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Designing a banana beer recipe

This work reports a strategy to design a craft banana beer recipe using the Giant Dwarf cultivar to obtain juice for usage as an adjunct, providing an important source of carbon, aroma, and flavor in the final product. To evaluate the proposed method, 18 different formulations were tested, 9 of which were carbonated with sucrose and 9 with banana juice. A factorial design was produced for the fermentation process, where the type of commercial yeast strain and the must/juice ratio were defined as factors, each factor composed of three levels. Three commercial yeast strains were tested in this work (Saflager W-34/70, Safale US-05 and Kolsch WLP029). Every formulation was sensory characterized through a hedonic test carried out by experts and potential consumers. Moreover, changes in the substrate and products, such as sugars, glycerol, ethanol and organic acids, were quantified by IR and UV detectors coupled to HPLC, in order to provide information which was associated with that acquired online by the temperature and ORP sensors. From the results, it can be concluded that the addition of intermediate and high quantities of banana juice to malt increases the concentration of fermentable sugars (glucose and fructose) and contributes to a balanced flavor and texture, based on the evaluating panel's criteria. Therefore, beer with a high content of ethanol and glycerol can be produced.

Descriptors: banana, beer, statistical analysis

1 Introduction

Beer is the second most consumed alcoholic beverage in the world with a total consumption of 34.8 % [1]. Moreover, it is well documented that craft beers have been continuously gaining market share from large national and international beer breweries [2]. The growth experienced by the craft beer industry is largely due to its capacity of innovation, creativity, and authenticity that typify craft beer as an experience, delivering a drink that offers pleasure, enjoyment, sense of identity, and belonging [3–5]. Therefore, the search for non-traditional and innovative raw materials that provide both volatile and non-volatile compounds, significantly contributing to the taste and aroma of beer, is continuously pursued within this industry.

Although, traditional craft beers are characterized by being elaborated mainly with water, malt, hops and yeast [6–8], the preferences of craft beer consumers have evolved given the innovation of new flavors by adjuncts [5]. For instance, the usage of cherries, strawberries and raspberries as adjuncts has been reported in the production of lambic, traditional Belgian beer [9]. These adjuncts are raw materials that are not traditional in the formulation of beer but are added to the process with a specific purpose. Usually, they are defined as „any source of fermentable sugar, which does not derive directly from barley“ [10]. Adjuncts can be classified into two groups according to the main ingredient: starch, which is usually cereal macerated together with the malt, or fermentable sugars, which do not require the previous maceration [10–12].

Although bananas are commonly consumed as fresh fruit, they can be used to obtain several agroindustrial products [13–18] like banana juice [19]. The usage of banana juice as an adjunct is rather interesting, since it is known that fruits and fruit juices provide attractive sensory characteristics and bioactive compounds that give important qualities in the health of consumers, as well as contribute to the oxidative stability of beer [20].

To determine the optimal fermentation conditions for designing a banana beer recipe with the best organoleptic profile, the analysis of the experimental data was divided into two parts. First, the sensory analysis data of the craft beer formulations was analyzed to select the beers that present the best organoleptic characteristics, according to the criteria of the evaluation panel. Moreover, the concentrations of sugars, ethanol, and organic acids present in the initial musts and in the resulting beers were analytically quantified and compared to elucidate the chemical differences attributed to the addition of banana juice. In the second step, the data obtained from the fermentation monitoring of the selected formulation were chemically characterized to associate the signal time evolution with the chemical changes during the process. This evaluation is essential considering that determining aromatically standardized beverages requires efficient analytical tools for characterization and algorithms, which eventually allow automatic production control

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[21, 22]. Automation, standardization, and adequate control reduce production costs and increase yield, while maintaining the desired product quality [23, 24].

Table 1 Fermentation stages: temperature changes (T) as a function of time for each strain used

	Initial stage		Intermediate stage		Final stage		Aging	
Yeast	T	Time	T	Time	T	Time	T	Time
Strain	(°C)	(days)	(°C)	(days)	(°C)	(days)	(°C)	(days)
Saflager	12.5–13	10	15.5–16	5	4.4	7	0–(–1)	8
Safale	17–18	10	19–20	3	4.4	7	0–(–1)	8
Kolsch	17–18	5	19–20	3	4.4	7	0–(–1)	8

2 Materials and methods

2.1 Raw materials

The wort, hops, and commercial yeasts (Saflager W-34/70, Safale US-05 and Kolsch WLP029), were provided by Cervecería de Colima. The wort was obtained from a local brewery production plant once the maceration and filtration processes were completed. Then, it was transported to the Agrobio-Technological Laboratory of the University of Colima and stored at –80 °C, while yeasts and hops were stored at 4 °C. Bananas from the Giant Dwarf cultivar (Musa AAA, subgroup Cavendish) with a minimum length of 13 cm were acquired from a local market when they were green. The banana bunches were ripened in laboratory conditions at 20 °C without atmospheric control. The color of the peel was monitored via image analysis and classified by stage, ranging from completely yellow to yellow with slight brown specks according to *Escalante-Minakata* et al. [25]. Then, the banana juice was obtained by using the methodology developed by *Ibarra-Junquera* et al. [19].

2.2 Experimental design

To find the best formulation, a factorial design of two factors with three levels was obtained. Factor A and B correspond to the commercial yeast strains (Saflager W-34/70, Safale US-05 and Kolsch WLP029) and the wort/banana-juice relation, respectively. Therefore, three percentage ratios (v/v) of 25 : 75, 50 : 50, and 75 : 25 were defined as the three levels. The experimental design (9 different combinations) was applied to two sets of must formulations: one carbonated with sucrose and one carbonated with banana juice as the carbon source.

2.3 Wort conditioning

After the wort reach the boiling point, magnum hops (14 % α-acid) were added in different concentrations so that the wort achieved a final concentration of 0.7 g/L of hops at (g)11 °Brix. Then, the wort was kept warm for 60 min before being cooled down to 4 °C. The banana juice was standardized with sterile distilled water at 11 °Brix and mixed with wort, according to the experimental design previously described.

2.4 Yeast propagation and inoculation

The yeast strains were propagated using a yeast starter medium, containing 120 g of malt extract (Bacto Malt Extract-Becton Dickinson), 1 g of casein peptone (Fluka analytical), and 1 g of yeast extract (MCDLAB) per liter of distilled water. The yeast biomass for the initial inoculation was cultivated as follows. An aliquot of each yeast strain was added to 50 mL of wort in a 125-mL flask and kept under constant stirring, 200 rpm at 24 °C for 18 h, then was centrifuged in sterile tubes at 4,300 rpm for 5 min at 4 °C. The supernatant was discarded, and the pellet obtained was resuspended in 500 mL medium and placed in a sterile 1000-mL flask. The culture was maintained under the above-mentioned culture conditions. After 18 h, the cell count (cell/mL) was obtained in a Neubauer chamber, which verified that the cell viability reached 90–95 %. After a concentration of 1 x 10^6 cell/mL per °Brix of must-juice was inoculated, the fermentations were carried out in amber glass jars equipped with a system for releasing airlook fermentation gases with 70 % ethanol to avoid contamination.

2.5 Fermentation process

The nine combinations determined by the factorial design were carried out in triplicate and kept at a constant temperature, according to the strain and stage of the fermentation process, as shown in table 1.

The initial fermentation condition and its time evolution were determined by quantifying sugar, glycerol, ethanol, and organic acid contents in 1 mL of must by HPLC coupled with IR and UV detectors.

2.6 Determination of glycerol, ethanol, sugar, and organic acid content

The determination of glycerol, ethanol, sugar, and organic acid was performed using a high pressure liquid chromatography system (HPLC, Shimadzu, LC-2030C, Prominence i, Japan), equipped with an Aminex HPC-87H column, detector UV set at 210 nm for organic acids, an IR detector for sugars, an autosampler set at 20 µL of injection volume, and temperature set at 25 °C. Sulfuric acid (5 mM), HPLC grade, Sigma-Aldrich (St. Louis, Mo, USA) was used as the mobile phase and set at a flow rate of 0.5 mL/min. The samples were diluted and filtered with a 0.45-µm membrane. The compounds were identified by retention times, and the quantification was determined using the standard curve. All analytical standards, including saccharose, glucose, fructose, glycerol, ethanol, oxalic, citric, malic, lactic and acetic acids, used in this work, were acquired from Sigma-Aldrich (St. Louis, Mo, USA)

2.7 Carbonation process

In order to reach a standard carbonation volume of 2.5 vol CO_2/L in the 18 different beers formulations, a second fermentation process was conducted directly in the bottle. For this purpose, 6.6 g sucrose per liter of beer was added as an additional carbon source. Banana juice was tested as the other carbon source. An inoculum of fresh yeast culture was then added directly to each 350-mL bottle, then

Table 2 **Sample coding for the sensory evaluation**

Carbonation source	Concentration	Safale yeast	Saflager yeast	Kolsch yeast
banana juice + fresh yeast	C1: 75/25	SAJB75	LLJB75	LKJB75
	C2: 50/50	SAJB50	LLJB50	LKJB50
	C3: 25/75	SAJB25	LLJB25	LKJB25
sucrose + fresh yeast	C1: 75/25	SASA75	LLSA75	LKSA75
	C2: 50/50	SASA50	LLSA50	LKSA50
	C3: 25/75	SASA25	LLSA25	LKSA25
banana juice + residual yeast	C2: 50/50		SLJB50	
	C3: 25/75		SLJB25	

stored for 15 days at a temperature ranging between 18–20 °C.

2.8 Sensory analysis

In order to classify the 18 different beer formulations with base in the sensory analysis, two additional samples were made under the same conditions with proportions of wort/ banana juice of 50/50 and 25/75. According to the evaluation panel, the criteria for better organoleptic characteristics includes taste, smell, color and general acceptance. The panel was organized into two groups with 10 people in each group: beer experts and typical potential consumers (see Fig. 3.5).

2.9 Statistical analysis

All quantitative determinations were performed in triplicate. All statistical analyses were performed using MatLab (MathWorks Inc., USA). Statistically significant differences ($P < 0.05$) were determined by ANOVA. Principal component analysis (PCA) was used as a tool to classify the sets of samples into groups based on homogeneous characteristics.

2.10 Bioreactor fermentation monitoring

After selecting the optimal banana beer recipe, according to the results analysis, the production was scaled to a 20-L bioreactor to monitor fermentation online and offline. The online monitoring of the redox potential was carried out with an ORP sensor (EasyFerm Plus ORP Arc 120, reference: 243050-Hamilton) equipped with a temperature measurement. For the offline monitoring, samples were collected from the beginning and to end of the fermentation process. Each sample was analyzed by HPLC to determine the contents of sugars, organic acids, and ethanol. For the control, wort was fermented with the same yeasts but without the addition of banana juice.

3 Results and discussion

Despite published literature on banana juice as an adjunct in brewing [7, 26], only the evaluation of the fermentation in terms of volumetric productivity, ethanol yield, and sugar consumption was reported, concluding that bananas can be used as an adjunct for brewing. Thus, further investigation is required to better characterize the produced beer through the obtain data related to its volatile profile and its online monitoring.

Therefore, in this work, different beer formulations were designed by adding banana juice as an adjunct. Before fermentation, the amount of adjunct added to the wort and the type of yeast were varied. To help characterize the organoleptic results, the concentrations of sugars, ethanol, and organic acids present in the initial wort and in the final beers were analyzed and contrasted.

3.1 Sensory evaluation

To elucidate the best organoleptic characteristics (taste, smell, and color) based on the criteria of the evaluation panel, PCA and ANOVA analysis were used. The obtained beers were classified into different groups according to the assessment of taste, smell, and color. PCA analysis indicates that the first two main components comprise 83.8 % of the total variance of the analyzed data. Figure 1 shows that the first main component (CP1) divides the beers into two groups according to the score for smell and taste, while the second component (CP2) divides the samples into two groups according to the score for color. The first group (red box) corresponds to the beers rated with a high score in smell and taste, and the second group (blue box) contains beers with low scores. Each of these groups are further subdivided into samples with a high color score (black letters) and samples with a low color score (pink letters). ANOVA results reveal significant differences in the three organoleptic variables among the divided groups, p-values are 0.0271 for color, 0.0011 for smell, and 0.0191 for flavor.

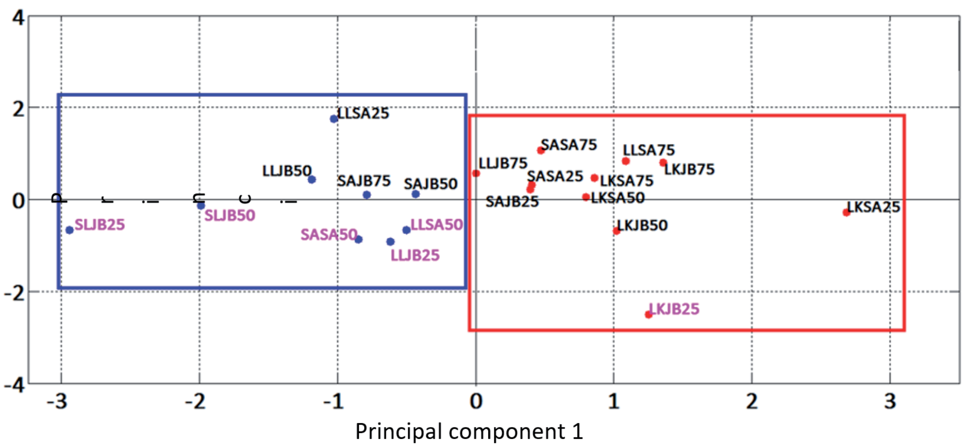

Fig. 1 **Classification of beers based on sensory evaluation. Observations with black and pink letters are qualified beers with high and low color scores, respectively**

In figure 1, it can be observed that most of the beers (90 %) in group one were rated with high scores for smell, taste,

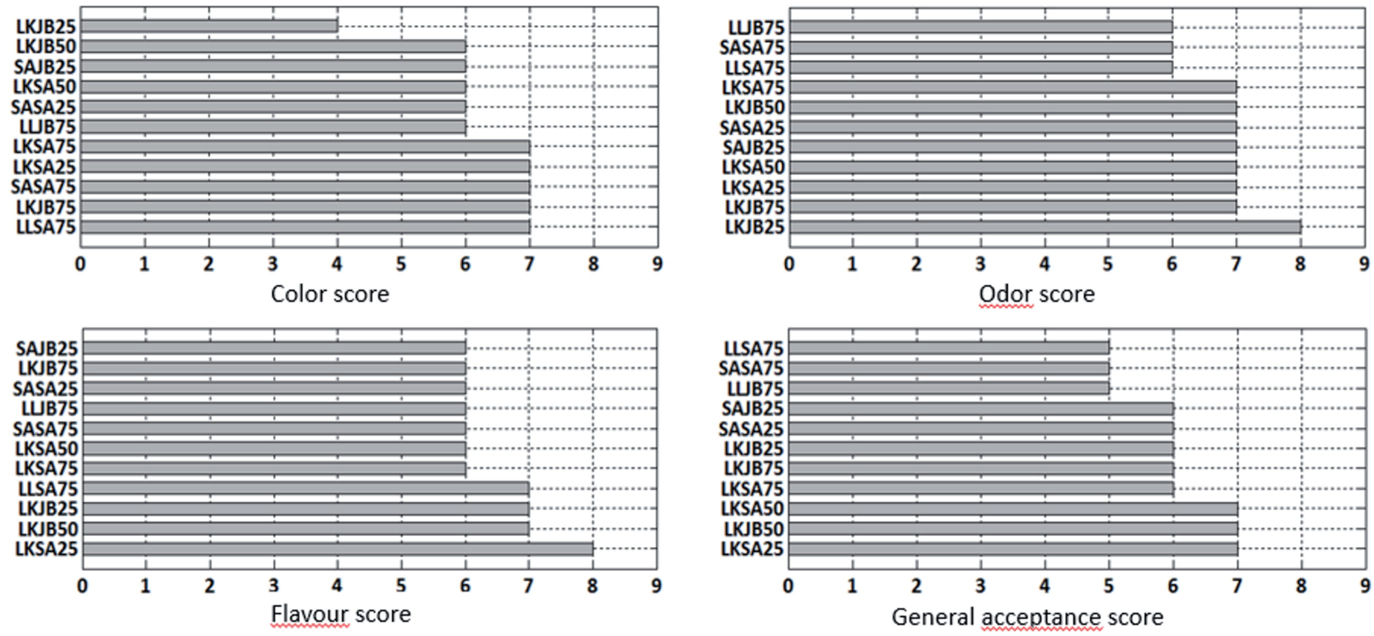

Fig. 2 Qualification of the beers in group one obtained by PCA and AC. Descriptions of scores are as follows. 1: I really dislike it; 2: I dislike it a lot; 3: I dislike it moderately; 4: I dislike it a little; 5: I don't like or dislike it; 6: I like it a little; 7: I like it moderately; 8: I like it a lot; 9: I like it very much

and color; 54 % of beers in the same group were prepared with the three proportions attached (75/25, 50/50, 25/75), fermented with Kolsch yeast, and carbonated with both sucrose and banana juice (LKSA75, LKSA50, LKSA25, LKJB75, LKJB50 and LKJB25).

Figure 2 displays the evaluations by the panelists based on descriptors of taste, smell, and color. Most of the samples scored between 6 and 7 for color, where 45 % of beers were liked moderately, and the remaining 55 % were liked a little. Based on smell, 27 % of the beers were liked a little, 64 % liked moderately, and the remaining 9 % liked a lot. In terms of taste, 73 % of the beers were liked a little, 18 % liked moderately, and the remaining 9 % liked a lot.

In addition, it can be observed that the beers with the best score in all aspects were those made with intermediate – high concentrations of adjunct and fermented with Kolsch yeast, with the LKSA25,

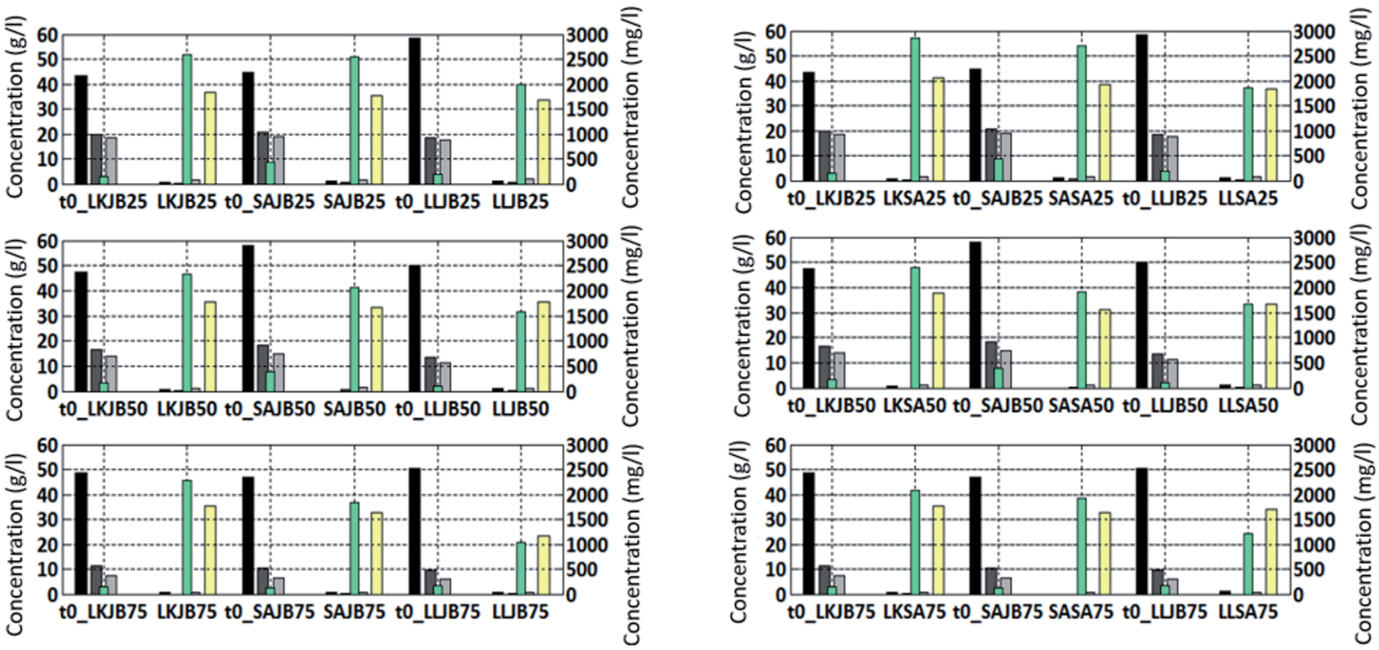

Fig. 3 The color bars represent the substrates and products concentration, as follows, sucrose in black, glucose in dark grey, fructose in light grey, ethanol in light yellow and glycerol in light green. Quantified by HPLC-UV-IR for wort and finished beers, where the first two letters of the sample label refer to yeast (LK: Yeast Kolsch, LL: Yeast Lager, SA: Yeast ale); the next two to the sugar used in carbonation (JB: Banana juice, SA: Sucrose); and the last two digits refer to the concentration of wort used in the formulation (75: 75 % wort, 50: 50 % wort, 25: 25 % wort). It was based on the same wort for each case of carbonation (t0_LKJB25, t0_LKJB50, t0_LKJB75, t0_LLJB25, t0_LLJB50, t0_LLJB75, t0_SAJB25, t0_SAJB50, t0_SAJB75)

LKJB50, and LKSA50 beers being more accepted.

3.2 Analysis of sugars, organic acids, and ethanol

The sugars quantified in this analysis include sucrose, glucose, and fructose and oxalic, citric, malic, lactic, and acetic acid were quantified as the organic acids. The results are summarized in figure 3, which indicates that the addition of banana juice to wort proportionally increased the concentration of glucose and fructose. It can also be observed that the sucrose, glucose, and fructose contents recorded in the beers are lower than those in beers prepared only with wort and that the concentration of glycerol and ethanol increased during fermentation. Thus, the higher concentrations of these compounds are attributed to the higher concentration of banana juice and sucrose as the carbon source in preparing the beers. In addition, it is noted that beers fermented with Kolsch yeast exhibit the highest concentrations of ethanol and glycerol in comparison with the other yeasts.

LKSA25, LKJB50 and LKSA50 proved to be the top-ranked beers based on the sensory analysis, presenting high scores for the organoleptic characteristics evaluation. These three beers also exhibit the highest ethanol and glycerol contents. In addition, the residual fructose content was higher in beer brewed with a higher concentration of banana juice and carbonated with sucrose (see Table 3), while the residual sucrose content was higher in beer brewed with an intermediate concentration of adjunct and carbonated with sucrose (LKSA50).

On the other hand, figure 4 reveals that in the wort, the concentrations of oxalic, lactic, and acetic acids decreased with the addition of banana juice compared to the wort prepared with a greater amount of adjunct, which implies a dilution effect. In contrast, the contents of citric and malic acids increased proportionally with the addition of banana juice. After fermentation, the contents of oxalic, acetic, and malic acids decreased, while citric acid increased. The concentration of lactic acid also increased but only in samples fermented with Kolsch and Ale yeasts. In in beers prepared with a greater amount of banana juice, the residual contents of malic and citric acids were higher, and those of oxalic, acetic, were lower.

From the sensory analysis of top-ranked beers (LKSA25, LKJB50 and LKSA50), the LKSA25 beer contained the highest concentrations of citric acid (1546.7 mg/L), malic acid (2081.6 mg/L), and acetic acid (149.7 mg/L); followed by LKJB50 with 1265.7 mg/L citric acid), 1526.4 mg/L malic acid, and 112.5 mg /L acetic acid; then LKSA50 (1152.6 mg/L

Table 3 Concentration of sugars and ethanol of the best qualified samples in the sensory analysis

SAMPLE	Glycerol (mg/L)	Sucrose (g/L)	Glucose (g/L)	Fructose (g/L)	Ethanol (g/L)
t0_LKJB25	142,768	43,281	19,900	18,292	0,000
LKSA25	2,858,272	0,733	0,191	1,483	41,181
t0_LKJB50	162,710	47,410	16,750	13,844	0,000
LKJB50	2,332,186	0,703	0,430	1,050	35,716
LKSA50	2,388,793	0,861	0,000	0,900	37,879

t0_LKJB25 and t0_LKJB50 are unfermented musts of formulations 25/75 and 50/50; LKSA25 is the beer of the formulation 25/75 carbonated with sucrose; LKJB50 and LKSA50 are the beers of the 50/50 carbonated formulation with banana juice and sucrose, respectively

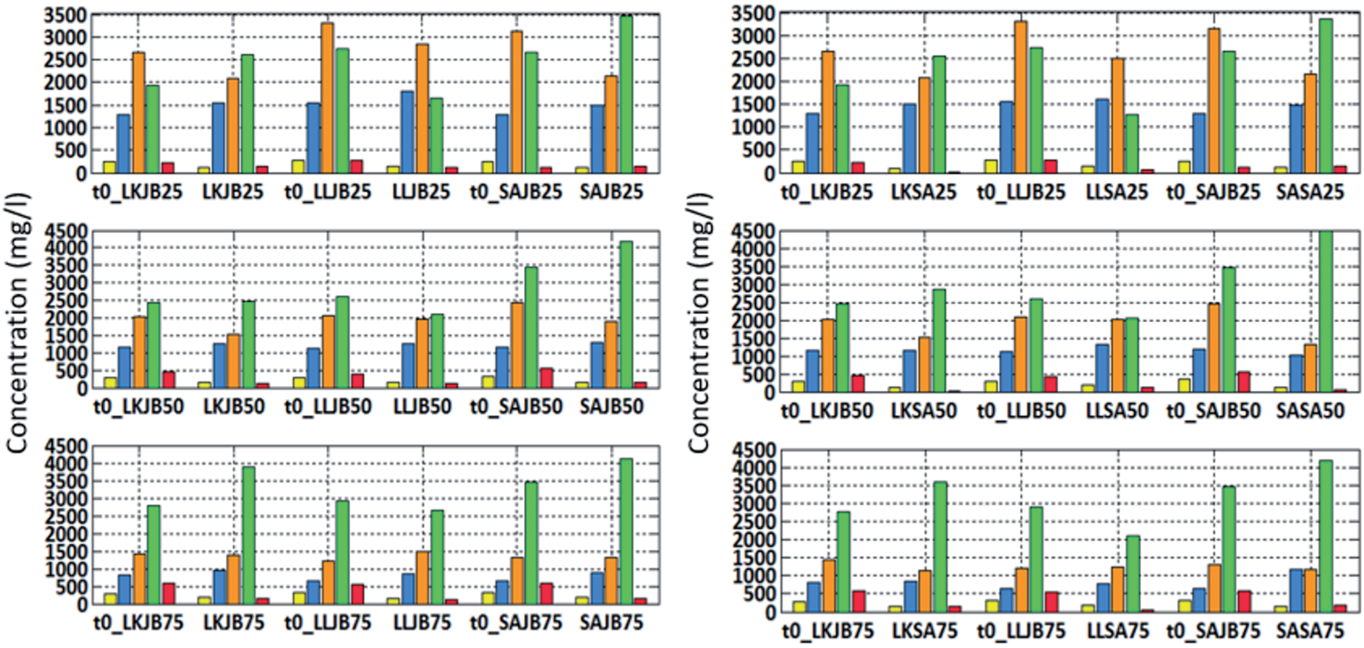

Fig. 4 Concentration of organic acids obtained by HPLC for musts and finished beers, where the first two letters of the sample label refer to yeast (LK: Yeast Kolsch, LL: Yeast Lager, SA: Yeast ale); the next two to the sugar used in carbonation (JB: Banana juice, SA: Sucrose); and the last two characters refer to the concentration of wort used in the formulation (75 :75 % wort, 50: 50 % wort, 25: 25 % wort). It was based on the same wort for each case of carbonation (t0_LKJB25, t0_LKJB50, t0_LKJB75, t0_LLJB25, t0_LLJB50, t0_LLJB75, t0_SAJB25, t0_SAJB50, t0_SAJB75). The color bars represents the organic acids concentration, as follows, oxalic acid in yellow, citric acid in blue, malic acid in orange, lactic acid in green and acetic acid in red

citric, 1510.4 mg/L malic, and 8.8 mg/L acetic acids).

Out of the three top-rated beers in the sensory analysis (LKSA25, LKJB50, and LKSA50), we can conclude that the LKSA50 beer contains the best chemical characteristics, which was prepared with 50 % wort, 50 % banana juice, fermented with Kolsch yeast, and carbonated with sucrose. This beer also exhibited a higher residual sucrose concentration and lower contents of citric, malic, and acetic acids compared to the other two beers. For this reason, this recipe was selected to scale its production and physicochemically characterize its fermentation.

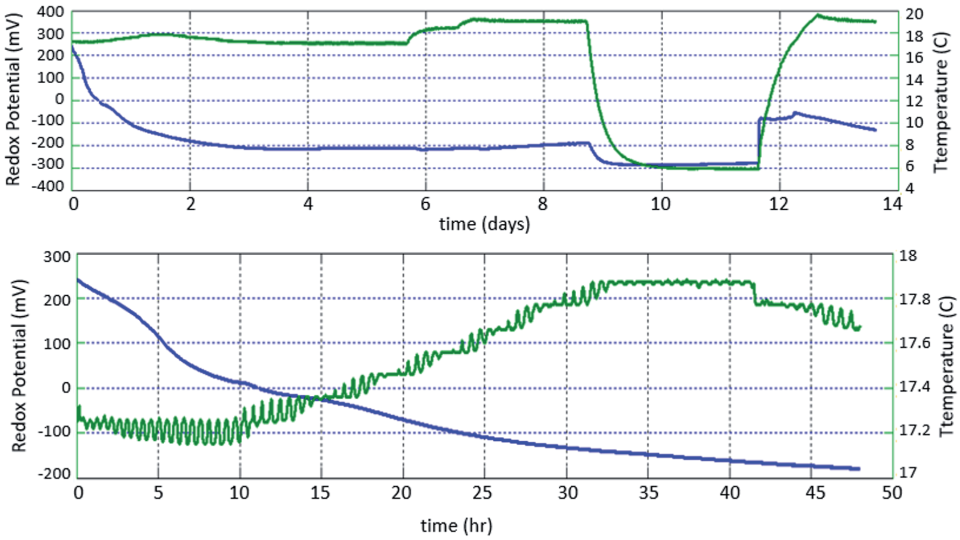

Fig. 5 Time evolution of redox potential (blue line) and temperature (green line) during fermentation of wort with banana juice as adjunct. The top graph shows the information obtained until the moment the beer was carbonated (between day 10 and 12). The bottom graph contains the information during the first 48 h of fermentation

Despite the fact that malt introduces glycerol to the must, the greatest amount of glycerol in beer actually comes from fermentation, when the yeast is exposed to extreme conditions of osmotic stress. To adapt to this environment, glycerol is produced as a compatible solute to prevent the diffusion of water from inside the cell to the surrounding environment, avoiding dehydration of yeast [27–29]. The results presented here indicate that beers fermented with Kolsch yeast contain the higher glycerol content compared with the other formulations. This can be considered as a positive feature since glycerol provides sweetness and also stabilizes yeast during the long fermentation process, indirectly contributing to the quality of organoleptic characteristics of alcoholic beverages [27, 30]. This explanation may support the preference of these beers by the evaluation panel. Moreover, since the main organic acids present in banana juice are malic, citric, and oxalic acid [31] and those in wort are citric, malic, lactic, and acetic acids [32], the combination of wort and banana juice increased citric and malic acids but decreased oxalic, lactic, and acetic acids via dilution.

3.3 Fermentation monitoring

Fermentation is the most critical stage of a beer's production process, in which a series of biochemical reactions occurs and generates products that characterize the quality of beer. However, this process can be affected by the variation of the operating conditions and by the raw materials that are added during production of the wort. All processes that involve living cells, such a beer production, often display high batch-to-batch variability. Therefore, online monitoring and certain control tools are essential to achieve efficient and reproducible results. A key factor in real-time control is the ability to measure critical variables online. While such variables are generally quantified by offline analysis, these procedures present a serious contamination risk for the bioprocess and a critical time delay for control purposes. Thus, in order to characterize the fermentation using both online and offline monitoring, the formulation consisting of 50 % wort and 50 % banana juice was prepared in a 20-L tank bioreactor and inoculated with Kolsch yeast under sterile conditions. During the entire fermentation process, ORP and temperature variables were monitored online. At the same time, samples were extracted during the time evolution of the fermentation for offline monitoring. Each sample was analyzed for the content of sugars, organic acids, and ethanol by HPLC.

Figure 5 displays the dynamics of the redox potential and temperature throughout the fermentation process. During the first 48 hours of fermentation, the redox potential decreased and temperature slightly increased, despite the room control temperature. After that time, both the redox potential and temperature remained under a steady state.

It is important to notice that the temperature variations, as a factor of fermentation, affect the redox potential. For instance, temperature was increased from 17 to 19 °C 5.70 days after the fermentation was initiated, then was kept constant for 4 days to favor the diacetyl yeast consumption. This increase in temperature caused a small decrease in redox potential from –211.16 to –219.4 mV, which increased gradually after the sixth day of fermentation. Then, the temperature was lowered to 6 °C for 11.65 days, after which the temperature was raised 19 °C, and sucrose was added to the beer to promote natural carbonation. During this process, the redox potential increased from –278 to –83 mV, but then slightly decreased again after 12 days.

3.4 Offline monitoring

The time evolution of the fermentation data confirms the relation between the decrease in sugar content (sucrose, glucose and fructose) and the increase in the ethanol and glycerol concentration. During the first three days of fermentation, the yeast metabolized the sucrose and glucose in the wort. Thus, the concentration of these sugars decreased considerably compared to their initial concentrations, but the fructose content did not vary much. Similarly, during this period of time, the yeast metabolized acetic and malic acids, and the production of ethanol, glycerol, and citric acid increased. Between days 3–9 of fermentation, the yeast began to

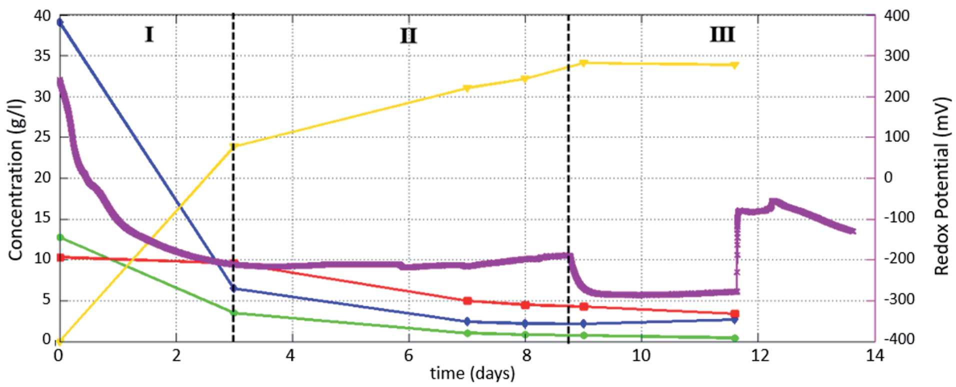

Fig. 6 **Different fermentation stages monitored by the ORP signal and its relationship with sugar consumption and ethanol production. Color of the lines are defined as follows. Blue is sucrose; green is glucose; red is fructose; yellow is ethanol; and purple is the ORP signal**

metabolize fructose and continued to slowly consume the sucrose and glucose present in the wort. The metabolic consumption of malic acid and acetic acid began to synthesize lactic acid, and the concentration of ethanol and glycerol continued to exhibit an exponential increase, but more slowly, because the slope of its graphs also decreased. Finally, the production of ethanol, glycerol, and organic acids as well as the consumption of sugars and organic acids became constant.

Figure 6 shows the variation of the redox potential (ORP) against sugar consumption and ethanol production during the fermentation of wort added with banana juice.

In this figure, it can be noticed that during the first three days of fermentation (stage I), the slope of ORP decreased exponentially, coinciding with the accelerated consumption of sucrose and glucose and the progressive increase in ethanol. After the third day (stage II), the ORP variation did not show significant fluctuations, although the concentration of sugars continued to decrease and ethanol increased. However, on the sixth day, ORP signal presented a small variation due to the increase in the process temperature, then began to increase. The consumption of sugars became more constant between the seventh and eighth day of fermentation. In the beginning of stage III, the ORP signal decreased again in response to the decrease in temperature, and at the same time, the concentration of glucose and fructose also decreased and ethanol increased slightly. The ORP increased again when sucrose was added to induce carbonation. It is pertinent to note that during the intermediate stage, although sugar consumption slowed down, ethanol production continued to show an exponential trend, and synthesis of lactic acid began. This may be explained by the continuous consumption of acetic and malic acids by yeast, from which both ethanol and lactic acid were synthesized [33]. The final stage of the fermentation is determined by the lack of change in the consumption of sugars and production of ethanol, glycerol, and citric acids.

During fermentation, yeast metabolizes both sugars and nutrients in the wort, subsequently producing ethanol and carbon dioxide and also secondary metabolites that change the composition of the wort. As this occurs, the resulting product is beer. However, the production and quality of these compounds depends on variable conditions of the fermentation, which affect the growth and multiplication of yeasts. For this reason, online process monitoring is essential to make any necessary changes in real-time to ensure an optimal product. Herein, we propose that the redox potential (ORP) and temperature sensors can be effectively used to monitor the fermentation process online in order to ultimately obtain a quality beer.

4 Conclusions

The addition of banana juice has demonstrated to be an attractive adjunct in brewing from both consumer and beer quality point of views. It provides both pleasant organoleptic characteristics for consumers and fermentable sugars to obtain ethanol economically, since it is rich in carbohydrates. The banana juice also supplies organic acids (citric and malic) that can be metabolized by yeast in the synthesis of other compounds, subsequently producing beers with a high content of ethanol and glycerol. According to the criteria of the evaluation panel, these characteristics contribute to the balanced flavor and texture of beer.

It was also concluded that the monitoring the fermentation of the wort with the addition of banana juice as an adjunct using the ORP signal proved to be a simple, economical, and practical alternative. As an indicative parameter, ORP is correlated with the metabolic activity and variation of yeasts with internal and external disturbances generated during fermentation, which reveals any influence on the development of the microorganism in real-time. In addition, by online monitoring of the ORP during fermentation, a behavior pattern for this parameter can be constructed and can serve as a reference for future fermentations carried out under the same conditions.

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