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Impact of an additional grinding step before apple cooking on environmental, nutritional and sensory qualities of puree: a case study for organic apple

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Abstract

Organic food processors are guided by the European Council (EC) legislation for developing their products. However, the choice of processing technology remains relatively large. To help processors choosing a technology in line with organic principles, the partners involved in the European project ProOrg have designed an assessment framework which has been tested in real conditions on the processing of organic apples in purees at a pilot scale. The assessment concerned the addition of a grinding step before heating. The effect of grinding was then evaluated on environmental, nutritional and sensory criteria. Sixteen indicators were selected to assess these three aspects and rated on a 5-points scale from much worse to much better. Nine of them obtained a higher score with the grinding step added, meaning that the quality was better. The overall score of the puree with grinding was higher than the reference (without grinding) for the three performed trials. The assessment framework was successfully applied to this case study but some improvements were proposed in order to enhance its robustness and to facilitate its comprehension and application. The assessment framework should be an interesting tool for organic food processors.

Keywords: assessment framework, multi-criteria, organic food processing,

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apple puree

1. Introduction

The consumption of organic processed foods is increasing in France and in Europe [1]. The organic food industries need to develop and innovate to meet the consumer expectations. In Europe, European Council legislation (CE n889/2008 and CE n 834/2007) regulates the organic food processing, by limiting the use of additives and processing aids. However, regulatory standards are still lacking for processing technologies [2]. In the context of the arising of the new organic regulation framework (CE n2018/848), the ProOrg project (2018-2021, Eranet Core Organic cofound) aims to contribute to sustainable innovations in the organic food sector through the development of a practical and flexible "Code of Practice" for organic food processors and labelling organizations. The upcoming regulation have been translated into practical assessment criteria in a discussion paper [3] to build the Code of Practice. The Code of Practice is composed of three tools: a management guideline for organic processors, an assessment framework for technologies and a communication guideline [4].

The assessment framework is a tool designed for assessing a processing technology and to help processors to select the processing technology the most in line with organic principles. Its development relies on the work of Kahl and colleagues [5, 6], who proposed the use of a multi-dimensional model to assess processed organic food quality. While nutritional and sensory qualities are often assessed together in food science, the environmental aspect of a process is generally assessed separately, through Life Cycle Analysis for example [7, 8, 9]. However, the qualities of an organic processed food is composed of these three aspects. The assessment framework is thus based on a multi-criteria evaluation and assesses the processing technology on three main aspects: environmental sustainability, nutritional quality, and sensory quality. The following case study aimed to test the Assessment Framework in real processing conditions to facilitate its practical application by providing improvement recommendations.

In France, the most processed fruit is apple. In 2016, 270 000 metric tons of dessert apples were used to produce applesauce, puree or baby food, which represented 72% of the volume of processed apples [10]. The consumption of fruits, fresh or processed, are highly encouraged by the global authorities, due to their positive health effects [11, 12, 13, 14, 15]. The evidences of the benefits of fruit consumption are more and more numerous and are attributed to their content of vitamins, minerals, dietary fiber, and potentially bioactive compounds such as polyphenols [16, 17, 18]. During the industrial process used to produce apple puree, raw apples are generally diced and then cooked twice : one at a temperature between 93 and 98 C for 4 to 5 min for blanching, and the other for pasteurization at 90 C during 20 min after refining [19, 20]. Reducing energy consumption in food processing is a way to lead to sustainable food processing systems [21, 22]. But a change in an operation unit such as heating treatment lead to nutritional and sensory modifications for the final product [23, 24, 7]. Therefore, reducing the heating treatment of the apple puree was an interesting case study to test the assessment framework of the ProOrg project.

This studied case focused on the first heating step, before refining. A reduced heating step coupled with a grinding step was compared to the classic heating process in which the whole raw fruit was heated. *A priori*, the classic heating of whole fruits required more heating energy and water, and lead to a heterogeneous cooking. The addition of a grinding step prior to the heating step could reduce these disadvantages but increase oxidation phenomena [25]. The assessment was performed in real conditions of processing with available data collected by the operator. The criteria tested to validate the process are the environmental aspect, *i.e* time of processing, the nutritional quality, *i.e* sugar, pH and total polyphenol content, and the sensory and organoleptic quality with consumer tests, viscosity and color measurements.

2. Material and methods

2.1. Material

This case study of apple puree processing took place in the EPLEFPA (Etablissement Public Local d'Enseignement et de Formation Professionnelle Agricole) du Valentin (Drme, France), a local public learning and vocational training establishment in the farming sector. This pedagogical farm is composed of a mixed cropping/breeding facility with an apple orchard (10 ha). The production system is entirely organic. A processing facility is available on the same site. Apple purees were produced from the organic apples growing on the farm. The apples were harvested at commercial maturity in September/October 2020 and then stored in a cold chamber at 3 ± 1 C during 1 to 3 months waiting for the different trials lead by students. Several varieties were used: Opal, Dalinette, Goldrush, Crimson Crisp and Story. The apple processing was performed within three trials in November 2020, December 2020 and January 2021, by students during their practical work. Two processing recipes were used (Figure 1). The existing process (PE) - already implemented in the facility - was applied on entire apples, which were at first heated at hot temperature (90C) during 30 min in a steam heating double wall jacketed kettle ('Biaujaud' manufacturer, France) with a capacity of 30 kg and then refined. The alternative process (PB) was conducted as follows: apples were ground through a knife mill (Simaco, France), heated at a moderate temperature (around 80C) in the same kettle as in the existing process, and then refined. This alternative process was tested for the first time in the facility, and need optimisation along batches and trials.

Three trials were performed for each process (with 2 to 4 batches at each time). A description of each trial is proposed in Table 1. Batches are not considered as strict replicates because optimisation was performed on each batch. During the trial 2 of alternative process (PB), three heating temperatures (70 C, 80 C and 90 C) were tested and during the trial 3 of alternative process (PB), three heating times were tested (4, 6 and 10 min). Different blends of apple varieties were used between trials, but the same blend was used between the existing and alternative processes for each trial (Table 1). Ascorbic acid (0,5 g/kg) was added during the refining step for existing process (PE) and just after the grinding step for alternative process (PB).

These two processes were compared in terms of environmental sustainability, nutritional quality, and sensory quality using the assessment framework built during the ProOrg project.

2.2. Assessment framework (AF)

The AF proposes a guidance on how to assess organic processing technologies on three main aspects: environmental sustainability, nutritional quality and sensory quality. It was constructed in keeping with the work of Kahl et al.[6]. It is composed of three steps:

1. Establishing the context ;
2. Assessment ;
3. Overall Evaluation.

During the first step, the studied system is defined: main processing steps, boundaries of the assessment, inputs and outputs of the system. The processing technology under assessment (the alternative process) is compared to a reference (the existing process). The choice of these processes depends on the purpose of the operator.

During the assessment, the criteria and parameters of the AF were selected according to available equipment and data. Data were collected for each indicator of the three aspects.

The overall evaluation of each process was then conducted and an overall score was calculated. For this purpose, raw values were first standardized into normalized dimensionless indicator scores with a base index 100 (100 is the new value for the indicator values of the existing process). These normalized scores were then converted into a rating scale (from -2, i.e. much worse, to 2, i.e. much better) (Table 2). All indicators were equally weighted in this case study. More details on the AF are provided by Horvat et al. [26]

The Impact (+ or -; Table 2) represents the direction of the rating scale (whether the scale is positive or negative). The positive scale is used for an indicator when a lower score indicates a worse performance. On the opposite, the negative scale is used when a lower score indicates a better performance.

The overall score was calculated for each trial separately.

2.3. Choice of indicators and data collection

The chosen indicators were assessed by collecting data during the three trials. The first trial corresponded to the first time for which the alternative process was tested. Thus, some indicators such as consumer rating, were not rated in this trial. All indicators were measured in the EPLEFPA by the students, except for the determination of total polyphenol content and dry matter, which were performed in the SQPOV unit (Scurit et Qualit des produits dOrigine Vgtale) at INRAE (Avignon, France).

Environmental sustainability. For the environmental sustainability aspect, the indicators were chosen for their facility of measurement. No sensors for water or electricity consumption were available in these trials. The heating duration and the duration of device use (grinding + heating + refining) were measured for each batch and added to obtained one value per trial. The cleaning duration was the sum of the cleaning duration before and after each trial. The yield of production was calculated by the ratio of the quantity of puree for 100 kg of apples. The speed of production was calculated by the ratio between the quantity of processed apples and the duration of device use (Table 3).

Nutritional quality. The nutritional indicators were selected according to the nutritional interests of apple puree. Sugar content and pH analysis were performed during trials (1 replicate per batch). Sugar content was measured through soluble solids content with an automatic refractometer (LR02, Maselli, Italy). A drop of puree was placed directly on the refractometer glass prism and soluble solids content was obtained as Brix. PH was measured by immersion of a pH meter (HI991001, HANNA Instruments, France) in a beaker filled with puree. Five hundred grams of puree for each trial were frozen at -18 C before analyzing phenolic composition [27]. The total polyphenol content analysis and dry matter measurements were replicated 3 times for each trial. The dry matter content (DMC) was estimated from the weight of freeze-dried samples upon reaching a constant weight (freeze-drier, 3 days). The freeze-dried samples were further used to quantify polyphenols by HPLC-DAD as described in Le Bourvellec et al. (2011). This data is presented as the sum of individual polyphenols and comprises procyanidins and monomeric flavanols, phenolic acids, dihydrochalcones and flavonols (Table 3).

Sensory quality. The sensory quality aspect was measured through instrumental and consumer tests (Table 3). Viscosity was measured with a Bostwick Consistometer (Endecotts Ltd, UK). The length of the fluid (cm) was measured 1 minute after 100 mL of puree begins to flow down. Color measurements were performed through image analysis. The sample pictures were analysed using ImageJ software (Version 1.48v, National Institutes of Health, USA). The mean values of colour parameters, i. e. L (lightness), a (green/red axis) and b (blue/yellow axis) were converted to standard values L*, a* and b* according to Yam and Papadakis [28]. Fifty-nine students of the EPLEFPA participated to the consumer test as naive panellists. They were asked to select their preferred product from a global point of view (paired preference test). Then they were asked to rate their satisfaction for both products in terms of texture and taste. Only the trials 2 and 3 were assessed in the consumer test. The test was performed in the conditions of a central location test (large tables, possibility to talk to each other, but not to discuss the samples) in the EPLEFPA [29]. Samples were presented in a randomized order across participants and were labeled with randomly selected three-digit number.

2.4. Statistical analysis

The means of DMC and of total polyphenol content were compared according to Student test with a level of significance at $p < 0,05$. Consumer test data were analysed according to binomial law with a probability of success of 1/2 and a level of significance at $p < 0,05$. The analyses were carried out using Excel (Version 2108, Microsoft Corporation, Redmond, USA).

3. Results

3.1. Step 1 of AF: Establishing the context, case boundaries and validate indicators

The assessment of the apple puree process was proposed to the EPLEFPA du Valentin to help them in the selection of their new line of production. The addition of a grinding step seemed to be an interesting lever for better control of the heating step, however, questions were raised about its impacts on the product qualities. Figure 1 shows processing steps of both existing (PE) and alternative (PB) processes. The boundary of the studied system was comprised between the end of washing step and the end of refining step. The chosen indicators for environmental, nutritional and sensory aspects are presented in Table 3.

The addition of a grinding step in apple puree process is known to have an impact on particle size and by consequence on apparent viscosity of the puree [24], but also to increase oxidation phenomena, leading to browning and micro nutrient losses [30, 19]. These facts explained why color, viscosity and total polyphenol content were selected as indicators. Moreover, pH, soluble solids and moisture content were also selected as quality instrumental parameters of the apple puree [31]. In this case study, simple indicators that could be monitored by technical operators were selected as environmental indicators, such as heating or cleaning duration.

3.2. Step 2 of AF: Assessment

The data were collected during three trials and can be found in the supplementary tables.

Focus on environmental sustainability: time/temperature combination. The heating duration was longer for the whole apple cooking in each trial (PE process). Without grinding, the whole apples were heated until their center reached a temperature of 90 C, i. e. during 30 min by batch, while the ground apples reached 80 C more rapidly (between 7,5 min and 17 min by batch on average). Without an electricity meter, it was difficult to conclude if the reduction of cooking time was correlated with a reduction of electricity use, due to the addition of the grinding step in the process.

Focus on nutritional quality: phenolic composition. The total polyphenol content, along with the details of phenolic composition are presented in Figure 2 and supplementary data. In trials 1 and 2, PB puree (with grinding) contained significantly lower total polyphenol content than in PE puree (without grinding) ($p < 0,001$). The grinding step led to a decrease of the polyphenol content due to enzymatic oxidation [25]. However, the early addition of ascorbic acid (before refining) and the shorter cooking time for PB puree should protect the polyphenols against oxidation. It seems that the optimization performed along the three trials allowed a reduction of the loss of the phenolic compounds due to oxidation during grinding. The delay between grinding, addition of ascorbic acid and then cooking had thus to be as shorter as possible. In trial 3, the high standard deviation made difficult to conclude. The difference of polyphenol content between PB and PE purees was not significant. However, it seems possible to limit or even avoid the loss of phenolic compounds due to oxidation through grinding by adding ascorbic acid.

Focus on sensory quality: consumer rating. The consumer rating was only performed for the trials 2 and 3. In both trials, the global enjoyment was the same for both tested products (no significant difference). In trial 2, there was no difference for texture ($p > 0,05$), but the taste of the PB puree (with grinding) was preferred ($p < 0,05$). The measurement of soluble solids content (Brix) showed a higher value in PB puree than in PE one (13,1 *vs* 10,6 Brix), which could explain the consumer preference for PB puree. In trial 3, the opposite was observed.

The texture of the PE puree was more satisfying ($p < 0,05$) and there was no difference for taste enjoyment ($p > 0,05$). The measurement of viscosity showed that the PB puree was thicker than the PE puree (1,5 cm for PB *vs* 5,8 cm for PE). Despite the non-significant differences, the rating scale proposed initially in the AF gave a score (-1 or 1) to the concerned indicators. We recommend to consider the significance of the different indicators when possible, and to give a 0-score to the non-significant data.

3.3. Step 3 of AF: Overall Evaluation

The three trials were evaluated separately. The collected data were normalized, and then ranged on a rating scale (Table 2). Non-significant data were considered to have the same class/score, so they were given a 0-score. With these notation rules, overall scores were obtained for each trial (Table 4).

The process with grinding (PB) was better rated than the process without grinding (PE) in each trial. Focusing on trial 3, the most optimized trial, the overall score of the process with grinding (PB) is close to 0, with a positive value of 0.071. Environmental sustainability aspect obtained a score of 0.657, nutritional quality a score of 0.000 and sensory quality a score of -0.444. Adding a grinding step to the process seemed to improve the environmental score, with the same nutritional quality, but with a decrease of the sensory score. This process needs some additional optimization, in order to improve the sensory quality of the apple puree.

Figure 3 shows the details of the overall score by aspects (green for sustainability, blue for nutritional quality and orange for sensory criteria). The red circle is the baseline for the existing process (without grinding) and the grey line represents the alternative process, i. e. with the grinding step.

Only 5 indicators over 16 were worse with the grinding step than without. In this third trial, the process with grinding was poorly ranked on cleaning duration, yield of production (significant refining losses), organic acid content, and texture/viscosity (product too thick).

4. Discussion

The apple puree case was simple, with only one ingredient and one additive (E300, ascorbic acid), so it was relatively easy to assess. This case study showed that the assessment framework (AF) is applicable in the field, but some improvements are necessary for a better on-site implementation.

Recommendation for assessment robustness: take several trials and replicates into account. Three trials were performed, allowing to test the robustness of the AF when data were collected several times. In this case study, despite the use of the same process, different results were obtained between trials, due to an optimization and a variability among conditions (variation in apples varieties, adjustments of the time/temperature couple...). Even if the objective of the AF is to assess optimized processes, it seems necessary to collect data several times to take into account the variability of the products. A data collection of 3 replicates seemed to be the minimum requirement for statistical analysis and data interpretation for assessment purpose.

Proposition of a new rating scale, with consideration of significance differences. This case study revealed some inconsistency in the scoring method. When three replications were obtained for both processes, statistical tests were performed on the dataset. Despite the large differences between the means of some indicators (such as total polyphenol content or global enjoyment for example) leading to a score of 1 or -1, these means were not significantly different. We proposed thus to integrate the results of the statistical test in the rating scale. When the difference was non significant, the indicator score is equal to 0. When the difference was significant, the indicator score was converted into rating scale according to the Table 2.

Reflections on the integration of sensory/consumer preferences. The sensory indicators were difficult to integrate to the assessment. The choice of the impact (+ or -) for some indicators (as color, for example) was not obvious, as well as the choice of grouping indicators under the same criterion. For example, we chose to group all the consumer rating indicators together. It could also be possible to group the texture enjoyment with the viscosity under a single texture criterion. The sensory criteria depend mainly on the market target of each company. The assessment usually performed is thus a gap analysis between the product and the target, or the preference of potential consumers. Using such criteria to assess a technology or a process in line with the organic principles seemed thus irrelevant. The use of sensory profile or instrumental measurements (more objective) could be more appropriate, but their impacts (+ or -) are very challenging to determine and condition the final overall score.

Need of simple tools and technical support to perform the Assessment methodology. The apple puree case was conducted by Lycee du Valentin and ITAB. The system boundary and the criteria selection were determined by the teachers of Lycee du Valentin during two virtual meetings under the guidance of ITAB. The data were collected by students during their practical work. The Assessment framework was well understood by the participants. The excel sheet built by ITAB was useful to collect data and calculate the overall score. However, technical support was necessary to help the operators with this tool.

Limitations of the case study. The real purpose of this case study was to test the AF in a real environment, not to provide an exhaustive comparison of the studied processes. Some choices were made to facilitate the data collection but limited the results of the case study. Some indicators came from indirect measurements (pH for approaching organic acid content, heating duration for approaching energy consumption for example) and probably approximated the results. Both compared unitary operations were based on heating treatment, but blanching could be performed with other technologies as high-pressure processing for example [32, 33].

5. Conclusion

This case study tested the assessment framework of the European project ProOrg with a multi-criteria evaluation of the grinding step added in the apple puree processing. The process with grinding was promising with an overall score above zero. This case study revealed a few lacks of the current assessment framework and some recommendations were proposed for its improvement to obtain more robust results. The assessment framework is applicable in every food sectors and is designed to help organic processors in selecting their process by taking into account environmental, nutritional and sensory criteria in the same time.

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References

[1] Agence Bio, Les Chiffres 2019 du secteur bio, Dossier de Presse (2020).

[2] J. Kahl, Organic Food Claims in Europe, Food Technology (2010) 38–46.

[3] A. Beck, U. Kretzschmar, F. Paoletti, R. Vidal, Assessment criteria for processing technologies based on eu regulation 2018/848.
URL `https://www.fibl.org/fileadmin/documents/shop/1208-discussion-paper-processing.pdf`

[4] Gawron, Paulina, Zanoli, Raffaele, Meier, Claudia, Beck, Alexander, Code of Practice for organic processors findings from the European project Pro Org (Feb. 2021).

[5] J. Kahl, T. Baars, S. Bgel, N. Busscher, M. Huber, D. Kusche, E. Rembialkowska, O. Schmid, K. Seidel, B. Taupier-Letage, A. Velimirov, A. Zalecka, Organic food quality: a framework for concept, definition and evaluation from the European perspective, Journal of the Science of Food and Agriculture 92 (14) (2012) 2760–2765. doi:10.1002/jsfa.5640.
URL http://doi.wiley.com/10.1002/jsfa.5640

[6] J. Kahl, F. Alborzi, A. Beck, S. Bgel, N. Busscher, U. Geier, D. Matt, T. Meischner, F. Paoletti, S. Pehme, A. Ploeger, E. Rembialkowska, O. Schmid, C. Strassner, B. Taupier-Letage, A. Zalecka, Organic food processing: a framework for concept, starting definitions and evaluation, Journal of the Science of Food and Agriculture 94 (13) (2014) 2582–2594. doi:10.1002/jsfa.6542.

[7] M. Rinaldi, P. Langialonga, R. Dhenge, A. Aldini, E. Chiavaro, Quality traits of apple puree treated with conventional, ohmic heating and high-pressure processing, European Food Research and Technology 247 (7) (2021) 1679–1688. doi:10.1007/s00217-021-03738-6.
URL https://doi.org/10.1007/s00217-021-03738-6

[8] A. J. Arnal, P. Royo, G. Pataro, G. Ferrari, V. J. Ferreira, A. M. Lopez-Sabiron, G. A. Ferreira, Implementation of PEF Treatment at Real-Scale Tomatoes Processing Considering LCA Methodology as an Innovation Strategy in the Agri-Food Sector, Sustainability 10 (4) (2018) 979, number: 4 Publisher: Multidisciplinary Digital Publishing Institute. doi:10.3390/su10040979.
URL https://www.mdpi.com/2071-1050/10/4/979

[9] A. Ladha-Sabur, S. Bakalis, P. J. Fryer, E. Lopez-Quiroga, Mapping energy consumption in food manufacturing, Trends in Food Science & Technology 86 (2019) 270–280. doi:10.1016/j.tifs.2019.02.034.
URL https://www.sciencedirect.com/science/article/pii/S0924224417303394

[10] FranceAgriMer, La Pomme en 2015-2016, Bilan de Campagne (2017).

[11] WHO, FAO (Eds.), Diet, nutrition, and the prevention of chronic diseases: report of a WHO-FAO Expert Consultation ; [Joint WHO-FAO Expert Consultation on Diet, Nutrition, and the Prevention of Chronic Diseases, 2002, Geneva, Switzerland], no. 916 in WHO technical report series, World Health Organization, Geneva, 2003, meeting Name: Expert Consultation on Diet, Nutrition, and the Prevention of Chronic Diseases.

[12] A. V. Rao, S. Agarwal, Role of antioxidant lycopene in cancer and heart disease, Journal of the American College of Nutrition 19 (5) (2000) 563–569. doi:10.1080/07315724.2000.10718953.

[13] S. T. Mayne, Beta-carotene, carotenoids, and disease prevention in humans, FASEB journal: official publication of the Federation of American Societies for Experimental Biology 10 (7) (1996) 690–701.

[14] P. Terry, E. Giovannucci, K. B. Michels, L. Bergkvist, H. Hansen, L. Holmberg, A. Wolk, Fruit, vegetables, dietary fiber, and risk of colorectal cancer, Journal of the National Cancer Institute 93 (7) (2001) 525–533. doi:10.1093/jnci/93.7.525.

[15] P. Pietinen, E. B. Rimm, P. Korhonen, A. M. Hartman, W. C. Willett, D. Albanes, J. Virtamo, Intake of dietary fiber and risk of coronary heart disease in a cohort of Finnish men. The Alpha-Tocopherol, Beta-Carotene Cancer Prevention Study, Circulation 94 (11) (1996) 2720–2727. doi:10.1161/01.cir.94.11.2720.

[16] C. Demign, S. Guyot, P. Vaysse, V. Ripetti-Ballester, J.-J. Kelner, O. Aprikian, C. Manach, C. Morand, C. Rmsy, Le rle des diffrents nutriments et de leurs possibles interactions dans les effets sant de la pomme, Fruits 58 (5) (2003) 297–306. doi:10.1051/fruits:2003017. URL https://doi.org/10.1051/fruits:2003017

[17] L. Hartley, E. Igbinedion, J. Holmes, N. Flowers, M. Thorogood, A. Clarke, S. Stranges, L. Hooper, K. Rees, Increased consumption of fruit and vegetables for the primary prevention of cardiovascular diseases, Cochrane Database of Systematic Reviews (6), publisher: John Wiley & Sons, Ltd. doi:10.1002/14651858.CD009874.pub2.
URL https://www.cochranelibrary.com/cdsr/doi/10.1002/14651858.CD009874.pub2/full

[18] N. P. Bondonno, C. P. Bondonno, N. C. Ward, J. M. Hodgson, K. D. Croft, The cardiovascular health benefits of apples: Whole fruit vs. isolated compounds, Trends in Food Science & Technology 69 (2017) 243–256. doi:10.1016/j.tifs.2017.04.012.
URL https://www.sciencedirect.com/science/article/pii/S0924224416305271

[19] J. Oszmiaski, M. Wolniak, A. Wojdyo, I. Wawer, Influence of apple pure preparation and storage on polyphenol contents and antioxidant activity, Food Chemistry 107 (4) (2008) 1473–1484. doi:10.1016/j.foodchem.2007.10.003.
URL https://doi.org/10.1016/j.foodchem.2007.10.003

[20] P. A. Picouet, A. Landl, M. Abadias, M. Castellari, I. Vias, Minimal processing of a Granny Smith apple pure by microwave heating, Innovative Food Science & Emerging Technologies 10 (4) (2009) 545–550. doi:10.1016/j.ifset.2009.05.007.
URL https://www.sciencedirect.com/science/article/pii/S1466856409000599

[21] W. Lee, M. R. Okos, Sustainable food processing systems - Path to a zero discharge: reduction of water, waste and energy, Procedia Food Science 1 (2011) 1768–1777. doi:10.1016/j.profoo.2011.09.260.
URL https://www.sciencedirect.com/science/article/pii/S2211601X11002616

[22] European Commission. Joint Research Centre., Best Available Techniques (BAT) reference document for the food, drink and milk industries: Industrial Emissions Directive 2010/75/EU (Integrated Pollution Prevention and Control)., Publications Office, LU, 2019.
URL https://data.europa.eu/doi/10.2760/243911

[23] A. Murtaza, A. Iqbal, K. Marszaek, M. A. Iqbal, S. Waseem Ali, X. Xu, S. Pan, W. Hu, Enzymatic, Phyto-, and Physicochemical Evaluation of Apple Juice under High-Pressure Carbon Dioxide and Thermal Processing, Foods 9 (2) (2020) 243, number: 2 Publisher: Multidisciplinary Digital Publishing Institute. doi:10.3390/foods9020243.
URL https://www.mdpi.com/2304-8158/9/2/243

[24] L. Espinosa, N. To, R. Symoneaux, C. M. G. C. Renard, N. Biau, G. Cuvelier, Effect of processing on rheological, structural and sensory properties of apple puree, Procedia Food Science, 11th International Congress on Engineering and Food (ICEF11) (2011) 513–520doi:10.1016/j.profoo.2011.09.078.
URL https://doi.org/10.1016/j.profoo.2011.09.078

[25] S. Guyot, N. Marnet, P. Sanoner, J.-F. Drilleau, Variability of the polyphenolic composition of cider apple (malus domestica) fruits and juices, Journal of Agricultural and Food Chemistry 51 (21) (2003) 6240–6247. doi:10.1021/jf0301798.
URL https://doi.org/10.1021/jf0301798

[26] A. Horvat, et al., Towards a framework to assess quality of processed organic food products, Trends in Food Science & Technology.

[27] C. Le Bourvellec, K. Bouzerzour, C. Ginies, S. Regis, Y. Pl, C. M. Renard, Phenolic and polysaccharidic composition of applesauce is close to that of apple flesh, Journal of Food Composition and Analysis 24 (4-5) (2011) 537–547. doi:10.1016/j.jfca.2010.12.012.

[28] K. L. Yam, S. E. Papadakis, A simple digital imaging method for measuring and analyzing color of food surface, Journal of Food Engineering 61 (1) (2004) 137–142. doi:10.1016/S0260-8774(03)00195-X.
URL https://doi.org/10.1016/S0260-8774(03)00195-X

[29] M. Hersleth, O. Ueland, H. Allain, T. Ns, Consumer acceptance of cheese, influence of different testing conditions, Food Quality and Preference 16 (2) (2005) 103–110. doi:10.1016/j.foodqual.2004.02.009.
URL https://www.sciencedirect.com/science/article/pii/S0950329304000308

[30] M. Colin-Henrion, De la pomme la pomme transforme: impact du procd sur deux composs d'intrt nutritionnel Caractrisation physique et sensorielle des produits transforms, Ph.D. thesis, Universit d'Angers (2009).

[31] A. Landl, M. Abadias, C. Srraga, I. Vias, P. A. Picouet, Effect of high pressure processing on the quality of acidified granny smith apple pure product, Innovative Food Science & Emerging Technologies 11 (4) (2010) 557–564. doi:10.1016/j.ifset.2010.09.001.
URL https://doi.org/10.1016/j.ifset.2010.09.001

[32] A. Kingsly, V. Balasubramaniam, N. Rastogi, Influence of High-Pressure Blanching on Polyphenoloxidase Activity of Peach Fruits and its Drying Behavior, International Journal of Food Properties 12 (3) (2009) 671–680, publisher: Taylor & Francis _eprint: https://doi.org/10.1080/10942910801993841. doi:10.1080/10942910801993841.
URL https://doi.org/10.1080/10942910801993841

[33] M. Mieszczakowska-Frac, K. Celejewska, W. Plocharski, Impact of Innovative Technologies on the Content of Vitamin C and Its Bioavailability from Processed Fruit and Vegetable Products, Antioxidants 10 (1) (2021) 54, number: 1 Publisher: Multidisciplinary Digital Publishing Institute.

doi:10.3390/antiox10010054.
URL https://www.mdpi.com/2076-3921/10/1/54

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Table 1: Description of the three trials

	Trial 1		Trial 2		Trial 3	
	PE	PB	PE	PB	PE	PB
Dates	13/11/20	03/11/20	11/12/20	15/12/20	22/01/21	26/01/21
Apple quantity (kg)	60	68	100	90,4	100	94,5
Apples varieties	Opal (50%), Crimson Crips (30%), Story(20%)		Opal (50%), Dalinette (50%)		Goldrush (50%), Dalinette (45%), Story (5%)	
Number of batches	2	2	4	3	4	3
Cooking temperature	90C	60C	90C	From 70 to 90C along the 3 batches	90C	80C
Non-evaluated indicators	Cleaning duration, Consumer Rating, Viscosity		-		-	
Comments	First try, the taken samples for data collection include pasteurization		First optimization (water addition in PE, loss of material during refining)		Second optimization (loss of material during refining)	

Table 2: Conversion of normalized score into rating scale

Rating Scale		Normalized score of the alternative technology	
		Impact +	Impact -
-2	much worse	< 50	> 150
-1	worse	50-99	101-150
0	the same	100	100
1	better	101-150	50-99
2	much better	> 150	< 50

Table 3: Aspects, criteria and indicators chosen for the assessment

Aspect	Criterion	Indicator	Parameter	Impact	Trials
Environmental sustainability	Energy resources	Heating duration	min	-	1, 2, 3
	Chemical resources	Cleaning duration	min	-	2, 3
	Profitability	Duration of device use	min	-	1, 2, 3
	Profitability	Yield of production	Kg puree /100kg apple	+	1, 2, 3
	Profitability	Speed of production	kg of apple /min	+	1, 2, 3
Nutritional quality	Macronutrients	Sugar content	Brix	-	1, 2, 3
	Macronutrients	Organic acid	pH	+	1, 2, 3
	Phenolic compounds	Total polyphenol content	mg/kg DM	+	1, 2, 3
	Fibers	Dry matter content	g/g	+	1, 2, 3
Sensory quality	Consumer Rating	Global enjoyment	Preference (%)	+	2, 3
	Consumer Rating	Taste enjoyment	Satisfaction (%)	+	2, 3
	Consumer Rating	Texture enjoyment	Satisfaction (%)	+	2, 3
	Texture measurement	Viscosity	cm	+	2, 3
	Coloration	Lightness	L*	+	1, 2, 3
	Coloration	Green-red axis	a*	-	1, 2, 3
	Coloration	Blue-yellow axis	b*	+	1, 2, 3

Table 4: Results of the Overall Evaluation of apple purees obtained with grinding (PB) or without grinding (PE). The * indicates missing data.

	Trial 1	Trial 2	Trial 3
Overall score	0.667*	0.222	0.071
Environmental score	1.333*	0.333	0.657
Nutritional score	0.333	0.333	0.000
Sensory score	0.333*	0.000	-0.444

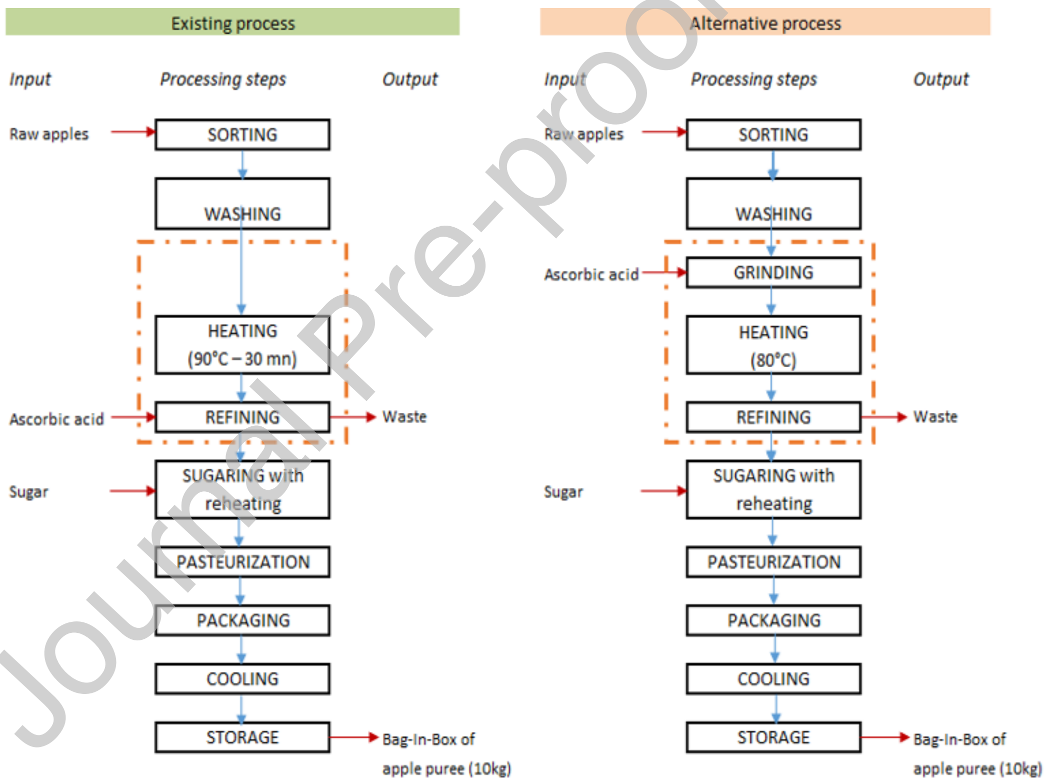

Figure 1: The main processing steps, inputs, and outputs of apple puree processing. Existing process: the entire apples are heated at hot temperature (90C) during 30 min, then they are refined (PE) ; Alternative process: the apples are ground before to be heated at a moderate temperature (around 80C), then are refined (PB). The boundaries of the studied system are represented by the orange dotted line.

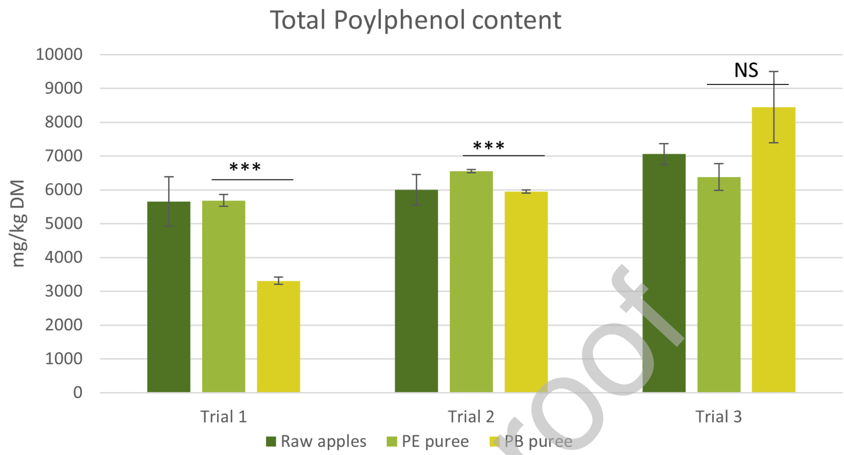

Figure 2: Total phenolic content of the three trials, for raw apples, PE purees (without grinding) and PB purees (with grinding). Three replicates were performed. Significance was calculated with a student test ($p < 0.05$).

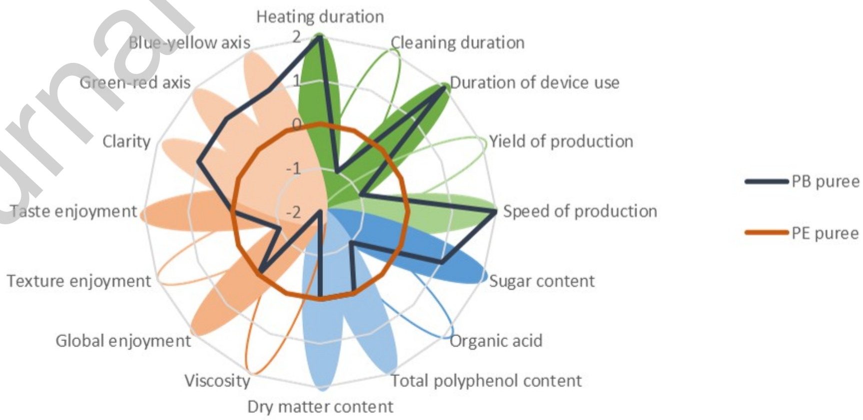

Figure 3: Spider map representing the score for each indicator with the red line for the scores of the PE purees (without grinding) and the grey line for the scores of the PB purees (with grinding). An uncolored petal represents a negative score for the alternative process.

1Declaration of interests

☒ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☐The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: