A comprehensive study on the characterisation properties of power ultrasound treated apple pomace powder and coffee silverskin powder

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Abstract

The study objective was to assess the effect of "power ultrasound (US)" at different intervals on the techno-functional properties of food co-product ingredients, apple pomace (AP) and coffee silverskin (CSS). The primary focus was on the characterisation of techno-functional properties of ingredients, which are necessary for suitable application in meat products, such as water absorption capacity (WAC), oil absorption capacity (OAC), colour evaluation, particle size and rheology. Improvement of techno-functional properties like WAC, OAC and particle size of ingredients can improve the water holding capacity, cook loss and emulsion stability of processed meat products thereby enhancing their eating quality. Aqueous solutions (10% w/v) of the individual ingredients were treated with US (20 kHz, 250 W) for 15 and 30 minutes and freeze-dried. Results of US treated AP showed that there was a rise in WAC ($P < 0.05$) and OAC ($P < 0.05$), whereas in CSS, there was an increase in WAC and OAC, but were not significant enough to prove the effect of US. Proximate analysis showed that US decreased moisture ($P < 0.05$) in both ingredients. Results showed that there was an increase ($P < 0.01$) in the protein (%) of CSS but no significant difference in protein (%) in AP samples. No significant difference was observed in fat, ash, fibre and apparent viscosity for both US treated ingredients. Colour difference (ΔE) showed that US produced visible colour changes in both AP and CSS. Particle size analysis showed there was an increase ($P < 0.01$) in D (3, 2) values of both ingredients. The results indicate that US treatment has beneficial impacts on the techno-functional properties of food co-products, AP and CSS powders.

Ethics declarations

Conflict of interest

The authors declare no conflict of interest.

Compliance with ethics requirements

Ethical approval was not required for this research.

Introduction

Consumer demands for high nutrition, enhanced quality and safer food products has led food industries to try various new alternative food processing techniques that showed some effectiveness in improving the product attributes. Therefore, developing new food products and innovative food processing techniques have been one of the most common challenges faced by food scientists and food industries for decades globally. One such innovative approach is the application of "power ultrasound (US)" in the food processing industry. US can be employed to solid, liquid, dispersions and gaseous media. US treatment is majorly used to accelerate mass transfer, microbial and enzyme activation or inactivation (depending on processing parameters and nature of the enzyme to be treated), drying and extraction, induction of oxidation/reduction reactions, extraction of proteins and other valuable molecules [1]. The modification of US on food products can be explained by cavitation, heating, dynamic agitation, shear stresses and turbulence phenomena [2, 3]. US has the ability to alter both the physical and chemical properties of food products [4]. Recently, huge interest has been shown by food industries in employing US, as a novel processing technology, to improve the quality and safety of food products [5, 6].

Studies suggest that US treatment on food ingredients can improve their techno-functional properties, and also assists in their effective distribution into food matrices, even on complicated matrices like processed meat [7], where sodium chloride diffusion within products was demonstrated to be enhanced after treatment [8]. It has been reported that US technology can improve water retention and oil absorption properties in meat and dairy ingredients, such as proteins, starches and lipids [6]. Jamalabadi, Saremnezhad, Bahrami, and Jafari [9] studied the effect of the US on the techno-functional properties of wheat starch suspensions. Results from their studies showed improvements in starch solubility and oil absorption properties when treated with a continuous sonication of 200 W, 24 kHz (100% amplitude) for 15 and 30 minutes using the probe with a vibrating tip of diameter 8mm.

Results of improved techno-functional properties were obtained in various studies involving US treatments of food ingredients, such as; potato, wheat, corn and rice starch [10], proteins and polysaccharides [11], jackfruit seed protein isolate [12], and myofibrillar proteins [13].

In recent decades, studies have been conducted to develop new functional food ingredients using US technology to improve the quality of food products [6]. Additionally, consumer interest in clean label ingredients, which are natural/organic and/or non-artificial/non-synthetic [7], has driven food industries to conduct research into potential uses for a novel, natural and under-utilised food ingredients. As mentioned above, reports [11], [12], [13] have shown the improvement of the meat products related techno-functional properties such as water holding and oil holding abilities, gelling properties and rheological characteristics, thereby making them a suitable functional meat ingredients. Dietary fibre is one such important ingredient that has been widely studied in functional meat products owing to its techno-functional and medicinal applications. Dietary fibres obtained from phyto-sources offer various techno-functional benefits that improve the technological qualities of food products [14]. Studies show that fibre inclusion in meat products improves techno-functional properties, such as; swelling ability, water holding and oil holding ability, gel forming ability, etc. [15, 16]. It is been noted that the inclusion of fibre in the diet can reduce colon cancer, diabetes, obesity, and cardiovascular diseases. Thus, dietary fibres obtained from various food sources are recommended to reduce various chronic diseases within the human body [17]. These dietary fibres, however, are not easily employed in meat products because of their carbohydrate-based polymer structure, which makes digestion difficult for humans [18] and negatively impacts functionality, thereby limiting their potential for use by the processed meat industry. Therefore, such dietary fibre sources require many physical and chemical modifications to improve their techno-functional and digestive properties. Application of the US can effectively assist in modifying the carbohydrate polymer structure [19] and previous studies have also shown that the US improves the water and oil holding capacity and solubility of the dietary fibre content [20, 21]. However, there is limited reporting on the impact that the US has on the techno-functional properties of dietary fibres [6].

Apple pomace (AP) powder and coffee silver skin (CSS) powder are fibre-rich food co-products and are the ingredients of interest in this research study. AP and CSS are obtained as under-utilised, co-products from apple juice and coffee powder processing, respectively. AP contains high quantities of pectin and polyphenols and possesses important techno-functional properties such as rheological and water holding capacities [22]. Similarly, CSS is a good source of protein and polyphenols. Both AP and CSS possess high dietary fibre contents as outlined previously, consisting of 78-89% and 86% dietary fibre, respectively. This could make them strong potential

functional ingredients for employment in meat products. Previous work conducted by our research group using both of these functional ingredients [23] showed that they can be used to improve the techno-functional properties when incorporated in Irish breakfast sausages as added phosphate replacers. However, as phosphate could not be totally replaced in our previous study, there was a requirement to implement additional and new strategies to improve the techno-functional properties of these two fibre-rich ingredients. From an extensive review of the scientific literature, no studies were detected reporting on the US improvement of techno-functional properties of AP and CSS to date. Thus, this study specifically focuses on treating two, novel, fibre-rich ingredients (AP powder and CSS powder) with US treatments at different intervals, and subsequently analysing the post-treatment characterisation changes in their physical and chemical properties, specifically those techno-functional properties of interest for meat-based product application.

Methods and materials

Sample preparation

Industrial co-products AP was sourced from Muns Agroindustrial S. L. (Lleida, Spain) while CSS was sourced from Illycaffé S.p.A (Trieste, Italy). Ingredient samples were oven-dried at mild temperature (to avoid the degradation of bioactive compounds) of 40 ^{o}C until constant weight and finely powdered using the laboratory mill (Perten Labmill 3100, PerkinElmer, Waltham, Massachusetts, USA). The powdered samples are stored in sealed pouches at 4 °C.

Sample treatment

Suspensions containing a 10% (w/v) (based on previous works, where higher concentration were too viscous) of finely powdered AP and CSS were made separately using distilled milli Q water. The solutions were well stirred using the magnetic stirrer (Hei-Mix S, Heidolph Instruments GmbH & Co.KG, Schwabach, Germany) and stored at 4^{o}C for one hour as pre-treatment sample preparation to aid the complete hydration and solubilisation of the ingredients. The solutions were then treated with a low-frequency and high power (20 kHz, 250 W) US treatment (UIP1000hdT, Hielscher Ultrasound technology, Germany) for two different time intervals of 15 and 30 mins. The selected time intervals were based on the study by Köhn et al [11] where the meat based ingredients were treated with US for 15 and 30 minutes. The US treatment was conducted in a temperature-controlled environment, where the temperature of the solutions was maintained below 20^{o}C during the entire treatment period using jacketed glass beakers attached with a recirculating chiller (Lauda Brinkmann Ecoline RE104, Delran, New

Jersey, USA). The US treated AP and CSS solutions were then freeze-dried (-25ºC/30ºC, pressure ~ 0 mbar) in an FD 80 model freeze dryer (Cuddon freeze-dry, New Zealand) and the powders were then stored in air-tight containers at 4ºC for further characterisation analysis. US treated and freeze-dried AP and CSS powders were analysed for changes in water and oil absorption capacity, colour changes, particle size modification, viscosity changes and proximate control changes against the untreated control powder samples. Although the freeze dried products retains most of their properties, improperly selected parameters could cause deterioration or changes to the techno-functional properties. This can be controlled by selecting the parameters that does not melt the water, since the liquid water could cause rheological changes [24]. Henceforth, in study, to eliminate this effect of freeze-drying on potential characterisation changes, both AP and CSS powders were firstly suspended in milli Q water and then freeze-dried without US treatment and then compared with the treated samples and control sample. In total, two controls (AP control and CSS control), two freeze-dried samples (APFD and CSFD), two samples US treated for 15 mins (AP 15 mins and CSS 15 mins), and two samples US treated for 30 mins (AP 30 mins and CSS 30 mins) were analysed. All treatments were repeated separately on three occasions for statistical validation.

Sample Analysis

Proximate compositional analysis

Total proximate composition for both powders was determined using the official AOAC methods. Moisture content in the sample powders was determined according to AOAC official method 925.10 [25] using TGM800 Thermogravimetric Moisture determinator (LECO, USA). Fat percentage in the powders was measured using the Oracle NMR Smart Trac rapid Fat analyser (CEM Corporation, USA) using AOAC official methods 985.14 [26]. Total protein content in the powders was determined using a LECO FP628 (LECO Corp, MI, USA) nitrogen analyser based on the Dumas method and according to AOAC method 992.15 [27], a conversion factor of 6.25 was employed for calculation. Inorganic ash content was determined using a Gallenkamp Muffle Furnace, AOAC Official Method 936.07 [28], pre-drying overnight at 550°C (Gallenkamp, UK).

Total dietary fibre content

The total dietary fibre (TDF), including insoluble dietary fibre (IDF) and soluble dietary fibre (SDF), was determined according to AOAC 991.43 [29] (enzymatic–gravimetric method) using Ankom automated dietary fibre analyser (Ankom, USA). Samples were dispersed in MES-TRIS buffer and were treated sequentially with a heat-stable α-amylase for 30 min at 100°C, while being treated in sequence with a protease for 30 min at 60°C,

and finally treated with an amyloglucosidase for 30 min at 60°C. Finally, the mixture was filtered in pre-weighed crucibles and the IDF was measured directly. From the filtrated portion, the SDF was precipitated with 95% ethanol at 4 × volume and then filtered. Both residues (insoluble and soluble) were washed with 78% ethanol, 95% ethanol and acetone respectively, and then dried, weighed, and corrected by protein and ash content. Protein content was determined with the Dumas method using a LECO FP-628 (LECO Corp., MI, USA) protein/nitrogen analyser, and 6.25 as the conversion factor for N (AOAC method 992.15 [27]). Ash was determined by AOAC method 936.07 [28], where samples were placed in a Gallenkamp muffle furnace (Gallenkamp, UK) at 550°C for overnight.

Water absorption and Oil absorption capacity

The water absorption capacity (WAC) and oil absorption capacity (OAC) of the treated ingredients were evaluated based on the method by Garcia-Vaquero, Lopez-Alonso, and Hayes [30], with some modifications. A sample of 0.5g of each ingredient was dispersed in 10g of water or vegetable oil, using a vortex mixer, and then allowed to stand for 30 min. The tubes were then centrifuged at 2200 X g for 30 min in a Sorvall Lynx 6000 centrifuge (Fischer Scientific Ireland, Dublin, Ireland). The supernatant was decanted and the tubes were then allowed to drain. After drying, the tubes were then weighed again with water/oil-absorbed ingredients in them. The water/oil absorption capacity of the ingredients was then calculated using the formula,

$$\text{Water/ Oil absorption capacity} = \frac{W_2 - W_1}{W_0} X\ 100 \qquad \text{(Eq. 1)}$$

Where W_0 is the weight of the dry sample (g), W_1 is the weight of the tube with the dry sample in it (g) and W_2 is the weight of the tube with centrifuged sediment (g). Readings were measured in triplicates.

Colour Evaluation

The effect of US treatment on the colour characteristics of different ingredients was measured using a Chroma meter CR410 (Konica Minolta, Tokyo, Japan)**.** Readings were measured in CIE L* (lightness), a* (redness/greenness), and b* (yellowness/blueness) system.

The colour of the freeze-dried AP and CSS powders was compared with the colour of control powder samples. Colour comparisons were performed using the ΔE^*_{ab} values which indicate the distance between any two colours in CIELAB space defined by its three orthogonal coordinates L^*, a^* and b^*. The total colour difference ΔE^*_{ab} values were calculated using the formula equation associated with the measurement [31] and differences would

only be apparent to experienced observers if 1<ΔE<2 and clear differences of colour could be observed if ΔE > 2.5. The equation as follows:

$$\Delta E^*_{ab} = \sqrt{(L^*_C - L^*_1)^2 + (a^*_C - a^*_1)^2 + (b^*_C - b^*_1)^2} \qquad \text{(Eq. 2)}$$

L^*_C, a^*_C and b^*_C were the colour attributes of the control sample and L^*_1, a^*_1 and b^*_1 were the colour attributes of the treated samples to compare.

Particle-size distribution

The particle-size distribution of both ingredients was studied using laser diffraction employing a particle-size analyser (Malvern Mastersizer 3000, Malvern instruments Limited, UK) equipped with a Hydro 2000SM sample dispersion unit (Malvern Instruments Limited, UK) at 25ºC. Particle size was expressed with the surface mean diameter (D [3, 2]) and the volume mean diameter (D [4, 3]). A refractive index of 1.52 and an absorption index of 0.01 were used.

Rheology

A 6% (w/v) of the ingredient dispersions were made using distilled water and stirred with a magnetic stirrer (Thermo Fisher Scientific). The rheological behaviour of the ingredients was studied using an oscillatory rheometer Anton-Paar (Anton–Paar Physica MCR301, Anton-Paar, Austria) coupled to a water bath (Julabo AWC 100, Germany) at 20^{O}C using the measuring system PP50 (parallel plates; plates diameter = 49.965mm) with a 0.5mm gap. Equilibration was initiated for 5 min followed by the pre-shear treatment at 1 s^{-1} for 10 s. It was then followed by the continuous shear rate ramps from 0.1 to 400 s^{-1} over 2 min [32]. The shear stress of the samples was measured throughout the experiment. The Power law (Eq. (3)) model was fitted to the experimental data using the rising curve:

$$\sigma = K \cdot \gamma^n \qquad \text{(Eq 3)}$$

where σ is the shear stress (Pa), γ is the shear rate (s^{-1}), K is the consistency index (Pa. s^n), n is the flow behaviour index (dimensionless).

Statistical analysis

Results from the different treatments were compared by one-way ANOVA followed by Post-Hoc analysis using Tukey's difference of $P < 0.05$ employing IBM Statistical Package for the Social Sciences (SPSS, v.24) (IBM

Corp., USA). The power-law model for viscosity co-efficient was fitted using the Sigmaplot version 14.0 (Systat Software, San Jose, CA). All experiments were repeated separately three times and results were expressed as mean ± standard deviation.

Results and Discussions

Proximate composition and Total dietary content

The results of proximate content, along with the total dietary fibre content, for both ingredients are summarised in Table 1. It was observed that US treatment did not produce any significant difference in the ash content of both the ingredients (AP and CSS), irrespective of the treatment duration. The total ash content of the CSS powder (4.78- 5.11%) was higher when compared to that of AP (1.37–1.47%). This could be due to the presence of a larger composition of inorganic minerals, including; potassium, calcium, magnesium, sulphur, phosphorus, iron and others. These minerals present in CSS are mostly essential micronutrients, which are responsible for various metabolic and physiological functions in the human body [33]. Similar to ash content, the US did not produce any significant trend or difference in the fat content of both ingredients. It was observed that both fat content of AP (0.48–0.77%) and CSS (1.03-1.35%) ingredients remained almost the same irrespective of the US and freeze-drying treatment. US application decreased ($P < 0.05$) moisture content in both food ingredients studied. The moisture content of both AP (7.88%) and CSS (8.65%) significantly decreased when treated with US for 15 mins (AP –6.0 %; CSS–7.5%) and 30 mins (AP 6.5%; CSS–7.3%). This could be probably explained by the drying and cooking effect caused by the cavitation mechanism of US treatment which can remove moisture [34, 35]. It was observed that the moisture content of AP freeze-dried samples was similar to that of US-treated samples, whereas there was a significant difference ($P <0.01$) between CSS freeze-dried samples and US-treated samples. This observation for CSS can be explained by the drying kinetics facilitated by US treatment [36].

Protein content results for both AP and CSS showed that there was an increase in protein content when both were treated with the US. There was an observed increasing trend in protein content in AP when treated with the US, however, the increase was not significant. There was a clearer case for CSS and US application increased ($P < 0.01$) protein content. This increase in protein content of the samples can be attributed to the reduced moisture content produced as a result of US drying kinetics [36]. It was evident from the results of CSS samples treated with US for 15 and 30 mins, where the reduction in moisture content had resulted in the concentration of protein content. On analysing the post-hoc studies, it was observed that there was no significant variation in protein content between samples where the US had been applied for different treatment durations. Thus, US treatment

increased ingredient protein content but did so only by physically lowering the moisture content of ingredients studied.

In respect of the dietary fibre content of the ingredients investigated, US treatment had no significant effects. The total dietary fibre (TDF) involving insoluble dietary fibre (IDF) and soluble dietary fibre (SDF) did not vary significantly with US treatment in the case of AP ingredients. The IDF ranged from 39.0-42.0% while the SDF ranged from 11.0 –12.0%. Differences in fibre content can be obtained by varying the milling time, where a reduction in particle size could result in the conversion of IDF to SDF owing to modifications in the structure and physicochemical properties [37]. This redistribution of IDF to soluble fractions was explained by the destruction of cellulose, hemicellulose and exposure of hydrophilic groups, produced because of milling [38]. In the case of CSS, US treatment had a significant effect ($P < 0.05$) on SDF. However, no significant effect was observed for TDF content ($P > 0.05$) which concludes that US treatment did not have any effect on altering the fibre content of the studied ingredients. Fibre is the main component of both ingredients under study and this high fibre content is important in numerous respects. The techno-functional properties of these rich dietary fibres in both ingredients make them potential new food ingredients for food and beverage industries [39]. For example, the techno-functional properties of dietary fibres in these ingredients can be used to improve emulsion stability, sensory properties and rheological properties of meat products [40]. The high SDF content in CSS can possibly be used to produce probiotic foods by promoting bacterial growth [41].

Water and Oil absorption Capacity

The water absorption capacity (WAC) and oil absorption capacity (OAC) are ingredient properties that must be understood if those ingredients are to be used in a processed meat product and can be defined as the ability of the ingredient to absorb or withhold water or oil, respectively, even after the application of an external force such as temperature [42]. The WAC values are responsible for the hydration properties of food ingredients, whereas the OAC determines the ability of an ingredient to bind with fat during food processing. Ingredients with greater oil and water binding properties can be used in food formulations such as meat and oil emulsion products [32, 43]. It is been reported that the presence of high TDF content in ingredients is responsible for the increased WAC of the same ingredients [44]. Both WAC and OAC values for ingredients are dependent upon the particle size of these ingredients. It is reported that the smaller the particle size, the higher the chances of increased WAC since the smaller particles possess a higher packing density. Additionally, the amount of OAC is dependent on ingredient properties like surface properties, overall charge density and the hydrophobic nature of the ingredient itself [33,

45]. Téllez-Morales et al. [6] outlined the positive impacts that US application could have on the WAC and OAC of food ingredients. Application of US to food ingredients physically alter their matrices so that there is an opening of structures, an increase in electrical charge, an exposure in hydrophilic and hydrophobic groupings, thereby altering and improving functionalities like WAC and OAC; much like that achieved through the addition of salt to processed meats.

The results of US impact on WAC and OAC for experimental ingredients used in this study is shown in Table 2. It was observed that WAC and OAC of AP powder significantly ($P < 0.01$) increased owing to the application of power US. It can be seen from the results that both WAC and OAC for AP also increased with increasing treatment duration. The WAC (3.50g water/g dry sample) and OAC (1.64g oil/g dry sample) values for AP treated with the US for 30 min were significantly higher ($P < 0.01$) than the one treated for 15 mins (WAC– 3.13g water/g dry sample; OAC– 1.36g oil/g dry sample). Thus, US application had significant impacts upon WAC and OAC for the AP ingredient (Table 2).

Both the WAC (3.03–3.62g water/g dry matter) and OAC (2.84–3.58g oil/g dry matter) were higher in CSS when compared with the WAC (2.92-3.50g water/g dry matter) and OAC (1.03–1.64g oil/g dry matter) values for AP. An increasing trend was observed in both WAC and OAC values for CSS when treated with US for 15 and 30 mins (Table 2). However, the trends observed were not significant to prove the effect of US on the ingredient's WAC and OAC properties. Since the WAC and OAC depends on the particle size [33], this non-significant increase in WAC and OAC can be attributed to the close range of particle size of the US treated CSS ingredients with that of control. In general, it was observed from the data, that US treatment had positive impacts upon the WAC and OAC of ingredients which plays an important role in the nutritional and sensory aspects of food products, especially processed meat products [46].

Particle Size Distribution

The results of particle size distribution analysis were presented in Table 3, in terms of surface mean diameter D (3, 2) and volume mean diameter D (4, 3). It was understood that the largest ingredient particles had the greatest influence on volume mean diameter D (4, 3), whereas the smaller particles had an influence on the surface mean diameter D (3, 2). It was found that D (4, 3) values for AP had a significant ($P < 0.01$) increasing effect due to the US treatment. The D (4, 3) values for AP treated with US for the 15 mins (150.67 µm) were higher than AP treated with the US for 30 mins (138.33 µm). An opposite trend was observed in CSS where the D (4, 3) values for CSS treated with US for 15 mins (169.67 µm) and 30 mins (193.33 µm) decreased when compared with the control

(201.67 µm). The possible explanation for this can be attributed to the shrinkage effect produced in the CSS due to freeze drying [24].

Results showed that there were a significant increase in D (3, 2) values for both AP ($P < 0.01$) and CSS ($P < 0.01$) when treated with the US for 15 and 30 mins. In the case of AP, D (3, 2) values for both treatment durations were similar (70 µm). However, for CSS, although D (3, 2) values for both treatment durations were significantly different when compared to control values, the range of difference were not higher as compared to AP. This explains the non-significant increase in WAC and OAC values of CSS. Also, The distribution of D (3, 2) values for AP (30–70µm) and CSS (96.4–118.3µm) was so small that this explains the increased values observed for WAC and OAC for both ingredients since the parameters are dependent on the particle surface area and smaller particles trap more water/oil due to their larger surface area and more opened structure [37, 47]. However, US treatment, which activates surface area, also explains the increased WAC and OAC values observed for ingredients when compared with that of control samples of a smaller size. Thus, the application of US produces changes in the particle size distribution of the ingredients and these changes can be attributed to the modifications in the rheological behaviour and technological properties of TDF, as well as the WAC and OAC of the ingredients [48].

Rheological Study

Food rheology is a useful tool for many applications in food processing and involves the study of the deformation and flow of foods under well-defined conditions. Food rheology is often confined to liquid food materials, but there is an increased interest in studying responses of both liquid and solid food materials to applied stress and strains. Put simply, it is defined as the study of both the elastic and plastic properties of foods [49]. Finally; viscosity refers to the internal resistance between the molecules against the flow of fluid [50]. It is an important characteristic of a fibre solution as it represents its behaviour pattern during various industrial processes such as mixing, grinding, coating, etc. [32]. The apparent viscosity at a shear rate 100 s^{-1} was used to calculate the significance as it would represent the process behavior as pumping, shaking and chewing [51].

In this study, Figure 1 shows the viscosity curve of the ingredients against shear stress. For both ingredients investigated in this study (from Fig. 1a, 1b), it was observed that viscosity decreased with an increased shear rate. Similar to the study of Gabiatti et al.[32], the fibre solutions were thixotropic i.e. the longer the ingredient underwent stress, the viscosity decreased until it reached an equilibrium level. It was observed from the viscosity curve that the apparent viscosity of the samples increased when they were treated with US for 30 mins for both

AP and CSS samples. There was a definite increase in the apparent viscosity at 100 s^{-1} shear rate, however, the increase was not significant enough to prove the effect of US treatment for both ingredient samples. Power-law model fitted data, from Table 4, showed that both samples possessed shear thinning properties ($n<1.0$). Analysis showed that the model resulted in excellent fits with high correlation coefficients (R^2), which increased with US treatment duration (R-square of 0.95 and 0.98 for AP treated with the US for 15 and 30 mins respectively; 0.96 for CSS treated with the US for 15 and 30 mins, respectively). The consistency coefficient (K), which represents the viscous nature of the ingredients [52], decreased with US treatment for both samples, along with the increase in flow behaviour index (n). It was referred from the study of Wang, Sun, Li, Adhikari, and Li [53] that the viscosity of fibre solutions increased with increase in product fibre content. Knowing the viscoelasticity of the ingredients is of high importance as they can be used to design and predict the product stability [54].

Colour Analysis

Colour parameters for food ingredients are extremely important since they largely affect the colour of the finished food products. Additionally, the colour of the product is responsible for the perception and reception of the food products by consumers [55]. Colour analysis of the ingredient samples was listed in Table 3. Analysis showed that for CSS, US treatment significantly increased ($P < 0.01$) lightness values (L*) in samples, while redness values (a*) for samples decreased significantly after treatment. There was no significant change in yellowness (b*) values. The change in the colour can be attributed to the freeze drying and the cooking effect produced by US that increases the darkness of the samples. However, in this study, results were in contrast to the reports of Vimercati et al. [56], where the freeze drying the CSS increased the darkness values.

For AP, an opposite trend to that observed for CSS was determined. There were significant differences between control and US treated AP samples in terms of L*, a* and b* values. It was found that L*(lightness) values for AP samples significantly decreased ($P < 0.01$) with US treatment for 15 and 30 mins. On analysis, it was determined that both yellowness (b*) and redness (a*) values for samples increased significantly ($P < 0.001$) with US treatment. This increase in darkness of the sample can be explained by the release of carotenoids by US treatment (apple peel consists of carotenoid and chlorophyll pigments) [57] and the browning effect caused by freeze drying [24].

Further sample analysis of colour difference (ΔE) values showed a clear difference in colour values observed. When the colour difference (ΔE) values are more than 2.5, then a clear difference in colour between samples can be observed by a normal observer [58]. It was observed from Table 3 that AP samples treated with US for 15

(6.43) and 30 mins (5.42); CSS samples treated with US for 15 (3.58) and 30 mins (2.66), both had colour difference values greater than 2.5 which signifies that the application of US treatment produced colour changes in the food ingredients when compared with control samples. Thus the application of US had a varied effect on both ingredient samples. These effects can be used to advantage in order to produce a product of the desired colour in a controlled treatment procedure.

Conclusion

US treatment of food ingredients has attracted scientific and commercial interest owing to its ability to improve various techno-functional properties associated with these ingredients. It is important to understand the optimal conditions required for the US to fully impact upon and exploit specific and desirable ingredient functionalities. The research undertaken in this study clearly demonstrated the physico-chemical changes induced in fibre-rich AP and CSS powders when treated with US (20kHz, 250W), being more evident at longer treatments times (15 vs 30 minutes). The application of US on both these ingredients produced enhanced physico-chemical properties, such as improvements in; WAC, OAC and viscosity values, which can be attributed to modifications in ingredient particle sizes as impacted by US; although the conditions employed in this research produced better and more significant improvements for the functional properties determined for AP as functional ingredient. This study suggests that further work should be carried out to assess the impact that US application has on enhancing ingredient functionalities and in the revalorisation of food co-products as functional ingredients in food formulations, specifically in meat products such as sausages and burgers .

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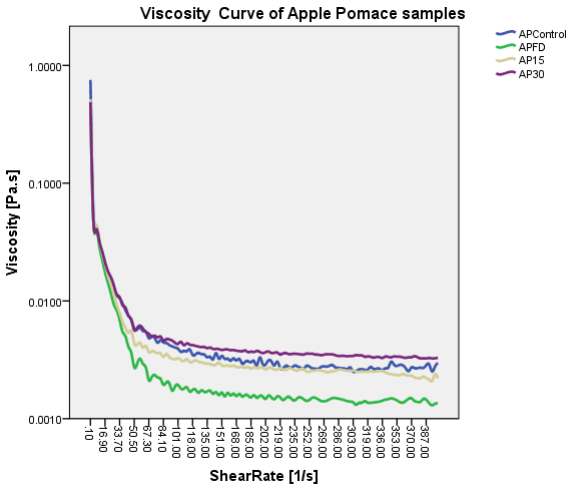
Figure 1. Viscosity curve of the fibre ingredients obtained from high-speed homogenisation using Anton Paar rheometer.

a. Viscosity curve of apple pomace samples



b. Viscosity curve of coffee silver skin samples

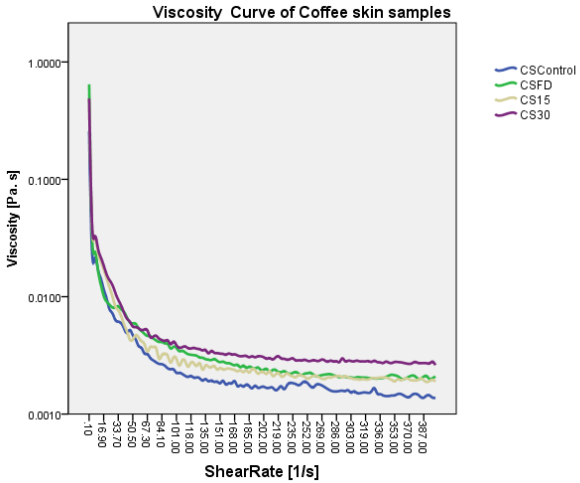


Table 1. The effect of Ultrasound on the proximate composition and total fibre content of the ingredients

	Apple Pomace					Coffee Silver skin				
	AP Control	**AP Freeze dried**	**AP US 15 min**	**AP US 30 min**	**p - value**	**CS Control**	**CS Freeze dried**	**CS US 15 min**	**CS US 30 min**	**p- value**
Ash %	1.42 ± 0.17	1.37 ± 0.15	1.47 ± 0.06	1.38 ± 0.21	0.73	4.83 ± 0.32	4.78 ± 0.27	5.11 ± 0.24	4.91 ± 0.42	0.31
Protein %	4.49 ± 0.35	4.43 ± 0.19	5.03 ± 0.52	5.00 ± 0.68	0.19	15.68 ± 0.39^{b}	16.01 ± 0.36^{b}	17.45 ± 0.69^{a}	17.10 ± 0.61^{a}	**< 0.01**
Moisture %	7.88 ± 1.51^{a}	6.05 ± 0.94^{b}	6.00 ± 0.71^{b}	6.50 ± 1.01^{a,b}	**0.02**	8.65 ± 0.26^{a}	8.13 ± 0.33^{a,b}	7.53 ± 0.80^{a,b}	7.29 ± 1.37^{b}	**0.04**
Fat %	0.48 ± 0.34	0.62 ± 0.27	0.67 ± 0.46	0.77 ± 0.27	0.54	1.03 ± 0.60	1.30 ± 0.37	1.35 ± 0.45	1.09 ± 0.51	0.61
TDF %	51.60 ± 1.57	53.01 ± 4.17	51.44 ± 3.00	51.58 ± 3.82	0.77	69.89 ± 2.63	66.43 ± 2.12	69.62 ± 3.45	77.94 ± 12.69	0.12
IDF %	40.46 ± 0.40	41.26 ± 3.18	40.34 ± 1.76	39.60 ± 4.15	0.84	62.90 ± 2.15	58.90 ± 1.62	61.92 ± 4.61	69.62 ± 14.13	0.59
SDF %	11.14 ± 1.69	11.74 ± 1.51	11.05 ± 3.12	11.99 ± 1.75	0.82	6.95 ± 1.31^{a,b}	7.53 ± 1.32^{b}	7.70 ± 2.29^{a,b}	8.32 ± 1.69^{a}	**0.04**

AP – Apple pomace; CS – Coffee silver skin; US – Power ultrasound treatment; TDF – Total Dietary fibre; IDF – Insoluble dietary fibre; SDF –soluble dietary fibre

$^{a-c}$ Mean values without the common letter in each testing parameter are significantly different (P < 0.05).

Table 2. Effect of ultrasound treatment on the water and oil absorption capacity of the ingredients

	Apple Pomace					Coffee Silver skin				
	AP Control	**AP Freeze dried**	**AP US 15 min**	**AP US 30 min**	**p - value**	**CS Control**	**CS Freeze dried**	**CS US 15 min**	**CS US 30 min**	**p- value**
WAC g water/g dry sample	2.92 ± 0.15^{c}	2.95 ± 0.09^{b,c}	3.13 ± 0.20^{b}	3.50 ± 0.19^{a}	**< 0.01**	3.19 ± 0.30	3.03 ± 0. 24	3.49 ± 0.23	3.62 ± 0.22	0.07
OAC g oil/ g dry sample	1.03 ± 0.04^{c}	1.22 ± 0.14^{b}	1.36 ± 0.11^{b}	1.64 ± 0.16^{a}	**< 0.01**	2.84 ± 0.19	2.86 ± 0.46	3.34 ± 0.73	3.58 ± 0.41	0.25

Where WAC – water absorption capacity; OAC – Oil absorption capacity; AP – apple pomace; CS- coffee silver skin; US – power ultrasound treatment

$^{a-c}$ Mean values without the common letter in each testing parameter are significantly different (P < 0.05).

Table 3. Results of particle size distribution analysis and colour analysis of apple pomace and coffee silver skin powders

	Apple pomace				Coffee silver skin			
	AP Control	**AP US 15 min**	**AP US 30 min**	**p - value**	**CS Control**	**CS US 15 min**	**CS US 30 min**	**p- value**
D (3,2) µm	30 ± 0.00^{b}	70 ± 0.00^{a}	70 ± 0.00^{a}	**< 0.01**	96.36 ± 9.80^{b}	109.67 ± 3.05^{a,b}	118.33 ± 1.15^{a}	**< 0.01**
D (4,3) µm	82.93 ± 2.65^{c}	150.67 ± 1.52^{a}	138.33 ± 4.72^{b}	**< 0.01**	201.67 ± 37.87	169.67 ± 8.62	193.33 ± 1.52	0.223
D 90 µm	193.33 ± 8.08^{c}	290.00 ± 1.73^{a}	266.67 ± 8.38^{b}	**< 0.01**	335.67 ±34.64^{a,b}	292.00 ± 21.07^{b}	346.33 ± 4.72^{a}	**0.037**
L*	30.88 ± 3.60^{a}	24.75 ± 1.16^{b}	25.56 ± 3.34^{b}	**< 0.01**	20.46 ± 0.85^{b}	24.04 ± 2.38^{a}	23.06 ± 1.51^{b}	**< 0.01**
a*	5.85 ± 0.62^{b}	6.84 ± 0.34^{a}	6.75 ± 0.49^{a}	**< 0.01**	6.50 ± 0.24^{a}	6.39 ± 0.20^{a,b}	6.16 ± 0.15^{b}	**0.007**
b*	21.35 ± 0.25^{b}	23.05 ± 0.95^{a}	22.94 ± 1.40^{a}	**0.001**	21.98 ± 0.56	21.81 ± 0.08	21.52 ± 0.80	0.308
ΔE		6.43	5.42			3.58	2.66	

$^{a-c}$ Mean values without the common letter in each testing parameter are significantly different (P < 0.05).

Table 4 Consistency co-efficient (K), flow behaviour index (n) and apparent viscosity of apple pomace and coffee silver skin ingredients treated with Ultrasound for 15 and 30 mins

	AP Control	**AP US 15 min**	**AP US 30 min**	**CS Control**	**CS US 15 min**	**CS US 30 min**
Consistency co-efficient K (Pa s^n)	2.36×10^{-2}	1.26×10^{-2}	1.09×10^{-2}	2.76×10^{-1}	2.24×10^{-2}	1.49×10^{-2}
Flow behaviour index n	0.623	0.744	0.856	0.194	0.674	0.734
R- squared R^2	0.897	0.950	0.982	0.726	0.964	0.965
Apparent viscosity at shear rate 100 s^{-1} (Pa. s)	3.94 ± 2.52	3.26 ± 0.53	4.33 ± 1.14	3.41 ± 1.93	2.94 ± 1.51	3.87 ± 1.47