



Bitki Bazlı Fonksiyonel Bir İçeceğin Çoklu Yanıt Modellemesi ve Kalite Optimizasyonu

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Öz

Son dönemde, sağlık açısından fayda sağlayan fonksiyonel yiyecek ve içecekler olan talep artış göstermektedir. Dünyanın pek çok yerinde bu ürünlere olan talep artmış; hastalıkların önlenmesi ve tedavisinde fonksiyonel yiyecek ve içeceklerin oynadığı kilit role dair farkındalık giderek yükselmiştir. Beslenme ve bitki biyoteknolojisi alanındaki hızla artan bilgi birikimi, gıda ve sağlığa ilişkin kavramları kökten değiştirmiştir. Bitki bazlı içecekler, açık ara en hareketli fonksiyonel içecek kategorisi olup besin öğeleri ve biyoaktif bileşenlerin vücuda alınması açısından mükemmel birer araçtır. Küresel ölçekte fonksiyonel içecekler içinde hızla büyüyen bir segmenti oluşturan bu ürünlere yönelik istek, tüketicilerin beslenme ile hastalıkların önlenmesi arasındaki ilişkiye dair bilinçlenmesiyle birlikte önemli ölçüde artmıştır. Bu çalışmada; havuç, ıspanak, Hindistan cevizi, hurma, sarımsak ve pancar kullanılarak geliştirilen toz formdaki fonksiyonel içecek, tepki yüzeyi metodolojisi ve arzu edilebilirlik fonksiyonları kullanılarak modellenmiş ve optimize edilmiştir. Çalışmada, 31 rastgeleştirilmiş deneme serisini içeren, kısıtlamalı D-optimal karışım deney tasarımı uygulanmıştır. Tasarım kısıtlamaları şu şekilde belirlenmiştir: havuç (%20–36), ıspanak (%20–36), Hindistan cevizi (%20–36), hurma (%20–36), sarımsak (%0,5–2) ve pancar (%0,5–2). Hazırlanan formülasyon örnekleri; standart prosedürler kullanılarak temel bileşen, fiziksel, fizikokimyasal, vitamin ve mineral içerikleri açısından değerlendirilmiş; ayrıca 50 tüketicinin katılımıyla 9 noktalı hedonik ölçek kullanılarak duyu analizi gerçekleştirilmiştir. Belirlenen optimizasyon hedefleri ve bireysel tepki arzu edilebilirlik indeksleri temel alınarak, her bir tepkiye karşılık gelen kontur grafiklerinin üst üste bindirilmesi sonucunda, 0,599'luk genel arzu edilebilirlik indeksine sahip optimize edilmiş bir toz içecek elde edilmiştir. Optimal toz içeceği sağlayan formülasyon; %21,70 havuç, %24,15 ıspanak, %28,32 Hindistan cevizi, %22,88 hurma, %0,96 sarımsak ve %2,00 pancar bileşiminden oluşmuştur. En uygun toz içeceğin kalite özellikleri şunlardır: %8,58 nem içeriği, %9,74 protein, %43,98 karbonhidrat, %6,56 lif, %20,17 yağ, 0,70 g/mL yığın yoğunluğu, 344,26 mL sulandırma indeksi, 14,45 °Brix toplam çözünür katı madde, 5,66 pH, %5,80 indirgen şeker, 0,21 mg/100 g B6 vitamini, 30,01 mg/100 g C vitamini, 2,31 mg/100 g demir, 237,43 mg/100 g potasyum, 40,62 mg/100 g kalsiyum, 66,76 mg/100 g sodyum, 32,08 mg/100 g magnezyum ve 6,69 genel kabul edilebilirlik değeri.

Anahtar kelimeler: Formülasyon, Modelleme, Optimizasyon, Çoklu yanıt, Arzu edilebilirlik

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Multi-response Modelling and Quality Optimization of Plant-Based Functional Beverage

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Abstract

In recent times, the demand for functional foods and beverages with health benefits has been increasing. Demand for these products has risen in many parts of the world, and there has been growing recognition of the key role that functional foods and beverages play in disease prevention and treatment. Rapidly increasing knowledge of nutrition and plant biotechnology has dramatically changed concepts of food and health. Plant-based beverages are by far the most active functional drink category; they are excellent vehicles for the delivery of nutrients and bioactive compounds. They constitute the fastest-growing segment of the functional beverage market worldwide, and as consumers have become more aware of the relationship between diet and disease prevention, demand for these products has grown significantly. In this study, a powdered functional beverage developed from carrot, spinach, coconut, date fruit, garlic and beetroot was modelled and optimized using response surface methodology and the desirability function. A constrained D-optimal mixture experimental design comprising 31 randomized experimental runs was employed. The design constraints were: carrot (20–36%), spinach (20–36%), coconut (20–36%), date fruit (20–36%), garlic (0.5–2%) and beetroot (0.5–2%). The formulated samples were evaluated for selected proximate, physical, physicochemical, vitamin and mineral properties using standard procedures, and sensory evaluation was conducted by 50 consumers using a 9-point hedonic scale. Superimposition of the contour plots corresponding to each response resulted in an optimized powdered beverage with an overall desirability index of 0.599, based on the set optimization goals and the individual response desirability indices. The formulation that produced the optimal powdered beverage consisted of 21.70% carrot, 24.15% spinach, 28.32% coconut, 22.88% date fruit, 0.96% garlic and 2.00% beetroot. The quality properties of the optimal powdered beverage were: 8.58% moisture content, 9.74% protein, 43.98% carbohydrate, 6.56% fibre, 20.17% fat, 0.70 g/mL bulk density, 344.26 mL reconstitution index, 14.45 °Brix total soluble solids, pH 5.66, 5.80% reducing sugar, 0.21 mg/100 g vitamin B6, 30.01 mg/100 g vitamin C, 2.31 mg/100 g iron, 237.43 mg/100 g potassium, 40.62 mg/100 g calcium, 66.76 mg/100 g sodium and 32.08 mg/100 g magnesium, with an overall acceptability value of 6.69.

Keywords: Formulation, Modeling, Optimization, Multi-response, Desirability

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1. Introduction

Beverages produced from plant materials such as nuts, grains, legumes, and seeds are variously referred to as plant-based beverages, non-dairy drinks, or milk substitutes. Beverages currently constitute the most active functional food category, largely because of their convenience and the possibility of meeting consumer demands for container contents, size, shape and appearance, as well as their ease of distribution and storage as refrigerated or shelf-stable products. Plant-based beverages are excellent vehicles for the delivery of nutrients and bioactive compounds, including vitamins, minerals, antioxidants, ω -3 fatty acids, plant extracts, dietary fibre, prebiotics and probiotics. They have attracted considerable attention as effective replacements for conventional dairy milk, offering options to people who follow a vegan or vegetarian diet and to those who are allergic to dairy proteins or are lactose intolerant [1-6].

In recent years, there has been a growing recognition of the key role of foods and beverages in disease prevention and treatment. Rapidly increasing knowledge of nutrition, medicine and plant biotechnology has dramatically changed concepts of food and health, and the demand for functional foods and beverages with health benefits has increased in many parts of the world. As consumers have become more aware of the relationship between diet and disease prevention, the desire for plant-based beverages has grown significantly, and a growing number of consumers now opt for plant-based milk substitutes for medical reasons or as a lifestyle choice. Recent studies show increased consumer interest in healthier foods, which has led the food industry towards the development of new products based on soy, with aspirations that go beyond the supply of basic nutrients and the satisfaction of consumers' taste. Beverages are no longer considered simply as thirst quenchers; consumers look for specific functionality in these drinks, which forms part of their lifestyle [7-21].

Many researchers report that the formulation of functional foods represents one of the most active areas of research and innovation, as reflected by the increasing number of scientific papers dealing with this topic. Formulation and blending constitute a simple and inexpensive technology for the development of new functional foods and have been used widely in food processing. Numerous plant foods, and physiologically active ingredients derived from plants, have been investigated for their role in disease prevention and health, and the application of novel processing technologies has made possible the production of a wider range of functional beverages [22-26]. A critical aspect that requires greater research focus, however, is the interaction that might occur when several ingredients are blended together, as the quality and/or functionality of the product may be affected by both the mixture proportions of the ingredients and the processing factors. This is where optimization becomes important. For systems containing multiple inputs and outputs, response surface methodology and the desirability function provide a robust modelling and optimization strategy. The objective of this work was therefore to model and optimize a plant-based functional beverage formulated from carrot, spinach, coconut, date fruit, garlic and beetroot.

Carrots contain numerous antioxidants, including beta-carotene, lutein and zeaxanthin, which can protect against oxidative stress and cellular damage caused by free radicals. The pigments found in various coloured roots provide a wide range of therapeutic benefits for human health. Antioxidants in carrots have been associated with a decreased risk of chronic illnesses, including some forms of cancer, cardiovascular diseases and neurological disorders. Their high beta-carotene content is converted to vitamin A in the body, and vitamin A plays a crucial role in maintaining good vision and in preventing age-related macular degeneration (AMD) and night blindness. Studies have suggested that carrot intake is associated with a lower risk of cardiovascular disorders, including hypertension and heart disease. The fibre and potassium contents in carrots also contribute to heart health. Carotenoids—a class of bioactive compounds that includes β - and α -carotene—are found in carrots and include provitamin A

carotenoids, which perform a vital function in antioxidant and anticancer action. Carrots exhibit anti-inflammatory qualities related to their bioactive substances, such as carotenoids and polyphenols. These compounds have been shown to reduce inflammation markers in the body and may help to ameliorate chronic inflammatory diseases [16, 21, 25, 27-28].

Spinach is a rich source of vitamins (such as vitamin A, vitamin C and vitamin K), minerals (including iron, calcium and magnesium) and antioxidants (such as lutein and zeaxanthin). It contains several phytochemicals, including flavonoids and carotenoids, which have been associated with a lower risk of some forms of cancer. It is rich in lutein and zeaxanthin, carotenoids that accumulate in the retina and protect against age-related macular degeneration. It is also rich in antioxidants that have been demonstrated to lower oxidative stress and inflammation, which are risk factors for cardiovascular disease. Spinach is well recognized for its antimicrobial, anticarcinogenic and antioxidant activity. Major micronutrients including iron, manganese, zinc and magnesium are abundant in spinach, which also contains trace amounts of vitamins E, A and C, folate, thiamine (B1), pyridoxine (B6) and riboflavin (B2). It is an excellent source of calcium, which is vital for bone health, and of vitamin K, which plays a critical role in bone metabolism. Spinach consumption has been associated with a lower risk of cardiovascular disease owing to its high content of dietary nitrates [4, 5, 18,19, 26, 27].

Coconut is a nutrient-dense fruit rich in vitamins, minerals and antioxidants. It is a good source of medium-chain triglycerides (MCTs), a form of saturated fat that is rapidly digested to yield energy. MCTs in coconut have been reported to enhance cognitive function and memory in persons with mild cognitive impairment. Coconut consumption has been associated with a reduced risk of cardiovascular disease that has been attributed to its high content of MCTs. It contains antioxidants that have been demonstrated to lower oxidative stress and inflammation, which are risk factors for cardiovascular disease. Coconut oil has also been proposed as a possible adjunct in the management of Alzheimer's disease owing to its capacity to provide an alternative energy source for brain cells [29-31].

Date fruit is a nutrient-dense fruit rich in vitamins, minerals, fibre and antioxidants. It is an excellent source of dietary fibre, potassium, magnesium and vitamin B6. Dates also contain numerous phenolic compounds, such as flavonoids and carotenoids. The fibre in dates acts as a prebiotic, promoting the growth of beneficial gut bacteria, supporting good digestion and helping to prevent constipation [24]. The antioxidants in dates protect the body from oxidative stress and inflammation, and may contribute to the prevention of chronic diseases. Date fruit has a sizable concentration of flavonoid glycosides, such as apigenin, quercetin, ferulic acid, *p*-coumaric acid and sinapic acid [27–30]. A systematic review and meta-analysis of randomized controlled trials found that date consumption significantly reduced fasting blood glucose levels and improved lipid profiles in individuals with type 2 diabetes. Most date cultivars contain three main sugars sucrose, fructose and glucose that the body can readily absorb for energy production [32-35].

Garlic has been used for centuries in various traditional medicine systems and is believed to possess numerous health benefits. Garlic contains antioxidants that help to neutralize harmful free radicals in the body. It contains many enzymes, minerals (germanium, calcium, copper, iron, potassium, magnesium, selenium and zinc), fibre, water and at least thirty-three sulfur-containing compounds. Proline, glycine, alanine, cysteine, valine, methionine, isoleucine, leucine, tryptophan, serine, glutamine, threonine, histidine, arginine, aspartic acid and phenylalanine are among the other 17 amino acids found in garlic. Antioxidants play a role in protecting cells from oxidative stress and reducing the risk of chronic diseases. Certain compounds in garlic have been found to possess anti-inflammatory properties, which contribute to its potential health benefits. Garlic is also believed to have immune-boosting properties and has been associated with a reduced risk of gastric cancer. Garlic extracts have demonstrated strong antioxidant, hypocholesterolaemic, hypolipidemic, antihypertensive, antidiabetic,

antithrombotic, anti-inflammatory, antiallergic, antiviral, antiprotozoal, anti-hyperhomocysteinaemic, antiparasitic and neuroprotective qualities. The combined biological activity of organosulfur compounds such as S-allyl-L-cysteine, diallyl disulfide, diallyl trisulfide, ajoene and allicin gives garlic its medicinal qualities [11, 20, 36-40].

Beetroot is a good source of vitamins, minerals and other nutrients; it is high in fibre, natural colourants, vitamins A, C and B, and antioxidants. Minerals such as manganese, sodium, potassium, magnesium, iron and copper are abundant in red beetroot, which also contains distinctive phytoconstituents with a number of therapeutic benefits. Beetroot is abundant in phenolic compounds, which have antioxidant properties, and betanin is the principal betacyanin present in the root. These vibrant root vegetables may offer protection against various malignancies, including colon cancer, and against heart disease [41-43].

2. Materials and Methods

2.1 Materials

The plant-based materials employed in this work were carrot, spinach, coconut, date fruit, garlic and beetroot (Figure 1). They were sourced from private farms in Gidan-Kwanu village, Minna, Niger State, Nigeria.

2.2 Methods

2.2.1 Processing of raw materials

Sorting, cleaning and washing of the plant materials were carried out to remove damaged units and to eliminate contaminants such as dirt, stones and other foreign material prior to the commencement of the formulation experiment. The carrots, beetroot and garlic were peeled, husked or otherwise trimmed to remove the outer skin, while the coconut was decorticated. The samples were then pre-treated and sanitized in a brine solution. All the materials were size-reduced and subjected to controlled oven-drying. The oven-dried samples were then pulverized individually and stored in airtight containers until required for the formulation experiments. The complete process is summarized in the flow diagram presented in Figure 2.



Figure 1. Raw materials used for the formulation: (a) carrot, (b) spinach, (c) coconut, (d) date fruit, (e) garlic, (f) beetroot

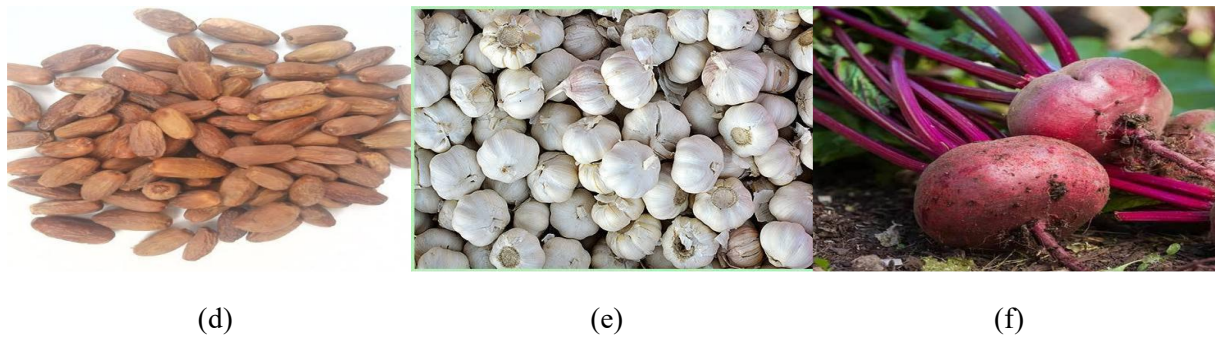


Figure 1. Raw materials used for the formulation: (a) carrot, (b) spinach, (c) coconut, (d) date fruit, (e) garlic, (f) beetroot(continue)

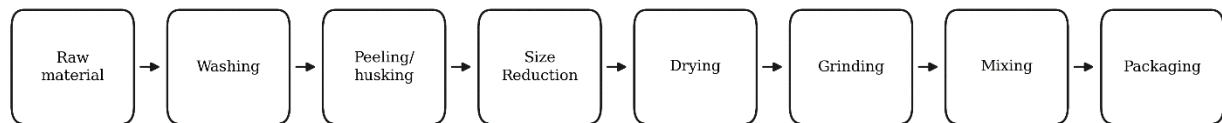


Figure 2. Flow diagram for the production of the plant-based functional powdered beverage

2.2.2 Experimental design

A six-component, constrained D-optimal mixture experimental design was employed to design the formulation experiments, yielding 31 experimental runs. The formulation design constraints were: carrot (20–36%), spinach (20–36%), coconut (20–36%), date fruit (20–36%), garlic (0.5–2%) and beetroot (0.5–2%). The design matrix is presented in Table 1. The formulation of the blends was based on this design matrix, and the formulated beverages were packaged in tea bags.

Table 1. Design matrix for the functional powdered beverage formulation experiments

Run	Carrot (%)	Spinach (%)	Coconut (%)	Date Fruit (%)	Garlic (%)	Beetroot (%)
1	36.0	22.9	20.1	20.0	0.5	0.5
2	20.0	20.0	36.0	21.5	0.5	2.0
3	36.0	20.0	20.0	20.0	2.0	2.0
4	21.0	20.4	21.2	36.0	0.5	1.0
5	31.3	20.0	20.0	27.1	1.1	0.5
6	22.6	27.7	20.0	25.6	2.0	2.0
7	20.0	21.5	36.0	20.0	2.0	0.5
8	23.5	31.0	22.1	20.9	2.0	0.5
9	20.8	20.0	20.0	36.0	1.2	2.0
10	21.5	20.0	20.0	36.0	2.0	0.5
11	20.0	20.0	29.1	29.9	0.5	0.5
12	27.1	24.5	20.0	27.4	0.5	0.5
13	20.0	21.5	36.0	20.0	2.0	0.5
14	20.8	20.0	20.0	36.0	1.2	2.0
15	23.0	20.0	36.0	20.0	0.5	0.5
16	36.0	20.0	21.5	20.0	0.5	2.0
17	20.0	25.2	24.8	28.5	0.5	1.0
18	23.8	20.0	22.9	29.7	2.0	1.5
19	20.0	28.6	27.7	22.3	0.5	0.9
20	30.7	23.5	20.0	22.3	1.5	2.0

Table 1. Design matrix for the functional powdered beverage formulation experiments (continue)

Run	Carrot (%)	Spinach (%)	Coconut (%)	Date Fruit (%)	Garlic (%)	Beetroot (%)
21	21.5	36.0	20.0	20.0	0.5	2.0
22	21.5	36.0	20.0	20.0	0.5	2.0
23	33.4	20.0	24.1	20.0	2.0	0.5
24	28.8	28.7	20.0	20.0	2.0	0.5
25	26.8	21.8	24.7	22.7	2.0	2.0
26	23.0	20.0	36.0	20.0	0.5	0.5
27	20.0	20.0	36.0	21.5	0.5	2.0
28	20.2	20.2	29.4	27.4	1.5	1.3
29	22.0	29.5	20.0	27.0	1.0	0.5
30	22.4	27.4	26.8	20.0	1.4	2.0
31	20.0	36.0	21.5	20.0	2.0	0.5

2.2.3 Determination of the response variables and sensory evaluation

Using standard methods, the formulated powdered beverages were analyzed and evaluated for moisture content, protein, carbohydrate, fibre, fat, bulk density, reconstitution index, total soluble solids, pH, reducing sugar, vitamin B6, vitamin C, iron, potassium, calcium, sodium, and magnesium [44]. Sensory evaluation was conducted on the reconstituted beverages by a panel of fifty (50) untrained consumer assessors drawn from the staff and students of the Federal University of Technology, Minna. Samples were served in coded, odour-free containers under identical lighting conditions and were presented in randomized order, with potable water provided for palate cleansing between samples. Assessors scored taste, colour, mouthfeel and appearance, and gave an overall acceptability rating, on a 9-point hedonic scale ranging from 1 (dislike extremely) to 9 (like extremely). The mean score of the fifty assessors was taken as the response value for each attribute.

3. Results and Discussion

3.1 Experimental Data

The data generated based on the D-Optimal mixture design are presented in Tables 2–5

Table 2. Proximate properties of the formulated functional powdered beverage

Run	Moisture Content (%)	Protein (%)	Carbohydrate (%)	Fibre (%)	Fat (%)
1	9	10.6	43.35	6	24
2	6.8	6.67	44.53	8	28
3	7.8	7.7	49	6.5	21
4	8.4	8.05	53.73	5	17.5
5	8	11.55	50.95	5.5	17.5
6	7.92	7.63	50.95	8.5	19.5
7	7	8.4	32.6	9	37
8	9.08	8.1	42.61	10	21
9	8.6	10.85	49.05	7	19
10	9.8	8.4	51.3	7.5	16
11	9.2	7.12	45.68	7.5	25
12	9.8	10.5	45.7	7	21
13	7	10.55	35.35	7.8	32
14	7.6	9.88	51.72	6.3	17
15	7	7.04	41.46	6.5	32

Table 2. Proximate properties of the formulated functional powdered beverage (continueu)

Run	Moisture Content (%)	Protein (%)	Carbohydrate (%)	Fibre (%)	Fat (%)
16	10	10.7	53.3	5.5	13
17	7.84	8.06	49	6.1	22
18	10.54	8.1	43.56	6.3	24.5
19	8.4	10.72	42.38	5.7	25.3
20	8	10	48.2	5.8	20
21	7.1	11.04	39.16	6.4	25
22	8.3	9.13	48.6	6.8	23
23	8	9.1	46.08	6.5	29.2
24	9.1	9.43	48.6	6.8	25.7
25	9.7	8.25	45.75	5.5	27.9
26	8	8.46	38.85	6.4	36.3
27	8.9	8.88	38.85	5.9	31.3
28	7.5	9.65	42.85	6.2	20.2
29	8.34	9.21	48.58	6	9.8
30	8.72	9.01	44.47	5.9	18.6
31	8.3	9.13	47.69	6.6	21.7

Table 3. Functional and physical properties of the formulated functional powdered beverage

Run	Bulk Density (g/ml)	Reconstitution index (ml)	Total Soluble Solids (Brix)	pH	Reducing Sugar (%)
1	0.67	246	10	6.06	4
2	0.65	258	30	6.11	11.2
3	0.63	376	10	6.02	4.01
4	0.66	300	10	6.06	4.1
5	0.68	296	30	6.05	10.18
6	0.68	438	10	6.1	4.1
7	0.71	272	20	6.17	9.21
8	0.71	382	10	6.41	4.1
9	0.67	442	10	5.97	4.1
10	0.62	304	10.5	5.98	4.8
11	0.63	448	20	6.07	8.91
12	0.69	354	10	5.99	4.1
13	0.73	418	20	6.1	8
14	0.68	292	10	5.99	4.1
15	0.69	342	10	6.14	4.1
16	0.7	284	10	5.98	4.1
17	0.65	298	10	6.14	4.1
18	0.71	320	10	6.08	4.1
19	0.74	336	10	6.19	4.1
20	0.68	245	10	6.08	4.1
21	0.71	312	10.5	6.06	4.3
22	0.68	392	14.1	6.02	6.41
23	0.7	412	12.8	6	7.05

Table 3. Functional and physical properties of the formulated functional powdered beverage (contineu)

Run	Bulk Density (g/ml)	Reconstitution index (ml)	Total Soluble Solids (Brix)	pH	Reducing Sugar (%)
24	0.66	280	9.9	6.07	6.55
25	0.65	408	15.6	6.01	7.15
26	0.71	302	20.8	6.05	6.5
27	0.68	401	12.2	6.03	3.5
28	0.68	256	9.7	6.15	1.4
29	0.69	400	13.7	6.11	1.42
30	0.71	442	17	5.09	3.56
31	0.71	416	8.2	6.1	3.53

Table 4. Vitamins and mineral contents of the formulated functional powdered beverage

Run	Vitamin B6 (mg/100g)	Vitamin C (mg/100g)	Iron (mg)	Potassium (mg)	Calcium (mg)	Sodium (mg)	Magnesium (mg)
1	0.28	27.28	1.72	230	40.4	70.12	28.11
2	0.1	29.41	2.11	227	36.32	63.6	28.72
3	0.41	30.8	1.63	233	49.63	67.2	27.11
4	0.12	26.14	1.72	204	31.11	50.72	30.18
5	0.37	28.62	0.98	228	43.62	66.11	30.72
6	0.17	29.32	1.08	234	41.11	65.24	29.63
7	0.17	25.61	1.63	228	40.63	66.11	30.72
8	0.18	24.32	2.04	247	40.62	60.78	31.22
9	0.16	26.31	1.92	239	44.11	55.11	26.72
10	0.16	22.68	0.92	246	41.06	55.72	26.04
11	0.17	24.11	1.42	243	39.16	68.11	31.24
12	0.24	26.71	2.22	243	49.22	70.11	29.24
13	0.13	26.04	2.1	228	38.72	65.27	32.11
14	0.13	26.72	2.22	225	30.84	68.32	29.22
15	0.16	27.66	2.63	229	38.32	73.16	28.63
16	0.5	32.11	1.94	234	41.11	70.14	31.72
17	0.3	28.62	2	242	43.62	74.18	27.11
18	0.33	28.98	2.14	248	38.62	72.12	28.72
19	0.24	30.11	2.28	237	47.24	70.12	28.72
20	0.24	32.63	1.92	241	45.18	68.72	33.33
21	0.31	30.11	2.16	240	43.37	65.28	28.71
22	0.21	30.27	2.19	243	39.91	65.24	28.72
23	0.32	27.24	2.22	241	45.14	70.6	34.12
24	0.28	27.29	2.26	237	45.14	70.6	34.13
25	0.26	29.97	2.3	238	45.14	70.6	34.14
26	0.22	27.34	2.33	234	38.13	65.21	28.76
27	0.19	30.2	2.37	229	38.13	65.31	28.74
28	0.2	27.67	2.4	227	45.14	70.61	34.14
29	0.21	26.14	2.44	226	38.13	64.32	28.94
30	0.22	30.47	2.47	224	45.14	60.46	30.13
31	0.19	27.35	2.51	223	41.74	69.31	29.94

Table 5. Average sensory scores of the formulated functional powdered beverage

Run	Taste	Colour	Mouth Feel	Appearance	Overall Acceptability
1	3.3	6.3	3.9	5.5	3.5
2	5.6	6.9	5.7	7.2	6.6
3	3.1	6.6	3	7.4	6.6
4	3.4	5.8	4.3	7.1	5.8
5	2.7	6.8	4	6.5	5.6
6	6	7.6	6.6	5.7	6.1
7	4.4	6.8	5.5	4.1	5.4
8	5	7.2	6.4	6.8	5.7
9	6.6	7.1	5.9	4.4	7.4
10	5.4	6.6	5.8	5.9	5.9
11	3.7	6	6.2	8.2	6.5
12	3.9	3.7	6.5	4.8	5.6
13	6.3	7.4	6.7	6.3	6.6
14	5.7	7.5	4.8	7.1	6.3
15	6.3	5.4	6.4	7.1	6.4
16	6.9	7.9	6.5	7.5	6.9
17	5.9	7.1	6.9	6.8	6.7
18	3	7	3.1	5.9	5.4
19	3.6	7.3	4.2	7.3	6
20	6.7	6.3	6.3	6.9	6.4
21	3.9	7.1	4.9	7.2	5.5
22	6.9	7.5	6.1	8	6.7
23	6.8	6.9	7	6.9	6.9
24	5.6	7.9	7	6.7	6.7
25	2.6	7.5	5.9	7.2	6.2
26	6.9	7.5	6.4	6.8	6.7
27	4.5	7.5	6	5.8	7.7
28	6.5	7.1	6.9	6.7	6.7
29	6.9	6.5	6.9	7	6.8
30	7.2	7	4.6	6.8	5.3
31	3.4	7.4	5.3	6.3	6.3

3.2 Statistical data analysis, optimization, and discussion

Experimental data were analysed and modelled using the Design-Expert software (version 13.0.0, Stat-Ease Inc., Minneapolis, USA). Scheffé canonical polynomial models (linear, quadratic and special cubic) were fitted to each response in terms of L-pseudo components, presented as equations 1–22 (Table 6). The coded equations are useful for identifying the relative impact of the ingredients proportions and for making predictions about the quality parameters for given levels of each ingredient proportion.

Table 6. Fitted scheffe polynomials/models in terms of L-Pseudo components, for the quality parameters of the formulated functional powdered beverage

Eq.	Response	Fitted Scheffé model (L-pseudo components)
(1)	Moisture content (%)	$y_{mc} = 7.48x_1 + 9.57x_2 + 5.41x_3 + 8.68x_4 + 637.15x_5 + 458.54x_6 + 9.42x_1x_2 + 13.39x_1x_3 + 6.39x_1x_4 - 706.63x_1x_5 - 467.12x_1x_6 + 7.20x_2x_3 - 3.86x_2x_4 - 702.22x_2x_5 - 524.13x_2x_6 + 7.33x_3x_4 - 673.04x_3x_5 - 466.32x_3x_6 - 664.77x_4x_5 - 493.89x_4x_6 - 1131.90x_5x_6$
(2)	Protein (%)	$y_{pc} = 10.83x_1 + 10.81x_2 + 7.69x_3 + 6.44x_4 - 536.47x_5 + 58.86x_6 + 0.5623x_1x_2 - 2.95x_1x_3 + 8.01x_1x_4 + 574.95x_1x_5 - 49.31x_1x_6 + 6.77x_2x_3 - 2.69x_2x_4 + 559.60x_2x_5 - 63.24x_2x_6 + 0.9068x_3x_4 + 610.45x_3x_5 - 57.14x_3x_6 + 604.27x_4x_5 - 13.39x_4x_6 + 249.11x_5x_6$
(3)	Carbohydrate (%)	$y_{cho} = 49.20x_1 + 44.94x_2 + 37.06x_3 + 52.02x_4 + 29.99x_5 + 62.66x_6$
(4)	Fibre (%)	$y_{fib} = 5.36x_1 + 6.86x_2 + 6.94x_3 + 6.11x_4 + 19.64x_5 + 1.82x_6$
(5)	Fat (%)	$y_{fat} = 20.11x_1 + 27.07x_2 + 36.88x_3 + 13.78x_4 + 3766.41x_5 + 620.74x_6 + 15.86x_1x_2 - 0.1403x_1x_3 + 22.20x_1x_4 - 3980.23x_1x_5 - 757.79x_1x_6 - 3.60x_2x_3 - 29.81x_2x_4 - 4173.75x_2x_5 - 685.78x_2x_6 + 2.06x_3x_4 - 4059.52x_3x_5 - 728.55x_3x_6 - 4092.18x_4x_5 - 527.61x_4x_6 - 4197.07x_5x_6$
(6)	Bulk density (g/mL)	$y_{bd} = 0.6705x_1 + 0.6991x_2 + 0.6823x_3 + 0.5824x_4 - 2.87x_5 - 12.62x_6 - 0.0298x_1x_2 + 0.1706x_1x_3 + 0.2366x_1x_4 + 3.53x_1x_5 + 14.67x_1x_6 + 0.1667x_2x_3 + 0.0631x_2x_4 + 3.94x_2x_5 + 14.46x_2x_6 - 0.0416x_3x_4 + 4.24x_3x_5 + 14.21x_3x_6 + 4.11x_4x_5 + 15.55x_4x_6 + 12.59x_5x_6$
(7)	Reconstitution index (mL)	$y_{ri} = +344.26$
(8)	Total soluble solids (°Brix)	$y_{tss} = 13.46x_1 + 10.03x_2 + 19.92x_3 + 11.74x_4 + 3.81x_5 + 5.97x_6$
(9)	pH	$y_{pH} = 5.94x_1 + 6.41x_2 + 6.38x_3 + 5.45x_4 + 122.54x_5 - 66.63x_6 - 0.1369x_1x_2 - 1.51x_1x_3 + 1.26x_1x_4 - 122.61x_1x_5 + 81.59x_1x_6 - 1.77x_2x_3 + 1.14x_2x_4 - 127.49x_2x_5 + 74.04x_2x_6 + 0.8662x_3x_4 - 127.75x_3x_5 + 73.83x_3x_6 - 121.82x_4x_5 + 87.81x_4x_6 - 98.70x_5x_6$
(10)	Reducing sugar (%)	$y_{rs} = 4.61x_1 - 0.7103x_2 + 6.66x_3 + 3.94x_4 + 1250.02x_5 + 2215.49x_6 - 0.7417x_1x_2 - 7.55x_1x_3 + 25.74x_1x_4 - 1289.55x_1x_5 - 2405.72x_1x_6 + 13.30x_2x_3 - 3.45x_2x_4 - 1318.96x_2x_5 - 2321.10x_2x_6 + 14.15x_3x_4 - 1330.56x_3x_5 - 2402.97x_3x_6 - 1371.49x_4x_5 - 2345.87x_4x_6 - 4350.79x_5x_6$
(11)	Vitamin B6 (mg/100 g)	$y_{vit\ B6} = 0.4165x_1 + 0.2103x_2 + 0.1630x_3 + 0.1597x_4 - 0.0451x_5 + 5.97x_6$
(12)	Vitamin C (mg/100 g)	$y_{vit\ C} = 29.12x_1 + 27.46x_2 + 27.08x_3 + 24.04x_4 + 14.71x_5 + 70.46x_6$

Table 6. Fitted scheffe polynomials/models in terms of L-Pseudo components, for the quality parameters of the formulated functional powdered beverage (contineu)

(13)	Iron (mg/100 g)	$y_{fe} = 0.8323x_1 + 4.61x_2 + 1.61x_3 + 1.51x_4 - 167.50x_5 - 154.78x_6 + 2.61x_1x_2 + 7.42x_1x_3 - 0.4833x_1x_4 + 180.91x_1x_5 + 176.13x_1x_6 - 2.46x_2x_3 - 2.51x_2x_4 + 159.28x_2x_5 + 138.25x_2x_6 - 0.6062x_3x_4 + 188.64x_3x_5 + 179.63x_3x_6 + 175.97x_4x_5 + 174.86x_4x_6 + 415.13x_5x_6$
(14)	Potassium (mg/100 g)	$y_{pot} = 213.77x_1 + 235.39x_2 + 224.61x_3 + 190.88x_4 + 6671.05x_5 + 9189.24x_6 + 86.75x_1x_2 + 60.33x_1x_3 + 104.65x_1x_4 - 6737.78x_1x_5 - 9457.95x_1x_6 + 97.14x_2x_3 + 59.07x_2x_4 - 7264.57x_2x_5 - 9717.35x_2x_6 + 149.54x_3x_4 - 7028.17x_3x_5 - 9840.42x_3x_6 - 6383.42x_4x_5 - 9251.60x_4x_6 - 19964.81x_5x_6$
(15)	Calcium (mg/100 g)	$y_{cal} = 44.90x_1 + 42.34x_2 + 38.77x_3 + 37.03x_4 + 62.61x_5 + 41.41x_6$
(16)	Sodium (mg/100 g)	$y_{sod} = 69.21x_1 + 76.46x_2 + 66.34x_3 + 37.14x_4 + 1354.35x_5 + 300.66x_6 + 1.71x_1x_2 + 16.23x_1x_3 + 45.03x_1x_4 + 1400.04x_1x_5 - 238.94x_1x_6 + 4.72x_2x_3 + 31.70x_2x_4 - 1537.67x_2x_5 - 401.10x_2x_6 + 71.03x_3x_4 - 1414.44x_3x_5 - 337.23x_3x_6 - 1255.93x_4x_5 - 6.08x_4x_6 - 1945.35x_5x_6$
(17)	Magnesium (mg/100 g)	$y_{mag} = 25.27x_1 + 23.85x_2 + 24.82x_3 + 26.44x_4 - 624.50x_5 - 139.30x_6 + 23.23x_1x_2 + 30.61x_1x_3 + 15.07x_1x_4 + 744.20x_1x_5 + 239.28x_1x_6 - 0.3944x_2x_3 + 1.22x_2x_4 + 781.21x_2x_5 + 220.98x_2x_6 + 22.39x_3x_4 + 798.60x_3x_5 + 208.21x_3x_6 + 680.09x_4x_5 + 216.45x_4x_6 + 286.40x_5x_6$
(18)	Taste	$y_{Taste} = 2.98x_1 - 2.02x_2 + 5.46x_3 + 3.04x_4 - 1279.97x_5 - 144.14x_6 + 9.39x_1x_2 + 11.26x_1x_3 - 12.66x_1x_4 + 1413.99x_1x_5 + 205.47x_1x_6 + 0.4262x_2x_3 + 20.62x_2x_4 + 1453.72x_2x_5 + 246.54x_2x_6 - 1.66x_3x_4 + 1397.66x_3x_5 + 158.71x_3x_6 + 1437.66x_4x_5 + 188.50x_4x_6 + 819.76x_5x_6$
(19)	Colour	$y_{colour} = 5.95x_1 + 6.72x_2 + 6.59x_3 + 5.81x_4 + 14.39x_5 + 14.98x_6$
(20)	Mouthfeel	$y_{mouth\ feel} = 2.63x_1 + 1.65x_2 + 4.82x_3 + 3.83x_4 - 150.90x_5 + 583.74x_6 + 11.53x_1x_2 + 14.18x_1x_3 + 0.4776x_1x_4 + 187.22x_1x_5 - 588.28x_1x_6 - 2.56x_2x_3 + 18.83x_2x_4 + 210.34x_2x_5 - 590.66x_2x_6 + 9.49x_3x_4 + 191.78x_3x_5 - 623.61x_3x_6 + 190.07x_4x_5 - 597.56x_4x_6 - 1068.40x_5x_6$
(21)	Appearance	$y_{Appearance} = +6.58$
(22)	Overall acceptability	$y_{Overall\ acceptability} = 3.39x_1 + 5.59x_2 + 6.54x_3 + 5.10x_4 - 161.85x_5 + 220.45x_6 - 0.5575x_1x_2 + 3.70x_1x_3 + 1.42x_1x_4 + 220.77x_1x_5 - 193.37x_1x_6 - 3.08x_2x_3 + 6.70x_2x_4 + 192.16x_2x_5 - 225.88x_2x_6 + 3.31x_3x_4 + 178.17x_3x_5 - 226.74x_3x_6 + 188.58x_4x_5 - 201.70x_4x_6 - 430.57x_5x_6$

In the Scheffé's polynomials, the response depends on the component proportions ($x_i \geq 0$ with $\sum x_i = 1$). The regression coefficients directly represent the expected responses to pure individual components as well as synergistic or antagonistic blending effects between components. Linear coefficients represent the expected response/output of the pure single component i (when $x_i = 1$ and all other $x_j = 0$). Binary

quadratic coefficients measure the non-linear blending (synergistic or antagonistic) deviation above or below the linear edge between two components i and j. Ternary cubic coefficients capture additional joint three-way interactive blending effects specific to mixtures involving components i, j, and k.. A synergistic effect means components boost each other to yield a higher-than-expected response (i.e. positive deviation - represented by positive main or interaction coefficients terms) while an antagonistic effect means they counteract each other to yield a lower-than-expected response (i.e. negative deviation - represented by negative main or interaction coefficients terms). A synergistic effect is visualized as a response surface edge or contour that curves upward above the linear plane. On the other hand, an antagonistic effect is visualized as a response surface that sags downward below the linear plane. From the Sheffe's models: garlic and beetroot had antagonistic effect (with -536.47 regression coefficient) on the protein content of the formulated functional powdered beverage; the ingredients had no interactive influences on the carbohydrate, fibre, total soluble solid, vitamin B6, vitamin C, and colour of the formulated functional powdered beverage; spinach had antagonistic effect (with -0.7103 regression coefficient) on the reducing sugar of the formulated functional powdered beverage; most of the ingredients interacted to antagonistically influence the moisture content, fat content, pH, reducing sugar, potassium, and sodium in the formulated functional powdered beverage. The negative interaction coefficients terms explain these; garlic had antagonistic effect (with -2.87 and -12.62 regression coefficients) on the bulk density of the formulated functional powdered beverage; the mean values of the reconstitution index and appearance data, with mean models, are the best representations of these two properties and the overall acceptability is negatively influenced by spinach, with -161.85 regression coefficient. Multi-response numerical and graphical optimization approaches exploiting the desirability function technique were used to generate the optimal formulation with the anticipated responses. Desired limits of the response variables, optimization goals and their objective functions were established, optimization constraints were clearly defined, and each response was transformed into an individual desirability index d_i in the interval 0–1 and the individual indices are combined into an overall desirability D as their weighted geometric mean [46]. The summary of the optimization constraints employed for the formulated powdered beverage were presented in Table 7.

Table 7. Optimization constraints for the formulated functional powdered beverage

Name	Goal	Lower Limit	Upper Limit	Lower Weight	Upper Weight	Importance
Carrot	target = 36	20	36	1	10	3
Spinach	target = 36	20	36	1	10	3
Coconut	target = 36	20	36	1	10	5
Date Fruit	target = 36	20	36	1	10	3
Garlic	target = 0.5	0.5	2	1	1	5
Beetroot	maximize	0.5	2	1	1	5
Moisture Content	target = 6.8	6.8	10.54	0.1	1	5
Protein	target = 11	6.67	11.55	0.1	10	5
Carbohydrate	target = 32.6	32.6	53.73	0.1	1	4
Fibre	target = 5	5	10	1	1	5
Fat	target = 9.8	9.8	37	1	1	5
Bulk Density	target = 0.62	0.62	0.74	0.1	1	3
Reconstitution index	target = 448	245	448	0.1	10	5
Total Soluble Solids	target = 30	8.2	30	0.1	10	5
pH	target = 5.09	5.09	6.41	0.1	1	5
Reducing Sugar	in range	1.4	11.2	1	1	3
Vitamin B6	target = 0.5	0.1	0.5	0.1	10	5
Vitamin C	target = 32.63	22.68	32.63	0.1	10	5
Iron	in range	0.92	2.63	1	1	3
Potassium	in range	204	248	1	1	3
Calcium	in range	30.84	49.63	1	1	3
Sodium	in range	50.72	74.18	1	1	3

Table 7. Optimization constraints for the formulated functional powdered beverage (contineu)

Name	Goal	Lower Limit	Upper Limit	Lower Weight	Upper Weight	Importance
Magnesium	in range	26.04	34.14	1	1	3
Taste	in range	2.6	7.2	1	1	3
Colour	in range	3.7	7.9	1	1	3
Mouth Feel	in range	3	7	1	1	3
Appearance	in range	4.1	8.2	1	1	3
Overall Acceptability	maximize	3.5	7.7	1	1	3

Based on the optimization constraints (Table 7), ninety-five optimization solutions were found, with the optimal solution annotated as “selected”. The best/optimal formulation conditions and quality properties for the optimal functional powdered beverage are summarized in Table 8. The optimal formulation conditions are the best that meet the specified optimization criteria. The factor settings (i.e. ingredients proportions values) are those that result in the highest desirability scores and indicate the region of the design space with the best acceptable outcome. Thus, ninety-five local optima were identified in this work, solution 1 being the best.

Table 8. Optimal formulation conditions and quality properties for the functional powdered beverage

Carrot	Spinach	Coconut	Date Fruit	Garlic	Beetroot					D_{index}
21.697	24.149	28.317	22.878	0.960	2.000					0.599
y_{mc}	y_{prot}	y_{cho}	y_{fib}	y_{fat}	y_{bd}	y_{ri}	y_{tss}			
8.583	9.740	43.982	6.562	20.172	0.700	344.258	14.453	0.599	0.599	
y_{pH}	y_{rs}	$y_{vit\ B6}$	$y_{vit\ C}$	y_{fe}	y_{pot}	y_{cal}	y_{sod}	y_{mag}		
5.659	5.803	0.211	30.011	2.312	237.425	40.620	66.759	32.077	0.599	
Taste	Colour	Mouth Feel	Appearance	Overall Acceptability						
7.200	7.292	6.691	6.577	6.690						0.599

y_{mc} = Moisture Content (%), y_{prot} = Protein (%), y_{cho} = Carbohydrate (%), y_{fib} = Fiber (%),
 y_{fat} = Fat (%), y_{bd} = Bulk Density (g/cm^3), y_{ri} = Reconstitution index (ml), y_{pH} = pH,
 y_{tss} = Total Soluble Solid (%), D_{index} = Overall Desirability, y_{rs} = Reducing Sugar (%),
 $y_{vit\ B6}$ = Vitamin B6 (mg), $y_{vit\ C}$ = Vitamin C (mg), y_{fe} = Iron (mg), y_{pot} = Potassium (mg),
 y_{cal} = Calcium (mg), y_{sod} = Sodium (mg), y_{mag} = Magnesium (mg), D_{index} = Overall Desirability

Figures 3–5 show the numerical optimization solution desirability bar graph, contour plot, and 3-D surface plot for the optimal formulated functional powdered beverage.

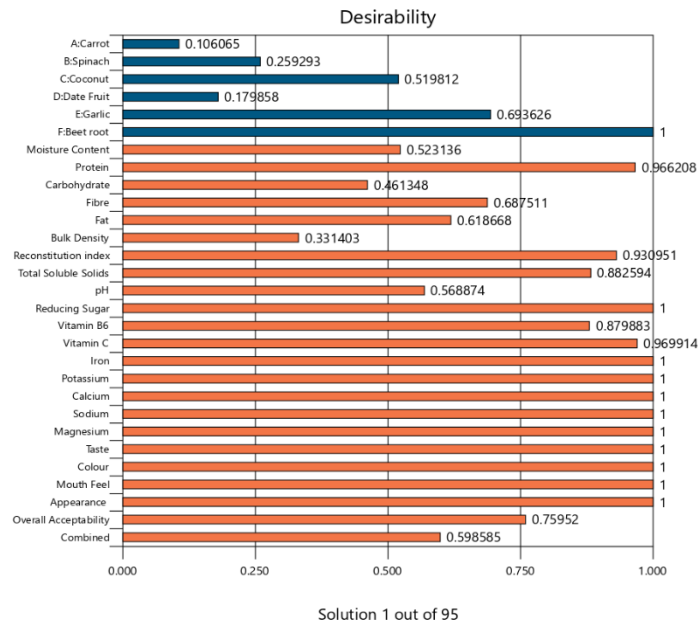


Figure 3. The desirability bar graph for the optimal formulated functional powdered beverage

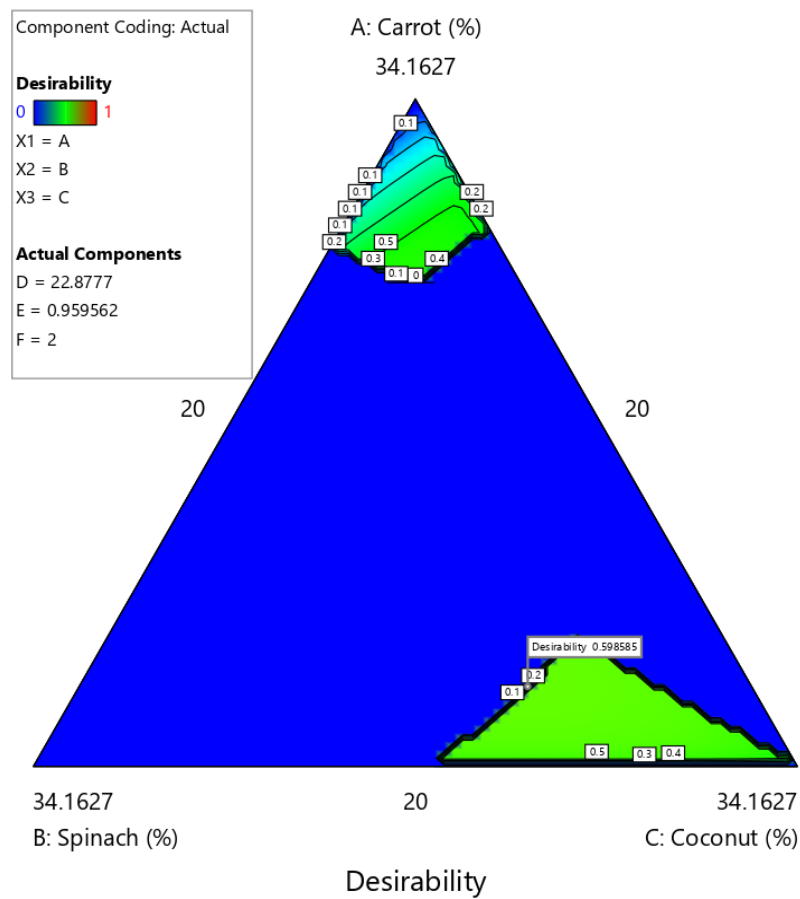


Figure 4. The desirability contour plot for the optimal formulated functional powdered beverage

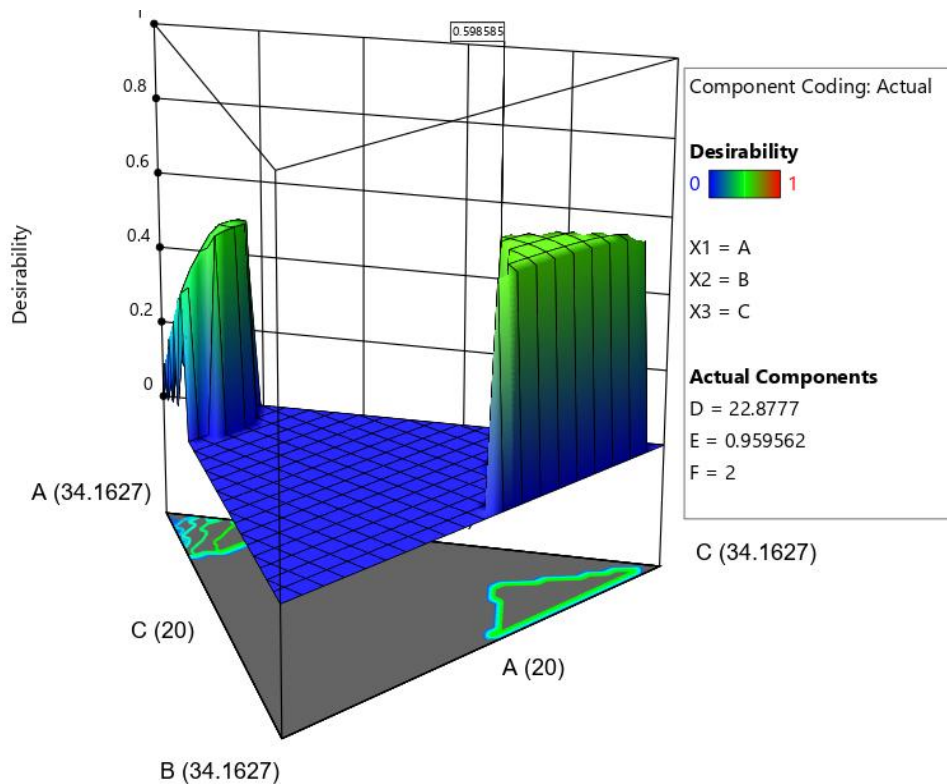


Figure 5. The desirability 3-D surface plot for the optimal formulated functional powdered beverage

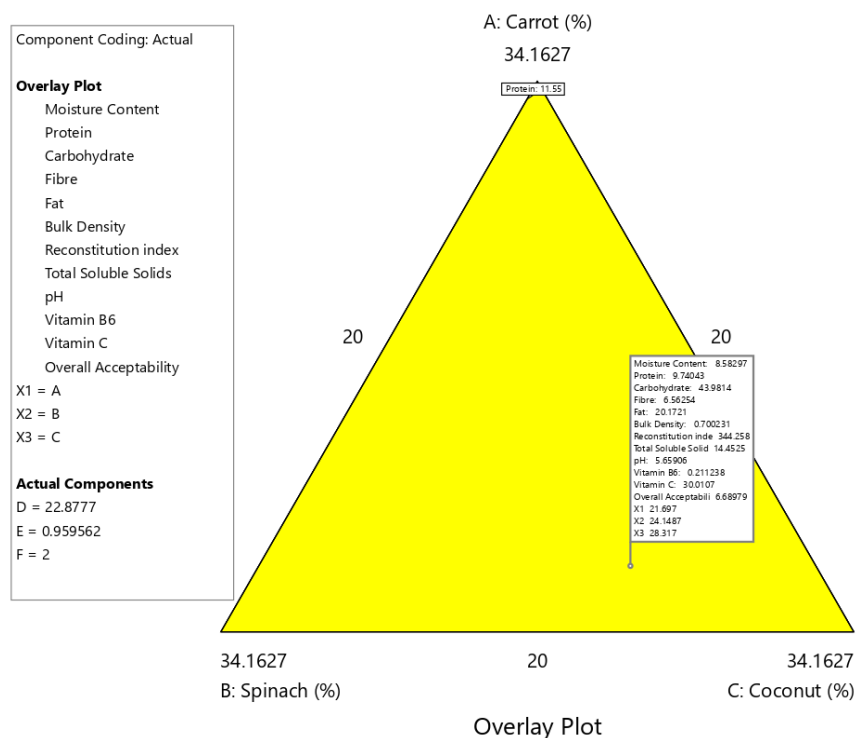


Figure 6. The graphical overlay contour plot for the optimal formulated functional powdered beverage.

The graphical optimization solution overlay contour plot, which summarizes the optimal ingredient proportions and the quality properties of the optimal formulated functional powdered beverage, is presented in Figure 6. The contours were 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. For

criteria that were specified as intervals, a blend of the acceptable and unacceptable colours was used to show where the interval limits are unacceptable.

In a ready-to-use therapeutic beverages formulation from graded ratios of rice, soybean, groundnut, carrot and date palm; the moisture content of the products ranged from 9.26 - 11.11%, crude fibre 2.39 - 2.79%, and ash 0.99 - 1.07%. The proportions of energy from the macronutrients were protein 6.85 - 9.75%, fat 6.81 - 26.49%, and carbohydrate 50.22 - 71.01%. While the vitamins A (1.14 -1.33mg), and E (20.20 – 20.27mg) and sodium (5.55 – 6.02mg) were within the recommended levels for RUTF, iron (0.68 – 0.85mg), potassium (16.22 – 24.24mg), copper (0.00 – 0.01mg), magnesium (4.27 – 5.22mg) and zinc (0.01 – 0.06mg) were slightly low. The RSG-RUTF-3 had the highest general acceptability score (7.17 ± 0.25) [45]. In another study, screening of 17 different commercial plant-based milk substitutes based on different cereals, nuts and legumes was performed, including the evaluation of physicochemical and glycaemic properties. This study demonstrated that nutritional and physicochemical properties of plant-based milk substitutes are strongly dependent on the plant source, processing and fortification. Most products showed low nutritional qualities. Therefore, consumer awareness is important when plant-based milk substitutes are used as an alternative to cow's milk in the diet [46].

4. Conclusion

This study presents a procedure for formulating and optimizing a functional powdered beverage from carrot, spinach, coconut, date fruit, garlic and beetroot against multiple quality responses. Optimization of functional powdered beverage production was accomplished by response surface methodology via the desirability function. The formulation that produced the functional powdered beverage of the highest overall desirability (0.599) was 21.70% carrot, 24.15% spinach, 28.32% coconut, 22.88% date fruit, 0.96% garlic and 2.00% beetroot. The quality properties of the optimal formulated powdered beverage were: 8.58% moisture content, 9.74% protein, 43.98% carbohydrate, 6.56% fibre, 20.17% fat, 0.70 g/mL bulk density, 344.26 mL reconstitution index, 14.45 °Brix total soluble solids, pH 5.66, 5.80% reducing sugar, 0.21 mg/100 g vitamin B6, 30.01 mg/100 g vitamin C, 2.31 mg/100 g iron, 237.43 mg/100 g potassium, 40.62 mg/100 g calcium, 66.76 mg/100 g sodium and 32.08 mg/100 g magnesium, with an overall acceptability value of 6.69.

5. Ethics Committee Approval and Conflict of Interest

Ethics committee approval was not required for this study. The author declares no competing interests. The author alone is responsible for the content and writing of the manuscript.

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7. Author Contribution Statement

In this study, the sole author was responsible for the conception of the idea; the methodology, the design of the experimental program, the analysis/interpretation of results, the writing up of the article and reviewing of the manuscript in terms of quality and content.

8. Ethical Statement Regarding the Use of Artificial Intelligence

No artificial intelligence-based tool or application was used during the preparation of this paper. The entire content of the study was produced by the sole author in accordance with scientific research methods and academic ethical principles.

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