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EFFECTS OF DYNAMIC HIGH PRESSURE MICROFLUIDIZATION ON THE PHYSICAL AND CHEMICAL PROPERTIES OF CARROT (*DAUCUS CAROTA* L.)

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Abstract

Effects of dynamic high-pressure micro-fluidization (DHPM) on the physical and chemical properties of carrot juice was investigated in the present study. Carotene content, turbidity, centrifugal sedimentation rate, soluble solids content, color, and particle size and distribution of the samples homogenized with different pressures were evaluated. When compared with the control sample, carotene content, turbidity, suspension stability, centrifugal sedimentation rate, color, and particle size and distribution of the carrot juice showed a significant difference at different pressures. The result indicated that DHPM could improve the physical and chemical properties of carrot juice, such as increased carotene content, stability and affecting color positively resulting in a desirable high-quality juice for the consumer.

Introduction

Carrot (*Daucus carota* L.) is one of the important root vegetables rich in bioactive compounds like carotene and dietary fibers with appreciable levels of several other functional components having significant health-promoting properties (Ariahu *et al*. 2021, Jivan *et al*. 2021). Carrot is rich in β-carotene and ascorbic acid, tocopherol and is classified as vitaminized food (Ana *et al.* 2021, Lyu *et al*. 2022). It also has carbohydrates, phosphorus, calcium, copper, iron, magnesium, manganese, phenolic compounds and sulfur (Emun *et al*. 2016). So, it is a source of a number of compounds that have documented antioxidant, antimicrobial, antiviral, anti-inflammatory, anti-allergenic, and even anti-cancer properties (Lee *et al*. 2018, Muhammad *et al*. 2018, Jayaprakasha *et al*. 2019). The carrot juice is a popular vegetable juice for consumers, it is rich in α-carotene and β-carotene, and is a natural source that provides pro-vitamin A and beta-carotene. Carrot juice is a major human dietary source of polyacetylenes, which have potentially positive effects on human health (Oladipupo *et al*. 2018). In recent years, a steady increase of carrot juice consumption has been reported in many countries.

Dynamic high-pressure micro-fluidization (DHPM) is a new technology that has been widely used in food industry. The technology uses the combined forces of high-velocity impact, high-frequency vibration, instantaneous pressure drop, powerful shear, cavitation force and ultra-high pressures, up to 200 MPa, with a very short treatment time (less than 5 s) (Ge *et al*. 2021, Zhong *et al*. 2019). In the case of micro-fluidization, the solution is pumped and split into two micro streams which are impacted or collided against each other in a chamber known as the interaction chamber where shear, turbulent and cavitation forces are generated (He *et al.*2015). There are some studies in the past about DHPM, Yu *et al* (2018) studied the effect of DHPM on rheological properties of taro (*Colocasia esculenta* (L). Schott) pulp, and Huang *et al* (2020) studied the effects of DHPM on physicochemical, thermal and structural properties of sugar beet pulp.

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Thus the present study was aimed to investigate the effect of pressures of DHPM on the physical and chemical properties of carrot juice.

Materials and Methods

Fresh carrots were purchased at a local super market (Zhengzhou, China). All chemical reagents are analytically pure. Fresh carrots cleaned with water, and cut into pieces, beat the pulp with water at the mass ratio of 1:4, the fruit pulp homogenized with dynamic high-pressure micro-fluidization device (2L, Stansted Fluid Power Ltd, UK) at 20 MPa, 40 MPa, 80 MPa,120 MPa, and 160 MPa for different times. All the liquid was collected into a container and then centrifuged using refrigerated centrifuge (HC-3618R, Anhui Zhongke Zhongjia Scientific Instrument Co., Ltd. China) at 5000 r/min for 6 min. Before using, the sample was refrigeration at 4°C.

Carotene content was determined by the Chinese national standard method (GB/T1229). Turbidity was determined by the method of Zhang *et al.* (2015) with certain modifications. Carrot juices were centrifuged at 3600 r/min for 6 min. The supernatant was poured into cleaned cuvettes and placed in a spectrophotometer that was calibrated, and the absorbances were measured at 600 nm.

Centrifugal sedimentation rate was determined by the method of Mirian *et al* (2013) with certain modifications was used to measure centrifugal sedimentation rate. Twenty grams of carrot juice were poured into centrifuge tube and centrifuged (6000 r/min, 15 min, 20°C), the weight of the carrot juice was described as G, then removing the liquid phase, after handstand 5 min, W was severed as the weight of the sediment, the centrifugal sedimentation rate was obtained using the following equation: centrifugal sedimentation rate = W/G × 100%.

The soluble solids content of the carrot juice samples were determined with a digital refractometer. Color measurements were performed by using automatic chromatic meter (Kangguang SC-80C, Beijing Jingyikang Optical Instrument Co., Ltd., China), and the chromaticity coordinates in the L*a*b* color space (CIELAB). L*indicates the lightness, and a*and b* are the chromaticity coordinates, h*(hue) values and E (color change) were calculated from a* and b* values. The samples were placed in glass cells and measurement was performed. L*, a*, b* color space was used for the measurement. Total color change (△E) was calculated following the formula of Vishwanath *et al*. (2011).

The particle size distribution measurement of the samples was determined by a Nanoparticle potentiometer (Zetasizer Nano ZS90, Malvern Ltd.UK).

All results are means of 3 independent batches of carrot juice and each sample was analyzed in triplicate. The results were expressed as mean value ± standard deviation (SD). Analysis of variance (ANOVA) was carried out using SPSS software version 22.0, the significance level was set at 0.05.

Results and Discussion

Effects of pressure of DHPM on carotenoids content of carrot juice are presented in Fig. 1. Results regarding carotenoids content of carrot juice have improvements when treated with DHPM compared to control (0.1MPa). From 20 MPa to 160 MPa, with the increase of pressure, the increasing rate of carotenoids from 6.46 ± 0.25 to 11.68 ± 0.25 μg/g. Maybe the change was caused by larger extrusion, hole and shear effect, and further increase in the degree of cell disruption makes more and more carotenoid being released. Effects of different pressures on color measurement of carrot juice are shown in Table 1.

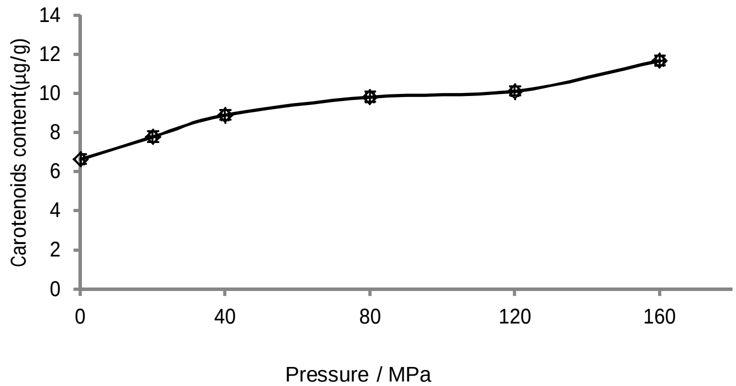

Fig. 1. Effect of pressure of DHPM on carotenoids content of carrot juice.

Tab 1. Effect of different pressures on color measurement of carrot juice.

Pressures	L*	a*	b*	ΔE
0.1 MPa	45.27 ± 0.25	16.03 ± 0.17	32.29 ± 0.21	0.00
20 MPa	47.15 ± 0.29	17.79 ± 0.14	34.25 ± 0.36	5.23 ± 0.22
40 MPa	47.73 ± 0.19	18.04 ± 0.16	34.99 ± 0.41	8.69 ± 0.27
80 MPa	47.74 ± 0.22	18.25 ± 0.10	35.73 ± 0.27	11.58 ± 0.24
120 MPa	47.63 ± 0.32	18.49 ± 0.39	36.04 ± 0.32	12.84 ± 0.34
160 MPa	48.21 ± 0.26	19.25 ± 0.32	36.22 ± 0.51	21.65 ± 0.45

The DHPM gave rise to color changes in the carrot juice. In particular, significant color differences were detected in untreated and treated juices. The brightness, the red and yellow bias of the carrot juice increased with the increase of pressure. Carotene is mostly responsible for the color. The change of carotene content was correlated with the change of color.

The turbidity value represents the insoluble suspended material that is contained in carrot juice. The insoluble suspended material not only relates to the content of suspended solids, but also relates to the composition of impurities, particle size, shape, and its reflection performance on the surface. Turbidity is an important physical and chemical indicator in the detection of fruit juice. Figure 2 show the effect of pressure of DHPM on turbidity of carrot juice. From 20 MPa to 160 MPa, with the increase of pressure, the increase of turbidity (absorbances) from 0.412 ± 0.010 to 0.579 ± 0.021. These changes are caused by imposed pressure which makes the size of carrot juice smaller and widely distributed in solution.

Most of the centrifugal precipitation substance are some colloidal substance and sedimentation of suspended solids, which results from that there is low viscosity in carrot juice system, and the pulp particles are a lack of adequate buoyancy to offset its own gravity. Fig.3 show the effect of pressure of DHPM on centrifugal sedimentation rate of carrot juice. From 20 MPa to 160 MPa, with the increase of pressure, the decrease of centrifugal sedimentation rate from 1.78 ± 0.01 to 0.81 ± 0.01. But the change was significant compared with the control(0.1MPa) ($p < 0.05$).

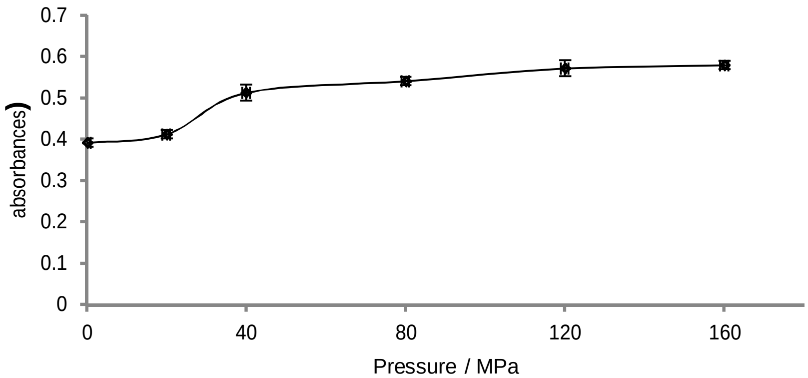

Fig. 2. Effects of pressure of DHPM on turbidity of carrot juice.

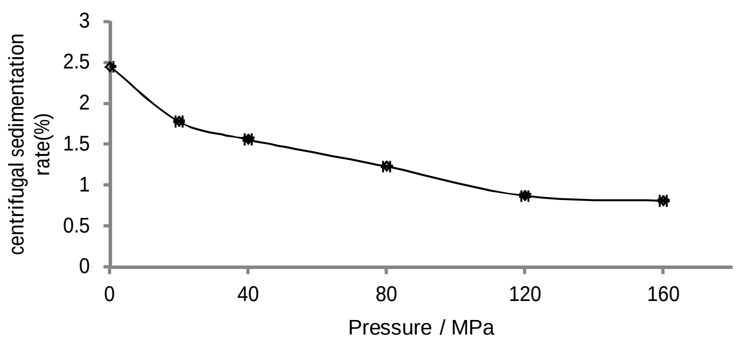

Fig. 3. Effects of pressure of DHPM on centrifugal sedimentation rate of carrot juice.

Figure 4 show the soluble solids content values of the homogenized carrot juices. Compared with untreated juice, pressure treatment increases the soluble solids content. The phenomenon can be interpreted as, after being treated with pressures, the pulp particles in carrot juice subjected to further breaking, and more soluble components (polysaccharide, acid, vitamin and other soluble components) dissolved into carrot juice, so the soluble solids content is higher than the control sample. However, with the increase of pressure and times, the soluble solids content have no change. It maybe because the pulp particles in carrot juices have been completely broken, the soluble substance has completely dissolved into carrot juice. So, a further increase in the pressure and the times cannot change the soluble solids content.

The particle size of a suspension could be considered as an important parameter to assess stability against sedimentation. With the increase of pressure, the particle size become smaller, and there was a significant difference between samples treated with different pressures ($p < 0.05$) (Fig. 5). These results are correlated with previous research for citrus juices (Enrique *et al.* 2011).

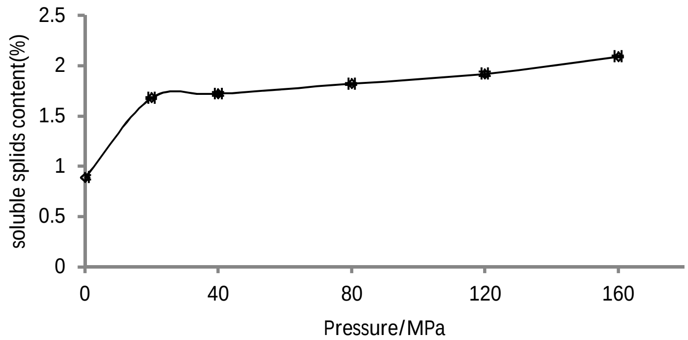

Fig. 4. Effects of pressure of DHPM on soluble solids content of carrot juice.

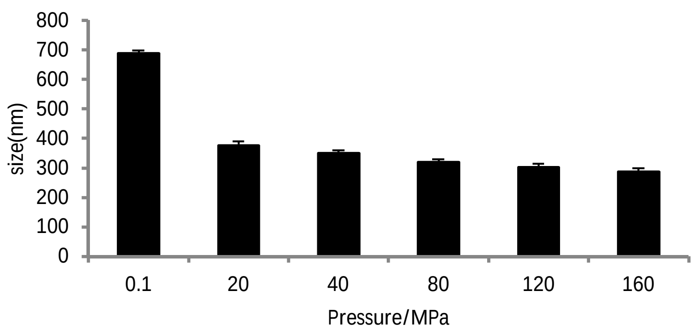

Fig. 5. Effects of DHPM on the particle size of carrot juice.

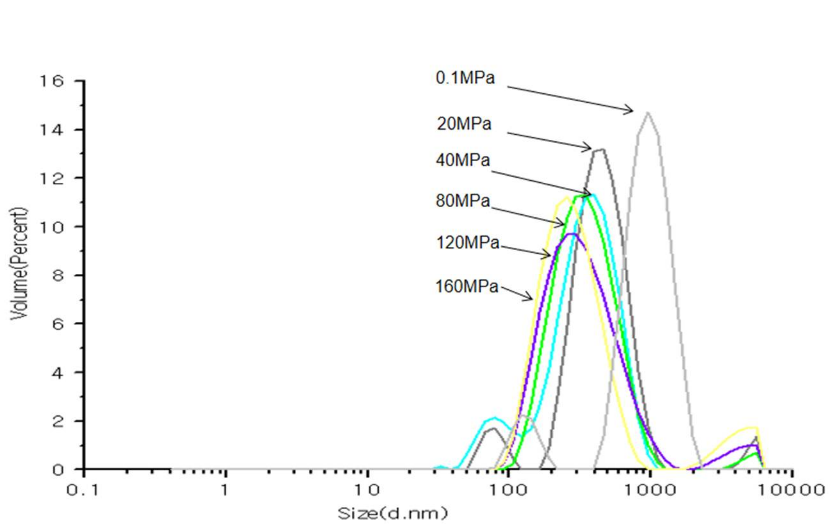

Fig. 6. Effect of DHPM on the particle size distribution of carrot juice.

Particle size distribution curves of carrot juices were performed by laser scattering capable of measuring in the range between 0.1 and 1000 nm. Particle size distribution curves of carrot juice showed a polydisperse distribution in differently treated samples (Fig.6). With the increase of pressure, the particle size of carrot juice significantly decreased, the peak shift to the left , the particle size range of carrot juice become narrow, which could be attributed to shear and impact force make carrot juices broken. As for carrot juice treated at 0.1 MPa, the particle size distribution was between 600-3000 nm. However, when pressure was applied above 40MPa, the particle size distribution was between 50-1000 nm.

DHPM significantly increased suspension stability and the soluble solids content, compared with the control sample, and make carrot juice pulp particle become smaller, increase the dissolution of carotenoids, improve the carotenoids content in carrot juice, deepened the color of the juice. DHPM can improve carrot juice that is treated by the traditional method and plays an important role in promoting the physicochemical properties of carrot juice. So, the application of DHPM has a very important significance, it will become an important technology employed on juice processing in the future.

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