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Colour and rheological properties of non-conventional grapefruit jams: instrumental and sensory measurement

Igual, M.[a], Contreras, C.[b], Martínez-Navarrete, N.[a,*]

[a] *Universidad Politécnica de Valencia, Food Technology Department, Food Investigation and Innovation Group, Camino de Vera s/n, 46022 Valencia, Spain*

[b] *Universidad Politécnica de Valencia, Institute of Food Engineering for Development, Camino de Vera s/n, 46022 Valencia, Spain*

Abstract

Alternative methods with which to obtain grapefruit jams have been applied. These include the use of osmotic dehydration (OD) and/or microwave energy (MW), as an alternative to conventional heating, and the incorporation of bamboo fibre together with pectin in order to increase the jam's consistency. Colour, consistency and rheological behaviour were measured and sensory evaluation was carried out to compare product quality. When compared to the fresh fruit, the greatest colour changes took place in those jams processed by MW and conventional heating, both of them showing lower L*, a*, b* and chrome values than the rest of the samples obtained by applying osmotic dehydration. By adding bamboo fibre, the colour of OD samples approaches that of fresh fruit. The higher yield stress, greater consistency and more viscoelastic behaviour was displayed by jams obtained by combining OD and MW processes. In the sensory analysis, the judges awarded this sample a better score. The sensory attribute product coverage in mouth was closely related to viscosity at a shear rate of 120 s^{-1} and consistency.

Keywords: osmotic dehydration, microwaves, bamboo fibre, rheology, colour.

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[*] Corresponding author: Tel.: +34 96 387 70 07x73655; fax: +34 96 387 73 69. E-mail address: nmartin@tal.upv.es (Martínez- Navarrete, N).

Nomenclature

a*	CIE-L*a*b* colour coordinate
a_w	water activity
b*	CIE-L*a*b* colour coordinate
C_{ab}*	chrome
G’	storage modulus
G’’	loss modulus
h_{ab}*	hue angle
k	Herschel-Bulkley rheological constant (Pa*s^n). Consistency parameter
L*	CIE-L*a*b* colour coordinate
n	Herschel-Bulkley rheological constant. Flow index parameter
RHA	relative hysteresis area
V_i	viscosity obtained at i s^{-1} (i= 40, 80 or 120 s^{-1})
ΔE	total colour difference
σ	shear stress (Pa)
σ_o	yield stress (Pa)
$\dot{\gamma}$	shear rate (s^{-1})

1. Introduction

Traditional jams and confitures are widely consumed by several groups of consumers at breakfast and in dairy products, bakery products and confectionery. They usually contain diverse sugars, essences, flavours, colouring foodstuffs, thickening agents, and consumable acids, and are preserved by appropriate methods (Kurz, Munz, Schieber &

Carle, 2008). Pectin is primarily used in the food industry as a gelling agent for jams, jellies, and other foods (El-Nawawi & Heinkel 1997). Nevertheless, other kinds of fibre could be used, depending on their impact on the final quality of the product. Numerous fibres have been isolated and characterized from completely different sources and incorporated into a wide variety of foods (Rosell, Santos & Collar, 2009). Bamboo dietary fibre can be obtained from the structure building components of the bamboo leaves. Some biologically active components in bamboo leaves and their potential health benefits have been widely studied (Lu, Wu, Tie, Zhang & Zhang, 2005; Lu, Wu, Shi, Dong & Zhang, 2006). The addition of bamboo fibre to fruit jams would contribute to increase the daily intake of dietary fibre and nutritive compounds.

Jams are a source of fruit which supply nutrients and antioxidant compounds. However, significant amounts of the beneficial fruit properties are lost due to the intense heat treatments applied to the fruit when elaborating jam. In order to better preserve jam quality, the osmotic dehydration process and the use of microwave energy have been proposed as alternatives to the traditional jam procedure. Osmotic dehydration at mild temperature is a technique that can be used to obtain jam without being so aggressive to the fruit (García-Martínez, Ruiz-Diaz, Martínez-Monzó, Camacho, Martínez-Navarrete & Chiralt, 2002). On the other hand, a review by Vadivambal & Jayas (2007) about changes in quality of microwave-treated agricultural products concluded that microwave heat treatment has many advantages compared to conventional methods and the quality of microwave-treated products is better or equal to that of conventional drying. The use of microwave energy has also been proposed as an alternative to traditional heat pasteurization in order to better preserve the natural organoleptic characteristics and essential thermolabile nutrients of grapefruit juice (Igual, García-Martínez, Camacho, Martínez-Navarrete, 2010). The shorter processing time required with this technology respect to conventional heating, due to the high penetration power of microwaves, seems to be responsible for this. Thus, microwave heat treatment does appear to have a high potential for the processing of agricultural products in the near future.

Variations in the manufacture will produce evident differences in the physical and sensory properties of the formulated products and these differences could influence consumer acceptance. An attractive colour is one of the most important quality characteristics for the grapefruit jam processing industry, besides the typical sweet–sour grapefruit flavor and convenient jam consistency (Wicklund, Rosenfeld, Martinsen, Sundfor, Lea, Bruun, Blomhoff & Haffner, 2005). Measurement of colour and consistency are a complex subject since it depends on consumer appreciation. For this reason, it is important to carry out a sensory analysis with an adequate number of assessors and establish the possible relationships between the instrumental measurements of the physical properties and sensory characteristics. CIEL*a*b* colour coordinates and the colour attributes of hue angle and chrome have been widely used in the objective measuring of food colour. On the other hand, jam consistency may be related not only to empirical measurements but also to fundamental rheological parameters, such as viscosity or loss and storage moduli.

The aim of this work was to compare the colour and consistency of different grapefruit jams obtained by both conventional and non-conventional techniques. Non-conventional methods included osmotic dehydration, microwave application and bamboo fibre incorporation. Sensory and instrumental analyses were performed to evaluate consistency and colour.

2. Materials and methods

2.1. Raw materials

2.1.1. Fruit

Grapefruits (*Citrus paradise* var. Star Ruby) from the city of Murcia were purchased from a local supermarket. The mean values (and standard deviation) of a_w, x_s, x_w and pH of grapefruit used were 0.988 (0.003), 0.120 (0.009), 0.8669 (0.0003) and 3.28 (0.02), respectively. Grapefruits were manually peeled, removing albedo and flavedo, and cut perpendicularly to the fruit axis, into 10 mm thick half slices.

2.1.2. Sucrose and osmotic solution

Food grade commercial sucrose was used to prepare jams. This was added directly to the fruit to formulate conventional and microwave (MW) jams. To obtain the product by osmotic dehydration (OD), a 65 ºBrix osmotic solution (OS) was prepared by mixing the sucrose with distilled water.

2.1.3. Gelling agent

Citrus peel high metoxy pectin (60% degree of esterification, Fluka Biochemika, Switzerland) and bamboo fibre (VITACEL®, Rosenberg, Germany) were used.

2.2. Jam preparation procedures

The following procedures were applied to obtain a 40-60 ºBrix product, as described by the Spanish quality norm for fruit jam (RD 670/1990, BOE Nº 130, 1990). In all the cases, the jam was placed in sterile glass jars and stored at room temperature for 24 h till analysis.

2.2.1. Conventional process

Fresh fruit (67 g grapefruit/100 g mixture) was pre-cooked at 85 ºC for 10 min, added with the sugar and potassium sorbate (32.99 and 0.01 g/100 g mixture, respectively) and cooked at 95-100 ºC for 20 min more. An electrical food processor (Thermomix TM 21, Vorwerk, Spain) was used for the process.

2.2.2. Microwave process.

Fresh fruit (67 g grapefruit/100 g mixture) was pre-cooked (900 W, 5 min), added with the sugar and potassium sorbate (32.99 and 0.01 g/100 g mixture, respectively) and cooked at 900 W for 10 min more. A household microwave (Moulinex 5141 AFW2, Spain) was used for the process.

2.2.3. Osmotic process.

Half slices of peeled grapefruit were placed at 50 mbar pressure for 10 min in the OS (ratio OS:fruit 5:1). Afterwards the atmospheric pressure was restored for 10 min more in order to promote the impregnation of the fruit with the OS. Finally, samples with the OS were heated to 40 °C (water bath P-Selecta Precisterm, Barcelona, Spain) with continuous stirring (200 rpm, Heidolph Instruments, RZR 2020, Schwabach, Germany) for 3 h, reaching ≈30 ºBrix. Osmo-dehydrated samples, potassium sorbate (0.01 g/100 g jam) and pectin (1 g/100 g jam) or pectin (1 g/100 g jam) + bamboo fibre (1 g/100 g jam) were ground together with part of the OS to obtain a jam with 60 g fresh fruit/100 g jam, and as gelling agent. The jams thus obtained were referred as OD and ODBF, respectively.

2.2.4. Combined osmotic-microwave process.

Jams obtained by means of the osmotic process described in paragraph 2.2.3 were cooked at 900 W for 5 min to obtain OD+MW and ODBF+MW samples.

2.3. Analysis

2.3.1. Physicochemical properties

Moisture content (x_w), ºBrix and water activity (a_w) were determined both for fresh grapefruit and all the formulated jams. The x_w was determined by drying the sample to constant weight at 60 ºC in a vacuum oven (AOAC method 934.06, 2000). ºBrix were measured in previously homogenized samples with a refractometer at 20 ºC (Zeiss, ATAGO model NAR-3T refractometer, Japan). A dew point hygrometer (FA-st Lab, GBX, France) was used to measure a_w. pH was measured by means of a CRISON pH-meter. Each analysis was carried out in triplicate.

2.3.2. Colour measurement

CIE-L*a*b* colour coordinates (10º observer and D65 illuminant) were obtained from the reflection spectrum (Minolta, CM 3600D, Tokyo, Japan).

2.3.3. Consistency

The flow distance of a controlled sample weight after 30 s was measured using a Bostwick consistometer. The distance the sample flows related to the weight of the sample (mm/g) was used to characterize the consistency (Bourne, 1982).

2.3.4. Rheological measurements

A controlled stress rheometer (Thermo Haake, RheoStress, Germany) at 25 ºC, with a plate-plate geometry (2 mm gap) was used for rheological analysis. Three consecutive up and down flow curves of each sample, previously relaxed for 900 s, were obtained from 0 to 200 s^{-1}. To obtain the storage and loss modulus of the samples, a dynamic rheological characterization of the samples was also performed, by applying a shear stress of 1 Pa at a frequency sweep of between 0.1 and 10 Hz. The linear viscoelasticity range of these conditions was previously verified.

2.4. Sensory evaluation

A panel of 50 tasters, 27 men and 23 women, carried out a sensory analysis of OD, OD+MW, MW and conventional jams. The age of the panellists ranged from 20 to 50 years old. The tasters were initiated according UNE-EN ISO 5492 classification and submitted to a basic training in which the significance and the way to evaluate the attributes were explained. Sensory analysis of samples consisted of a paired comparison test (UNE-EN ISO 5495). The attributes evaluated were colour saturation, luminosity, brightness and body or consistency, as defined in UNE-EN ISO 5492, extensibility (ease to extend the product on a smooth surface) and product coverage in mouth (amount of residual coating remaining on the surface of the mouth after swallowing the product). The score of each attribute is the sum of times each sample was chosen, based on that attribute, when compared with another. As each taster evaluates six pairs of samples, the maximum score for each attribute was 300. During test session, panellists worked in individual booths. Samples were served at room temperature in transparent plastic glass coded with three digit random numbers. Each panellist tasted approximately the same amount of each sample and mineral water was provided to the assessors to rinse their mouth.

2.5. Statistical analysis

Analysis of variance (ANOVA), with a confidence level of 95% ($p<0.05$), was applied using Statgraphics Plus 5.1 Software (Statistical Graphics Corporation, USA) to evaluate the differences among treatments. For each jam, ten and six replications of colour and rheological instrumental measurements, respectively, were considered. Principal Component Analysis (PCA) with varimax rotation was applied to the correlation matrix of the average values of colour parameters and to the correlation matrix of the average values of rheological parameters. Examining taster's sensorial analysis results by means of a Friedman analysis for the pairwise ranking test (Meilgaard, Civille, & Carr, 1999) enabled us to know in which attribute the samples showed significant differences. Moreover, another PCA was applied to explore the relationships between instrumental and sensory data. These analyses were performed using SPSS program version 16.0.

3. Results and Discussion

3.1. Physicochemical properties

Table 1 shows the values of ºBrix, x_w and a_w of the formulated jams. The range of ºBrix of formulated jams was between 45.2 and 59. As regards jam composition, the MW sample was similar ($p>0.05$) to the conventional product. This was expected, since the conditions of both processes were previously set to obtain a product with about 50 °Brix. The lowest values of ºBrix were observed for OD jams, where no thermal treatment was applied. In these cases, the way to increase the ºBrix of the jams would be increasing the osmotic treatment time. Nevertheless, as this would lead to a not so attractive process, the use of osmodehydrated fruit would be desirable to obtain low sugar jams. As expected, samples obtained by a combined process, which adds a thermal treatment, (OD+MW and ODBF+MW) showed significantly ($p<0.05$) higher ºBrix values than the other jams. The opposite trend was observed for x_w and consequently for a_w. From this point of view, to complement the osmotic process with a short microwave treatment may be recommended to increase the concentration of OD jams.

3.2. Colour measurement

The reflectance spectra in the visible region (400-700 nm) and the L* co-ordinate value for the studied jams are shown in Figure 1. For all of them, the typical spectral curve for red coloured products, with maximum reflectance values at wavelengths greater than 600 nm, can be observed. The samples submitted to thermal treatment were darker, probably due to non-enzymatic browning caused by sugar caramelization and Maillard reactions. The addition of bamboo fibre increased the reflectance and consequently the lightness of the samples, as a consequence its white characteristic colour. The a*-b* chromatic plane appears in Figure 2. The colour coordinates were used to calculate hue angle (equation 1) and chrome (equation 2). Jams showed significantly lower L*, a* and b* values than fresh fruit. As regards BF-free jams, small but significant ($p < 0.05$) differences were observed. Conventional and MW products showed the greatest hue angle (h_{ab}*=37 ± 2) and the lowest chrome value (C_{ab}*=17 ± 2), while OD ones showed the reddest tone (h_{ab}*=33.5 ± 0.6) and the purest colour (C_{ab}*=18.9 ± 0.9). OD+MW samples were closer in colour to conventional and MW ones than to OD.

$$h_{ab}* = \arctan \frac{b*}{a*} \qquad (1)$$

$$C_{ab}* = \sqrt{a*^2 + b*^2} \qquad (2)$$

When compared to fresh fruit, the colour difference (equation 3) of all thermal treated samples was ΔE = 19 ± 2 and, in the case of OD jam, it was 16.0 ± 0.8. When compared to conventional jams, those formulated by means of non-conventional technologies showed ΔE values of 0.7 ± 0.4, 3.0 ± 0.9 and 4 ± 2 for MW, OD+MW and OD, respectively. The whiteness of bamboo fibre induced a significant ($p < 0.05$) increase in both hue angle and chrome of jams, especially in MW treated samples. As a consequence, jams formulated with this fibre showed greater colour differences as compared to the conventional one, ΔE = 9 ± 2), but smaller total colour differences as compared to fresh fruit.

$$\Delta E = \sqrt{\Delta L*^2 + \Delta a*^2 + \Delta b*^2} \qquad (3)$$

On applying factor analysis to the average values of the instrumental colour coordinates and attributes obtained in the studied jams (Fig. 3), the first two factors showed eigenvalues of over 1. The consideration of both components accounted for 97.83% of the total variability. The first factor (F1), explaining 64.95% of the variability, was closely associated with L* (r=0.91), a* (r=0.95), b* (r=0.78) and C_{ab}* (r=0.89) values. The second factor (F2) accounted for 32.88% of the variability and it was mainly associated with the h_{ab}* (r=0.95) value. F1 clearly separated MW and conventional samples on the left-hand side, as a consequence of their lower values of L*, a*, b* and C_{ab}*. The fresh-fruit sample, on the right-hand side, showed higher values of these colour parameters. F2 separated osmotically treated samples, the thermal treatment and fibre addition increasing h_{ab}*values. Jams formulated with BF appear closer to fresh grapefruit than the other ones.

3.3. Consistency and Rheological measurements

Table 2 shows the values of the flow distance in the consistometer corrected by the sample weight. When compared to conventional obtained product, the application of microwaves produces jams that are significantly ($p<0.05$) more consistent. On the other hand, the OD sample was the least consistent (greatest distance covered), despite the presence of added pectin. Bamboo fibre incorporation significantly ($p>0.05$) increased the consistency of the samples.

Shear stress was measured as a function of shear rate. All the samples exhibited a non-Newtonian plastic and thixotropic behaviour. A lower shear stress was needed for the samples to reach the shear rate imposed in each up and down cycle. The area enclosed by the hysteresis loop is related to the degree of structural breakdown that occurred in the samples while shearing. For each up and down cycle, the area under the curve was calculated using the RheoWin 3.61 Data Manager software. The difference between the two areas related to the area of the up cycle was considered as the relative hysteresis area (Figure 4). Significant differences were obtained in RHA between cycles, with the most intense structural breakdown occurring between the first up and down sweep. At any sweep, the least resistant structure of all the jams was that of OD ones. The structure of both MW treated samples and those with added BF were more resistant to shear than conventional ones. The first up sweep was considered in order to model the rheological behaviour of samples. Above the yield point, shear thinning behaviour was observed, resulting in a decrease in the viscosity with shear rate (Fig. 5). Differences among samples were observed at shear rates lower than 70 s^{-1}. The highest viscosity values were obtained for OD+MW and ODBF+MW samples, while the lowest viscosity values were obtained for conventional and OD samples. These results agree with data obtained using the consistometer, were also low shear rates are imposed.

The rheological behaviour described by the flow curves for the first up sweep was fitted to the Herschel-Bulkley model (Table 2), with obtained R^2 values of over 0.868. Herschel-Bulkley parameters (consistency index, flow index and the yield shear stress) confirmed the above-described rheological behaviour: both OD+MW samples and those ODBF+MW, followed by MW, showed the greatest *k* values and the lowest *n* values, confirming the greater consistency and the less Newtonian behaviour of these samples. The yield stress of these samples (≈46 Pa) is on the limit of the gravitational force required for samples to flow in the consistometer. In the cases of the other samples, *k* did not show significant differences, although *n* followed the same behaviour as flow distance.

Storage and loss moduli are related to the “solid like” and “liquid like” properties of the samples, respectively, when the structure is not affected during the test (Dervisi, Lamb & Zabetakis, 2001). For all the samples, the G’ values were always higher than the G’’, which is the typical behaviour of gels with a predominant elastic character. The samples behaved in the same way over the entire frequency sweep under consideration. To compare the different samples, values at 1 Hz were selected (Table 2). As can be observed, OD+MW and ODBF+MW presented the highest values for G’ and G’’ and OD samples the lowest ones. For the OD samples, the incorporation of bamboo fibre and the application of MW increase the storage and loss moduli, thus contributing to the visco-elasticity of the system. The ODBF sample had the same properties as the conventional one. These results were coherent with the results of consistency, were no expected structural degradation occurs, and viscosity ones, obtained at greater shear stress.

A factor analysis of the average values of the consistency and rheological parameters corresponding to the studied jams (Fig. 6) showed that the first factor (eigenvalue >1) accounted for 92.06% of the total variability. This factor (F1) was strongly associated with all the analyzed variables. The results of this analysis clearly separate the jams depending on the process used to obtain them. When compared to conventional jam, the application of microwaves implies an increase of all the studied parameters, probably due to the greater natural fruit pectin solubilisation favoured by the higher temperature reached during this treatment (Contreras, Martín-Esparza, Martínez-Navarrete & Chiralt, 2008). The OD sample was that with lower value of the considered variables. In this case, a lower natural fruit pectin solubilisation occurs as the osmotic treatment was carried out at 40 ºC and the pectin added to the product formulation seems not to contribute to the same extent. Nevertheless, bamboo fibre incorporation significantly increased the measured parameters, leading to a product similar to MW one. When MW was combined with OD treatments, the presence of added pectin and bamboo fibre seem to favour entanglements of the network formed by hydrocolloids.

3.4. Sensory analysis

Figure 7 shows the sum of the scores of each jam for each evaluated attribute. In the case of the colour attributes, the MW sample showed the highest sensory colour saturation, followed by the conventional jam. The jam with the lowest colour saturation detected by the judges was the OD. Furthermore, the conventional and MW samples showed the highest brightness scores and the OD the lowest ones. Judges found no major differences in the luminosity of the jams and only the OD sample score was higher for this attribute. Regarding the results of Friedman’s T statistic test, colour saturation and brightness were the sensory attributes which showed statistically significant differences (α=0.05) in the studied samples. The Friedman's T values for these attributes were 110.5 and 81.2, respectively, with 7.81 being the theoretical T value (α=0.05).

The MW and conventional jams presented lower body or consistency and product coverage in mouth scores, whilst showing higher scores in extensibility. The OD+MW jam was the one most commonly chosen by the judges as having the most body or consistency, followed by OD. Pectin added to these jams could contribute to these sensations. According to the results of the Friedman analysis, body or consistency and extensibility were the attributes which showed statistically significant differences (α=0.05) in the studied samples. The Friedman's T values for these attributes were 51.8 and 9.2, respectively, with 7.81 being the theorical T value (α=0.05).

3.5. Relationship between instrumental and sensory data

As reported above, both instrumental and sensory methods detected significant colour and texture diferences among the studied jams. To explore the relationships between them, PCA was used to establish links between the perceived colour and the instrumental colour parameters, as well as those between the perceived oral texture and the measured rheological parameters. The colour results of the analysis are shown in Table 3. The first three components accounted for about 86% of the overall variance and a very large amount of that (73%) was absorbed by components 1 and 2. The parameters correlated to component 1 were both sensory and instrumental. Of all of them, colour coordinate a* showed the closest relationship (r=0.97), followed by C^*_{ab}, h^*_{ab}, L* and sensorial colour saturation and luminosity. The second component, explaining 15% of the variability, was associated with the colour coordinate b*, and finally sensorial luminosity was linked to component 3. Figure 8 shows the distribution, in the space relating to components 1 and 2, of the sensorial and instrumental parameters. There are three groups, one of which included only instrumental parameters such as the colour coordinates a*, b* and C^*_{ab}. The other groups include sensory and instrumental parameters, one containing the luminosity evaluated by the tasters and the colour coordinate L *. As expected, this indicates a close correlation between the coordinate and the clarity of the samples perceived by the judges. Finally, the last group is made up of the sensory parameters of colour saturation and brightness and the instrumental parameter h^*_{ab}. From this point of view, the colour saturation evaluated by judges was not well correlated with purity of colour, as expected. This indicates that observers find it easier to identify colour differences in terms of tone than in terms of chrome. Perhaps a better explanation of the colour saturation attribute must be provided to judges. In other studies (Tárrega & Costell, 2007), no significant correlations were found between sensory colour data and b* or C^*_{ab} parameters in vanilla dairy dessert.

Figure 9 shows the results of the PCA with respect to oral and instrumental textural parameters. Viscosity at different shear rates (40, 80 and 120 s^{-1}) and values of G' and G'' at 1 Hz were included in this analysis. The first two components showed eigenvalues higher than 1. The consideration of both components accounted for 96.53% of the total variability. The first component (C1), explaining 73.45% of the variability, was strongly associated with all the measured rheological parameters (n, σ_o, *k,* G', G'', V_{40}, V_{80} and V_{120}), consistence (distance/weight) and sensorial product coverage in mouth. The second one (C2) accounted for 23.08% of the variability and it was mainly associated with sensorial consistency and extensibility. The attribute of product coverage in the mouth was closely related to the viscosity measured at 120 s^{-1}. However, it had an inverse relationship with *n* and distance/weight. No correlation was observed between the other measured rheological parameters and the sensory attributes. From this result, it may be assumed that the shear rate generated in the mouth when tasting this kind of product is around 120 s^{-1}, which is in the range pointed out by Shama and Sherman (1973).

4. Conclusion

Heat treatment affects mainly the colour coordinates and chrome of jams, while osmotic treatment and the incorporation of fibre primarily affect the tone. Osmotic dehydration allows jams to be obtained which are closer in measured colour to fresh fruit. Bamboo fibre also contributed to the same effect, even when an intense heat treatment was applied to produce jams. Colour saturation evaluated by judges was closely related to hue angle instead of chrome. On the other hand, the thermal treatment contributes to increase solubilisation of the natural pectin present in the fruit thus increasing the consistency of the samples. This effect may also be supplied by adding bamboo fibre. The closest relationship between sensory and instrumental rheological measurements was obtained with product coverage in mouth and consistency or viscosity measured at 120 s^{-1}. This seems to be the shear rate generated in the mouth when tasting this kind of products.

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TABLE CAPTIONS

Table 1. Mean values (and standard deviation) of ºBrix, water activity (a_w) and moisture content (x_w) of formulated jams.

Table 2. Mean values (and standard deviation) of flow distance, rheological parameters of Herschel-Bulkley model and storage (G’) and loss (G’’) modulus values at 1 Hz.

Table 3. Colour results of the PCA for the instrumental and the sensorial parameters.

FIGURE CAPTIONS

Figure 1. Spectral reflectance curves and L* values of grapefruit jams.

Figure 2. Chromatic a*-b* plane indicating the greatest and the lowest hue angle (h^*_{ab}) and chrome (C^*_{ab}) values detected in grapefruit jams (△ Fresh-fruit, ◆ OD, ◇ ODBF, □ OD+MW, ■ ODFB+MW, • MW and ○ Conventional).

Figure 3. Factor analysis plot for grapefruit jams: instrumental colour parameters.

Figure 4. Relative hysteresis area as a function of shear cycles for jam samples. Different letters denote significant differences ($p<0.05$) among jams in each shear cycle.

Figure 5. Viscosity of jam samples (△ ODFB+MW, ● OD+MW, + MW, ◇ ODBF, ■ OD, and * Conventional) as a function of shear rate during the first up sweep.

Figure 6. Factor analysis plot for grapefruit jams: instrumental rheology and consistance parameters.

Figure 7. Sensory evaluation of colour (A) and oral texture (B) for grapefruit jams (□ OD, ◩ OD+MW, ■ MW and ■ Conventional). Maximum score 300.

Figure 8. Distribution of the first two components of instrumental and sensory colour parameters.

Figure 9. Distribution of the first two components of instrumental and sensory rheological parameters.

Table 1

Table 1. Mean values (and standard deviation) of ºBrix, water activity (a_w) and moisture content (x_w) of formulated jams.

Jam	ºBrix	a_w	x_w
OD	45.3 (0.2)^{a}	0.939 (0.003)^{a}	0.545 (0.002)^{a}
ODBF	45.2 (0.2)^{a}	0.937 (0.003)^{a}	0.548 (0.002)^{a}
OD+MW	53.0 (0.2)^{c}	0.904 (0.003)^{c}	0.381 (0.002)^{c}
ODBF+MW	59 (0.2)^{d}	0.881 (0.003)^{d}	0.317 (0.008)^{d}
MW	51.1 (0.2)^{b}	0.912 (0.003)^{b}	0.490 (0.002)^{b}
Conventional	50.9 (0.2)^{b}	0.910 (0.003)^{b}	0.493 (0.002)^{b}

The same letter in superscript within columns indicates homogeneous groups established by the ANOVA ($p<0.05$)

Table 2

Table 2. Mean values (and standard deviation) of flow distance, rheological parameters of Herschel-Bulkley model (consistency index *k*, flow index *n* and the yield shear stress σ_o)and storage (G') and loss (G'') modulus values at 1 Hz.

Jam	Distance/weight (mm/g)	Herschel-Bulkley model $\sigma = \sigma_o + k\,\dot{\gamma}^n$ First up sweep				G' (Pa)	G'' (Pa)
		σ_o (Pa)	*n*	*k* (Pa*s^n)	R^2		
OD	0.71 (0.02)^e	32 (2)^a	0.307 (0.014)^e	36.7 (1.7)^a	0.962	620 (37)^a	226 (13)^a
ODBF	0.58 (0.02)^d	39.7 (1.8)^b	0.236 (0.014)^d	38 (3)^a	0.919	935 (56)^b	332 (19)^c
OD+MW	0.27 (0.02)^b	45.9 (1.2)^c	0.111 (0.004)^b	56 (4)^c	0.885	1687 (101)^d	410 (24)^d
ODBF+MW	0^a	47.5 (1.1)^c	0.0718 (0.0014)^a	56 (4)^c	0.868	1729 (103)^d	442 (26)^d
MW	0.51 (0.02)^c	39 (2)^b	0.187 (0.009)^c	40 (4)^b	0.919	1152 (80)^c	287 (21)^b
Conventional	0.60 (0.03)^d	34 (3)^a	0.232 (0.012)^d	35 (4)^a	0.976	902 (54)^b	306 (18)^c

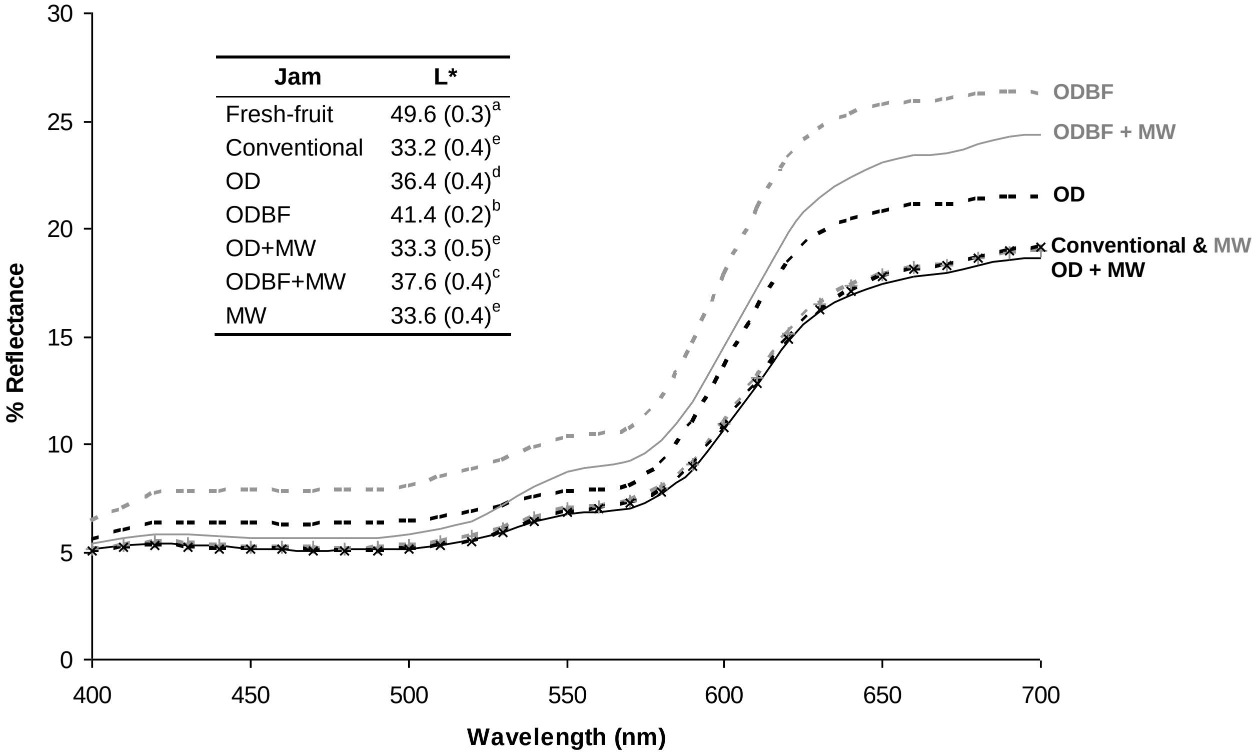
The same letter in superscript within columns indicates homogeneous groups established by the ANOVA ($p<0.05$)

Table 3

Table 3. Colour results of the PCA for the instrumental and the sensorial parameters.

	Component 1	Component 2	Component 3
Eigenvalue	4.580	1.231	1.041
Proportion	0.573	0.154	0.131
Cumulative	0.573	0.727	0.858
Eigenvector			
Sensorial evaluation parameters			
Colour saturation	-0.634	0.589	0.038
Luminosity	0.093	-0.332	0.902
Brightness	-0.614	0.236	0.425
Instrumental parameters			
L*	0.876	-0.216	-0.280
a*	0.968	0.173	0.074
b*	0.596	0.722	0.168
C^*_{ab}	0.942	0.308	0.099
h^*_{ab}	-0.920	0.162	0.042

Figure 1



Jam	L*
Fresh-fruit	49.6 (0.3)^{a}
Conventional	33.2 (0.4)^{e}
OD	36.4 (0.4)^{d}
ODBF	41.4 (0.2)^{b}
OD+MW	33.3 (0.5)^{e}
ODBF+MW	37.6 (0.4)^{c}
MW	33.6 (0.4)^{e}

Figure 1.

Figure 2

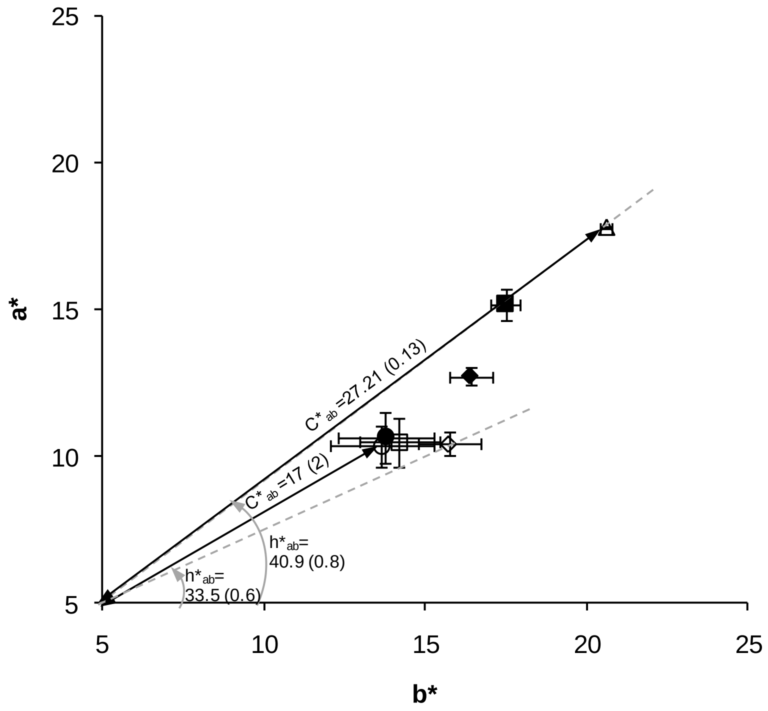


Figure 2.

Figure 3

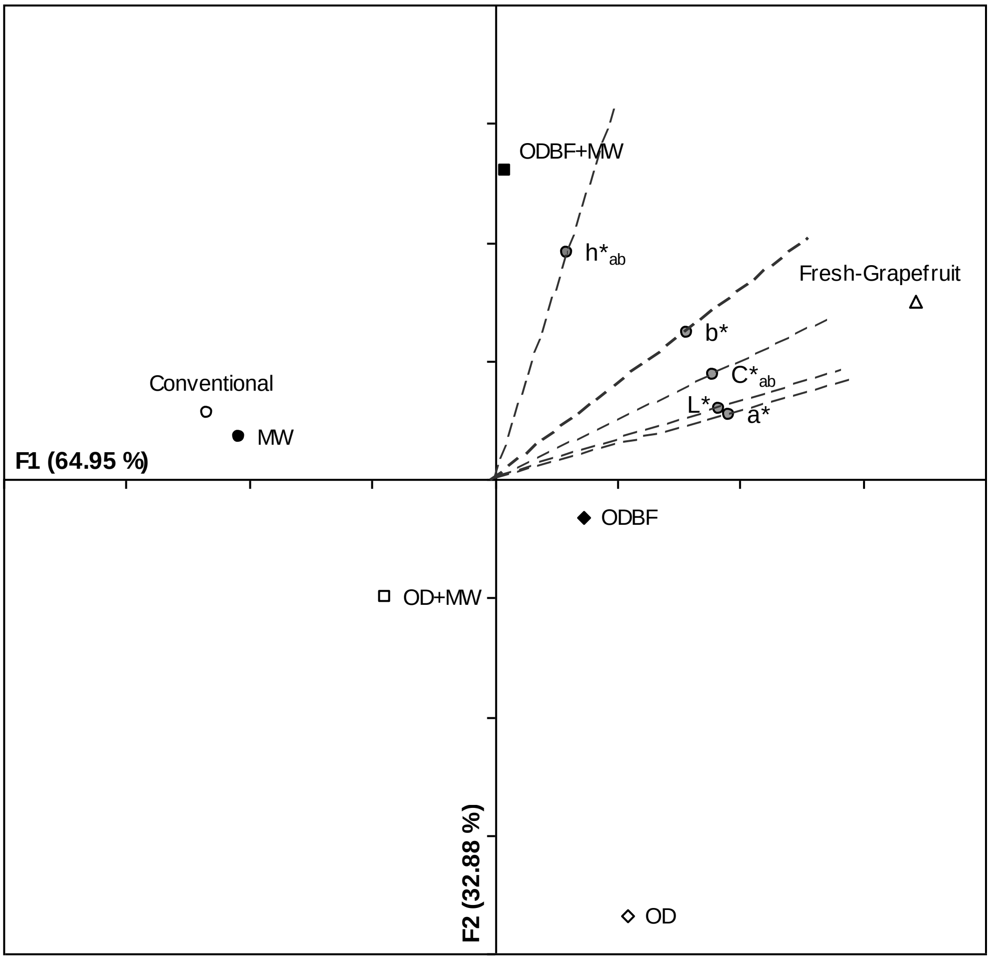


Figure 3.

Figure 4

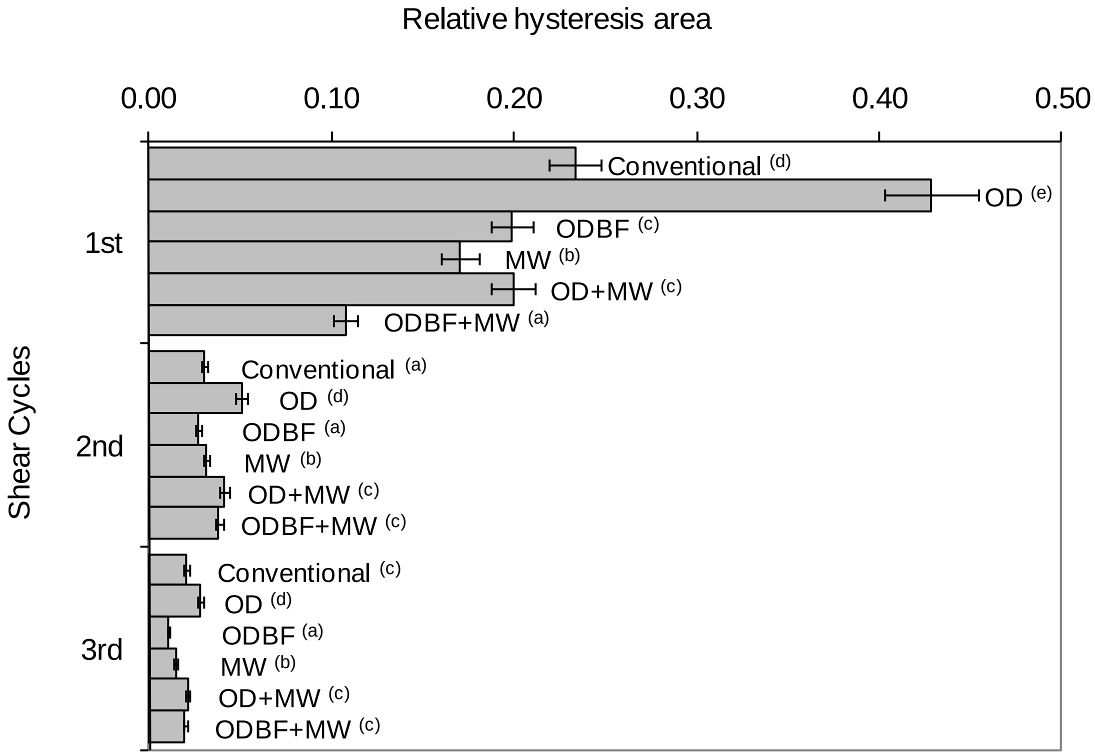


Figure 4.

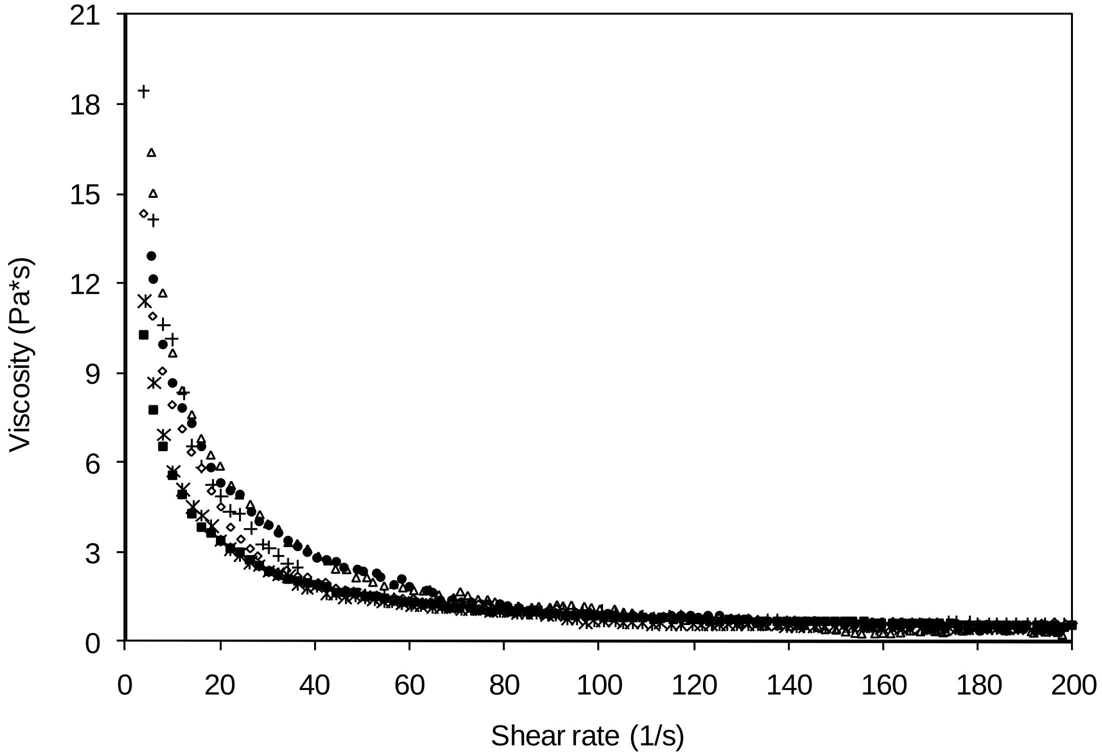

21
18
15
12
9
6
3
0
Viscosity (Pa*s)
0
20
40
60
80
100
120
140
160
180
200
Shear rate (1/s)

Figure 5.

Figure 6

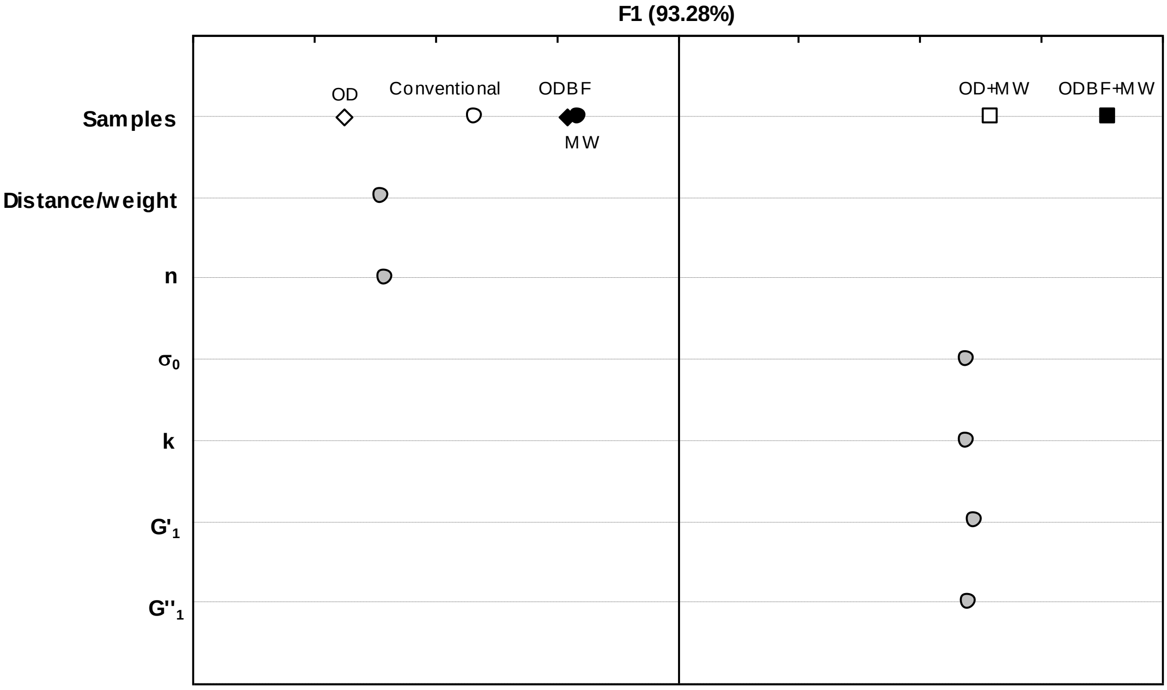


Figure 6.

Figure 7

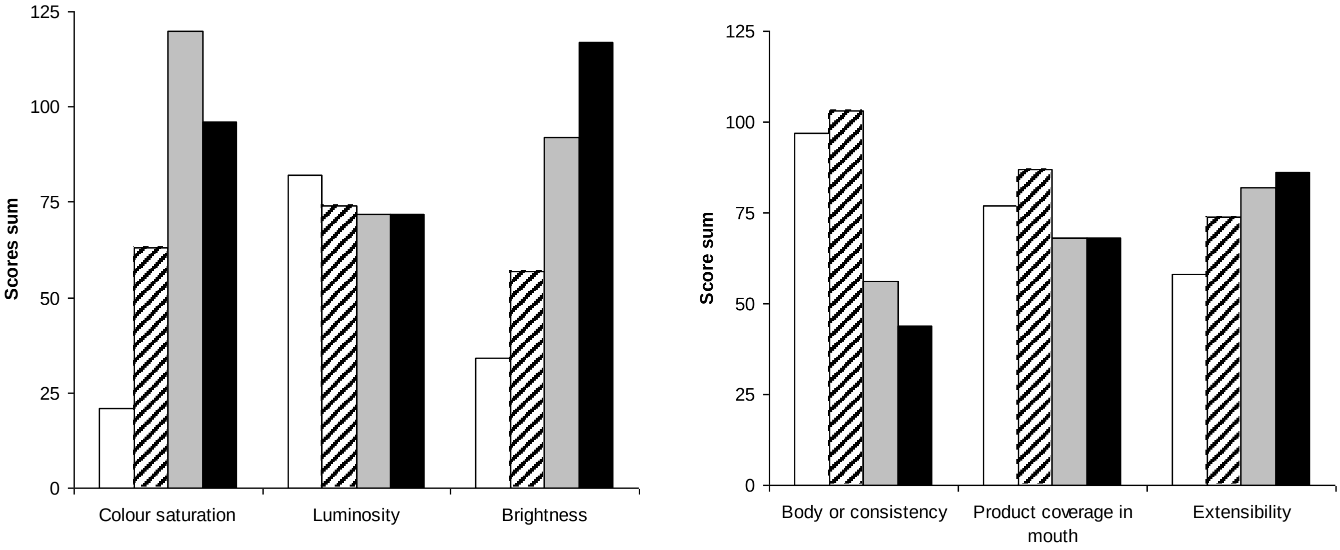


Figure 7.

Figure 8

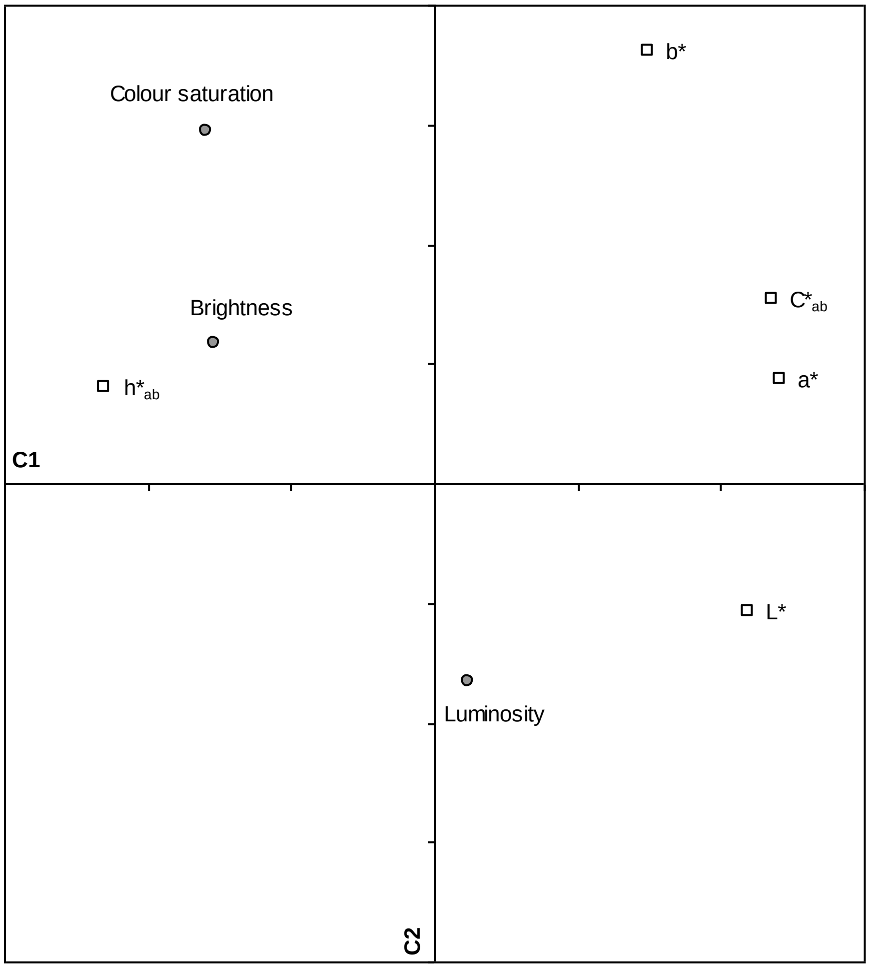


Figure 8.

Figure 9

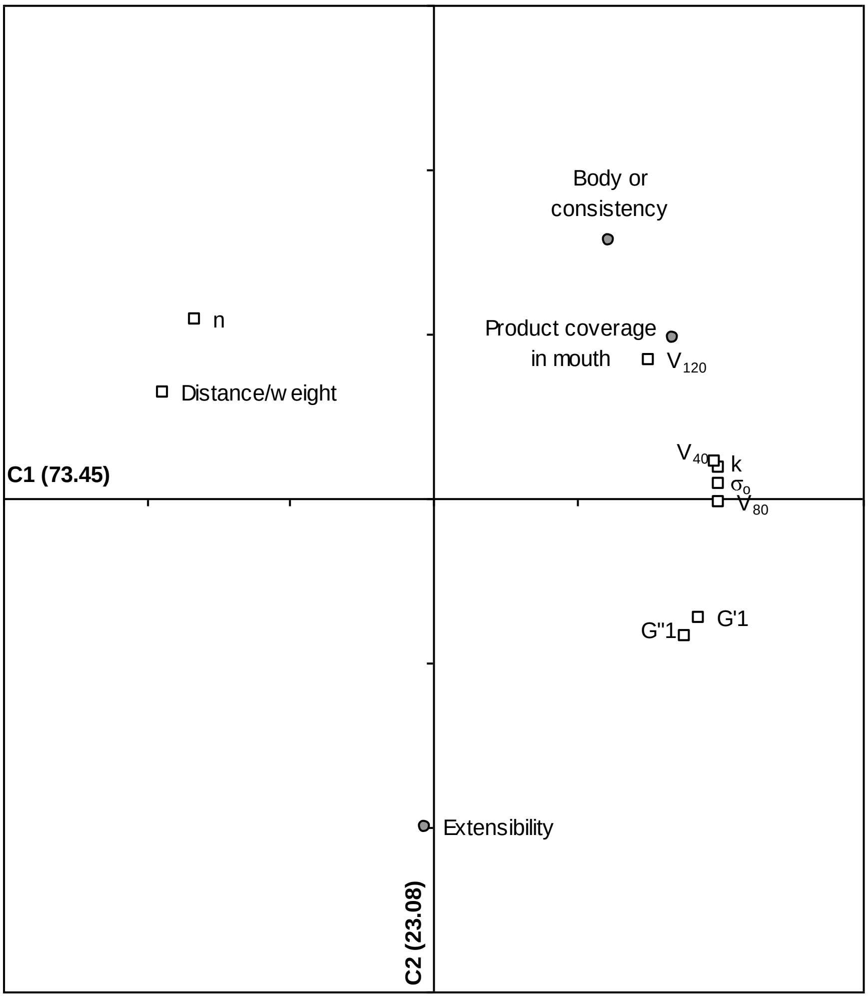


Figure 9.