Physicochemical models applied to a malt healthy-friendly soft drink production

Modelos físico-químicos aplicados à produção de um refrigerante de malte saudável

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ABSTRACT
The increasing demand for enzymatically hydrolyzed proteins, easily digestible carbohydrates, and nutritionally enriched beverages has propelled the popularity of malt-based health-friendly

soft drinks (MHFSDs). Ensuring consistent quality, safety, and flavor underscores the significance of comprehending MHFSDs' physicochemical attributes. Through the application of central composite rotational design (CCRD), the impact of light and dark malt extract concentrations (LME and DME) and added sugar (AS) on these attributes was assessed. CCRD facilitated the creation of predictive mathematical models for pivotal physicochemical properties in MHFSDs, including pH, acidity, reducing sugar, total sugar, and color. These properties exert substantial influence on MHFSDs' overall quality and sensory characteristics. The reliability in understanding MHFSDs' physicochemical attributes is confirmed by high determination coefficients (pH=0.98, acidity=0.87, reducing sugar=1.00, total sugar=0.98, luminosity dimension=0.98, red-green dimension=0.76, yellow-blue dimension=0.64). The integration of CCRD and mathematical models provides a systematic, data-oriented strategy for formulating health-friendly soft drinks that fulfill desired benchmarks, presenting consumers with a more health-conscious and enjoyable beverage alternative.

Keywords: malt health-friendly soft drink, central composite rotational design, physicochemical models, beverage production.

RESUMO

A crescente demanda por proteínas hidrolisadas enzimaticamente, carboidratos de fácil digestão e bebidas nutricionalmente enriquecidas impulsionou a popularidade dos refrigerantes saudáveis à base de malte (MHFSDs). A garantia de qualidade, segurança e sabor consistentes ressalta a importância de compreender os atributos físico-químicos dos MHFSDs. Por meio da aplicação de um projeto rotativo composto central (CCRD), foi avaliado o impacto das concentrações de extrato de malte claro e escuro (LME e DME) e do açúcar adicionado (AS) sobre esses atributos. O CCRD facilitou a criação de modelos matemáticos preditivos para propriedades físico-químicas essenciais em MHFSDs, incluindo pH, acidez, açúcar redutor, açúcar total e cor. Essas propriedades exercem uma influência substancial na qualidade geral e nas características sensoriais dos MHFSDs. A confiabilidade na compreensão dos atributos físico-químicos dos MHFSDs é confirmada pelos altos coeficientes de determinação (pH=0,98, acidez=0,87, açúcar redutor=1,00, açúcar total=0,98, dimensão de luminosidade=0,98, dimensão vermelho-verde=0,76, dimensão amarelo-azul=0,64). A integração do CCRD e dos modelos matemáticos fornece uma estratégia sistemática e orientada por dados para a formulação de refrigerantes saudáveis que atendem aos padrões de referência desejados, apresentando aos consumidores uma alternativa de bebida mais saudável e agradável.

Palavras-chave: refrigerante à base de malte e amigo da saúde, central composite rotational design, modelos físico-químicos, produção de bebidas.

1 INTRODUCTION

Globally popular, soft drinks significantly contribute to dietary energy intake (Fletcher et al., 2010). These beverages often contain preservatives, caffeine, flavorings, artificial sweeteners (e.g., aspartame, acesulfame potassium, sucralose), high-fructose corn syrup, and sugar. Initially prominent in developed nations, soft drinks now have a worldwide presence (Euromonitor International, 2019).

In recent decades, global carbonated beverage consumption surged from 4% in 1965 to 16% in 2019 (Action on Sugar, 2019). Although per capita consumption has slightly decreased lately, the United States remains the world's top consumer, closely trailed by Mexico, Chile, and Argentina (Euromonitor International, 2019). Predominantly, adolescents and young adults aged 15 to 17 constitute the main consumers, with approximately 50-60% of this age group consuming soft drinks daily (Australian Bureau of Statistics, 2015).

Around 50% of American adults consume a daily glass of soft drink, with Australian rates ranging from 40% to 50% (Miller et al., 2019; Roy Morgan Research, 2015). The easy accessibility of soft drinks in vending machines, stores, gas stations, and supermarkets, coupled with vigorous marketing, fuels ongoing consumption growth. Notably, in 2019, Coca-Cola invested over $280 million in advertising in the US (NCES, 2020).

Currently, the soft drink industry is shifting towards nutrition-focused products (Abera et al., 2022; Elgorashi & Sulieman, 2022; Hermann et al., 2022), offering an alternative to sugary drinks associated with higher risks of obesity (Chatelan et al., 2023), diabetes (Heisler et al., 2023), heart disease (Park et al., 2022), and other health concerns (Cortés-Valencia et al., 2022; Le Bodo et al., 2019). Health-friendly soft drinks, featuring ingredients like enzymatically hydrolyzed proteins and easily digestible carbohydrates, are gaining traction due to their enhanced nutritional value (Hafiz et al., 2022).

Abera et al. (2022) aimed to create a gluten-free, low-alcohol, shelf-stable soft drink using yellow maize and the natural preservative Moringa oleifera. They formulated three malt beverages, assessing physicochemical properties, antimicrobial effects, shelf life, and sensory traits. Results indicated maize's potential as a raw material for health-friendly soft drinks, enhancing nutrition and shelf life. In contrast, Elgorashi and Sulieman (2022) developed a non-alcoholic malt beverage with Feterita sorghum malt, optimizing malt and wort properties at 100 °C via decantation mashing due to sorghum starch gelatinization. Hermann et al. (2022) reviewed nutrient and bioactive content in non-alcoholic sorghum malt beverages, revealing rich carbohydrates, proteins, essential amino acids, vitamins, minerals, and antioxidant phenolic compounds in sorghum grain. Non-alcoholic sorghum malt beverages offer potential nutrient and bioactive sources.

The soft drink industry's role in the modern diet is pivotal, remaining a popular choice and yielding a global net profit of $10.38 billion. Notably, the health-friendly soft drink sector has grown notably by 6.8%, projecting production of 9463 L of such beverages by 2025 (Tireki, 2021). This upward trajectory emphasizes the escalating demand for health-friendly soft drinks, creating a valuable avenue for industry expansion (Trawiński & Skibiński, 2023). As consumer preference tilts towards healthier options, health-friendly soft drinks present substantial market potential, enabling the beverage sector to align with evolving customer needs and maintain market relevance (Todaro et al., 2023).

The escalating demand for barley as a prime beverage raw material (Abera et al., 2022; Sovacool et al., 2021) has spurred its dietary inclusion due to its diverse merits, encompassing low glycemic index, the potential for managing weight and heart disease, and rich content of phytochemical compounds and essential amino acids (Alu'datt et al., 2012; Baik & Ullrich, 2008). Furthermore, barley improves food product rheology. Controlled germination yields antioxidant-rich barley malt, leading to subsequent processes for producing liquid malt extract (Da Silva, Santos, Moraes, et al., 2023). This extract finds wide application as an additive and dietary supplement in the food industry, particularly for low-starch diets (Do et al., 2015).

Comprehending the physicochemical traits of these beverages is pivotal for quality control, safety, and taste consistency (Adams et al., 2020; Da Silva, Santos, Da Silva, et al., 2023). Eba et al. (2023) conducted a study in Côte d'Ivoire, evaluating elementary school-sold soft drinks' biochemical and physicochemical properties, along with health risks. Key properties like pH, sugar content, and additives unveiled potential health hazards, prompting risk-mitigating actions. Fletcher et al. (2010) discovered soft drink taxes marginally impact body mass index and obesity rates. Exploring soft drinks' physicochemical properties, like carbonation and sugar, aids in comprehending weight effects, fostering consumption reduction and public health improvement. These properties significantly shape soft drink sensory perception. Saint-Eve et al. (2009) revealed carbonation and sugar's roles in aroma release and flavor perception. Notably, carbonation enhances aroma compounds release, while sugar affects aroma perception. Grasping these dynamics could yield better-tasting soft drinks and an insightful consumer preference understanding (Yeo et al., 2023).

To achieve this, we utilized a central composite rotational design (CCRD) to evaluate the effects of light and dark malt extract concentrations (LME and DME) and added sugar (AS) on these attributes in a malt health-friendly soft drink. This method facilitates an exhaustive and organized exploration of ingredient interactions, furnishing valuable insights to optimize beverage formulation and meet consumer demands. In this article, we present comprehensive study findings, underscoring the relevance of this data for both the beverage industry and enthusiasts.

2 MATERIALS AND METHODS

The experimental procedures were performed at the Federal University of Espírito Santo campus in Alegre, ES, Brazil.

2.1 RAW MATERIALS AND SOURCES

A modified methodology from Brunelli et al. (2014) was employed to prepare batches of light and dark malt extracts. Light Pilsen malt and dark roasted malt were obtained from specialized beer product companies' websites. Light Pilsen malt was selected for its subtle flavor and pale color contribution. Conversely, dark roasted malt was chosen for its distinct color, flavor, and aroma, suited for stouts and porters (Moreira et al., 2013), aligning with our study's aim.

Worts were concentrated by evaporation to one-third of the initial volume. Mineral water and local crystal sugar were used for soda production in Alegre, ES, Brazil. Additionally, food-grade carbon dioxide (CO_2) and citric acid PA were applied as acidulants.

2.2 EXPERIMENTAL DESIGN AND OPTIMIZATION

For forecasting the impacts of light and dark malt extract concentrations (LME and DME) and added sugar (AS) on malt health-friendly soft drink (MHFSD) formulations, a central composite rotational design (CCRD) was employed. The CCRD encompassed six axial points (α ± 1.68) and a total of 15 experiments, detailed in Table 1.

Table 1. Real and coded (between parenthesis) variable values.

Trial	LME % (x_1)	DME % (x_2)	AS % (x_3)
1	2.00 (-1.00)	3.40 (-1.00)	2.50 (-1.00)
2	8.00 (+1.00)	3.40 (-1.00)	2.50 (-1.00)
3	2.00 (-1.00)	13.40 (+1.00)	2.50 (-1.00)
4	8.00 (+1.00)	13.40 (+1.00)	2.50 (-1.00)
5	2.00 (-1.00)	3.40 (-1.00)	9.50 (+1.00)
6	8.00 (+1.00)	3.40 (-1.00)	9.50 (+1.00)
7	2.00 (-1.00)	13.40 (+1.00)	9.50 (+1.00)
8	8.00 (+1.00)	13.40 (+1.00)	9.50 (+1.00)
9	0.00 (-1.68)	8.60 (0.00)	6.00 (0.00)
10	10.00 (+1.68)	8.60 (0.00)	6.00 (0.00)
11	5.00 (0.00)	0.00 (-1.68)	6.00 (0.00)
12	5.00 (0.00)	17.20 (+1.68)	6.00 (0.00)
13	5.00 (0.00)	8.60 (0.00)	0.00 (-1.68)
14	5.00 (0.00)	8.60 (0.00)	12.00 (+1.68)
15	5.00 (0.00)	8.60 (0.00)	6.00 (0.00)

Source: Elaborated by the authors

The study centered on dependent physicochemical properties. The examined ranges for lower and higher LME, DME, and AS levels were 0.00%–10.00%, 0.00%–17.20%, and 0.00%–

12.00%, respectively. The proposed mathematical models were validated using the F-test and determination coefficient (R^2), guided by Neto et al. (2010) methodology, with a 95% confidence level determining factor significance and interactions on responses.

For evaluating variable impacts, response surface methodology (RSM) was employed individually and in combination. Statistica 7.0® software facilitated the CCRD, while variance and regression analyses identified significant model parameters and regression coefficients. Using the least-square method, mathematical relationships were established via quadratic and linear polynomial models, capturing interaction influences (Myers & Montgomery, 1995), as depicted in Equation (1):

$$y = \beta_0 + \sum_{i=1}^{k} \beta_i x_i + \sum_{i=1}^{k} \beta_{ii} x_i + \sum_{i=1}^{k-1} \sum_{j=2}^{K} \beta_{ij} x_i x_j \qquad (1)$$

Where:

Y is the predicted response, β_0, β_i, β_{ii}, and β_{ij} are the regression coefficients of the applied model, X_i, and X_j are the coded independent variables.

2.3 MALT HEALTH-FRIENDLY SOFT DRINKS PRODUCTION

MHFSDs were batch-produced following Celestino's (2010) methodology (2010) with adaptation such as those done by Santos et al. (2023). The process entailed creating simple and compound syrups, then blending these syrups with other components for the final product.

For the simple syrup, a 2:1 blend of granulated sucrose and mineral water was heated to 82 °C, vacuum-filtered, cooled, and diluted to about 1.3 kg/L (60 °Brix).

Compound syrup involved incorporating barley malt extracts into the simple syrup per CCRD-defined concentrations. Equal acidulant amounts (0.3 g per 100 mL of syrup) were added to all samples sequentially, preventing precipitation and turbidity.

Water and compound syrup were mixed, placed in sanitized PET packaging, and carbonated. Stirring occurred for 15 minutes initially and intermittently for 3 hours, ensuring complete component homogenization, consistent uniformity, and product quality.

2.4 PHYSICAL-CHEMICAL ANALYSIS

This study entailed various analyses of malt health-friendly soft drinks, including pH, acidity, reducing sugars, total sugars, and color. Each analysis was performed thrice, following Adolf Lutz Institute (2008) protocols for beverages and sodas. Notably, the color analysis used a transmittance colorimeter (Spectrophotometer CM-5, Konica Minolta), aligned with Hunter Associates Laboratory (2001) guidelines for assessing luminosity, red-green, and yellow-blue color dimensions.

3 RESULTS AND DISCUSSION

Table 2 displays mean scores and standard deviations for each physicochemical properties derived from the CCRD application. pH ranged from 2.78 to 3.36, indicating slight to moderate acidity. Acidity spanned 0.30 to 0.40 g/100mL, yielding consistent acidity. Notably heterogeneous, reducing sugar content ranged from 0.99 to 30.50 g/L, suggesting diverse sweetness levels among MHFSD samples. Total sugar content varied from 17.38 to 205.59 g/L, reflecting broad sugar concentrations. Noteworthy color dimension fluctuations were observed: luminosity ranged from 0.51 to 75.98, red-green from 1.53 to 30.17, and yellow-blue from 0.32 to 63.55. These color diversities might influence consumer perception and preference.

Table 2. Mean scores and standard deviations for the physicochemical properties of MHFSD by applying CCRD.

Trial	pH	Acidity (g/100 mL)	Reducing sugar (g/L)	Total sugar (g/L)	Luminosity dimension	Red-green dimension	Yellow-blue dimension
1	2.88 ± 0.00	0.32 ± 0.00	4.01 ± 0.10	25.70 ± 0.28	41.94 ± 0.37	28.53 ± 0.06	63.55 ± 0.44
2	3.18 ± 0.00	0.35 ± 0.01	22.19 ± 0.11	48.86 ± 0.32	32.7 ± 0.28	30.17 ± 0.10	52.86 ± 0.44
3	3.07 ± 0.00	0.38 ± 0.00	5.98 ± 0.00	31.55 ± 0.21	0.90 ± 0.06	3.36 ± 0.15	1.10 ± 0.19
4	3.28 ± 0.00	0.40 ± 0.00	18.36 ± 0.19	50.65 ± 0.28	1.05 ± 0.07	4.34 ± 0.07	1.20 ± 0.17
5	2.78 ± 0.01	0.34 ± 0.00	5.60 ± 0.00	115.09 ± 0.29	32.57 ± 0.36	27.41 ± 0.12	52.16 ± 0.45
6	3.18 ± 0.00	0.30 ± 0.01	26.57 ± 0.12	137.21 ± 0.37	24.47 ± 0.14	24.60 ± 0.05	39.96 ± 0.26
7	3.06 ± 0.01	0.36 ± 0.01	10.67 ± 0.12	132.92 ± 0.31	0.67 ± 0.08	3.24 ± 0.07	0.94 ± 0.07
8	3.36 ± 0.00	0.38 ± 0.01	29.10 ± 0.00	154.15 ± 0.88	0.51 ± 0.05	2.03 ± 0.05	0.75 ± 0.05
9	2.84 ± 0.00	0.32 ± 0.01	0.99 ± 0.00	66.79 ± 0.37	9.03 ± 0.06	26.82 ± 0.15	14.13 ± 0.28
10	3.32 ± 0.00	0.38 ± 0.01	30.50 ± 0.10	88.29 ± 0.38	8.64 ± 0.09	26.44 ± 0.17	13.20 ± 0.15
11	2.98 ± 0.00	0.31 ± 0.00	11.95 ± 0.10	87.74 ± 0.38	75.98 ± 0.30	1.53 ± 0.03	15.74 ± 0.06
12	3.2 ± 0.00	0.40 ± 0.00	17.69 ± 0.21	69.69 ± 0.47	0.55 ± 0.06	2.24 ± 0.16	0.32 ± 0.05
13	3.11 ± 0.00	0.38 ± 0.00	14.11 ± 0.19	17.38 ± 0.42	5.33 ± 0.10	21.18 ± 0.33	7.99 ± 0.30
14	2.98 ± 0.00	0.39 ± 0.01	18.67 ± 0.06	205.59 ± 3.08	3.61 ± 0.03	14.92 ± 0.13	5.95 ± 0.21
15	3.08 ± 0.00	0.36 ± 0.00	17.13 ± 0.21	86.94 ± 1.16	7.95 ± 0.12	26.04 ± 0.10	12.28 ± 0.19

Source: Elaborated by the authors

Table 3 displays the results of the analysis of variance (ANOVA) for MHFSD's physicochemical properties via CCRD. The significance of linear, quadratic, and interaction effects was inferred from p-values below 0.05 (Neto et al., 2010). Noticeable differences were observed across all properties, with determination coefficients (R^2) indicating acceptable reliability (Rodrigues & Iemma, 2005).

Table 3. Analysis of variance applied to the studies of physicochemical properties of MHFSD by applying CCRD.

Source of variation	Sum of squares	Degree of freedom	Mean square	$F_{calculated}$	p	R^2	Adjust
pH						0.98	0.95
x_1	0.30	1.00	0.30	222.98	0.00		
x_1^2	0.00	1.00	0.00	0.32	0.59		
x_2	0.09	1.00	0.09	68.75	0.00		
x_2^2	0.00	1.00	0.00	0.79	0.40		
x_3	0.00	1.00	0.00	3.38	0.11		
x_3^2	0.00	1.00	0.00	0.33	0.58		
x_1x_2	0.00	1.00	0.00	3.38	0.11		
x_1x_3	0.00	1.00	0.00	3.38	0.11		
x_2x_3	0.00	1.00	0.00	2.70	0.14		
Error	0.01	7.00	0.00				
Total	0.42	16.00					
Acidity						0.87	0.70
x_1	0.00	1.00	0.00	4.32	0.08		
x_1^2	0.00	1.00	0.00	1.27	0.30		
x_2	0.01	1.00	0.01	32.94	0.00		
x_2^2	0.00	1.00	0.00	0.61	0.46		
x_3	0.00	1.00	0.00	0.71	0.43		
x_3^2	0.00	1.00	0.00	1.72	0.23		
x_1x_2	0.00	1.00	0.00	1.08	0.33		
x_1x_3	0.00	1.00	0.00	2.11	0.19		
x_2x_3	0.00	1.00	0.00	0.04	0.84		
Error	0.00	7.00	0.00				
Total	0.02	16.00					
Reducing sugar						1.00	0.98
x_1	1146.22	1.00	1146.22	1228.18	0.00		
x_1^2	5.43	1.00	5.43	5.82	0.05		
x_2	32.08	1.00	32.08	34.38	0.00		
x_2^2	11.80	1.00	11.80	12.64	0.01		
x_3	40.35	1.00	40.35	43.23	0.00		
x_3^2	2.60	1.00	2.60	2.78	0.14		
x_1x_2	24.29	1.00	24.29	26.03	0.00		
x_1x_3	25.85	1.00	25.85	27.70	0.00		
x_2x_3	28.13	1.00	28.13	30.14	0.00		
Error	6.53	7.00	0.93				
Total	1317.26	16.00					
Total sugar						0.98	0.96
x_1	1081.18	1.00	1081.18	11.15	0.01		
x_1^2	166.90	1.00	166.90	1.72	0.23		
x_2	11.19	1.00	11.19	0.12	0.74		
x_2^2	132.92	1.00	132.92	1.37	0.28		
x_3	35819.82	1.00	35819.82	369.44	0.00		
x_3^2	751.48	1.00	751.48	7.75	0.03		
x_1x_2	3.43	1.00	3.43	0.04	0.86		
x_1x_3	0.08	1.00	0.08	0.00	0.98		
x_2x_3	93.84	1.00	93.84	0.97	0.36		
Error	678.71	7.00	96.96				
Total	39175.77	16.00					
Luminosity dimension						0.98	0.94
x_1	23.76	1.00	23.76	1.03	0.34		
x_1^2	0.13	1.00	0.13	0.01	0.94		
x_2	4775.74	1.00	4775.74	206.13	0.00		
x_2^2	1247.88	1.00	1247.88	53.86	0.00		
x_3	33.12	1.00	33.12	1.43	0.27		

x_3^2	23.26	1.00	23.26	1.00	0.35		
x_1x_2	37.54	1.00	37.54	1.62	0.24		
x_1x_3	0.09	1.00	0.09	0.00	0.95		
x_2x_3	35.41	1.00	35.41	1.53	0.26		
Error	162.18	7.00	23.17				
Total	6619.24	16.00					
Red-green dimension						0.76	0.45
x_1	0.29	1.00	0.29	0.00	0.95		
x_1^2	1.11	1.00	1.11	0.02	0.91		
x_2	683.14	1.00	683.14	9.28	0.02		
x_2^2	802.38	1.00	802.38	10.90	0.01		
x_3	31.39	1.00	31.39	0.43	0.53		
x_3^2	76.53	1.00	76.53	1.04	0.34		
x_1x_2	0.11	1.00	0.11	0.00	0.97		
x_1x_3	5.51	1.00	5.51	0.07	0.79		
x_2x_3	2.27	1.00	2.27	0.03	0.87		
Error	515.42	7.00	73.63				
Total	2144.54	16.00					
Yellow-blue dimension						0.64	0.18
x_1	44.14	1.00	44.14	0.13	0.73		
x_1^2	210.23	1.00	210.23	0.60	0.46		
x_2	3891.97	1.00	3891.97	11.17	0.01		
x_2^2	60.92	1.00	60.92	0.17	0.69		
x_3	58.81	1.00	58.81	0.17	0.69		
x_3^2	42.84	1.00	42.84	0.12	0.74		
x_1x_2	64.98	1.00	64.98	0.19	0.68		
x_1x_3	0.41	1.00	0.41	0.00	0.97		
x_2x_3	70.09	1.00	70.09	0.20	0.67		
Error	2438.03	7.00	348.29				
Total	6794.86	16.00					

Source: Elaborated by the authors

3.1 pH

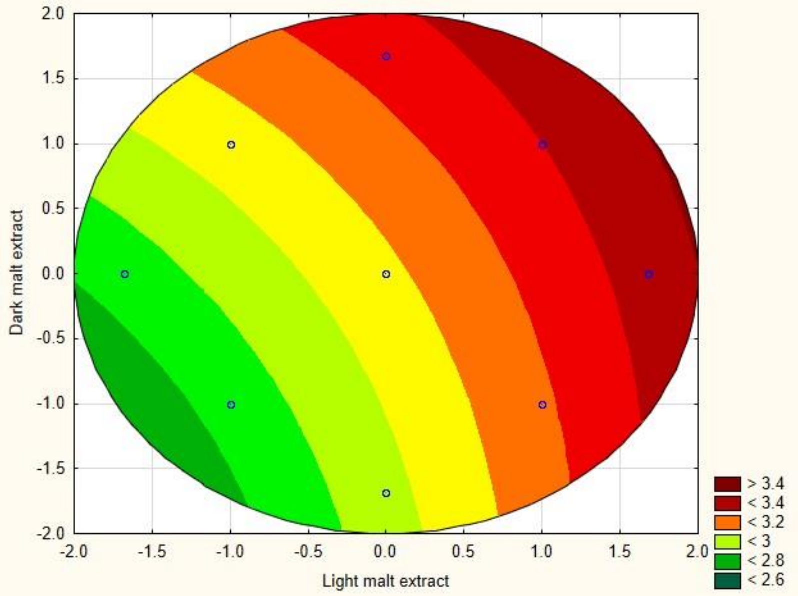
MHFSD's pH is affected by response variables with linear characteristics associated with x_1 and x_2. The mathematical representation of independent variables' significant impact on MHFSD's pH is presented in Equation (2). To visualize quadratic term contributions, surface response convex diagrams were employed as an alternative approach (Myers & Montgomery, 1995). Figure 1 exhibits the 2D response surface, offering a comprehensive depiction of pH behavior in MHFSD.

$$y = 3.08 + 0.15x_1 + 0.08x_2 \quad (2)$$

Where:

y is the pH of MHFSD, and x_1 and x_2 are the independent variables (LME and DME, respectively).

Figure 1. Response surfaces for the pH of MHFSD as a function of LME and DME.



Source: Authors

3.2 ACIDITY

The substantial influences of variables on MHFSD's acidity are mathematically depicted in Equation (3). Regression analysis reveals that, among the considered variables, solely the linear effect (x_2) emerges as a statistically significant parameter influencing MHFSD's acidity.

$$y = 0.36 + 0.03x_2 \quad (3)$$

Where:

y is the acidity of MHFSD, and x_2 is the independent variable (LME).

3.3 REDUCING SUGAR

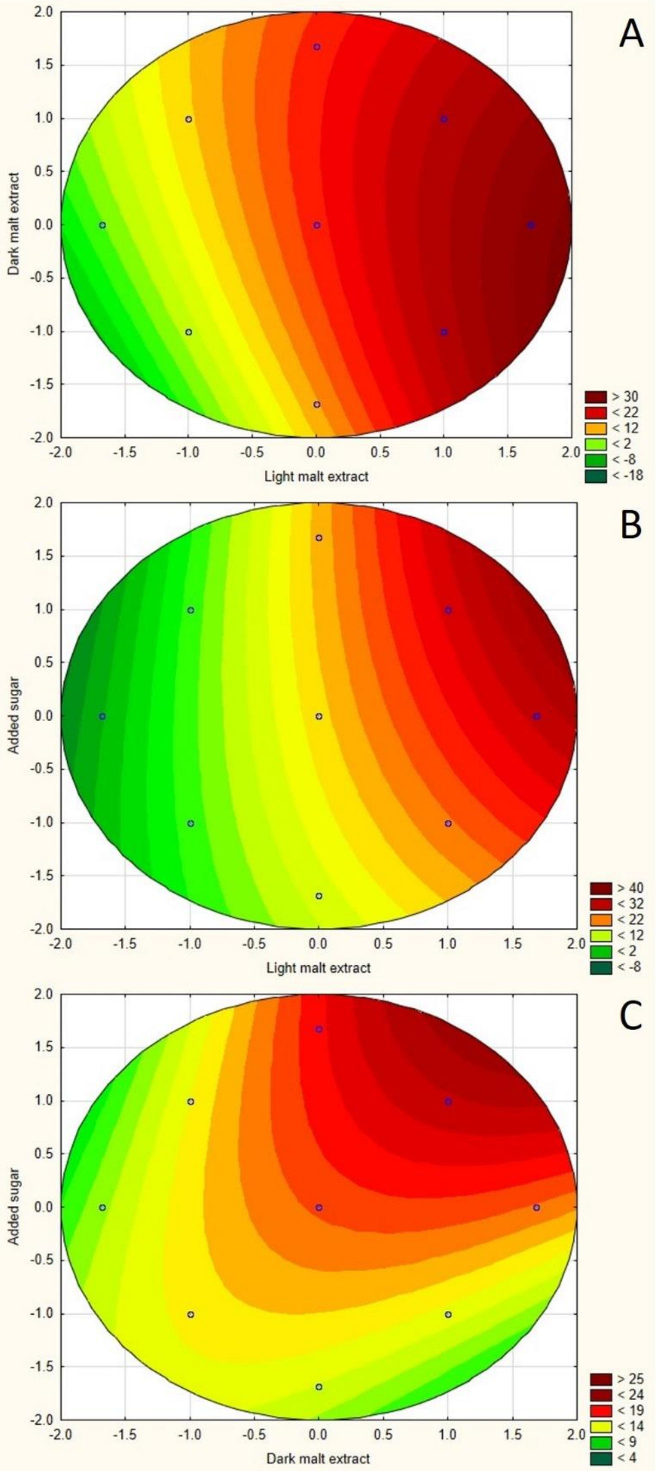
The impacts of response variables on MHFSD's reducing sugar content include linear influences from x_1, x_2, and x_3, alongside quadratic contributions from x_1^2 and x_2^2. The substantial effects of these variables on reducing sugar content are mathematically defined by the models in Equation (4). Figure 2 presents 3D response surfaces depicting MHFSD's reduced sugar content, visually illustrating the associations between independent variables and the beverage's reduced sugar levels.

$$y = 17.19 + 9.17x_1 - 0.69{x_1}^2 + 1.53x_2 - 1.02{x_2}^2 + 1.72x_3 - 1.74x_1x_2 + 1.80x_1x_3 + 1.88x_2x_3 \quad (4)$$

Where:

y is the reducing sugar of MHFSD, and x_1, x_2, and x_3 are the independent variables (LME, DME, and AS, respectively).

Figure 2. Response surfaces for the reducing sugar of MHFSD as a function of LME and DME (A), LME and AS (B), and DME and AS (C).



Source: Authors

3.4 TOTAL SUGAR

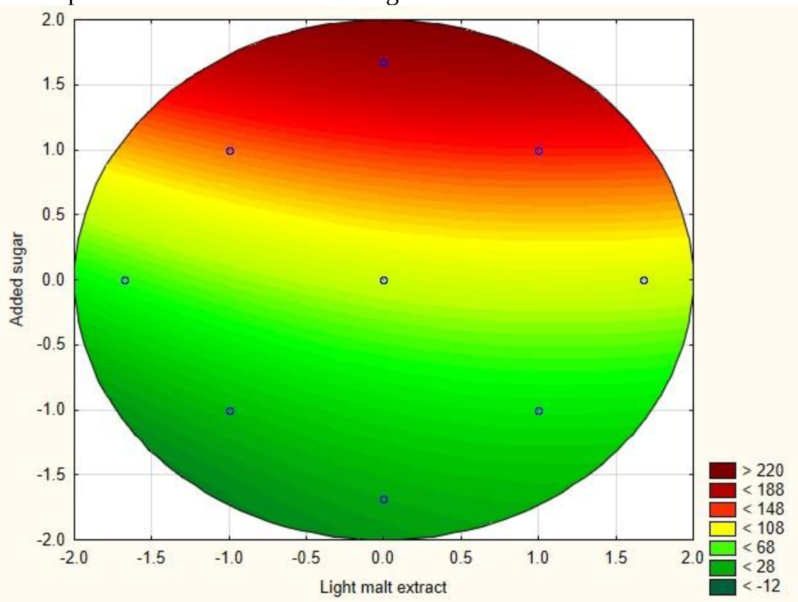
The influence of response variables on MHFSD's total sugar content involves linear impacts from x_1 and x_3, in addition to the quadratic effect of x_3^2. These noteworthy variable effects on total sugar content are mathematically elucidated by the models in Equation (5). Figure 3 provides visual insight into the relationships between independent variables and the beverage's total sugar content, depicting 3D response surfaces for MHFSD's total sugar.

$$y = 87.10 + 8.90x_1 + 51.64x_3 + 8.18{x_3}^2 \quad (5)$$

Where:

y is the total sugar of MHFSD, and x_1 and x_3 are the independent variables (LME and AS, respectively).

Figure 3. Response surfaces for the total sugar of MHFSD as a function of LME and AS.



Source: Authors

3.5 LUMINOSITY COLOR DIMENSION

Equation (6) expounds on the significant variable impacts on MHFSD's luminosity color dimension. Regression analysis demonstrates that both linear (x_2) and quadratic (x_2^2) effects are statistically significant parameters influencing MHFSD's luminosity color dimension.

$$y = 8.01 - 18.71x_2 + 10.54{x_2}^2 \quad (6)$$

Where:

y is the luminosity color dimension of MHFSD, and x_2 is the independent variable (DME).

3.6 RED-GREEN COLOR DIMENSION

Equation (7) clarifies significant variable impacts on MHFSD's red-green color dimension. As per the regression equation, both linear (x_2) and quadratic (x_2^2) effects are statistically significant parameters influencing MHFSD's red-green color dimension.

$$y = 26.01 - 7.08x_2 - 8.45{x_2}^2 \quad (7)$$

Where:

y is the red-green color dimension of MHFSD, and x_2 is the independent variable (DME).

3.7 YELLOW-BLUE COLOR DIMENSION

The impact of the response variable on MHFSD's yellow-blue color dimension is defined by the linear influence of x_2. The notable variable effect on the yellow-blue color dimension is mathematically elucidated by the models in Equation (8).

$$y = -16.89x_2 \quad (8)$$

Where:

y is the yellow-blue color dimension of MHFSD, and x_2 is the independent variable (DME).

3.8 APPLICATION IN MALT HEALTHY-FRIENDLY SOFT DRINK PRODUCTION

In a prior study (Santos et al., 2023), the objective was to formulate an MHFSD, considering sensory attributes and purchase intent. Mathematical models predicted the impact of LME, DME, and AS on these factors. A desirability function-based approach identified an optimal scenario with input parameters: 5.40% (0.13) LME, 14.11% (1.08) DME, and 10.80% (1.34) AS. The optimized MHFSD showed favorable sensory ratings: color (8.5), carbonation (6.0), flavor and overall impression (7.3), and purchase intent (3.3), indicating good acceptance.

These optimal LME, DME, and AS values were incorporated into mathematical models to assess MHFSD's physicochemical properties. Results included pH (3.19), acidity (0.39 g/100 mL), reducing sugar (23.93 g/L), total sugar (172.14 g/L), luminosity color (0.10), red-green color (8.51), and yellow-blue color (-18.24).

In comparison to commercial soft drinks with pH values of 2.5 to 3.5 (Chowdhury et al., 2019), MHFSD's pH aligned with mild acidity typical of carbonated beverages. MHFSD's acidity (0.39 g/100 mL) resembled diet-Coca Cola® (Ali & Tahmassebi, 2014).

Luminosity values reveal a dark coloration. Regarding shades, values along the red-green and yellow-blue axes signify a reddish and blueish hue (Hunter Associates Laboratory, 2001), consistent with the malt extracts employed in the optimized formulation. MHFSD's color metrics provide valuable information about visual attributes that can influence consumer preferences and perceptions.

MHFSD exhibited elevated sugar content compared to typical soft drinks (114.29 g/L) (Tahmassebi & BaniHani, 2020). This elevated sugar content warrants attention due to its association with potential health concerns stemming from extended and frequent consumption of high-sugar beverages (Krittanawong et al., 2023).

Krittanawong et al. (2023) investigated the precise correlation between consumption of sugar-sweetened and artificially sweetened beverages and cardiovascular health. Relevant studies linking these beverages to cardiovascular health were collected from various databases spanning from inception to September 2022, utilizing specific keywords. The analysis employed the DerSimonian & Laird random-effects method. Among 16 prospective studies, involving 1,405,375 individuals with a median follow-up of 14.8 years, heightened consumption of both sugar-sweetened and artificially sweetened beverages was linked to increased cardiovascular risks (hazard ratio [HR] of 1.27, 95% confidence interval [CI] 1.16-1.40, and risk ratios of 1.16, 95% CI 1.02-1.33), relative to lower consumption levels. Similarly, amplified consumption of artificially sweetened beverages, when compared to lower consumption, was also associated with elevated cardiovascular risks (HR of 1.32, 95% CI 1.12-1.57). Likewise, heightened consumption of sugar-sweetened beverages, in comparison to lower consumption, indicated greater cardiovascular risks (HR of 1.21, 95% CI 1.07-1.37, and risk ratios of 1.22, 95% CI 1.09-1.35). Although causality of cardiovascular/vascular morbidity remains unestablished, escalated consumption of sugar-sweetened and artificially sweetened beverages might be linked to an augmented risk of developing cardiovascular/vascular complications and mortality.

This insight gains importance in light of the proposition of health-friendly soft drinks aiming for enhanced nutritional value. It emphasizes the intricate task of achieving equilibrium among improving nutritional content, controlling sugar levels, and ensuring consumer acceptance of the product.

4 CONCLUSION

This research underscores the essential role of mathematical models in evaluating pH, acidity, reducing sugar, total sugar, and color in malt healthy-friendly soft drinks. Implementing these models enables the beverage industry to enhance production, ensure quality control, expedite new product development, reduce expenses, ensure regulatory compliance, and maintain consistent product quality.

The analysis of physicochemical properties in the optimized MHFSD formulation revealed acidity similar to standard soft drinks and visually appealing color dimensions. However, it's important to note that MHFSD had higher sugar content than typical commercial soft drinks. Further research is vital to understand the impact of these findings on consumer health and assess MHFSD's overall nutritional profile for informed consumption choices.

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ACRONYMS AND SYMBOLS

MHFSD	Malt health-friendly soft drink
CCRD	Central composite rotational design
LME	Light malt extract
DME	Dark malt extract
AS	Added sugar