EJFA Emirates Journal of Food and Agriculture

Emirates Journal of Food and Agriculture 36: 1–12
doi: 10.3897/ejfa.2024.118276

RESEARCH PAPER

Physicochemical, rheological, sensory, and proximal properties of yogurt flavored with *Aloe vera* gel

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Academic editor: Luigi Milella ♦ **Received** 5 January 2024 ♦ **Accepted** 6 April 2024 ♦ **Published** 7 May 2024

Abstract

Aloe vera leaves have a transparent mucilaginous, showing an important polysaccharides content and potential bioactive phytochemicals. This study evaluated the physicochemical, rheological, sensorial, and proximal properties of yogurt elaborated using *Streptococcus thermophilus* and *Lactobacillus bulgaricus* and flavored with *Aloe vera* gel. Previous studies have shown that the variation of some ingredients, such as the percentage of fat or inoculum, can modify the sensory and rheological characteristics of fermented dairy beverages. Different treatments were prepared using a 2^n factorial design varying the percentage of fat (2 and 3%), inoculum (2 and 3%), and *Aloe vera* gel (5 and 10%).All the samples presented pseudoplastic behavior, and the power law equation showed a better fit in all the samples. The higher percentage of inoculum decreased the fermentation time and increased the apparent viscosity. An increase in fat concentration amplified yogurt's pH, °Brix, and pseudoplastic behavior. Meanwhile, the gel increased the percentage of syneresis and decreased the apparent viscosity.The formulation with 3% fat, 3% inoculum, and 5% *Aloe vera* gel obtained higher values in these sensory parameters of smell, flavor, appearance, and acceptability. The production of supplemented probiotic yogurt- up to 5% *Aloe vera* gel is feasible from an industrial and consumer point of view since it shows acceptable sensory, nutritional, and microbiological characteristics.

Keywords

Apparent viscosity, consistency index, flow behavior index, power law, sábila

Introduction

Aloe vera or *Aloe barbadensis* Miller belongs to the Aloaceae family and is native to eastern and southern Africa (Sánchez-Machado et al. 2017). It is a plant that grows practically worldwide due to its versatility and adaptiveness to survive in hot-dry areas (Reynolds 2004; Sharma and Sharma 2018). The basal leaves of this plant have a transparent mucilaginous jelly known as *Aloe vera* gel; this makes up 65 to 80% of the total weight (Boudreau and Beland 2006). The gel comprises water (99%) and the polysaccharide glucose-mannose (Ray and Ghosh 2014). Also, it contains 75 potential bioactive phytochemicals, among the most important are anthraquinones (aloe-emodin, aloetic-acid, anthranol, isobarbaloin, emodin, ester of cinnamic acid), carbohydrates (monose, glucose, galactan, galactogalacturan, arabinogalactan, pectic substance, xylan, cellulose), chromones (aloesin, umbelliferone, and esculetin), proteins (lectins), enzymes (cellulase, catalase, amylase, lipase, oxidase), vitamins (B1, C, folic acid), and organic acid (arachidonic acid, salicylic acid, uric acid) (Hamman 2008; Balaji et al. 2015). The *Aloe vera* gel is used by cosmetic companies in moisturizers, soaps, sunscreens, and shampoos (Nandal and Bhardwaj 2012) due to its antifungal (Das et al. 2011), anti-inflammatory (Langmead et al. 2004), wound healing effects (Reynolds and Dweck 1999; Jamil et al. 2020), and anticancer properties (Maan et al. 2018; Majumder et al. 2019). While in the food industry, it is used to produce jams (Kanojia et al. 2018), ice creams (Ahlawat et al. 2014; Verma et al. 2018), and health drinks (Sharma et al. 2015; Tariq et al. 2023).

The dairy industry has to stay at the forefront to satisfy market needs through innovation and the development of new products with different flavors and high health benefits (Gehlhar et al. 2009). As part of this innovation, probiotic foods have emerged; one of these products is yogurt, which has several health benefits due to its microbiological and nutritional composition. According to the Food and Drug Administration (FDA), *yogurt* involves all those drinks obtained by milk fermentation produced by two species of bacterial cultures, *Streptococcus thermophilus* and *Lactobacillus bulgaricus* (Freitas 2017). The symbiosis of both lactic acid bacteria produces metabolites that influence the acidity and texture milk changes that are characteristic of yogurt (Chen et al. 2017; Krastanov et al. 2023). Recent studies have shown that yogurt also contains *Lactococcus lactis*, *Lactobacillus casei*, or different species of *Bifidobacterium* (Redondo-Useros et al. 2019). There is scientific evidence that this food regulates the intestinal microbiota (Yu et al. 2020), has an antihypertensive effect (Tavani et al. 2002; Dong et al. 2013), has a suppressing effect on *Helicobacter pylori* (Wang et al. 2004), is an excellent option for those who suffer from diabetes and lactose intolerance, because this drink is more easily digestible to milk or cheese (Freitas 2017), and has an effects on the immune system (Aattouri and Lemonnier 1997).

On the other hand, understanding the rheological properties is important because it allows for optimizing foods' physicochemical properties, sensory attributes, and nutritional value. Likewise, these values are fundamental in the transportation design through pipeline equipment and processes. Yogurt presents a complex flow behavior because its properties depend on shear stress and time. Previous studies have shown that the variation of some ingredients, such as the percentage of fat or inoculum, can modify the sensory and rheological characteristics of fermented dairy beverages (Meena et al. 2022; Atik et al. 2023).

This work aimed to examine the influence of the fat, inoculum, and Aloe vera gel percentage on the physicochemical (pH, acidity, Brix and syneresis percentage), rheological (apparent viscosity, consistency index, and flow behavior index), and sensory properties of yogurt. Including this mucilaginous jelly is expected to add nutritive and sensorial characteristics to this drink.

Methods

Extraction and characterization of *Aloe vera* gel

Organic and undamaged *Aloe vera* leaves were classified according to size and weight. The leaves were washed and peeled, and the gel was removed with a juice extractor (Oster, Fort Lauderdale, FL). The gel was filtered and pasteurized at 90 °C for 5 min to destroy the enzymes responsible for browning (Reyes-De-Corcuera et al. 2014).

The parameters evaluated in the gel were pH, °Brix, dry extract, and relative density. The pH was evaluated at 20 °C according to the INEN 0381 standard (Ecuadorian Standardization Service (INEN) 1986), using a potentiometer with glass electrodes (Crison, Spain). The measurement was carried out with approximately 10 g of gel homogenized with 100 ml of distilled water. The determination of the Brix degrees was carried out by what is described in the standard INEN 273 (Ecuadorian Standardization Service (INEN) 1990), using a digital precision refractometer (ATAGO Co., Ltd., Tokyo, Japan). The dry extract was determined according to the standard INEN 382 (Ecuadorian Standardization Service (INEN) 2013). An electric oven (Nüve FN055 Ankara, Turkey) was used at 70 °C until constant weight. The relative density was also determined according to the standard INEN 391 (Ecuadorian Standardization Service (INEN) 2012), using a 50 ml pycnometer. The average and standard deviation of three repetitions for each parameter are presented.

Physical and chemical analysis of milk

A physicochemical analysis was carried out on the two types of milk used to prepare yogurt: milk with 2% fat and milk with 3% fat. The parameters evaluated were density, acidity (% lactic acid), pH, mastitis test, fat percentage, and ash percentage. Six repetitions of each property were performed. The relative density was determined using a pycnometer (50 ml) according to the procedure described in the INEN 391 standard (Ecuadorian Standardization Service (INEN) 2012). Acidity was determined by titration using 0.1 N sodium hydroxide solution and phenolphthalein indicator solution according to the procedure described in the INEN 13 standard (Ecuadorian Standardization Service (INEN) 1984a). The result was expressed as a percentage of lactic acid. The pH was evaluated at 20 °C according to the AOAC 973.41 method (AOAC Association of Official Agricultural Chemists 2012), using a potentiometer with glass electrodes (Crison, Spain). The measurement was carried out with approximately 100 ml of milk with 250 ml of distilled water. The California Mastitis Test (CMT) was performed to evaluate if the number of somatic cells was above 200,000 cells/mL (McFadden 2011). Fat was determined by the Gerber method according to the procedure described in the INEN 12 standard (Ecuadorian Standardization Service (INEN) 1973). In this analysis, the sample is acidified and centrifuged, and the fat content in the product is read directly on the scale of the standardized butyrometer. Ash content was determined according to the procedure described in the INEN 14 standard (Ecuadorian Standardization Service (INEN) 1984b), using a muffle (model 367PE, Selecta, Barcelona, Spain) at 530° ± 20 °C until ashes free of carbon particles were obtained (approximately 3 hours). The average and standard deviation of three repetitions for each parameter are presented.

Preparation of Aloe vera yogurt

The different treatments were prepared using a 2^n factorial design, varying the percentage of fat (2 and 3%), inoculum (2 and 3%), and *Aloe vera* gel (5 and 10%). Table 1 shows the elaborated formulations.

Table 1. Formulations.

Code	%Fat	%Inoculum	%*Aloe vera* gel
A225	2	2	5
A221	2	2	10
A235	2	3	5
A231	2	3	10
A325	3	2	5
A321	3	2	10
A335	3	3	5
A331	3	3	10

The milk was filtered, and its non-fat solids were standardized to 18% by adding commercial whole milk powder (Nestlé, Ecuador). Subsequently, it was pasteurized at 90 °C for 5 min and cooled to 42 °C. The lactic culture was inoculated at this temperature with *Streptococcus thermophilus* and *Lactobacillus bulgaricus*. The milk coagulation was monitored for pH during the incubation period until reaching a pH of 4.6 (Peng et al. 2009). Acidity and °Brix were measured at time intervals during the yogurt incubation. Finally, the *Aloe vera* pulp was added, beaten, and stored in airtight jars at 10 °C.

Physical and chemical analysis of yogurt

The parameters evaluated at the end of the fermentation process were relative density, acidity (% lactic acid), pH, °Brix, and syneresis percentage. The pH was evaluated at 20 °C according to the AOAC 973.41 method (AOAC Association of Official Agricultural Chemists 2012), using a potentiometer with glass electrodes (Crison, Spain). Acidity was determined by titration according to the procedure described in the INEN 13 standard (Ecuadorian Standardization Service (INEN) 1984a). The determination of the Brix degrees was carried out using a digital precision refractometer (Atago Co., Ltd., Tokyo, Japan) (Ecuadorian Standardization Service (INEN) 1990). The percentage of syneresis was determined by the method reported by (González-Martınez et al. 2002). A sample of 25 g (at 4 °C) was centrifuged for 30 min at 350 rpm. Syneresis was reported as the percentage of whey released.

Rheological analysis

The rheological parameters were determined using rotational viscometers (DV-III Ultra LV, Brookfield Engineering Labs, Middleboro, USA). The system's temperature was set and maintained at 5 °C for the flow curve through a circulator water bath (DC30, Haake, Karlsruhe, Germany). The flow curves of the yogurts were determined using a shear rate from 1 to 100 s^{-1}. The rheological properties were fitted to the Power law, Herschel-Bulkley, and Casson models (Table 2). The average and standard deviation of six repetitions are presented.

Table 2. Equations are used for modeling the rheological behavior.

Model	Equation	Equation number	References
Power law	$\sigma = k(\dot{\gamma})^n$	1	Song et al. (2006)
Herschel-Bulkley	$\sigma = \sigma_0 + k(\dot{\gamma})^n$	2	Herschel and Bulkley (1926)
Casson	$\sigma^{0.5} = \sigma_0^{0.5} + k(\dot{\gamma})^{0.5}$	3	Casson (1959)

where σ is the shear stress (Pa), σ_0 is the yield stress, $\dot{\gamma}$ is the shear rate (s^{-1}), k is the consistency index (Pa×s^n), and n is the flow behavior index (dimensionless).

Sensory analysis

This analysis was made with a panel of 40 semi-trained tasters with excellent health conditions. The participants were aged between 20–25 years, this age group was selected because they are more likely to be potential users of this product. The percentages of males and females were 45% and 65%. A factorial arrangement of incomplete blocks was used to reduce subjectivity in the responses. The samples of the 8 treatments were assigned to each taster randomly, so 4 samples were analyzed for each taster. The parameters analyzed were color, smell, flavor, appearance, and general acceptability, using a 5-point hedonic scale (ranging from 1: not at all to 5: extremely).

Proximal and quality analysis of the best treatment

The treatment with the highest value in sensory analysis was analyzed for total solids, protein, ash, fat, and total carbohydrates. Also, these analyses were made on a sample of natural yogurt (made with whole milk – fat 3%) from a local traditional commercial brand (Toni, Tonicorp). Total solids were determined with AOAC 927.05 (AOAC Association of Official Agricultural Chemists 2012) by drying the sample at 100 °C for 12 h in a Vaciotem vacuum oven (J.P. Selecta, Barcelona, Spain). The amount of protein was determined by AOAC 2001.11 (AOAC Association of Official Agricultural Chemists 2012). This method is determined based on total nitrogen content by the Kjeldahl procedure. Ash content was determined according to the procedure described in the AOAC 930.30 method (AOAC Association of Official

Agricultural Chemists 2012), using a muffle (model 367PE, Selecta, Barcelona, Spain) at 550° ± 20 °C until ashes free of carbon particles were obtained. Fat was determined by the Gerber method according to the procedure described in the AOAC 2000.18 method (AOAC Association of Official Agricultural Chemists 2012), using a standardized butyrometer. Finally, the total carbohydrates were obtained by calculation. The average and standard deviation of three repetitions for each parameter are presented.

In addition, a mold and yeast analysis was carried out following the steps described in the AOAC 997.02 standard (AOAC Association of Official Agricultural Chemists 2012). 3M™ Petrifilm™ yeast and mold count plates (St. Paul, MN, USA.) were used in this analysis. The average and standard deviation of three repetitions for each parameter are presented.

Statistical analysis

The data were processed in the STATGRAPHICS CENTURION XVII Software, version 17.2.04 (Statgraphics Technologies, Inc., The Plains, VA, USA), using a multifactorial ANOVA with 95% confidence. Significant differences were calculated using Tukey tests. The goodness of the fitting in the rheological analysis was evaluated with the coefficient of determination (r^2).

Results

Characterization of Aloe vera gel

The leaves have variable lengths (43.55 ± 8.49 cm) and weights (430.55 ± 85.44 g). The pH presented a value of 4.7± 0.2 (Table 3); it can be considered that it is a medium acid food (group II from 4.6 to 5.3) (Gould and Gould 2001). The Brix degrees presented a low value (1 ± 0.5), and this is mainly due to the presence of small traces of monosaccharides (glucose, mannose, *L*-rhamnose, aldopentose) (Dagne et al. 2000). The amount of dry extract shows that it is a food with a high amount of water, which is why it is usually used as a moisturizer cosmetologically (Pegu and Sharma 2019). The relative density gave a value of 1.017 ± 0.002 g/cm^3. This parameter is crucial because it can be related to the structure of the gel (Chandegara et al. 2015). A similar value was reported by Mendes Aciole et al. (2020), 1.018 ± 0.008 g/cm^3, and by Pérez et al. (2019), 0.975 ± 0.009 g/cm^3.

Table 3. Physicochemical properties of *Aloe vera* leaf and pulp.

	Property	*Value
Leaf	Length (cm)	43.55 ± 8.49
	Width (cm)	5.8 ± 0.6
	Average weight (g)	430.55 ± 85.44
Pulp	pH	4.7 ± 0.2
	°Brix	1 ± 0.5
	Dry extract (%)	0.16 ± 0.012
	Relative density (g/cm^3)	1.017 ± 0.002

Milk analysis

Milk with 2% fat was compared with the values reported in the standard for semi-skimmed milk. At the same time, milk with 3% fat was compared with the values reported for whole milk. The evaluated parameters were found within the ranges established in the standard NTE INEN 701 (Ecuadorian Standardization Service (INEN) 2009) (Table 4).

Table 4. Physicochemical characterization of milk.

Parameter	Milk (3% fat)	Standard limit whole milk*	Milk (2% fat)	Standard limit semi-skimmed milk*
Temperature (°C)	26 ± 0.5	-	26 ± 0.5	-
Relative density (kg/m^3)	1031 ± 1	1028–1032	1030 ± 1	1029–1032
Acidity (% lactic acid)	0.15 ± 0.02	0.13–0.17	0.16 ± 0.02	0.14–0.17
pH	6.5 ± 0.2	6.4–6.8	6.5 ± 0.1	6.4–6.8
Mastitis	Negative	Negative	Negative	Negative
Fat (%)	3.2 ± 0.2	≥ 3	2.5 ± 0.2	1–2.9
Ash (%)	0.67± 0.02	0.65–0.8	0.71 ± 0.01	0.7–0.8

* Ecuadorian Standardization Service (INEN) (2009).

Yogurt fermentation

The formulations prepared with 3% inoculum reached a pH of 4.6 at 180 minutes, while the samples prepared with 2% inoculum reached this pH value at 210 minutes. The pH variation versus fermentation time is reported in Fig. 1A. This trend is conditioned by microbial growth (Molaee Parvarei et al. 2021). A latent phase is shown from minute 0 to 40 min. After an exponential decrease is shown, the decrease is more pronounced in formulations with a higher percentage of inoculum (3%). On the contrary, acidity variation increases with fermentation time (Fig. 1B). The increase in acidity destabilizes proteins because they reach the isoelectric point of casein (pH 4.6), and this change is the basis for producing yogurt (Lima Nascimento et al. 2023). Brix degrees vary during fermentation because the microorganisms consume the available sugars as part of their metabolism (Fig. 1C). Formulations made with whole milk (3% fat) have higher °Brix variation; however, all samples present a similar trend.

Physical and chemical analysis of yogurt

The average values of acidity, pH, °Brix, and percentage of syneresis are detailed in Table 5. The different treatments showed acidity values between 0.42 and 0.57% lactic acid. The statistical analysis showed no significant differences ($p < 0.05$) between the samples.

Values between 5.42 and 6.11 are observed in the pH; this shows the influence of the *Aloe vera* gel. Similar values

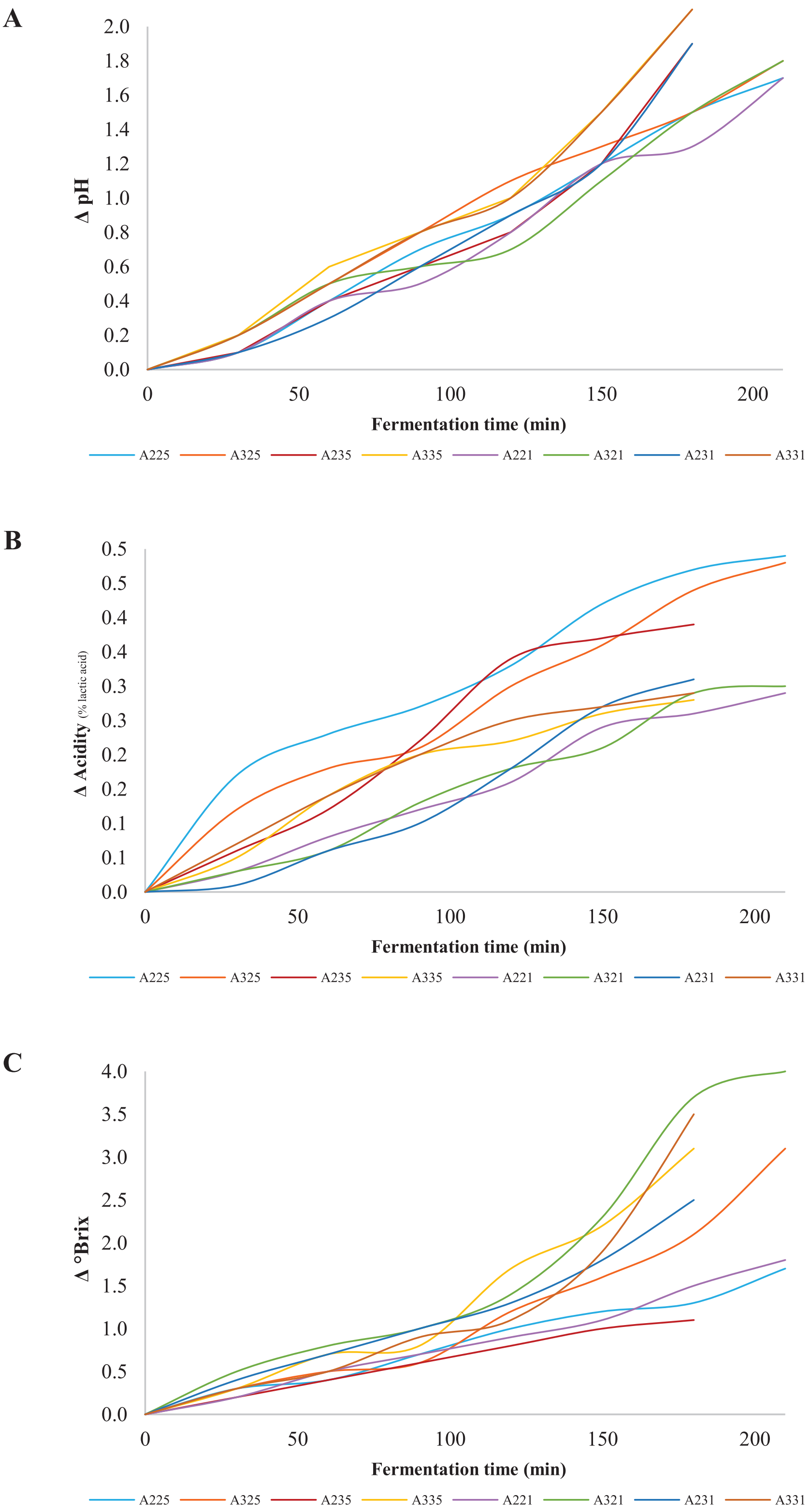

Figure 1. Changes in the **A** pH, **B** acidity, **C** °Brix during the fermentation.

were observed by Ikram et al. (2021) in yogurt with the addition of *Aloe vera* gel. The sample with 2% fat and 3% *Aloe vera* gel presents a value of 4.29 at 21 days of storage. In addition, significant differences ($p < 0.05$) are observed in the fat percentage. Samples made with whole milk have higher pH values. Guggisberg et al. (2009) show significantly higher pH values when yogurt is made from milk with high-fat percentages (3.5%).

Brix degrees have values between 1.5 and 3.3. This parameter shows significant differences ($p < 0.05$) between the three variables analyzed. Slightly higher values are observed in the samples made with 3% fat and 10% *Aloe vera* gel. The percentage of syneresis is related to eliminating whey from the casein micelles (Acevedo et al. 2010). Values between 58.6% and 71.9% were obtained, and no significant differences were evident between the treatments ($p < 0.05$).

Table 5. Mean values (and standard deviations) of the physicochemical parameters of yogurt.

Treatments	Acidity (% lactic acid)	pH	° Brix	Syneresis (%)
A225	0.45 ± 0.13 ^{eJx}	5.7 ± 0.12 ^{fJx}	1.5 ± 0.2 ^{fJy}	61.4 ± 1.2 ^{eJx}
A325	0.42 ± 0.09 ^{eJx}	5.91 ± 0.13 ^{eJx}	3.2 ± 0.4 ^{eJy}	67.4 ± 1.5 ^{eJx}
A235	0.48 ± 0.12 ^{eJx}	5.42 ± 0.19 ^{fJx}	1.5 ± 0.2 ^{fKy}	65.7 ± 1.7 ^{eJx}
A335	0.57 ± 0.08 ^{eJx}	6.11 ± 0.15 ^{eJx}	3.0 ± 0.1 ^{eKy}	69.0 ± 1.9 ^{eJx}
A221	0.47 ± 0.09 ^{eJx}	5.52 ± 0.16 ^{fJx}	2.1 ± 0.3 ^{fJx}	71.9 ± 1.2 ^{eJx}
A321	0.50 ± 0.08 ^{eJx}	5.92 ± 0.16 ^{eJx}	3.3 ± 0.2 ^{eJx}	60.0 ± 1.4 ^{eJx}
A231	0.50 ± 0.06 ^{eJx}	5.7 ± 0.16 ^{fJx}	2.4 ± 0.2 ^{fKx}	58.6 ± 1.3 ^{eJx}
A331	0.56 ± 0.08 ^{eJx}	5.93 ± 0.14 ^{eJx}	3.3 ± 0.3 ^{eKx}	63.3 ± 1.4 ^{eJx}

Different letters (e, f) represent significant differences ($p < 0.05$) by % fat; (J, K) represent significant differences ($p < 0.05$) by % inoculum; and (x, y) represent significant differences ($p < 0.05$) by % *Aloe vera*.

Rheological analysis

Fig. 2 shows the variation of apparent viscosity versus the deformation gradient. The values of this property ranged between 1.666 and 2.642 Pa×s at 1 s^{-1}, between 0.147 and 0.288 Pa×s at 50 s^{-1}, and between 0.096 and 0.160 Pa×s at 100 s^{-1}. Cayot et al. (2008) reported an apparent viscosity of 0.63±0.07 Pa×s at 50 s^{-1} for natural yogurt with 3.5% of fat and 1.70±0.35 Pa×s at 50 s^{-1} with 5% of fat. Meanwhile, sample A335 presents the highest values in the 5 to 100 s-1 range. A more significant amount of fat (3%) and inoculum (3%) considerably increases the viscosity of the yogurt.

The values obtained were adjusted to three equations describing viscous products' rheological behavior (Table 2). Determination coefficient values between 0.946 and 0.999 were obtained (Table 6). The highest values were obtained with the Power law equation.

Since the data fit better with the power law (Equation 1), a statistical analysis was carried out to analyze the

Table 6. Parameters obtained in the rheological mathematical modeling.

Treatments	Parameter	Models: Power law	Herschel-Bulkley	Casson
A225	Model constants	k: 2.029 n: 0.41	σ_0: 1.225 k: 1.140 n: 0.518	σ_0: 1.269 k: 0.211
	Adj. r^2	0.992	0.991	0.978
A325	Model constants	k: 2.132 n: 0.37	σ_0: 1.823 k: 0.753 n: 0.575	σ_0: 1.285 k: 0.185
	Adj. r^2	0.975	0.960	0.974
A235	Model constants	k: 2.437 n: 0.307	σ_0: 2.169 k: 0.707 n: 0.541	σ_0: 1.324 k: 0.149
	Adj. r^2	0.983	0.947	0.968
A335	Model constants	k: 2.141 n: 0.487	σ_0: 1.648 k: 1.019 n: 0.644	σ_0: 1.277 k: 0.298
	Adj. r^2	0.999	0.978	0.983
A221	Model constants	k: 2.545 n: 0.30	σ_0: 2.272 k: 0.727 n: 0.539	σ_0: 1.338 k: 0.149
	Adj. r^2	0.975	0.946	0.967
A321	Model constants	k: 2.64 n: 0.35	σ_0: 2.287 k: 0.883 n: 0.565	σ_0: 1.355 k: 0.190
	Adj. r^2	0.992	0.956	0.972
A231	Model constants	k: 1.67 n: 0.38	σ_0: 1.413 k: 0.607 n: 0.581	σ_0: 1.208 k: 0.172
	Adj. r^2	0.982	0.962	0.975
A331	Model constants	k: 1.954 n: 0.45	σ_0: 1.558 k: 0.861 n: 0.624	σ_0: 1.253 k: 0.250
	Adj. r^2	0.983	0.974	0.981

σ_0: yield stress (Pa); k: consistency index (Pa×s^n); n: flow behavior index (dimensionless).

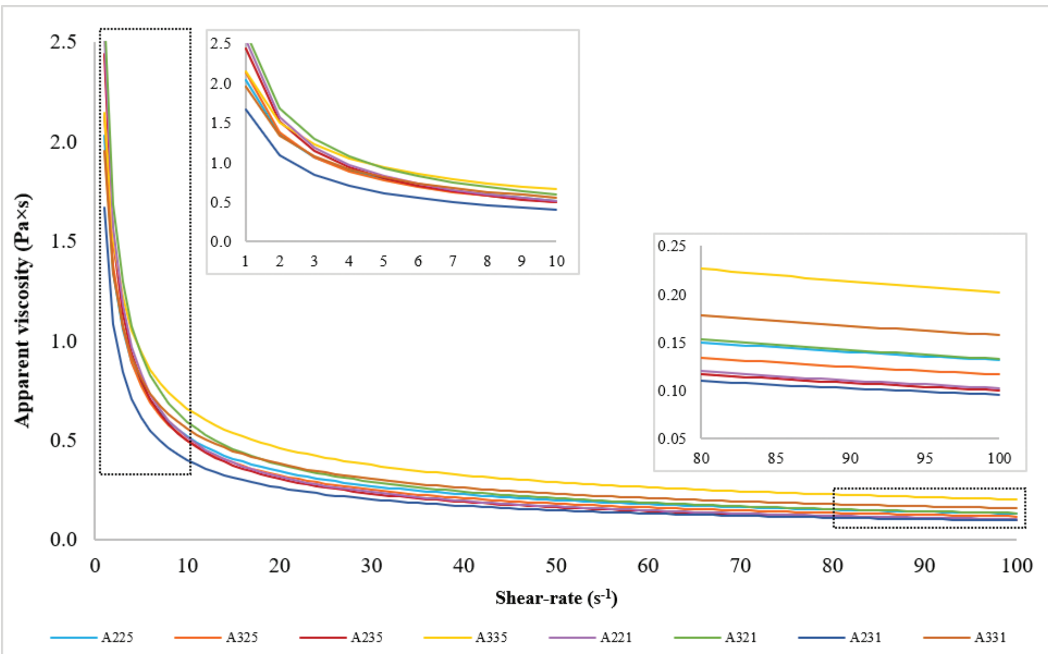

Figure 2. Relationship apparent viscosity (Pa×s) and shear rate (s^{-1}).

influence of the formulations on the rheological parameters n (flow behavior index) and k (consistency index). Higher values ($p < 0.05$) of n are observed in samples with 2% fat. This parameter reflects a deviation from Newtonian behavior. The further the value of n is from unity, the greater the pseudoplastic behavior of the sample. The addition of *Aloe vera* gel significantly increases the pseudoplastic behavior of yogurt. However, the consistency index (k) does not show significant differences ($p < 0.05$) between the formulations.

Table 7. Mean values (and standard deviations) of flow behavior index [n] and consistency index [k] (Pa × s^n).

Treatments	n	k (Pa×s)	r^2
A225	0.41 ± 0.05 ^{eKx}	2.029 ± 0.014 ^{eJx}	0.992
A325	0.37 ± 0.04 ^{eKx}	2.132 ± 0.566 ^{eJx}	0.96
A235	0.307 ± 0.112 ^{eJx}	2.437 ± 0.559 ^{eJx}	0.983
A335	0.487 ± 0.112 ^{eJx}	2.141 ± 0.262 ^{eJx}	0.999
A221	0.30 ± 0.07 ^{eKx}	2.545 ± 0.057 ^{eJx}	0.925
A321	0.35 ± 0.02 ^{eKx}	2.64 ± 0.05 ^{eJx}	0.992
A231	0.38 ± 0.05 ^{eJx}	1.67 ± 0.48 ^{eJx}	0.932
A331	0.45 ± 0.06 ^{eJx}	1.954 ± 0.205 ^{eJx}	0.983

Different letters (e, f) represent significant differences ($p < 0.05$) by % fat; (J, K) represent significant differences ($p < 0.05$) by % inoculum; and (x, y) represent significant differences ($p < 0.05$) by % *Aloe vera*.

Sensory analysis

Smell, flavor, and appearance show differences between the treatments (Fig. 3). Sample A335 (3% fat, 3% inoculum, 5% *Aloe vera*) obtain higher values in these sensory parameters (3.71±0.99, 3.86±1.09, and 3.86±1.09, respectively). Furthermore, this sample presents differences with the least valued treatment A221 (2% fat, 2% inoculum, 10% *Aloe vera*) which show values of 2.71±0.5, 1.14±0.65, and 1.14±0.65, respectively.

Proximal and quality analysis of yogurt

Table 8 presents the results of the proximal and quality analysis of the best treatment (A335) and the commercial natural yogurt. Commercial yogurt has higher values of total solids, protein, ash, fat, and total carbohydrates. This is because commercial brands usually add sugar, milk powder, corn syrup, gelatin, and carrageenan to the formulations to improve some technological and sensory characteristics. This brand reports these ingredients on its label.

Table 8. Proximal and quality analysis of yogurt.

Parameter	*Aloe vera* yogurt	*Natural yogurt	Standard limit
Total solids (%)	8.34±0.05	11±0.06	-
Protein (%N×6.25)	2.79±0.03	3.96±0.06	≥ 2.7**
Ash (%)	0.67±0.03	0.75±0.04	-
Fat (%)	2.7±0.1	2.6±0.1	≥ 2.5**
Total carbohydrates (%)	4.61±0.03	5.53±0.03	-
Molds (UFC/g)	<10	Negative	200–500**
Yeasts (UFC/g)	2.1×10^2	Negative	

* Brand Toni (composition in the label: protein 10 g, fat 8 g, total carbohydrates 13 g).
** Ecuadorian Standardization Service (INEN) (2011).

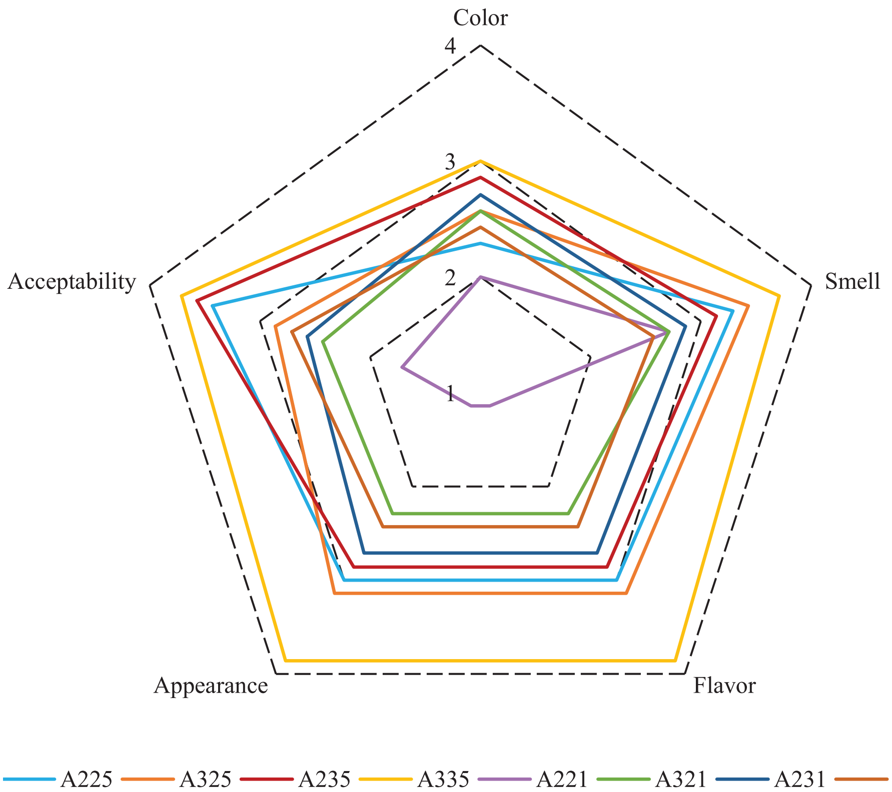

Figure 3. Sensory analysis of the treatments.

Discussion

Characterization of Aloe vera gel

The weights are within the range reported by Hazrati et al. (2017) at 270 days with different irrigation regimes and amounts of zeolite (332.05 to 624.13 g). These characteristics depend on soil conditions as well as the cropping system. For example, an increase of three times the amount of irrigated water (from 2 to 6 Lh^{-1}) generates a 13.2% increase in the weight of the leaves (Silva et al. 2010).

He et al. (2005) reported pH values of 4.5, similar to the 4.7± 0.2 measured in this research (Table 3). Other vegetables have similar values, such as bananas (4.5–4.7) (Booth and Kroll 1989) and tomatoes (3.99–4.75) (Murray 1996). This vegetable chemical parameter depends on geographical areas, seasonal variations, various cultivars, and maturity (Gould and Gould 2001). From a conservation point of view, it is sought that foods have pH values lower than 5.6 to avoid their susceptibility to damage caused by pathogenic bacteria (Rahman 2020).

Milk analysis

The milk type significantly influences the characteristics of the yogurt that is produced. For example, yogurt made with milk with a high-fat content has a creamier texture than that with a lower fat content (Tamime and Robinson 2007). From this, it can be predicted that samples made with whole milk (a_0) will have higher viscosity.

Physical and chemical analysis of yogurt

Different studies indicate that adding extracts from different plants before fermentation increases the metabolism of lactic acid bacteria. This increase is reflected in an increase in acidity in the final product. For example, Mohamed Ahmed et al. (2021) observed this increase by adding 0.2 g of argel (*Solenostemma argel* Hayne) leaf extract for each 100 mL (from 0.68 to 0.73% lactic acid). However, this increase in the present study was only observed between samples A335 (with 5% *Aloe vera* gel) and A331 (with 10% *Aloe vera* gel). The main reason for this difference is that in this study, *Aloe vera* gel was added when the fermentation was finished.

Natural yogurt shows a percentage of syneresis of 23 at 27% (Cardines et al. 2018); this shows the influence of the *Aloe vera* gel on the gel structure. It was previously reported that *Aloe vera* gel has a pH of 4.7 ± 0.2, making it an acidic food. According to Weiner and Nussinovitch (1994), adding acid fruit pulps forms weak gels that collapse, releasing a more significant amount of whey. The higher the percentage of syneresis, the more changes are observed in the product's viscosity (Sidira et al. 2017; Zhang et al. 2019). To reduce the percentage of syneresis in this type of yogurt, the total solids can be increased because it has been widely documented that prior standardization of milk contributes to reducing the release of whey in this type of beverage. For example, Mahdian and Tehrani (2007) reported a reduction in the syneresis percentage from 80 to 50% with an increase in total solids from 14 to 27%. Also, Shaker et al. (2000) show that the highest fat content (3%) increases the yogurt viscosity, which also significantly affects the gel firmness and decreases the degree of syneresis.

Rheological analysis

The samples show evidence of non-Newtonian behavior and exhibit a dependence on the shear rate. The exponential decreasing trend is characteristic of this type of drink. For example, Najgebauer-Lejko et al. (2020) reported this trend in yogurt with green and Pu-erh teas. According to Lee and Lucey (2006), the gel's physical properties influence the yogurt's rheological properties before the agitation produced by the viscometer. The most pronounced decreasing phase is observed between the shear rate 1 and 15 s^{-1}. In this phase, a breakdown of the clot structure formed during the fermentation of yogurt occurs due to the effort exerted. Subsequently, a trend close to linearity is observed from 15 to 100 s^{-1}. Sample A231 presents the lowest apparent viscosity values throughout the evaluated range (1 to 100 s^{-1}).

A more significant amount of fat (3%) and inoculum (3%) considerably increases the viscosity of the yogurt. This behavior has been widely studied because fat globules form part of the gel structure during yogurt fermentation (Van Vliet 1988). This result is significant because consumers typically look for yogurts with the creamy texture provided by milk fat (Cayot et al. 2008). On the other hand, a high amount of *Aloe vera* gel produces a reduction of this property. Pure *Aloe vera* gel shows low apparent viscosity values (2.4 Pa×s at 2 s^{-1} and 1 Pa×s at 20 s^{-1}) (Saad et al. 2021). The addition of this gel to the prepared natural yogurt will generate a reduction in the final apparent viscosity. The higher the percentage of gel addition, the more significant the decrease in apparent viscosity will be observed.

The values obtained were adjusted to three equations describing viscous products' rheological behavior (Table 2). The yield stress (σ_0) is the intercept on the stress axis, and the values were obtained by extrapolating the linear portion of the curve (Sherman 1970). This parameter relates to the initial stress the samples must receive to start flowing (Steffe 1996). Values between 1.208 and 2.289 Pa are observed. That is, it can be considered minimal compared to those reported in Greek yogurt (7.41±1.00 Pa), so this type of beverage cannot be considered plastic fluids (those that need higher initial threshold stresses) (Costa et al. 2019). The flow behavior coefficient ($n < 1$) shows the pseudoplastic comportment of the samples. These fluids are characterized by a reduction in viscosity when subjected to high shear stresses (Ares et al. 2007). The values of this parameter ranged between 0.3 and 0.64, and lower values were obtained with the Power Law.

Consistency index values range between 0.149 and 2.64 Pa×s^n. Slightly higher values were obtained with the Power Law.

Sensory analysis

The color shows a similar trend in all treatments (values between 2 and 3) because no colorant was added prior to the sensory analysis. To improve this characteristic, natural colorants such as lycopene, anthocyanin, and beta-carotene, or synthetic colors such as fast green FCF (42053) (Gawai et al. 2017), can be added in order to make it more attractive to the consumer. Globally, the analysis of acceptability showed an essential difference between the treatments. Sample A335 (3% fat, 3% inoculum, 5% *Aloe vera*) obtained higher values in this sensory parameter (3.71±1.07).

Once all the parameters have been analyzed, it is concluded that the best sensory treatment is A335 (3% fat, 3% inoculum, 5% *Aloe vera*).

Proximal and quality analysis of yogurt

The two samples analyzed present a higher percentage of protein and fat than reported in the local standard. Local regulations do not report ranges for the rest of the components; however, a minimal variation is observed between the study sample and the commercial one. Furthermore, the yogurt produced in the present study has the microbiological quality necessary for commercialization.

Conclusion

Aloe vera gel can be used to develop a yogurt that can be considered a probiotic due to the presence of *Streptococcus thermophilus* and *Lactobacillus bulgaricus*. The higher percentage of inoculum decreased the fermentation time and increased the apparent viscosity. The higher fat percentage increased yogurt's pH, °Brix, apparent viscosity, and pseudoplastic behavior (lower flow behavior index). The gel increased the percentage of syneresis due to the *Aloe vera* gel acidity and decreased the apparent viscosity. All the samples presented pseudoplastic behavior, and a breakdown of the clot structure formed during the yogurt fermentation was observed at low shear rate values. The power law equation showed a better fit in all the samples. From a sensory standpoint, differences were found between the samples. The formulation with 3% fat, 3% inoculum, and 5% *Aloe vera* gel obtained higher values in these sensory parameters of smell, flavor, appearance, and acceptability. The production of supplemented probiotic yogurt- up to 5% *Aloe vera* gel is feasible from an industrial and consumer point of view once it shows acceptable sensory, nutritional, and microbiological characteristics.

Funding

The author has no funding to report.

Competing interests

The author has declared that no competing interests exist.

Author contributions

Conceptualization, L.A. and W.C.; methodology, L.A., and W.C.; formal analysis, L.A and B.C.; mathematical adjustment, M.E.G., and B.C.; statistical analysis, M.E.G.; writing—original draft preparation, L.A., M.E.G., and B.C.; writing—review and editing, L.A. and C.S.; supervision, C.S.; funding acquisition, L.A. and C.S. All authors have read and agreed to the published version of the manuscript.

Acknowledgments

The authors are grateful to Dirección de Investigación y Desarrollo (DIDE) and the Technical University of Ambato (Ecuador), and to Escuela Superior Politécnica de Chimborazo (Ecuador) for financial support for the publication of this article.

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