https://doi.org/10.17113/ftb.62.02.24.8329 original scientific paper

Optimised Formulation of a New Sweet Apricot Kernel-Enriched Yoghurt: Assessment of Physicochemical, Sensory and Antioxidant Properties

Running head: A New Yoghurt Formulation Based on Sweet Apricot Kernels

Mohand Teffane[1*], Hafid Boudries[1], Mostapha Bachir-bey[2], Ahcene Kadi[1], Younes Arroul[1] and Abdeslem Taibi[1]

[1]Laboratoire de Biomathématiques, Biophysique, Biochimie et Scientométrie (L3BS), Faculté des Sciences de la Nature et de la Vie, Université de Bejaia, 06000 Bejaia, Algérie
[2]Laboratoire de Biochimie Appliquée, Faculté des Sciences de la Nature et de la Vie, Université de Bejaia, 06000 Bejaia, Algérie

Received: 17 August 2023
Accepted: 28 May 2024

SUMMARY

Research background. Incorporating sweet apricot kernel powder, a by-product of apricot processing, into yoghurt appears to be an especially intriguing option for innovating new food products. This study focused on formulating a novel yoghurt enriched with sweet apricot kernel powder, sugar and milk powder.

Experimental approach. Different yoghurts were prepared by mixing sweet apricot kernel powder, sugar, and milk powder, as ingredients based on the Simplex-Centroid Mixture design. The optimisation process took into account the physicochemical, antioxidant and sensory characteristics of yoghurt.

Results and conclusions. The results demonstrated that optimal values of sugar, milk powder, and apricot kernel powder were 3.073, 2.161, and 2.766 %, respectively. The physicochemical assays showed that the addition of apricot kernel powder led to a significant increase in total phenolic content, antioxidant activity, syneresis, viscosity, and acidity. Sugar and milk powder additions also had a significant influence on the taste, texture, and consistency of the yoghurt. Moreover, the enrichment of the product with apricot kernel powder significantly influenced the colour, odour, taste, texture, and

*Corresponding author:
Phone:+213658921655
E-mail: mohand.teffane@univ-bejaia.dz

consistency. In conclusion, the optimised enriched yoghurt with apricot kernel exhibited interesting phenolic content and antioxidant properties with sensory acceptability while reducing the amount of sugar and milk powder. This confirms the potential of using sweet apricot kernels as an ingredient in yoghurt production.

Novelty and scientific contribution. The use of a Simplex-Centroid Mixture design to optimise a new yoghurt formulation enriched with sweet apricot kernels reveals significant improvements in total phenolic content, antioxidant activity, and sensory acceptability. In addition, it allows for a reduction in sugar and milk powder requirements. Therefore, incorporating sweet apricot kernels into yoghurt presents a novel approach to enhancing its nutritional value and sensory appeal.

Keywords: yoghurt; sweet apricot kernel; antioxidant; optimisation; physicochemical; sensory property

INTRODUCTION

Apricot tree (*Prunus armeniaca* L.) is grown in 68 countries worldwide and produces approximately 3.84 million tons of apricot fruits. Apricots are primarily cultivated in the Mediterranean region (*1*–*3*). The processing of apricot fruit generates significant quantities of kernels, often discarded by industries, resulting in the loss of potentially valuable resources and posing environmental challenges (*4,5*). These kernels contain many beneficial compounds such as unsaturated fatty acids, proteins, bioactive components like phenolic acids, flavonoids, essential minerals and vitamins (*6*). Consequently, apricot kernels find various applications in the cosmetic, pharmaceutical, and food industries (*7*–*9*).

As far as our knowledge extends, the utilization of bitter apricot kernels in food production is severely restricted due to the presence of amygdalin. However, sweet and detoxified kernels have been used in the formulation of cookies (*9*–*11*), and dairy products (*12*–*14*).

Dairy products are widely consumed food items globally and have exhibited a substantial increase in consumption over the recent years (*15*). Among popular dairy products, yoghurt is highly valued by consumers. It has been known for centuries for its therapeutic benefits (*16*). It has been reported that yoghurt consumption contributes to alleviating diarrhoea, shortening colonic transit time, boosting immunity, and contributing to lower serum cholesterol levels (*16*).

In the continuation of the apricot kernel recovery work, food waste management is becoming an issue from both an environmental and economic perspective, as it not only reduces pollution but also offers new opportunities for economic development. Additionally, in the context of innovating new food products to satisfy consumers' needs for natural, nutritious products that are beneficial to health, dairy products encompass a wide range of products. The incorporation of sweet apricot kernel powder into yoghurt is highly desirable. However, no research has investigated optimising the amounts of sweet apricot kernels with sugar and milk powder and determining their effect on the physicochemical, antioxidant, and sensory attributes of yoghurt. This optimisation is necessary to reduce the quantity of incorporated ingredients and determine their effects and interactions in the yoghurt.

Therefore, the objective of the present study is to optimize the combination of three ingredients, incorporated in yoghurt using Simplex-Centroid Mixture design approach. The main goal is to develop a low-sugar and rich antioxidant yoghurt that not only complies with quality standards but also satisfied the sensory preferences of consumers. To achieve this, various physicochemical properties such as total phenolic content (TPC), 2,2-diphenyl-1-picrylhydrazyl free radical scavenging activity (DPPH-RSA), 2,2'-azino-bis(3-ethylbenzthiazoline-6-sulphonic acid radical scavenging activity (ABTS-RSA), syneresis, viscosity, pH and acidity, as well as sensory characteristics including texture, taste, and appearance are carefully assessed.

MATERIALS AND METHODS

Raw materials

Milk, sugar, and milk powder were purchased from a market in the city of Bejaia, Algeria. The sweet apricot kernels were kindly provided by the apricot processing industry N'gaous located in the Batna department, Algeria, during July 2021. They were ground and sieved to a diameter of less than 1 mm.

Physicochemical and antioxidant properties of sweet apricot kernels

The physicochemical and antioxidant characteristics of sweet apricot kernel powder were analysed using standard protocols reported in various studies. Moisture content was measured by drying 5 g samples at 105 °C until a constant weight was obtained using a ventilated oven (Memmert GmbH + Co.KG, Schwabach, Germany) (*5*). Ash content was determined by incinerating 5 g of sample in a muffle furnace at 600 °C during 4 hours (Nabertherm, LE 2/11/R6, Lilienthal/Bremen, Germany) (*17*). Lipids from sweet apricot kernel powder were extracted using ultrasound-assisted extraction (Branson Ultrasonics Corporation, 2510E-DTH, Danbury, USA) with n-hexane at 50 °C for 40 minutes. After filtering and evaporating the solvent, the oil yield was calculated (*18*). Total protein was assessed using the Bradford method (19) by mixing 200 µL of extract, obtained from 1 g of powder with 20 mL of 70 % ethanol for 24 hours, with 2.5 mL of Bradford reagent and measuring the absorbance at 596 nm. Carbohydrate content was determined by extracting 0.5 g of the sample with 20 mL of 80 % ethanol, followed by incubation at 95 °C and centrifugation; the supernatant (1 mL) was then mixed with 0.5 mL of 5 % phenol and 2.5 mL of sulfuric acid, and the absorbance was measured at 490 nm after a 20-minute incubation at 80 °C. (*20*). Total hydrogen cyanide (HCN) content was estimated by immersing 10 g of apricot kernel powder in a phosphoric acid solution, distilling the mixture, and titrating the distillate with $AgNO_3$ (*27*). Polyphenols were extracted by shaking 0.5 g of apricot kernel powder with 20 mL of 50 % acetone in a magnetic stirrer (AM4, VELP Scientifica, Usmate, Italy) (*21*). Total phenolic content (TPC) was measured using the Folin-Ciocalteu method, where extracts were reacted with Folin-Ciocalteu reagent and sodium carbonate, and absorbance was measured at 765 nm (*22*). Total flavonoid content (TFC) was determined by mixing 1 mL of extract with 1 mL of 2 % aluminium chloride solution and measuring absorbance at 430 nm (*23*) . Tannin content (TC) was measured by mixing 50 µL of extract with 1.5 mL of 4 % vanillin methanolic solution and HCl and measuring absorbance at 500 nm (*24*). The antioxidant activities (DPPH-RSA and ABTS-RSA) were conducted according to methods reported by Alam *et al*. (*25*) and Pérez-Chabela *et al*. (*26*), respectively. Samples were mixed with DPPH or $ABTS^+$ solutions and absorbance was measured after 30 minutes for DPPH-RSA at 517 nm or 6 minutes for ABTS-RSA at 734 nm, with results expressed as inhibition percentages.

Yoghurt preparation and experimental design

The yoghurts were processed following the method described by Felfoul *et al.* (*28*). The milk mixture with sugar, milk powder, and sweet apricot kernels powder was pasteurized at 85 °C for 30 minutes and then cooled to 45 °C. It was then filled into 180 mL plastic bottles and incubated at 45 °C for 6 hours with 0.01 g/L of lactic bacteria (*Streptococcus thermophilus* and *Lactobacillus delbrueckii* subsp. *bulgaricus*). After incubation, the yoghurts were cooled at 4 °C for 48 hours and mixed to disperse the apricot kernel skin for homogenization. They were then stored for further analysis. All experiments were repeated to ensure the reproducibility of the results.

To obtain an acceptable yoghurt product with optimal physicochemical, antioxidant, and sensory properties, a Simplex-Centroid Mixture design consisting of ten formulations. The design aimed to optimise and evaluate the effects of three ingredients: sugar (SGR) (X_1), milk powder (MP) (X_2), and sweet apricot kernel powder (SAK)(X_3). The total amount of added ingredients in each formulation was fixed at 8 % (*m*/*m*), and the proportions of the components were expressed as fractions of the mixture, with the sum of the ingredients (X_1+X_2+X_3=1) (coded value). The experimental design included ten combinations of the three factors at various levels, while the 11th formula (K) served as a negative control without any added ingredients (Table 1).

The statistical analysis of responses for each yoghurt formulation was performed using the JMP software (version 10.0.0) (*29*). The analysis of variance (ANOVA) was used to determine the significance of the independent variables and their interactions, as well as the statistical significance of the regression coefficients and the adequacy of the model fit. The level of significance for each predicted response was set at α=0.05. The polynomial model, represented by the basic equation Eq. 1.

$$Y=\beta_1X_1+\beta_2X_2+\beta_3X_3+\beta_{12}X_1X_2+\beta_{13}X_1X_3+\beta_{23}X_2X_3 \qquad /1/$$

where Y is the response (pH, acidity, viscosity, syneresis, TPC, DPPH-RSA, ABTS-RSA, taste, texture, consistency colour, odour, and overall acceptability); β_1, β_2, β_3, β_{12}, β_{13}, and β_{23} represent the coefficient of factors and their interactions; X represents the concentration of each ingredient: X_1 for sugar, X_2 for milk powder, and X_3 for sweet apricot kernel powder.

Physicochemical analysis and antioxidant properties of yoghurt

The pH and syneresis were determined using the method reported by Pachekrepapol *et al.* (*30*). After 24 hours of storage at 4 °C, the pH evaluation was conducted using a Sension+PH3 pH-meter (Hach, Colorado, USA). The pH measurement was performed directly on yoghurt samples at a temperature of approximately 14 °C.

For syneresis 5 g of yoghurt was centrifuged (Digicen 21R centrifuge, Orto Alresa, Madrid, Spain) at 2,000×g for 20 minutes at 4 °C. The degree of syneresis (%) was calculated using the equation Eq. 2.

$$\text{Syneresis}(\%)=(m_{\text{supernatant}}\ (\text{g})/m_{\text{yogurt sample}}\ (\text{g}))\cdot 100 \qquad /2/$$

Titratable acidity of the formulated yoghurts was measured using the method described by Pérez-Chabela *et al.* (*26*). Yoghurt samples (10 g) were mixed with 40 mL of distilled water and adding 3 drops of phenolphthalein then titrated with NaOH (0.1 N) until a slight pink colour appeared.

The viscosity of the formulated yoghurts was measured according to Felfoul *et al.* (*28*). The viscosity was determined using a viscometer (SNB-1, Precision Instruments, Shanghai, China), with a spindle No. 4 at 60 rpm for 30 seconds, and was expressed in P.as.

Phenolic compound extraction and antioxidant activity

The phenolic compounds were extracted using the method described by Pérez-Chabela *et al.* (*26*). Briefly, 1 g of sample was macerated in 40 mL acetone: water (1:2, v/v) for 30 min at room temperature (22 °C) using magnetic stirrer (AM4, VELP Scientifica, Usmate, Italy). The resulting crude extracts were then filtered and centrifuged at 25975×g 10 min.

The total phenolic content (TPC) was determined following the method described by Goli *et al.* (*31*). In brief, 0.2 mL of each extract was mixed with 1 mL of Folin-Ciocalteu reagent (diluted 1:10 with distilled water), followed by the addition of 0.8 mL of sodium carbonate solution (7.5 %, *m*/*V*).

The absorbance was recorded at 765 nm using a spectrophotometer (Shimadzu, UV mini1240, Suzhou Jiangsu, China) after 30min of incubation. The TPC was expressed in mg GAE/100 g of yoghurt.

The free radical DPPH scavenging was tested following the method described by Alam *et al.* (*25*). 1 mL of DPPH stock solution (0.5 mM) was diluted with methanol in order to obtain the absorbance of 0.80±0.01 at 517 nm. Then, 0.9 mL of DPPH diluted solution was added to 0.1 mL of extract. After an incubation for 30 min, the absorbance (*A*) was recorded at 517 nm. The inhibition percentage of DPPH free radical scavenging was calculated using the following formula /3/:

$$\text{DPPH-RSA}(\%)=[(A_{\text{Control}}-A_{\text{Sample}})/A_{\text{Control}}]\cdot 100 \qquad /3/$$

The antioxidant potential of $ABTS^{+}$ radical scavenging was tested according to Pérez-Chabela *et al.* (*26*). The $ABTS^{+}$ radical was generated by reacting 7 mM ABTS and 2.45 mM potassium persulfate after incubation for 12 h. The $ABTS^{+}$ solution was then diluted with distilled water until reaching an absorbance (*A*) of 0.70±0.02 at 734 nm. Then, 0.1 mL of extract was mixed with 0.9 mL of $ABTS^{+}$ working solution, and the absorbance was recorded after 6 minutes at 734 nm. The percentage of ABTS free radical scavenging was calculated using the following formula /4/:

$$\text{ABTS-RSA}(\%)=[(A_{\text{Control}}-A_{\text{Sample}})/A_{\text{Control}}]\cdot 100 \qquad /4/$$

Yoghurt sensory evaluation

The sensory attributes were evaluated according to the method described by Felfoul *et al.* (*28*). The yoghurt samples were taken out of the refrigerator and allowed at room temperature for approximately 1 min. The serving temperature range for the samples was approximately 10 to 12 °C. Each yoghurt sample was presented in a 35 mL plastic cup with a lid and each cup was labelled with an alphabetic code. The order of presentation of the samples was randomized, with 7 samples presented in the first session and 4 samples presented in the second tasting session.

For the evaluation, a panel of 18 individuals was invited to assess the colour, texture, consistency, odour, and taste of the yoghurt samples. The panel comprised 14 trained female experts and 4 untrained male participants, with ages ranging from 25 to 48 years. The overall acceptability of the yoghurts was evaluated using a 9-point hedonic scale, where 1: extremely unpleasant, 2: very unpleasant, 3: moderately unpleasant, 4: slightly unpleasant, 5: neither pleasant nor unpleasant, 6: slightly pleasant, 7: moderately pleasant, 8: very pleasant, and 9: extremely pleasant.

Statistical analyses

The means ± standards deviation of the trials were reported. To determine significant differences between the means at a significance level of 5 %, the one-way analysis of variance

(ANOVA) with the LSD-Fisher test was used to compare the means between physicochemical and antioxidants characteristics. For sensory characteristics, the Kruskal-Wallis: Conover-Iman test was used to compare the means. All mathematical calculations and statistical analyses were conducted using Statistica (version 13.3.0) (*32*), demo versions of the MS Office XLSTAT-Pro 2014 (*33*), and JMP (version 10.0.0) (*29*) software.

RESULTS AND DISCUSSION

Physicochemical and antioxidant properties of sweet apricot kernel

The physicochemical properties of the apricot kernel powder used in the yoghurt formulations were presented in Table 2. The moisture, ash, protein, lipids, and carbohydrate contents were estimated to be 8.85±0.88 %, 3.47±0.11 %, 1.33±0.19 %, 56.19±1.99 %, and 8.78±0.90 %, respectively. These results were corroborate with those of data obtained by Fayed, (*34*), and those obtained by Arafa, (*35*). These authors reported that the moisture content of apricot kernels ranges from 3.25 % to 13.56 %, depending on the variety. Femenia *et al.* (*36*) observed the moisture content ranging from 5.4 to 6.7 %, carbohydrate content (5 to 20 %), and lipids content (40 to 56 %). Similarly, Hayta and Alpaslan (*37*), reported that apricot kernels have carbohydrates ranged from 17 to 27.9 %, proteins (14.1 to 45.3 %), and lipids from 27.7 to 66.7 %. Furthermore, Mohamed *et al.* (*38*) reported an ash content of 2.2 %, carbohydrate content of 31.56 %, protein content of 22.6 %, and the lipids content of 42.8 % in apricot kernels.

The apricot kernel powder used in the yoghurt formulations exhibited a phenolic content of 271.92±3.66 mg GAE/100 g, flavonoid content of 1.79±0.25 mg GAE/100 g, and tannin content of 110.01±14.83 mg GAE/100 g. The antioxidant activity was measured to be 74.24±1.87 % for the ABTS-RSA and 34.04±2.78 % for the DPPH-RSA (Table 2). Similar to this data Tanwar *et al.* (*27*) who estimated a high content of tannins compared to flavonoids in apricot kernels, with total phenolic, tannin, flavonoids contents of 183.08±6.46 mg/100 g, 159.67±8.19 mg/100 g, 14.81±1.99 mg/100 g, respectively. Additionally, Rampáčková *et al.* (*39*), report that the total phenolic contents in apricot kernels ranged between 63.5-1277.3 mg GAE/100 g DW, and total flavonoids content ranged from 0 to 153.1 mg/100 g DW, with antioxidant activity ranging from 0.483 to 2.348 mg Trolox equivalent per 100 g. Moreover, Mohamed *et al.* (*38*), estimated total phenolic content of apricot kernels at 7.7 mg/100 g and the flavonoid content is 4.03 mg/100 g. It is important to note that variations in phenolic content among kernels can be attributed to several factors such as genetic diversity, geographical location, growth conditions, harvest time, soil composition, choice of extraction solvent, chemical composition, and analytical method employed (*22,40*).

The estimated HCN (hydrogen cyanide) content of sweet apricot kernels used in this study is observed to be 57.6±6.2 mg/100 g (Table 2). Recently, Pawar and Nema, (*41*), reported that the HCN content of apricot kernels varies according to the cultivar/variety, altitude of the region, and maturity. Based on the amount of HCN contained in the apricot kernels, they distinguished between sweet and bitter kernels. The bitter apricot kernel contains a large amount of HCN 220.55 to 317.7 mg/100 g, compared to sweet apricot kernels 30.20 to 79.20 mg/100 g (*41*). According to Tanwar *et al.* (*27*), the amount of HCN in wild apricot kernels is estimated at 136.85±2.67 mg/100 g. Generally, the hydrogen cyanide content in apricot kernels varies widely, ranging from 12.2 to 409 mg/100 g, with a mean content of 29.20 mg/100 g (*42*).

Physicochemical and antioxidant properties of yoghurt

The physicochemical properties of the yoghurt formulations are presented in Table 3. The pH values ranged between 4.47 and 4.70. Formulations coded E (0 % SGR, 8 % MP, and 0 % SAK), and H (0 % SGR, 0 % MP, and 8 % SAK), are yoghurts without sugar, presented the pH higher than 4.6. The acidity values of all formulations ranged between 7.6 and 12.3 g/L. The lowest and highest acidity values were observed in yoghurts A (8 %SGR, 0 % MP, 0 % SAK) and E (0 % SGR, 8 %MP, 0 % SAK), respectively. According to Zahan *et al.* (*43*), a total of 12 set-type yoghurt samples were used, with four sugar concentrations (0, 4, 5, and 12 %), and plain yoghurt had an average percentage of acidity (0.9 %) and pH (4.45). Additionally, Elkot *et al.* (*14*), reported that titratable acidity and pH in yoghurt samples supplemented with detoxified apricot kernel were between 0.61-0.75 % and 4.55-4.65, respectively. Furthermore, Karnopp *et al.* (*44*) reported pH values of 4.08-4.29 and acidity values of 0.64-0.77 % in yoghurt manufactured with grape skin flour, oligofructose, and purple grape juice.

Acidity and pH observed in the present study highlight the importance of milk powder and added sugar in achieving the desired pH and acidity. Milk powder and sugar play essential roles in yoghurt production because as they act as substrates in the metabolism of the lactic bacteria present in yoghurt, leading to the generation of lactic acid that acidified the medium.

Regarding viscosity and syneresis, it was observed that the formula E, with the highest viscosity (7.15 P.as), had the lowest syneresis rate (41.26 %), which was attributed to the effect of the milk powder (Table 3). The milk powder likely contains hydrophilic proteins that retain water, leading to an increase in viscosity. In agreement, Soukoulis *et al.* (*45*) observed that skimmed milk powder improves the textural quality and reduce the susceptibility of yoghurts to syneresis. Moreover, Celik *et al.* (*46*) reported that lower viscosity and greater syneresis were characteristics of fruit yoghurt. They explained that the addition of concentrated fruits decreases the water retention capacity of the proteins, thus diluting the protein content in the milk base, decreasing viscosity, and increasing syneresis in the fruit-flavoured yoghurt (*46*).

Formulations B (1.33 % SGR, 1.33 % MP, and 5.33 % SAK) and H (0 % SGR, 0 % MP, and 8 % SAK) showed higher TPC and mean values for ABTS-RSA and DPPH-RSA, indicating that apricot kernels are a good alternative for increasing the in vitro antioxidant activity of yoghurt (Table 3). However, these formulations were not the most preferred by the panellists in sensory evaluation. The ABTS-RSA assay is based on the generation of a blue/green $ABTS^+$ that is applicable to both hydrophilic and lipophilic antioxidant systems, whereas the DPPH-RSA assay uses a radical dissolved in organic media and is, therefore, applicable to hydrophobic systems (*47*).

Sensory *evaluation of yoghurt*

Sensory evaluation showed in Table 4 revealed that no significant difference in colour or odour was noticed between the 11 different yoghurt formulations, while other parameters such as taste, texture, and consistency were significantly influenced by the addition of sweet apricot kernel powder, sugar, and milk powder (p<0.05). Formulations E (0 % SGR, 8 % MP, 0 % SAK), H (0 % SGR, 0 % MP, 8 % SAK), and control yoghurt K (0 % SGR, 0 % MP, 0 % SAK) obtained the lowest average scores of overall acceptability, which were 4.61, 4.83, and 3.67, respectively. On the other hand, formulations C (5.33 % SGR, 1.33 % MP, 1.33 % SAK), and D (4 % SGR, 4 % MP and 0 % SAK), showed the highest average scores of overall acceptability, which were 6.06 and 6, respectively. According to Zahan *et al.* (*43*)**,** a higher concentration of sugar should lead to increasing preference. However, the acceptability of sweet taste varies among consumers. Furthermore, the variations in sensory scores of yoghurt samples generally depend on the types of milk, ferment, and manufacturing process involved.

According to Cheng *et al*. (*48*), certain naturally occurring volatile organic compounds (VOCs) in milk, as well as those induced by lactic acid fermentation, contribute to the diverse range of aromas and flavours perceived by the consumers. Kilcawley *et al.* (*49*), further reported that short-chain carboxylic acids, generally the most abundant chemical class of VOCs in many dairy products, are the main components responsible for sour taste and, in some cases, rancidity. These acids originate from a variety of sources and pathways, including lipolysis, carbohydrate metabolism, or amino acid metabolism, depending on the specific short-chain carboxylic acid. Moreover, volatile compounds such as aldehydes, ketones, sulphur compounds, terpenes, etc., present in dairy products like milk, derived from the degradation lactose, citrate, milk lipids, and milk protein, or generated after fermentation (e.g., yoghurt) such as acetaldehyde, also contribute to the variations in sensory scores of yoghurt samples (*48*).

Model fitting and regression analysis

The ANOVA results for the model fitted for physicochemical and antioxidant properties as well as sensorial evaluation of yoghurt are presented in Table 5. Experiments were conducted to collect data. All mathematical models were statistically significant ($p<0.05$), and the coefficients of determination (R^2) for pH ($R^2=0.960$), acidity ($R^2=0.966$), viscosity ($R^2=0.912$), syneresis ($R^2=0.961$), TPC ($R^2=0.962$), DPPH-RSA ($R^2=0.938$), ABTS-RSA ($R^2=0.939$), colour ($R^2=0.892$), odour ($R^2=0.914$), taste ($R^2=0.977$), texture ($R^2=0.954$), consistency ($R^2=0.933$), and overall acceptance ($R^2=0.951$) were high. This indicating that the models can well explain the effects of the factors, and the equations can be used to predict the responses.

Table 5 and Table 6 demonstrate the effects of SGR (X1), MP (X2), and SAK (X3) on the physicochemical, antioxidant and sensory characteristics of yoghurt. The linear effects were found to be significant (P<0.05). However, not all interactions between these ingredients were significant. The interactions of SGR*SAK (X1*X3) and MP*SAK (X2*X3) negatively affected the pH and DPPH-RSA, and positively affected the texture, odour, and colour characteristics. The interaction of MP*SAK (X2*X3) negatively influenced the viscosity. The taste characteristic was positively influenced by the interaction of SGR*SAK (X1*X3). Moreover, the overall acceptability of the product was positively influenced by all ingredients and their interactions in the final product.

In general, the optimised composition of the yoghurt formulation demonstrated a sensory acceptance and met the requirements of panellists in terms of organoleptic characteristics and physicochemical quality. The statistical models used were significant, considering all linear effects and interactions of the ingredients on enriched yoghurt with sweet apricot kernels as an ingredient, while remaining acceptable to consumers.

Interpretation of contour plots

The optimal proportions for ingredients observed in this study were found to be 0.384 sugar (SCR), 0.270 milk powder (MP), and 0.346 sweet apricot kernel (SAK), coded values. These values correspond to real values of 3.073 % SGR, 2.161 % MP, and 2.766 % SAK. The responses for this optimal combination in high desirability at 73.7 % are 4.51±0.05 for pH, 9.52±0.53 g/L for acidity, 5.12±0.79 P.as for viscosity, and 56.40±2.59 % for syneresis. The values for ABTS-RSA and DPPH-RSA are 51.99±6.79 % and 21.77±3.09 %, respectively. The value of TPC observed was 138.40±19.83 mg GAE/100 g. The maximum point hedonic scale ratings for sensory characteristics including colour, odour, taste, texture, and consistency are 6.35±0.28, 5.84±0.31, 6.03±0.24, 6.01±0.26, and 5.81±0.40, respectively (Fig. 1).

Regarding the effect of adding sweet apricot kernel powder on TPC, DPPH-RSA, ABTS-RSA, syneresis, viscosity, and acidity, a highly significant increase is observed ($P \leq 0.0001$). However, the addition of sweet apricot kernel powder decreases the pH, and the interaction between SAK powder and sugar and/or milk powder exerts a negative linear effect on viscosity and pH (Fig. 1, and Table 5).

Barakat and Hassan. (*50*) observed a significant ($P<0.05$) decrease in pH and an increase in acidity with the addition of pumpkin pulps in yoghurt. The addition of pumpkin alone increased viscosity; which was attributed to the acidity and available carbohydrates and fibres in pumpkin pulps, improving the network structure of stirred yoghurt curd and slightly increasing viscosity. Similarly, Abou-zeid (*51*), reported that the addition of fibres accelerated the rate of yoghurt acidification, and most enriched yoghurts also showed an increase in their apparent viscosity.

Therefore, the increase in viscosity and acidity in the present study, as well as the decrease in pH of the produced yoghurts, is probably due to the composition of sweet apricot kernels and an indicator of positive bacterial growth. Moreover, the negative effect of the MP* SAK interaction on viscosity can be explained by the presence and dispersion of apricot kernels skin parts throughout the formulated yoghurt, which creates gel breakage formed between milk protein, carbohydrates and fibres.

Lee *et al.* (*52*) reported that the addition of ginseng extracts provides nutritional components that promote the growth of lactic bacteria, leading to a more rapid increase in the number of viable bacteria, which lowers the pH of yoghurt by converting lactose into lactic acid. Moreover, Sansawat *et al.* (*53*) reported that the growth of lactic bacteria during yoghurt fermentation is responsible for the production of exopolysaccharides, which are directly proportional to higher viscosity. Additionally, yoghurt viscosity is affected by the number and strength of the bonds between casein micelles, forming casein aggregates from an isoelectric pH<4.9, with maximum gel stiffness at pH 4.6 (*53*).

According to Elkot *et al.* (*14*), the addition of detoxified and delipidated apricot kernel powder increases viscosity values in yoghurt. This increase may be attributed to the higher total solids and fibre content present in the powder. Furthermore, the powder is characterized by its high water hydration capacity, which influences the aggregation of the casein network in yoghurt through electrostatic interactions, and contributes to the overall resistance of the yoghurt. Soukoulis *et al.* (*45*) observed that skimmed yoghurts were firmer than whole yoghurts, and they reported that the increase in viscosity of non-fat yoghurts can be attributed to the higher protein content of skimmed milk compared to whole milk. Similarly, Brauss *et al.* (*54*) stated that yoghurts with higher fat content exhibited higher viscosity and smaller particle size relative to yoghurts with lower fat content.

The addition of sweet apricot kernel powder has a significant positive effect on the composition of total phenolic content (TPC) and antioxidant activity (DPPH-RSA, and ABTS-RSA) (Fig. 1). The yoghurt formulation containing 3.043 % of sugar, 2.161 % of milk powder, and 2.766 % of sweet apricot kernel was the optimal point of the experimental design, with a p-value of 0.01, indicating a satisfactory optimisation of the multiple responses. The yoghurt formulated presented 138.48±19.83 mg GAE/100 g of total phenolic content and scavenging activities of DPPH and ABTS radicals were 21.77 % and 51.99 %, respectively.

In the sensory evaluation, the addition of a high quantity of sweet apricot kernels increased appreciation of organoleptic characteristics by panellists up to an optimal point, influenced by interactions with other ingredients (SGR and MP), and resulted in increased acceptance scores. Specifically, the addition of sweet apricot kernel powder alone had a significant influence on colour, odour, taste, texture, and consistency (p<0.0001) (Fig. 1). However, the effect of its interaction with sugar significantly increased its appreciation for taste, colour, odour and texture up to a point, beyond which decreased among panel (p<0.05).

Moreover, the appreciation of taste is influenced by sugar and its interaction with sweet apricot kernel, as well as the non-appreciation of sweet apricot kernel powder. This can be attributed to the presence of tannins in the apricot kernels, which can contribute to an astringent taste and potentially affect the growth of lactic bacteria. Therefore, this can have an impact on the texture, viscosity, taste, and odour of the yoghurt.

It is also important to note that excessive sugar addition can result in an overly sweet taste and a too-thick yoghurt. The significant impact of sugar on the texture of yoghurt is worth considering. Sugar typically added to yoghurt to balance its natural acidity and improve texture. When added, sugar forms hydrogen bonds with proteins and attracts water, thereby increasing viscosity. It can also aid in the formation of a gel, helping the yoghurt maintain its shape and consistency.

Recent studies, such as the one conducted by Zadeh *et al.* (*55*), have shown that the addition of tannins to yoghurt does not significantly affect the number of lactic bacteria but can have an impact consumer acceptability. The preference for tannins varies depending on their origin, with higher preferences observed for tannins obtained from Quebracho wood. Furthermore, Ibrahim *et al.* (*56*) demonstrated that the use tannin-free pomegranate peels can improve the viability of probiotic cultures in yoghurt (*55*). Additional studies by Lee *et al.* (*52*), and Barakat and Hassan. (*50*) have shown that incorporating ginseng or pumpkin pulp extracts to yoghurt can affect sensory properties such as colour, taste, and overall acceptability.

A new product warrants a detailed sensory study, combining descriptive and consumer characteristics, particularly using the Check-All-That-Apply (CATA), Temporal Dominance of Sensations (TDS), and Flash Profile (FP) methods, to better understand the optimised formula product and clarify consumer preferences (*57,58*). Additionally, studies on the cultural acceptability of the product in retail settings will be necessary to ascertain the specific aroma profiles resulting from the interactions, with a parallel focus on understanding the cultural acceptability of such products (*48*).

In general, new or unfamiliar food products are often rejected by consumers and tend to receive lower appreciation scores for all sensory attributes (*48*). However, this does not diminish the interest in incorporating plant matrices such as fruit seeds as a source of probiotics for the lactic ferment and natural antioxidants. For example, Rosa *et al.* (*58*) reported that the addition of prebiotics to dairy products presents an excellent opportunity for the dairy industry, contributing to product diversification and aligning with the current trend toward functional foods. Thus, while feasible from a nutritional and commercial standpoint, preserving or improving the product's physicochemical and sensory properties (*58*).

Validation of models

The optimal region was determined by setting the objectives such as maximum viscosity, and syneresis, minimum acidity, pH within the range of 4.2-4.6, maximum TPC and antioxidant activity, maximum point hedonic scale in sensory characteristics including colour, odour, taste, texture, and consistency.

To validate the predicted optimal formula, an experiment with the optimised formulation was carried out in triplicate. The observed average values are not significant confirmed the validate of the models. It was found that there was no significant difference ($P > 0.05$) between the observed and predicted responses, indicating the adequacy of the optimisation process. According to the expert panel, the yoghurt optimised in this study was rated as 'slightly pleasant' the 6thpoint/ 9-point hedonic scale.

CONCLUSIONS

In conclusion, the Simplex-centroid mixture design was successfully predicted the optimal formulation of yoghurt using sweet apricot kernels, sugar, and milk powder. The addition of sweet apricot kernel powder had a significant positive effect on various parameters, including total phenolic content, antioxidant activity, syneresis, viscosity, and acidity. The inclusion of sugar and milk powder influenced the taste, texture, and consistency of the yoghurt. The optimised formulation consisted of 3.073 % sugar, 2.161 % milk powder, and 2.766 % sweet apricot kernel. These results confirmed the possibility of valorising sweet apricot kernels as ingredients in the production of yoghurts, while minimizing the amount of sugar and milk powder. Moreover, they provide guidance for future efforts in large-scale yoghurt formulation and processing conditions, with the goal of achieving a more favourable sensory profile and improve the acceptance of their products among a larger audience.

ACKNOWLEDGEMENTS

We are very grateful to the staff of N'gaous conserves SPA apricot processing plant company located in Batna, northeast part of Algeria, and to the Algerian Ministry of Higher Education and Scientific Research for the financial support particularly the DGRSDT.

FUNDING

None.

CONFLICT OF INTEREST

The authors declare no conflicts of interest, financial or otherwise.

AUTHORS' CONTRIBUTION

M. Teffane, M. Bachir-bey, H. Boudries conceived and planned the experiments. carried out the experiments. prepared all the samples and performed the statistical analysis. A. Kadi , Y. Arroul , A. Taibi , analysed the data and contributed to the drafting of the article. All authors helped shape the research, gave critical feedback, commented on the manuscript, and approved the final version.

ORCID ID

M. Teffane https://orcid.org/0000-0002-5797-7176

H. Boudries https://orcid.org/0000-0002-9662-6942

M. Bachir-bey https://orcid.org/0000-0002-9987-1505

A. Kadi https://orcid.org/0000-0003-1963-1016

Y. Arroul https://orcid.org/0009-0007-2039-961X

A. Taibi https://orcid.org/0000-0003-1677-7968

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Table 1. Coded and real values of the yoghurt formulations with addition of sugar, milk powder, and sweet apricot kernel powder

	Ingredient		
Formulation	X1 : Sugar/(g/100 g)	X2 : Milk powder/(g/100 g)	X3 : Sweet apricot kernel powder/(g/100 g)
A	1.000 (8.00)	0.000 (0.00)	0.000 (0.00)
B	0.167 (1.33)	0.167 (1.33)	0.667 (5.33)
C	0.667 (5.33)	0.167 (1.33)	0.667 (1.33)
D	0.500 (4.00)	0.500 (4.00)	0.000 (0.00)
E	0.000 (0.00)	1.000 (8.00)	0.000 (0.00)
F	0.333 (2.67)	0.333 (2.67)	0.333 (2.67)
G	0.167 (1.33)	0.667 (5.33)	0.167 (1.33)
H	0.000 (0.00)	0.000 (0.00)	1.000 (8.00)
I	0.000 (0.00)	0.500 (4.00)	0.500 (4.00)
J	0.500 (4.00)	0.000 (0.00)	0.500 (4.00)
K	0.000 (0.00)	0.000 (0.00)	0.000 (0.00)

Table 2. Physicochemical and antioxidant properties of the sweet apricot kernel used in the yoghurt formulations

Physicochemical property	Amount
Moisture/%	8.85±0.88
Ash/%	3.47±0.11
Carbohydrate/%	8.78±0.90
Protein/%	1.33±0.19
Lipid/%	56.19±1.99
TPC/(mg/100 g)	271.92±3.66
TFC/(mg/100 g)	1.79±0.25
TC/(mg/100 g)	110.01±14.83
DPPH-RSA/%	34.04±2.78
ABTS-RSA/%	74.24±1.87
HCN/(mg/100 g)	57.6±6.2

HCN=cyanidric acid, TPC=total phenolic content, TFC=total flavonoid content, TC=tannin content

Table 3. Physicochemical and antioxidant characteristics of the yoghurt formulations

Formulation	Physicochemical and antioxidant characteristics						
	pH	Acidity/(g/L)	Viscosity/(Pa·s)	Syneresis/%	TPC/(mg/100 g)	DPPH-RSA/%	ABTS-RSA/%
A	(4.62±0.03)^{abc}	(7.60±0.85)^{f}	(6.58±0.36)^{abc}	(62.24±0.65)^{ab}	(78.07±9.76)^{ef}	(22.06±3.06)^{bcd}	(42.93±1.75)^{e}
B	(4.53±0.01)^{bcd}	(9.90±0.14)^{bc}	(4.53±1.20)^{cd}	(56.54±1.79)^{def}	(200.91±10.98)^{a}	(24.30±1.23)^{bc}	(60.84±5.20)^{c}
C	(4.53±0.01)^{bcd}	(9.05±0.07)^{cde}	(5.79±1.73)^{abc}	(57.67±0.00)^{de}	(101.95±15.87)^{d}	(21.29±0.12)^{cd}	(39.10±2.60)^{e}
D	(4.65±0.01)^{ab}	(9.05±0.07)^{cde}	(6.94±0.47)^{ab}	(53.92±0.00)^{f}	(67.14±13.83)^{fj}	(21.18±1.82)^{cd}	(42.27±1.70)^{e}
E	(4.70±0.01)^{a}	(12.30±0.71)^{a}	(7.15±0.35)^{a}	(41.26±0.99)^{h}	(95.91±1.63)^{de}	(21.25±0.96)^{cd}	(42.46±5.56)^{e}
F	(4.55±0.16)^{bcd}	(9.25±0.35)^{cd}	(5.64±0.92)^{abc}	(55.05±0.19)^{ef}	(141.65±0.41)^{c}	(24.02±1.63)^{bc}	(52.09±0.72)^{d}
G	(4.62±0.05)^{abc}	(10.80±0.28)^{b}	(6.31±1.86)^{abc}	(49.25±2.76) ^{j}	(103.68±9.36)^{d}	(21.04±0.48)^{cd}	(55.0±0.72)^{cd}
H	(4.71±0.02)^{a}	(8.29±0.16)^{ef}	(5.06±1.14)^{c}	(61.56±1.15)^{abc}	(200.05±2.44)^{a}	(40.66±2.97)^{a}	(79.72±1.79)^{a}
I	(4.51±0.09)^{cd}	(10.60±0.14)^{b}	(2.91±0.22)^{de}	(58.27±3.56)^{cde}	(139.64±1.63)^{c}	(26.12±1.15)^{b}	(68.70±0.72)^{b}
J	(4.47±0.01)^{d}	(9.00±0.00)^{cde}	(5.18±1.30)^{bc}	(59.24±0.17)^{bcd}	(167.54±2.03)^{b}	(23.14±3.44)^{bcd}	(55.58±1.16)^{cd}
K	(4.53±0.06)^{bcd}	(8.50±0.71)^{def}	(2.19±0.21)^{e}	(62.95±0.98)^{a}	(52.76±2.44)^{j}	(19.15±0.29)^{d}	(37.64±1.43)^{e}

Results with different letters are statistically different for each row ($p<0.05$, a>b>c>d). Comparisons of samples were conducted by one-way analysis of variance (ANOVA) with the LSD-Fisher test

Table 4. Sensory evaluation of the yoghurt formulations

Formulation	Sensory evaluation					
	Colour	Odour	Taste	Texture	Consistency	Overall acceptability
A	(5.82±1.51)[a]	(5.18±1.24)[a]	(5.41±1.33)[abc]	(4.88±1.27)[bc]	(4.65±1.54)[b]	(5.28±1.18)[abc]
B	(5.94±1.76)[a]	(6.00±1.37)[a]	(5.61±1.75)[abc]	(5.72±1.74)[abc]	(5.44±1.72)[ab]	(5.67±1.19)[ab]
C	(6.39±1.24)[a]	(5.50±1.09)[a]	(6.07±1.98)[ab]	(5.83±1.58)[ab]	(5.72±1.74)[ab]	(6.06±1.88)[a]
D	(6.12±1.15)[a]	(5.29±1.16)[a]	(6.06±1.25)[ab]	(5.86±1.17)[ab]	(6.06±1.30)[a]	(6.00±1.06)[a]
E	(5.82±1.67)[a]	(5.12±1.80)[a]	(4.82±1.91)[c]	(5.53±1.84)[abc]	(6.48±1.74)[a]	(4.61±1.61)[cd]
F	(6.44±0.86)[a]	(5.83±1.29)[a]	(6.06±1.73)[ab]	(5.83±1.34)[ab]	(5.89±1.23)[a]	(5.78±1.80)[ab]
G	(6.07±1.49)[a]	(5.29±1.27)[a]	(5.27±0.90)[abc]	(6.08±1.04)[a]	(6.00±1.09)[a]	(5.38±1.36)[abc]
H	(5.50±2.33)[a]	(5.33±2.11)[a]	(4.89±1.64)[c]	(4.94±2.23)[abc]	(5.22±1.80)[ab]	(4.83±1.46)[bcd]
I	(6.20±1.42)[a]	(5.88±1.45)[a]	(4.94±1.84)[bc]	(5.88±1.67)[ab]	(6.06±1.65)[a]	(5.47±1.37)[abc]
J	(6.22±1.21)[a]	(6.00±1.08)[a]	(6.17±1.58)[a]	(5.78±1.40)[abc]	(5.39±1.94)[ab]	(5.78±1.80)[ab]
K	(5.59±1.70)[a]	(5.00±1.80)[a]	(4.35±2.06)[c]	(4.71±1.65)[c]	(4.41±2.00)[b]	(3.67±2.11)[d]

Results with different letters are statistically different for each row ($p<0.05$, a>b>c>d). Pairwise comparisons of samples were conducted using the Conover-Iman test. A 9-point hedonic scale ranging from 1 (extremely unpleasant) to 9 (extremely pleasant) was utilized

Table 5. ANOVA results for the model fitted for physicochemical, antioxidant properties and sensorial evaluation for yoghurt

Term	Coeff.	p-value	Coeff.	p-value	Coeff.	p-value	Coeff.	p-value	Coeff.	p-value	Coeff.	p-value	Coeff.	p-value
	pH		Acidity		Viscosity		Syneresis		TPC		DPPH-RSA		ABTS-RSA	
X_1	4.611	<0.0001*	7.672	<0.0001*	6.371	0.0003*	62.639	<0.0001*	73.701	0.0057*	22.343	0.0005*	41.894	0.0009*
X_2	4.704	<0.0001*	12.277	<0.0001*	7.233	0.0002*	41.358	<0.0001*	92.923	0.0024*	21.267	0.0006*	44.608	0.0007*
X_3	4.700	<0.0001*	8.390	<0.0001*	5.006	0.0008*	61.315	<0.0001*	204.984	0.0001*	39.630	<0.0001*	78.863	<0.0001*
X_1*X_2	0.016	0.893	-3.563	0.099	2.047	0.459	3.001	0.733	-59.722	0.395	0.047	0.9964	-8.562	0.711
X_1*X_3	-0.712	0.003*	4.504	0.054	-1.099	0.683	-16.997	0.107	149.440	0.076	-33.052	0.0279*	-35.869	0.171
X_2*X_3	-0.707	0.003*	13.13	0.474	-10.701	0.013*	20.462	0.067	4.925	0.941	-20.051	0.1099	23.930	0.328
R^2	0.960		0.966		0.912		0.961		0.962		0.938		0.939	
R^2 adj	0.908		0.924		0.804		0.913		0.914		0.862		0.864	
Model		0.007*		0.005*		0.030*		0.006*		0.006*		0.016*		0.015*
	Colour		Odour		Taste		Texture		Consistency		Overall acceptability			
X_1	5.873	<0.0001*	5.166	<0.0001*	5.407	<0.0001*	4.918	<0.0001*	4.739	<0.0001*	5.336	<0.0001*		
X_2	5.79	<0.0001*	5.065	<0.0001*	4.768	<0.0001*	5.564	<0.0001*	6.374	<0.0001*	4.570	<0.0001*		
X_3	5.451	<0.0001*	5.391	<0.0001*	4.910	<0.0001*	4.942	<0.0001*	5.186	<0.0001*	4.872	<0.0001*		
X_1*X_2	1.324	0.103	0.230	0.753	3.710	0.0024*	2.466	0.013*	1.922	0.098	3.866	0.005*		
X_1*X_3	2.332	0.021*	2.845	0.014*	4.164	0.0015*	3.246	0.005*	1.693	0.131	2.691	0.019*		
X_2*X_3	2.074	0.030*	2.407	0.024*	0.321	0.5839	2.338	0.015*	0.529	0.585	2.598	0.021*		
R^2	0.892		0.914		0.977		0.954		0.933		0.951			
R^2 adj	0.757		0.807		0.949		0.897		0.850		0.890			
Model		0.045*		0.030*		0.002*		0.008*		0.018*		0.010*		

Coeff.=regression coefficient, X_1=sugar, X_2=milk powder, X_3=sweet apricot kernel powder, *significant coefficient ($p<0.05$), R^2=coefficient of determination, R^2 adj=adjusted coefficient of determination

Table 6. The models developed for all physicochemical, antioxidant and sensory characteristics for enriched yoghurt

Parameters	Models
pH	$4.611X_1+4.704X_2+4.700X_3-0.712X_1X_3-0.707X_2X_3$
Acidity	$7.672X_1+12.277X_2+8.390X_3$
Viscosity	$6.371X_1+7.233X_2+5.006X_3-10.701X_2X_3$
Syneresis	$62.639X_1+41.358X_2+61.315X_3$
TPC	$73.701X_1+92.923X_2+204.984X_3$
DPPH-RSA	$22.345X_1+21.267X_2+39.630X_3-33.052X_1X_3$
ABTS-RSA	$41.894X_1+44.608X_2+78.863X_3$
Colour	$5.873X_1+5.788X_2+5.451X_3+2.332X_1X_3+2.074X_2X_3$
Odour	$5.166X_1+5.065X_2+5.391X_3+2.845X_1X_3+2.407X_2X_3$
Taste	$5.407X_1+4.768X_2+4.910X_3+3.710X_1X_2+4.164X_1X_3$
Texture	$4.918X_1+5.564X_2+4.942X_3+2.466X_1X_2+3.246X_1X_3+2.338X_2X_3$
Consistency	$4.739X_1+6.373X_2+5.186X_3$
Overall acceptability	$5.336X_1+4.570X_2+4.872X_3+3.866X_1X_2+2.691X_1X_3+2.598X_2X_3$

X_1=sugar, X_2=milk powder, X_3=sweet apricot kernel powder, TPC=total phenolic content, DPPH-RSA=2,2-diphenyl-1-picrylhydrazyl free radical scavenging activity, ABTS-RSA=2,2'-azino-bis(3-ethylbenzthiazoline-6-sulphonic acid radical scavenging activity

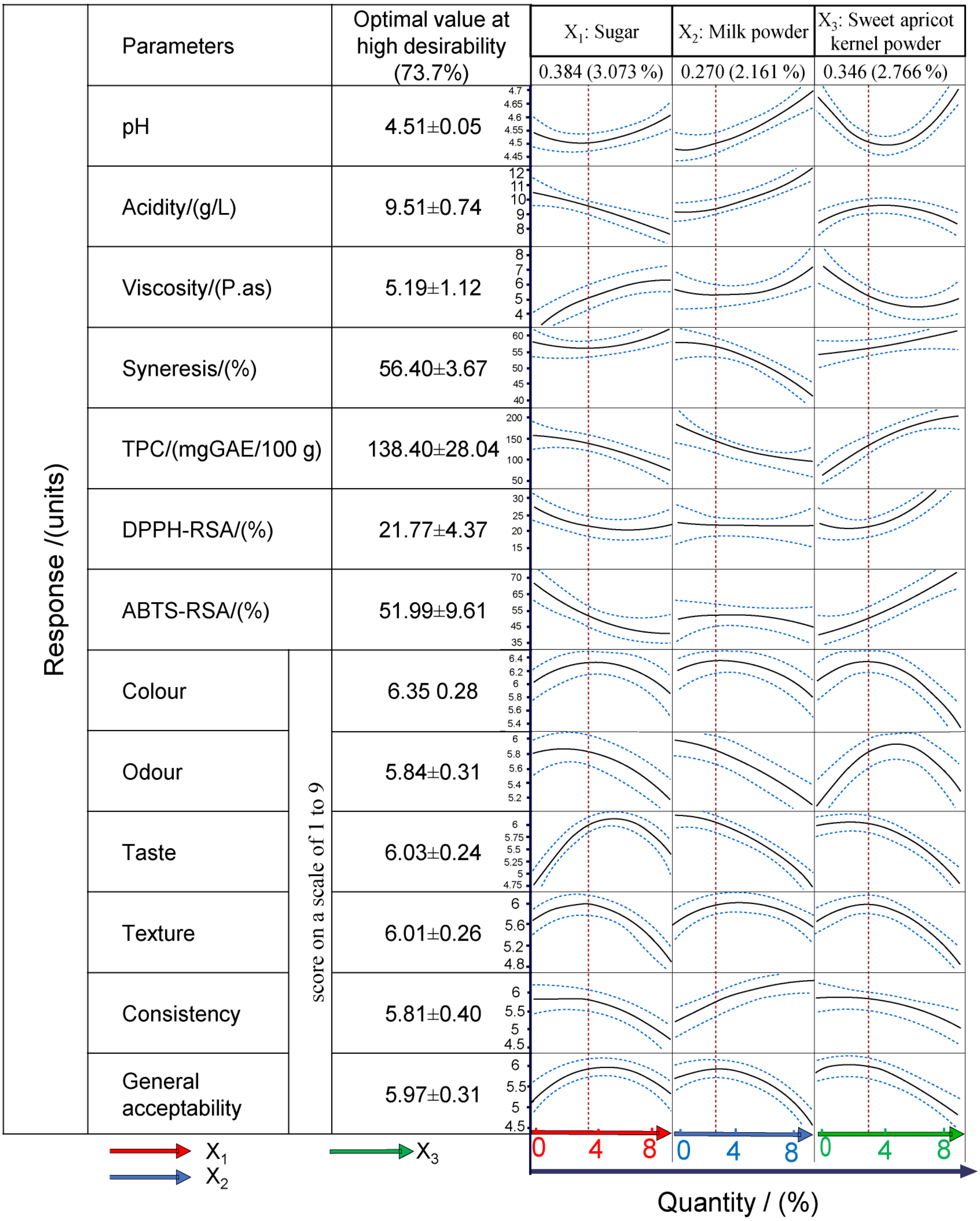

Fig. 1. Variation in the physicochemical, sensory, and antioxidant properties of yoghurt formulations in response to the quantity of sugar (SGR), milk powder (MP), and sweet apricot kernel powder (SAK)