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SHORT COMMUNICATION

Potentiality of freeze–thaw treatment to produce soft textured aonla (*Emblica officinalis*) candies

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Abstract Aonla, due to its astringency, is converted into various processed products. Candy is the most popular of among them. Commercially available aonla candies in India are hard in texture. However, soft textured candies are preferred more over harder ones. Hence, study was undertaken to produce soft textured candies. Whole fruits and fruit segments were blanched in boiled water, frozen in domestic freezer for 12 h and thawed at room temperature (15–20 °C). Fresh, blanched, frozen and thawed samples were subjected to textural analysis. Some of the blanched and thawed segments were used to prepare candies and subjected to textural analysis. Results indicated that force–deformation behavior of all samples differed significantly. Fresh, blanched, thawed and frozen segments required 14.39, 0.84, 0.22 and 0.18 N force, respectively to compress them till 1 mm deformation. Similarly, peak force (5 mm deformation) was maximum in fresh segments (172.25 N) followed by blanched (8.77 N), frozen (1.06 N) and thawed (0.85 N). Peak force values for control and soft candies were 13.14 and 6.86 N, respectively. Based on results, it was found that freeze–thaw treatment significantly reduced the firmness of segments and produced soft textured candies.

Keywords Aonla candy · Texture · Soft · Deformation · Freezing

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Introduction

Indian gooseberry (*Emblica officinalis*) popularly known as aonla is one of the most popular fruits in India. Owing to its rich vitamin C (400–445 mg/100 g), it possesses high antioxidant activity (Tarwadi and Agte 2007). Aonla has achieved a special place among the existing fruits and vegetables due to rising concern for health and nutrition. In Indian households, it is consumed regularly due to its medicinal quality and ayurvedic importance. It aids in digestion, treats fever, constipation etc. It is eaten for its blood purification properties along with added benefits to hairs and eyes. Aonla is mostly eaten in the form of processed products like candy, juice, preserve, squash, dried shreds, chutney, pickles, jam etc. Its raw fruit is strongly astringent and sour, due to which it is seldom preferred in raw form. Hence, processing of raw aonla fruits into different processed products becomes indispensable to make them more palatable.

Among various processed products, aonla candy is one of favorite foods among people from a wide range of age. Moreover, due to upsurge of life style diseases, the demand for aonla candies is increasing markedly. Therefore, large numbers of candying units, domestic and commercial, are engaged in aonla candy business. Aonla candying process involves osmotic drying of aonla segments using sugar syrup. During osmotic drying, sugar syrup of various strengths varying from 45 to 70 °C brix is impregnated in the fruit segments. Osmotic drying is carried out for a period of about 45–72 h followed by draining of excess syrup and drying the product to shelf stable moisture content (Adsare et al. 2016). Commonly, aonla candy prepared through conventional process has hard texture. Although, this product is being consumed extensively due to health benefits associated with aonla fruits, its acceptability and market value can be further enhanced by improving its textural quality. Food texture is one of the most important features influencing the consumers' acceptance of a food product. Soft textured candies or products of any fruit are more acceptable than their hard counterparts (Ansari et al. 2014). Ansari et al. (2014) reported that soft textured dried figs had more consumer acceptance than hard textured dried figs. Food texture is a complex feature and depends on several chemical and physical characteristics of the food product.

Texture of aonla candies depends on various intrinsic and extrinsic factors. Intrinsic factors include maturity of fruits, physico-chemical composition, variety etc. whereas extrinsic factors include concentration of sugar syrup, impregnation period, drying temperature and drying duration. In conventional candying process, aonla fruits are blanched, segmented and dipped into sugar syrup followed by draining and drying. Most of the times, this process leads to harder texture of candies. Also, this conventional process if not followed appropriately in sequential manner results in hard candies. Integration of some additional treatment in conventional candying process may be helpful to produce softer candies. From reported information, it was hypothesized that freeze–thaw treatment would be a probable step in candying process to produce soft textured candies.

Literature reveals that various studies have been conducted to understand the effect of freeze–thaw treatment on microstructure and texture of different foods (Boonsumrej et al. 2007; Sirijariyawat and Charoenrein 2012; Lina et al. 2014; Charoenrein and Owcharoen 2016; Tagubase et al. 2016). These studies demonstrated that freeze–thaw treatment resulted in textural changes in foods leading to food softening. Lim et al. (2004) noted that formation of ice crystals during freezing results in disruption of cell compartments that further brings textural changes. Indeed, due to very high moisture content of the fruits, they cannot be frozen without changes in texture, flavour, appearance and colour of freeze–thawed fruits. However, the major effect of freeze–thaw treatment on fruits is loss of tissue firmness and fruit softening (Coggins and Chamul 2004).

Fruit firmness mainly depends on turgor of the cells. Further, cell turgidity is based on intact cellular wall and intact cellular membrane (Mclellan et al. 1991). Reports indicate that ice crystals formed during freezing process break the cells and damage tissue integrity, thereby attaining irreversible structural and textural changes in foods (Buggenhout et al. 2006; Ramallo and Mascheroni 2010; Charoenrein and Owcharoen 2016). It is also reported that freeze–thaw treatment causes severe structural changes in fruits due to damage to pectic material of the cellular wall and middle lamella (Roy et al. 2001; Yashoda et al. 2006). Damage to the pectin is easily related to textural changes/softening in the fruits. In general, it is understood that the tissue softening in fruits is the result of cell wall degradation and damage to pectic materials that can be achieved through freeze–thaw treatment.

Thus, freeze–thaw treatment was found to be the most appropriate step to soften aonla fruits tissues. Literature reveals that no reported information is available on the application of freeze–thaw treatment to aonla fruits for production of soft textured candies. Hence, an attempt was made in present study to integrate the freeze–thaw treatment into the conventional candying process and to evaluate the potentiality of this treatment in producing the soft textured candies.

Materials and methods

Raw material

Mature aonla fruits cv. *Chikaiya;* (total soluble solids: 9.0°Bx; moisture content 85.32%, wb), grown in the field of ICAR-Central Institute of Postharvest Engineering and Technology, Abohar, Punjab were selected as raw material. Fruits were harvested in the month of December 2016, sorted and uniform sized fruits were selected for the experiment. In present study, fruits were divided into two lots of samples, whole fruits and fruit segments. Segments were obtained by cutting the aonla fruits along the stem–calyx axis of fruits.

Blanching

Whole aonla fruits and fruit segments were washed and subjected to hot water blanching in a stainless steel vessel at 98 ± 2 °C temperature. Fruits were loose wrapped in muslin cloth and were blanched for 10–12 min (Nath et al. 2016). After blanching, 25 whole fruits and segments were used to determine textural attributes whereas remaining samples were subjected to freeze–thaw treatment. 1 kg blanched fruit segments were directly used for preparation of candy and was termed as control treatment. The experimental plan in the form of flow chart is presented in Fig. 1.

Freezing–thawing

Blanched samples were subjected to slow freezing at − 8 °C in freezer of domestic refrigerator (Samsung, model: RT28/2008, gross volume: 280 L). Complete freezing of samples was achieved within 12 h of freezing. After freezing, 25 whole fruits and segments were used for studying textural attributes and remaining samples were kept for thawing. Process of thawing was executed at room

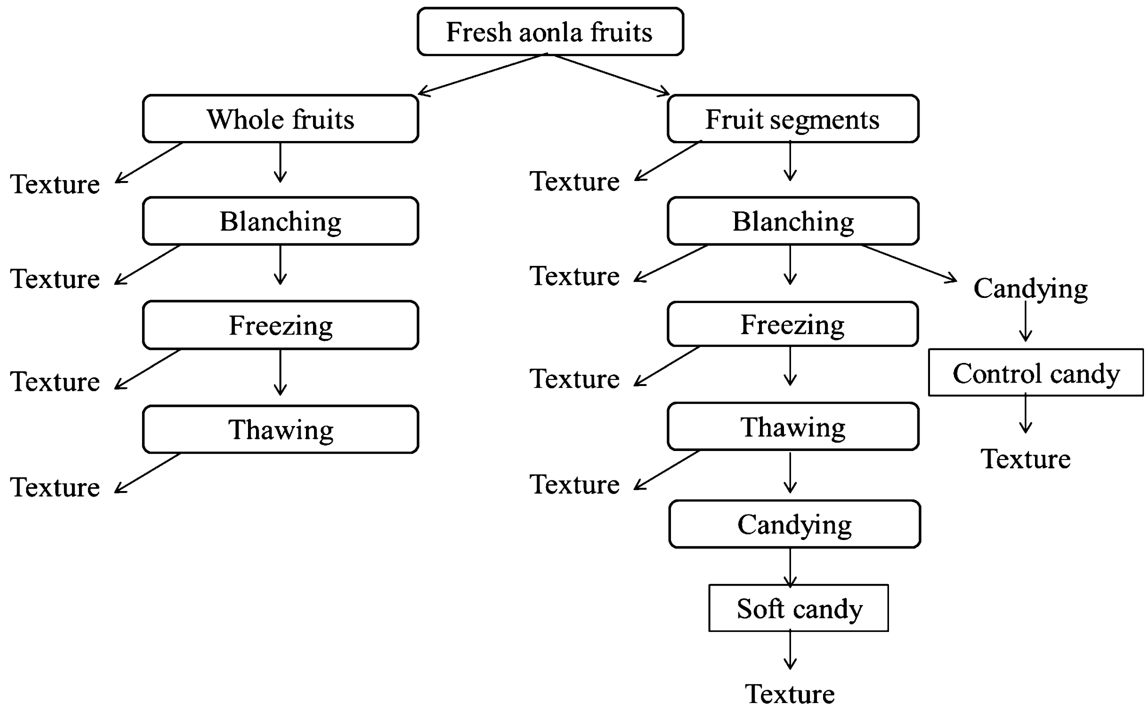

Fig. 1 Flow chart depicting scheme of texture determination of different samples

temperature (15–20 °C) and complete thawing was achieved within 2–3 h. Thawed whole fruits and segments were immediately evaluated for texture determination. 1 kg freeze–thawed segments were used for preparation of soft candy.

Candying

Osmotic solutions of 45, 55 and 68°Bx were prepared using sugar. Clean potable water was used to prepare osmotic solutions. Fruit segments were steeped in 45, 55 and 68°Bx osmotic solutions sequentially. Steeping time was fixed as 16 h for each osmotic solution. Complete steeping process took 48 h. Steeping was followed by draining the aonla segments by placing them on perforated aluminium trays for 10 h at room temperature (20–23 °C). After draining, the segments were dried in a hot air dryer at 50 °C for 8 h to prepare dried candies.

Textural analysis

Food texture is perceived through the sense of touch, either by pressing with hand or by chewing. In general, food texture may be defined as “a group of physical properties that arise from structural elements of food, are sensed by feeling of touch, are related to deformation, disintegration and flow of food under a force, and are measured objectively by functions of mass, time and distance” (Bourne 1982; Barrett et al. 2010). Food texture is mostly determined by sensory and instrumental methods. Determination of food texture through sensory methods is the simplest way to understand the softness of product. It is achieved through a panel of semi-trained or trained judges. Panel gives the sensory scores on the basis of the degree of softness/hardness of the product (Shobha et al. 2018). Instrumental methods involve puncture or compression test using texture analyzer, Shore-A durometer, Penetrometer, Instron universal testing machine etc. (Barrett et al. 2010; Radia et al. 2018). Nowadays, food texture is determined by using texture analyzer as it is the simplest method and can be applied to any type of food product. The puncture test performed using texture analyzer is a force measuring method having dimensions time, length and mass and it is probably the most frequently used method of textural analysis. This method consists of determining the force and deformation required to punch or push a probe into a food product to a depth that causes irreversible failure (Barrett et al. 2010). Modern techniques such as acoustic methods based on vibration techniques, differential scanning calorimetry, determining the scanning electron microscopic images etc. may also be used to characterize the structure and textural properties of food products (Barrett et al. 2010; Radia et al. 2018).

In present study, textural behavior of samples was determined using texture analyzer (Model *TA + Di*, Stable Micro Systems, UK). 25 samples from each step (fresh, blanching, freezing, thawing and candying) were subjected individually for compression loading. Uniaxial compression test was carried out by placing the samples between two parallel plates. Due to non-uniformity in the whole fruits at their natural rest positions, they were positioned in such a way that stem–calyx axis was parallel to probe surface. However, fruit segments were placed in their natural rest position. Pre-test, test and post-test speeds were fixed as 0.05, 0.01 and 10 mm/s, respectively. Distance (deformation depth) was fixed as 5 mm. Force–deformation curves were obtained from compression tests. Force for 1 mm deformation and peak force for 5 mm deformation were determined from curves. Deformation energy required for maximum deformation was also determined for all the samples. Deformation energy was defined as the area under fore-deformation curve up to the point selected as peak force.

Statistical analysis

Textural parameters (force at 1 mm deformation, peak force and deformation energy) of the aonla samples from each step were measured 25 times and the means were reported. Duncan's multiple range test was performed to test the statistical differences in these parameters. SPSS software (version 16.0) was used to conduct the tests. The significance was accepted at 5% levels of significance ($\alpha = 0.05$).

Results and discussion

Force–deformation behavior

All the samples showed different force–deformation behaviors under compression loading (Fig. 2). It is evident from Fig. 2 that linear force–deformation relationship was observed up to 1 mm deformation in fresh whole fruits, however at > 1 mm depth, compression force increased considerably as compared to the deformation. Such behavior might be attributed to the resistance offered by denser pulp due to initial compression. The moisture present in the fruit tissue was displaced due to initial stage of loading and made the pulp denser. Another reason for non-linear increase in the force might be the resistance offered by fruit stone after initial loading. No linear force–deformation relationship was observed in blanched and frozen whole fruits. On the contrary, thawed whole fruits showed linear increase in force and deformation throughout the test. Such behavior of thawed aonla fruits was attributed to the softening of internal tissues of fruits after freeze–thaw treatment. Reports show that freezing develops extracellular ice crystals which cause mechanical damage to fruits tissues and leads to fruit softening (Fernandez et al. 2006; Charoenrein and Owcharoen 2016). Soft tissues did not offer resistance to compressive loading and hence were compressed constantly throughout test.

Unlike whole fresh fruits, force applied to fresh segments was not proportional to deformation induced in the samples. Increase in force was more as compared to deformation (Fig. 2). Force–deformation curve of blanched segments indicates that there was almost linear increase in force and deformation till 2.5 mm depth, and force increased rapidly after this point. It might be due to increased internal stress after initial compression. Moisture was displaced from the tissues due to initial loading and compact mass was formed to resist the external compressive force. Frozen and thawed segments showed similar behavior. There was more deformation for smaller amount of force. Such force–deformation behaviors of frozen and thawed segments clearly indicated the softening of fruit segments.

Results (Fig. 2) also indicated that force–deformation behavior of candy without freeze–thaw treatment (control candy) was different than candy with freeze–thaw treatment. In case of control candy, compression force increased non-linearly with time. On the contrary, candy prepared using freeze–thaw treatment showed almost linear increase in force till 3 mm deformation. After 3 mm depth, increase in force was more as compared to deformation. Thus, from force–deformation curves, it can be stated that freeze–thaw treatment softened the tissues of fruits and produced softer candy.

Force required for 1 mm deformation

It is evident from Table 1 that force required to compress samples up to 1 mm deformation was significantly ($\alpha = 0.05$) different for different samples. Fresh whole fruits required 32.21 N force whereas thawed fruits required only 0.82 N force for 1 mm deformation. The highest peak force of fresh aonla fruits indicates that they had firm texture, whereas blanched, frozen and thawed samples showed constant decreasing peak forces thereby indicating a softer texture. Such variation in the texture of the different samples was due to the freezing and thawing treatment that caused the reduction in the firmness of the fruits by damaging the cell structure and colloidal systems after the formation of ice crystals (Yashoda et al. 2006; Tagubase et al. 2016). Our findings are in line with the observations made by Sirijariyawat and Charoenrein (2012) while studying freezing characteristics and texture variation after freezing and thawing of apple, cantaloupe, mango and pineapple fruits. The firmness values of all the frozen thawed fruit samples decreased with respect to that of the fresh fruit samples. During freezing the water in the samples formed ice crystals which negatively damaged the

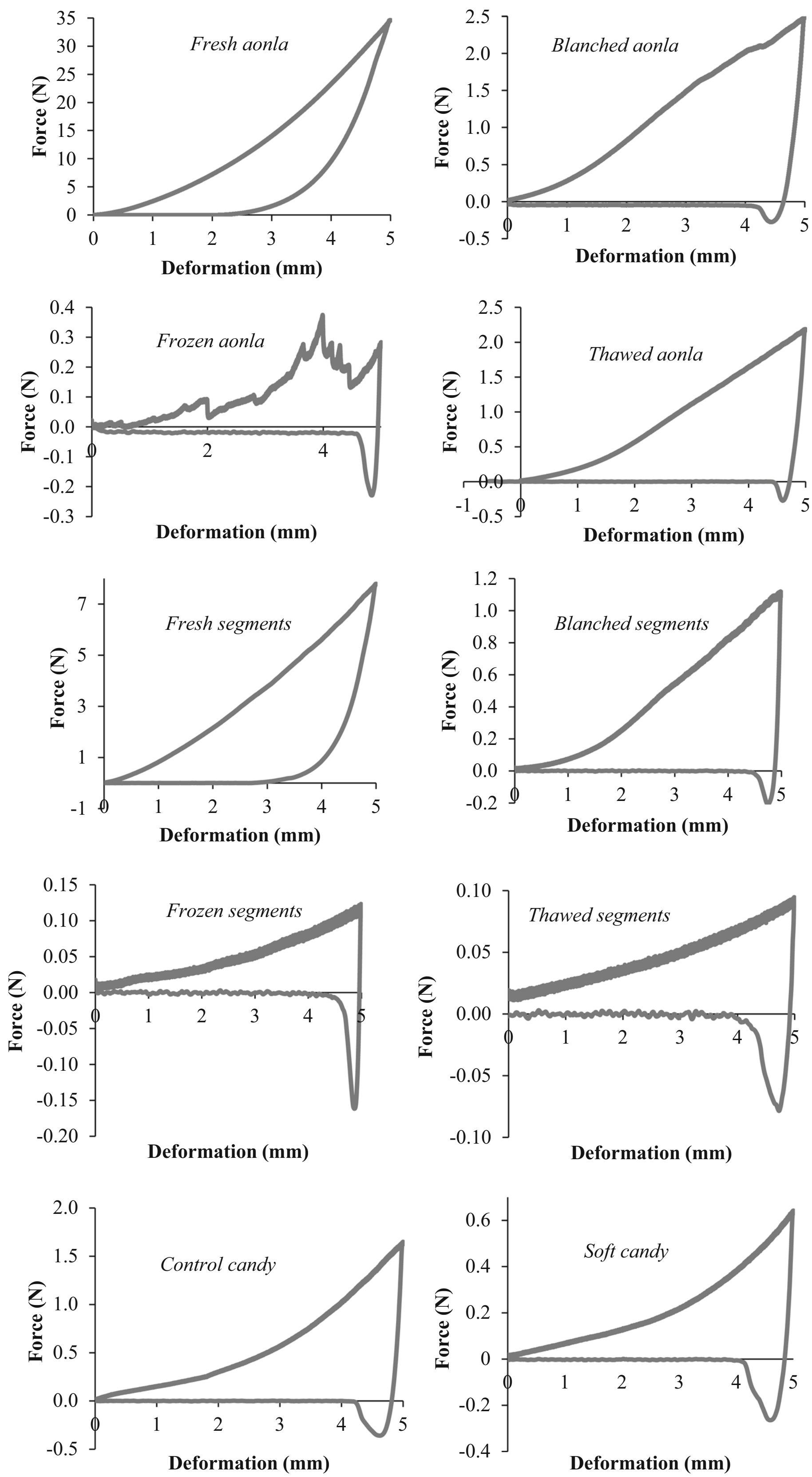

Fig. 2 Representative force–deformation curves of different samples

Table 1 Force, deformation and deformation energy of aonla samples

Sample	Force at 1 mm deformation (F1, N)	Force at 5 mm deformation (peak force F2, N)	Deformation energy (N-mm)
Whole aonla fruits			
Fresh	37.21 ± 7.47[d]	387.71 ± 56.30 [g]	784.56 ± 110.52 [g]
Blanched	2.90 ± 0.48[b]	34.08 ± 8.78[e]	70.23 ± 15.91[e]
Frozen	2.35 ± 2.13[b]	8.10 ± 3.74[c]	17.71 ± 8.94[c]
Thawed	0.82 ± 0.37[a]	5.56 ± 4.79[b]	12.45 ± 10.21[b]
Aonla segments			
Fresh	14.39 ± 4.77[c]	172.25 ± 33.85[f]	346.09 ± 76.97[f]
Blanched	0.84 ± 0.34[a]	8.77 ± 2.92[c]	18.31 ± 6.94[c]
Frozen	0.18 ± 0.05[a]	1.06 ± 0.29[a]	2.37 ± 0.62[a]
Thawed	0.22 ± 0.02[a]	0.85 ± 0.09[a]	2.07 ± 0.18[a]
Candy samples			
Control candy	1.16 ± 0.36[b]	13.14 ± 3.78[d]	22.00 ± 5.08[d]
Soft candy	0.64 ± 0.13[a]	6.86 ± 2.47[b]	11.36 ± 2.99[b]

Values in a column followed by same letter do not differ significantly ($\alpha = 0.05$)

Values are mean of 25 replications ± SD

cellular integrity of the cellular compartments reducing the turgor pressure and firmness values of the samples.

Peak force

Peak force was maximum (387.71 N) in fresh fruits followed by blanched fruits (34.08 N), frozen fruits (8.10 N) and thawed fruits (5.56 N). Similar trend was observed in fruit segments also. This data also verifies that freeze–thaw treatment reduced the firmness of the aonla segments and allowed to produce soft textured candies.

Deformation energy

Deformation refers to any change in the shape or size of an object due to applied force. Deformation energy significantly ($\alpha = 0.05$) varied with the treatment (Table 1). Fresh whole fruits had the highest values (784.56 N-mm) whereas thawed aonla had the lowest value (12.45 N-mm) of deformation energy among whole fruit samples. Similarly fresh segments required maximum deformation energy (346.09 N-mm) followed by blanched segments (18.31 N-mm), frozen segments (2.37 N-mm) and thawed segments (2.07 N-mm). Deformation energy for control candy was determined as 22.00 N-mm whereas it was 11.36 N-mm for soft (freeze–thaw) candy. Similar observations were found in case of freezing muskmelon spheres (cv. *Reticulatus naud*), pineapple, apple, mango, cantaloupe (Maestrelli et al. 2001; Ramallo and Mascheroni 2010; Sirijariyawat and Charoenrein 2012). Thus, it can be stated that freeze–thaw treatment reduced the deformation energy by almost 50%. In other words, aonla segments treated with freeze–thaw treatment required considerably low deformation energy to achieve desired deformation and thus indicated the softening of the candies.

Conclusion

Candy is a popular product of aonla fruits. However, most of the candies available commercially are hard in texture. Compared to hard texture candies, soft texture candies are preferred more by the consumers. Hence, present study was carried out to produce soft textured aonla candies. In present study, freeze–thaw treatment was integrated in the conventional candying process. Aonla fruits were blanched, segmented and fruits segments were subjected to freeze–thaw treatment prior to steeping in osmotic solution. During study, texture of fresh, blanched, frozen and thawed whole fruits as well as fruit segments was determined. Candies prepared through conventional process and process involving freeze–thaw treatment was also analyzed for texture. Results indicated that fresh whole fruits and fresh fruit segments required the highest force to achieve predetermined deformation. Fresh samples were followed by blanched, frozen and thawed samples. Similarly, candies prepared using conventional process required 13.14 N force whereas candies prepared by integrating the freeze–thaw treatment in the conventional process required only 6.68 N to achieve 5 mm deformation. From the results, it can be concluded that integration of freeze–thaw treatment in candying process helps to produce soft textured candies.

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