Effect of thermal and freezing treatments on rheological, textural and color properties of basil seed gum

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Abstract Hydrocolloids are macromolecular carbohydrates that are added to many foodstuffs to achieve the appropriate rheological and textural properties and to prevent syneresis or to increase the viscosity and stability of foodstuffs. In this study the effect of different thermal treatments (25, 50, 75, 100 and 121 °C for 20 min) and freezing treatments (−18 and −25 °C for 24 h) on rheological, textural and color change of basil seed gum as a new source of hydrocolloids was investigated. The results demonstrated that basil seed gum solutions had desirable rheological and textural properties. Power law model well described non-newtonian pseudoplastic behavior of basil seed gum in all conditions. When the hydrocolloid samples were heated or frozen, increase in viscosity of basil seed gum solutions was observed. Hardness, adhesiveness and consistency of basil seed gel for control sample were 13.5 g, 16.79, 52.59 g.s, respectively and all increased after thermal treatments. The results revealed that basil seed gum has the excellent ability to stand against heat treatment and the highest hardness, adhesiveness and consistency value of gum gels were observed in sample treated at 121 °C for 20 min. In addition this gum gel has the good ability to stand against freeze-thaw treatment and its textural properties improved after freezing. Therefore, basil seed gum can be employed as a textural and rheological modifier in formulation of foods exposed to thermal and freezing temperatures.

Keywords Basil seed gum · Hydrocolloid · Rheology · Texture · Thermal treatment

Introduction

Hydrocolloids are mostly complex carbohydrates which are used to improve consistency and textural characteristics (rheological properties) of liquid and semiliquid foodstuffs. Their activity depends on the kind and concentration of hydrocolloids, temperature and process condition, as well as solid content and chemical composition of foodstuffs (Hegeduşi et al. 2000; Salehi and Kashaninejad 2015). Temperature is a very important parameter in food and biological processes. On the other hand, many textural and rheological properties are temperature sensitive (Mao et al. 1999).

Thermal process design such as pasteurization, sterilization, evaporation, cooking, baking and drying for liquid foods with or without particulate requires accurate information on the flow behavior to arrive at processing conditions which ensure safety and improve quality. Hydrocolloids are commonly used as thickening agents to create products with proper qualities, mostly textural characteristics (Marcotte et al. 2001). Data on the rheological and textural characteristics of hydrocolloid solutions are needed for the selection of the suitable hydrocolloid for the best competence of the thermal and freezing process.

According to the increasing demand for hydrocolloids with specific functionality in the recent years, finding new hydrocolloid sources with appropriate properties is an active area of studies. Basil seed gum (BSG) is a novel hydrocolloid extracted from seeds of basil herb that some scientists recently tried to apply it as a thickening and gelling agent in the food industry due to its particular behavior and convenience of extraction.

Basil plant (*Ocimum basilicum*) comes from the genus *Ocimum* of *Lamiaceae* family consisting of 50 to 150 herbs and shrubs (Simon et al. 1999). It is popular aromatic and white-purple flowering herbs grown in India and Iran (Fekri et al. 2008). It is also cultivated in the warmer regions of Africa, Central and South America (Simon et al. 1999).

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Aside from its culinary use, basil extract have been used in food flavoring and in fragrances. Basil contains essential oil, rich in linalool and methylchavicol compounds, which are responsible for its aromatic properties. The outer layer of basil seed contains a pectinous matrix, which readily swells when soaked in water (Melo and Dsouza 2004). The seed has been used in traditional medicine for the treatment of coughs, sore throats, diarrhea, indigestion and kidney malfunctions (Simon et al. 1999).

Emulsifying properties of basil seed gum were evaluated in terms of emulsion droplet size distribution, rheological properties, visual phase separation, and adsorption properties by Osano et al. (2014). Basil seed gum demonstrated excellent emulsifying and stabilizing properties when compared to other polysaccharides. In another study, Khazaei et al. (2014) investigated the using of basil seed gum as a new film-forming material under the influence of addition of glycerol as plasticizer. This study revealed that the basil seed gum had a good potential to be used in producing edible films for various food applications.

Basil seed gum was used to stabilize ice cream, and its impact on selected physical and structural properties (BahramParvar and Goff 2013). The addition of basil seed gum reduced the rate of ice crystal growth by 30–40 % compared to the commercially stabilized ice creams.

Food products are generally subjected to thermal and physical treatments during processing, transportation, storage and distribution, which affect the rheological and textural properties of hydrocolloid solutions. Therefore, study the thermal and freezing properties is very essential to determine the ability of hydrocolloid to be used in food formulations. The effects of thermal and freezing treatments on rheology of gums such as *pseudomonas olerovorse* (Fereitas et al. 2009), locust bean gum (Kok et al. 1999), and carboxymethylcelluos (Rao et al. 1981) have been reported by other researchers. There are also some reportson the effect of thermal and freezing treatments on textural properties of extracted gums from different sources such as alginate (Roopa and Bhattacharya 2010), carrageenan (Szczesniak 1975) and gellan (Mao et al. 1999).

Since there is no published information about the effect of thermal and freezing treatments on the behavior of basil seed gum, the objective of this study was to investigatethe rheological and textural properties of basil seed gum under different thermal and freezing treatments.

Materials and methods

Seed gums

Basil seeds were purchased from a local market in Gorgan, Iran. The cleaned basil seeds were soaked in distilled water in

the ratio of 20:1 at 50 °C and pH 7 for 20 min. Separation of the gum from the swollen seeds was performed by passing the seeds through an extractor equipped with a rotating plate that scraped the gum layer on the seed surface. The extracted solution was then filtered and dried in an air forced oven at 50 °C for 24 h (Convection oven, Memmert Universal, Schwabach, Germany) and finally the powder was milled, packed and kept at cool and dry condition for further experiments. The maximum basil seed gum yield was 14.75 % at 50 °C for pH=7 and water/seed ratio 20:1.

Sample preparation

Basil seed solutions, 0.2 and 3 % (w/w), were prepared by dispersing the gum powder in distilled water (Magnetic stirrer, Falc Stirrer, UK). The solutions were kept onmixer (Memmert Universal, Schwabach, Germany) for 24 h to complete hydration. 0.2 % concentration of gum solution was used for evaluation of shear rate dependency and 3 % concentration was used for assessment of textural characteristics.

Thermal treatments

In order to study the effect of heat treatment on rheological, textural and color properties of basil seed gum, the solution was poured into test tubes and heat effect was evaluated at five levels including 25 (UT), 50, 75, 100 and 121 °C (T1-T4) for 20 min. Allthermal treatments were conducted in water bath, except 121 °C that was carried out in an autoclave. Come up time to reach the targeted temperature was not computed within processing time. Solutions were cooled to 25 °C before experiments.

Freezing treatment

In order to investigate the effect of freezing treatment on rheological, textural and color properties of basil gum, samples were frozen in a chest freezer at −18 (T1) and −25 °C (T2) for 24 h and then thawed at room temperature (25±2 °C) before experiments.

Rheological measurements

To find out the changes of rheological characteristics during thermal processing, viscosity of gum solutions were measured using a rotational viscometer (Model RVDV-II, Brookfield, Inc. USA). The rheological parameters of basil seed gum was studied using spindle YULA-I5 at shear rate of 6.12 to 245 1/s and 25±0.1 °C. Solution of gum samples were loaded into the coaxial cylindrical chamber (16 ml capacity; ULA-31Y, Brookfield, Inc. USA) for all experiments and were allowed to equilibrate at the desired temperature using a circulating water jacket (Model ULA-40Y, Brookfield, Inc. USA).

Shear rate dependency

Shear stress (τ)-shear rate ($\dot{\gamma}$) data was fitted with the power law model:

$$\tau = K_P \dot{\gamma}^n \quad (1)$$

where, K_P is the consistency coefficient (Pa. sⁿ) and n is the flow behavior index (Salehi et al. 2014). Modeling of data was performed with non-linear analysis functions and parameters associated with different models estimated from the experimental data using curve-fitting program (Curve Expert (1.34, 2003)).

Texture measurement

A texture analyzer (TA-XT Plus, Stable Micro Systems Ltd., Surrey, UK) was used for penetration measurements. Penetration test was achieved by a cylindrical probe with 6 mm diameter at 100 mm/min rate and 15 mm depth. During penetration test, the force dropped at the point where the gel broke, and later the resulting forces were due to continuing penetration up to the demanded depth. Three parameters (hardness, consistency and adhesiveness) were determined from penetration test (Angioloni and Collar 2009). All experiments were conducted at room temperatures (25 °C).

Color measurement

Color of gum solutions after treatment was measured using computer vision system. The system comprised of a digital camera (Panasonic, model DMC-FS, Japan), image-capturing box and image analysis software (Image j). A sample holder was placed at the bottom of the box and the digital camera was fixed 20 cm above the sample. Lighting system consisted of two fluorescent lamps which were turned on for 10 min before image-capturing. Identical volume of gum solutions (0.2 % w/v) were poured in to a small glassy plate placed on the sample holder which was covered with a white translucent background. The CIELAB or $L^*a^*b^*$ space was used to describe color. This color space is device-independent, creating consistent colors regardless of the device used to acquire the image. L^* is the luminance or lightness component, which ranges from 0 to 100, while a^* (green to red) and b^* (blue to yellow) are two chromatic components, with values varying from -120 to +120 (Briones and Aguilera 2005; Salehi and Kashaninejad 2014).

Statistical analysis

The data was statistically analyzed by factorial analysis of variance (ANOVA) at the 0.05 level of significance and means

comparison was performed by Duncan multiple range test. The statistical software used to evaluate the experimental design results was SAS (SAS software 9.1.3, 2003). All data was presented as a mean of each experiment. In this study, the effect of different thermal treatments (25, 50, 75, 100 and 121 °C for 20 min) and freezing treatments (-18 and -25 °C for 24 h) on rheological, textural and color change of basil seed gum as a new source of hydrocolloids was investigated.

Results and discussion

Effect of thermal and freezing treatments on rheological properties

The polysaccharide extracted from the basil seeds has been reported to contain two major fractions: an acid-stable glucomannan (43 %) with a ratio of glucose to mannose 10:2; and a (1–4) linked xylan (24.3 %) with acid side chains at C-2 and C-3 of the xylosyl residues. A minor fraction of glucan (2.31 %) was also reported in this polysaccharide (Anjaneyalu and Gowda 1979). Oscillatory measurements were used to investigate the effect of temperature and concentration on the viscoelastic and gelling properties of basil seed gum (Rafe and Razavi 2013). Exhibiting special rheological properties of basil seed gum makes it as a proper synergistic gel, which can be applied in real food systems such as dairy desserts. Frequency sweep showed BSG solution was a typical weak gel, and complex viscosity had linear correlation with frequency.

The flow curves of basil seed gum solutions are presented in Fig. 1. The apparent viscosity was decreased as the shear rate increased at all thermal conditions showing non-Newtonian shear thinning behavior. The rheological model parameters obtained by fitting the shear stress-shear rate data of basil seed gum after thermal treatment (25, 50, 75, 100 and 121 °C for 20 min) are summarized in Table 1.

Fig. 1 Effect of heat treatment on apparent viscosity of basil seed gum solution

Table 1 The rheological parameters of power law model obtained for basil seed gum solutions at different thermal conditions

Treatments	k_p (Pa. s ⁿ)	n_p	R^2
25 °C	0.057 ^c	0.56 ^a	0.999
50 °C	0.068 ^{bc}	0.51 ^{ab}	0.995
75 °C	0.077 ^{bc}	0.50 ^{ab}	0.999
100 °C	0.1 ^b	0.49 ^b	0.998
121 °C	0.18 ^a	0.42 ^c	0.996

The consistency coefficient (k), which is related to viscosity, increased significantly ($p < 0.05$) in basil seed gum after heating. All heat treatments had a significant effect on the consistency coefficient basil seed gum ($p < 0.05$) but no significant differences were observed between treatments 25, 50, 75 and 75, 100 °C. Heating at 121 °C for 20 min was the most effective treatment.

These results demonstrate that an irreversible intermolecular arrangement has occurred in basil seed gum by the heat treatment and it would contribute to increase the viscosity (Yamazaki et al. 2009). Semi-rigid chain conformation is also responsible for high shear thinning and accumulation and association leads to high viscosity at thermal treatment with high temperature. This result was in agreement with the finding of Lim et al. (2002) for native and hydroxypropylated (HP) waxy maize. Yamazaki et al. (2009) also reported heating of *Corchorus olitorius* L. solution at 60 °C for 30 min leads to increasing of solution viscosity. However, they reported lower viscosity at higher temperatures.

The flow behavior index (n) decreased with increasing temperature and the effect of temperature was significant. However, treatments of 50, 75 and 100 °C were not significantly different. Research shows that the behavior of non-Newtonian which is important when flow behavior index is less than 0.6 (Chinnan et al. 1985). The flow behavior index of all samples was below 0.6, indicating the behavior of this hydrocolloid is strong pseudoplastic. A high shear thinning behavior of polysaccharides allows liquid foods to be pumped easily and imparts a thinner consistency during swallowing (Vardhanabhuti and Ikeda 2006). Primary studies have correlated a higher degree of shear thinning with a lower degree of sliminess in the mouth produced by hydrocolloids (Szczesniak and Farkas 1962). Consequently, the mouth feel features provided by basil seed gum may be even better than carboxymethyl cellulose (CMC), pectin, carrageenan or monoi hydrocolloid based on the higher shear-thinning properties (Marcotte et al. 2001; Vardhanabhuti and Ikeda 2006).

Glicksman (1982) reported a similar reduction in xanthan solutions in distilled water after heating (115 °C–30 min) who also indicated that xanthan solution

(1 %) containing 0.1 % NaCl has a viscosity loss of less than 10 %.

Freeze-thaw stability is important in the frozen food industry, as it represents the ability of a product to maintain its composition and integrity after repeated cycles of freezing and thawing. The thawed liquid within the product causes larger ice crystals after refreezing leading to the breakdown of the structure in a product. Hydrocolloids are an important group of additives, which employed to keep and improve rheological properties of frozen foods (Chantaro and Pongsawatmanit 2010).

The apparent viscosity of basil seed gum solutions at temperatures of −18 and −25 °C are presented in Fig. 2. The apparent viscosity was decreased as the shear rate increased at both freezing conditions showing non-Newtonian shear thinning behavior. The rheological model parameters obtained by fitting the shear stress-shear rate data of basil seed gum after freezing treatment (−18 and −25 °C) are summarized in Table 2. The results show that consistency coefficient increased after freezing, but no significant differences were observed between freezing treatments.

When the temperature declines to below sub-zero, the unfrozen phase becomes maximally concentrated as more and more water molecules crystallize into ice, ultimately this phase will remain unfrozen due to the high concentration of present solutes. According to Akyurt et al. (2002), this unfrozen phase is highly viscous.

The polymer concentration increased by conversion of water to ice, which lead to chain aggregation and remained stable after freezing. This result was in agreement with the findings of Williams et al. (2009) for mixture curdlan gum/locust bean and curdlan/kappa carrageenan. Therefore basil seed gum is stable to freezing and is recommended for the purpose of reducing the damage caused by freezing.

Fig. 2 Effect of freezing treatment on apparent viscosity of basil seed gum solution

Table 2 The rheological parameters of power law model obtained for basil seed gum solutions at different freezing conditions

Treatments	k_p (Pa. s ⁿ)	n_p	R^2
25 °C	0.057 ^b	0.56 ^a	0.999
−18 °C	0.12 ^a	0.43 ^b	0.996
−25 °C	0.11 ^a	0.42 ^b	0.995

Effect of thermal and freezing treatments on textural properties

Hardness

Hardness is commonly measured to indicate the strength of the gel structure under compression. Hardness of basil seed gels was found to be stable over the thermal treatments based on the results obtained (Fig. 3). In penetration test, the hardness value of control sample was 13.5 g. However, no significant difference was found between the 25, 50 and 75 °C treatments. In penetration test, the highest hardness value was observed in sample treated at 121 °C for 20 min, suggesting high temperature produces a gel network with relatively high strength.

The thermal behavior of gels differs due to the junction zones and one of the major factors influencing the strength of junction zones is their length. Junction zones play a very important role in the gelling process of hydrocolloids. They also markedly influence the characteristics and functional behaviour of a particular gel. The number of molecules that form a junction zone is an important gel property determinant. During gelatin, junction zones are formed by three molecules through hydrogen bonding. More the number of molecules in the junction zone, more rigid will be the gel (Saha and Bhattacharya 2010).

Processing of the samples at higher temperatures induced the formation of harder gels. It may be hypothesized that an

higher temperature during gel formation may have more effectively opened and exposed the basil seed gum molecules favoring their interaction, the formation of junction zones, and resulted in a stiffer network. The very high conformational mobility of the basil seed gum chains might have favored the interaction among molecules (Chiavaro et al. 2007). This result was in agreement with the findings Roopa and Bhattacharya (2010) for alginate gel.

Despite the development of food products, unstable texture of frozen products against freezing is one of the main problems yet (Teng et al. 2013).

Texture instability remains the most important challenge for frozen food products, especially with inevitable post-production temperature fluctuations. Loss of moisture and changes in textural characteristics often results in significant reduction of product quality (Williams et al. 2009). The hardness of basil seed gel after freezing treatment is shown in Fig. 4. Based on the experimental results, significant changes in the hardness of the basil seed gel was occurred after freezing. Hardness of basil seed gel was completely stable against freezing at −18 °C for 24 h but with decreasing freezing temperature to −25 °C for 24 h hardness slightly increased. Teng et al. (2013) reported Sago and potato gels showed a significant increase in hardness after a freeze-thaw cycle. Marti de Castro et al. (1997) also observed the strength, hardness, cohesiveness and elasticity of sardine mince gels increased after freezing at −40 °C. Faydi et al. (2001) reported the formed gel at −60 °C was significantly stronger than that formed at −20 °C, perhaps because of the mean crystal size decreased with the cooling temperature.

Adhesiveness

Adhesiveness is basically a surface characteristic and depends on a combined effect of adhesive and cohesive forces, and other factors including viscosity and viscoelastic properties as well (Adhikari et al. 2001). Adhesiveness, which the work required to separate a surface from food materials, is an

Fig. 3 Effect of thermal treatments on the hardness of basil seed gum **Fig. 4** Effect of freezing treatments on the hardness of basil seed gum

important characteristic that could have both positive and negative consequences depending on the applications (Meiron and Saguy 2007). According to Fig. 5, adhesiveness of initial basil seed gel was 16.79 g.s and increased slightly after heat treatments in penetration test, but no significant differences were observed between treatments of 50, 75, 100 and 75, 100, 121 °C. Adhesiveness can be observed in two different ways: adhesion to manufacturing equipment or sticking to fingers and parts of the mouth and may be considered a positive characteristic for example in salad dressing, puddings, confectionary products, bakery goods or a negative characteristic for spaghetti and other pasta products, bread crumbs and some meat products (Fizman and Damasio 2000).

In the present study, basil seed gum had high levels of adhesiveness under thermal treatment. This gum could potentially be used in salad dressing formulations. Manufacturers and consumers, in most cases, prefer a salad dressing which clings to the salad and won't quickly collect in the bottom of the bowl (Hoefer 2004). Therefore, this high adhesiveness would be desirable in this type of product.

According to the penetration test, there was no significant changes ($p>0.05$) in adhesiveness of basil seed gum gel treated with freezing temperatures (Fig. 6) and this stability was also maintained with decreasing temperature to -25 °C. This behavior indicates the stability of the structure of basil seed gum against the freezing and freeze-thawing process. As a result, basil seed gum can be used in the formulation of frozen foods that adhesion factor is an important factor. Yu et al. (2010) also reported the cooked rice processed with higher freezing rates have higher adhesiveness.

Consistency

Consistency is defined as the work required attaining deformation indicative of internal strength of bonds within the product (Ahmed et al. 2005). The consistency alterations for the basil seed gum gels over heat treatments are showed in Fig. 7. The most significant alteration was occurred in sample

Fig. 5 Effect of thermal treatments on the adhesiveness of basil seed gum

Fig. 6 Effect of freezing treatments on the adhesiveness of basil seed gum

treated at 121 °C for 20 min, but no significant differences were observed between samples treated at 50, 75, 100 and 25, 75 °C.

These results approve the increased of junction zones of gel during heating because of existence of high amount of unsubstituted mannan regions. The prevalence of higher molecules in basil seed gum is likely responsible for the higher consistency of basil seed gum gels under thermal treatments (Chiavaro et al. 2007).

According to Fig. 8, consistency of basil seed gum gels increased after freezing treatment but it was not statistically significant ($p>0.05$). Consistency like adhesion was quite stable during freezing and freeze-thaw cycle and no significant changes during freezing treatments were occurred. This stability could show the strength of internal bonds of basil seed gum gel. This result demonstrates the improvement effect of freezing on the junction zone of basil seed gum polymers. Zeira and Nussinovitch (2004) Reported the consistency of freeze-thawed locust bean gum (LBG) solutions depend, among many other things, on the induced gelation conditions and the integrity of the relatively weak LBG gel network. Consequently, any disruption of the latter will result in alterations in the LBG gel's texture.

Fig. 7 Effect of thermal treatments on the consistency of basil seed gum

Fig. 8 Effect of freezing treatments on the consistency of basil seed gum

Effect of thermal and freezing treatments on color

Color measurement is a critical objective quality parameter that can be used for quality index measurements of raw and processed foods, quality control documentation and communication, for determinations of conformity of food quality to specifications, and for analyses of quality changes as a result of food processing, storage, and other factors (Esteller et al. 2006). The effect of thermal treatment on color of basil seed gum is given in Table 3. Comparing the results of colorimetric parameters L^* , a^* and b^* show that L^* parameter regularly increases with increasing the temperature and the most significant changes was occurred in the sample treated at 121 °C for 20 min but no significant differences were observed between samples treated at 25, 50, 75 and 100 °C. The b^* value of basil seed gum significantly decreased and a^* value of basil seed gum significantly increased by increasing temperature. Effect of freezing treatment on color of basil seed gum is given in Table 4. L^* parameter value of sample frozen at −18 °C was reduced compared to the control sample, but by increasing severity of the freezing to −25 °C, L parameter value didn't change significantly. The a^* value of sample frozen at −18 °C increased compared to the control sample and with decreasing the freezing temperature to −25 °C reduced. The b^* value of sample frozen at −18 °C decreased compared to the control sample and by increasing the severity of freezing temperature to −25 °C significantly increased.

Table 3 The color parameters of basil seed gum solutions at different thermal conditions

Treatments	L^*	a^*	b^*
25 °C	81.88 ^b	−21.57 ^c	24.86 ^a
50 °C	82.95 ^b	−20.035 ^c	23.87 ^a
75 °C	83.26	−12.305 ^b	12.030 ^b
100 °C	85.030 ^b	−2.23 ^a	4.70 ^c
121 °C	89.080 ^a	−2.18 ^a	1.98 ^d

Table 4 The color parameters of basil seed gum solutions at different freezing conditions

Treatments	L^*	a^*	b^*
25 °C	81.88 ^a	−21.57 ^c	24.86 ^a
−18 °C	65.87 ^b	−4.90 ^a	7.55 ^c
−25 °C	67.66 ^b	−8.80 ^b	11.88 ^b

In reality, basil seed gum solutions normally contain a range of different droplet sizes and the light waves are scattered differently by the droplets in each size class (McClements 2002). With increasing the viscosity of basil seed gum at high and freezing temperatures, the particle concentration increases, therefore lightness increases because more light is multiply scattered backwards by the droplets.

Conclusion

Basil seed gum is a new source of hydrocolloids that exhibited desirable rheological and textural properties. It was found that the thermal and freezing treatments did not have destructive effects on basil seed gum and the rheological properties of basil seed gum improved after heating and freezing treatments. The overall mechanical behavior evaluated by penetration test confirmed that basil seed gum gel had good texture characteristics and can preserve its gel integrity and resistance at different thermal and freezing conditions which is of great importance in the production. According to the results of this investigation, basil seed gum is heat and freeze-thaw stable in all rheological and textural properties. Therefore, basil seed gum can be used as a suitable gum in various industrial processes including cooking, pasteurization, sterilization and freezing.

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