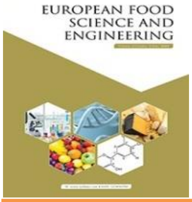

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Multiresponse optimization of value-added sesame seed candy

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ABSTRACT

Sesame seed candy, traditionally produced from sesame seeds and sugar, is a confectionery product. This study is aimed at developing value added candy from sesame seed, ginger, cinnamon, honey; and optimizing employing desirability function technique. Experiments were conducted using a four-component constrained D-optimal mixture-process experimental design and the formulated candies were characterized. The formulation design constraints were: sesame seed (40-70%), ginger (10-30%), cinnamon (10-30%), honey (10-30%); while the processing factors were roasting temperature (100-150 ºC) and roasting time (10-30 min). Consumer acceptability was measured by 50 semi-trained regular consumers using a 9-point hedonic scale. Optimal candy of highest desirability index of 0.506 was obtained from 43.53% sesame seed, 10% ginger, 16.47% cinnamon, and 30% honey, with 110 ºC roasting temperature. and 27 min roasting time. Quality properties of the optimal candy were 7.95% moisture content, 20.76% dietary fiber, 37.89% protein, 10.40% carbohydrate, 17.20% fat content, 249.71 mg calcium, 0.029 mg/100g vitamin C, 353.54 kcal energy value, 5.78 hardness, 6 taste, 5.74 colour, 5.87 chewiness, 5.92 gumminess, 5.6 crispness, 6.11 flavour, and overall acceptability of 6.20 score; based on 9-point hedonic scale. Compared with the traditional sesame seed candy, the optimal value-added sesame seed candy was of higher quality.

1. Introduction

The Sesame, a genus of Sesamum, is a member of the Pedaliaceae family. According to the difference in germplasm color, sesame can be classified as white sesame, black sesame, and yellow sesame, among which black and white sesame are the more common and widely grown dominant species. Sesame seeds are often used to make a variety of foods, such as sesame oil, sesame paste, or to decorate other foods. Sesame seeds are rich in fat, protein, minerals, vitamins, and dietary fiber. Sesame oil, which is obtained through traditional oil production methods, is rich in unsaturated fatty acids, fat-soluble vitamins, amino acids, etc. Studies have found that sesame seeds contain 21.9% protein and 61.7% fat, and are rich in minerals such as Fe and Ca. Sesame seeds are rich in nutrients and have the reputation of being an “all-purpose nutrient bank” and the “crown of eight grains (Wei et al., 2022).

Sesame seed candy is traditionally made from sesame, sugar and/or honey. It is popular from the Middle East through South Asia to East Asia; in Nigeria it is mostly consumed by children. The texture varies from chewy to crisp (Richardson, 2008). Sesame seed is one of the oldest oilseed crops known. It has one of the highest oil contents of any seed. It has been regarded as a health food for aging prevention and energy increasing (Obiamaka, 2019). However, sesame seed, the major ingredient in the candy production is deficient in many nutrients that the body needs. Hence, there is need to fortify the product by adding ingredients that will inject vitamins and minerals during processing to increase their nutritional value (Olson et al., 2021). Fortification is a proven, safe and cost-effective strategy for improving diets and for the prevention and control of micronutrient deficiencies. Malnutrition is commonly recognized as being among the most widespread and pernicious causes of human suffering throughout the world. FAO estimated that a total of 842 million people were undernourished in 2011-2013 and current statistics have not shown any improvement on this. About 45% of the 6.9 million child deaths in 2011 were linked to malnutrition. Some 162 million children under five years of age are stunted owing to chronic undernutrition and 99 million children are underweight (FAO, 2013). Multi-disciplinary, multifaceted, nutrition-sensitive food manufacturing approach is one of the effective vehicles in combating and tackling malnutrition that is prevalent in the rural communities of Africa. The objective

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of this study was to optimize the development of value-added sesame seed candy that can serve as an effective vehicle in combating and tackling malnutrition that is prevalent in the rural communities of Africa. Studies have shown that candies can be used to increase the nutritional status of consumers by incorporating nutrients such as protein and fiber from plant source which have health benefits. Sesame seed, the major ingredient in the candy production, has a composition of about 50-52% oil, 17-19% protein, 48.5% crude oil, 9.4% crude fiber, 4.2% ash, and 16-18% carbohydrate (Adebayo-Oyetoro et al., 2017).

This study presents a novel optimization procedure using RSM to optimize multiple responses, generate the optimal parameter-setting. and to determine the optimum ratio of sesame seed/ginger/cinnamon/honey formulations. Optimization is concerned with determining the best possible formulation from a set of factors (ingredients and & or process factors that meets desire responses (studied quality indices). Once the formulation experiments have been carried out and the experimental data gotten, based on the design matrix, multi-variate regression analysis on the experimental data are performed. Optimization commences after the multi-variate regression analysis, using the same experimental data from the formulation experiment. Quite a number of optimization techniques are usually employed. Numerical optimization will optimize any combination of one or more goals. The goals may apply to either factors (ingredients and processing parameters) or responses. The possible goals are: maximize, minimize, target, within range, none (for responses only) and set to an exact value (factors only). Weights (0.1 to 10) are assigned to goals to adjust the shapes of their desirability functions. Increased weight (up to 10) moves the result towards the goal. Also, the "importance" of a goal can be changed in relation to the other goals. If the researcher wants all goals to be equally important, at a setting of 3 pluses (+++) is given. If one goal to be most important, a setting of 5 pluses (+++++) is given (ReliaSoft, 2015). Using numerical optimization, via objective functions, optimal blends are predicted in form of optimization solutions indicating components combinations that meet specifications (optimal formulation conditions) and the "overall desirability index". A graph of desirability can be generated for any of the solutions found via numerical optimization. Individual response may also be graphed. Such individual response graph can be useful to see how a single response behaves in the vicinity of a particular optimum. In addition, the numerical optimization histograms, often referred to as the bar graph, can be generated. It is a simple view that shows the desirability for each factor and each response individually. Usually, the bottom histogram bar is the combined desirability of all the factors and responses. With multiple responses, regions where requirements simultaneously meet the critical properties are sought. By overlaying critical response contours on a contour plot the best compromise can be picked (the sweet spot). Graphical optimization displays the area of feasible response values in the factor space. Regions that do not fit the optimization criteria are shaded gray. Any "window" that is not gray shaded satisfies the goals for every response. In the graphical optimization solution overlay plot, the bright yellow (default) now shows where the entire range of all intervals meet the specified criteria. The dark gold corresponds to where the point estimate meets the criteria requirements, but part of an interval estimate does not (Goos & Jones, 2011; ReliaSoft, 2015). Optimization is concerned with determining the best possible formulation from a set of factors (ingredients and/or process factors that meets desire responses (studied quality indices). In a multi-response study, the degree to which all the optimization goals are met is "a compromised value referred to as overall desirability index" (Smith, 2005; Tsai et al., 2010; Wang & Fang, 2010). The aim of this research was to develop and optimize value added sesame seed candy. The objective was to find an optimum sesame seed/ginger/cinnamon/honey confection that would have improved nutritional values and consumer acceptance close to that of commercial sesame seed candy.

2. Materials and methods

2.1. Materials

Samples of white sesame seed (*Sesamum indicum L.*), of the Pedaliaceae family, common ginger (also known as Indian or Chinese ginger), cinnamon (cassia) and honey. were purchased from Kure market in Minna, Niger State, Nigeria. The preparation of sesame seed candy was carried out at the department of Agricultural and Bioresources Engineering laboratory, while the analyses were carried out at the department of Food Science and Technology laboratory at Federal University of Technology, Minna.

Reagents and apparatus

The analytical grade reagents used during the experiment include: ferric chloride, ammonium thiocyanate, ammonium solution, sulphuric acid (H_2SO_4). sodium hydroxide, ethanol, petroleum ether, hydrogen chloride (HCL), n-hexane and distilled water. The apparatus used during the experiment include: Kenwood electric oven (70L Convection Steel), burette (Boro 3.3. To DIN EN ISO 385), desiccator (Boro 3.3. DIN 12491), 1200 °C (2190 °F) laboratory muffle furnace, measuring cylinder (with glass hexagonal base), pipette (CellTreat 10 mL Serological), crucible (SKU: 034-5920230), stopwatch (A601X), digital weighting balance (Reshy Lab scale 3000 g), digital thermometer (Model: ACC550DIG), conical glass flask 500 mL, pyrex glass petri dishes, Maxi 60 60 4 gas cooker, stirrers (Scilogex SCI-120-HS) frying pan (Misen 5-Ply Stainless Steel Pan), stainless steel knife, stainless steel flat plates, spectrophotometer (UV-Vis 9300 / 9600) and parchment paper.

2.2. Methods

Sesame seed candy preparation

The sesame seed, ginger and cinnamon were washed to remove foreign materials and were then sundried. Ginger and cinnamon were milled and packaged separately. The first stage in the production of sesame seed candy is roasting of the seed. Though roasting is done traditionally by placing the seeds inside a frying pan on top of a stove, but in this work, a temperature-regulated oven was employed. The honey was placed in a saucepan over medium heat to froth and bubbled up after about 5 min. Guided by the matrix design (Table 1), the mixtures of roasted sesame seed, ginger, cinnamon were then poured gradually inside the honey syrup with a large spoon and gently stirred until a uniform sample was obtained.

Table 1. Design matrix for the value-added sesame seed candy formulation experiments.

Run	Sesame seed (%)	Ginger (%)	Cinnamon (%)	Honey (%)	Roasting temperature (ºC)	Roasting time (min)
1	40.0	10.0	30.0	20.0	150	10
2	40.0	20.0	30.0	10.0	150	10
3	40.0	20.3	19.1	20.6	100	10
4	40.0	20.3	19.1	20.6	100	10
5	40.0	19.7	20.7	19.5	150	10
6	70.0	10.0	10.0	10.0	150	10
7	56.8	20.2	13.0	10.0	150	30
8	56.4	10.0	12.1	21.5	150	10
9	55.5	21.6	11.4	11.4	100	30
10	40.0	10.0	30.0	20.0	150	30
11	42.3	12.8	14.9	30.0	150	10
12	55.5	11.6	22.9	10.0	100	30
13	43.1	16.9	10.0	30.0	100	10
14	40.0	20.0	10.0	30.0	150	30
15	40.0	19.5	19.8	20.7	150	30
16	41.3	13.3	30.0	15.4	100	30
17	40.0	27.0	10.0	23.0	150	10
18	43.6	10.0	16.4	30.0	150	30
19	55.3	10.0	13.9	20.8	100	30
20	40.0	28.8	21.2	10.0	100	10
21	55.4	10.0	22.3	12.3	150	30
22	56.0	11.6	22.3	10.0	100	10
23	40.0	21.7	28.3	10.0	150	30
24	40.0	21.5	28.5	10.0	124	27
25	40.0	10.0	20.8	29.3	100	10
26	40.0	19.7	20.7	19.5	150	10
27	55.8	10.0	13.2	21.0	100	10
28	70.0	10.0	10.0	10.0	150	30
29	41.4	30.0	10.0	18.7	100	10
30	40.9	30.0	10.0	19.1	100	30
31	40.0	28.2	21.8	10.0	100	30
32	40.0	20.2	19.2	20.6	100	30
33	43.8	16.2	10.0	30.0	100	30
34	43.3	30.0	16.7	10.0	150	10
35	47.7	12.3	10.0	30.0	119	22
36	55.4	21.4	11.5	11.7	100	10
37	70.0	10.0	10.0	10.0	100	10
38	56.0	20.8	10.0	13.2	150	10
39	55.2	13.7	10.0	21.0	150	30
40	70.0	10.0	10.0	10.0	100	30
41	40.0	19.5	19.8	20.7	150	30
42	40.0	10.0	20.0	30.0	100	30
43	47.8	10.0	20.8	21.4	144	20
44	50.0	10.0	30.0	10.0	107	20
45	48.1	20.6	19.9	11.5	125	13
46	55.2	12.3	21.6	10.9	150	10
47	43.5	30.0	12.4	14.1	150	30
48	41.6	13.8	30.0	14.6	100	10
49	40.0	20.2	19.2	20.6	100	30
50	55.5	21.6	11.4	11.4	100	30

The sesame seed candy dough was then cooled, formed and cut into desired shape with the aid of a knife. This preparation of the sesame seed candy was based on the design matrix.

Experimental design for the value-added sesame seed candy formulation experiments

Design-Expert software (version 13, Stat-Ease Inc., USA) was used for experimental design and statistical evaluation of data. A four-component constrained D-optimal mixture-process experimental design, totaling 50 randomized experimental runs, was employed. Four major variable components with two processing factors were investigated. The respective formulation design constraints were: sesame seed (40%-70%), ginger (10%-30%), cinnamon (10%-30%), and honey (10%-30%). The processing factors investigated were roasting temperature (100-150 ºC) and roasting time (10-30 min). The quality properties of the value-added sesame seed candy monitored were: moisture content, dietary fiber, protein, carbohydrate, fat content, calcium, vitamin C, energy value, hardness, taste, colour, chewiness, gumminess, crispness, flavour, and overall acceptability. The design matrix for the D-Optimal mixture – process design is presented in Table 1. The formulation of the blend with the processing parameters were based on the design matrix.

Proximate analysis and sensory evaluations

Most of the quality characteristics of the value-added sesame seed candy which were measured using the methods described by the Association of Analytical Chemist with some modifications by some researchers (AOAC, 2002; Crisan & Sands, 2008; El-Ishaq & Obirinakem, 2015; Christian et al., 2019). The sensory evaluation of the samples was conducted using a total of 30 semi-trained panelists. The samples were evaluated for taste, flavour, sweetness, colour, texture and overall acceptability. A 9-point hedonic scale ranging from 9 = like extremely and 1= dislike extremely was used to evaluate the samples.

2.3. Experimental data

Formulated value-added sesame seed candy samples were analyzed and evaluated for the moisture content, dietary fiber, protein, carbohydrate, fat content, calcium, vitamin C, energy value, hardness, taste, colour, chewiness, gumminess, crispness, flavour, and overall acceptability (Tables 2 and 3).

Table 2. Quality properties of the formulated value-added sesame seed candy.

Run	Moisture content (%)	Dietary fiber (%)	Protein (%)	Carbohydrate (%)	Fat content (%)	Calcium (mg)	Vitamin C (mg/100g)	Energy value (kcal)
1	6.80	23.61	20.25	19.06	26.28	273.00	0.00	393.76
2	7.40	20.14	21.13	21.13	26.20	269.00	0.00	304.84
3	7.60	20.63	24.85	17.31	25.11	233.00	0.00	398.23
4	9.60	21.11	20.65	19.30	25.34	234.00	0.04	387.90
5	6.40	22.63	19.25	21.54	26.18	216.00	0.02	398.78
6	4.60	19.84	21.00	25.95	24.11	222.00	0.03	304.78
7	5.20	19.72	25.76	20.49	24.33	241.00	0.00	399.97
8	4.20	21.66	19.56	26.46	23.62	256.00	0.00	396.66
9	7.40	22.06	20.88	23.58	21.14	278.00	0.06	368.10
10	8.20	21.72	20.65	25.21	20.22	281.00	0.03	365.42
11	7.20	20.11	30.80	13.91	21.48	283.00	0.03	372.16
12	10.60	20.63	28.70	14.46	20.11	291.00	0.04	353.63
13	7.00	19.84	38.50	10.24	19.92	206.00	0.00	369.74
14	9.80	19.33	42.00	4.84	19.33	218.00	0.00	360.13
15	6.20	19.78	43.50	3.11	17.41	216.00	0.00	343.13
16	8.40	21.62	41.65	3.00	20.33	233.00	0.07	361.57
17	8.60	21.63	31.50	11.84	21.63	247.00	0.07	368.03
18	7.60	20.11	33.25	15.26	19.48	272.00	0.05	369.36
19	7.20	20.22	35.00	14.02	18.36	262.00	0.04	361.32
20	6.20	20.63	33.60	13.61	20.66	252.00	0.02	375.18
21	9.00	23.24	28.72	16.22	18.22	271.00	0.00	365.43
22	5.20	22.11	29.33	18.33	20.63	273.00	0.00	376.31
23	6.80	23.24	25.66	19.80	19.11	222.00	0.00	354.19
24	7.40	23.00	25.38	20.60	18.32	227.00	0.00	348.80
25	6.00	22.14	26.11	21.92	18.73	229.00	0.00	360.69
26	6.90	21.43	24.74	18.48	23.72	240.00	0.02	386.33
27	6.10	20.77	27.79	19.18	21.68	256.00	0.03	382.97
28	6.10	20.54	24.63	22.73	21.16	264.00	0.05	379.91
29	7.10	20.22	32.96	12.61	21.86	221.00	0.03	378.99
30	8.50	19.91	40.27	7.19	18.10	222.00	0.05	352.76
31	8.40	21.21	34.65	10.99	19.07	235.00	0.04	354.21
32	8.50	20.86	37.52	9.49	17.95	240.00	0.04	349.56
33	8.50	19.88	41.37	7.61	16.96	238.00	0.00	348.56
34	6.60	21.12	23.45	19.21	24.73	228.00	0.02	393.24
35	7.60	20.10	35.52	12.43	19.16	245.00	0.04	364.29
36	6.00	20.65	26.82	19.14	22.66	242.00	0.00	387.78
37	5.00	20.74	22.52	24.66	22.91	264.00	0.00	394.94
38	5.80	20.59	22.50	22.08	24.45	241.00	0.03	398.38
39	7.30	20.23	31.20	16.09	19.92	249.00	0.05	368.46
40	6.30	20.44	29.58	19.48	19.21	265.00	0.05	369.16
41	8.30	21.02	32.37	12.91	19.89	241.00	0.04	360.12
42	8.70	20.88	38.95	9.09	16.95	252.00	0.04	344.74
43	7.10	21.39	26.75	18.52	21.49	257.00	0.03	374.47
44	6.90	22.40	24.38	20.51	21.25	269.00	0.00	370.83
45	6.60	21.43	24.65	19.55	23.07	245.00	0.00	384.46
46	5.70	21.82	18.16	25.39	24.70	261.00	0.00	396.55
47	8.00	20.34	32.74	12.54	20.60	225.00	0.05	366.50
48	6.90	22.37	24.99	18.96	22.30	258.00	0.00	376.51
49	8.50	20.86	37.52	9.49	17.95	240.00	0.04	349.56
50	7.40	20.35	33.80	14.03	18.99	243.00	0.05	362.26

Table 3. Sensory properties of the formulated value-added sesame seed candy.

Run	Hardness	Taste	Colour	Chewiness	Gumminess	Crispness	Flavour	Overall acceptability
1	6.4	6.1	6.3	5.7	6.4	5.9	5.9	6.2
2	4.8	4.6	5.3	5.5	5.7	4.6	5.1	5.7
3	5.2	5.1	5.7	5.7	6.0	4.9	5.6	5.5
4	4.9	5.1	5.4	6.0	5.5	5.2	5.7	5.6
5	5.8	5.3	6.6	6.0	6.0	5.6	5.7	5.9
6	6.2	4.4	5.7	5.2	4.8	6.2	4.9	5.4
7	6.9	4.9	5.9	5.5	5.1	6.1	6.1	6.1
8	6.0	6.3	6.9	6.0	6.2	5.8	6.7	6.9
9	6.0	5.8	6.3	6.0	5.2	6.2	5.9	6.2
10	7.1	6.7	6.6	6.6	6.4	6.5	6.4	6.6
11	6.8	6.4	6.3	6.2	6.5	6.1	6.6	6.7
12	6.4	6.1	6.6	6.2	5.5	5.3	5.7	6.5
13	6.3	6.3	6.6	6.3	6.7	5.4	6.3	6.5
14	6.7	6.5	6.0	6.9	6.0	6.6	6.8	7.2
15	6.3	5.5	6.2	5.8	5.7	5.1	5.9	6.5
16	6.2	5.5	5.0	5.9	5.3	5.7	5.8	6.1
17	6.6	5.8	6.3	6.1	6.2	5.5	5.9	6.2
18	6.2	6.1	6.4	6.0	6.3	5.6	6.5	6.5
19	5.8	5.6	5.9	5.8	6.1	5.3	6.0	5.8
20	5.4	5.4	5.9	5.6	5.5	5.2	5.5	5.6
21	6.0	5.5	6.2	6.2	5.9	5.4	5.3	6.2
22	5.1	5.1	4.8	5.2	5.6	5.1	5.3	5.4
23	5.9	5.1	5.7	5.6	6.0	5.8	5.3	5.8
24	5.2	5.7	6.1	6.0	6.1	5.9	5.6	5.9
25	5.0	5.7	5.5	5.8	6.2	5.4	6.0	6.5
26	5.3	5.0	5.5	5.4	5.9	5.7	5.4	5.9
27	5.3	4.7	5.2	5.3	5.2	5.1	4.8	5.3
28	4.6	4.4	4.3	5.0	5.0	5.1	4.4	4.8
29	5.3	5.4	5.4	5.5	5.8	5.0	5.6	5.7
30	4.9	4.9	6.0	5.8	5.7	5.9	5.4	5.3
31	5.5	5.0	5.9	5.5	5.4	5.7	5.0	5.6
32	5.7	4.7	6.2	5.5	5.6	5.9	5.3	5.8
33	5.9	5.6	6.1	5.7	6.0	5.9	5.7	6.1
34	6.0	6.2	5.3	6.0	5.1	5.4	6.2	6.2
35	6.4	6.2	5.7	5.7	5.4	5.6	6.3	6.3
36	6.2	6.0	6.0	6.4	6.1	5.9	6.5	6.3
37	6.2	5.6	5.8	5.3	5.3	5.7	6.0	6.4
38	6.1	5.6	5.7	5.7	6.0	5.6	6.0	6.3
39	6.8	6.2	6.4	6.1	6.3	6.3	6.4	6.8
40	6.2	5.6	5.5	5.4	6.0	5.6	5.6	6.2
41	6.4	5.3	5.9	5.9	5.6	5.7	5.7	5.7
42	5.8	5.7	5.4	5.9	6.0	5.6	6.0	6.2
43	6.4	5.7	6.0	6.0	5.5	5.8	6.1	6.1
44	6.2	5.1	5.7	5.8	5.5	5.2	5.5	5.9
45	5.1	4.9	5.2	5.2	5.6	5.2	5.1	5.3
46	5.4	5.7	5.4	5.2	5.5	5.7	5.5	5.6
47	5.1	5.1	5.2	5.6	5.6	5.3	5.6	6.0
48	5.3	5.1	5.2	5.3	5.3	5.3	5.1	5.5
49	5.2	4.8	5.3	4.9	5.5	5.4	4.7	5.3
50	5.2	5.0	5.7	5.2	5.8	5.3	5.5	5.5

2.4. Numerical and graphical optimization of formulated value-added sesame seed candy

In this work, the numerical and graphical optimization approaches, exploiting desirability function technique, were utilized to generate the optimal formulation with the anticipated responses. Desired limits of response variables, optimization goals, and their objectives functions were decided, optimization constraints were clearly defined and individual response is scaled to objective function called "individual desirability index". The summary of the optimization constraints employed for the formulated noodles are presented in Table 4.

3. Results and Discussion

3.1. Optimization of formulated value-added sesame seed candy

Since many variables were being investigated (ingredients and process parameters) and many responses were involved in the study, numerical optimization approach, exploiting the desirability function technique; was utilized to generate optimal formulation with the anticipated responses. Based on the criteria constraints (Table 4), fifty-two desirability formulation solutions (component proportions and process parameter values) were found as summarized in Table 5; with the quality properties of the optimal formulation presented in Table 6.

Table 4. Optimization constraints for the formulated value-added sesame seed candy.

Name	Goal	Lower Limit	Upper Limit	Lower Weight	Upper Weight	Importance
Sesame Seed	target = 50	40	70	1	10	3
Ginger	in range	10	30	1	1	3
Cinnamon	target = 30	10	30	1	10	5
Honey	target = 30	10	30	5	10	5
Roasting Temperature	target = 100	100	150	1	1	3
Roasting Time	target = 10	10	30	1	1	3
Moisture Content	minimize	4.2	10.6	1	1	3
Dietary fiber	in range	19.33	23.61	1	1	3
Protein	target = 42	18.16	43.5	5	10	5
Carbohydrate	minimize	3	26.46	1	1	3
Fat Content	minimize	16.95	26.28	1	1	3
Calcium	maximize	206	291	1	1	5
Vitamin C	target = 0.07	0	0.07	1	10	3
Energy value	target = 395	304.78	399.97	1	10	5
Hardness	in range	4.5667	7.1	1	1	3
Taste	in range	4.4	6.6667	1	1	3
Colour	in range	4.3333	6.8667	1	1	3
Chewiness	in range	4.8667	6.8667	1	1	3
Gumminess	in range	4.8	6.7	1	1	3
Crispness	maximize	4.5517	6.5517	1	1	3
Flavour	maximize	4.4	6.8333	1	1	3
Overall Acceptability	maximize	4.7667	7.2333	1	1	3

Table 5. Optimal formulation conditions for the formulated value-added sesame seed candy.

No	Sesame Seed	Ginger	Cinnamon	Honey	Roasting Temperature	Roasting Time	Desirability	
1	**43.534**	**10.000**	**16.466**	**30.000**	**109.611**	**27.101**	**0.506**	**Selected**
2	43.536	10.000	16.464	30.000	109.782	27.098	0.506	
3	43.539	10.000	16.461	30.000	109.390	27.132	0.506	
…	……….	………	………	………	………………	…………	………	
25	49.182	10.000	12.193	28.625	147.618	28.424	0.400	
26	40.834	10.000	30.000	19.166	100.000	27.876	0.351	
27	49.985	16.493	12.254	21.268	100.000	23.555	0.320	

Table 6. Quality properties of the optimally formulated value-added sesame seed candy.

No	Moisture content	Dietary fiber	Protein	Carbohydrate	Fat content	Calcium	Vitamin C	Energy value	Desirability	
1	**7.949**	**20.761**	**37.886**	**10.396**	**17.198**	**249.705**	**0.029**	**353.541**	**0.506**	**Selected**
2	7.948	20.761	37.872	10.403	17.190	249.799	0.029	353.616	0.506	
3	7.953	20.760	37.920	10.377	17.198	249.653	0.029	353.429	0.506	
….	……..	………	…….	……….	………	………..	………	……….	………	
25	7.831	20.403	35.281	12.154	18.723	269.471	0.036	363.079	0.400	
26	7.750	22.238	34.934	11.325	19.703	252.115	0.061	363.457	0.351	
27	7.739	20.476	33.691	13.949	21.300	232.852	0.036	368.581	0.320	

Continue

No	Hardness	Taste	Colour	Chewiness	Gumminess	Crispness	Flavour	Overall Acceptability	Desirability	
1	**5.783**	**5.999**	**5.743**	**5.873**	**5.921**	**5.600**	**6.108**	**6.195**	**0.506**	**Selected**
2	5.779	6.005	5.747	5.875	5.921	5.603	6.110	6.197	0.506	
3	5.786	5.994	5.738	5.870	5.921	5.598	6.106	6.192	0.506	
….	……..	……..	…….	…………	……….	………	………	……….	……….	
25	6.681	6.520	6.305	6.184	5.632	5.910	6.509	6.914	0.400	
26	6.549	5.559	5.528	5.896	6.090	5.739	6.142	6.005	0.351	
27	6.501	4.942	5.757	5.651	6.385	5.408	5.613	5.654	0.320	

Solution 1 (with the comment "selected") is the one that best meet the specified criteria. The factor settings (i.e. ingredients proportions and processing parameters values) are those that result in the highest desirability scores and indicates the island of the design space/response surface with the best acceptable outcome. So, in this work we have fifty-two islands (local optima), with island 1 (solution 1) being the best. Figure 1 shows the numerical optimization solution desirability bar graph for the optimal value-added sesame seed candy while the graphical optimization solution overlay contour and overlay mix-process plots are presented as Figures 2 and 3.

The graphical optimization solution overlay contour and overlay mix-process plots give the summary or details of the optimal conditions and quality properties of the optimal value-added sesame seed candy. The contours are plotted at the limits specified by the "set criteria". The bright yellow defines the acceptable factor settings while the grey defines the unacceptable factor settings. If intervals are included in the criteria, then a blend of the acceptable and unacceptable colors is used to show where the interval limits are unacceptable.

The composition of sesame seeds comprises 45-65% oil, a noteworthy source of plant-based protein with content ranging from 19 to 35% per 100 g of seeds, 14 to 20% carbohydrates, and 15 to 20% hull material. Studies conducted by other researchers have shown that sesame seeds and sesame oil are richer in phytochemicals and have higher nutritional value than other parts of the sesame plant. Sesamin, sesamol and other chemical components have a variety of pharmacological effects and are of great benefit to human health, and can be used in the treatment of diseases such as anti-inflammatory, antioxidant, anti-cancer, antimelanogenic, auditory protection, anti-cholesterol, and anti-aging, and have a protective effect on the heart, liver, and kidneys (Ahmed et al., 2020; Wei et al., 2022; Yüzer & Gençcelep, 2023; Mostashari et al., 2024). Studies have shown that candies can be used to increase the nutritional status of consumer by incorporating nutrients such as protein and fiber from plant source, which have health benefits. Candies increases consumers' satiety and pleasure (Wang & Fang, 2010). The quality properties of the optimal candy gotten from this research were 7.95% moisture content, 20.76% dietary fiber, 37.89% protein, 10.40% carbohydrate, 17.20% fat content, 249.71 mg calcium, 0.029 mg/100g vitamin C, 353.54 kcal energy value, From the result of the study, the optimal value-added sesame seed candy was higher quality in comparison with the traditional sesame seed candy.

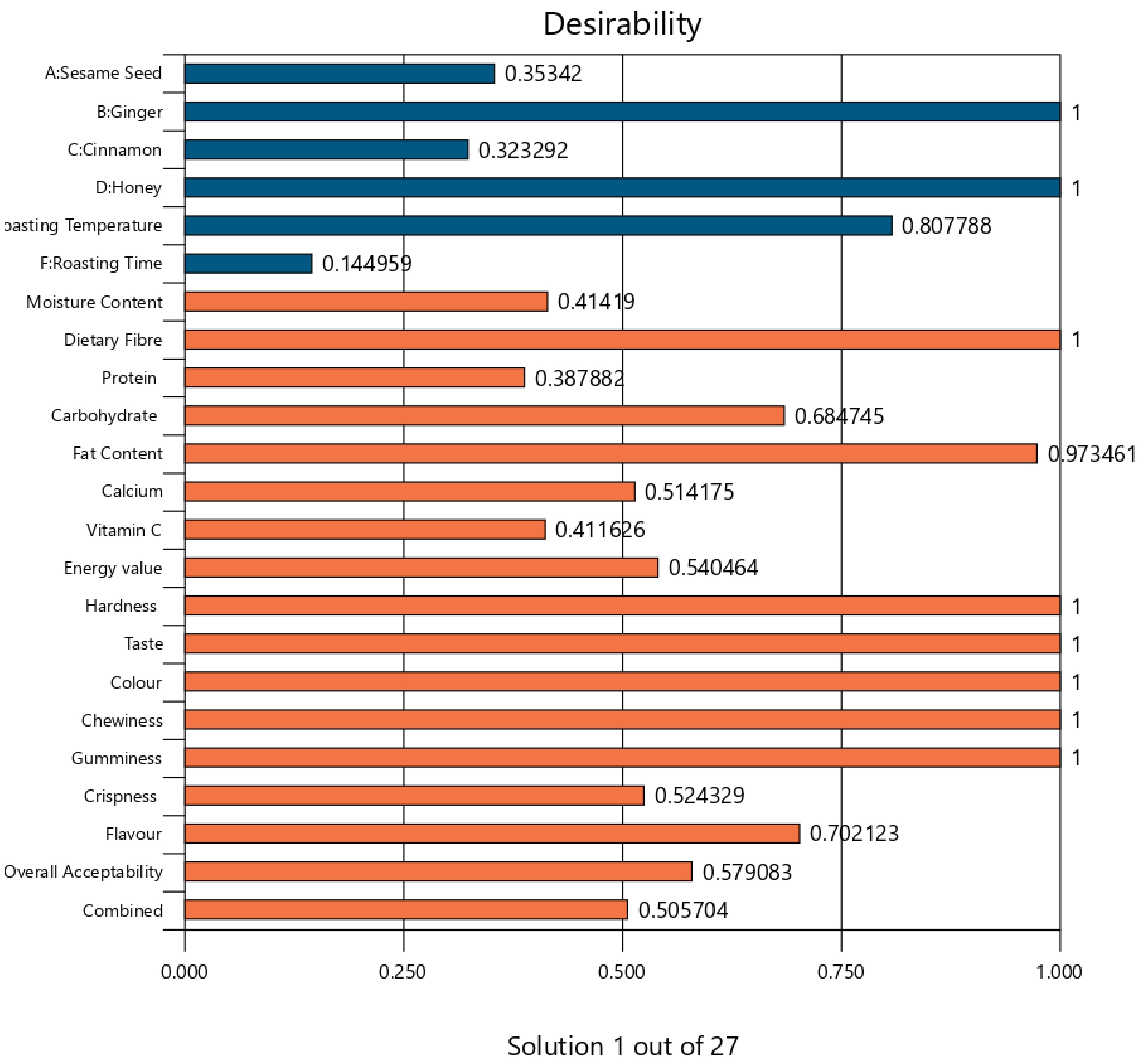

Figure 1. The numerical optimization solution desirability bar graph for the optimal value-added sesame seed candy.

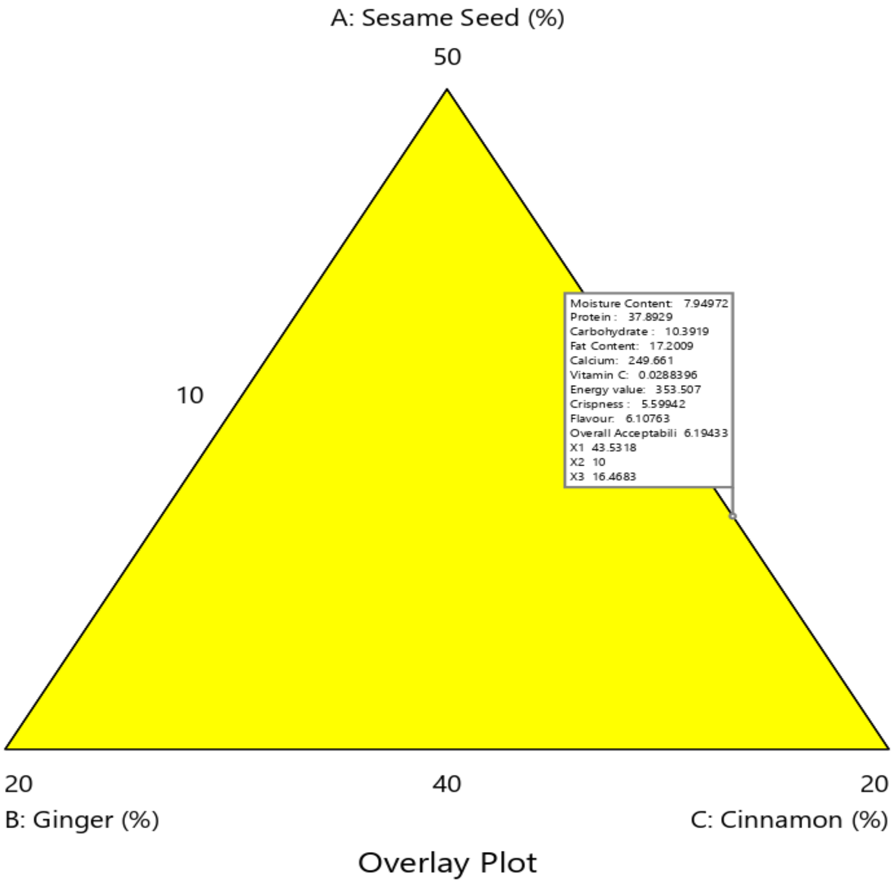

Figure 2. The graphical optimization solution overlay contour plot for the optimal value-added sesame seed candy.

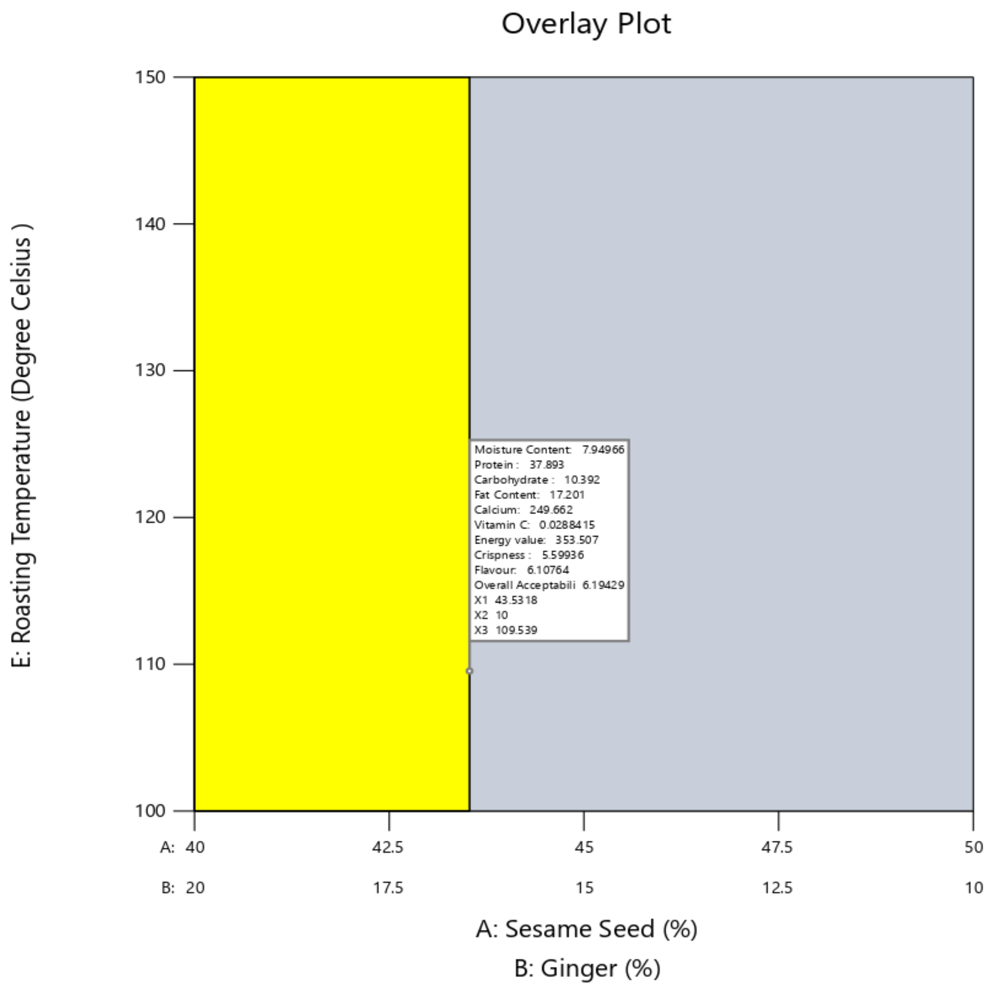

Figure 3. The graphical optimization solution overlay mix-process plot for the optimal value-added sesame seed candy

4. Conclusions

This study presents a novel procedure that optimizes products/processes with multiple responses. Optimization of value-added sesame seed candy production was accomplished by response surface methodology. The combinations of 43.5% s sesame seed, 10% ginger, 16.47% cinnamon, and 30% honey, with 110 °C roasting temperature and 27 min mixing time, gave the highest desirability index of 0.506. The optimum ranges as well as the quality properties of the optimal product indicated that the developed value-added sesame seed candy was of higher quality, when compared with the traditional sesame seed candy. The developed optimal product is nutritionally superior with higher consumer acceptability and sensory characteristics comparable to commercial traditional sesame seed candy.

Conflict of Interests

The authors declare that they have no competing interests.

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