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Reprocessing effect on the quality of domestically cooked (boiled/stir-fried) frozen vegetables

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Abstract

This was a study of the effect on quality parameters of reprocessing (blanching at 97 °C during increasing times + freezing) prior to domestic cooking (boiling or stir-frying) of frozen green peas (cv. *Mastim*) and beans (cvs. *Paloma* and *Moncayo*). Results were compared with frozen control samples directly boiled or stir-fried. Kramer shear was the most suitable mechanical test for evaluating the effect of reprocessing on mechanical behaviour in both boiled and stir-fried frozen vegetables. Reprocessing significantly affected mechanical behaviour of both green bean varieties with both cooking methods. Reprocessed products were softer than those supplied by the industry, and softening was significantly greater the longer the blanching time. The colour was more uniform and homogenous in boiled than in stir-fried reprocessed vegetables; colour parameters showed that reprocessing affected the colour of stir-fried samples more significantly than that of boiled samples. In all the studied vegetables, less chlorophyll and more ascorbic acid were retained when samples were stir-fried than when they were boiled, although chlorophyll and ascorbic acid decreased with increasing reprocessing time in both cooking methods. In the two frozen green bean varieties in particular, SEM microphotographs confirmed the results of mechanical tests, indicating that with both cooking methods, mechanical parameters were lower in the reprocessed samples in the controls. The shortest reprocessing procedure (blanching at 97 °C for 2, 3 min + freezing), as a compromise among quality parameters, could shorten the time required for domestic stir-frying of frozen green peas and boiling or stir-frying of frozen green beans.

Keywords Pisum sativum · Phaseolus vulgaris · Reprocessing · Texture · Boiling · Stir-frying

Introduction

The market for ready meals in Spain expanded rapidly in the period 1995-1999, with growth underpinned by beneficial macroeconomic conditions and increasing demand for convenience foods [1]. Demand is driven by a younger generation of consumers, familiar with fast food and more open to international trends, and with lifestyles that prompt them to consume timesaving convenience foods. Frozen ready meals are the largest sector in terms of volume and value; there is an increasingly wide variety of frozen ready meals available in Spain. A whole range of frozen vegetable-based ready meals has been launched by the industry in the last year. Marketing is focused on convenience, as these products require only 5-10 minutes preparation.

There are several different stages in the production of frozen vegetables during which there can be significant loss of product quality: initial processing (blanching) and preparation prior to freezing; freezing; frozen storage following freezing; and above all, final cooking prior to consumption [2]. The processes that can reduce the final quality of frozen vegetables therefore need to be studied separately; however, it must be borne in mind that there are significant interactions between them. For example, it is known that the main loss of nutrients in frozen vegetables typically occurs during blanching, a high temperature process which inactivates enzymes that cause deterioration in colour, flavour and odour [3-5]. More delicate methods of blanching, such as the use of blanchers with integrated blanching-cooling plant, have been developed to prevent this [6]. However, the influence of the different final cooking methods on the texture, colour and nutrient retention of the frozen vegetables is largely unknown.

Proper cooking of a frozen vegetable, viewed as the final stage in the overall process, may ultimately determine the texture and the consumer quality of a frozen vegetable. Alvarez and Canet [7] used rheological properties from four objective methods as firmness indicators to establish the kinetics of thermal softening of potato tissue cooked by steaming, steaming + hot air, and microwaving. Comparison of kinetic parameters showed that steaming produced a greater degree of softening than the other two cooking methods used, although the study was conducted on raw potato tissues that had not been blanched or frozen prior to cooking. Folate contents in fresh, boiled and stir-fried vegetables were compared, although cooking methods were not examined as a factor in the frozen product [8]. The effects of domestic cooking methods (including boiling, steaming, microwaving, baking and stir-frying) on different nutrients in a range of vegetables have also been studied [9]. In this case, the vegetables concerned were commonly consumed products, including frozen peas. It was concluded that methods involving short cooking times and minimal water should be used for best nutrient retention during cooking. In the Spanish frozen vegetable market there is growing demand for stir-fried vegetable mixes [1], and therefore more studies should focus on how domestic stir-frying affects the different frozen vegetables contained in such mixes.

And yet, there are no studies that deal with the reprocessing of frozen vegetables. Alvarez and Canet [10] showed that pre-cooling (3 °C/30 min) prior to freezing mitigated negative cracking caused by fast freezing rates in frozen potato tissues. The added expense of developing a new processing operation to shorten final domestic cooking time could well be worthwhile in view of the increasing consumer demand for such timesaving convenience foods.

The first object of the present research was to study and compare the effect of two commonly used domestic cooking methods (boiling and stir-frying) on different quality parameters of frozen green peas and beans. The second was to ascertain, in each studied frozen vegetable, the effect on the cited quality parameters of reprocessing (consisting of a second conventional blanching at 97 °C for a range of times, followed by freezing) prior to the both final cooking methods.

Material and methods

Test material. The raw material, supplied by the industry (Valencia, Spain), consisted of 60 kg of frozen peas (*Pisum sativum* L., cv. *Mastim*) and 120 kg of frozen green beans (*Phaseolus vulgaris* L.) belonging to two different varieties (cv. *Paloma* and cv. *Moncayo*). The *Paloma* variety is a round green bean, while the *Moncayo* variety is flat: therefore, the two could be expected react differently to reprocessing and cooking methods. The frozen material was stored at –24 ºC for the days prior to reprocessing. In each of the three studied products, after reprocessing (blanching and freezing), half of the samples were boiled and the other half stir-fried. Non-reprocessed samples of each studied frozen vegetable were boiled or stir-fried as controls.

Reprocessing treatments. Reprocessing treatments consisted in subjecting the stored frozen samples supplied by the industry to conventional blanching at 97 °C for 2, 4 and 8 min for green peas and 3, 6 and 12 min for both green bean varieties. Throughout this study, the three different blanching times are designated as *reprocessing a*, *reprocessing b* and *reprocessing c* respectively. After blanching , all the samples were cooled in iced water to 20 °C throughout the tissue. Samples were then immediately frozen in a lab-freezer (Frigoscandia, Helsingborg, Sweden, Mod. 0-6373) by air blasting at -40°C until the temperature at the thermal centre reached -18 °C. Samples were then packed in polyethylene plastic, sealed under light vacuum (-0.05 mPa) on a Multivac packing machine and then stored at -24 °C until cooking by boiling or stir-frying.

Domestic cooking treatments. Two domestic cooking methods, boiling and stir-frying, were applied to the frozen stored samples. Boiling and stir-frying of the samples were conducted according to the specifications used by the industry [11]. In green peas, the boiling procedure was as follows: 640 ml of water with 4 g of salt was heated to boiling; pea samples of 400 g were then added, and when the mixture returned to the boil, 5 min were counted. The procedure for green beans was: 400 ml of water with 4 g of salt was brought to the boil; bean samples of 200 g were then added, and when the mixture returned to the boil, 8 min were counted. Stir-frying of all samples (green peas and both green bean varieties) was performed in a frying pan with four tablespoons of olive oil. Once the oil reached 150 °C, 400 g of product was added and the mixture stirred gently (shear rate ≈ 10 s^{-1}) with a spoon for 8 min. After either boiling or stir-frying, all samples were kept at room temperature until the tissue temperature was 20 °C throughout. The various quality measurements were then made at this temperature. In each treatment, water, air, oil and product temperatures were monitored by K-type thermocouples using hardware and software systems that permit real-time data gathering, storage and calculation of processing rates [12].

Mechanical characterization. A TA.Hdi texturometer (Stable MicroSystems Ltd, Godalming UK) was used for mechanical characterization and evaluation of texture. Kramer shear tests (n = 5) were performed with a Kramer Shear Cell 10 Blade (Fig. 1A) on samples of 50 ± 1 g of green peas or beans placed on the cell base. The deformation rate was 400 mm min^{-1}. For green peas, multiple penetration tests (n = 5) were performed using a Multiple Pea Ring (Fig. 1B). In this test, 18 peas were simultaneously penetrated by 18 indentations at a deformation rate of 400 mm min^{-1}. For green beans of both varieties, Warner Bratzler tests (n = 5) were performed with a Warner Bratzler shear blade (Fig. 1C). In green beans (cv. *Paloma*), Warner Bratzler tests were performed on samples consisting of three different bean pieces, which were placed horizontally on the slotted blade insert. The beans were then cut across their longitudinal axis by the Warner Bratzler blade at a deformation rate of 300 mm min^{-1}. In the case of (cv. *Moncayo*) green beans, the Warner Bratzler tests were performed on samples consisting of six different bean pieces placed horizontally to form a double layer: the three lower beans were placed on the slotted blade insert and the three upper ones were placed on top of them with the diagonal fibres orientated in opposite directions. This arrangement makes for a flatter and more stable sample configuration at the start of the assay. The beans were then likewise cut across their longitudinal axis at a deformation rate of 400 mm min^{-1}. The Kramer shear force-deformation curves were used to determine multiple penetration and Warner Bratzler shear tests, maximum forces, F_{KSC}, F_{MP} and F_{WB} (N), curve slopes in the linear zone, S_{KSC}, S_{MP} and S_{WB} (N mm^{-1}) and areas under the curve up to maximum forces, A_{KSC}, A_{MP} and A_{WB} (N mm).

Other quality assessments. Determinations of dry matter were conducted where the samples were dried at a temperature of 75 °C until they reached constant weight. Dry matter was measured on 10 g of product per treatment with nine replicates (n = 9). Green pea and bean skin colour was measured with a Hunterlab Tristimulus colorimeter, Model D25A-9 (Hunter Associates Laboratory, Inc., Fairfax, VA). About 50 g of sample was placed side by side in a 50-mm×50-mm cell. Eight measurements per treatment (n = 8) were recorded on the surface of the products. Results were expressed in L*a*b* scale, where L* indicates the luminescence, a* represents the green-red colour axis and b* the blue-yellow axis. Cartesian coordinates were transformed to polar coordinates and the saturation index (r) and coloration (θ) were calculated. Colour differences with respect to non-reprocessed controls were also obtained [13]. Green pea and bean chlorophylls (n = 5) were determined by spectrophotometry [14]. Ascorbic acid content (n = 3) was determined following the official methods of analysis [15]. A 5-member panel trained for frozen vegetable products conducted sensory analysis for colour, texture and taste following a descriptive quantitative method adapted for each product [16]. Scores were awarded on a scale of 1 to 5, in which 1 indicated total absence of the sensory attribute and 5 a very definite attribute.

Tissue structure. Tissue structure was examined by SEM using a Hitachi model S-2500 microscope [17, 18]. Tissue samples were fixed in 50 or 70% ethyl alcohol (90 ml), glacial acetic acid (5 ml), and formol (5 ml) for 2 h and dehydrated in increasing concentrations of ethanol, from 70% to 100%. The samples were immersed once for 15 min in ethanol concentrations of 70%, 80% and 90% and twice for 1 h in 100% ethanol. Finally, the specimens were preserved in acetone until processed in a critical-point drier, then mounted and sputter-coated with platinum (400-Å) in a P-S1 diode sputtering system metallizer. Photomicrographs were taken with a Mamiya camera using Ilford 6x9 cm FF-4 film. Films were processed following the standard method; magnifications were x60, x24 and x31 (1 cm = 165 μm, 1 cm = 416 μm, and 1 cm = 321.5 μm respectively).

Statistical analysis. Individual experiments were performed in duplicate, so data represent the mean of two independent assays. In the three studied vegetables, the effect of the different reprocessing procedures on the quality parameters was analysed by one-way analysis of variance for each of the two complete processes (ending with domestic boiling or stir-frying). The least significant difference test (LSD) was used for means comparison, with a 99% confidence interval for quality parameters and 95% for sensory attributes. STATGRAPHICS Version 5.0 (Manugistics Inc., Rockville, MD, USA) was used in this study [19].

Results and discussion

Table 1 shows the average values and comparisons of means of mechanical parameters and dry matter contents for the different reprocessing procedures in frozen green peas subjected later to the two cooking methods (boiling and by stir-frying). For both cooking methods, reprocessing significantly affected Kramer shear mechanical parameters and dry matter contents. Reprocessing before either boiling or stir-frying did not significantly affect the multiple penetration parameters. Multiple penetration tests were performed on relatively small samples of product (18 individual green peas) and therefore did not appear suitable to detect the effect of reprocessing on cooked frozen green peas. The behaviour of Kramer shear parameters differed depending on the cooking method. When pea samples were subjected to final boiling, Kramer maximum force values (F_{KSC}) showed that with *reprocessing a*, the shortest blanching time, the product was significantly harder than when non-reprocessed or blanched for longer. The observed hardening could be the result of retrogradation of the gelatinised starch during the two cooling periods following blanching [7, 20]. Kramer slope values (S_{KSC}) also evidenced hardening of the reprocessed product with respect to the control sample, although there were no significant differences in relation to blanching times. Kramer area values (A_{KSC}) decreased significantly with reprocessing and blanching time, probably in response to product hardening; consequently, force-deformation curves presented superior slopes and inferior areas. On the contrary, however, when frozen pea samples were stir-fried, the Kramer force values (F_{KSC}) of samples subjected to *reprocessing a* (with the shortest blanching time) indicated that these were significantly softer than non-reprocessed peas. The increase of F_{KSC} and S_{KSC} in *reprocessing b, c* shows that softening was not more pronounced with increased reprocessing time. This is probably because stir-frying is a much less homogeneous cooking method than boiling, allowing no subsequent water uptake and possibly masking the effect of blanching time. Note how the values of mechanical parameters and dry matter contents were much higher after stir-frying than boiling, even in control samples. The results showed that stir-frying produced a higher loss of moisture in the product, which could at least partially explain why tissues were more firmly textured in stir-fried than in conventionally boiled samples. In potato tissue, a comparison of kinetic parameters has shown that steaming produces greater softening than steaming+hot air or microwaving [7]. In this last study, the loss of sample moisture would account for the increase in the firmness ratios, especially in steaming+hot air treatments, resulting in a potato that is firmer but whose texture is unacceptable to the consumer. On the other hand, stir-frying of vegetables and meat entails a short cooking time and high rates of heat and mass transfer [21]. The degree of cooking depends on the internal temperature reached at the thermal centre of the product, the heating method and the heating rate attained in the treatment [22]. The average product temperature stabilized around 80°C during the stir-frying process, which may also explain why the texture of stir-fried vegetables was firmer than the texture of vegetables cooked in water. Figure 2 shows microphotographs corresponding to green pea control samples processed by the industry up to the frozen stage then boiled (Fig. 2a) or stir-fried (Fig. 2b); these are compared with microphotographs corresponding to green pea samples processed by the industry up to the frozen stage, subjected to *reprocessing b* (blanching at 97 °C for 4 min + freezing) and finally boiled (Fig. 2c) or stir-fried (Fig. 2d). Note that final stir-frying (Fig. 2b) did not cause more mechanical damage to the sample structure than final boiling (Fig. 2a). Only, after stir-frying the cells were more turgid and looked more compacted, possibly because the degree of pectin depolymerization and deesterification reached in the cell wall and the interlamellar region was lower. This could explain why mechanical parameters were higher when product was boiled as opposed to stir-fried. After *reprocessing b* prior to boiling (Fig. 2c), cells appeared only slightly more expanded than without reprocessing (Fig. 2a), whereas when *reprocessing b* was applied prior to stir-frying (Fig. 2d), the cells were more compacted with greater cell separation than without reprocessing. However, in both cooking methods, cell damage was not noticeably greater when product was reprocessed; this would explain why there were no significant differences between the mechanical parameters of the control samples without and with *reprocessing b* prior to both boiling and stir-frying (Table 1).

Table 2 shows average values and comparisons of means for mechanical parameters and dry matter contents resulting from the different reprocessing procedures in frozen green beans (cv. *Paloma* and cv. *Moncayo*) when subsequently boiled or stir-fried. All the Kramer shear and Warner Bratzler parameters indicated that with either cooking method, reprocessed frozen *Paloma* green beans were softer than their respective controls. Moreover, softening was more pronounced the longer the blanching time. The effect of reprocessing was not significant only in the Warner Bratzler slopes (S_{WB}) for boiled green beans. These slopes were also not significantly affected by blanching time in stir-fried samples. The results for reprocessed frozen *Moncayo* green beans were very similar. All mechanical parameters in the latter product were lower in the reprocessed samples than in the corresponding control with both cooking methods; in addition, the parameter values decreased significantly with increasing blanching time. Again, the effect of reprocessing was not significant only in Warner Bratzler slopes (S_{WB}) for boiled green beans. Samples subjected to *reprocessing a* followed by stir-frying presented an unexpectedly high value for Warner Bratzler area (A_{WB}). As in the case of green peas, in both green bean varieties all mechanical parameter and dry matter content values were higher after stir-frying than after boiling, possibly because the internal temperature reached in their thermal centres was lower. For both varieties and both cooking methods, the effect of reprocessing was most significantly detected by Kramer shear force and area (F_{KSC}, A_{KSC}). Note also that although the differences between the varieties are evident, Kramer shear values were very similar in both round and flat green bean varieties.

As the microphotographs of frozen green bean samples (cv. *Paloma* and cv. *Moncayo*) show (Figure 3), there was much less cell damage in boiled (Figs 3a, 3e) and stir-fried (Figs. 3b, 3f) control samples than in samples subjected to *reprocessing b* prior to boiling (Figs. 3c, 3g) and stir-frying (Figs. 3d, 3h). A second blanching for 6 min followed by re-freezing prior to cooking clearly produced solubilization of the middle laminae, increasing cell separation and in some cases causing the breach of cell walls. Microphotographs confirm the results of the mechanical tests: i.e., that in both varieties and with both cooking methods, all mechanical parameters were lower in the reprocessed samples than in the controls.

Table 3 shows the effects of reprocessing and cooking method on the colour parameters of all the studied frozen vegetables. In both boiled and stir-fried frozen green peas, the effect of reprocessing on colour parameters was almost non-significant. As the table shows, a*, saturation (r) and coloration (θ) values were higher when the samples were subjected to *reprocessing b* combined with stir-frying. In the boiled samples, colour differences between each reprocessed sample and its control were much smaller at all the different reprocessing times, indicating that boiling in water, combined with reprocessing, produced a pea with more uniform and homogeneous colour than stir-frying. In frozen *Paloma* green beans cooked by either method, reprocessing significantly increased saturation (r) and decreased coloration (θ). In the stir-fried samples, reprocessing also significantly affected colour parameter (b*), raising the value of the blue-yellow colour axis. In stir-fried frozen *Moncayo* green beans, luminescence L* increased and colour parameter (a*) decreased with increasing blanching time. The longest blanching (*reprocessing c*) reduced the greenness of this bean variety, as confirmed by their lower coloration (θ). Also, in both green bean varieties the colour differences between each reprocessed sample and its industrial control were much smaller and were similar in boiled samples subjected to different reprocessing times. Colour parameters indicated that the colour of the stir-fried samples was more significantly affected than that of the boiled samples by reprocessing prior to cooking.

Figure 4 shows chlorophyll (Chph*a*, Chph*b* and ratio Chph*a*/Chph*b*) and ascorbic acid contents of boiled and stir-fried frozen vegetables. In all the studied vegetables chlorophyll contents were higher in boiled than in stir-fried samples; this was to be expected, since as noted above, greenness was affected more negatively by stir-frying than by boiling. Ascorbic acid contents, on the other hand, were lower in the boiled samples. Pither and Edwards studied the effects of cooking methods on nutrients in a range of vegetables [9]. For best nutrient retention during cooking, the authors concluded that methods involving short cooking times and minimal water should be used. Similarly, more folate was retained in stir-fried than in boiled vegetables [8]. Our results show that ascorbic acid retention in the studied vegetables is greater with stir-frying than with boiling. In both boiled and stir-fried green peas (Figs. 4a, 4b), reprocessing prior to cooking caused a reduction in both chlorophyll and ascorbic acid contents, this reduction being more significant the longer the blanching time. In both green bean varieties (cv. *Paloma* and cv. *Moncayo*) (Figs. 4c, 4d and 4e, 4f, respectively), reprocessing also had a very significant effect on ascorbic acid contents with both cooking methods, sample contents decreasing with increasing reprocessing time. In both boiled and stir-fried frozen *Moncayo* green beans, reprocessing significantly affected chlorophyll content, which decreased with increasing blanching time, whereas in frozen *Paloma* green beans the effect of reprocessing on chlorophylls was less significant, chiefly affecting Chph *b* (Fig. 4c, 4d).

Table 4 shows the effects of reprocessing and cooking method on the scores assigned by the panellists to texture, taste and colour attributes of frozen green peas. Of the boiled samples, the control supplied by the industry and cooked without reprocessing scored highest for skin and tissue firmness, mealiness, sweetness, authentic taste, greenness, shine and colour uniformity. However, these scores did not differ significantly from the scores awarded to samples subjected to the three reprocessing procedures before boiling. Similarly, in the stir-fried samples the non-reprocessed control scored best for skin and tissue firmness, mealiness, sweetness, authentic taste, greenness and shine. Here, on the other hand, reprocessing with increasing blanching time significantly reduced the scores awarded to skin firmness, sweetness, authentic taste, greenness and shine, while increasing the scores for mealiness, brownness and colour uniformity. The findings suggest that consumers would possibly not detect the effect of reprocessing prior to cooking in the sensory attributes of boiled frozen green peas, but they would detect its effect in the sensory attributes of stir-fried frozen green peas, especially with the longest blanching time. Therefore, when the product is intended for stir-frying, it appears that greater attention must be paid to the complete process of frozen green pea production. A comparison of scores awarded to boiled and stir-fried samples shows that scores were generally higher in the stir-fried than in the boiled samples, indicating a consumer preference for stir-frying rather than boiling frozen green peas.

Table 5 shows the effects of reprocessing and cooking method on scores awarded to texture, taste and colour attributes for green beans of both varieties. In both boiled and stir-fried frozen *Paloma* green beans, non-reprocessed control samples scored high for tenderness and fibrosity, although not significantly higher than reprocessed samples. The lowest firmness scores were recorded for *reprocessing b* and *reprocessing c* in both cooking methods. The controls scored highest for sweetness, authentic taste, greenness, shine and colour uniformity, whether boiled or stir-fried. Reprocessing significantly affected scores for sweetness, authentic taste, off-colours, greenness and colour uniformity in the boiled samples and significantly affected scores for sweetness, bitterness, greenness, off-colours and colour uniformity in stir-fried samples. In both boiled and stir-fried *Moncayo* green beans, non-reprocessed controls scored low for tenderness; this score was not significantly different in samples subjected to *reprocessing a*. With both cooking methods, the controls scored highest for firmness, while the samples subjected to *reprocessing b* and *c* scored significantly lower. In the boiled samples, the non-reprocessed control scored highest for sweetness, authentic taste, greenness, shine and colour uniformity; reprocessing significantly affected scores for sweetness, greenness and shine. In the stir-fried samples again, the control scored highest for sweetness, authentic taste, greenness, shine and colour uniformity, and reprocessing significantly affected scores for sweetness, authentic taste, greenness, shine and colour uniformity. Reprocessing with increasing blanching time significantly reduced the scores awarded for firmness, sweetness, authentic taste, greenness, shine and colour uniformity in both boiled and stir-fried frozen green beans (cv. *Paloma* and cv. *Moncayo*). The results suggest that consumers would possibly detect the effect of reprocessing on the sensory attributes of both boiled and stir-fried frozen green beans of both varieties. Therefore, whether the product is intended for boiling or stir-frying, the same care should be taken at all stages in the process of producing frozen green beans. In addition, a comparison of scores for boiled and stir-fried samples of both varieties shows that scores were similar for boiled and stir-fried samples, indicating a comparable consumer preference for both boiled and stir-fried frozen green beans.

Since scores for sensory texture attributes confirm consumer acceptance of the texture of either boiled or stir-fried vegetables supplied by the industry, there are some conclusions to be drawn. In green peas, mechanical behaviour showed that reprocessing may not be a suitable treatment when the product is intended for boiling, since it caused product hardening. In this case, to obtain an optimum texture comparable to that of the industrial control, the product would have to be boiled for longer than is currently the case. However, when frozen green peas were subjected to *reprocessing a*, consisting in blanching at 97 °C for a short time

(2 min) followed by freezing, the stir-fried product was softer than that supplied by the industry (Table 1). Therefore, to obtain a product with an optimum texture comparable to that of the green pea control sample, this reprocessing could shorten the time required for domestic stir-frying by some minutes.

Reprocessing had a more significant effect on the mechanical behaviour of both green bean varieties with both cooking methods; it significantly softened the products, to a greater extent the longer the blanching time. Hence, in both green bean varieties, if the aim is to obtain a product with optimum texture comparable to that of control samples, the most rigorous pre-treatment (*reprocessing c*: blanching at 97 °C, 12 min + freezing) could be expected to substantially shorten the required boiling and stir-frying times, thus addressing consumer demand for time saving (< 8 min currently required). However, in all the frozen vegetables, it was also found that chlorophyll and ascorbic acid contents decreased more significantly with increasing blanching time. What is therefore needed is a reasonable compromise among the various quality parameters. In stir-fried frozen green peas and in boiled and stir-fried frozen green bean of both varieties, the least rigorous procedure (*reprocessing a*: blanching at 97 °C, 2, 3 min + freezing) produced products that were softer than control samples but without significant detriment to the rest of the quality parameters. Hence, the shortest reprocessing procedure should be enough to shorten the required boiling and stir-frying times by several minutes. Further research is needed to determine the effect on the quality parameters of frozen vegetables when prior *reprocessing a* is combined with shorter final boiling and stir-frying times.

Acknowledgements The authors wish to thank the Higher Education and Scientific Research Department of the Ministry of Education and Science for financing project PTR-0418-OP (transfer of research results), and also Unilever Foods España S.A. for participating in the project.

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Legends

Fig. 1 Mechanical test cells used in the texture characterization of green peas and beans; A: HDP/KS 10 Kramer shear cell; B: HDP/MPT Multiple pea ring; C: Warner Bratzler shear blade set

Fig. 2 Microphotographs corresponding to green pea tissues (cv. *Mastim*); a: green peas processed by the industry up to the frozen stage and boiled; b: green peas processed by the industry up to the frozen stage and stir-fried; c: green peas processed by the industry up to the frozen stage, subjected to *reprocessing b* (blanching at 97 °C for 4 min + freezing) and boiled; d: green peas processed by the industry up to the frozen stage, subjected to *reprocessing b* and stir-fried. 1 cm <> 165 μm

Fig. 3 Microphotographs corresponding to green bean tissues; a: green beans (cv. *Paloma*) processed by the industry up to the frozen stage and boiled; b: green beans (cv. *Paloma*) processed by the industry up to the frozen stage and stir-fried; c: green beans (cv. *Paloma*) processed by the industry up to the frozen stage, subjected to *reprocessing b* (blanching at 97 °C for 6 min + freezing) and boiled; d: green beans (cv. *Paloma*) processed by the industry up to the frozen stage, subjected to *reprocessing b* and stir-fried; e: green beans (cv. *Moncayo*) processed by the industry up to the frozen stage and boiled; f: green beans (cv. *Moncayo*) processed by the industry up to the frozen stage and stir-fried; g: green beans (cv. *Moncayo*) processed by the industry up to the frozen stage, subjected to *reprocessing b* and boiled; h: green beans (cv. *Moncayo*) processed by the industry up to the frozen stage, subjected to *reprocessing b* and stir-fried. Figs. 3a-3d: 1 cm <> 416 μm. Figs. 3e-3h: 1 cm <> 321.5 μm

Fig. 4 Effect of reprocessing and domestic cooking method on chlorophyll (Chph*a*, Chph*b* and ratio Chph*a*/Chph*b*) and ascorbic acid content for frozen green peas (Figs. a, b), frozen green beans (cv. *Paloma*) (Figs. c, d) and frozen green beans (cv. *Moncayo*) (Figs. e, f). In plots, b: vegetable samples processed by the industry up to the frozen stage and boiled; rab: vegetable samples processed by the industry up to the frozen stage, subjected to *reprocessing a* and boiled; rbb: vegetable samples processed by the industry up to the frozen stage, subjected to *reprocessing b* and boiled; rcb: vegetable samples processed by the industry up to the frozen stage, subjected to *reprocessing c* and boiled; sf: vegetable samples processed by the industry up to the frozen stage and stir-fried; rasf: vegetable samples processed by the industry up to the frozen stage, subjected to *reprocessing a* and stir-fried; rbsf: vegetable samples processed by the industry up to the frozen stage, subjected to *reprocessing b* and stir-fried; rcsf: vegetable samples processed by the industry up to the frozen stage, subjected to *reprocessing c* and stir-fried

Table 1. Effect of reprocessing and domestic cooking method on mechanical parameters and dry matter content for frozen green peas (cv. *Mastim*). F_{KSC} Kramer maximum force, A_{KSC} Kramer area, S_{KSC} Kramer slope, F_{MP} multiple penetration maximum force, A_{MP} multiple penetration area, S_{MP} multiple penetration slope, DM dry matter

Treatment applied to frozen green pea samples	F_{KSC} (N)	A_{KSC} (N mm)	S_{KSC} (N mm^{-1})	F_{MP} (N)	A_{MP} (N mm)	S_{MP} (N mm^{-1})	DM (%)
Boiling[a]	810.64 a	4463.24 a	37.94 a	29.71 a	118.52 a	5.15 a	21.51 a
Reprocessing a + boiling	875.39 b	4393.00 a, b	45.19 b	27.90 a	124.59 a	2.97 a	20.97 a, b
Reprocessing b + boiling	824.75 a	4189.63 b, c	43.53 b	30.16 a	127.54 a	3.15 a	21.84 a
Reprocessing c + boiling	839.81 a	4081.88 c	44.35 b	29.14 a	122.43	3.95 a	20.34 b
LSD, 99%	*33.55*	*257.33*	*4.31*	*5.02*	*20.9*	*3.82*	*1.03*
Stir-frying[b]	1123.93 a	5494.29 a	60.40 a, b	36.48 a	157.20 a	5.84 a	44.00 b
Reprocessing a + stir-frying	874.47 c	4131.81 c	49.65 b	34.44 a	141.02 a	3.27 a	35.94 d
Reprocessing b + stir-frying	1069.36 a, b	4697.48 b	65.91 a	38.68 a	162.17 a	4.13 a	47.06 a
Reprocessing c + stir-frying	954.21 b, c	4112.04 c	58.85 a, b	32.38 a	140.44 a	4.08 a	40.72 c
LSD, 99%	*130.48*	*552.06*	*10.9*	*7.75*	*54.28*	*3.53*	*1.67*

[a]Control sample: supplied frozen by the industry and boiled
[b]Control sample: supplied frozen by the industry and stir-fried
Reprocessing a: blanching at 97 °C for 2 min and freezing
Reprocessing b: blanching at 97 °C for 4 min and freezing
Reprocessing c: blanching at 97 °C for 8 min and freezing

Table 2 Effect of reprocessing and domestic cooking method on mechanical parameters and dry matter content of frozen green beans (cv. *Paloma* and cv. *Moncayo*). F_{KSC} Kramer maximum force, A_{KSC} Kramer area, S_{KSC} Kramer slope, F_{WB} Warner Bratzler maximum force, A_{WB} Warner Bratzler area, S_{WB} Warner Bratzler slope, DM dry matter

Treatment applied to frozen green bean samples	F_{KSC} (N)	A_{KSC} (N mm)	S_{KSC} (N mm^{-1})	F_{WB} (N)	A_{WB} (N mm)	S_{WB} (N mm^{-1})	DM (%)
Green beans (cv. *Paloma*)							
Boiling[a]	334.33 a	1047.31 a	78.50 a	18.66 a	68.29 a	4.74 a	8.82a
Reprocessing a + boiling	280.49 a, b	939.55 a, b	54.70 b	19.06 a	57.40 a, b	5.04 a	8.02 a, b
Reprocessing b + boiling	266.21 b	824.09 b	58.17 b	17.68 a	50.56 a, b	4.91 a	7.42 b
Reprocessing c + boiling	200.57 c	657.42 c	40.90 b	13.26 b	43.73 b	3.44 a	7.27 b
LSD, 99%	*53.92*	*125.00*	*20.19*	*3.53*	*18.5*	*1.79*	*0.83*
Stir-frying[b]	509.54 a	1518.37 a	114.48 a	30.43 a	76.48 a	7.89 a	19.28 b
Reprocessing a + stir-frying	401.22 b	1164.97 b	92.01 a	25.69 a	81.53 a	4.90 b	17.08 c
Reprocessing b + stir-frying	309.51 c	932.01 c	67.18 b	19.89 b	54.44 a, b	4.47 b	21.36 b
Reprocessing c + stir-frying	204.96 d	642.39 d	47.04 b	16.97 b	41.77 b	3.73 b	15.52 c
LSD, 99%	*48.34*	*136.53*	*24.29*	*5.58*	*27.73*	*2.93*	*1.68*
Green beans (cv. *Moncayo*)							
Boiling[a]	328.76 a	984.85 a	64.08 a	24.36 a	116.27 a, b	4.17 a	8.57 a, b
Reprocessing a + boiling	293.40 a	901.92 a	62.83 a	26.73 a	158.26 a	3.85 a	9.01 a
Reprocessing b + boiling	216.11 b	687.81 b	47.00 a, b	18.61 b	81.71 b	2.75 a	7.89 b
Reprocessing c + boiling	165.50 c	535.90 c	34.50 b	16.79 b	87.34 b	2.73 a	8.36 a, b
LSD, 99%	*47.48*	*116.67*	*20.44*	*3.35*	*55.42*	*2.59*	*1.11*
Stir-frying[b]	542.00 a	1656.12 a	115.58 a	37.30 a	198.41 a	5.72 a, b	17.35 a
Reprocessing a + stir-frying	425.97 b	1234.24 b	87.58 a, b	37.57 a	172.16 a, b	8.86 a	17.70 a
Reprocessing b + stir-frying	330.90 c	1048.99 b, c	68.71 b, c	28.04 b	119.04 c	4.65 b	17.97 a
Reprocessing c + stir-frying	233.72 d	748.04 c	46.56 c	18.99 c	95.22 c	4.96 a, b	16.79 a
LSD, 99%	*38.56*	*318.39*	*32.66*	*6.01*	*78.56*	*4.19*	*2.11*

[a]Control sample: supplied frozen by the industry and boiled
[b]Control sample: supplied frozen by the industry and stir-fried
Reprocessing a: blanching at 97 °C for 3 min and freezing
Reprocessing b: blanching at 97 °C for 6 min and freezing
Reprocessing c: blanching at 97 °C for 12 min and freezing

Table 3 Effect of reprocessing and domestic cooking method on instrumental colour parameters for frozen green peas and beans. L* luminescence, a* green-red colour axis, b* blue-yellow colour axis, r saturation index, θ coloration, E colour difference respects to controls

Treatment applied to the frozen vegetable samples	L*	a*	b*	r	θ	E
Green peas (cv. *Mastim*)						
Boiling[a]	41.34 a	-19.52 a	33.93 a	38.51 a	2.09 a	0.00
Reprocessing a + boiling	39.58 a	-19.20 a	33.38 a	39.16 a	2.09 a	1.88
Reprocessing b + boiling	40.64 a	-19.30 a	34.78 a	39.78 a	2.08 a	1.38
Reprocessing c + boiling	40.94 a	-19.33 a	34.74 a	39.77 a	2.08 a	1.59
LSD, 99%	*2.92*	*2.15*	*3.79*	*4.19*	*0.03*	
Stir-frying[b]	38.41 a	-14.71 a	27.45 a	31.18 a	2.06 a, b	0.00
Reprocessing a + stir-frying	35.39 a	-18.57 b	31.22 a	36.38 b	2.10 a	6.19
Reprocessing b + stir-frying	35.34 a	-15.40 a, b	29.73 a	33.50 a, b	2.05 b	2.38
Reprocessing c + stir-frying	37.81 a	-14.76 a	30.47 a	33.87 a, b	2.02 b	3.87
LSD, 99%	*3.22*	*3.50*	*4.20*	*5.10*	*0.05*	
Green beans (cv. *Paloma*)						
Boiling[a]	34.08 a	-11.81 a	22.66 a	16.87 a	2.02 a	0.00
Reprocessing a + boiling	32.02 a	-11.60 a	25.04 a	27.67 b	2.01 a	1.29
Reprocessing b + boiling	32.61 a	-11.80 a	25.53 a	28.13 b	2.00 a	1.95
Reprocessing c + boiling	33.09 a	-9.22 b	24.76 a	26.45 b	1.93 b	2.65
LSD, 99%	*2.41*	*1.48*	*3.53*	*3.03*	*0.05*	
Stir-frying[b]	33.54 a, b	-10.62 a	16.05 a	19.82 a	2.17 a	0.00
Reprocessing a + stir-frying	33.06 a	-10.43 a	18.53 a, b	21.30 a, b	2.08 a, b	2.52
Reprocessing b + stir-frying	36.75 b	-9.62 a	23.98 c	25.90 b	1.95 b	8.60
Reprocessing c + stir-frying	34.01 a, b	-9.33 a	21.79 b, c	23.74 a, b	1.97 b	5.89
LSD, 99%	*3.28*	*3.52*	*5.29*	*5.18*	*0.19*	
Green beans (cv. *Moncayo*)						
Boiling[a]	35.50 a	-8.26 a	21.59 a	23.16 a	1.93 a, b	0.00
Reprocessing a + boiling	37.10 a	-9.21 a	22.64 a	24.46 a	1.96 a	2.14
Reprocessing b + boiling	34.29 a	-6.83 a	19.52 a	20.72 a	1.90 a, b	2.79
Reprocessing c + boiling	37.68 a	-7.33 a	24.61 a	25.74 a	1.86 b	3.84
LSD, 99%	*7.08*	*2.89*	*5.93*	*6.31*	*0.08*	
Stir-frying[b]	36.04 a	-11.39 a	23.00 a	25.81 a	2.04 a	0.00
Reprocessing a + stir-frying	36.43 a	-11.35 a	25.06 a	27.59 a	1.99 a, b	2.10
Reprocessing b + stir-frying	38.71 a, b	-10.66 a, b	24.33 a	24.25 a	1.98 a, b	4.58
Reprocessing c + stir-frying	41.87 b	-7.67 b	22.96 a	26.60 a	1.89 b	6.02
LSD, 99%	*5.10*	*3.39*	*5.56*	*5.90*	*0.08*	

[a]Control sample: supplied frozen by the industry and boiled
[b]Control sample: supplied frozen by the industry and stir-fried
Reprocessing a: blanching at 97 °C for 2 min and freezing
Reprocessing b: blanching at 97 °C for 4 min and freezing
Reprocessing c: blanching at 97 °C for 8 min and freezing

Table 4 Effect of reprocessing and domestic cooking method on sensory attributes (texture, taste and colour) for frozen green peas (cv. *Mastim*)

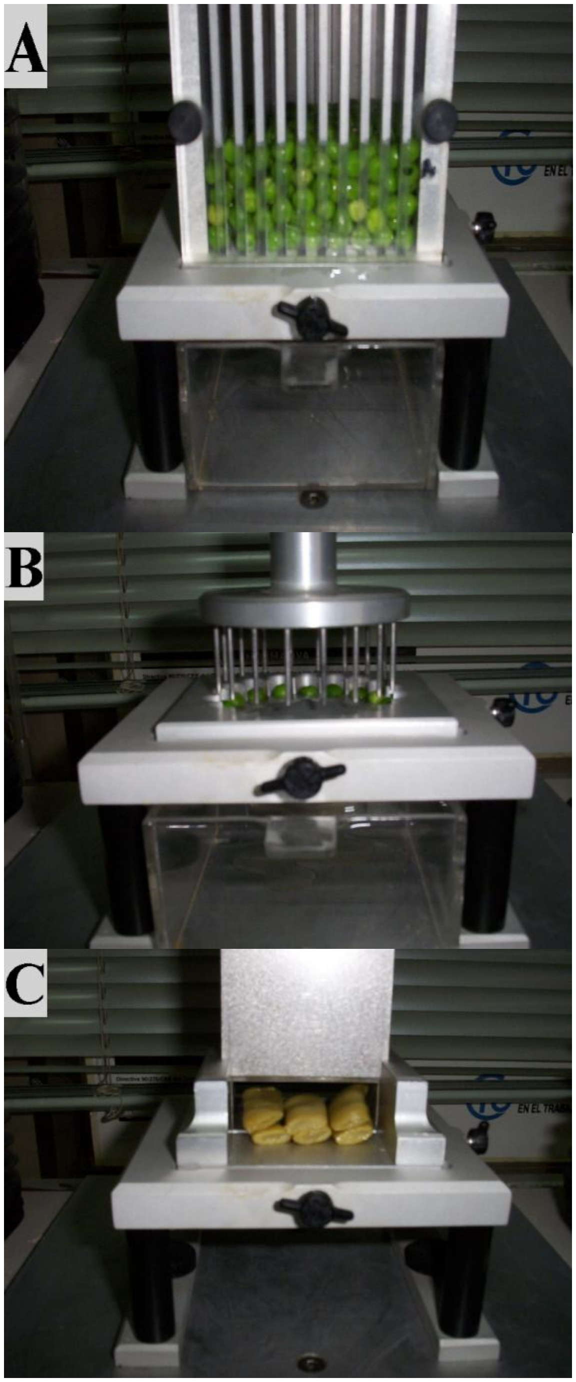
Sensory attributes	Texture			Taste			Colour				
Treatment applied to the frozen green peas samples	Skin firmness	Tissue firmness	Mealiness	Sweet	Bitter	Authentic taste	Greenness	Yellowness	Brownness	Shine	Uniformity
Boiling[a]	2.80 a	2.00 a	1.80 a	2.80 a	1.00 a	3.00 a	3.00 a	1.20 a, b	1.00 a	2.80 a	4.40 a
Reprocessing a + boiling	2.60 a	1.40 a	1.20 a	1.80 b	1.20 a	2.40 a	2.80 a	1.00 a	1.20 a	2.40 a	4.20 a
Reprocessing b + boiling	2.40 a	1.20 a	1.60 a	2.00 b	1.20 a	2.20 a	2.40 a	1.60 b	1.00 a	2.20 a	3.60 a
Reprocessing c + boiling	2.60 a	1.40 a	1.40 a	2.00 b	1.20 a	2.40 a	2.40 a	1.20 a, b	1.00 a	2.40 a	4.40 a
LSD, 95%	*1.36*	*0.90*	*0.95*	*0.64*	*0.52*	*1.02*	*0.90*	*0.56*	*0.30*	*1.02*	*0.97*
Stir-frying[b]	3.60 a	1.60 a	1.00 a	3.80 a	1.00 a	3.80 a	3.60 a	1.00 a	2.60 a	3.20 a	2.60 a
Reprocessing a + stir-frying	2.40 b	1.20 a	1.20 a, b	2.80 a, b	1.00 a	3.00 b	2.80 a	1.20 a	1.20 b	2.40 b	4.00 b
Reprocessing b + stir-frying	2.40 b	1.00 a	1.80 c	2.60 a, b	1.00 a	3.20 a, b	2.80 a	1.00 a	1.80 a, b	2.00 b	3.20 a, b
Reprocessing c + stir-frying	1.60 b	1.00 a	1.60 b, c	2.40 b	1.00 a	3.00 b	2.60 a	1.20 a	2.20 a, b	2.60 a, b	3.20 a, b
LSD, 95%	*1.20*	*0.67*	*0.56*	*1.25*	*0.00*	*0.64*	*1.06*	*0.42*	*1,24*	*0.76*	*0.87*

[a]Control sample: supplied frozen by the industry and boiled
[b]Control sample: supplied frozen by the industry and stir-fried
Reprocessing a: blanching at 97 °C for 2 min and freezing
Reprocessing b: blanching at 97 °C for 4 min and freezing
Reprocessing c: blanching at 97 °C for 8 min and freezing

Table 5 Effect of reprocessing and domestic cooking method on sensory attributes (texture, taste and colour) for frozen green beans (cv. *Paloma* and cv. *Moncayo*)

Sensory attributes	Texture			Taste				Colour			
Treatment applied to the frozen green beans samples	Tender-ness	Firmness	Fibrosity	Sweet	Bitter	Authentic taste	Off-taste	Greenness	Off-colour	Shine	Uniformity
Green beans (cv. *Paloma*)											
Boiling[a]	4.00 a	1.60 a, b	1.40 a	2.20 a, b	1.20 a	2.60 a	1.00 a	3.80 a	1.40 a	2.60 a	4.00 a
Reprocessing a + boiling	4.00 a	1.80 a	1.20 a	2.40 a	1.00 a	2.00 b	1.00 a	2.80 b	1.20 a	2.40 a	3.20 a, b
Reprocessing b + boiling	3.80 a	1.20 b, c	1.20 a	2.40 a	1.00 a	1.80 b	1.20 a	2.60 b	1.60 a, b	1.80 a	3.00 a, b
Reprocessing c + boiling	4.20 a	1.00 c	1.20 a	1.40 b	1.20 a	1.80 b	1.20 a	2.00 b	2.60 b	1.60 a	2.20 b
LSD, 95%	*0.92*	*0.56*	*0.79*	*0.97*	*0.42*	*0.56*	*0.42*	*0.99*	*1.18*	*1.08*	*1.04*
Stir-frying[b]	3.40 a	2.20 a	1.60 a	3.00 a	1.20 a, b	2.60 a	1.00 a	3.80 a	1.00 a	3.60 a	4.00 a
Reprocessing a + stir-frying	3.60 a	2.20 a	1.60 a	2.40 a, b	1.60 a	2.20 a	1.20 a	3.80 a	1.60 a, b	3.40 a	4.00 a
Reprocessing b + stir-frying	3.60 a	1.60 a, b	1.20 a	2.20 a, b	1.00 b	2.00 a	1.00 a	3.00 b	1.60 a, b	3.20 a	3.80 a, b
Reprocessing c + stir-frying	4.20 a	1.20 b	1.40 a	1.80 b	1.00 b	2.00 a	1.00 a	2.40 c	2.20 b	2.60 a	3.00 b
LSD, 95%	*0.97*	*0.64*	*0.85*	*1.10*	*0.47*	*1.06*	*0.30*	*0.56*	*1.02*	*1.36*	*0.87*
Green beans (cv. *Moncayo*)											
Boiling[a]	3.40 a	2.20 a	1.20 a	2.20 a	1.00 a	2.20 a	1.00 a	3.00 a	1.00 a	2.40 a	4.00 a
Reprocessing a + boiling	3.80 a, b	1.80 a, b	1.60 a	1.80 a, b	1.00 a	1.80 a	1.00 a	3.00 a	1.20 a	2.40 a	4.00 a
Reprocessing b + boiling	4.20 b	1.20 b, c	1.20 a	1.60 a, b	1.00 a	1.60 a	1.00 a	2.20 b	1.20 a	1.80 a, b	3.60 a
Reprocessing c + boiling	5.00 c	1.00 b	1.20 a	1.20 b	1.00 a	1.60 a	1.00 a	1.80 b	1.20 a	1.20 b	3.80 a
LSD, 95%	*0.73*	*0.70*	*0.64*	*0.64*	*0.00*	*0.67*	*0.00*	*0.64*	*0.52*	*0.95*	*1.25*
Stir-frying[b]	3.20 a	2.20 a	1.00 a	3.20 a	1.20 a	3.00 a	1.00 a	3.20 a	1.20 a	3.80 a	4.20 a
Reprocessing a + stir-frying	3.20 a	2.20 a	1.20 a	2.60 a, b	1.00 a	2.20 b	1.00 a	3.00 a	1.20 a	3.40 a	3.40 a
Reprocessing b + stir-frying	4.00 b	1.60 a, b	1.20 a	2.00 b	1.00 a	2.00 b	1.00 a	2.20 b	1.60 a	2.00 b	2.40 b
Reprocessing c + stir-frying	4.00 b	1.20 b, c	1.00 a	2.20 b	1.00 a	2.20 b	1.00 a	2.00 b	1.60 a	1.40 b	3.40 a
LSD, 95%	*0.79*	*0.64*	*0.42*	*0.99*	*0.30*	*0.79*	*0.00*	*0.64*	*0.82*	*1.31*	*0.97*

[a]Control sample: supplied frozen by the industry and boiled
[b]Control sample: supplied frozen by the industry and stir-fried
Reprocessing a: blanching at 97 °C for 2 min and freezing
Reprocessing b: blanching at 97 °C for 4 min and freezing
Reprocessing c: blanching at 97 °C for 8 min and freezing


A
B
C

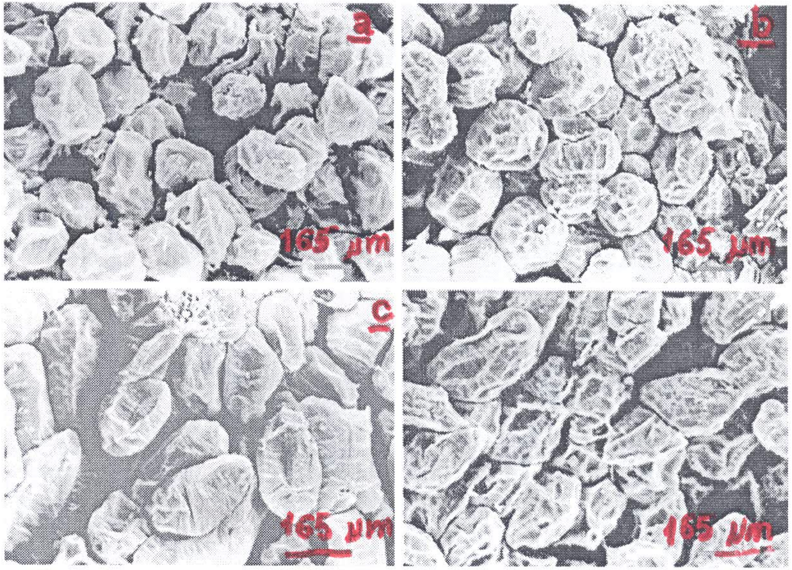
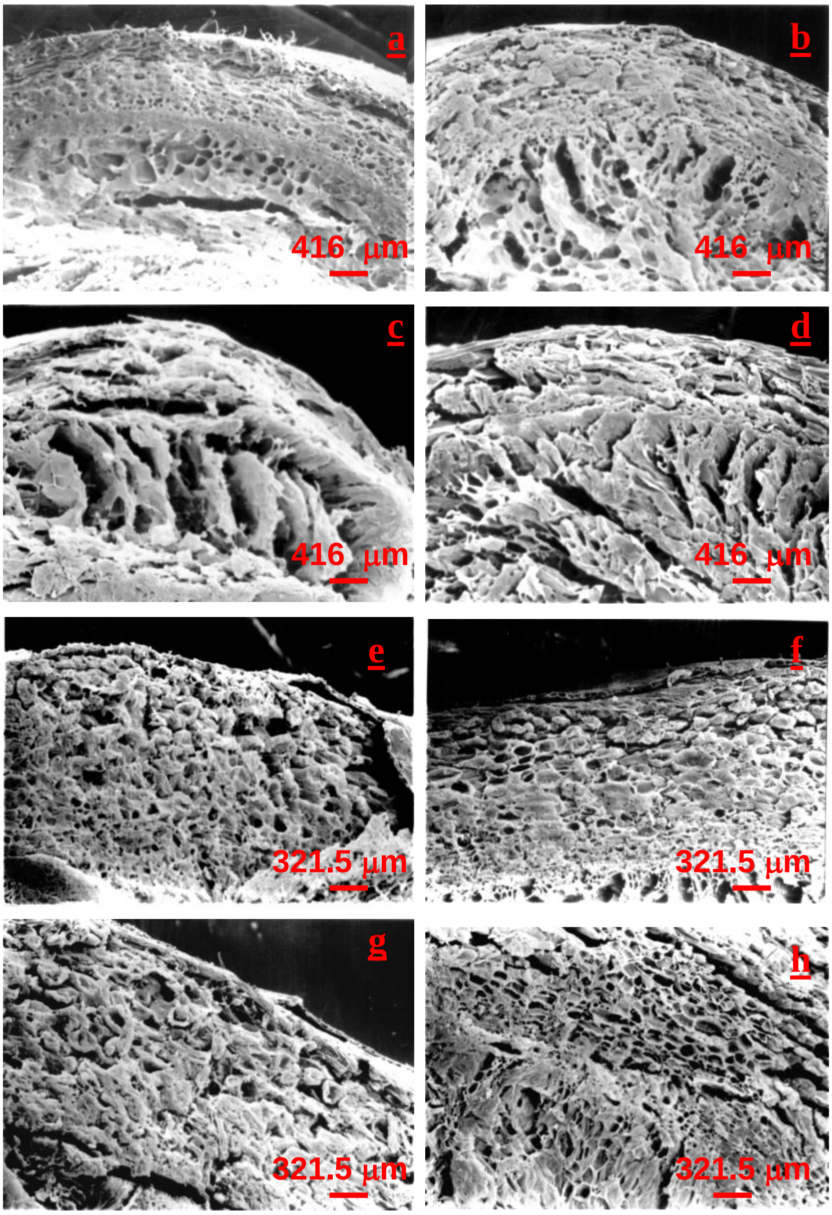


Fig. 2a–d Microphotographs corresponding to green pea tissues (cv. *Mastim*). **a** Green peas processed by the industry up to the frozen stage and boiled. **b** Green peas processed by the industry up to the frozen stage and stir-fried. **c** Green peas processed by the industry up to the frozen stage, subjected to reprocessing b (blanching at 97 °C for 4 min+freezing) and boiled. **d** Green peas processed by the industry up to the frozen stage, subjected to reprocessing b and stir-fried. 1 cm=165 μm


a
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b
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c
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d
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e
321.5 µm
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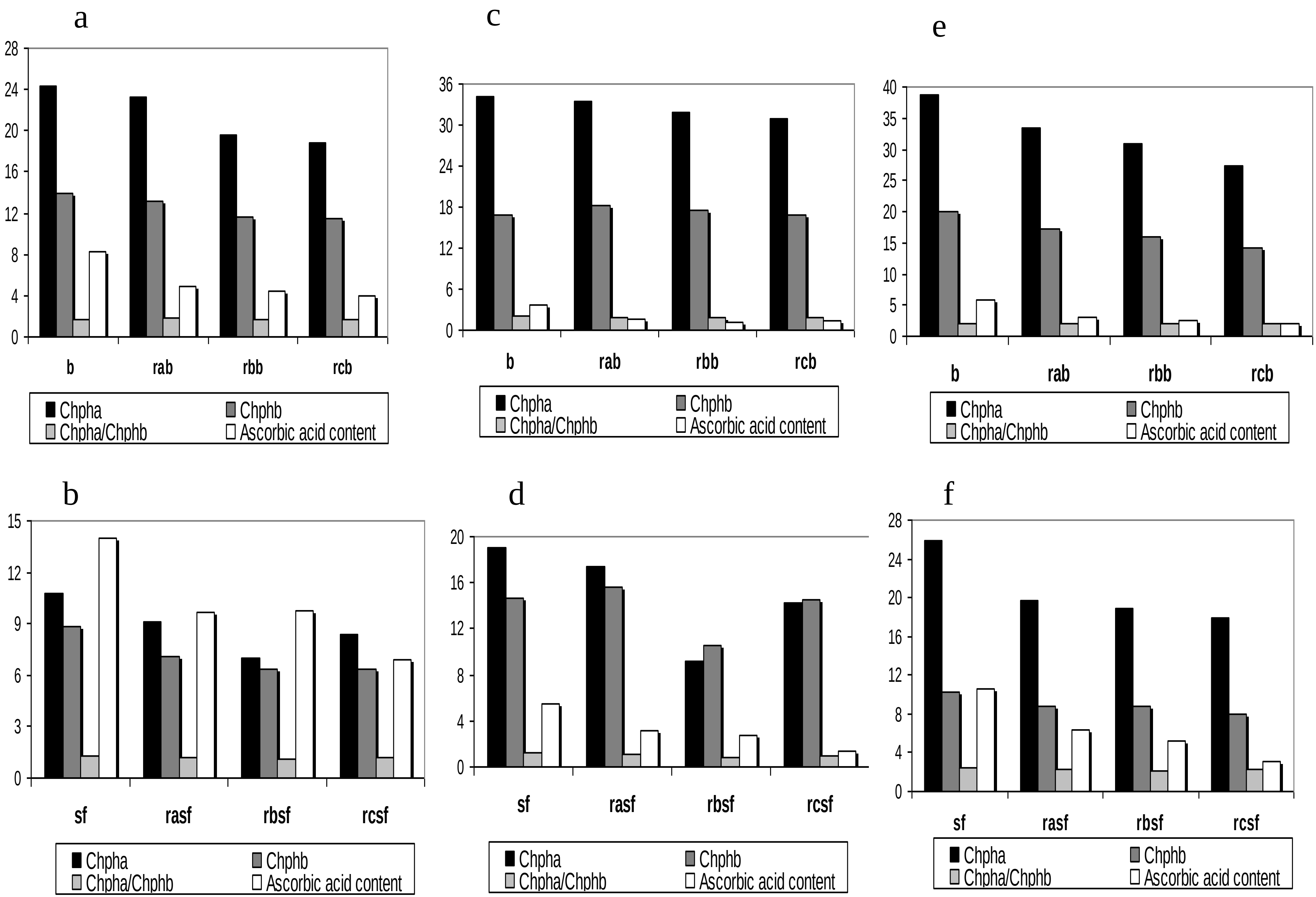
a
28
24
20
16
12
8
4
0
b
rab
rbb
rcb
Chpha
Chphb
Chpha/Chphb
Ascorbic acid content
c
36
30
24
18
12
6
0
b
rab
rbb
rcb
Chpha
Chphb
Chpha/Chphb
Ascorbic acid content
e
40
35
30
25
20
15
10
5
0
b
rab
rbb
rcb
Chpha
Chphb
Chpha/Chphb
Ascorbic acid content
b
15
12
9
6
3
0
sf
rasf
rbsf
rcsf
Chpha
Chphb
Chpha/Chphb
Ascorbic acid content
d
20
16
12
8
4
0
sf
rasf
rbsf
rcsf
Chpha
Chphb
Chpha/Chphb
Ascorbic acid content
f
28
24
20
16
12
8
4
0
sf
rasf
rbsf
rcsf
Chpha
Chphb
Chpha/Chphb
Ascorbic acid content