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Fermentation Kinetics, Microbiological and Physical Properties of Fermented Soy Beverage with Acai Powder

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Abstract: In this study, the effects of the fermentation kinetics, determination of the number of lactic acid bacteria, texture, water holding capacity, and color of fermented soy beverages with acai powder (3 and 6% w/v) were investigated. The addition of acai powder significantly influenced the fermentation kinetics based on changes in pH, accelerating fermentation in the initial period. The results showed that the acai additive did not affect the enumeration of *Lactobacillus acidophilus* and *Bifidobacterium animalis* subsp. *lactis*. The presence of acai inhibited the proliferation of *Streptococcus thermophilus* compared to the soy beverage without acai powder added. However, the higher the acai additive, the more *Streptococcus thermophilus* bacteria were detected: 4.39 CFU/g for 6% acai powder sample and 3.40 CFU/g for 3% acai powder sample. The addition of acai to the soy beverage reduced its firmness, consistency, cohesiveness, and viscosity index after fermentation. A slight difference was observed in the lightness and whiteness of fermented soy beverages with 3% and 6% acai powder.

Keywords: fermentation kinetics; texture; acai; non-dairy yogurt alternatives; plant-based yogurt

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1. Introduction

Yogurt is one of the most popular fermented products consumed worldwide. The popularity and acceptance of this particular type of product are due to its taste and health benefits. Its nutritional value stems from the presence of bioactive components such as protein, essential amino acids, lactic acid, and vitamins. In general, yogurt is a fermented milk product providing digested lactose and viable bacterial strains, typically *Streptococcus thermophilus* and *Lactobacillus delbrueckii* subsp. *bulgaricus*. At the beginning of the 20th century, it was stated that the regular consumption of fermented milk products, especially yogurt, prolongs human life, resulting in the increased commercial production of yogurt [1,2]. Mostly, yogurts are made from cow's, goat's, or sheep's milk, but plant-based milk alternatives have become increasingly sought after [3]. According to reports, instead of cow's milk, fermented beverages with lactic acid bacteria can be produced from rice, coconut, soy, or nuts [4]. Fermented beverages include various rice drinks [5], rice-based yogurts [6], cocoghurts [7], soy-yoghurts [8], soyghurts [9], and nut beverages [10]. Those who are dairy intolerant, or who prefer a non-dairy alternative, such as vegans, may consume a plant-based yogurt alternative [11].

Although consumers seek new products, they are mostly satisfied with alternatives to traditional products that are similar in appearance and texture to dairy products. Vegan yogurt (VAY) is a fast-growing stage market in Europe because of the increasing trend of plant-based dairy alternatives [12,13]. The global market size of VAY in 2020 was estimated at USD 2.02 billion and is expected to expand at a Compound Annual Growth Rate (CAGR) of 18.9% between 2020 and 2027 [14]. Among plant sources used for yogurt production, soy has been particularly successful over the last few decades. This is due to the presence of the quantity, quality, and functional properties of the protein, especially for those who are cow's milk protein intolerant. Nutritionally beneficial compounds found in soy beverages are syringic and chlorogenic acids [15]. Soy beverages also have a high content of essential fatty acids and fiber and are recognized for their high mineral (including calcium, phosphorus, and iron) and low sodium content. Since it is a plant-based product, it is free of cholesterol, gluten, and lactose [16], and can be a growth medium for the lactic acid bacteria widely used in yogurt fermentation [17,18]. Plant-based yogurts can be also produced with various fruits, e.g., banana [19], strawberry [20], and mango [21].

Acai berries grow on tropical palm trees of the genus *Euterpe*, and are native to the Amazon and several Caribbean islands. To prepare them for consumption, the berries are macerated in water to separate the seeds and obtain a thick purple drink ("acai pulp"). Acai fruit can be consumed directly as a pulp or added to other foods [22]. The thick purple drink contains protein (2.4%) and lipids (5.9%) [23]. Acai fruit pulp is rich in protein and has high energy and nutritional value. It contains various biologically active phytochemicals and large amounts of mono- and polyunsaturated fatty acids, not present in most fruits and berries. In addition, among the acai berry's valuable components are vitamin A, vitamin C, calcium, iron, and dietary fiber [24]. Furthermore, acai has been used as an additive in foods mainly for its antioxidant and flavor properties, e.g., meatballs [25], muffins [26], and cheese [27].

The addition of acai powder affects not only the nutritional value, but also the texture parameters, which has a significant impact on the choice of the product by the consumer [27]. According to da Silva et al., Greek yogurt with acai has an acceptability index of 93.11% [28]. Color is also an important factor affecting acceptability [29]. The color of acai juice yoghurt is similar to commercial blueberry yoghurt [30,31]. It is also important that yogurt with fruit (e.g., mango pulp or acai) can cause a higher rate of syneresis [32].

The presented study aimed to determine the kinetics of fermented soy beverage fermentation as well as to demonstrate the effect of acai powder on the course of the fermentation process based on changes in pH and the number of yogurt bacteria. This study provides vital knowledge regarding the formulation of plant-based yogurts. In addition, the texture profile, color, and syneresis were analyzed, which are important factors for consumer acceptability.

2. Materials and Methods

2.1. Fermented Soy Beverage Preparation

The following products were used in the experiment: acai powder (*Euterpe oleracea*; fruit powder extracted from acai, energy 226 kcal/100 g, fat 1.04 g/100 g, carbohydrates 8.28 g/100 g, and protein 2.95 g/100 g, purchased from Vitline, Białystok, Poland) and unfermented soy beverage (Organic Soya drink, Alpro, Ghent, Belgium; energy 32 kcal/100 mL, fat 1.9 g/100 mL, sugars 0.0 g/100 mL, and protein 3.3 g/100 mL).

Three fermented soy beverages were produced: without acai powder (SB), soy beverage with 3% acai powder (*w*/*v*; sample code SB_3.0), and soy beverage with 6% acai powder (*w*/*v*; sample code SB_6.0). The fermented soy beverages were prepared using a starter culture: *Streptococcus thermophilus*, *Lactobacillus acidophilus*, and *Bifidobacterium animalis* subsp. *lactis* (Lyofast SAB 440B, Sacco Cadorago, Italy; 10 units/25 L soy beverages). Fermentation conditions were as follows, 37 °C until pH 4.50 was achieved. Fermentation was performed in a thermally insulated coagulation steel tank SKM50, Plevnik d.o.o., Dobrova, Slovenia). Then, two-stage cooling of 15 °C/15 min was carried out. The product was poured into unit transparent glass containers with v = 150 mL (total volume of 210 mL, Ø = 70 mm, a wall thickness of 0.8 mm, an overall height 75 mm and a nominal height 53 mm) and further cooled to 6 °C. The samples were analyzed within first 24 h of the obtained finished product. Until then, the samples were stored at 4 ± 0.3 °C.

2.2. Fermentation Kinetics

pH was measured using a pH-meter (CP-502, Elmetron, Zabrze, Poland) with an ESAgP-301W electrode (Eurosensor, Gliwice, Poland). Monitoring of pH during the fermentation process was carried out over a 1050-min period, with 30 min measurement interval [33].

2.3. Determination of the Number of Bacteria

Determination of the number of *Lactobacillus acidophilus*, *Bifidobacterium animalis* subsp. *lactis*, and *Streptococcus thermophilus* was described by Fathy et al. [34]. MRS of pH 5.5 was used for *Lactobacillus acidophilus* (Merck KgaA, Darmstadt, Germany); MRS agar with 0.05% (*w*/*v*) L-cysteine hydrochloride and 0.3% (*w*/*v*) lithium chloride was used for *Bifidobacterium animalis* subsp. *lactis*; M17 agar was used for *Streptococcus thermophilus* (BTL, Łódź, Poland). Cultures were incubated using a thermostat (WTB Binder, Tuttlingen, Germany).

2.4. Profile Texture Analyses

The texture parameters (firmness, consistency, cohesiveness, and viscosity index) were measured using TA-XTplus (Stable Micro Systems, Surrey, UK) and A/BE attachment (disc Ø = 35 mm). Measurement conditions: distance 30 mm, pretest 1.0 mm/s, and post-test 10.0 mm/s [29]. The results were recorded in Texture Exponent E32 version 4.0.9.0 software (Godalming, Surrey, UK).

2.5. Determination of Water Holding Capacity

The water holding capacity (WHC) of the samples is defined as its ability to hold all or part of its water. Sample (30 g) was centrifuged at 4 °C for 15 min (Relative Centrifugal Force RCF = 10,732, 30°; model 260; MPW MED Instruments, Warsaw, Poland). The supernatant was collected and weighed, and WHC was calculated according to the following formula [29]:

$$\mathrm{WHC}\ (\%) = (1 - \mathrm{W}_1/\mathrm{W}_2) \cdots 100 \tag{1}$$

where W_1 is the weight in grams of the supernatant after centrifugation and W_2 is the weight of the sample in grams.

2.6. Color and Gloss

Measurements were using an X-Rite SP-60 camera (X-Rite, Grandville, MI, USA). The whiteness index (WI), yellowness index (YI), and chroma (C*) were calculated using the equation [35]:

$$\mathrm{WI} = 100 - [(100 - \mathrm{L}^*)^2 + \mathrm{a}^{*2} + \mathrm{b}^{*2}]^{0.5} \tag{2}$$

$$\mathrm{YI} = 142.86\ \mathrm{b}^* \cdot \mathrm{L}^{*-1} \tag{3}$$

$$\mathrm{C}^* = (\mathrm{a}^{*2} + \mathrm{b}^{*2})^{0.5} \tag{4}$$

The gloss was measured using the gloss meter (DT 268, TestAn, Gdańsk, Poland), measurement geometry 60°.

2.7. Statistical Analyses

Verification of statistical hypotheses was achieved using a level of significance of $\alpha = 0.05$. The samples were evaluated by one-way analysis of variance (ANOVA) followed by Tukey's HSD post hoc test for multiple comparisons. Kolmogorov–Smirnov and Anderson–Darling tests were used as the most frequently goodness-of-fit tests [36]. The Monte Carlo simulation method was applied and the simulated values were limited to a range of 0.5–99.5%. The kinetics of pH changes during fermentation was based on distributions: Weibull and normal. Equal grouping probabilities for chi-square statistics were employed. Data were analyzed using Statistica data analysis software (Statistica, version 13, TIBCO Software Inc., Palo Alto, CA, USA).

3. Results and Discussion

3.1. Kinetics of pH Changes during Fermentation

Based on pH changes, it was found that the addition of acai powder significantly impacted the change of pH during fermentation process (Figure 1). The addition of 3% acai powder decreased pH of the soy beverage from 6.17 to 5.51 (ΔpH τ0 = 0.66; $p < 0.05$). At 6% acai powder, pH of soy beverage was 5.13 before fermentation. The initial pH differences were caused by the acidity of the acai powder added, which was pH 2.5. During the first 30 min of fermentation, the highest rate (V_m) of pH change in the soy beverages with acai was recorded (0.0030 and 0.0057 pH/min, respectively), while in the soy beverage without the addition of acai the observed changes were insignificant (V_m = 0.007 pH/min; Table 1). pH value of soy beverage without acai powder (sample SB) decreased from 6.14 to 4.50 after 270 min, sample SB_3.0 from 5.51 to 4.50 after 630 min, sample SB_6.0 from 5.13 to 4.50 after 840 min. Freitas et al. [37] analyzed the fermentation process of acai juice, showed an increase in viable cell counts up to 10 h of fermentation, and then it remained constant until 24 h of fermentation. The same authors chose 22 h for the optimal fermentation time. Fermentation to pH 4.50 is sufficient to inhibit the growth of pathogenic microorganisms. In our research, the longest fermentation was carried out for 14 h (in the case of soy beverages with acai powder). Atik et al. [38] showed kinetic parameters of acidification of Spirulina platensis-fortified kefir samples. The authors showed that the time needed to reach pH 4.50 for soymilk with spirulina (0.25% or 0.50%) was 12.17 and 12.20 h, respectively; for almond milk with spirulina (0.25% and 0.50%) is 17.35 and 16.08 h respectively. The quick initiation and conducting of the fermentation process to the maximum acidification rate (ΔpH) was an important factor to avoid the growth of undesirable bacteria, LABs are supposed to dominate. This may suggest a correlation between acai and the multiplication and activity of lactic acid bacteria (LAB) responsible for fermentation. The starter culture used in this experiment was mainly used in milk fermentation [39–41]. Hati et al. [42] showed better growth, acidification, proteolysis, and antimicrobial profiles in milk compared to soy milk fermented by a typical LAB. The matrix of soy beverages lacks lactose, as well as possessing a different carbohydrate composition, and can act as a source of many potential antimicrobial inhibitors [43]. This can slow down or inhibit the fermentation process. However, fermentation must be rapid to achieve quick acidification. Slow fermentation promotes a high risk of spoilage of the microorganism development [44]. The pH range and presence of LAB influence the degradation of anti-nutritional compounds in the fermented matrix [45]. Thus, the type of bacteria, inoculum size, temperature, time conditions, and added ingredients significantly affect the pH of fermented soy beverages. For example, pH can be 5.1 after 330 min of fermentation [46], 4.33 [47], from 3.43 to 5.55 [48], or 4.0 after approximately 12 h of incubation [49].

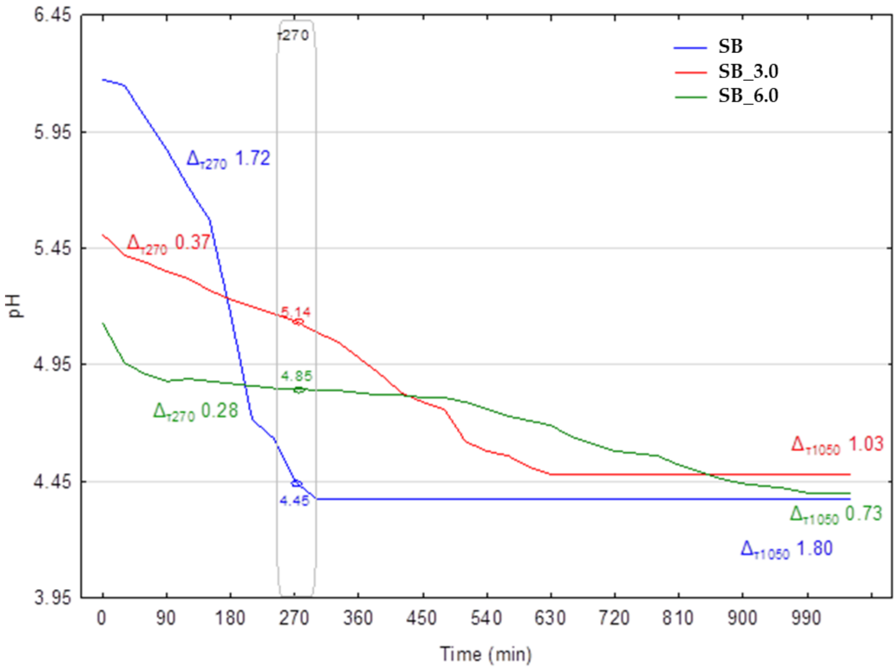

Figure 1. pH changes during the fermentation of soy beverages with acai powder. SB: fermented soy beverage; SB_3.0: fermented soy beverage with 3% acai powder; SB_6.0: fermented soy beverage with 6% acai powder. Figure was prepared using the Statistica data analysis software.

Table 1. Kinetic characteristics of fermentation soy beverages with acai powder.

	SB	SB_3.0	SB_6.0
V_m (pH/min)	0.0069 ^{c}	0.0030 ^{a}	0.0057 ^{b}
T_m (min)	210 ^{b}	30 ^{a}	30 ^{a}
$T_{e\,4.50}$ (min)	270 ^{a}	630 ^{b}	840 ^{c}

SB: fermented soy beverage; SB_3.0: fermented soy beverage with 3.0% additive acai powder; SB_6.0: fermented soy beverage with 6% acai powder; V_m: maximum acidification rate; T_m: time at which V_m is reached; T_e: time to reach pH 4.50; $^{a–c}$: different small letters in the superscript in rows indicate statistically significant differences at the level $p = 0.05$.

The experimental fermentation time was determined until pH of at least 4.50 was reached in the soy beverages without additives, which was achieved in τ270 min. Meanwhile, the changes in pH of the soy beverages with 3% and 6% acai powder were significantly smaller (ΔpH τ270 = 0.37 and ΔpH τ270 = 0.28, respectively). Alignment to the declared pH of 4.50 in the acai soy beverages took place as late as 630 and 840 min of fermentation ($p < 0.05$, Table 1). The observed time shift was the reason for the statistical analysis of the distribution and simulation (Table 2). Using the parameters of the adjusted distributions for simulation purposes, a panel of common values (41–74%) indicated a pH value of 4.72. Similar values (±1%) were confirmed by the correlation matrices: pH 4.73 (soy beverages without acai powder), 4.78 (SB_3.0), and 4.72 (SB_6.0). However, it was a value far from the expected pH below 4.50. Therefore, the final pH cannot be taken from the simulation calculations. In accordance with the declared pH of 4.50 and good microbiological practice, the fermentation time of soy beverages with acai powder should be extended to 630 and 840 min for 3% and 6% of the additive, respectively.

Table 2. Various structural properties of the distribution change of pH during the fermentation of soy beverages with acai powder.

Distribution		SB	SB_3.0	SB_6.0
Weibull	KS	0.383	0.227	0.133
	AD	7.134	2.615	0.829
	Chi-square	101.000	42.944	5.944
Normal	KS	0.415	0.235	0.176
	AD	7.693	2.780	1.166
	Chi-square	83.667	45.278	6.778

SB: fermented soy beverage; SB_3.0: fermented soy beverage with 3.0% additive acai powder; SB_6.0: fermented soy beverage with 6% acai powder; KS: Kolmogorov–Smirnov statistic; AD: Anderson–Darling statistic.

The technological goals primarily related to texture can be achieved. However, a further topic for consideration and research may be to investigate the levels of compounds responsible for aroma (including lipoxygenase activity), sensory, and functional properties (e.g., content and bioavailability of protein hydrolysis compounds). A study by Abdelghani et al. [50] showed that total phenol content, aglycone isoflavones, daidzein, and genistein in a soy beverage increased with increasing fermentation time with probiotic bacteria. An important aspect was the ability of fermentation to sufficiently reduce the raffinose, verbascose, and stachyose content of the beverage as anti-nutritional substances. These raffinose-family oligosaccharides can lead to flatulence [51].

3.2. Microbiological Properties of Fermented Soy Matrix

Fermented soy beverages with and without acai powder (at 37 °C to pH 4.50) have been shown to contain *Lactobacillus acidophilus*, *Bifidobacterium animalis* subsp. *lactis*, and *Streptococcus thermophilus* (Table 3). The addition of acai powder to soy beverages had no effect on the amount *Lactobacillus acidophilus* and *Bifidobacterium animalis* subsp. *lactis* ($p > 0.05$). The obtained results showed that the presence of acai inhibited the proliferation of *Streptococcus thermophilus* compared to the soy beverage without acai powder added ($p < 0.05$). The higher the percentage of acai powder added, the more *Streptococcus thermophilus* bacteria were determined. The addition of 6% acai powder resulted in *Streptococcus thermophilus* 4.39 log CFU/g, but it was still less than in fermented soy beverages without the additive (5.17 log CFU/g; $p < 0.05$). The lowest number of *Streptococcus thermophilus* was found in the beverage with 3% acai powder added, which could be associated with the highest pH (pH 5.14). At lower pH, the highest number of *Streptococcus thermophilus* bacteria was observed. It should be noted that all three types of samples were inoculated with the same (type and dosage) starter culture, because, as shown by Cais-Sokolińska et al. [52], reduction in *Streptococcus* relative to *Lactobacillus* in the starter culture (from 1:1 to 2:3) reduced pH from 4.34 to 4.29 in fermented cow's milk. Thus, the results obtained indicated a different behavior of LAB bacteria (from starter cultures) in soy beverages than in milk. Rekha and Vijayalakshmi [53] reported that fermented soymilk (12 h) *Lactobacillus delbrueckii* subsp. *bulgaricus* had a content of 7.75 log CFU/mL and *Lactobacillus plantarum* 7.57 log CFU/mL. Lovabyta et al. [54] showed that fermented soy milk had a very high number of *Streptococcus thermophillus* 1.85 × 109 CFU/mL (9.27 log CFU/mL). Lambertus et al. [55] fermented soygurt for 5 h and displayed high LAB (7.99–9.75 log CFU/g). The growth and viability of the starter cultures-derived LAB was an important criterion for the evaluation of fermented products and their health-promoting properties. Proper LAB levels resulted in product acidification, pH changes, which ultimately affected the degree of protein gelation. Many factors can influence the differential growth of different types of LAB in the presence of acai powder, including, e.g., change in redox potential, proteolytic activity of bacteria and release of low molecular weight peptides into the environment, or content of organic acids. According to Santo et al. [56] the addition of acai pulp to milk favored an increase in *Lactobacillus acidophilus*, *Bifidobacterium animalis* subsp. *lactis* and *Bifidobacterium longum* counts at the end of four weeks of cold storage. Our research shows, that the acai powder additive did not affect the account of *Lactobacillus acidophilus* and

Bifidobacterium animalis subsp. *lactis*, but the higher the acai powder additive, the more *Streptococcus thermophilus* bacteria were detected. However, the development of fermented soy beverage technology depends on strain selection for ability to grow in the substrate as well as ability to compete or even establish a synergy between strains [57]. Antimicrobial effect of acai by Belda-Galbis et al. [58] depends on the content of phenols, which are characterized by bacteriostatic and bactericidal properties e.g., against *Listeria innocua* as a non-pathogenic surrogate for *Listeria monocytogenes*. Wang et al. [59] demonstrated that at pH 5.5, the transformation of soy protein colloidal solution to soy protein curd occurred. The cited examples indicated that it was possible to create a product formulation based on fermented soymilk with a high LAB count. Fermentation using LAB can promote the development of products that are more acceptable and attractive to future consumers [60].

Table 3. Viable counts of bacteria in soy beverages with acai powder.

Microbial Species	SB	SB_3.0	SB_6.0	MSE
Lactobacillus acidophilus (log CFU/g)	4.66 ^{a}	3.95 ^{a}	4.28 ^{a}	0.16
Bifidobacterium animalis subsp. *lactis* (log CFU/g)	4.50 ^{a}	4.51 ^{a}	4.49 ^{a}	0.04
Streptococcus thermophilus (log CFU/g)	5.17 ^{c}	3.40 ^{a}	4.39 ^{b}	0.82

SB: fermented soy beverage; SB_3.0: fermented soy beverage with 3.0% additive acai powder; SB_6.0: fermented soy beverage with 6% acai powder; MSE: mean square error of inter-group variability; $^{a–c}$: different small letters in the superscript in rows indicate statistically significant differences at the level p = 0.05.

3.3. Texture and Water Holding Capacity

Our study showed that the addition of acai powder (regardless of quantity) to soy beverages reduced the firmness, consistency, cohesiveness, and viscosity index of fermented soy beverages ($p < 0.05$; Table 4). The addition of 3% and 6% acai powder caused the following: firmness decreased 2.9-fold and 3.2-fold (respectively) and cohesiveness as much as 5.7-fold and 8.7-fold (respectively) compared to sample SB (fermented soy beverage without acai powder). No significant differences were found between the addition of 3% and 6% acai powder ($p > 0.05$). Instrumental analysis of individual texture parameters differentiated the viscoelastic properties of the studied fermented soy beverages within a very narrow range. The observed decrease in the parameter values resulted in an increasingly loose consistency of the soy beverages. Hence, beverages with added acai powder were looser and visually resembled drinking yogurt. However, soy beverages without added acai powder showed the consistency of traditional stirred yogurt. It is known that fermentation can improve the flavor and texture of soy beverages [23]. Liu et al. [61] indicated that the texture of soya yogurt was rough compared to the softer texture of traditional cow's milk yogurt. In addition, it was characterized by high hardness and low WHC. According to Guo and Yang [62], the fermentation process of soy beverages led to the aggregation of soy proteins, and the resulting microstructure determined the texture of the final product. The authors also highlighted that the forces that stabilized the conformation of the soy protein molecule were influenced by heat, pressure, shear force, pH change, and ionic strength during processing. In our research, the addition of 3% acai powder to soy beverage significantly decreased the initial pH (as we stated earlier), which affected the fermentation kinetics and, hence, the texture of the final product. de Oliveira et al. [27] analyzed the cheese Petit Suisse with acai, suggesting that the addition of acai not only increased the nutritional value of the product, but also that the analysis of texture parameters is important from the point of view of influencing its choice by the consumer.

Table 4. Texture profile of fermented soy beverage with acai powder.

Texture Parameters	SB	SB_3.0	SB_6.0	MSE
Firmness (g)	62.83 ^{b}	21.38 ^{a}	19.69 ^{a}	2.65
Consistency (g·s)	1513.08 ^{b}	419.84 ^{a}	369.03 ^{a}	6038.80
Cohesiveness (g)	133.07 ^{b}	23.45 ^{a}	15.29 ^{a}	61.06
Viscosity index (g·s)	313.07 ^{b}	16.40 ^{a}	21.81 ^{a}	217.45

SB: fermented soy beverage; SB_3.0: fermented soy beverage with 3.0% additive acai powder; SB_6.0: fermented soy beverage with 6% acai powder; MSE: mean square error of inter-group variability; $^{a–b}$: different small letters in the superscript in rows indicate statistically significant differences at the level $p = 0.05$.

The addition of acai powder in the production of fermented soy beverages lowered WHC to ca. 50% ($p < 0.05$). This showed that soy beverages with acai had higher syneresis. In the case of fermented soy beverage SB; SB_3.0; SB_6.0 calculated WHC was 67.50, 30.17, and 30.84%, respectively. This was probably related to the lower pH and WHC of the acai powder. During the acidification of plant-based yogurts, the destabilization of the proteins resulted in the formation of a weak gel, promoting serum separation [63]. According to Mei et al. [64], WHC in soya yogurts was 48.13%, which corresponded to higher solvation of the micellar system, more branched soybean yogurt microstructure, and higher pH values leading to increased syneresis. It is known that syneresis is a very important physical factor for yogurt quality, which occurs due to the compression of three-dimensional structure of the protein network. As a result, a decrease in the protein binding power occurs and the expulsion of water from the yogurt. Texture defects in fermented beverages are caused by changes in the apparent viscosity and syneresis, which affects the unfavorable perception of these products by consumers [65]. Oyeniyi et al. [66] showed the percentage of syneresis in soya yogurts ranged between 37.75% and 54.09%. In our research, we observed that the addition of acai powder in the production of fermented soy beverages decreased WHC. However, the addition of acai and the composition of the soya drink affected the syneresis. Importantly, soy protein is less effective than casein in the binding of water. Silva et al. [67] showed that the addition of soy extract to the matrix (milk) improved WHC both after production and during storage. However, Yang and Li [68] showed that reconstituted skimmed milk yogurt had a lower WHC (85.1%) than soy yogurt (87.5–92.4%). Gallina et al. [32], analyzing yoghurts with mango pulp, grape, red fruits, mango/passion fruit, and red fruits/acai, also observed a decrease in pH, as well as a higher rate of syneresis. In addition, other factors affecting syneresis include e.g., total dry matter content, temperature changes, mechanical factors (e.g., shaking), type of culture, low acid production during fermentation, and high acidity during the storage. The same authors suggest that the addition of fruit to yoghurts may increase the rate of syneresis and result in a weak gel, due to the acidity of the pulp and the decrease of total solids, leading to changes in the structure of the protein network [32].

3.4. Color and Gloss

The obtained results indicated that the addition of 3% and 6% acai powder to the production of fermented soy beverages (as opposed to the texture parameters shown earlier), produced differences in lightness and calculated indices: whiteness (WI), yellowness (YI) and chroma (C*) ($p < 0.05$; Table 5). There was only a minor difference of ca. 6% ($p < 0.05$) for L* and WI. Analysis of parameter C* in sample SB_3.0 compared to SB_6.0 displayed an increase up to 30%. A significant change was observed in YI in sample SB_6.0, which decreased 5.8-fold compared to sample SB_3.0. Figure 2 shows the visual differences of fermented soy beverages with acai powder added compared to the control sample. Mei et al. [64] analyzed the color of soyabean yogurt and demonstrated negative a* (red-green axis) values. Grasso et al. [18] compared the color of plant-based yogurts and indicated that the soy samples had higher b* values (yellow color) than other yogurts. The same researchers reported that color was an important consideration for the acceptability of food products by consumers and CIELAB system color results.

Table 5. Color and gloss of fermented soy beverage with acai powder.

	SB	SB_3.0	SB_6.0	MSE
L *	57.16 [c]	46.18 [b]	43.36 [a]	0.01
WI	56.39 [c]	46.08 [b]	43.21 [a]	0.01
YI	20.46 [c]	5.38 [b]	0.92 [a]	<0.01
C *	8.20 [c]	3.21 [a]	4.18 [b]	<0.01
Gloss (GU)	26.88 [a]	57.40 [b]	24.16 [a]	37.08

SB: fermented soy beverage; SB_3.0: fermented soy beverage with 3.0% additive acai powder; SB_6.0: fermented soy beverage with 6% acai powder; L *: lightness; WI: whiteness index; YI: yellowness index; C *: chroma; MSE: mean square error of inter-group variability; [a–c]: different small letters in the superscript in rows indicate statistically significant differences at the level $p = 0.05$.

SB SB_3.0 SB_6.0

Figure 2. Fermented soy beverages with acai powder. SB: fermented soy beverage; SB_3.0: fermented soy beverage with 3.0% additive acai powder; SB_6.0: fermented soy beverage with 6% acai powder.

Gloss analysis showed that fermented soy beverage with 3% acai powder had 2-fold higher gloss compared to the control sample (SB), but the addition of 6% acai powder decreased the gloss (Table 5).

4. Conclusions

Determination of the fermentation kinetics of fermented soy beverage with acai powder based on changes pH allowed for the development of a technology for obtaining functional foods. The fermentation kinetics analysis of the soy beverage's matrix highlighted the advisability of acai powder addition. The time to reach maximum acidification rate was 7-fold shorter after the addition of acai powder. Additionally, the determination of the texture and color parameters of fermented soy beverages provided vital data regarding the possibility of modeling and/or changing these parameters through the addition of acai powder. The beverages with the addition of acai powder visually resembled drinking yogurt.

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