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High-Pressure and Heat Pretreatment Effects on Rehydration and Quality of Sweet Potato

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ABSTRACT

The effects of high-pressure and heat pretreatments, used prior to drying, on the rehydration rate and quality of sweet potato was investigated. Sweet potato was pressurized at 200 Mpa for 5 min and heat treatment was performed at 100°C for 5 min. Three different types of pretreatments were performed: heat treatment, heat treatment after high-pressure treatment and high-pressure treatment after heat treatment. There were no differences in the color parameters (L*, C* and h) and gelatinization rate of rehydrated sweet potato exposed to the three different pretreatments. However, heat treatment after high-pressure treatment resulted in pronounced texture improvement compared to the other pretreatments. The relative hardness of the rehydrated sweet potato exposed to heat treatment after high-pressure treatment was higher than with the other pretreatments. Furthermore, it was found that the rehydration rate of sweet potato exposed to heat treatment after high-pressure treatment was lower than either heat treatment or high-pressure treatment after heat treatment. Heat treatment after high-pressure treatment prior to drying prevented cubes of sweet potato from collapsing during rehydration. This study shows that in sweet potato, the use of heat treatment after high-pressure treatment prior to drying could serve as an effective method for texture improvement.

Key words: High-pressure, sweet potato, pretreatment, drying, rehydration

INTRODUCTION

Processed foods are normally changed in numerous ways from their fresh counterparts with regard to appearance, flavor, texture, nutrient content and microbiota. Consumers demand high quality and convenient products with natural flavor and taste and greatly appreciate the fresh appearance of minimally processed food (Anjum *et al.*, 2006). Processing of foods by high pressure offers unique advantages over traditional thermal treatments, as it exerts antimicrobial effects without changing the sensory and nutritional quality of foods. One of the advantages of this technology is that, because it does not use heat, sensory and nutritional attributes of the product remain virtually unaffected, thus yielding products of better quality than those processed using traditional methods. Traditional food-processing methods have relied on high temperatures as a way to ensure prolonged shelf-life and food safety. However, the use of such high temperature is commonly known to cause detrimental changes to the processed products (Yang and Gadi, 2008). Several vitamins degrade under heat treatment, as do color and flavor compounds. Additionally, texture is also negatively affected. Once affected, the vegetable tissues frequently soften and chemical compounds need to be added to regain firmness. Thermal processing possesses many advantages and applications in food manufacturing, but the use of heat has its drawbacks. Although, the first studies on the application of high pressure in food technology were carried out at the end of the 19th century (Hite, 1899), interest in high-pressure processing of food developed only after 1970, principally due to a lack of suitable equipment before that time and has increased considerably over the last decade or so. In 1990, the first high-pressure-processed food, a fruit jam, was introduced onto the Japanese retail market (Thakur and Nelson, 1998), recently, a number of other high-pressure-processed food products have been launched, including oysters in the USA, orange juice in France and guacamole in Mexico (Balasubramaniam *et al.*, 2008; Hugas *et al.*, 2003). There is interest in the use of high-pressure treatment as a novel food processing technique. High-pressure treatment acts on non-covalent interactive forces (Cheftel, 1992; Tauscher, 1995; Heremans, 1995), which stabilize the structure of biopolymers such as proteins and polysaccharides. The use of high-pressure technology in food processing has steadily increased during the past 20 years.

Blanching is a thermal treatment applied to inactivate enzymes catalyzing reactions that degrade vegetable products during storage. This thermal treatment stabilizes food through its capacity to destroy microorganisms and inactivate enzymes (Rahman and Perera, 1999). Additionally, it improves the color of products by preventing discoloration and improving brightness, thereby making the product more attractive for consumption (Brewer *et al.*, 1995; Kilara *et al.*, 1984). The necessity of blanching vegetables for improved product quality prior to dehydration has been recognized since 1929 (Dietrich *et al.*, 1955). Estiaghi *et al.* (1994) determined the effect of high-pressure treatment on the drying, rehydration, texture and color of green beans, carrots and potatoes. The results of their study indicated that pressure-treated samples had a texture nearest to that of the raw material and there were no major differences in color. Al-Khuseibu *et al.* (2005) showed that high-pressure treatment before air drying improved moisture transfer and that dried and rehydrated high-pressure-treated samples had a hardness value close to that of fresh samples. In the present study, the effects of high-pressure and heat pretreatments used prior to the drying of sweet potatoes were examined. The pretreatments prior to drying were carried out in three different ways and the following characteristics were assessed: rehydration rate, color measurements, rheological test and gelatinization rate. Sweet potato (*Ipomoea batatas* Lam.) is an important agricultural product and is available in both fresh and dried forms in Japan.

MATERIALS AND METHODS

Materials: This research was conducted during April 2008 to 2009 April at Nihon University. Sweet potato was purchased from the local market. The middle section of the sweet potato was used and was cut into cubes (20×20×10 mm) prior to pretreatments and testing.

Pretreatment and drying: Sweet potato was pretreated by heat treatment, high-pressure treatment after heat treatment or heat treatment after high-pressure treatment. The samples were vacuum packed with 5 mL of water in heat sealed triple nylon bags (MICS Chemical Co. Ltd., Aichi, Japan). All heat treatments were performed at 100°C for 5 min. After heat treatment, the bags were cooled down in flowing water. All high-pressure treatments were performed at 200 Mpa for 5 min using a high-pressure apparatus (Syn corporation, Kyoto, Japan), which consisted of a high-pressure vessel connected to a hand pump. Pressure was built up slowly using a pressurization rate of 100 Mpa min^{-1} and the pressure was released using a pressurization rate of 200 Mpa min^{-1}. Pretreated samples were spread on the plate and frozen at -30°C. Drying was carried out in freeze dryer, the vacuum level was less than 13.3 Pa (Fig. 1).

Rehydration and determination of reducing sugars: The weight of dried sweet potato cubes was measured and the samples were then immersed in 1000 mL of distilled water at 70°C and allowed to rehydrate for 8 min. At the end of the rehydration period, the sample was removed and blotted with paper towel to eliminate excess surface water. The mass of the dried and rehydrated samples were measured by an analytic balance. Rehydration of the sample was calculated as follows:

$$R (\%) = M_t/M_0 \times 100$$

where, M_t and M_0 are the sample mass at time t (rehydrated samples) and zero (dried samples), respectively. All the experiments were carried out in triplicate and mean values were used in subsequent calculations.

The reducing sugars of rehydrated samples were measured by the procedure of Nelson and Somogy (Somogyi, 1952). Dehydrated and rehydrated samples were crushed in 50 mL of water and centrifuged (3000x g, 5 min, 4°C). Supernatant (1 mL) was added to 1 mL copper reagent. The solutions were placed in a boiling water bath for 15 min and then cooled under running water. Nelson solution (1 mL) was added and then allowed to stand for 15 min and the absorbance was measured at 660 nm. Each sample was run in a minimum of triplicate.

Color measurement: Color measurement was performed using a colorimeter CR-200 (Minolta Camera Co. Ltd., Tokyo, Japan). The colorimeter was calibrated with a white standard tile (L = 92.8, a = -0.8, b = 0.1). Color was recorded using the CIE-L* a* b* uniform color space. The L* variable represents brightness (black-white), with lower values indicating deep browning. The a* variable represents red-green, with lower values indicating more greenness. The b* variable represents yellow-blue, with lower values indicating more blueness. The three CIE-L*, a* and b* values were further used to calculate the color saturation index, Chroma (Chroma = $[a^{*2}+b^{*2}]^{1/2}$) and hue angle (Hue = $\tan^{-1}$ (b*/a*)). Each sample was run a minimum of three times.

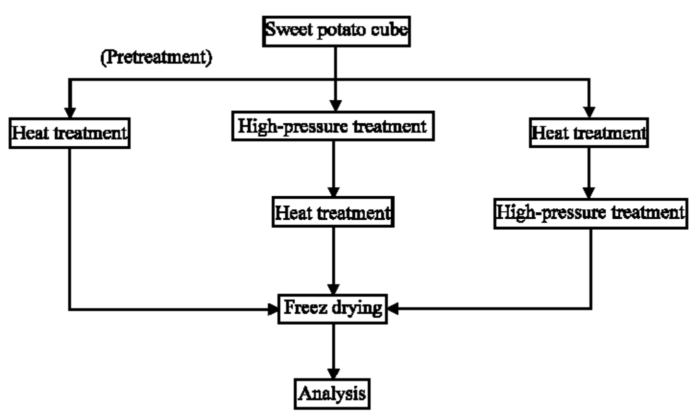

Fig. 1: Schematic overview of experimental setup

Measurement of the degree of gelatinization: Differential scanning calorimetry measurements were used to measure the degree of gelatinization. The instrument used was a DSC 8320L (Rigaku Co. Tokyo, Japan). Samples (27.5 mg) were sealed in an aluminum pan and experiments were conducted at a heating rate of 5°C min^{-1} over a temperature range of 30-120°C. An empty pan was used as a reference. Each sample was run a minimum of three times.

Rheological testing: Rheological testing of the hardness of rehydrated sweet potato was determined using a CR-200D Rheometer (Sun Sci. Co. Ltd., Tokyo, Japan). A V-type plunger was used with a clearance of 1 mm and compression speed of 1.0 mm sec^{-1}. Sample hardness was defined by the maximal force required to compress the sample and the relative hardness was defined as follows:

$$\text{Relative hardness} = \frac{\text{(Hardness of each pretreatment)}}{\text{(Hardness of heat treatment)}}$$

Each sample was run a minimum of three times.

RESULTS AND DISCUSSION

Rehydration rate and content of reducing sugars in sweet potato: A high degree of rehydration was shown with heat treatment and high-pressure treatment after heat treatment (Fig. 2). The rehydration rate of the samples subjected to heat treatment after high-pressure treatment was lower than the other pretreatments (Fig. 2). The rehydration rates in the heat-treated samples and the samples subjected to high-pressure treatment after heat treatment were ≈120, ≈10% greater than in the samples subjected to heat treatment after high-pressure treatment (Fig. 2). Rehydration is a very important quality in dried foods because of its effects on food texture (Krokida and Philippopoulos, 2005; Lewicki and Wiczlowska, 2006). Singh *et al.* (2006) found that rehydration rates of sweet potato slices were dependent of drying condition and rehydration temperature. Furthermore, Eshtiaghi *et al.* (1994) observed that several vegetables that were blanched with high-pressure treatment exhibited low rates of rehydration and their textures were harder than non-high-pressure-treated vegetables. The rehydration kinetics of high-pressure-treated and dehydrated pineapple was found to be lower than non-high-pressure-treated pineapple (Rastogi *et al.*, 2000); it is considered that a possible reason for the reduction of rehydration rates could be attributed to structural changes caused high-pressure pretreatment. Therefore, heat treatment after high-pressure treatment of sweet potato prior to dehydration improved the rehydration rate.

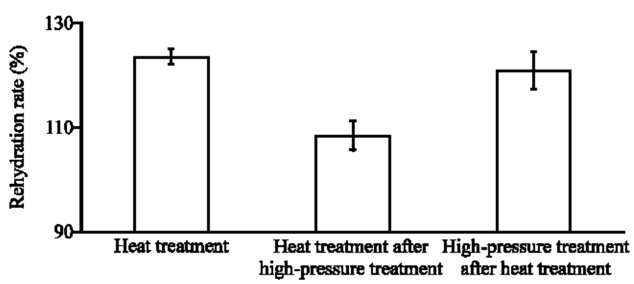

Fig. 2: Effect of various pretreatments on the rehydration rate of dehydrated sweet potato

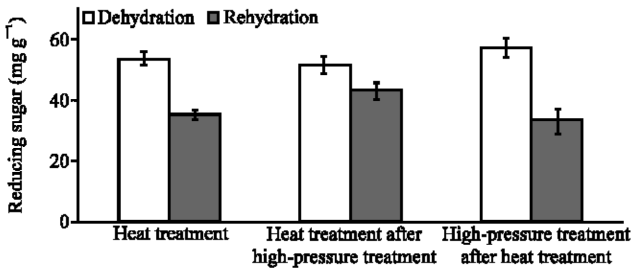

Fig. 3: Change in reducing sugar content of dehydrated and rehydrated sweet potato after various pretreatments

The method of pretreatment did not affect the content of reducing sugars in dehydrated sweet potato (Fig. 3). This suggests that high-pressure pretreatment did not cause differences in the loss of reducing sugars. Butz *et al.* (2002) studied the influence of high-pressure treatment on sugars, ascorbic acid and carotenoids in fruit and vegetable products. They reported that there was no significant difference between the non-pressure and high-pressure treatments with respect to sucrose in products from various fruits and vegetables. In this study, the amount of reducing sugars in rehydrated sweet potato was increased by heat treatment after high-pressure treatment as compared to both heat treatment and high-pressure treatment after heat treatment (Fig. 3). However, heat treatment after high-pressure treatment is not thought to induce production of reducing sugars. As Fig. 2 shows, the rehydration rate in heat treatment after high-pressure treatment is lower than that seen with the other pretreatments. Therefore, the concentration of reducing sugars in heat treatment after high-pressure treatment was higher than that of the other pretreatments. This result shows that heat treatment after high-pressure treatment prior to dehydration improves the palatability of rehydrated sweet potato.

Color measurement: The L* values were about 61.46-63.09 for pretreated sweet potato and about 86.75-87.10 for dehydrated sweet potato (Table 1). In addition, rehydrated sweet potato showed a 69.86-71.86 L* value (Table 1). This result indicates that the dehydrated sweet potato resulted in increased brightness compared to the pretreated and rehydrated sweet potato. While the C* value of pretreated and dehydrated sweet potato decreased compared to those of rehydrated sweet potato, the C* values of pretreated and dehydrated sweet potato were about 31.58-34.16, which indicates a median chroma value (Table 1). The C* value of rehydrated sweet potato was about 39.75-41.49, which indicates slightly more darkening than other samples (Table 1). Sweet potato contains polyphenol oxidase that catalyzes the oxidation of phenolic compounds. Phenolic compounds have been reported to be responsible for enzymatic darkening. Enzymatic darkening of sweet potato is mainly caused by polyphenol oxidase (Euclides *et al.*, 1992). Rehydrated sweet potato exhibited a trend to high C* values that is due to residual polyphenol oxidase. The dehydrated sweet potato h value was decreased as compared to pretreated and rehydrated sweet potatoes (Table 1). But there were no significant differences between the types of pretreatment. The h values of all samples were about 104, indicating a yellow color (Table 1).

Effect of degree of gelatinization and rheological change by pretreatment: Sweet potato high-pressure treatment did not result in complete gelatinization (2.5%, Table 2). However, heat treatment and the combination of heat treatment and high-pressure treatment resulted in complete gelatinization (Table 2). Bauer and Knorr (2005) studied the effects of gelatinization in wheat, tapioca and potato starches by high-pressure treatment (0-700 Mpa, 15 min, 29°C) and reported that wheat starch showed an approximately 20% gelatinization rate at 200 Mpa. However, tapioca and potato starches were not gelatinized by high-pressure treatment (200 Mpa, 15 min, 29°C). In this study, high-pressure treatment was carried out at 200 Mpa for 5 min (25°C). Therefore, the degree of gelatinization of pressurized sweet potato was not increased as compared to heat treatment and combination of heat treatment and high-pressure treatment.

Heat treatment after high-pressure treatment resulted in a relative hardness firmer than heat treatment alone or high-pressure treatment after heat treatment (Fig. 4). The relative hardness of high-pressure treatment after heat treatment approached that of the heat-treated sweet potato (Fig. 4). It was clearly demonstrated that heat treatment after high-pressure treatment increased

Table 1: Effect of various pretreatments on pretreated, dehydrated or rehydrated sweet potato color parameters

Treatments	L*	C*	h
Pretreated sweet potato			
Heat treatment	62.80±3.84	33.72±2.02	109.50±1.29
Heat treatment after high-pressure treatment	63.09±2.74	33.32±1.67	109.23±1.73
High-pressure treatment after heat treatment	61.46±3.41	34.16±1.59	109.80±0.90
Dehydrated sweet potato			
Heat treatment	87.10±1.39	31.58±1.20	102.05±0.41
Heat treatment after high-pressure treatment	86.75±2.75	32.40±1.25	102.03±0.38
High-pressure treatment after heat treatment	86.77±1.98	32.58±1.19	102.00±0.28
Rehydrated sweet potato			
Heat treatment	70.22±10.45	40.61±7.22	104.56±3.98
Heat treatment after high-pressure treatment	71.86±10.36	41.49±7.75	104.56±4.17
High-pressure treatment after heat treatment	69.86±8.480	39.75±5.45	104.56±3.42

Table 2: Effect of various treatments on sweet potato gelatinization

Treatments	Degree of gelatinization (%)
Non-pretreatment	0.0
High-pressure treatment	2.5
Heat treatment	100.0
Heat treatment after high-pressure treatment	100.0
High-pressure treatment after heat treatment	100.0

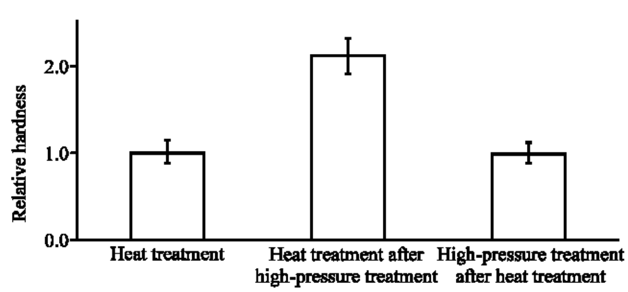

Fig. 4: Relative hardness of rehydrated sweet potato exposed to various pretreatments.

the relative hardness. Several researchers have reported that vegetables become softer after heat treatment and that this is the result of a loss of turgor and/or complex chemical changes in the cell wall matrix polysaccharides (Greve *et al*., 1994; Ng and Waldron, 1997). The decrease in hardness of heat-treated sweet potatoes is due to beta-eliminative degradation of pectin (Sila *et al*., 2006). However, sweet potatoes exposed to heat treatment after high-pressure pretreatment did not undergo softening, indicating that the beta-elimination reaction of pectin is inhibited by this treatment combination. Eshitiaghi *et al*. (1994) and Al-Khuseibu *et al*. (2005) showed that high-pressure treatment resulted in a texture similar to that of the raw materials. Sila *et al*. (2006) reported that high-pressure pretreatment retards the rate of thermal softening. Moreover, high-pressure treatment, as a treatment prior to drying, resulted in carrot with a similar hardness value to that of fresh samples, whereas heat-treatment resulted in a softer texture. Basak and Ramaswamy (1998) suggested that the most probable reason for the texture change under high-pressure treatment was due to pectinmethylesterase (PME) activity and increased compactness of the cellular structure as a result of tissue degassing. In this study, sweet potato processed with heat treatment or high pressure after heat treatment was softened, which is thought to be due to heat inactivation of PME, at 100°C, which resulted in a beta-elimination reaction of pectin. In contrast, sweet potato pretreated with heat treatment after high-pressure treatment was firmer than other pretreatments. Therefore, high-pressure treatment alone may not inactivate PME and serves to maintain a low degree of pectin methylation, which forms calcium bridges between the free carboxyl groups of adjacent pectin molecules, thereby resulting in a firmer texture.

CONCLUSIONS

The effects of high-pressure and heat pretreatments prior to the drying of sweet potatoes was investigated. The use of heat treatment after high-pressure treatment prior to the drying of sweet potato resulted in a lower rehydration rate than either heat treatment or high-pressure treatment after heat treatment. In contrast, there were no differences in color parameters or the degree of gelatinization by the three different pretreatments. However, rehydrated sweet potato exposed to heat treatment after high-pressure treatment had a high relative hardness and reducing sugar content than the other pretreatments. Therefore, the use of high-pressure pretreatment prior to drying has the potential to be a useful tool in improving the texture of rehydrated sweet potato.

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