Modeling and Optimization of Physicochemical, Antioxidant, and Sensory Properties of Banana-Cucumber-Turmeric Smoothie using Extreme Vertices Mixture Design

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Abstract

Smoothie was formulated from banana, cucumber, and turmeric with an extreme vertices mixture design, and its physicochemical, antioxidant, and sensory properties were determined using standard methods. The properties were subjected to modelling followed by validation of the models by using relevant indices: determination (R^2), average absolute deviation (AAD), bias factor (Bf), and accuracy factor (Af), and then optimized. The coefficients of determination were between 0.62 and 0.87, average absolute deviation values were near zero, and bias and accuracy factors were almost 1. While banana and cucumber increased total soluble solids and titratable acidity, turmeric increased the pH of the smoothie. Only turmeric had an increasing effect on the antioxidant properties of the smoothie. Meanwhile, all the components of the smoothie enhanced the sensory properties. The proportion of banana, cucumber, and turmeric in the optimized formulation was 0.62, 0.30, and 0.08, respectively. The models showed the capability of adequately predicting the properties of the smoothie, as demonstrated by the values of indices for validation. The smoothie could be a functional beverage with enhanced properties, especially antioxidant properties. Further research is needed to ensure the shelf stability of the formulated smoothie for commercialization, wide distribution, and marketing.

Keywords:
Banana-cucumber-turmeric smoothie, Modelling, Optimization, Properties

Introduction

Fruits and vegetables are a good source of essential nutrients such as vitamins and minerals, and they play significant roles in ensuring balanced human diets. They are utilized as food and refreshment, and can also be used as medicine due to the valuable bioactive phytochemicals they possess (Asad, 2020). Fruits and vegetables are easily grown globally, especially in sub-Saharan Africa, where malnutrition and avoidable illnesses exist. They are harnessed in tackling these challenges via regular consumption by the populace (Adeyeye et al., 2023).

Banana (*Musa* spp.) is a tropical fruit rich in resistant starch, dietary fibre, vitamins, minerals, and diverse bioactive phytochemicals (Sidhu & Zafar, 2020). Meanwhile, the fruit of the cucumber (*Cucumis sativus*) is consumed globally for numerous benefits such as hydration, provision of nutrients, and medicine (Sharma et al., 2022). Turmeric (*Curcuma longa*) is a vegetable commonly used mainly as a spice and colorant in food. It can also be utilized because of its impressive antioxidant and medicinal properties and rich phytochemicals (Eissa et al., 2024).

In Nigeria, bananas, cucumbers, and turmeric, among other fruits and vegetables, are easily grown due to the prevailing conducive weather conditions. They can be sustainably processed into such products as smoothies. This will ensure the expansion of the utilization of these fruits and vegetables and the creation of a complementary smoothie product that is nutritious and possesses medicinal value (Nowicka et al., 2017). Smoothie is a semi-liquid beverage blending fruits and vegetables (Kidoń &

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Uwineza, 2022). Its market grows steadily in the developing world, and it has been projected that a whopping 2.9 billion US dollars could be generated as revenue from fruit juice and smoothies put together (Statista, 2024).

Mixture design is a statistical tool for optimizing products by studying the components of a mixture. It is applied in food formulations, including smoothies (Sharma et al., 2025).

While some researchers have been able to produce and characterize smoothies from different combinations of fruits and vegetables (Popescu et al., 2018; Alake et al., 2022; Nieva et al., 2022), specific research efforts on smoothies from banana, cucumber, and turmeric are very rare. Furthermore, modelling and optimizing smoothies' properties, such as the one from banana, cucumber, and turmeric, would allow for customizing consumers' requirements while ensuring quality and formulation of optimized properties. Therefore, this present study was geared towards producing smoothies from banana, cucumber, and turmeric as a functional beverage, as well as modelling and optimizing the key properties of the smoothies using an extreme vertices mixture design.

Materials and Methods

Materials

Banana (*Musa sapientum*), cucumber (*Cucumis sativus*), and turmeric (*Curcuma longa*) were sourced from *Shasha* market, Osogbo, Osun State, Nigeria.

Chemical reagents

All the reagents used were of analytical grade. Methanol 2, 2-diphenyl-1-picrylhydrazyl hydrate (DPPH), and 2,2'-azino-bis (3-ethylbenzothiazoline-6-sulfonic acid (ABTS) powders were purchased from Sigma-Aldrich (St. Louis, USA). While other reagents used were sourced from Loba Chemie Pvt. Ltd. (Colaba, India).

Production of smoothie samples

Banana-cucumber-turmeric smoothie (BCTS) samples were produced as shown in the flow chart (Figure 1). Ripe banana, fresh cucumber, and turmeric were washed with potable water, trimmed, peeled, and cut into pieces using a stainless steel knife. The fruits and vegetables were weighed and formulated by using an extreme vertices mixture design as shown in Table 1, to obtain eighteen (18) replicated experimental runs for validity and reliability (Akinwande et al., 2024) with banana, cucumber, and turmeric having the design spaces, 0.40 - 0.75, 0.20 - 0.50, 0.05 - 0.10, respectively.

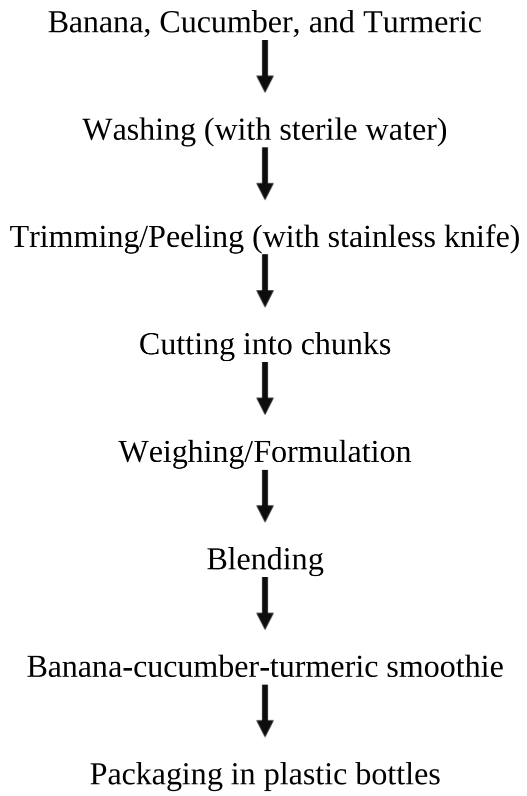

Figure 1: Flow chart of banana-cucumber-turmeric smoothie (BCTS) production

Table 1: The formulation and experimental runs for banana-cucumber-turmeric smoothie

Treatment	Banana(x_1)	Cucumber (x_2)	Turmeric (x_3)
1	0.40	0.50	0.10
2	0.75	0.20	0.05
3	0.66	0.28	0.06
4	0.58	0.35	0.08
5	0.64	0.28	0.09
6	0.45	0.50	0.05
7	0.51	0.43	0.06
8	0.64	0.28	0.09
9	0.66	0.28	0.06
10	0.49	0.43	0.09
11	0.40	0.50	0.10
12	0.45	0.50	0.05
13	0.49	0.43	0.09
14	0.70	0.20	0.10
15	0.70	0.20	0.10
16	0.51	0.43	0.06
17	0.58	0.35	0.08
18	0.75	0.20	0.05

The summation of the proportions (∑xi) of banana (x_1), cucumber (x_2), and turmeric (x_3) gave unity as shown in Equation (1).

$$\sum xi = x_1 + x_2 + x_3 \quad (1)$$

The mixture was blended to produce a banana-cucumber-turmeric smoothie (BCTS) sample. The sample was then packaged in plastic bottles and frozen (-4 °C) till they were needed for analyses.

Determination of physicochemical properties

The total soluble solids (TSS), pH, and total titratable acidity (TTA) were determined as described by AOAC (2023). A hand-held refractometer and a pH meter were used to measure TSS and pH, respectively. For TTA, about 10 ml of sample was put in a flask, and then 10 ml of distilled water was added for dilution. One or two drops of phenolphthalein indicator were mixed with the mixture. This was followed by titration with 0.1 N sodium hydroxide (NaOH) from a burette to the endpoint. The TTA was determined using the volume of the base used (Equation (2)).

$$\text{TTA (g/100g)} = \frac{\text{N x v x eq. W1}}{\text{W2 x 10}} \quad (2)$$

N is NaOH's normality, V is NaOH's volume (mL, eq. W_1 is the weight equivalent (malic acid), and W_2 is the weight of the smoothie sample.

Determination of antioxidant properties

The ability of the formulated samples to scavenge for free radicals was assessed with the stable radical of 2, 2-diphenyl-1-picrylhydrazyl hydrate (DPPH) and also 2,2'-azino-bis (3-ethylbenzothiazoline-6-sulfonic acid (ABTS) (Girgih et al.2011; Jan et al. 2013). For DPPH, sample concentrations were adjusted to obtain 1mg/1ml methanol, followed by centrifugation, and the supernatant (1 mL) obtained was thoroughly mixed with 0.3 mM DPPH in methanol (1 mL), followed by vortexing for 1 min. The mix was subjected to incubation for 30 min in a dark enclosure. The colour change (violet to yellow) was determined by using a spectrophotometer at an absorbance of 517 nm against 1 mL DPPH solution (control) with methanol (1 mL) used as the blank. Ability to scavenge for free radicals (DPPH (%)) was calculated (Equation (3)).

$$\text{DPPH (\%)} = \frac{\text{A control} - \text{A smoothie sample}}{\text{A control}}\, x\, 100 \quad (3)$$

A is Absorbance taken at 517 nm

The ability of BCTS to scavenge for ABTS radical was determined by preparing 2,2'-zino-bis (3-ethylbenzothiazoline-6-sulfonic acid) radical ($ABTS^{\cdot +}$). About seven mM ABTS aqueous solution was mixed with a solution of 2.45 mM potassium persulfate, followed by storage in a dark enclosure for about 12 h at about 26 °C. The radical solution was subjected to dilution to give an absorbance value close to 0.75 ± 0.025 at 734 nm in ethanol. Thereafter, 1 ml aliquot of the extracts was mixed with $ABTS^+$ solution (1 ml) after 6 min incubation, and then absorbance at 734 nm against ethanol (the blank) was measured. The ability to scavenge for radical (ABTS (%) was calculated (Equation (4).

$$\text{ABTS (\%)} = \frac{\text{A control} - \text{A smoothie sample}}{\text{A control}}\, x\, 100 \quad (4)$$

A is Absorbance taken at 734 nm

Sensory evaluation

The sensorial properties of BCTS samples were assessed based on the method of Oyedokun et al. (2022). Fifty panelists familiar with smoothies were used to determine the properties - colour, taste, and overall acceptability. The properties were rated on a hedonic scale ranging from 1 to 7, with 1, 2, 3, 4, 5, 6, and 7 representing dislike immensely, dislike moderately, dislike slightly, neither like nor dislike, like slightly, like moderately, and like significantly, respectively.

Analysis of data

Statistical regression analysis was run on the experimental data generated (Minitab Software, Coventry, UK), and the generated statistical models were in the form (Equation (5) as described by Oladeji et al. (2024):

$$Y = \alpha_1 x_1 + \alpha_2 x_2 + \alpha_3 x_3 + \alpha_{12} x_1 x_2 + \alpha_{13} x_1 x_3 + \alpha_{123} x_1 x_2 x_3 + \ldots \quad (5)$$

Where Y is a property; α_1, α_2, α_3, α_{12}, α_{13}, α_{123} et cetera are regression coefficients; x_1, x_2, and x_3 are linear factors, while x_1x_2, x_1x_3, and $x_1x_2x_3$ etc. are interaction factors.

Indices for validating generated statistical models

In addition to the coefficient of determination (R^2), other indices used for validating the generated statistical models were average absolute deviation (AAD), bias factor (Bf), and accuracy factor (Af) (Akinwande et al., 2024; Oladeji et al., 2024) as shown in the Equations (6-8) below:

$$AAD = \frac{[\sum_{I=1}^{N} (\frac{|yi,exp. - yi,pred.|}{Yi,exp.})]}{N} \quad (6)$$

$$Bf = 10^{\frac{1}{N}\sum_{I=1}^{N} Log(\frac{Yi,pred.}{Yi,exp.})} \quad (7)$$

$$Af = 10^{\frac{1}{N}\sum_{i=1}^{N}|\log(\frac{Yi,pred.}{Yi,exp.})|} \quad (8)$$

AAD is average absolute deviation, Bf is bias factor, and Af is accuracy factor.

Optimization of the properties of the smoothie

The optimization of the properties of the smoothie was performed as described by Oladeji et al. (2024) using the response optimizer (Minitab Statistical Software, Minitab Ltd., Coventry, UK). All the properties were maximized except TTA, which was minimized.

Results and Discussions

Physicochemical properties of banana-cucumber-turmeric smoothie

The models representing total soluble solids (TSS) (y_1), pH (y_2), and total titratable acidity (TTA) (y_3) of banana-cucumber-turmeric smoothie (BCTS) are shown in Equations (9) - (11), respectively.

$$y_1 = 17.86x_1 + 3.46x_2 - 0.14x_3 \quad (9)$$

$$y_2 = 4.33x_1 + 5.36x_2 + 5.73x_3 \quad (10)$$

$$y_3 = 4.87x_1 + 14.18x_2 - 151.60x_3 - 43.30x_1x_2 + 108.50x_1x_3 + 533.00x_1x_2x_3 \quad (11)$$

The indices' values for the models' validation, as derived from both experimental and predicted data of the properties (Table 2), are shown (Table 3).

The values for the coefficient of regression (R^2) ranged from 0.62 to 0.83, and the ones for average absolute deviation (AAD) were between 0.02 and 0.26. Meanwhile, bias factors (Bf) and accuracy factors (Af) ranged from 1.00 to 1.11 and 1.02 to 1.22, respectively. The statistical indices' values reflected the models' capability to predict the physicochemical properties.

The linear factors, x_1 and x_2, had a significant ($p < 0.05$) increasing effect on TSS, with banana having a far greater positive impact than cucumber (Figure 2). TSS positively correlates with a beverage's sugar content and is therefore usually linked to the sweetness of foods and drinks (Andrade et al., 2021). The increase in TSS with an increase in banana in BCTS could be due to relatively higher sugar content in banana than in cucumber, as it has been reported that ripe banana has more sugars than the unripe one (Watharkar et al., 2020). This indicates that bananas could play a pivotal role in enhancing the sweet taste and other organoleptic properties of BCTS. However, the linear factor, x_3, had a significant ($p < 0.05$) decreasing effect on TSS (Figure 2), suggesting that turmeric may not play a sweetening function in the smoothie. The decrease in TSS with an increase in turmeric in the present study is similar to decreases in soluble solids reported for juices and jams formulated with turmeric (Ogori et al., 2021; Adeoti et al., 2021; Sun et al., 2023).

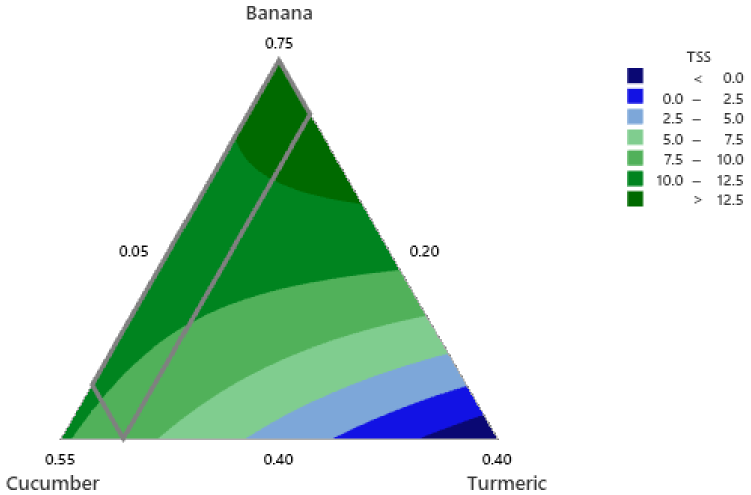

Figure 2: Mixture contour plot for total soluble solids (TSS) of banana-cucumber-turmeric smoothie

For pH, all the linear factors had a significant ($p < 0.05$) increasing effect on the property, with turmeric having the most significant impact (Figure 3). This could be due to turmeric's high pH values (6.10 – 6.80), as Emelike (2020) reported for turmeric powders subjected to different processing methods. Several researchers reported an increasing effect of turmeric on the pH in drinks containing turmeric as one of the ingredients. For instance, an increase in the pH values from 3.77 to 3.90 as the percentage of turmeric increased in pineapple juice fortified with turmeric had been reported (Sun et al., 2023). An increase in pH from 2.4 to 2.5 in the zobo drink with an increase in the percentage of turmeric was reported by Idowu-Adebayo et al. (2021). Since an increase in pH indicates a reduction in a drink's acidity, it could be an ideal drink for consumers

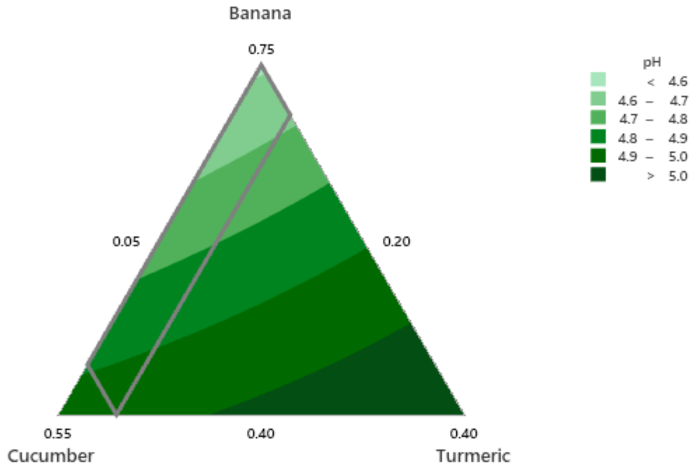

Figure 3: Mixture contour plot for the pH of the banana-cucumber-turmeric smoothie

Table 2: The physicochemical properties of banana-cucumber-turmeric smoothie

Treatment	Banana (x_1)	Cucumber (x_2)	Turmeric(x_3)	TSS (°brix)		pH		TTA (g/100g)	
				Exp.	Pred.	Exp.	Pred.	Exp.	Pre.
1	0.40	0.50	0.10	8.40	8.86	4.90	4.98	0.22	0.22
2	0.75	0.20	0.05	13.40	14.08	4.60	4.61	0.45	0.48
3	0.66	0.28	0.06	13.70	12.78	4.60	4.70	0.38	0.32
4	0.58	0.35	0.08	10.80	11.47	4.80	4.80	0.29	0.40
5	0.64	0.28	0.09	12.50	12.33	4.70	4.74	0.47	0.38
6	0.45	0.50	0.05	11.70	9.76	4.80	4.92	0.40	0.40
7	0.51	0.43	0.06	9.20	10.62	4.90	4.86	0.34	0.35
8	0.64	0.28	0.09	12.30	12.33	4.70	4.74	0.47	0.38
9	0.66	0.28	0.06	13.10	12.78	4.50	4.89	0.38	0.32
10	0.49	0.43	0.09	9.90	10.17	5.10	4.99	0.43	0.46
11	0.40	0.50	0.10	8.70	8.86	4.90	4.99	0.22	0.22
12	0.45	0.50	0.05	9.90	9.76	5.00	4.92	0.40	0.40
13	0.49	0.43	0.09	10.40	10.17	4.90	4.89	0.43	0.46
14	0.70	0.20	0.10	13.00	13.18	4.70	4.68	0.03	0.08
15	0.70	0.20	0.10	14.50	13.18	4.70	4.68	0.03	0.08
16	0.51	0.43	0.06	10.30	10.62	4.90	4.86	0.34	0.35
17	0.58	0.35	0.08	11.20	11.47	4.90	4.80	0.29	0.40
18	0.75	0.20	0.05	13.50	14.08	4.70	4.61	0.45	0.48

TSS and TTA represent total soluble solids and total titratable acidity, respectively.

Table 3: Coefficient of regression for physicochemical properties of banana-cucumber-turmeric smoothie

Coefficient	Total soluble solids	pH	Total titratable acidity
α_1	17.86*	4.33*	4.87*
α_2	3.46*	5.36*	14.18*
α_3	-0.14*	5.73*	-151.60*
α_{12}	-	-	-43.30*
α_{13}	-	-	108.50*
α_{123}	-	-	533.00*
R^2	0.83	0.62	0.82
AAD	0.05	0.02	0.26
Bf	1.00	1.00	1.11
Af	1.05	1.02	1.22

*Shows significance at $p < 0.05$. α_1, α_2, and α_3 are linear regression coefficients of banana, cucumber, and turmeric, respectively. α_{12}, α_{13}, α_{123} are interaction regression coefficients of banana and cucumber; banana and turmeric; banana, cucumber and turmeric; respectively. R^2 is the coefficient of determination; AAD is the average absolute deviation; and Bf and Af are the bias and accuracy factors, respectively.

In the case of TTA, linear and interaction factors were significant ($p < 0.05$) with banana and cucumber having an increasing effect, and turmeric having a decreasing impact, on the TTA of BCTS (Figure 4). This could stem from low acidity (0.31 – 1.61%) of turmeric as reported by Emelike (2020). However, the interaction effect of banana and cucumber decreased the TTA of BCTS. On the contrary, the interaction effect of banana, turmeric, and the banana, cucumber, and turmeric, increased the TTA of BCTS. The rise in TTA could be due to the synergistic effects of the fruit and vegetable phytochemicals. This is similar to the increase in TTA with the inclusion of turmeric into pineapple juice (Sun et al., 2023; Yusufali et al., 2024).

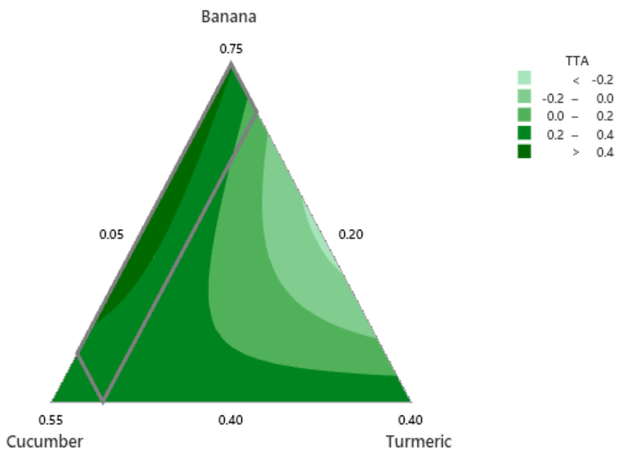

Figure 4: Mixture contour plot for total titratable acidity (TTA) of banana-cucumber-turmeric smoothie

Antioxidant properties of banana-cucumber-turmeric smoothie

The models that were generated for 2,2-diphenyl-1-picrylhydrazyl (DPPH) (y_4) and 2,2'-Azino-bis(3 3-ethyl benzothiazoline-6-sulfonic acid (ABTS) (y_5) of BCTS are shown in Equations (12) and (13), respectively.

$$y_4 = 13.20x_1 - 96.80x_2 + 381.00x_3 + 333.40x_1x_2 - 457.00x_1x_2x_3 \quad (12)$$

$$y_5 = -21.90x_1 - 91.00x_2 + 424.00x_3 + 253.00x_1x_2 - 184.00x_1x_3 - 1335.00x_1x_2x_3 \quad (13)$$

The models' validation indices and their values using experimental and predicted data for the properties in Table 4 are presented (Table 5).

While the coefficient of regression (R^2) for DPPH was 0.65 that of ABTS was 0.62. AAD was near 0 for both antioxidant properties, while Bf and Af were almost 1. The indices' values indicate the models' capability to predict the antioxidant properties. In the case of DPPH, all the linear and interaction factors, except $x_1x_2x_3$, had a significant ($p < 0.05$) effect on the antioxidant property levels. While banana and turmeric had an increasing effect, cucumber had a decreasing impact on the antioxidant property (Figure 5). This implies that turmeric and banana could boost the antioxidant property level of the BCTS. This corroborates previous studies showing that adding turmeric increases the antioxidant properties of foods and drinks (Britto et al., 2020; Sidhu & Zafar, 2020). However, the interaction factor, x_1x_2, had an increasing effect on DPPH of the BCTS; the effect was less pronounced than that of the linear factor of turmeric. This could be due to the lower antioxidant properties of the phytochemicals in banana and cucumber (Shariff et al., 2021).

While linear factors x_1, x_2, and x_3 exerted a significant ($p < 0.05$) effect, the interaction factors were not crucial regarding the ABTS scavenging property of the BCTS. As banana and cucumber exerted decreasing effects, turmeric greatly affected the ABTS scavenging property of the BCTS (Figure 6). BCTS with a relatively large quantity of turmeric could be utilized as a functional beverage to ameliorate health issues related to oxidative stress (Wu et al., 2024).

Sensory properties of banana-cucumber-turmeric smoothie

The colour models (y_6), taste (y_7), and overall acceptability (y_8) of BCTS are represented by Equations (14) - (16), respectively. The indices for model validation and their values derived from experimental and predicted data (Table 6) are presented in Table 7.

$$y_6 = 5.16x_1 - 2.64x_2 + 4.10x_3 + 19.44x_1x_2 - 3.30x_1x_3 \quad (14)$$

$$y_7 = 5.38x_1 + 0.91x_2 + 4.10x_3 + 12.41x_1x_2 + 3.00x_1x_3 \quad (15)$$

$$y_8 = 13.69x_1 + 25.65x_2 - 220.20x_3 - 67.30x_1x_2 + 153.20x_1x_3 + 870.00x_1x_2x_3 \quad (16)$$

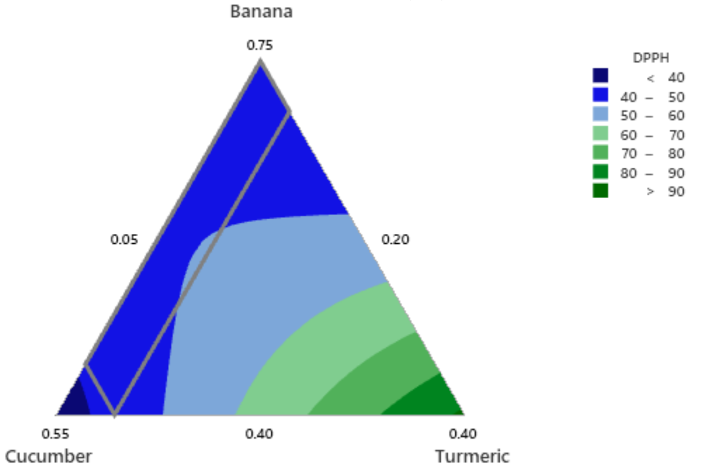

Figure 5: Mixture contour plot for 2,2-diphenyl-1-picrylhydrazyl (DPPH) of banana-cucumber-turmeric smoothie

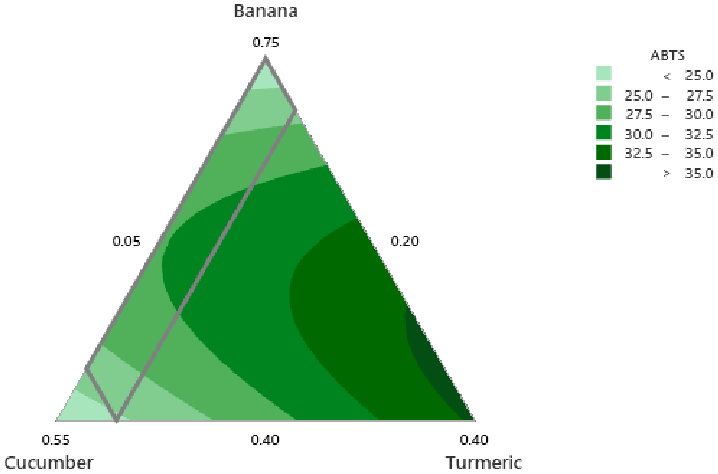

Figure 6: Mixture contour plot for 2,2'-Azino-bis(3- ethyl benzothiazoline- 6- sulfonic acid scavenging property of banana-cucumber-turmeric smoothie

The R^2 for colour, taste, and overall acceptability were 0.87, 0.72, and 0.74, respectively, and AAD, Bf, and Af values for all the properties were close to 0, 1, and 1, respectively. The indices' values indicate the models' capability to predict the sensory properties.

All the linear and interaction factors had a significant ($p < 0.05$) influence on the BCTS colour (Figure 7). All the factors except x_2 and x_1x_3 had an increasing effect on the colour. The positive impacts banana and turmeric had on the colour of BCTS could be due to their intrinsic beta-carotene and curcumin, respectively (Moniharapon et al., 2022; Okwunodulu et al., 2023). However, their interaction factor had a decreasing effect on the colour of BCTS. The decreasing effect of cucumber on the colour rating of BCTS could be due to chlorophyll, which had been previously reported to account for the inferior appearance of bulk-packed cucumber (Nunes et al., 2011).

Table 4: The experimental and predicted values for 2-diphenyl-1-picrylhydrazyl radical and 2,2’-Azino-bis(3- ethyl benzothiazoline- 6- sulfonic acid of banana-cucumber- turmeric smoothie

Treatment	Banana (x_1)	Cucumber (x_2)	Turmeric (x_3)	DPPH (%)		ABTS (%)	
				Exp.	Pred.	Exp.	Pred.
1	0.40	0.50	0.10	43.67	43.38	27.11	24.68
2	0.75	0.20	0.05	41.05	42.46	21.75	22.61
3	0.66	0.28	0.06	51.45	47.76	31.34	28.46
4	0.58	0.35	0.08	48.51	49.67	28.13	30.31
5	0.64	0.28	0.09	49.53	48.09	28.54	29.26
6	0.45	0.50	0.05	43.07	41.32	26.88	26.11
7	0.51	0.43	0.06	43.28	47.42	27.55	29.42
8	0.64	0.28	0.09	49.58	48.09	28.53	29.26
9	0.66	0.28	0.06	51.68	47.76	31.75	28.46
10	0.49	0.43	0.09	48.93	48.22	31.05	28.84
11	0.40	0.50	0.10	43.56	43.38	21.34	24.68
12	0.45	0.50	0.05	43.09	41.32	26.58	26.11
13	0.49	0.43	0.09	48.54	48.22	31.33	28.84
14	0.70	0.20	0.10	41.66	42.67	26.88	26.72
15	0.70	0.20	0.10	41.36	42.67	26.73	26.72
16	0.51	0.43	0.06	43.05	47.42	27.82	29.42
17	0.58	0.35	0.08	48.22	49.67	28.32	30.31
18	0.75	0.20	0.05	41.05	42.46	21.83	22.61

DPPH and ABTS represent 2,2-diphenyl-1-picrylhydrazyl radical and 2,2’-azino-bis (3-ethyl benzothiazoline-6-sulfonic acid, respectively.

Table 5: Coefficient of regression for 2-diphenyl-1-picrylhydrazyl radical and 2,2’-Azino-bis(3- ethyl benzothiazoline- 6- sulfonic acid of banana-cucumber- turmeric smoothie

Coefficient	2,2-diphenyl-1-picrylhydrazyl	2,2’-Azino-bis(3- ethyl benzothiazoline- 6- sulfonic acid
α_1	13.20*	-21.90*
α_2	-96.80*	-91.00*
α_3	381.00*	424.00*
α_{12}	333.40*	253.00
α_{13}	-457.00	-184.00
α_{123}	N/A	-1335.00
R^2	0.65	0.62
AAD	0.04	0.06
Bf	1.00	1.00
Af	1.04	1.11

*Significant at $p < 0.05$. α_1, α_2 and α_3 are linear regression coefficients of banana, cucumber, and turmeric, respectively. α_{12}, α_{13}, α_{123} are interaction regression coefficients of banana and cucumber; banana and turmeric; banana, cucumber and turmeric; respectively. R^2 is the coefficient of determination; AAD is the average absolute deviation; Bf and Af are the bias and accuracy factors, respectively.

All the linear factors, and the interaction factor x_1x_2, exerted a significant ($p < 0.05$) positive impact on the taste of the BCTS, with banana and its interaction with cucumber having more impact. However, all the components played a positive role in defining the taste of BCTS (Figure 8), suggesting acceptability to smoothie consumers.

Meanwhile, for overall acceptability, all the factors had significant ($p < 0.05$) effects (Figure 9). While linear effects x_1 and x_2, interaction effects x_1x_3 and $x_1x_2x_3$, impacted positively, linear effect x_3 and interaction effect x_1x_2 negatively impacted the overall acceptability of BCTS. However, it is noteworthy that the interaction factor $x_1x_2x_3$ had the most significant positive impact on the overall acceptability of BCTS. This implies that the components may play synergistic roles, such as sweetening and colouring functions, to enhance the overall acceptability of BCTS.

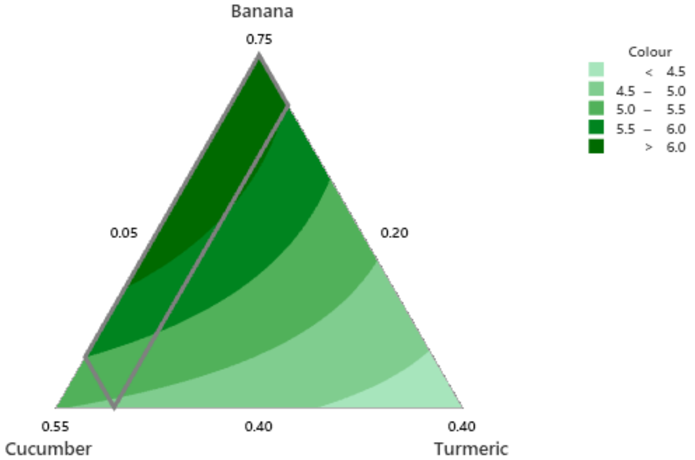

Figure 7: Mixture contour plot for the colour of the banana-cucumber-turmeric smoothie

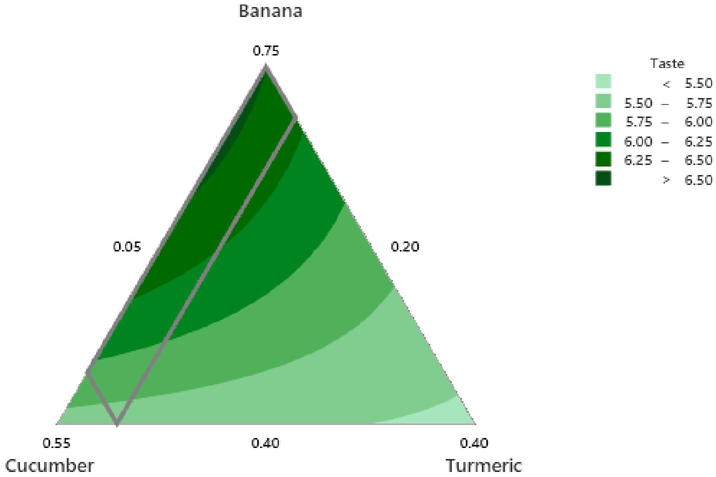

Figure 8: Mixture contour plot for the taste of the banana-cucumber-turmeric smoothie

Table 6: Sensory properties of banana- cucumber- turmeric smoothie

Treatment	Banana (x_1)	Cucumber (x_2)	Turmeric (x_3)	Colour		Taste		Overall acceptability	
				Exp.	Pred.	Exp.	Pred.	Exp.	Pre.
1	0.40	0.50	0.10	4.78	4.91	5.54	5.62	6.08	6.35
2	0.75	0.20	0.05	6.46	6.34	6.66	6.40	6.58	6.56
3	0.66	0.28	0.06	6.20	6.35	6.12	6.46	6.28	6.35
4	0.58	0.35	0.08	5.90	6.12	6.28	6.35	6.68	6.53
5	0.64	0.28	0.09	6.30	6.14	6.50	6.38	6.58	6.61
6	0.45	0.50	0.05	5.48	5.51	5.88	5.94	6.08	6.10
7	0.51	0.43	0.06	6.02	5.91	6.40	6.20	6.22	6.25
8	0.64	0.28	0.09	6.30	6.14	6.50	6.38	6.58	6.61
9	0.66	0.28	0.06	6.02	6.35	6.12	6.46	6.28	6.35
10	0.49	0.43	0.09	5.90	5.64	6.16	6.07	6.60	6.67
11	0.40	0.50	0.10	4.78	4.91	5.54	5.62	6.66	6.35
12	0.45	0.50	0.05	5.48	5.51	5.88	5.94	6.08	6.07
13	0.49	0.43	0.09	5.90	5.64	6.16	6.07	6.60	6.67
14	0.70	0.20	0.10	5.94	5.98	6.28	6.30	6.18	6.18
15	0.70	0.20	0.10	5.94	5.98	6.28	6.30	6.18	6.18
16	0.51	0.43	0.06	6.02	5.91	6.40	6.20	6.22	6.25
17	0.58	0.35	0.08	5.90	6.12	6.28	6.35	6.68	6.53
18	0.75	0.20	0.05	6.46	6.34	6.40	6.40	6.58	6.56

Table 7: Coefficient of regression for sensory properties of banana-cucumber-turmeric smoothie

Coefficient	Colour	Taste	Overall acceptability
α_1	5.16*	5.38*	13.69*
α_2	-2.64*	0.91*	25.65*
α_3	4.10*	4.10*	-220.20*
α_{12}	19.44*	12.41*	-67.30*
α_{13}	-3.30*	3.00	153.20*
α_{123}	N/A	N/A	870.00*
R^2	0.87	0.72	0.74
AAD	0.03	0.02	0.01
Bf	1.00	1.00	1.00
Af	1.03	1.02	1.01

*Shows significance at $p < 0.05$. α_1, α_2, and α_3 are linear regression coefficients of banana, cucumber, and turmeric, respectively. α_{12}, α_{13}, α_{123} are interaction regression coefficients of banana and cucumber; banana and turmeric; banana, cucumber and turmeric; respectively.

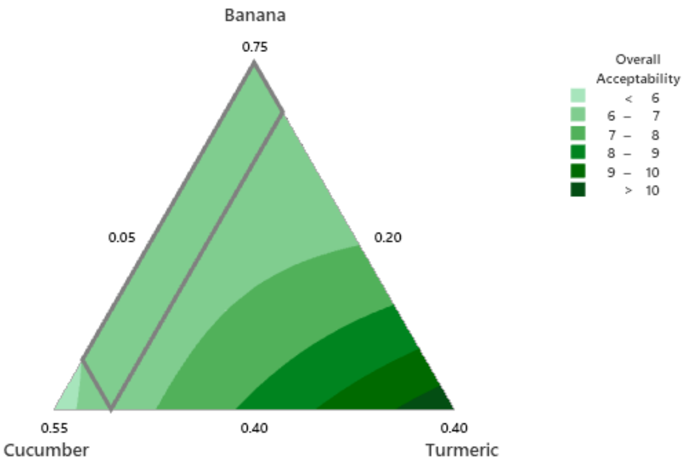

Figure 9: Mixture contour plot for overall acceptability of banana-cucumber-turmeric smoothie

Optimization of the properties of banana-cucumber-turmeric smoothie

The multi-response optimization of the properties of BCTS (Table 8) showed that BCTS with proportions of 0.62, 0.30, and 0.08 for banana, cucumber, and turmeric, respectively, had optimal properties. BCTS with optimal properties could be utilized as a functional beverage with good antioxidant and sensory properties, with minimal acidity for a wide range of consumers, including those intolerant of highly acidic drinks. This is in line with the findings of Kharsa (2024), who deployed response surface methodology to successfully optimize antioxidant properties of a smoothie from carrot, lettuce, beet, pineapple, and banana as a functional drink.

Table 8: Multi-response optimization of physicochemical, antioxidant, and sensory properties of banana-cucumber-turmeric smoothie

Parameters	Goal	Lower	Target	Upper	Solution
Banana	Within range	0.40	-	0.75	0.62
Cucumber	Within range	0.20	-	0.50	0.30
Turmeric	Within range	0.05	-	1.00	0.08
TSS (°brix)	Maximize	8.80	14.50	14.50	11.99
pH	Maximize	4.50	5.10	5.10	4.77
TTA (g/100g)	Minimize	0.03	0.03	0.45	0.31
DPPH (%)	Maximize	41.05	51.68	51.68	48.86
ABTS (%)	Maximum	21.34	31.75	31.75	30.16
Colour	Maximize	4.78	6.48	6.48	6.02
Sweetness	Maximize	5.54	6.66	6.66	6.32
Overall acceptability	Maximize	6.00	6.68	6.68	6.62

TTA, TSS, DPPH, and ABTS represent total titratable acidity, total soluble solids, 2, 2-Diphenyl-1-picrylhydrazyl radicals, and 2, 2'-Azino-bis (3-ethylbenzothiazoline- 6-sulfonic acid), respectively.

Conclusion

This study produced BCTS from banana, cucumber, and turmeric using an extreme vertices design, the first of its kind. The models generated for the key properties of BCTS reflected the capability of predicting the properties, as their R^2 ranged from 0.62 to 0.83, AAD values were near zero, and Bf and Af were almost 1. The models would be valuable tools for customizing consumers' requirements by smoothie vendors. Although all the components of BCTS played one positive role or the other in improving the physicochemical and sensory properties, turmeric specifically increased the antioxidant properties of BCTS. This showed that BCTS can be utilized as a functional health beverage. Also, the properties of BCTS were successfully optimized with the proportions 0.62, 0.30, and 0.08 for banana, cucumber, and turmeric, respectively. This formulation would ensure uniformity in the properties of BCTS during its production and contribute to cost control. However, there is a need for further research on ensuring shelf stability of the formulated smoothie, which is germane to commercialization, wide distribution, and marketing. Such research may focus on maintaining the smoothie at low temperatures that will inhibit both enzymatic and spoilage microorganisms or subject it to fermentation to produce microbial inhibitory substances.

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