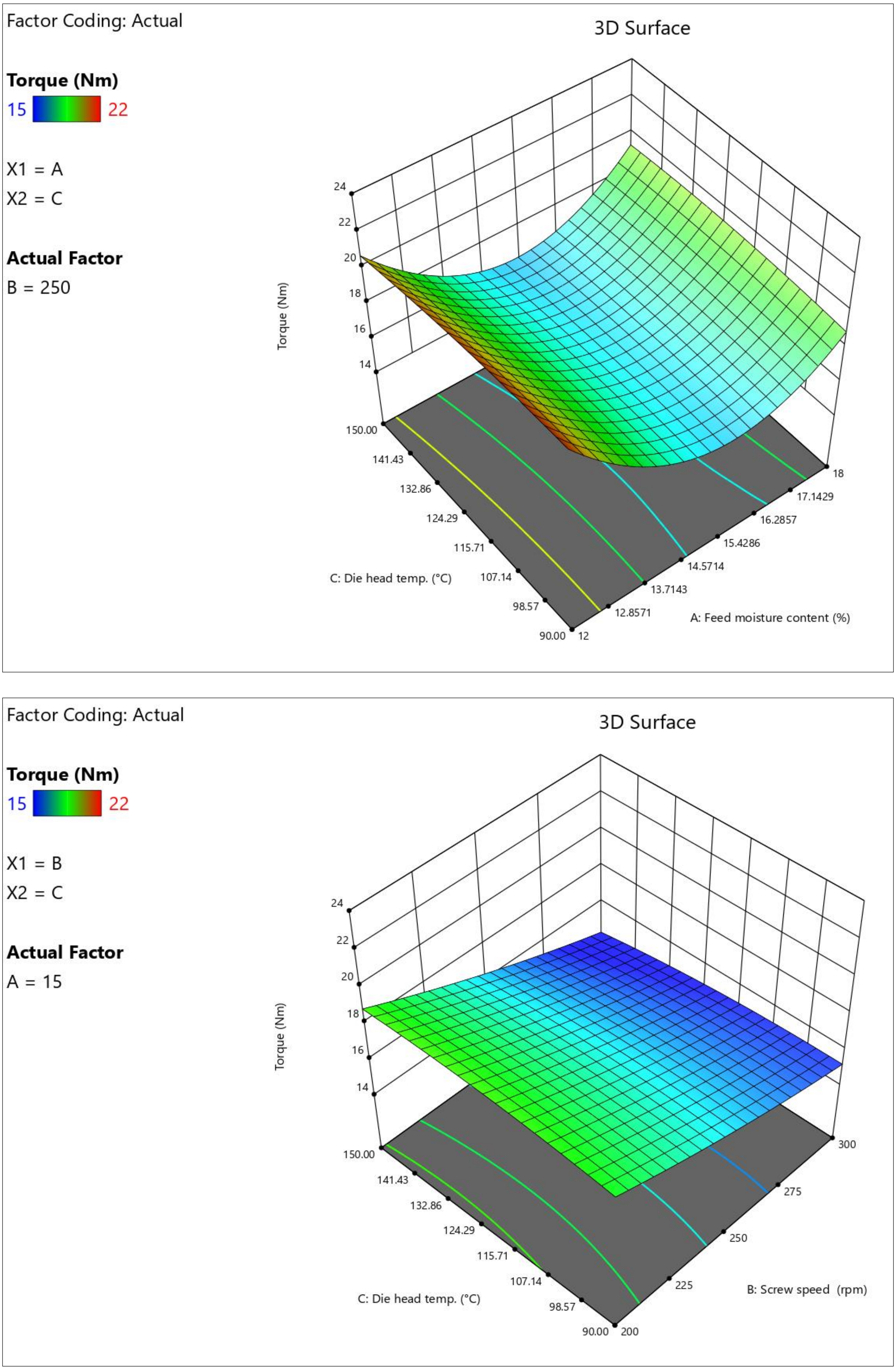
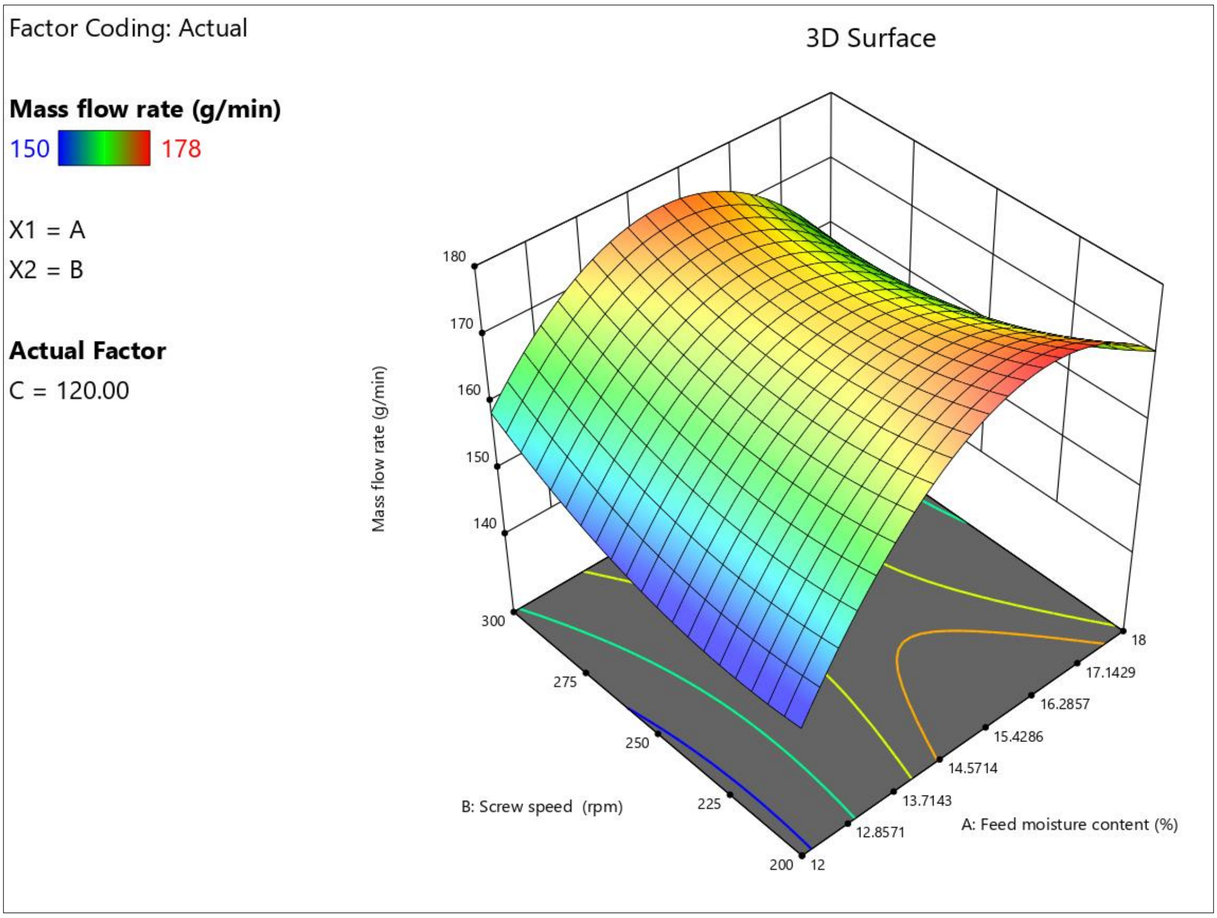


Fig 4: Effect of feed moisture content, screw speed and die head temperature on Machine torque

3.2.5 Mass flow rate

Table 4 provides the experimental data on the mass flow rate observed under various treatment conditions during the extruded product preparation process, ranging from 150 to 178 g/min. Figure 5 illustrates the response surface depicting the mass flow rate dynamics of the extruded product. The mass flow rate initially increased with rising feed moisture content up to 16%, after which it decreased with further increases in moisture content. Maximum mass flow rate (178.28 g/min) was predicted at 16% feed moisture content and 200 rpm screw speed. From the contour map analysis, it was observed that the mass flow rate increased up to 15.46% feed moisture content and 120 °C die head temperature, reaching 172.2 g/min. Subsequent increases in these parameters led to a decrease in mass flow rate. Furthermore, the contour map indicated an increase in mass flow rate with die head temperature up to 137.86 °C, beyond which the rate declined. Similarly, the mass flow rate decreased initially with screw speed up to 212.63 rpm, followed by an increase up to the maximum speed of 300 rpm. The highest predicted mass flow rate (179.21 g/min) occurred at 200 rpm screw speed and 137.86 °C die head temperature. Consistent with findings by Shruthi *et al.* (2017) [31], the study confirms that higher die head temperatures reduce feed material viscosity, facilitating easier flow from the extruder and thus increasing mass flow rate. Detailed regression analysis and ANOVA results for the mass flow rate are summarized in Table 5, offering comprehensive insights into the factors influencing mass flow rate during the twin-screw extrusion process for extruded product manufacturing.



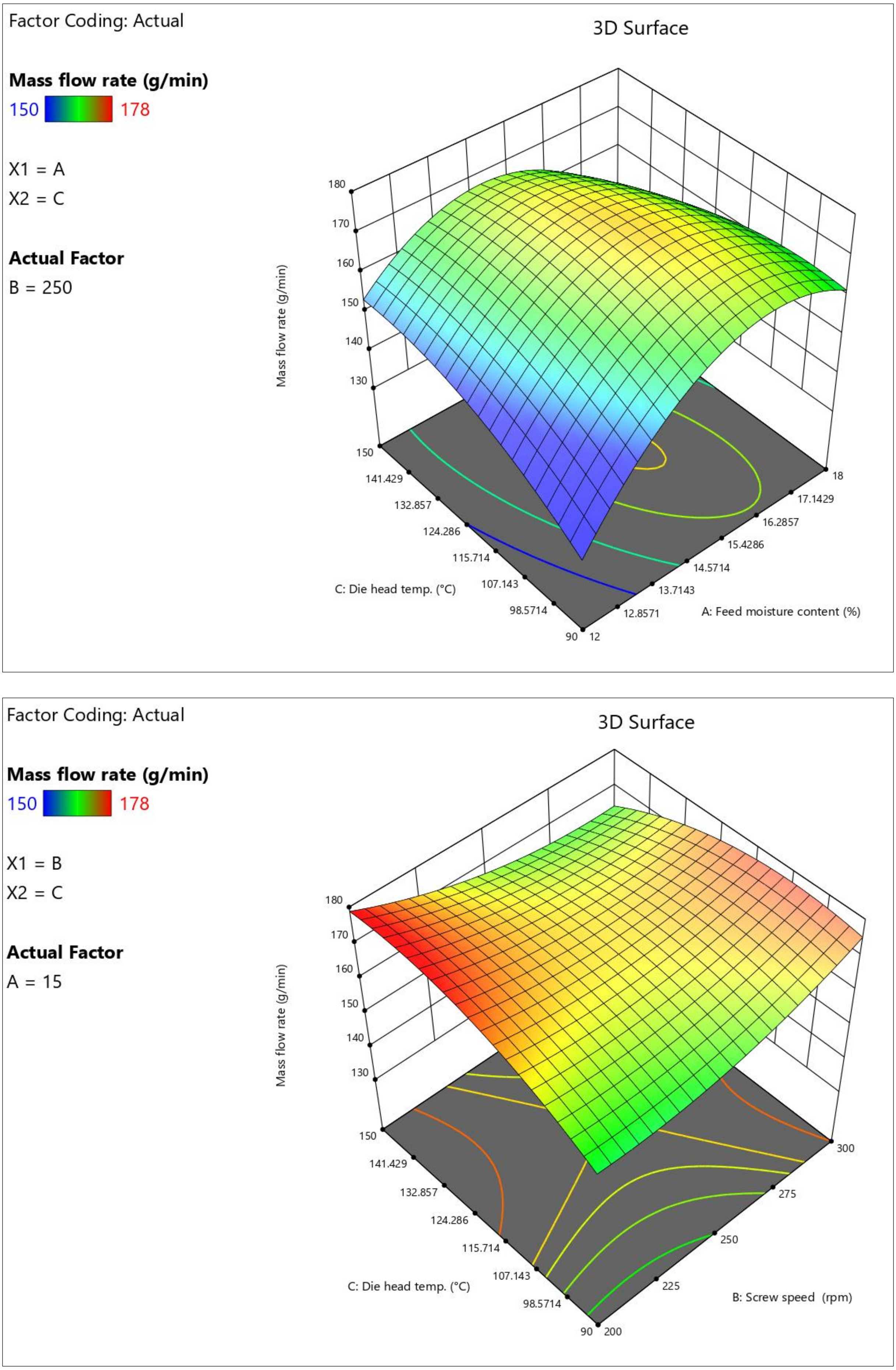


Fig 5: Effect of feed moisture content, screw speed and die head temperature on Mass flow rate

3.3 Empirical models

The derived model, giving the empirical relation between the response variables and test variables in coded units, was obtained as under:

Bulk density = $0.0776 + 0.0015 \ast A + 0.0026 \ast B - 0.0103 \ast C + 0.0005 \ast AB - 0.0108 \ast AC - 0.0067 \ast BC + 0.0065 * A^2 - 0.0043 \ast B^2 + 0.0014 \ast C^2$

Specific length = $113.48 - 0.3185 \ast A + 1.89 \ast B + 9.82 \ast C - 0.5375 \ast AB + 0.3950 \ast AC - 0.0800 \ast BC - 2.05 \ast A^2 + 2.61 \ast B^2 - 4.89 \ast C^2$

Expansion ratio = $2.86 - 0.0945 \ast A + 0.0375 \ast B + 0.1487 \ast C + 0.0238 \ast AB - 0.0012 \ast AC + 0.0188 \ast BC - 0.1261 \ast A^2 + 0.0861 \ast B^2 - 0.0306 \ast C^2$

Machine torque = $16.70 - 0.6124 \ast A - 1.17 \ast B - 0.0732 \ast C - 0.125 \ast AB - 0.125 \ast AC - 0.125 \ast BC + 1.32 \ast A^2 - 0.0865 \ast B^2 - 0.0903 \ast C^2$

Mass flow rate = $171.75 + 3.31 \ast A - 0.1964 \ast B - 0.8820 \ast C - 2.13 \ast AB - 3.13 \ast AC - 2.38 \ast BC - 6.09 \ast A^2 + 1.52 \ast B^2 - 2.02 \ast C^2$

Where, A, B and C are the coded factors of feed moisture content, screw speed and die head temperature, respectively.

Table 5: ANOVA table and regression coefficients for response surface quadratic model of different machine parameters and physical parameters of extruded products

Source	Bulk density (g/cm^3)	Specific length (mm/g)	Expansion ratio	Machine Torque (Nm)	Mass flow rate (g/min)
Intercept	**0.0776**	**113.48**	**2.86**	**16.70**	**171.75**
			Linear terms		
A	0.0015	-0.3185	-0.0945**	-0.6124*	3.31**
B	0.0026	1.89	0.0375	-1.17***	-0.1964
C	-0.0103**	9.82***	0.1487***	-0.0732	0.8820
			Interaction terms		
AB	0.0005	-0.5375	0.0238	-0.1250	-2.13
AC	-0.0108**	0.3950	-0.0012	0.1250	-3.13*
BC	-0.0067*	-0.0800	0.0188	-0.1250	-2.38
			Quadratic terms		
A2	0.0065**	-2.05*	-0.1261***	1.32***	-6.09***
B2	-0.0043*	-2.61*	0.0861**	0.0865	1.52
C2	0.0014	-4.89**	-0.0306	-0.0903	-2.02
			Indicators for model fitting		
R^2	0.8824	0.9411	0.9430	0.8875	0.8703
Adj-R^2	0.7765	0.8881	0.8918	0.7862	0.7535
Pred-R^2	0.3145	0.6339	0.6954	0.2611	0.5837
Adeq Precision	10.9835	13.8869	16.3996	11.5074	10.2570
F-value	8.33	17.76	18.39	8.76	7.45
Lack of fit	NS	NS	NS	NS	NS
C.V.%	8.96	3.15	2.52	4.54	2.26

3.4 Optimization and validation of process variables

The optimum conditions for developing an extruded product through the blending of pearl millet flour and defatted peanut flour were determined using numerical optimization techniques with Design Expert software version 13 (State-Ease Inc., Minneapolis, MN, USA). Table 6 outlines the main criteria and constraints applied during the optimization process. Equal importance i.e. weightage of 3, was assigned to all independent variables and responses in the optimization. The optimal treatment conditions identified were as follows: feed moisture content of 15% (w.b.), screw speed set to 267 rpm, and die head temperature maintained at 134 °C. Subsequently, experiments were conducted using these optimized conditions to validate the model predictions. The results demonstrated that the experimental values closely matched the predicted values obtained from the optimized model (Table 6). This high level of agreement suggested a strong fit between the observed and predicted responses, indicating the accuracy and validity of the developed regression models.

Overall, the close correspondence between observed and predicted outcomes confirmed the effectiveness of the optimized conditions in producing the desired extruded product, validating the reliability of the experimental approach and model predictions.

Table 6: Constraints, criteria and output for numerical optimization of extruded products

<table>
<tr><th colspan="6">Variables</th></tr>
<tr><th colspan="2">Constraint</th><th colspan="2">Goal</th><th>Importance</th><th>Optimum value</th></tr>
<tr><td colspan="2">Feed moisture content (%w.b.)</td><td colspan="2">In the range</td><td>3</td><td>14.877 ≈ 15</td></tr>
<tr><td colspan="2">Screw speed (rpm)</td><td colspan="2">In the range</td><td>3</td><td>266.594 ≈ 267</td></tr>
<tr><td colspan="2">Die head temperature (°C)</td><td colspan="2">In the range</td><td>3</td><td>133.678 ≈ 134</td></tr>
<tr><th colspan="6">Responses</th></tr>
<tr><th>Constraint</th><th>Goal</th><th>Importance</th><th>Predicted value</th><th>Experimental value</th><th>Deviation (%)</th></tr>
<tr><td>Bulk density (g/cm^3)</td><td>None</td><td>3</td><td>0.068</td><td>0.062</td><td>-8.82</td></tr>
<tr><td>Specific length (mm/g)</td><td>None</td><td>3</td><td>118.36</td><td>108.59</td><td>-8.25</td></tr>
<tr><td>Expansion ratio</td><td>Maximum</td><td>5</td><td>3.01</td><td>2.94</td><td>-2.33</td></tr>
<tr><td>Machine torque (Nm)</td><td>None</td><td>3</td><td>15.95</td><td>15.00</td><td>-5.96</td></tr>
<tr><td>Mass flow rate (g/min)</td><td>None</td><td>3</td><td>170.57</td><td>163.00</td><td>-4.44</td></tr>
</table>

4. Conclusion

It could be concluded from the study that the defatted peanut flour can suitably be used for the extrusion cooking process only if mixed properly with pearl millet flour as a base material due to its high protein content, which restricts product gelatinization and limits the product expansion during extrusion cooking. Defatted peanut flour can be used as functional ingredient in the production of extruded snack products due to its high protein content and nutritional value. Among the different experimental conditions, the optimized condition was obtained as 135% feed moisture content, 267 rpm screw speed and 134 °C die head temperature.

5. References

1. AOAC. Official Methods of Analysis of the AOAC International. 18th ed. Gaithersburg, MD, USA: AOAC; c2005.
2. Adesina AA, Sowbhagya CM, Bhattacharya S, Zakiuddin Ali S. Maize-soy-based ready-to-eat extruded snack food. Journal of Food Science and Technology. 1998;35(1):40-43.
3. Alam MS, Kaur J, Khaira H, Gupta K. Extrusion and extruded products: changes in quality attributes as affected by extrusion process parameters: a review. Critical Reviews in Food Science and Nutrition. 2016 Feb 17;56(3):445-73.
4. Anderson RA, Conway HF, Peplinski AJ. Gelatinization of corn grits by roll cooking, extrusion cooking and steaming. Starch-Stärke. 1970;22(4):130-5.
5. Baik BK, Powers J, Nguyen LT. Extrusion of regular and waxy barley flours for production of expanded cereals. Cereal Chemistry. 2004 Jan;81(1):94-99.
6. Bhople S, Singh M. Effect of iron enrichment on the physical properties of rice-based extruded snacks. International Journal of Agriculture Sciences. 2017;9(24):4282-4284.
7. Davara PR, Muliya MH, Dabhi MN, Sangani VP. Physical and functional properties of extruded snack products prepared by blending defatted peanut flour with corn flour. International Journal of Agriculture, Environment and Biotechnology. 2022;15:347-358.
8. Deshpande HW, Poshadri A. Physical and sensory characteristics of extruded snacks prepared from foxtail millet-based composite flours. International Food Research Journal. 2011 May 1;18(2).
9. Ding QB, Ainsworth P, Plunkett A, Tucker G, Marson H. The effect of extrusion conditions on the functional and physical properties of wheat-based expanded snacks. Journal of Food Engineering. 2006 Mar 1;73(2):142-148.
10. Fan J, Mitchell JR, Blanshard JM. The effect of sugars on the extrusion of maize grits: I. The role of the glass transition in determining product density and shape. International Journal of Food Science & Technology. 1996 Feb;31(1):55-65.
11. Faubion JM. Functionality of grain components in extrusion. Cereal Foods World. 1982;27:212-214.
12. Gat Y, Ananthanarayan L. Effect of extrusion process parameters and pregelatinized rice flour on physicochemical properties of ready-to-eat expanded snacks. Journal of Food Science and Technology. 2015 May;52:2634-2645.
13. Geetha HP, Mathad PF, Nidoni U, Ramachandra CT. Development of foxtail millet-based extruded food product. International Journal of Food Science and Technology. 2016;6(2):11-22.
14. Gojiya D, Davara P, Gohil V, Dabhi M. Process standardization for formulating protein-augmented corn-based extrudates using defatted sesame flour (Sesame oil industry waste valorization). Journal of Food Processing and Preservation. 2022 Dec;46(12).
15. Gopalan C, Rama-Sastri BV, Balasubramanian SC. Nutritive Value of Indian Foods. National Institute of Nutrition, ICMR, Hyderabad, India.
16. Kain RJ, Chen Z, Sonda TS, Abu-Kpawoh JC. Study on the effects of enzymatic hydrolysis on the physical, functional and chemical properties of peanut protein isolates extracted from defatted heat pressed peanut meal flour (*Arachis hypogaea* L.). Pakistan Journal of Nutrition. 2009 Nov 4;8(6):818-825.
17. Kanojia V, Singh M. Extruded Product Quality Assessment Indices: A Review. International Journal of Agriculture Sciences. 2016;8(54):2928-2934.
18. Kaur P, Singh N, Pal P, Kaur A. Traditional and improved paddy varieties: Composition, protein, pasting, and gluten-free chapati making properties. Cereal Chemistry. 2018 Sep;95(5):666-678.
19. Khuri AI, Cornell JA. Response Surface Design and Analysis. Marcel Dekker, Inc.
20. Kokini JL, Chang CN, Lai LS. The role of rheological properties on extrudates expansion. In: Kokini JL, Ho CT, Karwe MV, editors. Food Extrusion: Science and Technology. Dekker; 1992. p. 631-652.
21. Lakshmi Devi N, Shobha S, Alavi S, Kalpana K, Soumya M. Utilization of extrusion technology for the development of millet-based complementary foods. Journal of Food Science and Technology. 2014 Oct;51:2845-2850.
22. Linko P, Colonna P, Mercier C. HTST-extrusion of cereal-based materials. Advances in Cereal Science and Technology. 1981;4:145-235.
23. Lowry OH, Rosebrough NJ, Farr AL, Randall RJ. Protein measurement with the Folin phenol reagent. Journal of Biological Chemistry. 1951 Nov 1;193(1):265-275.
24. Ma T, Wang Q, Wu H. Optimization of extraction conditions for improving solubility of peanut protein concentrates by response surface methodology. LWT-Food Science and Technology. 2010 Nov 1;43(9):1450-5.
25. Montgomery DC. Design and Analysis of Experiments. John Wiley & Sons; c2017.
26. Mościcki L, van Zuilichem DJ. Extrusion-cooking and related technique. In: Extrusion-Cooking Techniques: Applications, Theory and Sustainability. 2011 Jan 26:1-24.
27. Myers RH. Response Surface Methodology. Distributed by Edwards Brothers Inc., Ann Arbor, Michigan; c1976.
28. Nielsen SS. Phenol-sulfuric acid method for total carbohydrates. Food Analysis Laboratory Manual. 2010:47-53.
29. Rehrah D, Ahmedna M, Goktepe I, Yu J. Extrusion parameters and consumer acceptability of a peanut-based meat analogue. International Journal of

Food Science & Technology. 2009 Oct;44(10):2075-2084.
30. Sapariya PS, Sangani VP, Davara PR. Effects of Process Parameters on Rice-Based Extruded Snack Food. International Journal of Agriculture, Environment and Biotechnology. 2022;15:407.
31. Shruthi VH, Hiregoudar S, Nidoni U, Ramachandra TC, Jhadav K. Effect of temperature, feed moisture and feed composition on the physical properties of corn extrudates. Environment & Ecology. 2017 Jul;35(3):1610-1617.
32. Shukla P, Sudhakar A, Sharma A. Study of machine parameters in twin-screw extruder for pulses-based extrudate. Agricultural Engineering International: CIGR Journal. 2021 Dec 30;23(4).
33. Soumitra Banerjee SB, Amit Ghosh AG, Pratap Chakraborty PC. Characteristics of effect of temperature and moisture on lentil-based extruded expanded product and process optimisation.
34. Stojceska V, Ainsworth P, Plunkett A, İbanoğlu Ş. The effect of extrusion cooking using different water feed rates on the quality of ready-to-eat snacks made from food by-products. Food Chemistry. 2009 May 1;114(1):226-232.
35. Yatin MK, Garg VK, Sharma DK. Effect of feed and machine parameters on physical properties of extrudate during extrusion cooking of pearl millet, sorghum and soybean flour blends. International Journal of Food and Nutritional Science. 2015;4(5):58-63.