***Original Research Article***

**Development of a plant-based functional yogurt to address nutritional deficiencies: The role of dates (*Phoenix dactylifera*) and beetroot (*Beta vulgaris*)**

**Abstract:**

With increasing consumer demand for nutritious foods, the food industry is striving to develop formulations that offer high nutritional value and sensory quality beyond expectations. This study aimed to evaluate the effect of supplementation with date powder and beetroot extract on the physicochemical, functional, sensory, and microbiological properties of soy-based yogurt. The yogurt was formulated using a central composite design to optimize three parameters: the soybean-to-water ratio, the quantity of date powder, and the volume of beetroot juice. The responses analyzed included pH, °Brix, and viscosity. Sensory and microbiological quality evaluations were performed on the optimal product and the control product. The analyses showed that the formulated yogurts had pH values ranging from 2.49 to 5.42, °Brix values between 10.50 and 19.16 °B, and viscosities ranging from 140 to 6575 mPa.s. The optimal production conditions for the enriched yogurt were 161.76 g/400 mL for the soybean-to-water ratio, 25 mL for beetroot juice, and 25 g for the amount of date powder. Under these conditions, the theoretical and experimental values for pH, °Brix, and viscosity were very close, with insignificant differences (pH: 4.50 and 4.47; °Brix: 14.02 and 14.67; viscosity: 1958.95 and 1973 mPa.s). Sensory evaluation revealed that the enriched yogurt had properties comparable to the control product. Microbiologically, the enriched yogurt contained a significantly higher concentration of viable lactic acid bacteria (8.72 ± 0.04 Log CFU/mL) compared to the control yogurt (7.60 ± 0.02 Log CFU/mL). These results provide a solid foundation for the development of functional plant-based yogurts, which could help reduce the prevalence of anemia and other nutritional deficiencies in vulnerable populations.

**Keywords:** soy, beetroot, date, functional yogurt, physicochemical properties, optimization, central composite design.

1. **INTRODUCTION**

Yogurt is a functional food widely consumed worldwide due to its rich nutritional profile and numerous health benefits. The global yogurt market was valued at approximately $99,553.38 million in 2019 and is projected to reach $141,829.25 million by 2025. This significant growth is largely attributed to rising consumer awareness of yogurt's health benefits (Abdi-Moghadam *et al*., 2023). It contains vitamin D, calcium, proteins, and live bacteria. These bacteria, such as *Lactobacillus bulgaricus* and *Streptococcus thermophilus*, play an essential role in improving intestinal transit, nutrient absorption, restoring gut flora balance, and strengthening the immune system. In Cameroon, particularly in the northern region, where the diet primarily consists of cereals low in protein, such as rice and maize, yogurt represents an important complementary nutrient source (Ntentie *et al*., 2022). However, its production predominantly relies on animal milk, whose availability and accessibility remain limited in this region.

The average milk consumption in Cameroon estimated at 7.81 kg per capita per year, is significantly lower than the global average of 45 kg per capita per year (ACDIC, 2006). This deficit is due to low local production, forcing the country to import large quantities of milk. However, the current socio-economic context, marked by rising prices and supply difficulties, emphasizes the need to develop alternatives to cow’s milk for yogurt production. This need is further heightened by growing concerns over cow's milk allergenicity, lactose intolerance, and the search for vegetarian alternatives (Silva *et al*., 2020).

Among these alternatives, soy milk appears promising. It is relatively economical, rich in protein, and contains adequate amounts of essential amino acids necessary for a balanced diet (Qin *et al*., 2022). Additionally, soy has proven health benefits, including reducing plasma cholesterol and improving bone mineral density. It is also a source of bioactive molecules, such as isoflavones, which play a crucial role in preventing cardiovascular and renal diseases (Yamagata and Yamori, 2021). These characteristics make soy milk a key ingredient in developing functional yogurts.

Consumers are increasingly demanding nutritional quality in food products. The enrichment of yogurt with functional ingredients, such as fruits and vegetables, has been widely explored to meet this demand. Recent studies have highlighted the beneficial effects of incorporating ingredients such as spirulina (Sengupta and Bhowal, 2017), moringa powder (Ponka *et al*., 2022), or various fruits rich in bioactive compounds (Oliveira *et al*., 2015**;**de Morais *et al.*, 2024). However, limited attention has been paid to the use of combined dates and beetroot as enriching ingredients in yogurt, despite their abundance and high nutritional value.

Dates (*Phoenix dactylifera*) are particularly interesting due to their high content of natural sugars, soluble and insoluble fibers, and phenolic compounds with antioxidant properties. Their consumption promotes the growth of beneficial gut bacteria and inhibits pathogenic species (Abumaali *et al*., 2023**;**Subhash *et al*., 2024). Similarly, beetroot (*Beta vulgaris*) is an exceptional source of phytonutrients, including betalains, flavonoids, and nitrates *(Rehman et al*., 2023). These compounds have health benefits, including better tissue oxygenation, reduced oxidative stress, and a supply of essential minerals such as iron and magnesium (Mirmiran *et* *al*., 2020**;** Bangar *et al*., 2022 **;** Sentkowska and Pyrzyńska, 2023). Incorporating these ingredients into soy yogurt could not only improve its nutritional and functional qualities but also help prevent anemia, a common public health problem in certain vulnerable populations.

This study aims to formulate a functional yogurt based on soy milk enriched with date powder and beetroot extract. The primary objective is to optimize production conditions to improve the product's physicochemical, sensory, and functional properties while exploring its potential to address current nutritional challenges. The originality of this study lies in the combined use of two locally valued ingredients, rarely studied in functional yogurt formulation. These findings thus contribute to developing innovative plant-based dairy products that meet consumers' needs for nutritious, economical, and accessible alternatives.

**2 MATERIALS AND METHODS**

**2.1 Materials**

The plant materials used for producing the enriched soy yogurt included soybeans (*Glycine* *max*), dates (*Phoenix dactylifera*), and red beets (*Beta vulgaris*), all purchased from the Dang market in Ngaoundéré. Additionally, a lyophilized starter culture containing *Lactobacillus bulgaricus* and *Streptococcus thermophilus* was obtained from a local supermarket.

**2.2. Preparation of Date Powder and Determination of Proximate Composition**

The dates were carefully washed, dried using absorbent paper, and manually pitted. The flesh was then sliced into thin pieces using a stainless-steel knife before being dried in an oven at 40 °C for four days. The dried pieces were ground and sieved to obtain a homogeneous powder (particle size of 200 µm). The yield of date powder was calculated based on the initial fruit mass.

The proximate composition of the date powder was determined using AOAC (AOAC, 2000) methods. Analyses included moisture, crude protein, crude lipids, crude fiber, and ash content. The total sugar content was determined using the DNS method described by Fischer and Stein (Fischer and Stein, 1961), while the method described by Cortés-Rojas and Oliveira (Cortés-Rojas and Oliveira, 2012) was used to evaluate the solubility index.

**2.3 Preparation of Beetroot Extract and Determination of Phytochemicals**

The beets were manually cleaned to remove impurities, peeled, and cut into small pieces using a knife. These pieces were blended with water in a 1:5 (w/v) ratio. The resulting slurry was filtered through a muslin cloth to obtain a homogeneous beetroot extract. The phenolic compound content of this extract was determined using the method described by Borjan *et al*. (2022).

**2.4 Production of Soy Milk**

Soy milk was prepared using a method adapted from Udeozor (2012). One kilogram of sorted and washed soybeans was soaked in three liters of potable water for 10 hours. The soaked beans were manually dehulled, blanched at 80 °C for 5 minutes, drained, and weighed. The beans were then blended with potable water in varying soybean-to-water ratios (w/v) as shown in Table 1, using an electric blender. The resulting slurry was filtered through a cotton cloth to obtain soy milk.

**2.5 Production of Enriched Soy Yogurt with Dates and Beetroot**

Four hundred milliliters (400 mL) of soy milk, prepared with different soybean-to-water ratios, were mixed with varying amounts of date powder and sugar, with the latter added to reach a final concentration of 7.5% (w/v). The mixtures were pasteurized at 95 °C for 5 minutes and cooled to 65 °C. At this temperature, beetroot extract was added in proportions outlined in Table 1. The samples were homogenized, cooled to 42 °C, and inoculated with 1.5% (w/v) lyophilized starter culture. The mixture was incubated at 42–45 °C for six hours. After fermentation, the samples were rapidly cooled and stored at 4 °C until use.

**2.6 Response Surface Methodology (RSM)**

The response surface methodology (RSM) was employed to optimize the production conditions for yogurt enriched with date powder and beetroot extract. The factors studied (Table 1) included the soybean-to-water ratio (X1, 120–240 g/400 mL), beetroot extract volume (X2, 25–100 mL), and date powder quantity (X3, 25–75 g). A face-centered central composite design (FCCD) was used to study the effect of these variables on the responses: pH (Y1), viscosity (Y2), and total soluble solids expressed in °Brix (Y3).

A second-order polynomial model was used to predict the responses while considering interactions between the factors. Regression coefficients for linear, quadratic, and interaction terms were determined, and model significance was evaluated through analysis of variance (ANOVA). Optimal conditions were derived by simultaneously maximizing the three responses.

**2.7 Analysis of Enriched Yogurt**

The pH of the soy yogurt samples was directly measured using an appropriate pH meter. Before use, the pH meter was calibrated with buffer solutions of pH 4.0, 7.0, and 9.0 and rinsed with distilled water. The pH probe was then inserted into 25 mL of yogurt sample, and the reading was recorded.

Viscosity was measured using a Brookfield viscometer (model DV-E) equipped with a rotating spindle (spindle no. 3) at 20 revolutions per minute, maintained at a constant temperature of 25 °C for 5 minutes. The samples, previously stored at 4 °C, were brought to ambient temperature before analysis. A 10 mL yogurt sample was transferred to a beaker, and the spindle was immersed before starting the viscometer. Results were expressed in millipascal-seconde (mPa-s).

 Total soluble solids content (°Brix) was measured using a handheld refractometer (model RX-7000i, ATAGO CO. LTD, Japan). A drop of yogurt sample was placed on the refractometer prism, and the reading was taken directly through the device’s eyepiece under light. Results were expressed in °Brix.

**2.8 Enumeration of Lactic Acid Bacteria**

Lactic acid bacteria were enumerated on MRS agar following the Standardization Administration of China (Standardization Administration of China, 2023)standard method. Twenty-five grams (25 mL) of soy yogurt were aseptically transferred to a stomacher bag containing 225 mL of sterile 0.9% saline solution and homogenized using a stomacher (Stomacher, IUL Instruments, Spain) for 60 seconds.

Aliquots of 1 mL from serial dilutions (1:10, prepared with 0.9% saline) of each sample were inoculated onto Petri dishes, followed by the addition of MRS medium. After incubation, results were expressed as colony-forming units (CFU) per mL of sample.

**2.9 Sensory Evaluation**

The sensory characteristics of the yogurt, including appearance, taste, aroma, mouthfeel, and texture, were evaluated by a panel of 30 untrained individuals. Twenty freshly prepared yogurt samples were removed from the refrigerator one hour before the evaluation to bring them to optimal tasting temperature. Each sample was presented in a plastic cup labeled with a three-digit code to ensure anonymity. The presentation order of the samples was randomized to avoid bias. Sensory attributes were scored using a nine-point hedonic scale (Al-Nabulsi *et al*., 2014) : 1 = dislike extremely, 2 = dislike very much, 3 = dislike moderately, 4 = dislike slightly, 5 = neither like nor dislike, 6 = like slightly, 7 = like moderately, 8 = like very much, and 9 = like extremely.

**2.10 Statistical Analysis**

Statistical analysis of the experimental data was conducted using Analysis of Variance (ANOVA) with Statgraphics Centurion 19 (version 19.1.1). The Response Surface Methodology (RSM) was performed using Design Expert 13 (version 13.0.5.0). Regression analysis was used to evaluate the significance of each regression coefficient and the goodness of fit of the models. Differences were considered statistically significant when p-values were less than 0.05.

**3 Results and Discussion**

**3.1 Chemical Composition and Bioactive Compounds**

The chemical composition of date powder and beetroot extract is presented in the table 2. The table shows that the dry matter (DM), ash, protein, and lipid content of dates are 94.26 ± 0.67%, 5.38 ± 0.01 g/100 g DM, 4.93 ± 0.54 g/100 g DM, and 0.64 ± 0.00 g/100 g DM, respectively. It also highlights that carbohydrates are present in the largest proportion (83.49 ± 0.93 g/100 g DM). These results confirm the observations reported by Assirey (2015), who also noted a predominance of carbohydrates (contents ranging from 71.2 to 81.4 g/100 g DM) in dates varieties from Saudi Arabia. These carbohydrates include non-reducing sugars such as sucrose, reducing sugars like glucose, maltose, and fructose, as well as traces of polysaccharides. The ash content in date powder (5.38 ± 0.01 g/100 g DM) reflects its richness in minerals, while the high solubility index (87.84 ± 2.43%) highlights its suitability for homogeneous incorporation into food matrices like yogurt.

Regarding bioactive compounds, the total phenolic content of date powder is 827 ± 20.51 mg gallic acid equivalent (GAE)/100 g DM, which is higher than the values reported by Bano et al. (2022) for several date varieties from Pakistan (424.09 ± 3.54 to 457.68 ± 3.73 mg GAE/100 g). However, Aleid and Haddadin (2023) measured an even higher phenolic content (1833.52 ± 8.5 mg GAE/100 g), suggesting that differences may be attributed to environmental factors (climate, soil fertility), agronomic practices (maturity stage, harvesting methods), and cultivar variations.

For beetroot extract, the total phenolic content is relatively moderate (63.33 ± 7.44 mg GAE/100 mL) but sufficient to confer significant antioxidant properties. Beetroot is also known to contain betalains, flavonoids, and other biologically active phytonutrients that complement its functional profile (Mirmiran *et al*., 2020**;** Bangar *et al*., 2022)**;** Sentkowska and Pyrzyńska, 2023).

These results indicate that date powder and beetroot extract are promising ingredients for enriching functional products, not only in terms of nutrients but also bioactive compounds. Their incorporation into soy-based yogurt could thus add value to this product in terms of both nutritional and functional quality.

**3.2 Modeling the Impact of Factors on Physicochemical Characteristics**

Table 3 presents the results of the physicochemical analyses (pH, °Brix, and viscosity) performed on the enriched soy yogurt samples after storage at 4 °C for 24 hours. The measured parameters varied significantly between samples depending on the experimental conditions. The pH ranged from 2.49 (sample E15) to 5.42 (sample E3). These differences are mainly due to variations in the soybean-to-water ratios and the amount of date powder used. These results corroborate those of Ponka *et al*. (2022), who observed similar values (3.66 ± 0.01 to 4.11 ± 0.01) in yogurts enriched with moringa powder. Likewise, Sengupta and Bhowal (2017)reported comparable pH values (3.43 ± 0.01 to 5.55 ± 0.01) in soy yogurts enriched with spirulina powder (*Spirulina platensis*).

Viscosity ranged from 140 mPa.s (E9) to 6575 mPa.s (E1). High viscosity was observed in samples with a higher soybean-to-water ratio and a greater quantity of date powder, attributed to the increased total solid content. These observations align with the findings of Behnia *et al*. (2013), who showed that solids, such as proteins and sugars, enhance water retention and viscosity.

The total soluble solid content (°Brix) varied between 10.5 °B (E15) and 19.16 °B (E1). This variation was influenced by the quantity of date powder and the soybean-to-water ratio. A larger volume of beetroot extract tended to dilute the soluble solids, thereby reducing the °Brix values.

**3.3 Regression Equations and Model Fitting for RSM**

Second-order polynomial models were developed to predict the responses (pH, viscosity, °Brix) based on the factors studied. The regression equations obtained are presented below:







The regression coefficients for each response were evaluated using analysis of variance (ANOVA) (Table 4). The predictive models for pH, viscosity, and °Brix in enriched soy yogurt showed strong reliability. The *p*-values for all responses (0.0077, 0.0001, and 0.0008) confirm their statistical significance. The coefficient of determination (R²) values were 90.43% (pH), 95.83% (viscosity), and 95.13% (°Brix), indicating that the models effectively explain the variability of the responses. Among them, the viscosity model demonstrated the highest accuracy with an adjusted R² of 93.33%, followed closely by °Brix and pH. These results validate the models' robustness for optimizing enriched soy yogurt formulations.

**3.4. Effects of Factors and Interactions**

Table 5 presents the coefficients and significance levels of the studied factors. It shows that the pH of soy yogurt is significantly influenced by the soybean-to-water ratio (factor A) and the quantity of date powder (factor C). The AC interaction is also significant. The pH tends to increase with a higher soybean-to-water ratio, likely due to the basic nature of certain amino acids in soybeans, such as lysine. Date powder, which is rich in neutral carbohydrates, also contributes to this increase.

The viscosity of soy yogurt is crucial for its potential commercialization. Table 5 indicates that viscosity is primarily affected by the soybean-to-water ratio (A) and the volume of beetroot extract (B). A significant interaction between A and B was identified. An increase in the soybean-to-water ratio leads to higher viscosity due to the increased solid content (proteins and sugars) in the soy yogurt. Conversely, larger amounts of beetroot extract reduce viscosity, likely by diluting the protein matrix and increasing the dispersion of protein aggregates.

Table 5 shows that total soluble solids (°Brix) are influenced by all three factors (A, B, C), as well as the quadratic effect of 𝐴2. The quantity of date powder and the soybean-to-water ratio increase the °Brix, while a higher volume of beetroot extract reduces this response.

**3.5 Visualization of Interactions**

Figures 1a and 1b illustrate the combined effects of the factors on pH and viscosity, respectively. For instance, Figure 1a shows that pH reaches its maximum (approximately 5.4) when the soybean-to-water ratio is 180/400 and 75 g of date powder is added. Figure 1b highlights a significant increase in viscosity with a higher soybean-to-water ratio but a progressive decrease with increasing volumes of beetroot extract.

**3.6 Simultaneous Optimization of All Responses and Experimental Validation of Optimal Conditions**

The simultaneous optimization of the characteristics of soy yogurt was performed using the desirability function approach (DFA). This method assigns a desirability value to each condition, ranging from 0 to 1. A value of 0 represents no desirability, while a value of 1 corresponds to the maximum achievable desirability, based on the defined constraints. The constraints of this optimization are summarized in Table 6.

The results of this optimization are presented in Table 6. The combined optimal conditions for all responses were a soybean-to-water ratio of 161.76 g/400 mL, 25 mL of beetroot juice, and 25 g of date powder. Under these conditions, the predicted values for physicochemical parameters were as follows: pH (4.50), °Brix (14.02), and viscosity (1958.93 mPa.s). These results corresponded to an overall desirability value of 0.93 (Table 6).

To evaluate the adequacy of the predictive model, an experiment was conducted under these optimal conditions. The experimental values obtained were very close to the predicted values (Table 7) : pH (4.47 ± 0.21), °Brix (14.67 ± 0.58), and viscosity (1973 ± 110.58 mPa.s). These results demonstrate the accuracy and reliability of the response surface methodology (RSM) for optimizing the formulation of functional yogurt.

**3.7 Sensory and Microbiological Characteristics**

The acceptability of a food product by consumers is closely linked to its organoleptic properties. Table 8 presents the average scores for various sensory analysis parameters for the optimized sample and the control sample.

This table shows that both the control and optimized samples achieved high scores for most evaluated parameters, particularly overall acceptability, color, and acidity. No significant differences were observed for these parameters (p ≥ 0.05). However, the sweetness of the optimized sample was significantly more appreciated than that of the control sample. Conversely, the texture of the control sample was judged significantly better than that of the optimized sample. These results align with the findings of Assia (2012), who evaluated the sensory qualities of five cow milk yogurts enriched with date powder. Boulkour found that the enriched samples were sweeter than the control but that the control sample was creamier and firmer.

Regarding the microbiological analysis, Table 8 shows that the number of lactic acid bacteria in the control yogurt (7.60 ± 0.02 Log CFU/mL) was lower than that in the yogurt enriched with date powder and beetroot extract (8.72 ± 0.04 Log CFU/mL). This confirms earlier observations (Subhash *et al*., 2024). This effect could be attributed to the soluble dietary fiber content of the date powder and the presence of small molecules, such as amino acids, peptides, and nucleotides, which are essential for the growth of lactic acid bacteria, thereby increasing their population.

**4 CONCLUSION**

This study demonstrated that dates offer significant nutritional benefits and are a rich source of natural sugars, which can be used as a substitute for sugar in the creation of various value-added products. Additionally, date powder and beetroot extract can be utilized as sources of bioactive compounds, paving the way for the development of functional yogurts. Based on the results obtained through the response surface methodology (CCD), the ideal production conditions for enriched yogurt were determined as follows: a soybean-to-water ratio of 161.76 g/400 mL, 25 mL of beetroot juice, and 25 g of date powder. The yogurt enriched with date powder and beetroot extract showed a positive impact on the quantity of lactic acid bacteria and on certain sensory characteristics. These results thus provide a theoretical foundation for the development of new functional yogurts. Furthermore, the presence of iron in beetroot extract could help reduce the prevalence of anemia among pregnant women. Consequently, this type of yogurt could serve as an innovative functional food in the dairy industry. For future studies, it is recommended to determine the complete proximate composition of the enriched yogurt and evaluate its shelf life to ensure long-term stability.

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**Table and figure** **captions**

### ****Table 1.**** Independent variables and their levels for enriched soy yogurt optimization

**Table 2. Chemical composition of date powder and beetroot extract**

\*GAE: Gallic Acid Equivalent.

**Table 3. Experimental results of enriched soy yogurt analysis**

**Table 4 : Model validation characteristics for pH, Viscosity, and °Brix in enriched soy yogurt**

**Table 5 : Significance levels of factors for pH, viscosity, and °Brix**

**Table 6 : Optimal conditions for the production of enriched soy yogurt based on response surface methodology (RSM)**

**Table 7 : Model validation - comparison of predicted and observed responses for enriched soy yogurt**

### Table 8 : ****Comparison of sensory and microbiological characteristics between control and optimized enriched soy yogurt****

**Figure 1**. **3 D surface plot for interaction between factors : a- effect of soybean-to-water ratio and date powder on the pH of enriched soy yogurt ; b - effect of soybean-to-water ratio and beetroot extract on the viscosity of enriched soy yogurt**

### ****Table 1.**** Independent variables and their levels for enriched soy yogurt optimization

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Independent Variable** | **Symbol** | **-1** | **0** | **+1** |
| Soybean-to-Water Ratio (g/400 mL) | A | 120 | 180 | 240 |
| Date Powder (g) | B | 25 | 62.5 | 100 |
| Beetroot Extract (mL) | C | 25 | 50 | 75 |

**Table 2.** Chemical composition of date powder and beetroot extract

|  |  |  |
| --- | --- | --- |
| Parameters | Date Powder | Beetroot Extract |
| Dry matter (%) | 94.26 ± 0.67 | / |
| Ash (g/100 g DM) | 5.38 ± 0.01 | / |
| Total sugars (g/100 g DM) | 83.49 ± 0.93 | / |
| Lipids (g/100 g DM) | 0.64 ± 0.00 | / |
| Proteins (g/100 g DM) | 4.93 ± 0.54 | / |
| Solubility index (%) | 87.84 ± 2.43 | / |
| Phenolic compounds\* (mg GAE/100 g and mg GAE/100mL) | 827 ± 20.51 | 63.33 ± 7.44 |

\*GAE: Gallic Acid Equivalent.

**Table 3.** Experimental results of enriched soy yogurt analysis

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Run | Soybean-to-Water Ratio g/400 mL | Beetroot Extract mL | Date Powder g | pH | Viscosity mPa.s | °Brix |
| 1 | 240 | 25 | 75 | 5.31 | 6575 | 19.16 |
| 2 | 240 | 62.5 | 50 | 4.93 | 3590 | 15.75 |
| 3 | 180 | 62.5 | 50 | 5.42 | 2559.5 | 16.16 |
| 4 | 240 | 100 | 75 | 4.98 | 2020 | 16.16 |
| 5 | 180 | 62.5 | 50 | 4.93 | 2149 | 15.83 |
| 6 | 180 | 62.5 | 75 | 5.42 | 3209 | 18.75 |
| 7 | 240 | 25 | 25 | 4.95 | 5750 | 15.41 |
| 8 | 120 | 100 | 75 | 5.01 | 340 | 14.25 |
| 9 | 120 | 25 | 25 | 3.33 | 140 | 11.67 |
| 10 | 180 | 100 | 50 | 5.34 | 1220 | 15.00 |
| 11 | 180 | 25 | 50 | 5.03 | 2850 | 17.25 |
| 12 | 120 | 25 | 75 | 4.66 | 330 | 16.50 |
| 13 | 120 | 62.5 | 50 | 4.27 | 295 | 12.75 |
| 14 | 240 | 100 | 25 | 4.20 | 1770 | 11.25 |
| 15 | 120 | 100 | 25 | 2.49 | 169.95 | 10.50 |
| 16 | 180 | 62.5 | 25 | 4.99 | 2140 | 11.63 |
| 17 | 180 | 62.5 | 50 | 4.77 | 1103 | 16.88 |

### ****Table 4 :** Model validation characteristics for pH, Viscosity, and °Brix in enriched soy yogurt**

|  |  |  |  |
| --- | --- | --- | --- |
| **Response** | **Significance Threshold (p-value)** | **R² (%)** | **Adjusted R² (%)** |
| **pH** | 0.0077 | 90.43 | 78.11 |
| **Viscosity** | 0.0001 | 95.83 | 93.33 |
| **°Brix** | 0.0008 | 95.13 | 88.87 |

**Table 5 :** Significance levels of factors for pH, viscosity, and °Brix

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Interactions | Coefficient (pH) | *p*-value (pH) | Coefficient (Viscosity) | *p*-value (Viscosity) | Coefficient (°Brix) | *p*-value (°Brix) |
| A | 0.4605 | 0.0050 | 1843 | 0.0001 | 1.60 | 0.0033 |
| B | -0.1250 | 0.3104 | -1012.51 | 0.0001 | -1.70 | 0.0024 |
| C | 0.5425 | 0.0021 | 250.41 | 0.1338 | 3.25 | 0.0001 |
| AB | -0.0750 | 0.5758 | -1071.87 | 0.0001 | -0.6250 | 0.1710 |
| AC | -0.3375 | 0.0334 | 89.37 | 0.6138 | 0 | 1.0000 |
| BC | 0.2012 | 0.1593 | -74.37 | 0.6739 | 0 | 1.0000 |
| A² | -0.6552 | 0.0209 | - | - | -1.99 | 0.0260 |
| B² | -0.0677 | 0.7680 | - | - | 0.5070 | 0.4971 |
| C² | -0.0502 | 0.8265 | - | - | -0.7430 | 0.3289 |

**Table 6 :** Optimal conditions for the production of enriched soy yogurt based on response surface methodology (RSM)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Parameters | Goal | Lower Limit | Upper Limit | Optimal Conditions |
| A: Soybean-to-Water Ratio | Is in range | 120 | 240 | 161.763 |
| B: Beetroot Extract (mL) | Is in range | 25 | 100 | 25 |
| C: Date Powder (g) | Is in range | 25 | 75 | 25 |
| pH | Target = 4.5 | 4.2 | 4.6 | 4.500 |
| Viscosity (mPa.s) | Maximize | 1000 | 2000 | 1958.926 |
| °Brix | Target = 14.83 | 10.5 | 18 | 14.016 |
| Desirability | - | - | - | 0.924 |

**Table 7 :** Model validation - comparison of predicted and observed responses for enriched soy yogurt

|  |  |  |  |
| --- | --- | --- | --- |
| Parameter | Predicted Response | Observed Response | 95% Prediction Interval (PI) |
| pH | 4.50 | 4.47 ± 0.21 | [3.63316, 5.36687] |
| Viscosity (mPa.s) | 1958.95 | 1973 ± 110.58 | [1022.92, 2894.97] |
| °Brix | 14.02 | 14.67 ± 0.58 | [11.931, 16.1006] |

### Table 8 : **Comparison of sensory and microbiological characteristics between control and optimized enriched soy yogurt**

|  |  |  |
| --- | --- | --- |
| **Parameters** | **Control** | **Optimized sample** |
| **Sweetness** | 6.56 ± 1.03ᵇ | 7.38 ± 1.47ᵃ |
| **Color** | 7.00 ± 0.89ᵃ | 7.06 ± 1.18ᵃ |
| **Texture** | 6.88 ± 1.31ᵃ | 5.81 ± 1.87ᵃ |
| **Acidity** | 7.38 ± 1.14ᵃ | 7.44 ± 0.73ᵃ |
| **Viscosity** | 7.06 ± 1.23ᵃ | 5.50 ± 2.00ᵇ |
| **Overall Acceptability** | 7.00 ± 1.10ᵃ | 7.13 ± 1.26ᵃ |
| **Lactic Acid Bacteria (Log CFU/mL)** | 7.60 ± 0.02 | 8.72 ± 0.04 |

(a)



(b)



**Figure 1**. **3 D surface plot for interaction between factors : (a)- effect of soybean-to-water ratio and date powder on the pH of enriched soy yogurt ; (b) - effect of soybean-to-water ratio and beetroot extract on the viscosity of enriched soy yogurt**