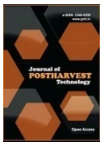

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RESEARCH ARTICLE

Effect of size reduction operation on particle size distribution, carotenoid content, hydration and functional characteristics of dehydrated carrot shreds

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ABSTRACT

The present study involves use of size reduction operation at different intervals of time on particle size distribution of carrot powder. Grinding is an energy driven process and involves generation of heat that significantly affects the heat liable components at molecular as well as macro level. A decrease in carotenoid content of around 1.5 to 7.6 % was observed during the grinding operation of carrot shreds at 30 to 150 seconds. Particle size distribution presented a bimodal curve with finer fractions increasing at the expense of coarse particle upon increasing the time of operation. A steady increase in water solubility index and water absorption index from 25.84 to 38.14 % and 10.57 to 12.91 g/g respectively, was observed as particle size decreased towards <75 µm. Furthermore a similar trend was witnessed in case of water holding capacity and swelling capacity.

Keywords: Carrot, carotenoids, functional properties, hydration characteristics, particle size distribution.

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INTRODUCTION

Carrot (*Daucus carota*) is an important member of Umbelliferae family mainly used for its roots both in fresh as well as processed forms (Haq and Prasad, 2015). Carrot is recognized as the lone and only form of root vegetables known to have high percentages of carotenoids in their cellular matrix (Rodriguez-Amaya, 2001). The root has a distinctive characteristic structure consisting of two major portions, a central core surrounded by continuous cortex. Carrot, like other members of its fruit and vegetable family, contains higher amounts of moisture content making them highly perishable particularly in tropical and sub-tropical regions. Size reduction of materials involves lowering down the sizes of larger materials into smaller ones by atomization as in case of liquids

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and grinding in case of solids with both processes implicating materials reaction to shear. Grinding results in development of smaller material fractions by fracturing larger particles via mechanical means along the weaker lines resulting in the development of higher temperatures causing undesirable changes in foods (Saravacos and Kostaropoulos, 2002).

Particle size distribution (PSD) is an important and critical variable in a lot of industrial operations mostly in pharmaceuticals and mining. The relation of product quality and performance with size distribution further strengthens the need for accurate measurement of products particle size distribution. The role of PSD in determining physical and chemical properties of particulate matter is important and very critical (Matljevic, 1991). The particle size of flour is known to have an evident effect on quality of end product in addition to affecting various processing techniques (Sullivan et al., 1960). The most common method of particle size measurement is sieving involving use of sieve shaker due to its ease and simplicity. Present study focuses on evaluating the effect of grinding time on degradation of carotenoids and determining the particle size distribution of the powders. In order to determine the use of different fractions in product development the powders will be assessed for different hydration characteristics.

MATERIALS AND METHODS

Materials and Moisture content measurements

The carrots were washed and shredded with a stainless steel shredder to ease out the process of moisture removal. The dehydration conditions for the current study were selected based on our previous work (Haq et al., 2015; Haq et al., 2018) and involved use of a cabinet drier. Moisture content of dehydrated carrots was analysed as per standards of AOAC (2000). Around 10 g of dehydrated sample was taken in pre-weighed petri-plates and placed in a hot air oven maintained at a temperature of 105 ^{o}C for 4-6 hours or until the consecutive weight measurement show constant readings. After moisture removal the petri-plates were cooled in a desiccator and were weighed for calculation of moisture content by following equation:

$$\textbf{\% Moisture content (\%)} = \frac{Weight\ loss\ of\ sample\ during\ drying}{Weight\ of\ sample} \times 100$$

Grinding operation and experimental setup

Dried carrot shreds were grinded for different time periods i.e., 30, 60, 90, 120 and 150 seconds by using an electric grinder. The powdered samples were stored in air tight containers in a freezer in order to prevent degradation from non-enzymatic browning.

Determination of total carotenoids

Samples were estimated for total carotenoids by acetone extraction (Park, 1987) followed by filtration by using a whatman filter paper in order to remove the suspended solids from liquid phase and enhancing the filtration process by application of vacuum. The extraction process for samples continued until there was no visible leaching of color from the solids. Afterwards the pigment within extracts were transferred into a lipophilic petroleum ether phase use a glass separation flask. To enhance the separation process few milliliters of water were added into the flask. Once extracted the volume was made up in a volumetric flask and scanned in UV-Vis region of spectrum and peak wave length was used for calculation of total carotenoids by using following formula.

Total carotenoids (µd/g) = $\left[\frac{A \times Vol \times 10^6}{A_{1cm}^{1\%} \times 100}\right] / W$

Where, A stands for absorbance, $A_{1cm}^{1\%}$ is extinction coefficient of solvent and W is sample weight.

Particle size distribution of powders

The powdered fractions obtained by grinding at different time intervals were analyzed for particle size distribution by using a laboratory scale sieve shaker as per ASAE standard S319.3 (ASAE, 2003). Different standardized wire mesh screens (18, 46, 72, 100, 200 BSS) with pore sizes of 850, 500, 210, 150 and 75 microns were stacked according to their decreasing pore size, starting from the top with mesh of higher size opening and eventually finishing at bottom with a solid pan. Pores of the each mesh allowed particles of lower sizes equivalent to that of screen size to pass through the respective screen openings resulting in the separation of the sample into different mass fractions. Samples (100 g) were poured in the top sieve followed by sieve shaking for at least 10 minutes as reported by Mani et al. (2004) for fibrous material. The mass fractions retained on each sieve were collected and recorded for their weight on an electronic digital balance (Ishida MB-150) with an accuracy of ±0.001g. An average of different mass fractions was taken from the three replications. The range of particle size retained on each screen is presented in Figure 1. The presence of successive sieves in gradual order of their size further refines the particle size in different fractions. The shaded area for each sieve depicts overall range of particles that would pass through screen in absence of the sieve with lower pore size. Experimental particle size distribution curves were obtained by plotting percent weight of different mass fraction with respect to their particle sizes.

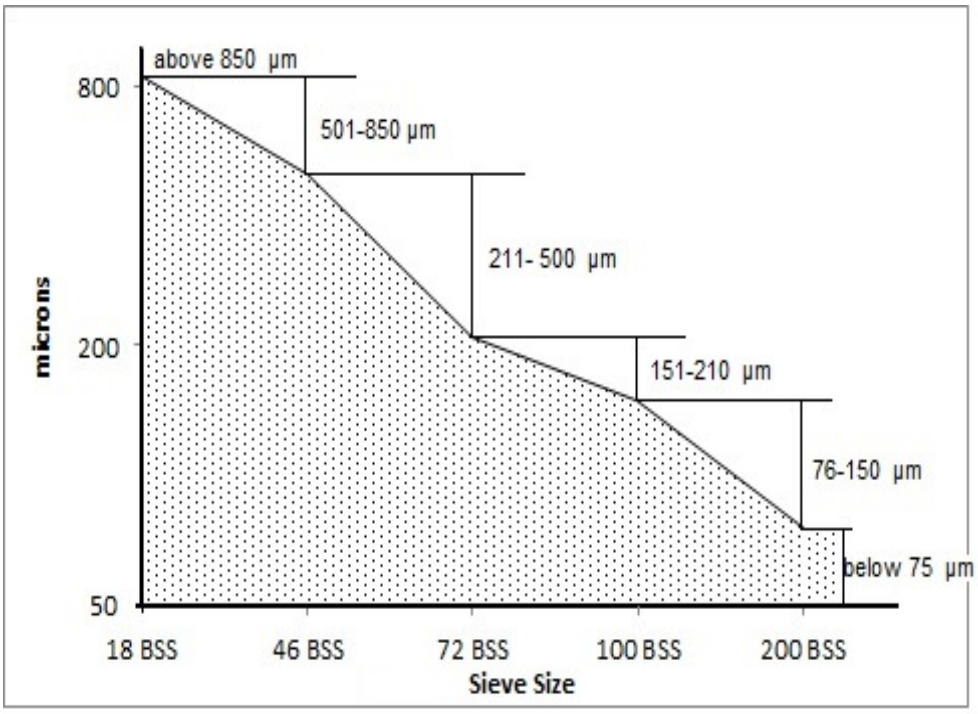

Figure 1. Diagram representing range of particle sizes retained within each nominal sieve

Water hydration and functional properties

Water solubility index (WSI) and water absorption index (WAI)

Water solubility index of carrot powders was determined by as per the method of Cortes-Rojas and Oliveira (2012). Sample weight of about 1 g was taken into a centrifuge tube and added with 100 ml distilled water. The mixture was thoroughly mixed and stirred by using a magnetic stirrer. The mixture was kept at a temperature of 37 ^{o}C in a water bath for about 30 minutes followed by centrifuging at 10,000 rpm for 15 min. The centrifugation process aided in separation of supernatant collected in a pre-weighed dish and dried in a hot air oven at 105 ^{o}C until its constant weight. The water solubility index (%) was calculated as percent solid mass present within supernatant with respect to amount of initial sample weight. The amount of water retained by the sediment is used for calculating its water absorption index by oven drying it at 105 ^{o}C to get sediment dried weight. Water absorption index also known as water retention capacity is the volume of water adhered to hydrated fibers even after application of external force. The water solubility index as well as water absorption index of the different samples was calculated by following equations:

$$\textbf{Water solubility index (\%)} = \frac{Weight\ of\ dry\ solids\ in\ supernatant}{Weight\ of\ sample} \times 100$$

$$\textbf{Water absorption index (g/g)} = \frac{Weight\ of\ water\ in\ sediment}{Weight\ of\ dried\ sediment}$$

Water holding capacity (WHC)

Water holding capacity and swelling capacity of carrot powders was determined as per the procedure followed by Zhu et al. (2015). Water holding capacity measures the overall quantity of water fixed with the hydrated fiber in absence of any external force with exception of atmospheric pressure and earth's gravity. Sample weight of 1 g was accurately weighed and transferred into a glass test tube added with 30 ml of distilled water. The mixture was allowed to rehydrate for 18 h followed by removal of liquid entity by vacuum filtration. The residue weight hydrated with water was recorded and the dry weight of residue was determined by oven drying at 105 ^{o}C until a measurements of constant weight was achieved.

Swelling capacity (SC)

Swelling capacity measures the ratio of hydrated volume of sample when immersed in surplus amount of water to the actual weight of sample is termed as swelling capacity. A graduated measuring cylinder or test tube was used for measuring the swelling capacity and involved filling it with 0.2 g of powdered sample along with 10 ml water. The mixture was allowed to rehydrate for 18 h and after the requisite time volume of fibers was measured and used for calculating swelling capacity of sample.

$$\textbf{Water holding capacity (g/g)} = \frac{Hydrated\ residue\ weight - weight\ of\ dry\ residue}{Weight\ of\ dry\ residue}$$

$$\textbf{Swelling capacity (ml/g)} = \frac{Volume\ of\ hydrated\ sample}{Initial\ weight\ of\ sample}$$

Wettability (s) and sedimentation time (s)

The wettability of powdered carrot samples was measured as per procedure of Vissotto et al. (2010). Wettability of samples was calculated by calculating the time a 1.0 g sample takes to completely submerge below the water surface at 25 ^{o}C. Around 400 ml of distilled water in a 500 ml beaker was sprinkled with test powder and recorded for the time taken by powders to overcome surface tension of water by using a stopwatch.

Sedimentation time of different powdered samples was determined by measuring the time a dispersed sample on the surface of water takes to completely settle down under the influence of gravity. About 1.0 g of sample was dispersed in a 500 ml beaker filled with distilled water and the time taken by different powders to settle down was noted and labelled as sedimentation time.

RESULTS AND DISCUSSION

Moisture Content

Drying process of carrot shreds was continued until the consecutive measurements were almost equal. Total moisture content of dried carrot shreds after drying operation was around 5.93 % on dry basis. Dried carrot shreds were ground into powders as mentioned in the aforementioned section (Haq et al., 2016).

Effect of grinding on total carotenoids

Considerable changes in total carotenoid levels of carrot powder was observed during the size reduction process of carrot shreds with an overall decrease from 62.93 to 58.17 mg/100g (Figure 2). The pattern of losses in different samples is presented graphically in Figure 3 with almost a near linear relationship existing between grinding time and percent loss. The possible reason for incurrence of losses may be attributed to the generation of heat that increases with grinding time resulting in degrading the amount of total carotenoids. The generation of more surface area by grinding together with application of heat promotes free radical oxidation resulting in degradation of carotenoids (Suvarnakuta et al., 2005). A strong positive correlation between antioxidant activity and total carotenoids was observed in the samples with correlation coefficients of 0.93. Similar results of correlation between the carotenoids and antioxidant activity was also reported by Bozalan and Karadeniz (2011).

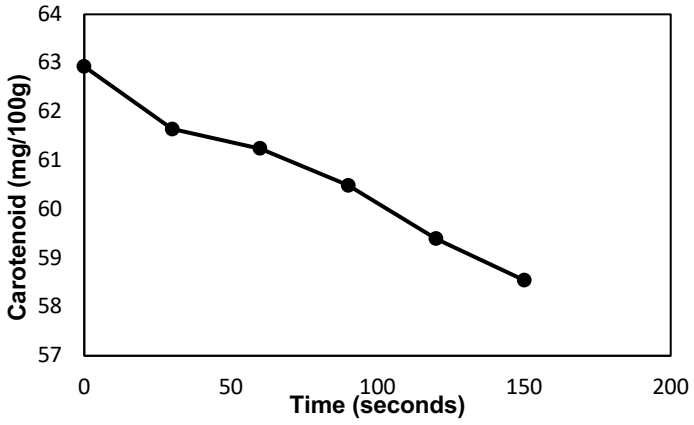

Figure 2. Total carotenoid content in carrot powder as affected by grinding time

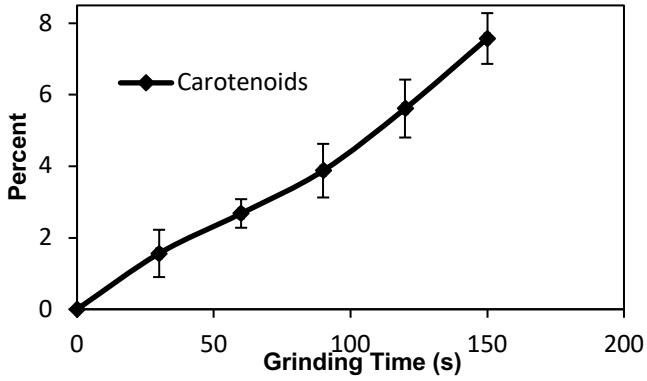

Figure 3. Carotenoid losses incurred during grinding of carrot powder

Particle size distribution as affected by grinding conditions

The particle size distribution of carrot fractions at different grinding periods is illustrated in Figure 3. A distinct multimodal PSD for powdered samples is visible in Figure 4. The range of particle size retained on each individual sieve is depicted in Table 1 and their corresponding volume fractions are presented in Figure 1. Increased grinding time resulted in decreasing the volume of higher sized powder particles into finer fractions.

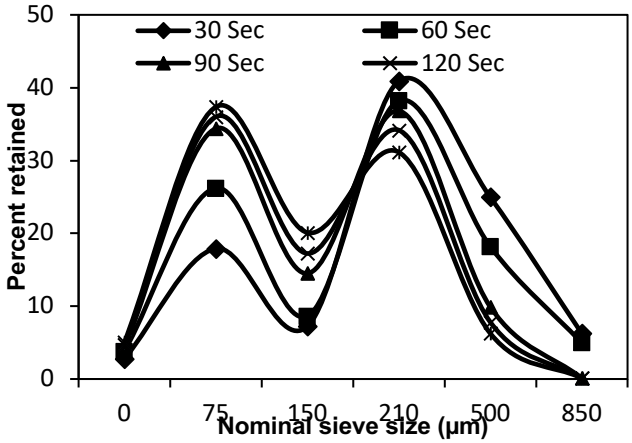

Figure 4. Particle size distribution of carrot powders at different intervals grinding time

Particle size decrease was observed in powdered fractions retained on sieves with pore openings of 210 to 850 µm and in spite of different size reduction conditions sieve with 210 µm pore size still retained higher proportion of overall powder fractions. Increase in finer powder fractions of powder had direct relation with grinding time occurring as a shift of bimodal curve towards the finer fractions. PSD of smaller powder fractions (<75 µm) was indistinguishable and the grinding time increased the volume of 75 µm at the expense of 210 µm. Rozalli et al. (2015) reported shorter grinding time produces larger sized particles that changed almost to normal distribution upon increasing grinding time. Studies of Lima et al. (2000), Servais et al. (2002) and Deniz et al. (2008) have also reported similar multimodal PSD of food components. Grinding time of carrot shreds for development of powders can be selected as per the requirements of the formulation. If the product formulation desires use of

coarser fractions time for the grinding operation has to be minimum as illustrated in the Figure 4, and vice versa. For an efficient product development process and for energy conservation the role of grinding time on particle size distribution can be of utmost importance.

Water solubility index (WSI) and water absorption index (WAI)

Water solubility index of different carrot powders, shown in Table 1, ranged from 25.84 to 38.14 % for carrot powders of different sizes. The solubility index showed a direct relation with powder particle size in powdered samples with finer particles providing higher values of solubility index. As size reduction involves an increase in the surface area, thereby enhancing the mass transfer gradient and the obvious reason for a higher WSI of finer particles. Solubility of different carrot powders was lower than solubility of different spray dried powders as reported by Abadio et al. (2004) and de Oliveira et al. (2009). The presence of insoluble fibrous tissues in powders may be responsible for conferring a comparatively lower solubility to these powders. The values of solubility from current research were closely related with values of tomato pulp powder developed by de Sousa et al. (2008).

Water absorption index of different carrot powders ranged from 10.57 to 12.91 g/g (Table 1). Water absorption index gives volume of sample after its swelling in surplus water and maintaining its integrity in aqueous solution. Water absorption is directly related with the polysaccharides and more its concentration in a sample more will be its WAI. The WAI of finer powders was more than coarser powder particles in both samples. The finer particles are in possession of more surface area enabling higher water binding sites to get exposed to adjacent water, thereby resulting in overall increase of WAI (Zhao et al., 2009). The WAI of powders is known to increase by incorporating fiber rich materials as shown by the studies of Larrea et al. (2005) and Chaplin (2003).

Table 1. Functional and water hydration properties of different fractions of carrot powders

Particle size (µm)	WAI (g/g)	WSI (%)	SC (ml/g)	WHC (g/g)	Wettability (sec)	Sedimentation time (sec)
>851	10.57 ± 0.11a	25.84 ± 0.28e	12.70 ± 0.16a	14.78 ± 0.15a	3.59 ± 0.16f	3.86 ± 0.12f
850-501	11.98 ± 0.13b	26.07 ± 0.25e	13.50 ± 0.14b	16.15 ± 0.17b	4.93 ± 0.14e	6.29 ± 0.16e
500-211	12.08 ± 0.15b	27.64 ± 0.31d	14.60 ± 0.17c	16.64 ± 0.15c	7.35 ± 0.12d	9.71 ± 0.15d
210-151	12.53 ± 0.15c	30.18 ± 0.29c	15.40 ± 0.15d	16.91 ± 0.18c	9.62 ± 0.22c	11.89 ± 0.21c
150-76	12.72 ± 0.21cd	35.20 ± 0.33b	16.50 ± 0.19e	17.74 ± 0.16d	10.98 ± 0.25b	14.36 ± 0.19b
<75	12.91 ± 0.16d	38.14 ± 0.36a	17.40 ± 0.21f	18.35 ± 0.19e	13.05 ± 0.15a	20.28 ± 0.22a

Different superscripts on values within a column shows a statistical difference at $p<0.05$ significance level. WAI) water absorption index; WSI) Water solubility index; SC) Swelling capacity; WHC) Water holding capacity

Water holding capacity (WHC) and swelling capacity (SC)

The water holding capacity of different sized carrot powders showed a similar trend with WAI. The water holding capacity was greater than WAI as there wasn't any application of external force and the values ranged from 14.78 to 18.35 g/g (Table 1). The structure of porus matrix formed mainly by chains of polysaccharides is largely associated for holding sufficient quantities of water due to hydrogen bonding and this property of matrix is related to water holding capacity of sample (Kethireddipalli et al., 2002). The water holding capacity of ginger also increased with ultrafine grinding (Zhu et al., 2015) whereas hydration properties of dietary fiber from coconut also improved upon reduction of its particle size from 1127 to 599 µm (Raghavendra et al., 2004).

Swelling capacity also falls under hydration property of sample and was influenced by size reduction operation with finer fractions with additional surface area taking up more water from surroundings resulting in greater extent of swelling for particles with lower particle size. The swelling capacity of carrot powders increased as particle size decreased with values ranging from 12.70 to 17.40 (Table 1). The swelling capacity of ginger powder also increased upon its size reduction as shown by study of Zhu et al. (2015). In addition to the matrix composition of powders, increase in the surface area had a profound effect on different hydration properties.

Wettability (s) and sedimentation time (s)

Wettability and sedimentation rate of carrot powders increased with gradual minimization of particle size in carrot powders. The wettability and sedimentation rate of different powder fractions ranged from 3.59 to 13.05 s and 3.86 to 20.28 s, respectively (Table 1). The particle size and density of fluid play an important role for determining wettability and sedimentation time of a particulate matrix. As wettability only involves time taken by particles to submerge below aqueous surface, therefore the values are generally lower when compared to sedimentation time that involves proper settling of particles at the bottom. Wettability measures ability of the powdered samples to overcome surface tension of water (Fang et al., 2008). Moreover the higher particle size isn't severely affected by fluid density and gravitational pull exceeds in its case thereby taking a very low time for submerging and settling. The wettability of finer particles was similar to spray dried date powder prepared with malto-dextrin as carrier agent (Manickavasagan et al*.,* 2015). The low mass of finer particles and aqueous density enabled smaller sized particles to remain suspended for a considerable time due to their Brownian motion. The wettability of finer fractions increased by 263.51 % when compared with coarser powder fractions. Powder wettability depends on powder density, surface charge, particle size, surface area, porosity and occurrence of amphipathic substances. Particle swelling hinders and lowers down wettability of powders that can even be diminished and whey protein concentrate is its perfect example (Faldt and Bergenstahl, 1996; Kim et al., 2002).

CONCLUSION

As the carotenoids are liable to degradation due to heat and the heat generation in grinding process results in degradation of carotenoids. Increase in the hydration characteristics of carrot powders by grinding were associated to increased surface area. The higher surface area to mass ratio of finer carrot powders enhanced the settling time so as to overcome the buoyant and gravitational forces. Particle size distribution of carrot powders enables use of different powder fractions into various product formulations viz. finer fractions for development of beverages, coarser fractions in baking formulations and different processed food products. Need for controlling the size of powders also arises as very fine powders tend to agglomerate due to the different interaction forces between the particles, therefore to weed out the use of surfactants.

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