Upcycling of food side streams: the benefits of twin-screw granulation of apple pomace

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Key words

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Introduction

Sustainable food production and circularity in the food industry are of critical importance to reduce our carbon food print. Food side streams, although rich in nutrients, have poor techno-functional properties, which limits their use in food application. For example, apple pomace, which is the major by-product of the juice industry, is hardly used for pectin extraction or as animal feed. Most of it ends as waste, as its poor solubility does not allow for its further use as food ingredient.

To date, there is still a knowledge gap and a lack of technology to modify the pomace and improve its properties. Some authors (1, 2, 3) have shown that chemical, enzymatic, and/or mechanical treatments lead to the disruption of the cell wall, which then can modify the techno-functional properties of apple pomace. For this reason, extrusion technology, as a continuous and versatile process, is a promising way to ensure the use of apple pomace in other applications. During the extrusion process, material is heated and sheared simultaneously.

Schmid et al (2021) (4) have already demonstrated that by extruding apple pomace, the water holding capacity increases and the amount of soluble fibers increases, which helps the water-based extraction of pectic compounds. However, the authors used a rod strand die at the end of the extruder. Hence, an additional milling step of the extrudate was required to use and characterize the newly functionalized apple pomace. For this reason, this work opted for twin-screw granulation to functionalize the apple pomace. By using an open discharge (see Figure 1) on the end of the extruder barrel, materials can be granulated/agglomerated. This improves the flow properties of the material, could rupture the cell wall, and create porous structures that improve the water binding capacity. All of this is possible without having to mill the extrudate

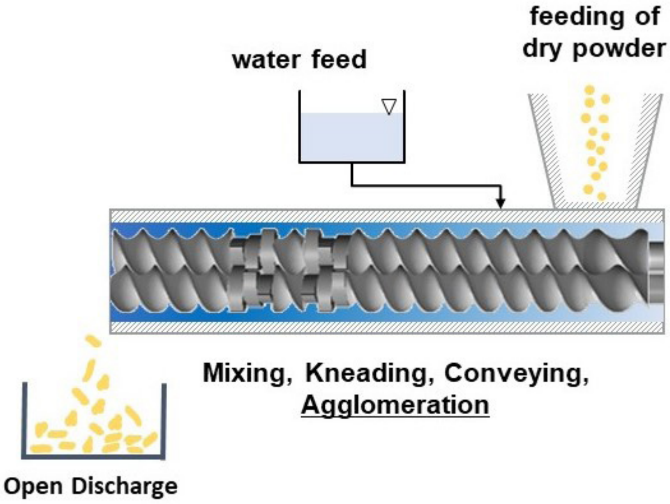

Figure 1: Schematic of granulation process using twin-screw extrusion.

Materials and methods

Extrusion trials

Extrusion trials were conducted using a 11 mm co-rotating Thermo Scientific™ Process 11 Twin-screw Extruder. The extruder has a split-barrel design, with a length to diameter ratio (L/D) of 40. The barrel is fully ported and each of its eight sections can be cooled or heated independently. The extruder was used with the granulation kit, composed of shafts with 40 ¾ L/D length, a shaft holder, and an open discharge. The solids were fed with a gravimetric twin-screw feeder, and a peristaltic pump for water feeding.

Apple pomace (0.2, 0.4, or 0.6 kg/h) was fed into the first section; water (0.06, 0.12, or 0.18 kg/h) was added in the second section. The water to solid ratio remained constant throughout the whole process at 23 wt% added water. Extrusion experiments were performed applying screw speeds of 400 or 600 rpm. The barrel temperatures were adjusted to $T_{barrel2}$= 40 °C, $T_{barrel3}$= 60 °C, $T_{barrel4}$= 80 °C, $T_{barrel5-7}$= 120 °C, as proposed by Schmid et al. (2021) (4).

Rheological characterization

Dispersions of raw or granulated apple pomace and water were made by mixing 1 g of sample with 20 mL of tap water. The dispersion was quickly stirred and immediately placed between the plates of the rheometer for measurement.

Oscillatory measurements were conducted using a rotational rheometer, the Thermo Scientific HAAKE™ Mars™ iQ Air Rheometer, equipped with plate-plate measurement geometry. The measurement gap was adjusted to 1.5 mm.

After being placed for measurement, samples underwent oscillatory shear at 20 °C with an amplitude of 1% and a frequency of 1 Hz over 20 minutes. 60 measurement points were recorded. The measurements were conducted within the linear viscoelastic region to avoid a destruction of a network.

Scanning Electron Microscope

The samples were observed using a Phenom XL scanning electron microscope, using high vacuum. All samples were fixed onto aluminum holders with double sided carbon adhesive discs. All images were taken at an operating voltage of 15 kV.

Results

The techno-functional properties of apple pomace were improved by the wet granulation process. The material resulted in a porous powder with high water binding capacity and the ability to gel the immediately after the addition of water (see Figure 2).

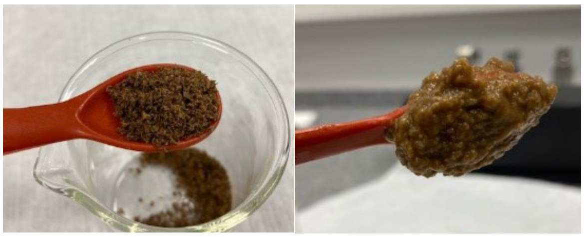

Figure 2: Granulated apple pomace (left), granulated apple pomace with added water (right).

Influence of throughput

The residence time of apple pomace inside the extruder depends on the total throughput. Doubling the total throughput reduces the material residence time in half. Such alterations lead to different exposures to shearing and heat that can result in different degrees of cell wall rupture. Therefore, although the material is exposed to the same processing conditions, the resulting properties may vary.

In order to check if the residence time affects the gelation, properties of granulated apple pomace were measured using time sweeps. As seen in Figure 3, all samples form a gel / paste when mixed with water, as the storage moduli of all samples is greater than their respective loss moduli.

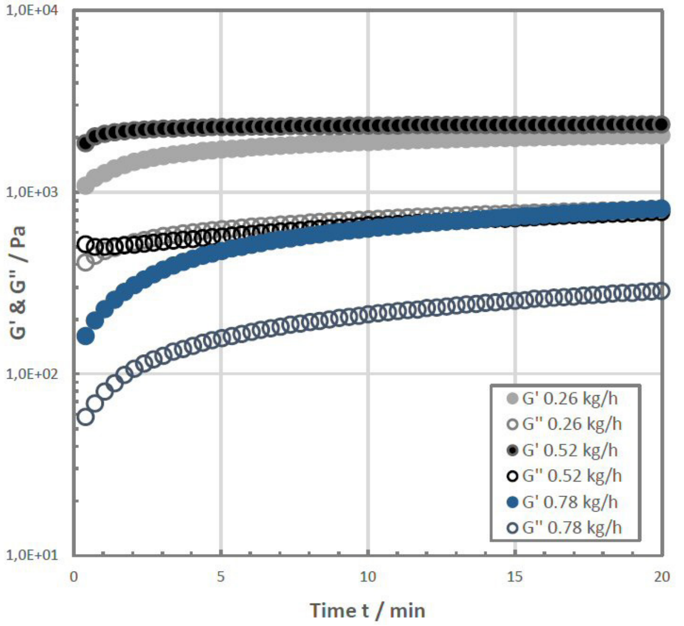

Figure 3: Time sweeps of granulated apple pomace and water processed at varying throughputs; constant process conditions: 400 rpm screw speed, 40/60/80/100/120/120/120 °C barrel temperature, 23 wt% added water.

However, as depicted in Figure 3, the gel strength and gelation kinetics depend on the residence time inside the extruder. The rupture of the cell wall requires a minimum amount of energy input over a certain time, so the polysaccharides responsible for the gelation and water binding can be released. This could an explanation why the depicted samples display different gelation behaviors over time, even though the screw and temperatures were kept constant.

Besides determining the residence time inside the extruder, the throughput influences the resulting particle size and compactness in a granulation process. The compactness can also affect the gelation kinetics, as the pore size distribution of the granules determine the swelling properties of the particles. The surface properties of the particles were assessed by means of scanning electron microscopy. Selected images are found in Figure 4.

As seen in Figure 4, the total throughput during the extrusion process influences the surface properties of the granules. A lower throughput leads to looser and more porous particles. This could be due to the low filling of the screws and barrel. On the other hand, high throughputs result in more compact structures. The porosity of the granules could be a reason why the samples show different gelling behaviors, as demonstrated in Figure 3.

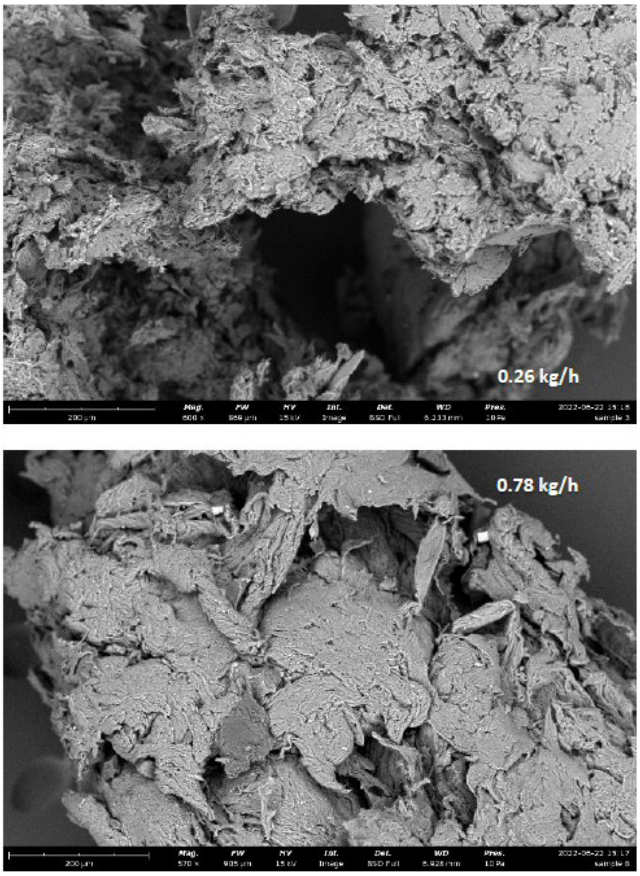

Figure 4: Scanning electron micrograph of granulated apple pomace, granulated with 23 wt% added water. Upper micrograph: 0.26 kg/h throughput. Bottom micrograph: 0.78 kg/h throughput.

Influence of screw speed

As seen in the previous section, the functionalization of the apple pomace requires a certain amount of mechanical and thermal energy input in order to properly access the intracellular polysaccharides. Therefore, the effect of the screw speed on the gelation/swelling properties of granulated apple pomace was tested. Increasing the screw speed does not affect the residence time. However, it increases the shearing stress and can also lead to a material temperature rise due to friction. This can cause extrusion-based degradation. Some authors have demonstrated that non-enzymatically treated apple pomace (5) and chokeberry pomace (6) are sensitive to thermo-mechanical stress, which can reduce the gelation and water-binding capacity of these material.

As seen in Figure 5, the increase in screw speed does affect the gelation kinetics and ability of the granulated apple pomace.

Increasing the screw speed from 400 to 600 rpm changes the gelling/swelling properties. Those properties of the apple pomace decrease significantly, as seen in the overall decrease of the storage and loss modulus. As previously stated, this could be caused by the degradation of polysaccharides.

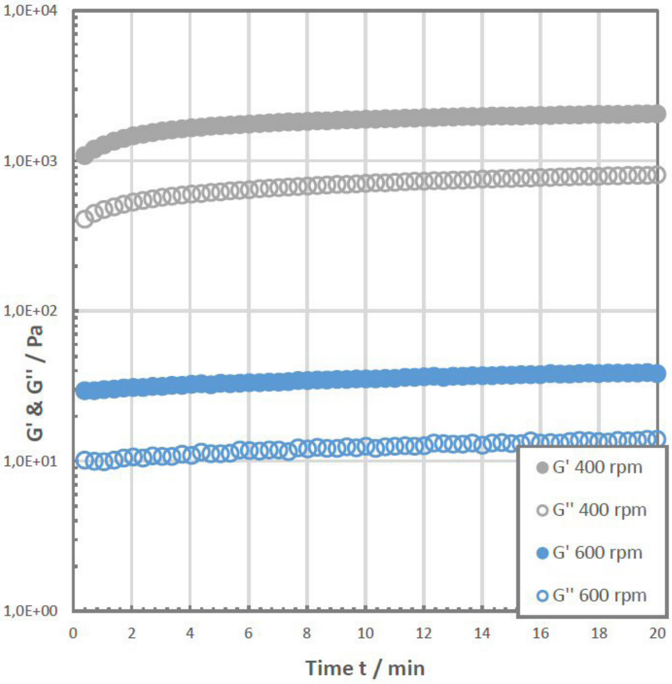

Figure 5: Time sweeps of granulated apple pomace and water processed at varying screw speeds; constant process conditions: 0.26 kg/h throughput, 40/60/80/100/120/120/120 °C barrel temperature, 23 wt% added water.

Conclusions

This application note showcases the functionalization of apple pomace from commercial fruit juice production by twin-screw granulation. The results showed that by varying the throughput, different gelling/swelling properties can be achieved. Moreover, the limits of the treatment were shown. It was demonstrated that too-high thermo-mechanical treatments can lead to polysaccharide degradation, which decreases the gelling properties of apple pomace. In all, twin-screw granulation is a promising technology to functionalize waste streams from the food industry.

References

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