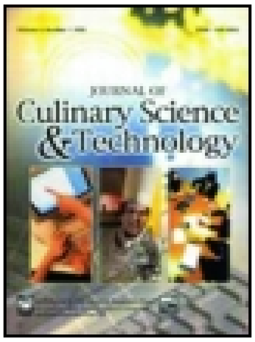

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ABSTRACT
Carrot processors produce approximately 175,000 tons of waste annually in the United State of America. Carrot waste conversion is important to the carrot processing industry as this waste is rich in bioactive compounds and dietary fiber. We evaluated the effects of hydraulic press and expeller press on liquid and bioactive compound extractions. Mechanical separation of carrot mash by expeller pressing improved liquid extraction over the hydraulic press while simultaneously increasing the total solid, carotenoid, and polyphenol contents. Compared to untreated control mash, mechanically treated mash had higher fat-binding capacity. Our study indicates that further conversion of carrot mash could lead to better value streams for this byproduct.

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Food waste; carrot mash; functional properties; carotenoids; expeller press; hydraulic press

Introduction

The Food and Agriculture Organization of the United Nations (FAO) estimated that one-third of the edible food produced for human consumption is wasted each year, equating to almost 1.3 billion metric tons (Gustavsson, Cederberg, Sonesson, van Otterdijk, & Meybeck, 2011). In developing and industrialized countries, food losses and waste cost 310 USD billion and roughly 680 USD billion each year, respectively (Food and Agriculture Organization of the United Nations, 2019). Food loss and waste have a direct impact on the world's food supply and represent a major expenditure of resources, including water, land, energy, labor, and capital. In addition, wholesome food going to waste can be used to nourish families in need. In 2018, 14.3 million U.S. households (11.1%) were food insecure. These households had difficulty providing enough food to all members due to a lack of financial resources (Coleman-Jensen, Rabbitt, Gregory, & Singh, 2019). In the U.S., food waste is the largest contributor to landfills, which are the third-largest source of methane emission, a potent greenhouse gas that contributes to climate change (USDA, 2015).

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This waste of our natural resources was identified more than a decade ago, causing more and more legislations to be established. Recently, the United Nations prioritized a comprehensive approach to the reduction of food waste by reducing, recovering, redistributing, and reusing food waste generated in production and supply chains (United Nations, 2020).

While efforts to eliminate food waste at the consumer level are of primary importance, the waste generation at the production and processing levels must not be ignored (California Department of Food and Agriculture, 2017). California continues to lead the US in fresh and processed vegetable production, accounting for the annual production of nearly 60% of fresh market vegetables, which generates nearly 7.6 USD billion from 80% of the fresh carrot production in the US. (Parr, Bond, & Minor, 2019). The processing of fresh cut and peeled carrots results in the generation of large amounts of waste, which contains valuable bioactive compounds that can be utilized for animal and human consumption instead of a simple discharge. Large-scale commercial carrot processors can produce up to 175,000 tons of carrot waste annually (K. Williams, personal communication, May 3, 2018). Carrot waste exists in two forms, pomace, and mash. Pomace is the byproduct of carrot juice, and mash is the byproduct of peeling and cutting of ready-to-eat carrot products (i.e., peeled baby carrots, matchsticks, shredded carrots, and carrot chips). Carrot waste is unique because it is often edible and nutrient-dense, compared to cauliflower or broccoli waste, which is mainly leaves and stalks.

Numerous studies have investigated the functional properties and potential uses of carrot pomace (Adeola et al., 2017; Filipini, 2001; Gull, Prasad, & Kumar, 2015; Kumari & Grewal, 2007; Mahsa, Vosooghi Poor, Gholamreza, Jalal, & Asgar, 2017; Psimouli & Oreopoulou, 2017; Schweiggert, 2004; Stoll, Schweiggert, Schieber, & Carle, 2003a; Turksoy, Keskin, Ozkaya, & Ozkaya, 2011; Turksoy & Ozkaya, 2011). Carrot pomace has the following composition: 52% total dietary fiber, 42% insoluble dietary fiber, and 9% soluble dietary fiber (Hernández-Alcántara, Totosaus, & Pérez-Chabela, 2016). The functionality of dietary fiber is directly related to the structure of the polysaccharides, which can be modified. Soluble and insoluble dietary fibers differ in their functional and physiological properties (Wichienchot & Ishak, 2017). Among these properties, water-holding capacity (WHC) and fat-binding capacity (FBC) are the two most important ones because they can prevent water and fat loss, respectively, during cooking and displaying. The WHC of carrot dietary fiber is in the range of 18–23 g water/g fiber (Fuentes-Alventosa, Rodríguez-Gutiérrez, Jaramillo-Carmona, & Espejo-Calvo, 2009; Robertson, Eastwood, & Yeoman, 1980), which is about three times higher than citrus fiber (FiberStar, 2019). Furthermore, cooking loss is reduced by 6.5% when 1% barley-beta glucan and carrot fiber are added to fresh beef and turkey sausage, which is a huge benefit to the meat industry (Ben Slima et al., 2019).

Considering the potential connection between an over consumption of animal fat and a high risk of obesity, arteriosclerosis, and coronary heart disease (de Vries, 2007; Hu et al., 2000; Xu et al., 2006), it is very important to reduce fat contents in processed meat products by adding dietary fiber (Ben Slima et al., 2019).

Another important property of fibers is the swelling capacity (SC). Carrot dietary fiber and coconut fiber have a similar SC (18.95–23.40 mL water/g dry matter), which is noticeably higher than that of apple and citrus fibers (6.11 mL water/g dry matter) (Chantaro, Chiewchan, & Devahastin, 2008; Figuerola, Hurtado, Estévez, Chiffelle, & Asenjo, 2005; Raghavendra, Rastogi, Raghavarao, & Tharanathan, 2004).

Carrot pomace has been added to foods, such as breads, cakes, dressings, and high-fiber biscuits (Filipini, 2001; Kumari & Grewal, 2007). However, very little research has been conducted on carrot mash. The functionalities of carrot pomace and carrot mash are likely different, because of the differences in manufacturing processes used to obtain pomace (grinding, pressing, and heat treatments) and mash (cutting, peeling, and polishing), which impact the fiber composition and structure.

In this study, we investigated the mechanical treatments of carrot mash with respect to increasing the extraction of liquid, carotenoids, and polyphenols. The impact of these mechanical treatments on the functions of WHC, FBC, and SC were evaluated.

Materials and methods

Characterization of carrot mash

Carrot mash was obtained from a commercial carrot growing and processing company in Arvin, California. Carrots were grown in various regions of California, Nevada, and Washington in ideal conditions year-round. Once harvested, the carrots were transported to processing facility and sorted into different processing tracks. Carrot mash (100 kg) was collected and immediately stored in 22 kg plastic buckets in dark at −20°C until use.

Mechanical separation of carrot mash

Mechanical separation of carrot mash into liquid and solid fractions was performed using either a hydraulic Welles Juice Press (Samson Brands, Danbury, CT, USA) or a Newtry CN-92 G Expeller Press (BEAMNOVA, Guangdong, China). Following the separation, liquid and solid portions of the carrot mashes were analyzed.

Percent extractable matter

After the mechanical press of 280 g carrot mash, the liquid and solid portions' weights were recorded. The percent extractable matter of the liquid (PEM_L) and solid (PEM_S) fractions were calculated as follows:

$$PEM_L = \frac{Liquid\ wt(g)}{Initial\ wt(g)} X100 \tag{1}$$

$$PEM_S = \frac{Solid\ wt(g)}{Initial\ wt(g)} X100 \tag{2}$$

Total solids content

Total solids content (TS) was determined for each fraction recovered from the hydraulic or expeller press. Approximately 7 g carrot mash was weighed and placed in a drying oven (NAPCO Model 620, Thermo Scientific, Waltham, MA, USA) at 100°C for 24 h. The TS was calculated using the following equation:

$$TS(\%) = \frac{Dried\ wt(g)}{Initial\ wt(g)} X100 \tag{3}$$

Carotenoid content

Carotenoid in the mash was extracted by hydraulic or expeller press, and their contents were determined according to the method described by Lee (2001). Carrot mash samples were homogenized for 30 s using a mixture of hexane, acetone, and ethanol (50:25:25 v/v) in blender (Vitamix Professional Series 500, Cleveland, Ohio, USA). The homogenized samples were then centrifuged (Eppendorf 5810 R Centrifuge, Hauppauge, NY, USA) for 5 min at 5432 x g and 5°C. After centrifugation, the upper organic layer containing color and hexane was transferred to a 25 mL volumetric flask and adjusted to 25 mL with additional hexane. Absorbance was measured at 450 nm with a Genesis-5 Spectronic spectrophotometer (Thermo Scientific, Waltham, MA, USA). Carotenoid content was calculated according to Beer's law (ε = 2,505 ml/mg/cm).

Total polyphenol content

Phenolic content was determined using a modified Folin-Ciocalteu method described by Waterhouse (2002). Carrot mash samples were similarly processed as described above (carotenoid content). Briefly, 70 mL deionized water and 5 mL Folin-Ciocalteu reagent were added to 1 mL carrot sample or standard solutions (50–500 mg/L gallic acid) prior to incubation at room temperature for approximately 8 min. Then, 15 mL of 20% Na_2CO_3 (w/v) aqueous solution was added, and the final volume was adjusted to 100 mL with deionized water. The mixture was incubated for 2 h at 20–25°C. Absorbance were read at 760 nm with a Genesis-5 Spectronic spectrophotometer (Thermo Scientific, Waltham, MA, USA). Results were calculated to express mg gallic acid equivalent (GAE) per gram of sample based on a calibration curve obtained using gallic acid.

Functional properties

The functional properties of unpressed, expeller-pressed, and hydraulic-pressed carrot mashes were evaluated. Mash was dried at 40°C for 24 h in a Harvest Saver R4 drying oven (Commercial Dehydrator Systems, Inc. Eugene, OR, USA), ground using a blender (Vitamix Professional Series 500 Cleveland, OH, USA) at speed 4, and filtered through a #20 mesh sieve (0.85 mm pore size).

Water-holding capacity

Water Holding Capacity (WHC) was determined as described by (Raghavendra et al., 2004). Dried carrot mash (0.50 g) was added to 15 mL water. After 24 h, the supernatant was filtered through a sintered glass crucible under vacuum. The weight of the hydrated residue was recorded before being dried at 105°C for 2 h to obtain the residue dry weight.

The WHC was calculated as:

$$WHC\left(\frac{g\ water}{g\ dry\ mash}\right) = \left[\frac{(residue\ hydrated\ weight - residue\ dry\ weight)}{(residue\ dry\ weight)}\right] \quad (4)$$

Fat-binding capacity

Fat-binding capacity (FBC) was determined using the modified Beuchat method (Beuchat 1977). Canola oil (5.6 g) was added to dried carrot mash (1.0 g). The slurry was vortexed for 30 s, incubated for 30 min at 25°C, and centrifuged at 1,610 × g for 25 min. The decanted supernatant was weighed and retained oil per gram of sample was calculated.

$$Fat\ Binding\ Capacity\left(\frac{g}{g}\right) = \frac{Weight\ of\ decanted\ supernatant}{Weight\ of\ initial\ sample} \quad (5)$$

Swelling capacity

Swelling capacity (SC) was determined according to Raghavendra et al. (2004). Twenty-five mL deionized water was added to dried carrot mash (1 g) into a 50 mL graduated cylinder, which was covered with parafilm to reduce evaporation. The samples were incubated at room temperature for 24 h. Then, the volume of the swollen sample was measured, and SC was expressed as mL water per g carrot mash.

$$Swelling\ Capacity\left(\frac{mL}{g}\right) = \frac{Volume\ occupied\ by\ sample}{Original\ sample\ weight} \tag{6}$$

Statistical analysis

Statistical analysis on all tests was reported as means ± standard deviation of three replicates. Statistical differences were evaluated using one-way ANOVA and pair-wise comparisons were evaluated using Tukey's *post hoc* tests using JMP Pro 12 ($P < .05$; SAS Institute, Cary, NC).

Results and discussion

Percent extractable matter

Percent extractable matter (PEM) was used to compare the separation of liquid and solid fractions by the two mechanical presses (expeller and hydraulic) (Table 1). Regardless of extraction type, 93% of the liquid and solid fractions was recovered from carrot mash, illustrating that both solid and liquid are effectively separated during processing. Percentage extractable matter of liquid (PEM_L) recovered from the expeller press was 9.5% higher ($P < .05$) than the PEM_L obtained with the hydraulic press. However, the percentage extractable matter of solid (PEM_S) from the hydraulic press was significantly higher than from the expeller press (24% vs. 17%). *Citrus depressa* processed by screw press had a 42.5% higher juice yield compared to that of belt-pressing (Takenaka et al., 2007). Similarly, screw pressing produced higher apple juice yields than basket pressing (Kobus, Nadulski, Anifantis, & Santoro, 2018). Belt-pressing and basket pressing are similar to hydraulic pressing in that they all use compressive force to extract liquid from solids. While a screw press and expeller press both use high shear to extract liquid from solids.

Hydraulic pressing is less invasive, as it uses only compressive rather than high shear force, as in the case of the expeller press. The shearing of carrot cells in the mash by the expeller press damages the cells and increases liquid release (Jaeger, Schulz, Lu, & Knorr, 2012; Nadulski et al., 2015). In accordance with

Table 1. Impact of two physical extraction methods on the percent extractable matter in commercially produced carrot mash.

Extraction method	PEM_L	PEM_S
Expeller press	76.04 ± 3.44[a]	16.60 ± 3.09[a]
Hydraulic press	69.44 ± 5.16[b]	23.77 ± 0.36[b]

Values are means and standard deviations of 3 replicates.
Values in the same column with different letters are significant difference ($p < 0.05$).
PEM_L: Percentage extractable matter of liquid; PEM_S: Percentage extractable matter of solid

Table 2. Impact of two physical extraction methods on the moisture content of commercially produced carrot mash.

Extraction method	Moisture (%)
Unpressed	95.30 ± 0.51^{a}
Expeller press	83.33 ± 2.98^{b}
Hydraulic press	86.67 ± 4.12^{b}

Values are means and standard deviations of 3 replicates.
Values in the same column with different letters are significant difference (p < 0.05).

the previous reposts, our results demonstrate that the less invasive compression by the hydraulic press released less liquid from the solid fractions.

Prior to extraction, the moisture of carrot mash was 95.3%, which is significantly higher than those (83.3–86.7%) of hydraulic and expeller mashes after pressing (Table 2). The extracted juice is composed of water, carotenoids, soluble carbohydrates, and pectin (Di Giacomo & Taglieri, 2009; Nadulski et al., 2015).

Total solids content

There was no significant difference between the solid contents of the carrot mash produced by the expeller or hydraulic press (Table 3). The solid contents from the expeller and hydraulic-pressed mashes were significantly higher than those of the liquid fractions from both pressing methods, but the solid contents were not significantly different. Wilczynski, Kobus, and Dziki (2019) reported that apple juice produced by screw press had significantly higher soluble solids compared to that produced by basket press. They attributed this to the fact that the screw press produces a wider opening in the cell membrane and thereby higher nutrient release. We did not observe any significant difference in the solid contents of the liquid fraction between press treatments. This may be due to the nature of our product. Our carrot mash contains only the outer peeling of the carrot, not the whole root. The unit operations involved in baby carrots production, including washing, cutting, peeling, and shaping, may have ruptured cell membranes allowing nutrients to leach out.

Table 3. Impact of two physical extraction methods on the total solid contents in commercially produced carrot mash.

Carrot mash sample	Liquid fraction (%)	Solid fraction (%)	Total solid content (%)
Expeller	1.03 ± 0.43 ^{a}	16.62 ± 4.32^{b}	17.65 ± 4.21^{b}
Hydraulic	0.60 ± 0.30 ^{a}	14.34 ± 5.59^{b}	14.94 ± 5.44^{b}

Values are means and standard deviations of 3 replicates.
Values with different letters are significant difference (p < 0.05).

Table 4. Impact of two physical extraction methods on the carotenoid contents in commercially produced carrot mash.

Carrot Mash Sample	CC (mg/kg) Liquid fraction	CC (mg/kg) Solid fraction	Total CC (mg/kg)
Unpressed	N/A	N/A	0.08 ± 0.01 [c]
Expeller press	0.69 ± 0.02[a]	0.19 ± 0.00[a]	0.88 ± 0.01[a]
Hydraulic press	0.12 ± 0.00[b]	0.36 ± 0.04[b]	0.49 ± 0.03[b]

Values are means and standard deviations of 3 replicates.
Values in the same column with different letters are significant difference ($p < 0.05$).
CC: Carotenoid Content

Carotenoid Content

The carotenoid content (CC) of carrot mash is shown in Table 4. Mechanical separation of the carrot mash significantly increased the extraction of carotenoids. The disruption of the cell walls allows for higher extraction of β-carotene, regardless of the pressing method (Moelants et al., 2012). Jaeger et al. (2012) found that pulsed electric field-based disintegration of cells reduces the particle size and increases the released carotenoid content to 48.5 mg/L.

Compared to the hydraulic press, the expeller press extracts a higher carotenoid amount, which could be explained by the breakdown and release of the trapped carotenoid crystals in the cells (de la Rosa, Alvarez-Parrilla, & Gonzalez-Agular, 2010). The carotenoid content (CC) in the liquid fraction of the expeller press was significantly higher (0.69 ± 0.02) than that in the liquid portion from the hydraulic press (0.12 ± 0.00). No significant differences in CC are observed when carrot mash is finely ground prior to carotenoid analysis (Stoll, Schweiggert, Schieber, & Carle, 2003b). A higher value of CC in our study than Stoll et al. (2003a,b) was observed in our study (40 ppm) was reported for carrot pomace when finely ground. This could be attributed to the difference between the two carrot studies. We evaluated CC contents in carrot liquid and solid while Stoll et al. (2003a) focused on carrot pomace only. Considering the gradual increase in carotenoid content from the skin to the core of a carrot, higher CC values in carrot pomace compared to carrot mash are expected (de la Rosa et al., 2010). Overall, the high shear from the expeller press was more effective at extracting total carotenoids than the hydraulic press (or unpressed mash), presumably because expellers are more efficient at rupturing the cell walls and leads to the release of trapped compounds (Jeffery, Holzenburg, & King, 2012; Knockaert, Lemmens, Van Buggenhout, Hendrickx, & Van Loey, 2012).

Total polyphenol content

The polyphenol content in the liquid fraction of the two pressed samples were not significantly different, but the content significantly increased in the solid

Table 5. Impact of two physical extraction methods on the total polyphenol contents in commercially produced carrot mash.

Carrot Mash Sample	Polyphenol – liquid (mg GAE[1]/100 g)	Polyphenol – solid (mg GAE/100 g)	Total polyphenol (mg GAE/100 g)
Unpressed	N/A	N/A	57.54 ± 20.56^b
Expeller press	61.09 ± 8.17^a	51.75 ± 11.92^a	112.84 ± 13.53^a
Hydraulic press	62.34 ± 5.77^a	81.76 ± 4.09^b	144.10 ± 1.70^a

Values are means and standard deviations of 3 replicates.
Values in the same column with different letters are significant difference ($p < 0.05$).
GAE: Gallic acid equivalents.

fraction of the hydraulic-pressed mash (81.76 ± 4.09) compared to that in the solid fraction of the expeller-pressed mash (51.75 ± 11.92). The total phenolic content in unpressed carrot was 57.54 ± 5.14 mg GAE/100 g, which significantly increased after expeller and hydraulic pressing (by 196% and 250%, respectively; Table 5). Alasalvar, Grigor, Zhang, and Quantick (2001) reported a total phenolic content in whole orange carrots (16.21 ± 0.21 mg/100 g), which is lower than our values (57.54 mg GAE/100 g in unpressed mash).

The phenolic content in a carrot is higher in the peel than in the core (Sharma, Karki, Thakur, & Attri, 2012). The peel contains 54.1% of the total phenols, while the phloem and xylem tissues contain only 39.5% and 6.4% total phenols, respectively. Therefore, the higher phenolic content reported in carrot mash than in whole carrots is expected (Alasalvar et al., 2001).

Our study showed higher amounts of phenol compounds in the pressed samples, presumably due to the mechanical force that releases more bound phenols (Parthasarathi, Subramanian, & Sathyamurthy, 2005). Similarly, black carrot peels (5,170 mg GAE/100 g dry weight) and black carrot pomace (4,151 mg GAE/100 g dry weight) accounted for a higher polyphenol percentage compared to whole black carrots (54,743 mg GAE/100 g dw), likely due to the release of bound compounds upon the breakdown of cellular components (i.e., cellulose and cellulose-pectin composites) (Kamiloglu et al., 2016).

Water-holding capacity

Water-holding capacity (WHC) is defined as the "ability of a matrix of molecules, usually macromolecules at low concentrations, to physically entrap certain amounts of water under the application of an external or gravitational force" (Reid & Fennema, 2008). WHC of carrot mash significantly decreased with mechanical treatment, with no significant difference observed between the two mechanical treatments (Figure 1).

As the fiber size increases, so does the volume of trapped water (Thebaudin, Lefebvre, Harrington, & Bourgeois, 1997). It has been known that mechanical treatments can damage the fiber chains and reduce their ability to trap water (Zhao, Wu, Wang, Jing, & Yue, 2017). More specifically, mechanical

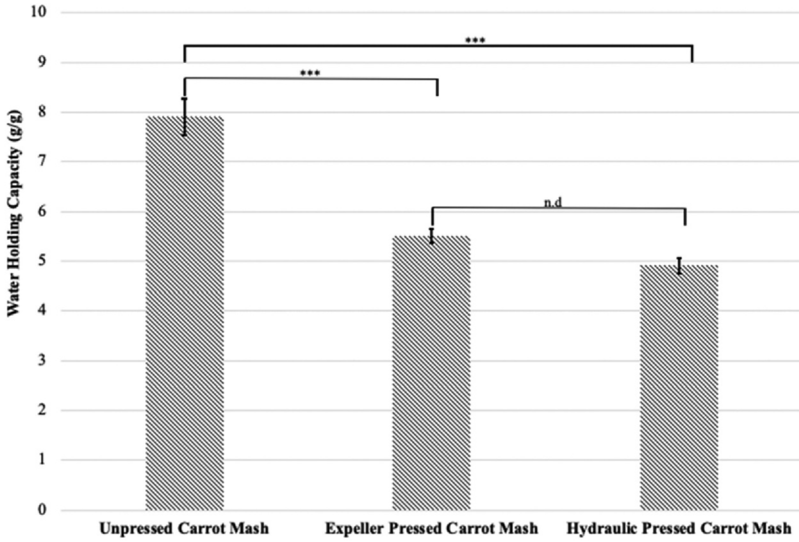

Figure 1. Impact of two physical extraction methods on the average water-holding capacity of carrot mash. ***p < .001; n.d. = no significant difference ($p < .05$).Error bars represent standard deviations.

treatments can collapse the porous matrix formed by the carbohydrate chains that can hold liquids (Gao, Chen, Zhang, & Meng, 2020).

Insoluble dietary fiber, alcohol-insoluble fiber, and water-insoluble fiber of carrot pomace were reported as 13.20 mL/g, 8.73 mL/g, and 18.70 mL/g, respectively (Chau, Chen, & Lee, 2004). The WHC of carrot fibers was reported to be 17.90–23.30 g/g (Robertson et al., 1980). Previous studies reported higher WHC values than our findings: 7.91 g/g for unpressed, 5.51 g/g for expeller-pressed, and 4.91 g/g hydraulic-pressed mash. These differences could be attributed to the differences in the nature of the substrates.

The porous structure formed by polysaccharide chains in plant materials holds large amounts of water through hydrogen bonds, thereby conferring beneficial functionality to plant materials (Sharoba, Farrag, & Abd El-Salam, 2013). Two important factors affecting the functionality of these polysaccharide chains are the ratio of insoluble to soluble dietary fiber and the particle size of the product (Jaime et al., 2002). Carrots are rich in soluble fibers such as pectin, which have a higher WHC than insoluble fibers, and could explain the high WHC in carrot fibers.

The WHC of carrot pomace (19.72 g/g) is higher than that of orange peels, potato peels, and green pea peels (16.39, 15.62, and 13.48 g/g, respectively) (Sharoba et al., 2013). The total dietary fiber content of carrot pomace is 69.85%, which is lower than that of potato and green bean peels (73.25% and 71.30%, respectively). The total dietary fiber content of untreated mash was 75.90 ± 7.24%, which is in the range reported by Sharoba et al. (2013) for carrot pomace (69.85%).

The dietary fiber content of coconut waste after extraction of coconut milk (63.25%) was lower than that of the carrot mash (75.90%). However, their WHC was similar, with the values of 7.1 g/g – 7.9 g/g for coconut residue and unpressed carrot mash, respectively (Raghavendra et al., 2004). The WHC of coconut residue was higher than that of any other dietary fiber residues, including apple, potato, and wheat bran fibers (Raghavendra et al., 2004). These results imply that the waste from carrot processing could provide benefits similar to those of coconut fiber waste, which would be better than apple, potato, or wheat bran fiber.

Fat-binding capacity

Fat-binding capacity (FBC) is the ability of the fibers to absorb and encapsulate fat. Numerous factors impact the FBC of plant polysaccharides, including density, thickness, hydrophobic particle nature, particle size, and insoluble dietary fiber content (Sharoba et al., 2013). The FBC of unpressed and mechanically treated carrot mashes are shown in Figure 2. Unpressed carrot mash had an FBC of 1.91 g/g, which increased to 5.26 and 5.56 g/g for expeller-pressed and hydraulic-pressed carrot mash, respectively.

Surface properties contribute to the FBC of dietary fibers (Femenia, Lefebvre, Thebaudin, Robertson, & Bourgeois, 1997; Lopez et al., 1996). Mechanical disruption of the fiber may change the surface properties by

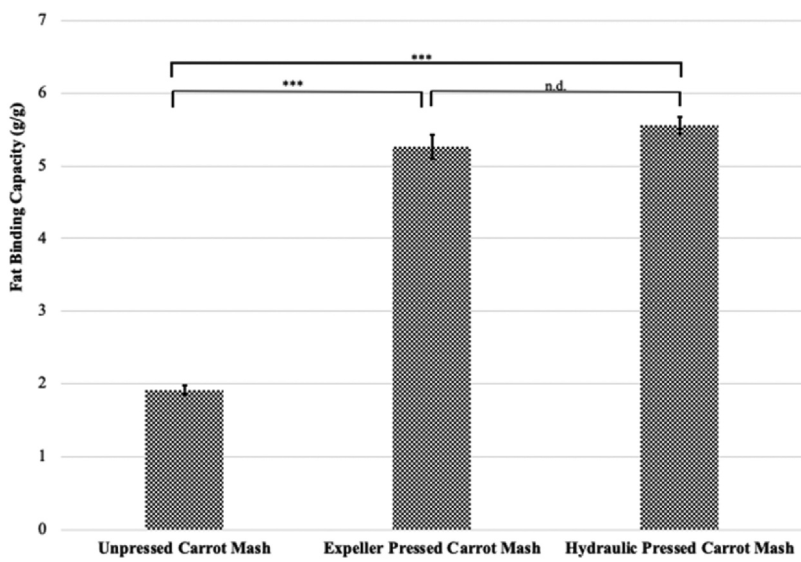

Figure 2. Impact of two physical extraction methods on the fat-binding capacity of carrot mash. ***p < .001; n.d. = no significant difference ($p < .05$).Error bars represent standard deviations.

bringing more hydrophobic regions to the surface. Additionally, fibers with a more porous structure have a higher affinity for oil (Gao et al., 2020).

The oil-holding capacity of carrot pomace was reported as 3.95 ± 0.17 g/g, which was higher than that of orange peel waste but lower than that of potato and green bean peels (Sharoba et al., 2013). Our results showed a higher FBC for expeller-pressed mash (5.26 ± 0.16 g/g) and hydraulic-pressed mash (5.56 ± 0.1 g/g) than unpressed control mash. The FBC of asparagus pomace increased from 1.85 g/g to 2.45 g/g as the fiber particle size decreased from 0.12 mm to ~0.03 mm, but as the fiber particles continued to decrease to ~0.005 mm, the FBC decreased to 2.02 g/g (Gao et al., 2020). The combination of mechanical pressing and dehydration may have reduced the size of the fibers and created a more porous structure compared to unpressed mash. Fibers from carrot pomace may be able to stabilize food emulsions with a high fat content, which supports our results (Sharoba et al., 2013).

Swelling capacity

Swelling capacity (SC) is defined as the ratio of the volume occupied when the sample is immersed in excess water after reaching equilibrium to the initial sample weight (Raghavendra et al., 2004). Importantly, WHC measurement includes a step to force water out of the structure by centrifugation or vacuum filtering, whereas SC measurement does not include this step. The SC of fibers can have a significant effect on physiological activities. A fiber with increased

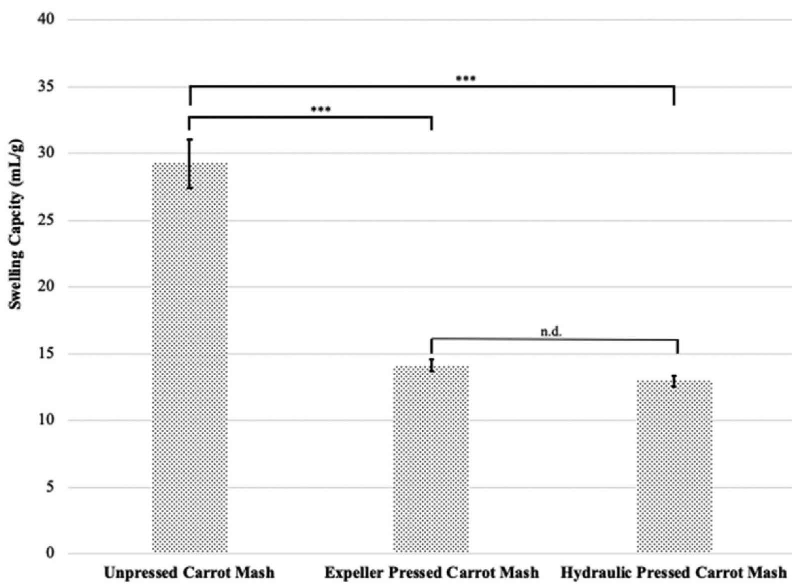

Figure 3. Impact of two physical extraction methods on the swelling capacity of carrot mash. ***p < .001; n.d. = no significant difference (*p* < .05).Error bars represent standard deviations.

SC can promote gastrointestinal motility and defecation, helping to prevent constipation. The SC of unpressed and mechanically treated carrot mashes is shown in Figure 3. The SC of unpressed carrot mash was 29.23 ± 1.81 mL/g, which was significantly lower than those (14.14 ± 0.45 mL/g and 12.96 ± 0.39 mL/g) of expeller and hydraulic mashes, respectively. The SC decreases with decreasing particle size, which is likely caused by damage to the fiber matrix during grinding (Raghavendra et al., 2004).

The SC of insoluble carrot fiber was 7.50 cm^3 ± 0.50 (Thebaudin et al., 1997). A slightly lower capacity was reported for coconut residue (20 mL/g) than that of our unpressed carrot mash (29.23 mL/g) (Raghavendra et al., 2004). The coconut fiber content is 63.25%, which was lower than the fiber content of our carrot mash (75.90%). In addition, the soluble dietary fiber content of coconut residue was 4.53%, while the soluble dietary fiber content of our carrot mash was 19.70%. Soluble dietary fiber is important for the functionality of dietary fibers because they (pectin and gums) possess higher WHC than cellulose fibers (Sharoba et al., 2013). The same study showed the SC of carrot pomace to be 23.96 ± 0.58 mL/g, which was lower than the unpressed mash in our study, but "higher swelling capacity" matrix (Sharoba et al., 2013). Both expeller and hydraulic pressing of carrot mash did not significantly increase the SC of the carrot mash.

Conclusion

Compare to previous studies on carrot byproducts, our study is unique in respect to using two main factors, (1) carrot mash rather than carrot pomace (carrot juice waste), and (2) commercially produced carrot byproducts rather than laboratory-made pomace.

We observed that more liquid and carotenoids were extracted from the carrot mash upon using expeller pressing. This extracted liquid and carotenoids can be further reprocessed and implemented into a vitamin-rich beverage. As a result, both the water and the carotenoids could generate an additional revenue to carrot processors. Mechanical treatment resulted in an increase in the FBC and SC of dried carrot mash, which could justify its use for the development of a functional beef patty.

Disclosure statement

In accordance with Taylor & Francis policy and our ethical obligation as researchers, we report that we have no potential competing interests.

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References

Adeola, A. A., Idowu, M. A., Adepoju, Y. D., Adesina, O. T., Oyewade, S., Olunlade, B. A., & Ohizua, E. I. R. (2017). Chemical, functional and sensory properties of water yam, pigeonpea and carrot pomace flour blends. *Annals Food Science and Technology*, *18*(1), 57–64.

Alasalvar, C., Grigor, J. M., Zhang, D., & Quantick, P. C. (2001). Comparison of volatiles, phenolics, sugars, antioxidants, vitamins, and sensory quality of different colored carrot varieties. *Journal of Agricultural and Food Chemistry*, *49*(3), 1410–1416. doi:10.1021/jf000595h

Ben Slima, S., Ktari, N., Triki, M., Trabelsi, I., Moussa, H., Makni, S., . . . Ben Salah, R. (2019). Effects of two fibers used separately and in combination on physico-chemical, textural, nutritional and sensory properties of beef fresh sausage. *British Food Journal*, *121*(6), 1428–1440. doi:10.1108/BFJ-06-2018-0388

Beuchat, L. R. (1977). Functional and electrophoretic characteristics of succinylated peanut flour protein. *Journal of Agricultural and Food Chemistry*, *25*, 258–261. doi:10.1021/jf60210a044

California Department of Food and Agriculture. (2017). California agricultural statistics review 2016–2017. https://www.cdfa.ca.gov/Statistics/PDFs/2016-17AgReport.pdf

Chantaro, P., Chiewchan, N., & Devahastin, S. (2008). Production of antioxidant high dietary fiber powder from carrot peels. *Food Science and Technology*, *41*(10), 1987–1994. doi:10.1016/j.lwt.2007.11.013

Chau, C. F., Chen, C. H., & Lee, M. H. (2004). Comparison of the characteristics, functional properties, and in vitro hypoglycemic effects of various carrot insoluble fiber-rich fractions. *Lwt-Food Science and Technology*, *37*(2), 155–160. doi:10.1016/j.lwt.2003.08.001

Coleman-Jensen, A., Rabbitt, M. P., Gregory, C. A., & Singh, A. (2019). Household food security in the United States in 2018, ERR-270.

de la Rosa, L., Alvarez-Parrilla, E., & Gonzalez-Agular, G. (Eds.). (2010). *Fruit and vegetable phytochemicals: Chemistry, nutritional value and stability* (1st ed.). Ames, Iowa: Wiley-Blackwell.

de Vries, J. (2007). The obesity epidemic: Medial and ethical considerations. *Science and Engineering Ethics*, *13*(1), 55–67. doi:10.1007/s11948-007-9002-0

Di Giacomo, G., & Taglieri, L. (2009). A new high-yield process for the industrial production of carrot juice. *Food and Bioprocess Technology*, *2*(4), 441–446. doi:10.1007/s11947-009-0207-x

Femenia, A., Lefebvre, A.-C., Thebaudin, J.-Y., Robertson, J. A., & Bourgeois, C.-M. (1997). Physical and sensory properties of model foods supplemented with cauliflower fiber. *Journal of Food Science*, *62*(4), 635–639. doi:10.1111/j.1365-2621.1997.tb15426.x

FiberStar. (2019). *Product specification citri-fi 100FG*. River Falls, WI: Author.

Figuerola, F., Hurtado, M. L., Estévez, A. M., Chiffelle, I., & Asenjo, F. (2005). Fibre concentrates from apple pomace and citrus peel as potential fibre sources for food enrichment. *Food Chemistry*, *91*(3), 395–401. doi:10.1016/j.foodchem.2004.04.036

Filipini, M. (2001). Preparation, application, and evaluation of functional food additives from organic residues using carrot pomace and wheat bread as the model system. *Bulletin, Institute for Food Technology*.

Food and Agriculture Organization of the United Nations. (2019). Key factors on food loss and waste you should know! http://www.fao.org/savefood/resources/keyfindings/en/

Fuentes-Alventosa, J. M., Rodríguez-Gutiérrez, G., Jaramillo-Carmona, S., & Espejo-Calvo, J. A. (2009). Effect of extraction method on chemical composition and functional characteristics of high dietary fibre powders obtained from asparagus by-products. *Journal of Food Chemistry*, *113*, 665–671. doi:10.1016/j.foodchem.2008.07.075

Gao, W., Chen, F., Zhang, L., & Meng, Q. (2020). Effects of superfine grinding on asparagus pomace. Part I: Changes on physicochemical and functional properties. *Journal of Food Science*, *85*(6), 1827–1833. doi:10.1111/1750-3841.15168

Gull, A., Prasad, K., & Kumar, P. (2015, Sep). Effect of millet flours and carrot pomace on cooking qualities, color and texture of developed pasta. *Lwt-Food Science and Technology*, *63*(1), 470–474. doi:10.1016/j.lwt.2015.03.008

Gustavsson, J., Cederberg, C., Sonesson, U., van Otterdijk, R., & Meybeck, A. (2011). *Global food losses and food waste - extent, causes and prevention*. Rome, Italy.

Hernández-Alcántara, A., Totosaus, A., & Pérez-Chabela, M. L. (2016). Evaluation of agro-industrial co-products as a source of bioactive compounds: Fiber, antioxidants, and prebiotics. *Acta Universitatis Cibiniensis Series E: Food Technology*, *20*, 3–16. doi:10.1515/aucft-2016-0011

Hu, F. B., Rimm, E. B., Stampfer, M. J., Ascheiro, A., Spiegelman, D., & Willet, W. C. (2000). Prospective study of major dietary patterns and risk of coronary heart disease in man. *American Journal of Clinical Nutrition*, *72*. doi:10.1093/ajcn/72.4.912

Jaeger, H., Schulz, M., Lu, P., & Knorr, D. (2012). Adjustment of milling, mash electroporation, and pressing for the development of a PEF-assisted juice production on an industrial scale. *Innovative Food Science & Emerging Technologies*, *14*, 46–60. doi:10.1016/j.ifset.2011.11.008

Jaime, L., Molla, E., Ferndandez, A., Martine-Cabrejas, M., Lopez Andreu, F., & Esteban, R. (2002). Structural carbohydrates differences and potential source of dietary fiber of onion (Allium cepa L.) Tissues. *Journal of Agricultural and Food Chemistry*, *50*, 122–128. doi:10.1021/jf010797t

Jeffery, J., Holzenburg, H., & King, S. (2012). Physical barriers to carotenoid bioaccessibility. Ultrastructure survey of chromoplast and cell wall morphology in nine carotenoid-containing fruits and vegetables. *Journal of the Science of Food and Agriculture*, *92*, 2594–2602. doi:10.1002/jsfa.5767

Kamiloglu, S., Capanoglu, E., Bilen, F., Gonzales, G. B., Grootaert, C., Van de Wiele, T., & Van Camp, J. (2016). Bioaccessibility of Polyphenols from Plant-Processing Byproducts of Black Carrot (Daucus carota L.). *Journal of Agricultural and Food Chemistry*, *64*, 2450–2458. doi:10.1021/acs.jafc.5b02640

Knockaert, G., Lemmens, L., Van Buggenhout, S., Hendrickx, M., & Van Loey, A. (2012). Changes in β-carotene bioaccessibility and concentration during processing of carrot puree. *Food Chemistry*, *133*(1), 60–67. doi:10.1016/j.foodchem.2011.12.066

Kobus, Z., Nadulski, R., Anifantis, A., & Santoro, F. (2018). Effect of press construction on yield of pressing and selected quality characteristics of apple juice.

Kumari, S., & Grewal, R. B. (2007). Nutritional evaluation and utilization of carrot pomace powder for preparation of high fiber biscuits. *Journal of Food Science and Technology-Mysore*, *44*(1), 56–58.

Lee, H. (2001). Characterization of Carotenoids in Juice of Red Navel Orange (Cara Cara). *Journal of Agricultural and Food Chemistry*, *49*, 2563–2568. doi:10.1021/jf001313g

Lopez, G., Ros, G., Rincon, F., Periago, M. J., Martınez, M. C., & Ortuno, J. (1996). Relationship between Physical and Hydration Properties of Soluble and Insoluble Fiber of Artichoke. *Journal of Agricultural and Food Chemistry*, *44*(9), 2773–2778. doi:10.1021/jf9507699

Mahsa, M., Vosooghi Poor, Z., Gholamreza, M., Jalal, J., & Asgar, F. (2017, 2017). Effects of carrot pomace powder and a mixture of pectin and xanthan on the quality of gluten-free batter and cakes. *Journal of Texture Studies*, *48*(6), 616–623. doi:10.1111/jtxs.12276

Moelants, K., Lemmens, L., Vandebroeck, M., Van Buggenhout, S., Van Loey, A. M., & Hendrickx, M. E. (2012). Relation between Particle Size and Carotenoid Bioaccessibility in Carrot- and Tomato-Derived Suspensions. *Journal of Agricultural and Food Chemistry*, *60*(48), 11995–12003. doi:10.1021/jf303502h

Nadulski, R., Grochowicz, J., Sobczak, P., Kobus, Z., Panasiewicz, M., Zawiślak, K., … Żukiewicz-Sobczak, W. (2015, Jan). Application of freezing and thawing to carrot (Daucus carota L.) Juice Extraction. *Food and Bioprocess Technology*, *8*(1), 218–227. doi:10.1007/s11947-014-1395-6

Parr, B., Bond, J. K., & Minor, T. (2019). Vegetable and Pulses Outlook. Retrieved Date from https://www.ers.usda.gov/webdocs/outlooks/93033/vgs-362.pdf?v=5140.3.

Parthasarathi, R., Subramanian, V., & Sathyamurthy, N. (2005). Hydrogen Bonding in phenol, water, and phenol-water clusters. *Journal of Physical Chemistry*, *109*, 843–850. doi:10.1021/jp046499r

Psimouli, V., & Oreopoulou, V. (20172017). Carrot fibre enrichment of fat reduced cake. *Quality Assurance and Safety of Crops & Foods*, *9*(3), 265–274. doi:10.3920/qas2016.0965

Raghavendra, S. N., Rastogi, N. K., Raghavarao, K. S. M. S., & Tharanathan, R. N. (2004). Dietary fiber from coconut residue: Effects of different treatments and particle size on the hydration properties. *European Food Research and Technology*, *218*, 563–567. doi:10.1021/jp046499r

Reid, D., & Fennema, O. (2008). *Fennema's Food Chemistry* (4th ed.). Boca Raton, FL: Taylor & Francis Group.

Robertson, J. A., Eastwood, M. A., & Yeoman, M. M. (1980). An Investigation into the physical properties of fibre prepared from several carrot varieties at different stages of development. *Journal of the Science of Food and Agriculture*, *31*(7), 633–638. doi:10.1002/jsfa.2740310703

Schweiggert, U. (2004). Carrot pomace as a source of functional ingredients. *Fluss Obst*, *71*, 136–140.

Sharma, K. D., Karki, S., Thakur, N. S., & Attri, S. (2012, Feb). Chemical composition, functional properties and processing of carrot-a review. *Journal of Food Science and Technology*, *49*(1), 22–32. doi:10.1007/s13197-011-0310-7

Sharoba, A. M., Farrag, M. A., & Abd El-Salam, A. M. (2013). Utilization of some fruits and vegetables waste as a source of dietary fiber and its effect on the cake making and its quality attributes. *Journal of Agroalimentary Processes and Technologies*, *19*, 429–444.

Stoll, T., Schweiggert, U., Schieber, A., & Carle, R. (2003a, Apr). Application of hydrolyzed carrot pomace as a functional food ingredient to beverages. *Journal of Food Agriculture & Environment*, *1*(2), 88–92.

Stoll, T., Schweiggert, U., Schieber, A., & Carle, R. (2003b). Process for the recovery of a catorene-rich functional food ingredient from carrot pomace by enzymatic liquefaction. *Innovative Food Science and Emerging Technologies*, *4*, 415–423. doi:10.1016/S1466-8564(03)00060-2

Takenaka, M., Nanayama, K., Isobe, S., Ozaki, K., Miyagi, K., Sumi, H., … Ohta, H. (2007). Effect of extraction method on yield and quality of citrus depressa juice. *Food Science and Technology Research*, *13*(4), 281–285. doi:10.3136/fstr.13.281

Thebaudin, J. Y., Lefebvre, A. C., Harrington, M., & Bourgeois, C. M. (1997). Dietary fibres: Nutritional and technological interest. *Trends in Food Science & Technology*, *8*(2), 41–48. doi:10.1016/S0924-2244(97)01007-8

Turksoy, S., Keskin, S., Ozkaya, B., & Ozkaya, H. (2011, Jul-Oct). Effect of black carrot (Daucus carota L. ssp sativus var. atrorubens Alef.) fiber addition on the composition and quality characteristics of cookies. *Journal of Food Agriculture & Environment*, *9*(3–4), 57–60.

Turksoy, S., & Ozkaya, B. (2011, Nov). Pumpkin and carrot pomace powders as a source of dietary fiber and their effects on the mixing properties of wheat flour dough and cookie quality. *Food Science and Technology Research*, *17*(6), 545–553. doi:10.3136/fstr.17.545

United Nations. (2020). Sustainable development goals. https://www.un.org/sustainabledevelopment/.

USDA. (2015). Food Waste FAQ's. https://www.usda.gov/oce/foodwaste/faqs.htm

Wichienchot, S., & Ishak, W. R. B. W. (2017). Prebiotics and dietary fibers from food processing by-products. In A. K. Anal (Ed.), *Food processing by-products and their utilization* (pp. 137–174). Hoboken, NJ, USA: John Wiley & Sons Ltd.

Wilczynski, K., Kobus, Z., & Dziki, D. (2019). Effect of press construction on yield and quality of apple juice. *Sustainability*, *11*(13), 3630. doi:10.3390/su11133630

Xu, J., Eilat-Adar, S., Loria, C., Goldbourt, U., Howard, B. V., Fabsitz, R. R., . . . Lee, E. T. (2006). Dietary fat intake and risk of coronary heart disease: The strong heart study. *The American Journal of Clinical Nutrition*, *84*(4), 894–902. doi:10.1093/ajcn/84.4.894

Zhao, Y., Wu, X., Wang, Y., Jing, R., & Yue, F. (2017). Comparing physicochemical properties of hawthorn superfine and fine powders. *Journal of Food Processing and Preservation*, *41*(2), e12834. doi:10.1111/jfpp.12834