Received: 17 December 2018 | Revised: 4 March 2019 | Accepted: 26 April 2019
DOI: 10.1111/jtxs.12406

RESEARCH ARTICLE

Journal of Texture Studies WILEY

Instrumental measurement of pomegranate texture during four maturity stages

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Abstract

Texture of pomegranate fruit and arils are the main quality attributes in the food process industries. In this study, the texture properties of pomegranate fruit and arils (cv. "Ashraf") at four different stage of maturity (88, 109, 124, and 143 days after full bloom) were evaluated using the puncture test (rupture force and rupture energy) and compression test (bioyield force, rupture energy, and young modulus). The tests showed that all studied textural parameters were sensitive textural parameters for distinguishing the maturity stages. Rupture force and rupture energy of pomegranate fruit were determined at top, middle, and bottom positions of the fruit. The results showed that compression load values of aril increased with advances in maturity stage of fruit, while puncture load values of fruit decreased. The textural properties of pomegranate fruit and arils exhibited a strong dependence ($p < .05$) on the degree of maturity at harvesting time. Also results showed that rupture force of three different studied positions of fruit was severely different. The highest and lowest values were observed at top and middle position, respectively.

KEYWORDS
aril, compression test, maturity, pomegranate fruit, puncture test, texture

1 | INTRODUCTION

Pomegranate fruit is one of the most productive fruit in the Middle Eastern countries. According to statistical data, Iran with an annual production of 16.5 million tons of pomegranate fruits was in the second rank of the world in 2017 (Pomegranate Festival kicks off in Tehran, 2017). The edible fresh part of the pomegranate fruit, arils, is mainly consumed directly, but sometimes used after separation of seeds, for the preparation of fresh juice consumption or canned beverages, even alcoholic beverages, jellies, jams, and for flavoring and coloring agents (Arendse, Fawole, Magwaza, Nieuwoudt, & Opara, 2018; Szychowski et al., 2015). In Iran, the arils separated from the rind's pomegranate fruit and thin inner membrane (locular septa) manually which can be very difficult. On the other hand, the textural properties of fruits is the result of a combination of factors inherent to their structure, morphological composition, maturity stage, differences among varieties and even among fruits of the same variety, and handling conditions after harvest (Fawole & Opara, 2013a; Jbir, Hasnaoui, Mars, Marrakchi, & Trifi, 2008; Melgarejo, Martinez, Hernandez Fca, Martinez, & Martinez-Murcia, 2009). The textural properties mainly depend on the speed of metabolic changes and are not constant over time (Bentini, Caprara, & Martelli, 2009; Gao, Pitt, & Bartsch, 1989). So, information on the pomegranate fruit-arils texture and their dependency on maturity progress are essential for a rational design of an efficient dehulling system and equipment for mechanical separation of arils and other processes.

During the last 40 years, many valuable research works have been made clear the need to determine the textural properties for each fruit in particular due to the close relationship between these

This article was published on AA publication on: 08 May 2019.

properties with its degree of susceptibility to the different types of mechanical damage and ripening (Barchi, Berardinelli, Guarnieri, Ragni, & Totaro, 2002; Berardinelli, Donati, Giunchi, Guarnieri, & Ragni, 2005; Dan, Okuhara, & Kohyama, 2006; Fridley & Adrian, 1996; Giongo, Poncetta, Loretti, & Costa, 2013; Haciseferogullari, Gezer, Özcan, & MuratAsma, 2007; Lewis, Yoxall, Marshall, & Canty, 2008; Murcia, Miyamotoa, Varma, Ossa, & Arola, 2018; Pallottino, Costa, Menesatti, & Moresi, 2011; Pérez-López et al., 2014; Ragni & Berardinelli, 2001; Shiu, Slaughter, Boyden, & Barrett, 2015; Shulte-Pason, Timm, Brown, Marshall, & Burton, 1990; Sirisomboon, Tanaka, & Kojima, 2012). Many of these researchers have used experimental tests (quasi-static mechanical tests) to obtain objective data on mechanical and textural properties of fruits. Also as it was stated by many researches, compressive force-crosshead displacement curves are widely used to measure textural properties in agro-food products; initial slope, maximum force, energy until failure, and other curve-related parameters have been described and correlated with textural parameters of agro-food products (Dan et al., 2006; Giongo et al., 2013; Lewis et al., 2008; Murcia et al., 2018; Pallottino et al., 2011; Shiu et al., 2015).

Two main forces are encountered on pomegranate during handling after harvest: compression force and puncture force. The compression force is experienced by the arils and the puncture force is experienced by the whole fruit and its peel. Excessive compression results in bruising and breakage (Sirisomboon et al., 2012). Punctures increase wound respiration, enhancing general deterioration, and decreasing the visual appearance aspects (Allende, Desmet, Vanstreels, Verlinden, & Nicolaï, 2004). So information on texture of both pomegranate peel and aril are essential to monitor process of postharvest in pomegranate industry. Literature review showed that despite an extensive research on some physical properties of pomegranate fruit has been reported (Al-Said, Opara, & Al-Yahyai, 2009; Fawole & Opara, 2013b; Szychowski et al., 2015), due to complex structure of pomegranate fruit very limited research has been conducted on texture of pomegranate fruit and arils.

Hence, to gain knowledge about fruit texture in pomegranate a puncture test on the whole fruit and a compression test on aril were performed with the objective of determining the texture parameters' (puncture force, rupture energy, bioyield force, and modulus of elasticity) sensitivity in differentiating the maturity of pomegranate fruits and to intensively evaluate the behavior of the textural properties of pomegranate fruit, rind, and aril during normal ripening. The results can be used in the determination of optimal time for fruit harvesting according to the future use before postharvesting and packaging stages.

2 | MATERIALS AND METHODS

2.1 | Raw material

Pomegranates (cv. Ashraf) from commercial orchard in Shahidabad Village, Behshahr County, Mazandaran Province (36.2262° N, 52.5319° E), Iran were used for all the experimental tests presented in this study. According to Fawole and Opara (2013b), maturity is the principal factor that affects the physical and mechanical properties of pomegranate. In this article, the hand-harvested of crops were started on August 31, 2014, when it was possible to squeeze juice from fruit arils, and ended in October 2014 at fruits' commercially full ripe stage. The 100 sample pomegranate fruits studied correspond to four maturity stages based on the subjective evaluation of the skin texture of the fruit, immature stage: hard texture (S1); fairly Half-ripe stage: Fairly firm texture (S2); half-ripe stage: firm texture (S3), and full ripe stage: soft texture (S4; Figure 1). The harvest of each maturity stage was made at 88, 109, 124, and 143 days after full bloom (DAFB), respectively. The fruits were immediately placed in the boxes to protect from injuries. Then, they were transported to the physical properties laboratory, Department of Biosystems Engineering, Ferdowsi University of Mashhad. The fruit's surface was cleaned manually and tested at room temperature.

2.2 | Instrumental analysis: Puncture test

The puncture test was done by a stainless-steel 5-mm cylindrical probe which was attached to moving platform of an Instron Universal Testing Machine (Model H5KS, Tinius Olsen Company; Figure 2). The apparatus was supplied with a load cell of 500 kgf. The system accuracy was ±0.001N in force and 0.001 mm in deformation. The penetration speed was set on 10 mm/min. The samples were positioned on the fixed plate considering puncture position. The rupture test was initiated until rupture occurred as is denoted by a rupture point in the force–deformation curve. As soon as the rupture point was detected, the test was stopped. When the rupture was occurred, the test was flowed to 10 mm of probe length. Duplicate puncture tests were performed on opposite sides of equatorial region of each sample. The parameter evaluated were rupture energy (J) required for initial rupture and peak force (N) required to puncture fruit skin that was taken as fruit puncture resistance at three equidistance positions along the equator (top, middle, and bottom of pomegranate samples). The average of these three measurements was used to represent the textural properties for each sample. All the mechanical parameters were studied for 25 fruits from each studied maturity stages.

2.3 | Instrumental analysis: Compression test

Aril uniaxial compression tests were applied by an Instron Universal Mechanical Testing Machine (Model H5KS, Tinius Olsen Company) with a load cell of 500 kgf and a cylindrical compression probe with a diameter of 40 mm. (Figure 3). Each individual aril was loaded between two parallel plates of the machine compressed at the preset condition: pretest speed 1.5 mm/min, the test speed of 0.5 mm/min, and 0.2N trigger force (Al-Said et al., 2009; Fawole & Opara, 2013b). The textural profile graphs were interpreted using force (N) and distance (mm) as the two fundamental variables. Also the acquisition data carried out on these textural profiles was operated by the software provided with the Instron machine. The parameter evaluated were bioyield force (N), the young modulus, or elasticity (N/mm^2), extracted as the slope on the force–distance curve of the bioyield point, and rupture energy (J) as the maximum energy required for complete breakage of an individual aril (Al-Said et al., 2009; Bchir et al., 2012; Fawole & Opara, 2013b). All the

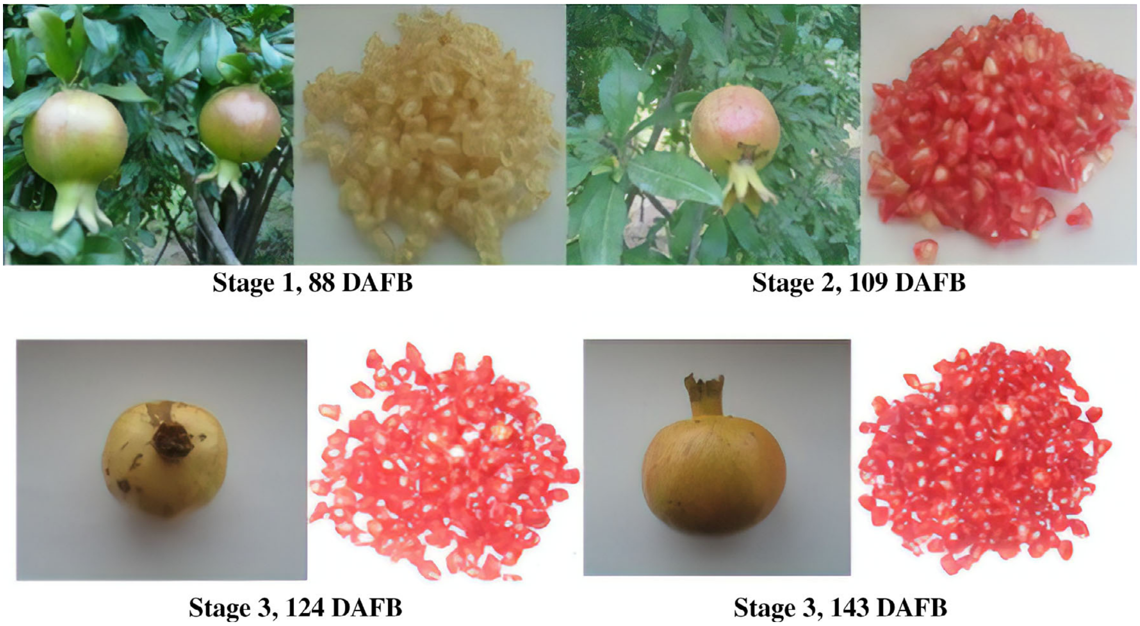

FIGURE 1 Fruit and arils of pomegranate (cv. "ASHRAF") cultivar at different maturity stages. Immature stage: 88 DAFB; half-ripe stage: 109 DAFB; fairly half-ripe stage 124: DAFB; and full-ripe stage: 143 DAFB. DAFB, days after full bloom

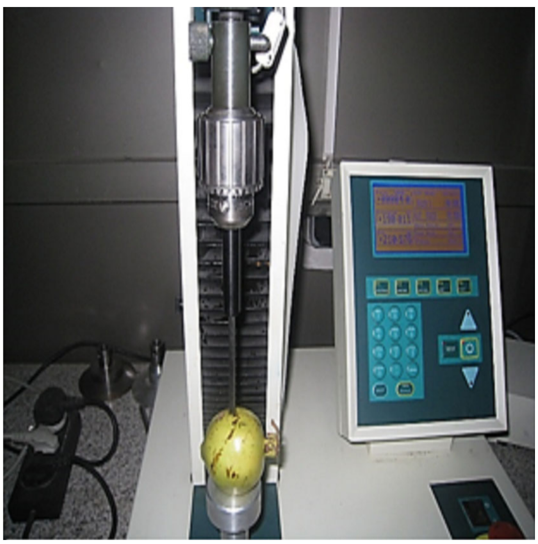

FIGURE 2 Location on the fruit where mechanical properties were measured by penetration probe

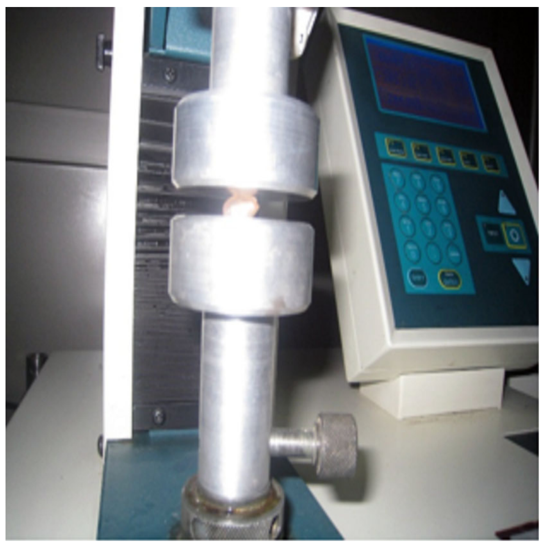

FIGURE 3 Location on the aril where mechanical properties were measured by uniaxial compression test

mechanical parameters were studied for 25 arils from each fruit in each studied maturity stages.

2.4 | Data analysis

As it was stated earlier, the data acquisition carried out on the textural profiles operated by the software provided with the Instron machine. A completely randomized experimental design was used to determine textural properties of the pomegranate fruits and arils. All data were subjected to one-way analysis of variance, ANOVA using SPSS16 software. The *F* test was used to determine the significance of independent variable (maturity stage), and significant differences of means were compared using the Duncan's multiple ranges test at 5% significant level.

3 | RESULTS AND DISCUSSION

3.1 | Textural dynamics

Table 1 shows the experimental data on textural parameters of pomegranate fruit and aril as affected by maturity stage. As it can be found

TABLE 1 Changes in textural properties of pomegranate fruit and aril harvested at four maturity stages

		Maturity stage			
Test	Property	S1	S2	S3	S4
Compression	Bioyield force (N)	4.2ᵃ	5.2ᵇ	5.8ᶜ	6.22ᵈ
	Young modulus (N/mm²)	2.6ᵃ	3.4ᵇ	4.2ᶜ	5.3ᵈ
	Rupture energy (J)	0.014ᵃ	0.016ᵃ	0.018ᵇ	0.019ᵇ
Puncture	Puncture force (N)	50.12ᵃ	45.12ᵇ	42.4ᶜ	40.3ᵈ
	Rupture energy (J)	0.118ᵃ	0.998ᵃ	0.885ᵇ	0.789ᵇ

Note: Means with same letters in each row are not significantly different ($p < .05$).

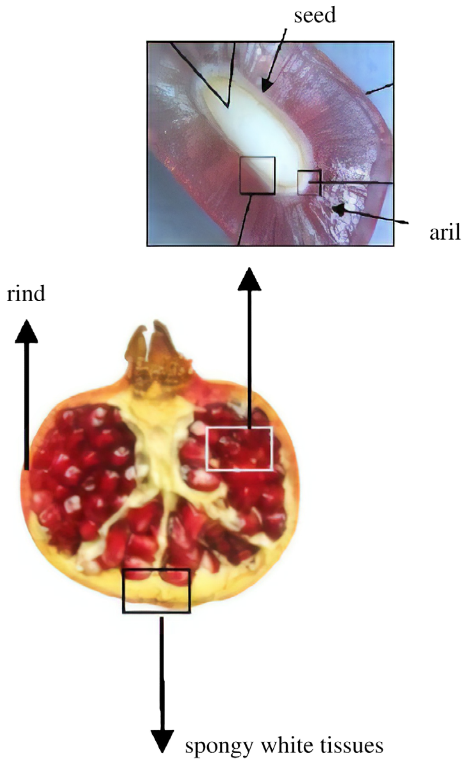

FIGURE 4 Overview of four major tissue types of pomegranate fruit

from this Table, the maturity stage of the fruit significantly influenced the values of studied textural parameters ($p < .05$). The results showed that compression load values of aril increased with advances in maturity stage of fruit, while puncture load values of fruit decreased. The investigators believed that these discrepancies could be due to the cell structure and the volume of rind and arils of pomegranate, as maturity advances. The different response exhibited by the fruit texture as a result of maturity stage demonstrated its nonhomogenous texture. As it was stated by other researchers, pomegranate texture is composed of four major tissue types (rind, aril, seed, and spongy white tissues) with different mechanical properties (Al-Said et al., 2009; Castro-Giráldez, Fito, Ortolá, & Balaguer, 2013; Fawole & Opara, 2013b; Szychowski et al., 2015). These tissues are illustrated in Figure 4. Aril and seed tissues are located in the center and tends to be the firmest part of the fruit. Spongy white tissue is located on either side of each aril and tends to be the least firm. According to Castro-Giráldez et al. (2013), there are also intercellular spaces that act as built-in notches and stress concentrators. Decreases in the puncture load values of the rind tissue may be related to the degree of alteration of the components, which constitute the primary cell wall of rind, as a result of the degree of tissue maturity progression. Fawole and Opara (2013b) studied texture dynamics of two local varieties of pomegranate fruit (cvs. "Bhagwa" and "Ruby") along the DAFB over two different year seasons. They have reported that the trend in puncture force (N) was similar for both cultivars. They found that force required to puncture fruit to a depth of 8.9 mm decreased at first and then increase dramatically. There were significant differences ($p < .05$) in the textural properties (rupture force, bioyield point, and modulus of elasticity) of arils among the maturity stages investigated for both cultivars. Also they have stated that aril rupture force increased with advances in maturity stage of fruit. In their research, dynamics of elastic modulus of fruit arils along the days after full bloom showed an increase at first and then increase dramatically. So as it was found from their research and results of previous studies having a broad and more exhaustive view of pomegranate fruit growing conditions and genetics (cultivar difference) changes during development are necessary to investigate textural dynamics of pomegranate fruit in further studies (Al-Said et al., 2009; Szychowski et al., 2015).

3.2 | Aril compression testing up to rupture

Compression tests results, run on aril samples, are reported in Table 1. In this table, all textural parameters as a function of maturity stage are presented. For all studied textural parameters, the highest values were obtained at Stage 4 while the lowest values was at Stage 1. So, the pomegranate aril at Stage 4 required more rupture energy. The average rupture energy at this stage was about 0.0196 J. Also as it was stated earlier, the statistical analysis showed the maturity stage had significant effect ($p < .05$) on all studied parameters. In this research, the experimental compression data varied within a range of values as following: (a) bioyield force between 4.2 and 6.22N; the young modulus 2.6 and 5.3 N/mm^2; and rupture energy 0.014 and 0.019 J. Fawole and Opara (2013b) have reported 4.4–6.46N and 5.01–7.40N for bioyield force of "Bhagwa" and "Ruby" cultivars of pomegranate aril during fruit maturity, respectively. Also the ranges of young modulus was obtained as 4.4–5.2 N/mm^2 and 4.1–7.4 N/mm^2 in their study, respectively. These differences in textural properties could be the

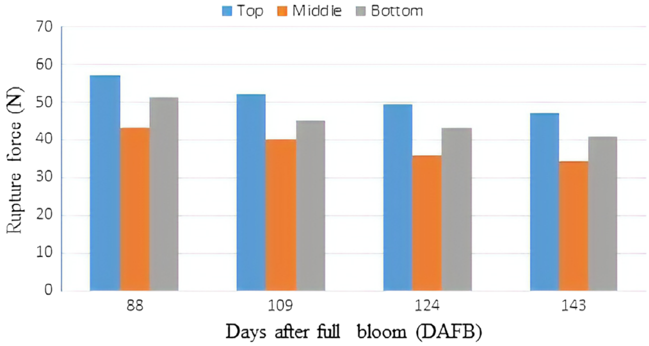

FIGURE 5 Change in rupture force of Ashraf pomegranate variety at three studied different positions on the fruit

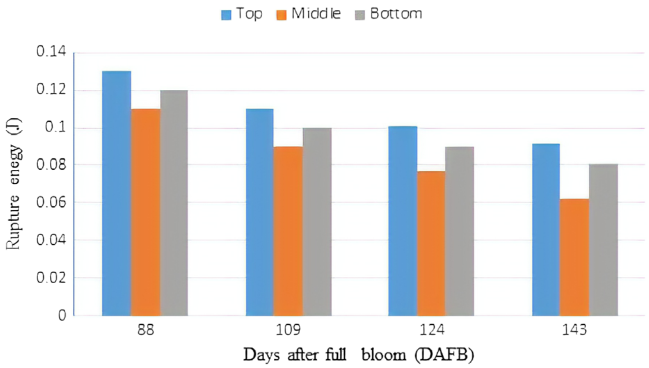

FIGURE 6 Change in rupture energy of Ashraf pomegranate variety at three studied different positions on the fruit

result of the individual cultivars properties and different environmental and growth conditions of cultivars.

As it can found from Figure 5, the force required to puncture fruit to a depth of 10 mm decreased significantly as the fruit advanced in maturity from S1 to S4. Other researchers have reported a decrease in rupture force of fruits with maturity or during storage. Judith and Tianxia (2002) found a decreasing trend from 15 to 2N during fruit maturity. Qin, Rongchao, Qiao, and Yao (2006) observed flesh rupture force decreasing dramatically at 6 days after harvest. Nnadozie et al. (2007) reported the apple fruit softening during cold air storage. Mansouri, Khazaei, Hassan-Beygi, and Mohtasebi (2011) also obtained a decrease in rupture force of pomegranate fruits during fruit storage after harvest. However, Fawole and Opara (2013b) found that force required to puncture fruit to a depth of 8.9 mm decreased at first and then increase dramatically. Also results showed that rupture force of three different studied positions of fruit was severely different (Figure 5). It may be due to variation in thickness of rind at these positions. The same results also were reported by Mansouri et al. (2011) to study mechanical properties of pomegranate fruit at three different positions on the fruit.

Figure 6 displays rupture energy of pomegranate fruit that measures at top, middle, and bottom of fruit. As it is clear in this figure, the highest and lowest values were observed at top and middle position, respectively. These results could be attributed to their cellular structure or thickness of the rind. The same results and justification were reported by Mansouri et al. (2011) for pomegranate fruit. Also the mean values of rupture energy decreased with advancing fruit maturity.

4 | CONCLUSION

Two testing procedures have been used to obtain textural properties of pomegranate fruit and aril. The experiments were done on samples (pomegranate fruit and aril) of four maturity stages (88, 109, 124, and 143 DAFB) using the puncture test and compression test. The plate compression tests evaluated the textural properties of whole pomegranate aril, such as bioyield force, rupture energy, and young modulus. Also rupture energy required for initial rupture and peak force required to puncture fruit skin were obtained by rupture test. Rupture force and rupture energy of pomegranate fruit were determined at top, middle, and bottom positions of the fruit. The results can be used summarized as follows:

1. This study displayed that textural dynamics of pomegranate fruit rind and arils change significantly ($p < .05$) with advancing maturity. Textural characteristics such as aril bioyield force and young modulus, which are most correlated to inner turgor pressure within the arils as a result of juice content, might also be used to distinguish pomegranate maturity stages.
2. The results showed that compression load values of aril increased with advances in maturity stage of fruit, while puncture load values of fruit decreased. The different response exhibited by the fruit texture as a result of maturity stage demonstrated its non-homogenous texture.
3. The pomegranate aril at Stage 4 required more rupture energy. The average rupture energy at this stage was about 0.0196 J.
4. Also results showed that rupture force of three different studied positions of fruit was severely different. It may be due to variation in thickness of rind at these positions. The highest and lowest values were observed at top and middle position, respectively.

This finding may be useful to the pomegranate aril industry, which requires prior knowledge of the edible portion of the investigated cultivars during fruit development.

Also, the interpretation of the obtained results can be used by pomegranate growers to monitor fruit maturity characteristics before harvesting.

ACKNOWLEDGMENTS

The authors would like to thank the Ferdowsi University of Mashhad for providing the laboratory facilities and financial support through the project number of 28580.

ETHICAL STATEMENTS

Conflict of Interest

No conflict of interests is involved in this work.

Ethical Review

This study was approved by the Institutional Review Board of Ferdowsi University.

Informed Consent

All subjects involved in the assessment were signed the informed consent.

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How to cite this article: Khodabakhshian R, Emadi B, Khojastehpour M, Golzarian MR. Instrumental measurement of pomegranate texture during four maturity stages. *J Texture Stud*. 2019;1–6. https://doi.org/10.1111/jtxs.12406