JOURNAL OF AGRICULTURAL AND FOOD CHEMISTRY

Sensory and Foaming Properties of Sparkling Cider

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The effect of yeast strain and aging time on the chemical composition, analytical, and sensory foam properties of sparkling ciders has been studied. The analytical foam parameters (foamability, HM; Bikerman coefficient, Σ; and foam stability time, T_s) were significantly influenced by aging and yeast strain. The sensory attributes (initial foam, foam area persistence, bubble size, foam collar, and overall foam quality) improved with aging time. Likewise, the yeast strain positively influenced the assessment of initial foam, foam area persistence, number of bubble chains, and overall foam quality. Significant and positive correlations were found between alcoholic proof, dry extract, total and volatile acidities, total phenols and total proteins, and Σ, whereas HM was negatively correlated with specific gravity, alcoholic proof, dry extract, and total proteins.

KEYWORDS: Cider; foam measurements; sensory analysis; chemical composition

INTRODUCTION

Foam is one of the most important characteristics of sparkling beverages, because it is the first attribute that consumers perceive. The formation and stability of foam have been considered as the main characteristics defining the foam phenomenon (*1*); likewise, the presence of small bubbles slowly rising through the liquid is greatly appreciated, their persistence being often related by consumers to the bubble size (*2*). Liger-Belair and others (*3*) pointed out the impact of gas bubbles on the overall sensorial perception of sparkling wine by ejecting aroma molecules. Thus, great research has been focused to the study of the different aspects of foam and bubble formation in beverages.

From the optimization of the Mosalux technique (*1*), several studies have been conducted to ascertain the influence of different technological factors on foam quality. The present information about sparkling wines relates foam quality to the usual technological factors, such as grape variety (*4*−*9*), aging time (*4*, *7*, *10*), yeast strains (*10*), and fining treatments (*11*).

The influence of chemical composition on the foam characteristics of wines has been studied by many authors. Nitrogen compounds, mainly amino acids, and polysaccharides are positively correlated to foam formation and stability (*4*, *5*, *8*, *12*). The influence of proteins on these foam parameters is still difficult to ascertain, since some authors have found positive correlations with foam formation (*13*), whereas other authors have described the opposite (*9*). Some nonvolatile acids, such as tartaric and malic acids, also have a positive influence on foam formation (*7*, *8*), while ethanol, volatile acidity (VA), and total sulfur dioxide have a negative contribution to this parameter (*7*). Diffusion of CO_2 molecules through a liquid medium, and then, the presence of trains of bubbles in sparkling and carbonated beverages may be influenced by many components, as suggested by Liger-Belair and others (*14*).

Recently, Gallart and others (*15*) have established positive relationships between foam characteristics, as measured by the Mosalux method, and sensory assessment of foam attributes in Spanish sparkling wines.

Cider making is one of the most important food industries in Asturias. Recently, the sparkling cider, made from cider apple pressing and second fermentation in a bottle, has been produced aiming at covering in the market the position of the high quality cider products. Relevant steps in the making of this product are the selection of the proper yeast strains to conduct the second fermentation process and the aging time on lees.

In this paper, the influence of yeast strain and aging time on the foam characteristics of sparkling cider has been analyzed. Likewise, the relationships between these parameters, sensory assessment, and chemical composition of ciders were evaluated.

MATERIAL AND METHODS

Cider Making. Thirty tons of Asturian cider apples was washed, milled, and macerated at 7−10 °C for 12 h in a dynamic macerator. In this period, several 2 h removing cycles were performed. The free-run must obtained was poured into a steel tank and kept at 10 °C, to be added to the must obtained by pressing. After the maceration period, the apple pomace was pressed by means of an automatic Bucher-Guyer press (pressing cycle, 2 h). The yield of this process was 72% (v/w). The final must (20000 L) was allowed to spontaneously ferment in one tank at 14 °C.

Alcoholic and malolactic fermentations took place in 3 months. Then, cider was run off from the lees, matured for 2 more months, in the presence of 40 mg/L of total sulfur dioxide. Finally, the base cider was filtered through a ceramic cross-flow 0.22 μm filter (Millipore Corp., Bedford, MA).

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10.1021/jf0514524 CCC: $30.25
Published on Web 11/23/2005

Sparkling ciders were produced from the same base cider by the Champenoise method. Sucrose (18 g/L) and bentonite (3 g/HL) were added prior to inoculation with selected yeasts (2% of pure cultures). One-half was inoculated with a cider yeast (C6), belonging to the SERIDA collection (*Saccharomyces bayanus*); the other half was inoculated with a commercial yeast, LEVULINE CHP (Groupe Oeno, France), recommended for sparkling wine making (*Saccharomyces cerevisae*), which will be referred to as "wine yeast" from now on. Inoculated ciders were bottled and left in a horizontal position at 13−15 °C. The second fermentation finished in 21 days, reaching a final pressure in the bottle of 7 bar. Once this process had finished, the maturation of ciders on lees for 15 months started. Samplings were done every 3 months, from 3 to 15, when disgorgement had been done. The final product was obtained by restoring the lost volume with the same base cider.

Measurement of Foaming Properties. Two bottles of the final product were taken and pooled at each sampling time. Samples of cider were passed through hydrophilic cotton, and thoroughly degassed at vacuum with agitation during 10 min. Then, they were centrifuged at 5000*g* for 10 min to remove particles.

Measurements were done by means of a graduated 25 mL buret, fitted at the bottom with a porous 0.4 mm glass frit and connected to the gas bottle by a flexible tube, through which a constant flow of carbon dioxide (30 mL/min) was introduced.

Ten milliliters of cider was carefully poured in the buret, and carbon dioxide was injected. Three parameters were measured as follows: foamability (HM), expressed in millimeters, is according to Gallart and others (*16*), the maximum height reached by the foam column; foam stability height (HS), expressed in millimeters, is the foam height reached after 10 min of flowing CO_2; and T_s, expressed in seconds, is the time until all bubbles collapse when the gas flow is interrupted. Each determination was visually done in triplicate. From HS, the Bikerman coefficient (Σ), expressed in seconds, was calculated. It is defined as the ratio of foam stability volume (mL) to flow rate (mL/s). Between measurements, the buret was successively cleaned with methanol (3 × 10 mL) and water (3 × 10 mL) and finally rinsed with the sample to be analyzed (3 × 10 mL).

Sensory Analysis. Samples were assessed in three sessions by six people belonging to the technical staff of the cider cellar and the SERIDA. Ciders were randomly presented at 8 °C, in flute type glass. The ciders were slowly poured into the glasses, avoiding to stand the bottle during dispensing. The attributes were assessed as follows: initial foam, foam persistence area, number of nucleation sites, size of bubbles, foam collar, and overall foam quality. Definitions for the attributes and the scales used for sensory evaluation are summarized in **Table 1**.

Other Analysis. Enological parameters [specific gravity (SG), pH, alcoholic proof (AP), total dry extract (TDE), total acidity (TA), volatile acidity (VA), total sulfur dioxide, free amino nitrogen (FAN), and pressure in bottle (*P*)] were done according to the European Union Official Methods of Analysis (*17*). Total soluble proteins (TP) were determined by the Bradford method, using bovine serum albumin as standard (*18*), and total phenols (TPh) were quantified by the methodology described by Montreau (*19*).

Statistical Analyses. The statistical methods used for data analysis were as follows: analysis of variance to test the main effects of the two factors studied (yeast strain and aging time), the interaction, and the error terms being pooled; Duncan test for mean comparisons; and Pearson correlation analysis. The SPSS v.11.5.1 for Windows statistical package was used for data processing.

RESULTS AND DISCUSSION

Foaming Properties. Taking into account the conclusions from Gallart and others (*16*), we will characterize cider foam properties by means of the parameters HM, Σ, and T_s. Changes in foaming properties throughout aging in bottle are represented in **Figures 1−3**.

The repeatability, expressed as variation coefficients of the foam parameters ranged between 0.1 and 18.8%. The largest differences among replicates were obtained for Bikerman coefficients, independently of the value levels. The greatest repeatability was found for HM and T_s.

The results showed that both aging time and yeast strain significantly influenced changes in HM, in agreement with the results obtained in sparkling wines (*7*, *10*). Values for maximum

Table 1. Visual Sensory Attributes Evaluated in Sparkling Ciders

sensory attributes	description	scores	
initial foam	that formed immediately after pouring the cider	abundant	3
		normal	2
		poor	1
foam area persistence	the time needed for disappearance of the initial foam	fast	3
		normal	2
		slow	1
number of nucleation sites	number of bubble chains	more than five	4
		less than five	3
		none	2
		excess	1
bubble size	observed in the middle of the distance from the origin to the cider surface	small	3
		medium	2
		large	1
foam collar	bubble lace formed around the cider surface	total and thin	5
		total and thick	4
		partial	3
		surface	2
		none	1
overall foam quality	assessment of general foam quality	excellent	7
		very good	6
		good	5
		fair	4
		bad	3
		very bad	2
		deficient	1

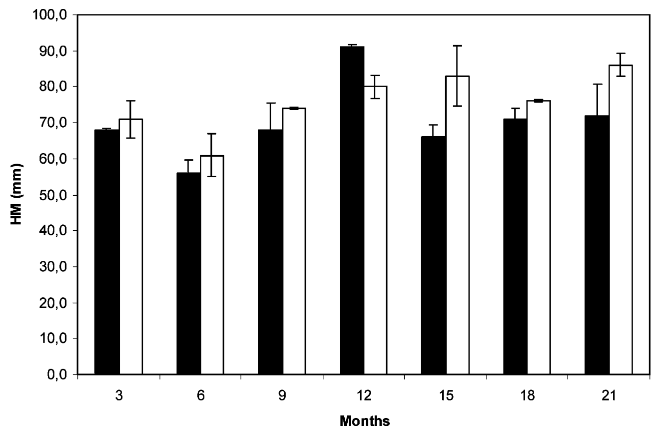

Figure 1. Changes in foamability of sparkling ciders during aging time on the lees. Identification of samples: ■, cider yeast; □, wine yeast.

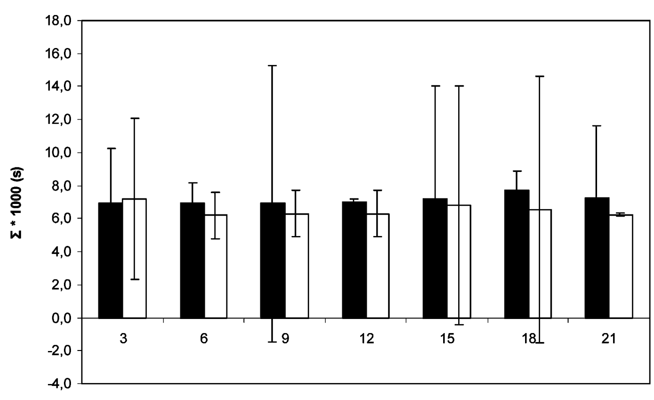

Figure 2. Changes in the Bikerman coefficient of sparkling ciders during aging time on the lees. Identification of samples is as in **Figure 1**.

Table 2. Changes of the Foam Characteristics of Sparkling Ciders during Aging Time[a]

foaming parameters	factors influence: yeast strain	factors influence: aging	yeast strains	aging (months): 3	6	9	12	15	18	21
HM (mm)	**	***	wine	71.0 b	60.7 a	74 bc	79.7 de	83 ef	76.3 cd	85.6 f
			cider	67.7 bc	55.7 a	68.0 bc	91 d	66.3 b	70.7 bc	72.3 c
$\sum \times 1000$ (s)	**	NS	wine	7.2 c	6.2 a	6.3 ab	6.3 ab	6.8 bc	6.5 ab	6.2 ab
			cider	6.9 a	6.9 a	6.9 a	7.0 a	7.2 ab	7.7 b	7.3 ab
T_s (s)	NS	***	wine	19.0 bc	17.0a	19.0 bc	17.3 a	18.3 ab	20.0 c	18.3 ab
			cider	19.0 bc	15.3 a	20.3 c	19.0 bc	17.7 b	19.7 c	20.0 c

[a] Results are the means of three determinations. Mean values in the same row with the same letter are not significantly different at the 5% confidence level (Duncan's test). NS, not significant. **, significant at the 0.05 level. ***, significant at the 0.01 level.

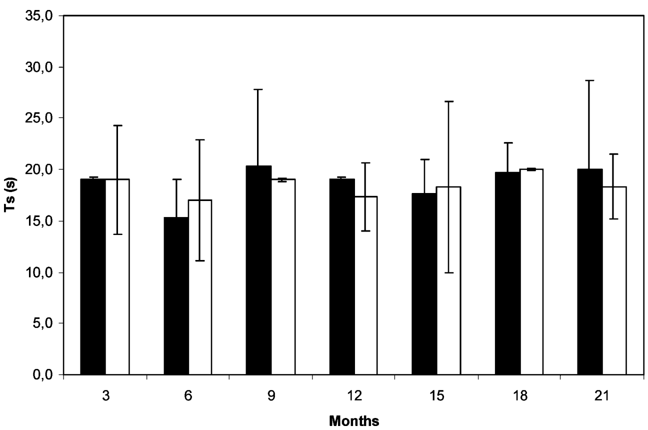

Figure 3. Changes in foam stability time of sparkling ciders during aging time on the lees. Identification of samples is as in **Figure 1**.

height (HM) ranged between 55 and 91 mm. Ciders made with the wine yeast showed a significantly higher ability to foam (HM) than those made with cider yeast (**Table 2**). Also, aging time had a significant influence on HM variation. The trends shown by the two yeasts were also differentiated throughout the sampling time. Thus, the wine yeast strain presented the highest values for HM by 21 months, whereas the cider yeast did around 12 months (**Figure 1**).

In general, the parameters related with foam stability had the highest values near the end of the sampling period. As seen in **Figure 2**, cider yeast produced ciders with higher values for the Bikerman coefficient ($\sum$), while foam stability time (T_s) values were similar among ciders, independently of the yeast strain (**Figure 3**). Bikerman coefficients ($\times 1000$) ranged between 6.2 and 7.7 s, the effect of yeast significant at the 5% level, whereas T_s ranged between 15 and 20 s, with a significant effect of the aging time (**Table 2**). Positive and significant correlations between T_s and HM (0.330, $p = 0.033$), T_s, and $\sum$ (0.287, $p = 0.065$) were observed, in agreement with previous results in Spanish sparkling wines (*15*).

Those facts could be explained by the metabolic activity of yeasts throughout the aging time. Studies made on beer showed that polysaccharides released from the cell walls of yeast have strong foam-stabilizing properties. This foam-stabilizing quality of polysaccharides is possibly linked to the relative proportion of polypeptides associated with them, which is characteristic of yeast strains and growing conditions (*20*).

In **Table 3** are presented the mean values and 95% confidence intervals for the chemical composition of sparkling ciders. As seen, the cider yeast strain produced beverages with higher AP, TDE, TA, VA, TPhs, and TPs than the wine yeast strain. No significant differences were found for SG, pH, and *P*.

An analysis of correlation was performed to test the influence of the physicochemical composition of ciders on the foam parameters. On one hand, negative and significant correlations were obtained between HM and SG, AP, TDE, and TP. The pressure at 20 °C had a highly significant correlation with HM, which means that large amounts of CO_2 will benefit foam formation in cider, by the continuous and gradual release of gas, as observed in beer (*20*). On the other hand, $\sum$ positively correlated with AP, TDE, TA, VA, TPh, and TP. Total sulfur dioxide had a negative effect on $\sum$. The parameter T_s presented slightly significant and negative correlations with SG and pH (**Table 4**).

Table 3. Mean Values and Confidence Interval for Chemical Characteristics of Sparkling Ciders

parameters	yeast strain	mean	95% CI
SG (g/L)	wine	0.99662	NS
	cider	0.99659	
pH	wine	3.60	NS
	cider	3.61	
AP (% v/v)	wine	7.21	7.19–7.22
	cider	7.37	7.35–7.40
TDE (g/L)	wine	21.16	21.09–21.23
	cider	21.72	21.61–21.82
TA (g sulfuric/L)	wine	3.16	3.13–3.18
	cider	3.25	3.20–3.30
VA (g acetic/L)	wine	1.00	0.98–1.01
	cider	1.06	1.04–1.09
SO_2 (mg/L)	wine	48	47–49
	cider	44	40–47
FAN (mg N/L)	wine	0.94	0.90–0.98
	cider	0.87	0.85–0.89
TPh (mg tannic acid/L)	wine	462	452–472
	cider	488	476–499
TP (mg BSA/L)	wine	39	38–41
	cider	52	47–56
$P_{20°}$ (bar)	wine	5.4	NS
	cider	4.8	

The positive relationships obtained between alcohol content and TA on the foam stability height have been previously observed (*5*, *9*). In the case of sparkling ciders, VA had a positive effect on $\sum$, in opposition to that described for wines (*7*). However, the positive effect of the TPh content on $\sum$ was in disagreement to previous results in wines (*6*). The negative influence of TP on HM of sparkling ciders was also described before in wines (*13*). No significant correlations were found between the FAN and the foam parameters.

These facts should be explained on the basis of the physics of foam. Foam is a colloidal system in which gas bubbles (CO_2) are dispersed in a liquid (cider). Its stability depends on those factors affecting the thickness of the film involving the gas bubble, namely, drainage of liquid from films, disproportionation

Table 4. Correlation between Foam Parameters and Chemical Composition of Sparkling Ciders[a]

	HM (mm)	Σ (s)	T_s (s)
SG (g/L)	−0.397 ($p = 0.009$)	−0.250 ($p = 0.111$)	−0.267 ($p = 0.087$)
pH	0.001 ($p = 0.997$)	0.022 ($p = 0.888$)	−0.295 ($p = 0.058$)
AP (% v/v)	−0.359 ($p = 0.020$)	0.593 ($p < 0.001$)	−0.104 ($p = 0.511$)
TDE (g/L)	−0.392 (0.010)	0.331 ($p = 0.032$)	−0.112 ($p = 0.479$)
TA (g sulfuric/L)	0.210 ($p = 0.182$)	0.451 ($p = 0.003$)	0.083 ($p = 0.600$)
VA (g acetic/L)	0.149 ($p = 0.347$)	0.550 ($p < 0.001$)	0.138 ($p = 0.384$)
SO_2 (mg/L)	0.243 ($p = 0.121$)	−0.497 ($p = 0.001$)	0.023 ($p = 0.883$)
FAN (mg N/L)	−0.215 ($p = 0.172$)	−0.224 ($p = 0.154$)	−0.076 ($p = 0.634$)
TPh (mg tannic acid/L)	0.172 ($p = 0.276$)	0.466 ($p = 0.002$)	0.088 ($p = 0.581$)
TP (mg BSA/L)	−0.403 (0.008)	0.277 (0.076)	−0.083 ($p = 0.603$)
$P_{20°}$ (bar)	0.566 ($p < 0.001$)	−0.038 (0.813)	0.232 ($p = 0.139$)

[a] Significance level for Pearson correlation coefficients was taken at 5%.

Table 5. Sensory Assessment of Visual Attributes of Sparkling Ciders[a]

	factor			months						
visual attributes	yeast strain	aging	yeast strain	3	6	9	12	15	18	21
initial foam	***	**	wine	2.17 a	2.17 a	2.83 bc	2.33 ab	2.83 bc	2.00 a	3.00 c
			cider	3.00 b	2.50 a	2.67 ab	3.00 b	2.83 ab	2.83 ab	3.00 b
foam area persistence	***	***	wine	2.25 ab	1.83 a	2.67 b	2.67 b	2.33 ab	2.67 b	1.83 a
			cider	2.25 b	1.83 ab	2.17 b	3.00 c	2.33 b	1.33 a	1.50 a
number of nucleation sites	***	ns	wine	3.64 b	4.00 b	4.00 b	4.00 b	4.00 b	1.40 a	4.20 b
			cider	4.00 a	4.00 a	3.80 a	4.00 a	3.80 a	3.80 a	4.00 a
bubble size	ns	***	wine	2.09 a	2.20 a	3.00 b	3.00 b	2.80 ab	2.60 ab	3.00 b
			cider	2.60 ab	3.00 b	2.80 ab	3.00 b	2.40 a	2.60 ab	3.00 b
foam collar	ns	**	wine	4.18 a	4.00 a	4.00 a	4.20 a	4.00 a	4.20 a	5.00 a
			cider	4.00 a	4.60 b	4.80 b	4.00 a	4.00 a	4.60 b	5.00 b
overall foam quality	***	***	wine	3.91 b	5.40 c	4.25 bc	5.40 c	4.40 bc	2.00 a	5.20 c
			cider	4.90 ab	5.40 b	5.60 b	5.00 ab	4.00 a	5.80 b	6.00 b

[a] Results are the means of three determinations. Mean values in the same row with the same letter are not significantly different at the 5% confidence level (Duncan's test). NS, not significant. **, significant at the 0.05 level. ***, significant at the 0.01 level.

Table 6. Correlation Coefficients and Significance Levels (p) between Sensory Assessments of Foam Attributes and Foam Properties of Sparkling Ciders ($\alpha = 0.05$)

	initial foam	foam area persistence	number of nucleation sites	bubble size	foam collar
foam area persistence	−0.725 ($p = 0.008$)				
number of nucleation sites	0.732 ($p = 0.007$)	−0.426 ($p = 0.167$)			
bubble size	0.667 ($p = 0.018$)	−0.471 ($p = 0.123$)	0.585 ($p = 0.046$)		
foam collar	0.023 ($p = 0.942$)	−0.462 ($p = 0.130$	0.070 ($p = 0.830$)	0.325 ($p = 0.302$)	
overall foam quality	0.703 ($p = 0.011$)	−0.765 ($p = 0.004$)	0.795 ($p = 0.002$)	0.718 ($p = 0.008$)	0.447 ($p = 0.145$)

(gas diffusion from smaller bubbles into bigger ones), bubble size and coalescence (film rupture), together with the physicochemical characteristics of the liquid medium, mainly the surface tension and viscosity (*21*). Therefore, those elements possessing the ability to reduce the surface tension and to increase the viscosity, such as proteins and polysaccharides, will contribute to stabilize the foam. In this sense, the positive influence of the AP and TDE on Σ could be explained on the basis of their contribution to the viscosity and surface tension of cider. In our work, protein content had a significant negative effect on HM (**Table 4**); however, as reported previously, the effect of proteins on foam characteristics is related to their hydrophobicity and flexibility rather than their content (*22*−*24*). Our results could be explained on the basis of the recent findings from Blanco Gomis and others (*25*). These authors have described the protein profile of cider, the main part characterized as hydrophilic, the most hydrophobic ones being linked to polyphenols. TA and VA have a positive influence on Σ, which is in agreement with the fact that electrostatic attractions between proteins become higher reducing interfacial tension (*26*), thus, stabilizing foams. Also, the enhancing effect of phenols on Σ could be associated with their ability to interact with proteins through hydrogen bonds. In this sense, Sarker and others (*27*) have demonstrated in model systems that (+)-catechin produced an increase in foamability and stability of foam by increasing the rigidity of the interfacial air−liquid layers.

Sensory Analysis. Visual attributes were evaluated according to Gallart and others (*15*), with the following modifications: the attribute "foam area persistence" was also assessed, because it is usually appreciated for sensory quality of cider. The measurement scale was the same as that for "initial foam" described by the aforementioned authors. Neither the effervescence speed nor the origin of bubbles were evaluated (**Table 1**). The sensory panel was consistent at evaluating all of the foam attributes of cider, the effect of the taster being not significant at the 5% level.

On one hand, the aging time had a significant influence on the evaluation of the initial foam, foam area persistence, bubble size, foam collar, and overall foam quality. On the other hand, the yeast strain factor was significant for all of the attributes except bubble size and foam collar (**Table 5**).

Surface-active macromolecules absorb on the surface of a rising bubble, modifying the transfer of CO_2-dissolved molecules through the bubble interface (*14*), thus influencing the growth of bubbles. The release of macromolecules as a consequence of the autolysis of yeasts during aging time could explain the influence of this factor on the assessment of bubble size. However, the effect of the yeast strain on the number of bubble chains seems more difficult to explain, since several studies have shown that small particles attached to the glass can act as nucleation sites for bubble chains (*2*, *28*, *29*). In general terms, foam quality improved as aging increased, the ciders made by fermentation with the cider yeast strain being the best evaluated (**Table 5**).

As far as we can know, these results have been described for the first time. For instance, Gallart and others (*15*) described a significant influence of grape variety and harvest on the overall assessment of foam quality of Spanish sparkling wines, whereas Hidalgo and others (*10*) did not find a significant influence on the foam sensory attributes of any of the factors studied (aging time and yeast strain), although two of the yeast strains produced wines with better effervescence and smaller bubble size.

In **Table 6** are shown the correlation coefficients between the different foam attributes. Correlation values higher than 0.500 were found for almost all of the descriptors assessed, except foam collar. The overall foam quality was positively correlated with number of nucleation sites, bubble size, and initial foam and negatively correlated with foam area persistence (**Table 6**). The last fact can be explained because it is assessed with the usual standards for natural cider, so that, as higher the stability of foam, the lower the score (*30*). Thus, even though the correlation found between the overall quality evaluated by the tasting panel and that calculated was highly significant, the correlation coefficient was lower than that described elsewhere (*15*). Therefore, visual quality of sparkling cider is defined by high initial foam, bubble persistence, bubble size (small), and low foam area persistence, which is basically in agreement with that described by Gallart and others (*15*) in Cava wines. The relation between bubble size and overall quality obtained in this paper was also adjusted to that pointed out by Liger-Belair and others (*2*) for Champagne wines.

In disagreement with a previous report (*15*), no correlations were found among the analytical foam parameters and the sensory attributes of sparkling ciders. However, it is worth to noting that, for example, HM and initial foam increased with aging (**Tables 2** and **5**), which is concomitant with a higher score for overall foam quality (**Table 5**).

In conclusion, the results obtained were in agreement with many other previous reports, namely, the effect of aging on lees and the influence of proteins, AP, or acidity on the foam properties of cider. We cannot be certain that the influence of yeast strain on foaming properties and sensory quality of foam that was observed in this study with this particular cider could be considered general, but the possibility that it is seems promising from the technological point of view. In any case, more research is needed to relate the analytical foam properties or chemical composition of ciders to the complexity of foam quality assessment.

LITERATURE CITED

(1) Maujean, A.; Poinsaut, P.; Dantan, H.; Brissonet, F.; Cossiez, E. Étude de la tenue et de la qualité de mousse des vins effervescents. II. Mise au point d'une technique de mesure de la moussabilité, de la tenue et de la stabilité de la mousse des vins effervescents (1). *Bull. O.I.V.* **1990**, *711*−*712*, 405−426.

(2) Liger-Belair, G.; Marchal, R.; Robillard, B.; Vignes-Adler, M.; Maujean, A.; Jeandet, P. Study of effervescence in a glass of Champagne: Frequencies of bubble formation, growth rates and velocities of rising bubbles. *Am. J. Enol. Vitic*. **1999**, *50*, 317−323.

(3) Liger-Belair, G.; Lemeresquier, H.; Robillard, B.; Duteurtre, B.; Jeandet, P. The secrets of fizz in Champagne wines: A phenomenological study. *Am. J. Enol. Vitic*. **2001**, *52*, 88−92.

(4) Andrés-Lacueva, C.; Gallart, M.; López-Tamames, E.; Lamuela-Raventós, R. M. Influence of variety and aging on foaming properties of sparkling wine (Cava). 1. *J. Agric. Food Chem*. **1996**, *44*, 3826−3829.

(5) Andrés Lacueva, C.; Lamuela-Raventós, R. M.; Buxaderas, S.; de la Torre Boronat, M. C. Influence of variety and aging on foaming properties of Cava (sparkling wine). 2. *J. Agric. Food Chem*. **1997**, *45*, 2520−2525.

(6) Girbau-Solà, T.; López-Tamames, E.; Buján, J.; Buxaderas, S. Foam aptitude of Trepat and Monastrell red varieties in Cava elaboration. 1. Base wine characteristics. *J. Agric. Food Chem*. **2002**, *50*, 5596−5599.

(7) Girbau-Solà, T.; López-Barajas, M.; López-Tamames, E.; Buxaderas, S. Foam aptitude of Trepat and Monastrell red varieties in Cava elaboration. 2. Second fermentation and aging. *J. Agric. Food Chem*. **2002**, *50*, 5600−5604.

(8) López-Barajas, M.; López-Tamames, E.; Buxaderas, S.; de la Torre Boronat, M. C. Effect of vinification and variety on foam capacity of wine. *Am. J. Enol. Vitic*. **1998**, *49*, 397−402.

(9) Andrés-Lacueva, C.; López-Tamames, E.; Lamuela-Raventós, R. M.; Buxaderas, S.; de la Torre Boronat, M. C. Characteristics of sparkling base wines affecting foam behaviour. *J. Agric. Food Chem*. **1996**, *44*, 989−995.

(10) Hidalgo, P.; Pueyo, E.; Pozo-Bayón, M. A.; Martínez-Rodríguez, A. J.; Martín-Álvarez, P.; Polo, M. C. Sensory and analytical study of Rosé Sparkling wines manufactured by second fermentation in the bottle. *J. Agric. Food Chem*. **2004**, *52*, 6640−6645.

(11) Marchal, R.; Chaboche, D.; Douillard, R.; Jeandet, P. Influence of lysozyme treatments on Champagne base wine foaming properties. *J. Agric. Food Chem*. **2002**, *50*, 1420−1428.

(12) Moreno-Arribas, V.; Pueyo, E.; Nieto, F. J.; Martín-Álvarez, P. J.; Polo, M. C. Influence of the polysaccharides and the nitrogen compounds on foaming properties of sparkling wines. *Food Chem*. **2000**, *70*, 309−317.

(13) Pueyo, E.; Martín-Álvarez, P. J.; Polo, M. C. Relationship between foam characteristics and chemical composition in wines and Cavas (sparkling wines). *Am. J. Enol. Vitic*. **1995**, *46*, 518−524.

(14) Liger-Belair, G.; Prost, E.; Parmentier, M.; Jeandet, P.; Nuzillard, J.-M. Diffusion coefficients of CO_2 molecules as determined by ^{13}C NMR in various carbonated beverages. *J. Agric. Food Chem*. **2003**, *51*, 7560−7563.

(15) Gallart, M.; Tomás, X.; Suberbiola, G.; López-Tamames, E.; Buxaderas, S. Relationship between foam parameters obtained by the gas-sparging method and sensory evaluation of sparkling wines. *J. Sci. Food Agric.* **2004**, *84*, 127−133.

(16) Gallart, M.; López-Tamames, E.; Buxaderas, S. Foam measurements in wines: Comparison of parameters obtained by gas-sparging method. *J. Agric. Food Chem*. **1997**, *45*, 4687−4690.

(17) *Official Methods of the European Union*; Ministerio de Agricultura, Pesca y Alimentación, Ed.; Ministerio de Agricultura, Pesca y Alimentación: Madrid, 1998; Vol. II.

(18) Bradford, M. A. A rapid and sensitive method for the quantification of microgram quantities of proteins utilizing the principle of protein-dye binding. *Anal. Biochem.* **1976**, *72*, 248−255.

(19) Montreau, F. Sur le dosage des composes phénoliques totaux dans les vins par la méthode Folin-Ciocalteu (Total phenol analysis in wines by the Folin-Ciocalteu method). *Connaiss. Vigen Vin* **1972**, *6*, 397−404.

(20) Bamforth, C. W. The foaming properties of beer. *J. Inst. Brew*. **1985**, *91*, 370−383.

(21) Prins, A. Principles of foam stability. In *Advances in Food Emulsions and Foams*; Dickinson, E., Stainsby, G., Eds.; Elsevier Applied Science: London and New York, 1988; pp 91−122.
(22) Damodaran, S. Protein-stabilized foams and emulsions. In *Food Proteins and Their Applications*; Damodaran, S., Paraf, A., Eds.; Marcel Dekker: New York, 1997; pp 57−110.
(23) Leiper, K. A.; Stewart, G. G.; McKeown, I. P. Beer polypeptides and silica gel. Part II. Polypeptides involved in foam formation. *J. Inst. Brew*. **2003**, *109*, 73−79.
(24) Ferreira, I. M. P. L. V. O.; Jorge, K.; Nogueira, L. C.; Silva, F.; Trugo, L. C. Effects of the combination of hydrophobic polypeptides, iso-α-acids, and malto-oligosaccharides on beer foam stability. *J. Agric. Food Chem*. **2005**, *53*, 5976−4981.
(25) Blanco Gomis, D.; Expósito Cimadevilla, Y.; Junco Corujedo, S.; Gutiérrez Álvarez, M. D. Fractionation and characterization of soluble proteins from cider. *Food Chem*. **2003**, *83*, 507−513.
(26) Zayas, J. F. Foaming properties of proteins. In *Functionality of Proteins in Food*; Springer-Verlag: Berlin, 1997; pp 260−309.
(27) Sarker, D. K.; Wilde, P. J.; Clark, D. C. Control of surfactant-induced destabilization of foams through polyphenol-mediated protein−protein interactions. *J. Agric. Food Chem*. **1995**, *43*, 295−300.
(28) Liger-Belair, G.; Marchal, R.; Jeandet, P. Close-up on bubble nucleation in a glass of Champagne. *Am. J. Enol. Vitic.* **2002**, *53*, 151−153.
(29) Liger-Belair, G.; Vignes-Adler, M.; Voisin, C.; Robillard, B.; Jeandet, P. Kinetics of gas discharging in a glass of Champagne: The role of nucleation sites. *Langmuir* **2002**, *18*, 1294−1301.
(30) Mangas, J. J.; Moreno, J.; Rodríguez, R.; Picinelli, A.; Suárez, B. Analysis of polysaccharides in cider. Their effect on sensory foaming properties. *J. Agric. Food Chem.* **1999**, *47*, 152−156.

Received for review June 21, 2005. Revised manuscript received October 20, 2005. Accepted October 25, 2005. We are indebted to CICYT (Project AGL2001-0713) and the cellar "El Gaitero, S.A." (Villaviciosa, Asturias) for financial support.

JF0514524