Particle size and hydration properties of dried apple pomace: effect on dough viscoelasticity and quality of sugar-snap cookies

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Abstract

Apple pomace (AP) is a by-product of the juice industry, rich in dietary fiber (45.06%), which is generated in large quantities. The objectives of the present work were to evaluate the effect of the particle size and the level of replacement with AP on the quality of sugar-snap cookies. Dehydrated AP was ground to three different particle sizes (d (4,3) = 362, 482, 840 µm) to substitute 15% and 30% of wheat flour in cookie formulations. The quality of dough and cookies was evaluated in terms of rheological properties, color, texture and global acceptability of the final product. When the AP particle size decreased, the water absorption properties (WHC, WBC) were higher (33 and 10 % respectively for the lowest and the highest particle size). For both replacement levels the smallest particle size (362 µm) led to the highest dynamic moduli of dough. The spread ratio (SR) of the cookies diminished when the particle size decreased (from 6.4 to 4.8 corresponding to AP840 and AP362 respectively). The lowest SRs were obtained for the 30% replacement level except for AP362. When employing AP with the largest particle size (840 µm) the cookies were less hard (48.7N). The addition of AP to sugar-snap cookies led to higher global acceptability scores than for control cookies. The sensory attribute that most differentiated the cookies with AP was their pleasant taste being the taste score always higher than the control one.

Keywords: by-product; bagasse; dietary fiber; hydration properties; cookie quality

Introduction

The industry of fruit juice and other derivatives such as nectars and soft drinks generates a large amount of by-products that can harm the environment, because they are generally prone to microbial deterioration. Therefore the efficient utilization of these by-products, with low cost and environmentally friendly processes, is increasingly important (Schieber et al. 2001). They can be recovered and used as a value-added ingredient in different products since they provide dietary fiber, as well as bioactive compounds such as polyphenols and essential oils (Elleuch et al. 2011).

Among the main by-products of fruits/fruit processing generated worldwide, those from citrus (15 million tons / yr), grape (7 million tons / yr), and apple (4 million tons / yr) stand out (Lin et al. 2013). In the world production of apple, 25%-30% is destined for processing, the concentrated apple juice being the main product (65%) (Bhushan et al. 2008). The apple juice industry generates large quantities of apple pomace (AP), which is the product obtained after juice extraction (25%-30% of the total weight of the fresh apple), consisting mainly of pulp / peel (95%), seeds (2%-4%), and stem (1%), according to the juice extraction process (O'shea et al. 2012). This by-product is characterized by its high content in carbohydrates and dietary fiber, and significant amounts of phenolic compounds (Leyva-Corral et al. 2016; Dhillon et al. 2012). Apple fiber is mainly composed of cellulose (43.6%), hemicellulose (24.4%), lignin (20.4%) and pectins (11.7%) (Nawirska and Kwaśniewska 2005).

Dietary fiber intake for adults should be 25 g/day for a diet2000 Kcal/day (ADA Report, 2002; WHO Technical Report, 2003). For children older than 2 years, it is recommended an amount of fiber equal to their age plus 5 g/day (ADA Report, 2002). In coincidence, FAO/WHO recommends 25g/day in order to help preventing diet-related chronic diseases (WHO Technical Report, 2003). Since there is an increasing concern respect to reach adequate levels of fiber intake, the developing of fiber-enriched products and the assessment of new sources of fiber have gained growing interest.

Apple pomace has been used in baked goods such as bread, cakes, and cookies (Quiles et al. 2016; Sudha et al. 2016; Jung et al. 2015; Rocha Parra et al. 2015a). The baked products that are more suitable for the use of these by-products are cookies and cakes because they usually include appreciable amounts of sugar and fat in their composition, thus masking a little the undesirable flavors. Besides, in the particular case of cookies is not necessary to develop a gluten network, and the negative effects of reducing the gluten level by substituting wheat flour by another ingredient are not so important (Gómez and Martinez 2017).

Different works on cookies with the addition of AP have been reported (Jung et al. 2015; Kohajdová et al. 2014; Singh et al. 2012). In these works, wheat flour has been replaced with apple pomace in quantities ranging from 5% to 25%, and AP with particle sizes between 200 and 500 µm have been assayed. In general, these authors found that the replacement of wheat flour by AP in cookies produces two effects, the first one is the reduction of the spread ratio and the second one, the reduction of the hardness with respect to the control (without apple pomace). However, they worked with a single particle size. The particle size, as well as other physical properties such as porosity, and the specific surface can be altered according to the process that is used to prepare the by-product. Among the different procedures, grinding can modify the physical properties of the fiber and therefore change the hydration properties thereof (Guillon and Champ 2000). It is important to take this point into account, because different particle sizes will alter the hydration properties of the system in a different way and therefore influence the quality parameters of the processed product. Several authors have reported the effect of the particle size on the hydration properties of AP (Liu et al. 2011; Grover et al. 2003). In cookies, it has been found that a smaller particle size in the flour used increases the hardness, in comparison with flours of greater particle size (Dayakar Rao et al. 2016; Zucco et al. 2011; Mancebo et al. 2015).

The objective of this work was to evaluate the effect of apple pomace of three particle sizes (d (4.3) = 362, 482, 840 µm) at two replacement levels (15 and 30%) on the quality of sugar-snap cookies, in terms of dough rheology, quality characteristics and sensory evaluation of the final product.

Materials and methods

Materials

Crude apple pomace provided by Jugos SA (Villa Regina, Rio Negro, Argentina), wheat flour (WF) (11.42 g/100 g moisture; 10.43 g/100 g protein) supplied by Harinera Castellana S.L. (Medina del Campo, Valladolid, Spain), white sugar (AB Azucarera Iberia, Valladolid, Spain), 100% vegetable margarine (Argenta crema, Puratos, Barcelona, Spain), sodium bicarbonate (Manuel Riesgo S.A., Madrid, Spain) and local tap water were used. Vegetable margarine contained refined palm oil, sunflower palm oil, water, emulsifiers (mono and diglycerides of vegetable fatty acids), sorbic acid, color and flavoring agents.

Methods

Apple Pomace treatment and characteristics

For drying apple pomace, a forced convection oven (ESTIGIA, La Plata, Argentina) at 50 °C was employed for 24 h. Dried apple pomace was ground with a sieve size of 0.75 mm (Cross Beater Mill, PULVERISETTE 16, Idar-Oberstein, Germany). Composition was determined according to AOAC methods (1990): moisture, method 964.22; protein, method 979.09; ash, method 923.03; total dietary fiber, method 991.4; fat, method 920.39. Carbohydrates were calculated by difference. Assays were performed in duplicate.

The powder obtained was sterilized at 121 °C for 20 min in a steam autoclave (VZ, Ciudadela, Argentina) to eliminate yeasts and molds (natural flora). Afterwards the AP was re-ground using two different ring sieves (0.5 mm and 0.2 mm) (Ultra-Centrifugal Mill, Retsch, ZM 200, Hann, Germany). The particle size of ground AP was determined as the volume fraction-length mean diameter (d(4,3)) using a laser diffraction technique with a Malvern Mastersizer 3000 E (Malvern Instruments Ltd., Malvern, Worcestershire, UK). The refractive index used was 1.54. The sample was automatically suspended by the equipment. Each sample was measured three times to obtain the mean. For color determination 1.5 g of each powder was weighed in a glass capsule 2 cm high and 9 cm in diameter; the measurements were made in triplicate, with a Minolta CN-508i spectrophotometer (Minolta, Co. LTD, Tokyo, Japan) using the D65 illuminant with the 2-standard observer. Results are expressed in the CIE L*, a*, b* color space. Assays were performed in triplicate.

Hydration and oil absorption properties of AP and wheat flour

The different fractions of apple pomace and wheat flour were characterized by their hydration and oil absorption properties. Water holding capacity (WHC) is defined as the grams of water retained per gram of sample when not submitted to stress. It was determined according to the AACC method 88-04 (AACC, 2012). Five grams of each sample were dispersed in 100 mL distilled water in a graduated cylinder and left to rest for 24 h. Then, the excess water was removed and the swelled solid was weighed; the retained water was calculated by difference. Water binding capacity (WBC) is expressed as the grams of water that remain bound to the sample after employing low-speed centrifugation. It was determined upon AACC method 56-30.01 (AACC, 2012). Five grams of each sample were mixed with 25 mL of distilled water in a Falcon tube and then centrifuged (2000 x g, 10 min). All the assays were performed in duplicate.

The oil absorption capacity (OAC) was determined according to Lin et al. (1974). It was calculated as grams of oil bound per gram of sample on dry basis. One hundred miligrams of each sample were mixed with 1 mL of vegetable oil in an Eppendorf tube. The mixture was well stirred (30 min) in a vortex mixer and then centrifuged (3000x g, 4ºC, 10 min). Then, the supernatant was extracted with a pipette, the tubes were overturned for 25 min to drain the oil and the residue was weighed. This assay was performed by triplicates.

Cookie preparation

Cookies were prepared according to the procedure of Mancebo et al (2018) that is schematized in Figure 1. Seven different cookie formulations (control and two replacement levels: 15% and 30% for each particle size of AP) were prepared. Each cookie formulation was made by duplicate. The same amounts of ingredients were used in all cases but water varied in order to reach a final moisture content of 15 %. The amounts of the ingredients (on 100 g dough basis) were: WF or AP-WF mixture, 43.3 g; sugar, 31.2 g; margarine, 19.4 g; water, 5.2 g and sodium bicarbonate, 0.9 g. The cookie used as control sample was made with wheat flour and without AP. Each batch consisted of 18 cookies. A Kitchen Aid 5KPM50 mixer (Kitchen Aid, Benton Harbor, MI, USA) was used and the pieces of dough were laminated in a Salva L-500-J sheeter (Salva, Lezo, Spain). An electric modular oven was employed for baking. Cookies were preserved in polypropylene bags at 20 °C until analysis.

Dough rheology properties

Rheological measurements were taken using a controlled strain rheometer (Thermo Scientific Haake RheoStress1, Thermo Fisher Scientific, Schwerte, Germany) with parallel-plate geometry (60-mm diameter titanium serrated plate-PP60 Ti) with a 3-mm gap and a Phoenix II P1- C25P water bath for temperature control (set at 25 °C). Before measuring, the dough was left resting for 800 s. The linear viscoelasticity region (LVR) was determined through a stress sweep range of 0.1-100 Pa at a constant frequency of 1 Hz. On the basis of the results obtained, a stress value included in the LVR was used in a frequency sweep test at 25 °C with a frequency range of 0.1-10 Hz. Average stress values for frequency sweeps were: 4 Pa for control dough, 8 Pa for dough with 15% replacement and 15 Pa for dough with 30% replacement. Values of elastic modulus (G' [Pa]), viscous modulus (G'' [Pa]), and tangent δ (G'' /G') were obtained for different frequency values (ω [Hz]). Samples were analyzed in duplicate.

Cookie properties

After cooling during an hour at room temperature, six cookies of each formulation were individually weighed. A caliper was used for measuring the diameter and thickness of the cookies. The average diameter or width of each cookie was calculated as the mean of two perpendicular diameters. With these six mean values the average width (W) was determined. The average thickness (T) was also calculated. The spread ratio (SR) of the cookies was expressed as the average width (W) divided by the average thickness (T).

The texture properties of cookies were studied by a three-point bending test, carried out at room temperature with a TA-XT2 texture analyzer (Stable Microsystems, Surrey, UK) controlled by the Texture Expert software. Eight cookies of each formulation were measured 24 h after baking. The experiment conditions were the same used by Mancebo et al. (2018): distance between supports, 30 mm; trigger force, 5 g; probe travel distance, 30 mm; pretest speed, 1.0 mm s^{-1}; test speed, 2.0 mm s^{-1}; and posttest speed, 10.0 mm s^{-1}. The maximum force (N) and the displacement at rupture (mm) were measured.

The surface color of six sugar-snap cookies from each formulation was measured at the center point of the upper surface with a Minolta CN-508i spectrophotometer (Minolta, Co. LTD, Tokyo, Japan) using the D65 illuminant with the 2-standard observer. Results are expressed in the CIE L*, a*, b* color space.

Cookie acceptability

For the hedonic sensory evaluation of cookies, 63 volunteers (19 males, 44 females) that were regular cookie consumers were invited to perform the test. The range of ages was 18-64 years with the following distribution: 78% between 18-24 years old, 17 % between 25-34 years old and 5% elder than 35 years. The attributes that were evaluated were appearance, odor, texture, taste and overall appreciation on a nine-point hedonic scale. The scale of values ranged from "like extremely" to "dislike extremely" corresponding the highest and lowest scores to “9” and “1” respectively (Mancebo et al. 2015). Samples were analyzed one day after baking. Whole cookies were labeled with four-digit random numbers and served in random order. Each evaluator received four cookies on a dish: the control cookie and cookies with AP362, AP482 and AP840at the replacement level of 15%.

Statistical analysis

The analysis of variance (ANOVA) was applied and post Tukey's HSD was used to assess significant differences (confidence interval of 95%). The analysis was performed using Statgraphics Plus V5.1 software (Statpoint Technologies, Warrenton, USA).

Results and Discussion

Apple pomace powder characteristics

The dried AP was a slightly brown and aromatic powder. Its composition was (on 100 g basis) as follows: moisture, 12.1±0.2 g; protein, 4.74±0.04 g; ash, 1.30±0.01 g; total dietary fiber, 45.1±0.1 g; fat, 1.86±0.01 g; and carbohydrates different from fiber (calculated by difference), 34.9 g. Results of the measurements of particle size distribution are shown in Figure 2. Besides the lowest mean particle size, the more ground apple pomace (0.2 mm sieve) exhibited a more narrow range of sizes. The three obtained AP powders had the following (d(4,3)): 840 µm, 482 µm, 362 µm and were named AP840, AP482 and AP362, respectively.

Apple pomace and dough characteristics

The particle sizes and the physical characteristics of the different fractions of ground AP are shown in Table 1. Apple Pomace exhibited enhanced hydration capacity compared to WF as shown by the higher values of WHC and WBC. In a previous work, it was reported that another hydration property of AP, the water imbibing capacity (WIC) which is governed by capillary forces was much higher than WIC of the refined rice flour or cassava starch. This behavior was related to the great fiber content of AP, which is rich in cellulose, pectin, and hemicelluloses (Rocha Parra et al. 2015b).

For AP, WHC values ranged from 6.7 to 8.93 and WBC increased from 5.16 to 5.63; both parameters showed a significant positive correlation between them ($r=0.9750$, $p<0.05$). When AP of different particle sizes was compared, it was found that as the particle size decreased, the hydration capacities (WHC, WBC) were significantly higher ($p<0.05$). The increase of hydration properties at lower particle sizes has been reported for various types of flours such as chestnut (Ahmed et al. 2016) and sorghum (Dayakar Rao et al. 2016) and also for carrot pomace (Chau et al. 2007). This increase can be associated with the greater surface area (De La Hera et al. 2013; Chau et al. 2007; Robertson and Eastwood 1981). On the other hand, the particle size does not have a clear influence on the OAC.

As expected, the highest L* and the lowest values for a* and b* were shown by WF. The AP characteristic brown color can be attributed to the partial caramelization of apple sugars during the drying process, in addition to Maillard reactions that occur between proteins and sugars as explained by Caparino et al. (2012). A significant effect of the particle size on L* of AP was found, with values increasing from 40.1 to 54.1 (for AP840 and AP362, respectively). Luminosity values were in agreement with those reported for apple pomace by other authors (Lavelli and Kerr 2012). The values of a* is negative for green and positive for red, and b* is negative for blue and positive for yellow. The values of a* were not significantly different among AP samples, but a tendency to increase the reddish color was found as the particle size decreased. AP840 had the lowest value of b* (10.5) and there was a significant difference ($p<0.05$) when compared to AP362, which presented the highest value of b * (18.18). The changes observed in L* and b* values could be attributed to the oxidation of certain components, which would be more favored in the product with the smaller particle sizes due to the greater surface that is exposed. The color of the powders made up of larger particles was less uniform than that of samples with smaller particles, leading to higher standard deviations for AP840 values.

The mechanical spectra of the doughs are shown in Figure 3. For all samples G' > G'', with a slight dependence on frequency, indicating that all doughs exhibited a predominantly solid behavior. The type of viscoelastic behavior of doughs was affected by the addition level and particle size of AP. The dynamic moduli were higher for doughs with AP than for WF dough. Besides, for the highest sustitution level (30%) the dynamic moduli were higher than for the lowest level of AP. Mancebo et al. (2018), Laguna et al. (2014) also found an increase in G' and G'' values when partially susbtituting wheat flour by insoluble fibers. Apple pomace has a high content of total dietary fiber, which is mostly insoluble (Rosell et al. 2009; Sudha et al. 2007). Figure 3b and 3c show the influence of the particle size on the dynamic moduli at each level of sustitution with AP: when the particle size decreases the value of both moduli increases. When WF was substituted with AP, the value of the loss tangent decreased, and for the two levels of added AP (15% and 30%) it was found that as the particle size decreases, the loss tangent decreases, indicating that the elastic behavior predominates over the viscous one.

There are discrepancies about the influence of particle size on the rheological behavior of dispersed systems. Mancebo et al. (2015) found that the dough elastic moduli of gluten-free sugar-snap cookies prepared with different flours (yellow maize, precooked yellow maize, buckwheat, teff and short-grain and long-grain rice flour) increased when the flour particle size decreased. Mancebo et al. (2018) also stated that in the case of insoluble fibers, besides the influence of hydration properties, the particle size and geometry are important factors influencing dough rheology. These authors found that the addition of pea and potato fibers led to cookie doughs with lower dynamic moduli G', G'' and G* than coarse bamboo fibers, that were lengthier and more flat. However, opposite trends have been reported by some authors (Petrović et al. 2015; Moreira et al. 2010) who found that the larger particle sizes in defatted wheat germ flour and chesnut flour increased the value of the dynamic moduli (G', G") in oscillatory assays. This lack of agreement in the results from different researchs could be caused by the differences between the materials assayed in each case and the particular way they interact with other components of the system, particularly water. In the present work, AP362 showed higher water and oil absorption capacities than AP systems with larger particle sizes (Table 1), which could lead to more interaction with water and fat in cookie dough and consequently, higher modulus values.

Cookie characteristics

In Figure 4, the visual characteristics of cookies can be observed, and the physical characteristics are summarized in Table 2. Snap-cookie quality can mainly be described by two parameters, the diameter, which is directly related to the spread ratio (SR), and the hardness, which depends on the cookie structure. The SR is likely affected by the water-binding components of the dough (Pareyt and Delcour 2008). For SR, the highest values were observed in the control sample. Comparatively, cookies with AP362 presented the lowest SR values, with significant differences ($p<0.05$) with respect to the other formulations with AP 840 and AP482. A significant negative correlation ($r=-0.9702$, $p<0.05$) was found between the SR of cookies and G" of doughs. It was also observed that for the smallest particle size of AP used, there was no influence of the substitution level. However, a significant ($p<0.05$)

influence of the substitution level was observed for samples with AP840 and AP482; SR decreased when the level of substitution was 30%, as is shown in Figure 4. Cookies with 30% of WF replacement not only had lower SR but also a smoother and less cracked surface.

These results coincide with those reported by Toledo et al. (2017) and Naknaen et al. (2016), who pointed out that the incorporation of fruit by-products reduces the SR, due to the water absorption capacity of the fibers present in them. Similarly, Mancebo et al. (2018) reported a decrease in the SR in cookies in which wheat flour had been replaced with 15% of different insoluble fibers, and found a strong negative correlation between the water absorption properties and SR. In the present study, a significant ($p<0.05$) negative correlation was found between the WHC of AP and SR of cookies at a 15% level of replacement and between both water absorption properties (WHC/WBC) and SR at a 30% level of replacement.

With respect to texture, it was found that all cookies enriched with AP were harder (higher maximum force F) than WF control (31N), and the hardest cookies (F= 75-77 N) were obtained with the AP of the smallest particle size. However, no clear trend was found in the rupture displacement (mm). The F value of cookies, obtained from the texture assays, significant and positively correlated with the elastic and viscous moduli of dough ($r=0.9815$, $r=0.9788$, respectively, $p<0.05$) and negatively with the loss tangent ($r=-0.9886$, $p<0.05$), demonstrating the strong influence of the rheological parameters of dough on the hardness of the final product. Moreover, the spread of cookies during baking negatively correlated with F ($r=-0.9136$, $p<0.1$). These results are in agreement with those reported by other authors who replaced WF with different ingredients such as chickpea flour (Mieszkowska and Marzec 2016) or different soluble and insoluble fibers (Mancebo et al. 2018) in the preparation of cookies. Cookies prepared with finer flours were harder than those made with coarser flours, probably due to the more compact structure of cookies obtained with fine flours. These results are in agreement with Mancebo et al. (2015) who reported that the hardness was significantly affected by the particle size probably because cookies made from fine flour had a more compact structure. Sozer et al. (2014) reported the same trend for biscuits added with wheat bran of two different particle sizes. These authors found that fine bran incorporation increased the hardness of biscuits which visually exhibited a more compact structure than biscuits with coarse bran. In addition, biscuits with coarse bran were rougher and more easily broken down in sensory assays.

The results of color measurements are shown in Table 2. The cookies with addition of AP were darker (lower L* value). Generally, the incorporation of a flour obtained from a fruit by-product in cookies leads to a reduction of L* values (Toledo et al. 2017). No clear trend was found at 15% of replacement; when the particle size decreases the lightness also decreases. With 30% of replacement the darkest cookies were obtained and interestingly, there was no influence of the particle size of the AP, probably because the main factors for color development were browning reactions (Maillard reaction and caramelization) that depend on the sugar content.

When the parameter a* was evaluated, it was found that it presents positive values and a tendency to increase (i.e., a tendency to reddish values) when the AP particle size decreases. The lowest value of a* corresponded to the control cookie. The value of a* increased significantly by increasing the replacement level only for the smallest particle size (AP362). For all particle sizes, the value of b * increased significantly when the replacement level was higher.

Sensory acceptability

The sensory evaluation was carried out only on the cookies with a 15% replacement level, since cookies with 30% replacement presented an excessively hard texture and also had an excessively sweet and bitter taste. The results of the cookie sensory evaluation are shown in Figure 5. Although the particle size did not lead to significant differences in the texture, many evaluators said that they found those cookies with the smallest particle size harder and more compact. On the other hand, certain evaluators felt AP840 had a grainy texture, which was not considered unfavorable.

Although the addition of fruit and vegetable by-products generally decreases the global acceptability of breads, cookies and cakes (Gómez and Martinez 2017), in the present work, no significant differences were observed with respect to the control cookie when the different parameters were evaluated, with the exception of the taste. When the taste of the cookies containing AP was evaluated, significantly higher scores than the control were obtained for cookies with AP (independently of the particle size).

Conclusions

Apple pomace (AP), a vegetable by-product rich in fiber that is generated in large quantities by the juice industry can be a good alternative for enriching different foods. Particularly, the results of the present work show that cookies can be successfully enriched and the replacement of wheat flour by 15 % or 30% of AP could allow attaining levels of fiber of 3-6% in the finished product. Sensory analysis demonstrated that the obtained product with a 15% of replacement had a level of acceptance similar to the control cookie and its taste obtained even a higher score than control. From a technological point of view, one of the main aspects to be taken into account for converting this by-product into an adequate food ingredient is the degree of grinding, since the particle size had a significant influence on dough and cookie attributes. Apple pomace of the greatest particle size rendered less hard cookies with a higher spread ratio which are desirable attributes. Moreover, the level of replacement of wheat flour with apple pomace is another important factor in order to attain a good balance between the enrichment with fiber and the technological quality. Each particular fruit by-product would deserve a specific evaluation of its potential as food ingredient but the results obtained with AP are encouraging respect to the use of this and other pomaces as sources of fiber for healthier foods.

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Table 1. Wheat flour (WF) and apple pomace (AP) hydration properties and oil absorption capacity.

	d (4,3) (μm)	WHC	WBC	OAC	L*	a*	b*
WF	95±1a	1.53±0.01 a	1.94±0.02 a	2.02±0.02 ab	90.0±1 c	-0.17± 0.01 a	8.4±0.3 a
AP840	840±2 d	6.7±0.3 b	5.16±0.05 b	1.9±0.1 a	40.1±4.1 a	6.5±1.2 b	10.5±2.7ab
AP482	482±2 c	6.8±0.3 b	5.3±0.2 bc	2.1±0.1 ab	48.1±4.6 ab	7.39±0.03 b	14.8±1.5bc
AP362	362±6 b	8.93±0.08 c	5.63±0.06 c	2.52±0.01 c	54.1± 0.3 b	7.86± 0.06 b	18.18±0.01c

Mean ±SD; different letters within a column indicate significant differences ($p<0.05$). WBC, Water Binding Capacity; WHC, Water Holding Capacity; OAC, Oil absorption capacity.

Table 2. Cookie properties

	F max (N)	Displacement (mm)	Spread Ratio	L*	a*	b*
Control	31.3±7.5 a	0.8±0.3 d	8.3±0.5 d	64.0±1.8 d	1.6±0.7 a	18.3±1.2 e
AP840 15%	48.7±3.9 b	0.7±0.2 bcd	6.4±0.2 c	48.3±1.4c	5.9±0.4 b	13.5±0.8 cd
AP840 30%	49.2±7.9 b	0.48±0.09 a	5.5±0.1 b	42.7±1.1a	6.0±0.3 bc	10.6±0.5 a
AP482 15%	49.9±10.7 b	0.50±0.08 ab	5.5±0.4 b	46.6±0.7 b	6.3±0.4 cd	12.8±0.6 bc
AP482 30%	63.0±7.9 c	0.6±0.1 abc	4.9±0.1 a	42.9±0.5 a	6.6±0.2 d	11.0±0.5 a
AP362 15%	74.6±6.3 d	0.7±0.1 cd	4.8±0.1 a	47.3±0.9 bc	6.6±0.2 d	13.7±0.4 d
AP362 30%	77.7±6.9 d	0.6±0.1 abcd	4.8±0.2 a	43.1±0.8 a	7.6±0.3 e	12.0±0.4 b

Mean ±SD; different letters within a column indicate significant differences ($p<0.05$).

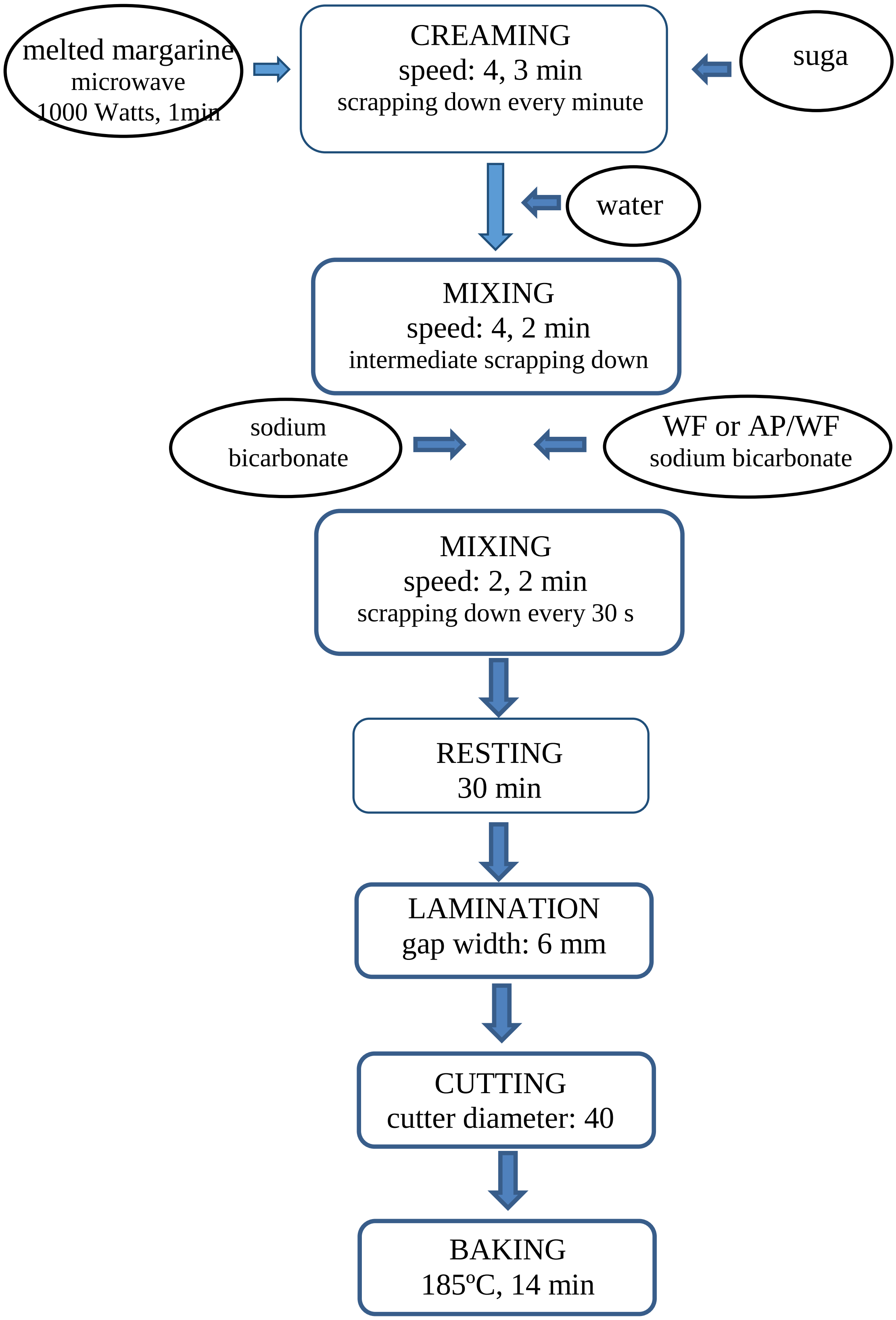

Figure 1. Flow-sheet for cookie preparation based on Mancebo et al. (2018)

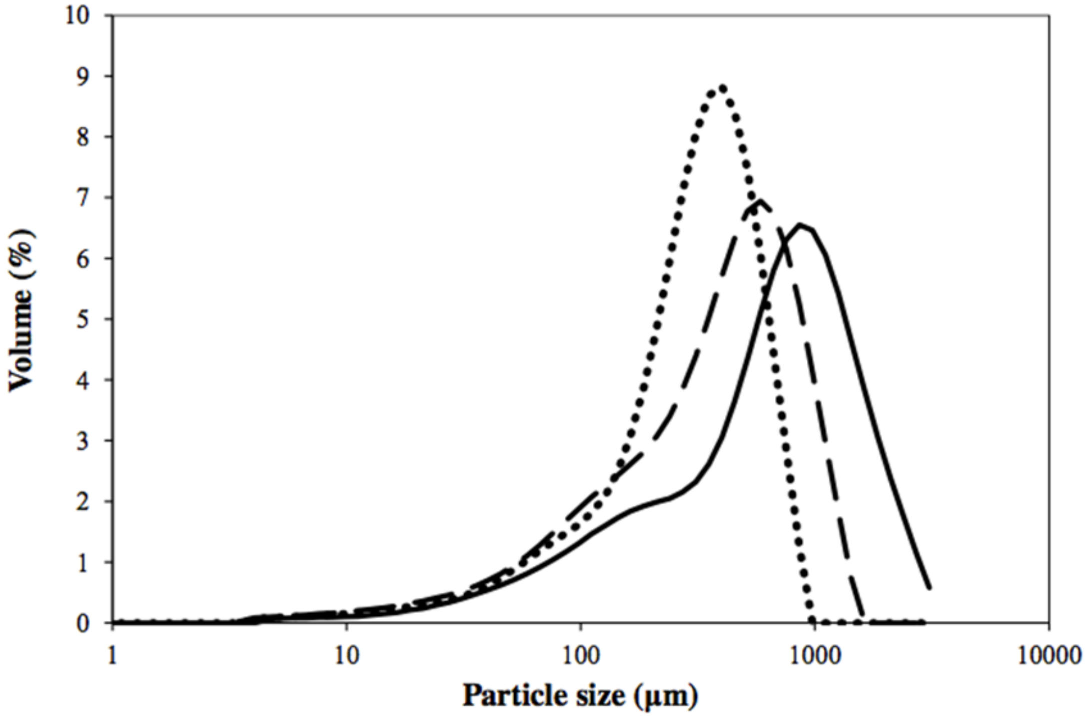

Figure 2. Particle size distribution for AP powders for AP840 (whole line), AP482 (dashed line), AP362 (dotted line)

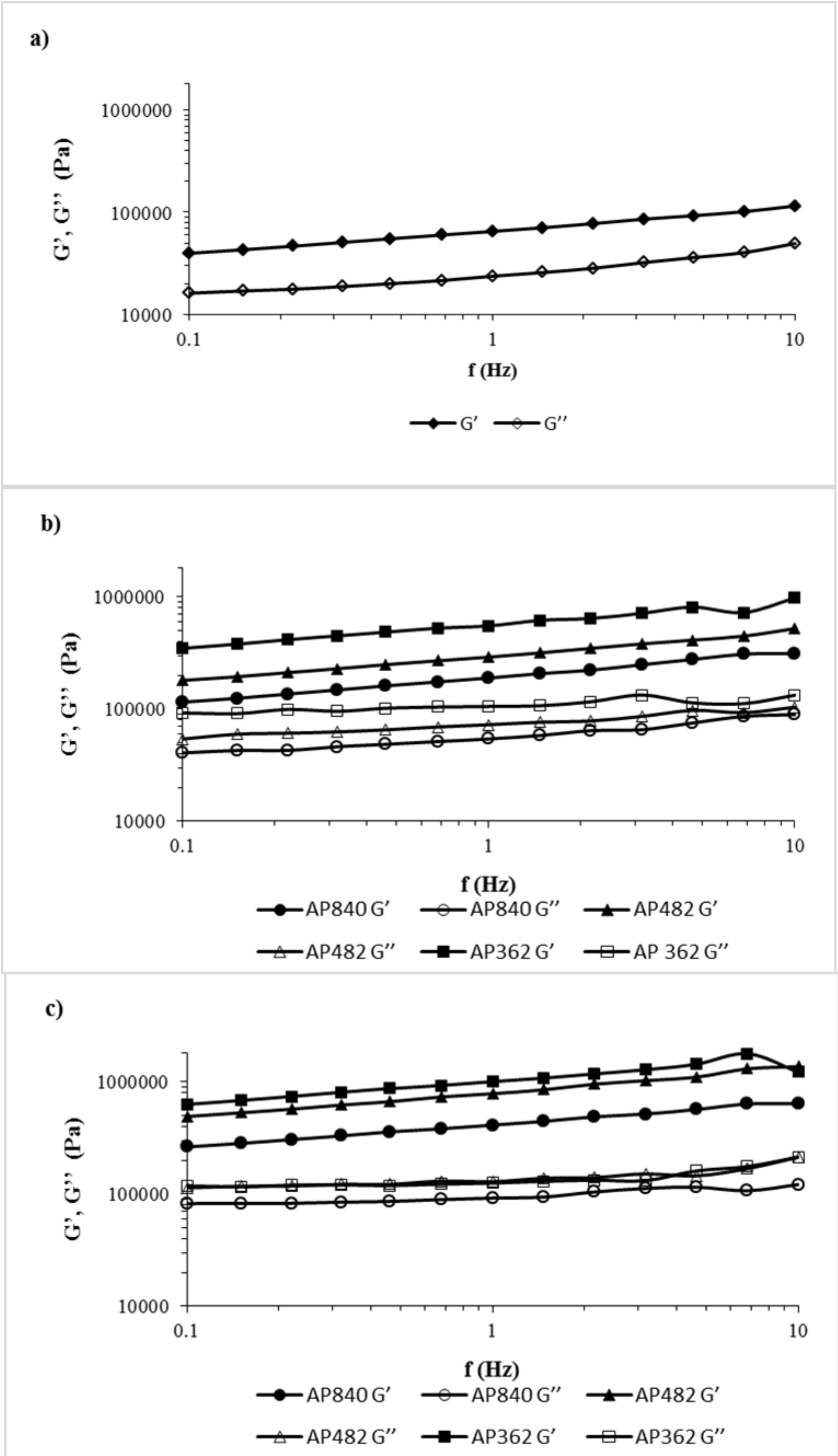

Figure 3. Typical mechanical spectra for doughs with three different particle sizes of apple pomace and two different replacement levels of AP. a) control, b) 15%, c) 30%. d(4,3): AP840= 840 μm, AP482=482 μm, AP362=362 μm

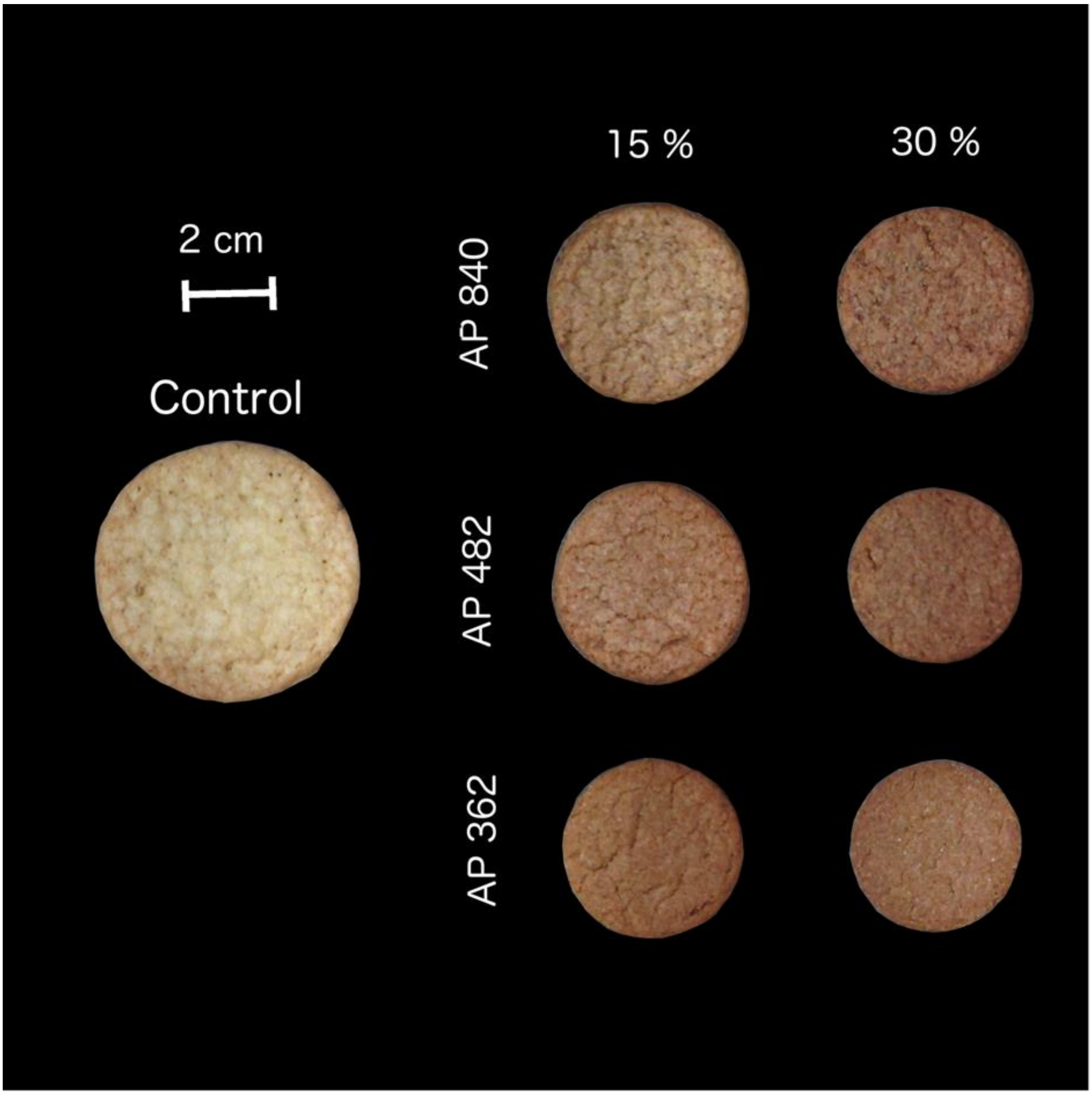

Figure 4. Image of sugar-snap cookies made from wheat flour and AP. d(4,3): AP840= 840 µm, AP482=482 µm, AP362=362 µm

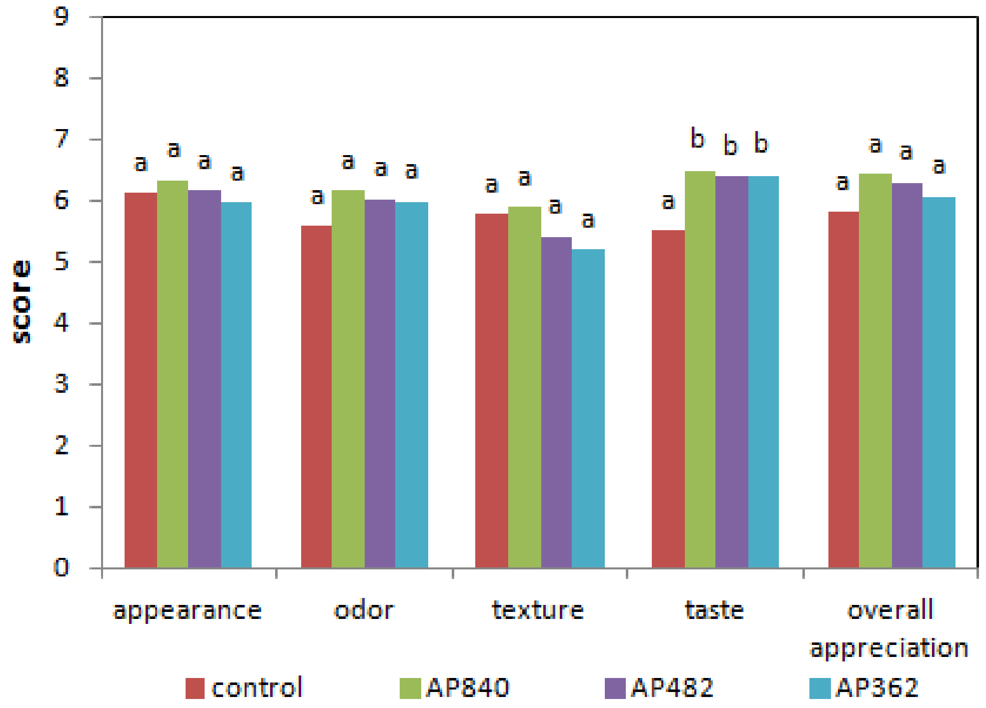

Figure 5. Sensory scores of sugar-snap cookies substituted with 15% apple pomace flour of different particle sizes. d(4,3): AP840= 840 µm, AP482=482 µm, AP362=362 µm. Different letter above bars indicate significant differences among samples ($p<0.05$)