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Instrumental texture profile analysis (TPA) of date fruits as a function of its physico-chemical properties

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ABSTRACT

Instrumental texture profile analysis (TPA) of nine batches of date flesh with different quality levels was performed and the parameters were related to its physico-chemical properties (i.e., color, mass, length, width of whole date fruit as well as moisture, crude fiber, fructose, glucose, sucrose, and pectin contents). Results of instrumental TPA showed significant linear correlation of hardness with moisture content, crude fiber and pectin content ($p < 0.05$), adhesiveness with color a, b values ($p < 0.05$) and L value ($p < 0.1$), springiness 1 with color b value ($p < 0.1$), chewiness 1 with moisture content, length of whole date fruit, crude fiber and pectin content ($p < 0.05$), gumminess 1 with pectin ($p < 0.05$) and crude fiber ($p < 0.10$), elasticity 1 with pectin ($p < 0.05$), crude fiber and with color b value ($p < 0.1$), and cohesiveness 1 with mass of whole date fruit ($p < 0.10$). Principal component analysis (PCA) identified six groups of variables to differentiate the dates and cluster analysis was used to group the products based on the TPA attributes and physico-chemical properties. Dates available in the market can be classified into three different groups namely hard-resilient, soft-springy and firm-adhesive. The results in this study could be used to explore the main instrumental textural attributes important for the classification of dates.

1. Introduction

Dates (*Phoenix dactylifera* L.) are considered as a commercially important agricultural commodity as well as vital element of the daily diet, and a nutritious food in the Arabian world (Khan et al., 2008; Al-Farsi and Lee, 2008). Dates are usually consumed fresh or processed into various products. Edible dates pass through four distinct stages of ripening known locally as *kimri*, *khalal*, *rutab* and *tamar*. Dates are consumed at *khalal* and *rutab* stages as fresh fruits and mainly at the *tamar* stage in dried form (Singh et al., 2012). The dates at *tamar* stage are perceived as hard and raisin-like with the least moisture and a sweet taste (Ahmed et al., 1995; Rahman and Al-Farsi, 2005; Singh et al., 2012). Different varieties of dates vary in their chemical composition especially sugars and dietary fibers (Mustafa et al., 1986; Ahmed et al., 1995; Rahman and Al-Farsi, 2005). These chemical compositions are supposed to be directly influence the structure, sensory and textural properties (Rahman and Al-Farsi, 2005). Drying of dates at *tamar* stage may alter the texture of fruits considerably, as a result dates become hard and chewy (Rahman and Al-Farsi, 2005).

From the consumers' point of view texture, flavor and nutritional value are an important attributes for the acceptance of food and essential features for the estimation of its quality (Moskowitz and Drake, 1972; Wills et al., 1998; Ismail et al., 2008). Textural attributes can be measured using a texture profile analyzer (TPA), which helps in quality control and product development to quantify desired characteristics. Hardness and energy of rupture for four classes (i.e. based on mass and size) of Atrophy kernel were increased with the increase of mass and size (Karaj and Muller, 2010). Penetration force of different varieties of dates as a function of mass, size and proximate composition were reported without any attempt to develop correlation between penetration force and measured characteristics (Nadeem et al., 2011). Previously, instrumental TPA of date flesh (*tamar* stage of maturity) was measured as a function of its moisture content (Rahman and Al-Farsi, 2005). It was observed that hardness, resilience and chewiness increased exponentially with the decrease of water content, whereas cohesiveness, adhesiveness and springiness showed a peak at around 21.5% water content. The trends or curvatures above and below the peaks were different for cohesiveness, adhesiveness, and springiness (Rahman and Al-Farsi, 2005). Instrumental texture (firmness,

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hardness, brittleness, adhesiveness or stickiness) of 3 types of formulated candy from dates was measured and reported that butter increased the rigidity while nuts in powder form increased the hardness by reinforcing the date paste (Al-Rawahi et al., 2005). Further, same researchers compared instrumental and sensory TPA of formulated date candies and suggested that there could be a possibility of correlating instrumental and sensory methods (Al-Rawahi et al., 2006). Recently, rheological and instrumental TPA of two types of date paste was measured and reported that hardness, gumminess, chewiness and adhesiveness of black paste (higher solid content) was higher than golden date paste (Razavi and Karazhiyan, 2012).

Instrumental texture of dates was mainly measured as a function of moisture content, however other physico-chemical properties of the date fruits may also affect the instrumental texture. Therefore, the overall objective of this study was to measure the instrumental texture profile of nine batches of dates with different quality levels and to determine the relationships of TPA parameters with 14 physico-chemical properties. In addition, the main principal components (i.e. group of variables) affecting the instrumental texture and classification of date fruits available in the market were studied based on the instrumental TPA and physico-chemical properties.

2. Materials and methods

2.1. Materials

Nine batches of dates (*tamar* stage of maturity) with different quality levels were purchased from the local market at Muscat and stored at −20 °C until used for assessments. The quality levels were assessed mainly by visual appearance in terms of color, shape, size, surface integrity and glossiness. The purchased dates were pitted manually before further experimental measurements.

2.2. Physico-chemical properties

Moisture content and crude fiber were determined according to AOAC methods (1995). Moisture content was measured gravimetrically by drying 5 g of dates in an oven at 105 °C for at least 18 h. For the determination of crude fiber, 1 g of date sample was digested with boiling sulfuric acid (0.25 N) and then filtered. The residue was further digested with boiling sodium hydroxide (0.30 N) and filtered. The residue, containing soluble fiber and ash, was washed with acetone. The crude fiber was then determined by burning the sample in a furnace at 550 °C (i.e. difference between residue and ash content). Length and width of 20 whole date fruits were measured by electronic digital caliper and mass of 20 whole date fruit were measured in an electronic balance to the nearest 0.0001 g. Color of 20 fruits was measured using a Minolta Colorimeter (Minolta CR-310, Minolta, Japan) at room temperature (25 ± 2 °C). The equipment was calibrated with a white standard calibration plate provided by the manufacturer. Results were expressed in color L, a, b values. L value is ranging from 0 (black) to 100 (white); red/green (a) ranging from −100 (green) to +100 (red); yellow/blue (b) ranging from −100 (blue) to +100 (yellow) (Rahman et al., 2012). The pH values were recorded using pH meter (Metrohm 744, USA) from dates-water mixture (i.e. 10 g date flesh in 100 ml distilled water). Moisture content, crude fiber and pH values were measured in triplicates.

2.3. Sugar analysis

Free sugars were determined by HPLC as described by Guizani et al. (2010). Five grams of pitted dates were boiled in 20 g of deionized water for 10 min to inactivate enzymes present in the fruits. The evaporated water was compensated and then homogenized in a blender (Braun multiquick 5, 4191, Poland). Homogenized sample (5 g) was refluxed with 20 ml of 85% aqueous ethanol for 15 min. The liquid extract was collected and the residue was refluxed again with 20 ml of 75% aqueous ethanol. Then two extracts were mixed together and dried completely in a rotary evaporator (R-215-Buchi, Switzerland). The residue was dissolved in known volume of deionized water, filtered through a cellulose acetate filter paper (size: 0.45 μm) and analyzed by HPLC (Agilent 1100, USA) equipped with a Supelcosil™ LC-SI column (250 mm × 4.6 mm ID, particle size 5 μm, Supelco Park, Bellefonte, PA, USA) with a refractive index detector (Agilent RID 1100). A sample of 20 μl was injected in the system and eluted by 75:25 acetonitrile:water solution at a flow rate of 1 ml per min. The temperature of the column compartment as well as the temperature of the detector was maintained constant at 40 °C. The integrator was calibrated with external standards consisting of glucose, fructose and sucrose (0.1 g/100 ml solution).

2.4. Galacturonic acid analysis

Galacturonic acid (GA) was assessed by adapting the method described by Anthon and Barrett (2009). A buffered copper solution was prepared by adding 46.4 g sodium chloride, 6.4 g sodium acetate, and 2.0 ml glacial acetic acid to 160 ml water. Once dissolved, 1 g copper sulphate was added and the pH was adjusted to 4.8 with sodium hydroxide. The solution was diluted to a final volume of 200 ml. Dates sample of 0.5 g was added 50 ml distilled water and heated for 15 min at 95 °C. Evaporated water was compensated by adding distilled water. The mixture was then blended and filtered using Whatmann filter paper No. 1. The filtrate was placed in test tubes and 1 ml of copper solution was added. Test tubes were heated at 95 °C for 1 h in water bath. After removal from the water bath, 1 ml of diluted Folin-Ciocalteu reagent (40 folds with water) was added, vortexed and the absorbance was measured at 750 nm. A standard curve for GA was prepared using a standard stock solution (SS1, 20 mg GA ml^{-1}). A second stock solution (SS2) of 200 μg ml^{-1} was prepared by dilution. Serial dilutions were then prepared by taking 25–150 μl of SS2 and diluted to a final volume of 1 ml in test tube. The standard curve was drawn based on the absorbance at different concentrations (μg ml^{-1}) of galacturonic acid. The analysis was performed in triplicate.

2.5. Instrumental texture profile analysis (TPA)

Texture Profile Analyzer (Model: TAXT2i, Stable Micro Systems, Surrey, England) was used to measure the force–time curve following the method of Rahman and Al-Farsi (2005) and Rahman and Al-Mahrouqi (2009). The equipment was set to zero automatically lowering the plate until the bottom surface of plate just reached in contact with the sample table. The load cell was calibrated with a 2.5 kg weight. All experiments were conducted at room temperature (25 ± 2 °C). One pitted date was divided into two equal halves and one side was placed over another. It was then pressed under a flat surface metal cylinder until it reached a flat slab. A square slab of 15 mm × 15 mm was cut and placed carefully on the center of the TPA instrument's platform and compressed twice to 75% of the original height at the compression rate of 1 mm/s. When the compression stroke was completed, plunger abruptly reversed direction and started its upward stroke at 10 mm/s. Then a second compression–decompression cycle was performed on the same sample. All operations were automatically controlled by the texture analyzer. The instrument automatically recorded the force–displacement or force–time curve. Six or seven replicates were conducted for each types of date fruit (Rahman and Al-Farsi, 2005; Rahman and Al-Mahrouqi, 2009).

From the force–displacement or force–time graph of two compression–decompression cycles, the following attributes were determined: hardness (HA), adhesiveness (AD), springiness (SP), cohesiveness (CO), resilience (RE), gumminess (GU), chewiness (CH) and modulus (E). Hardness (HA) is defined as the force (N) needed to attain a given deformation, adhesiveness (AD, area A_3) as the work (N s) needed to overcome the attractive force between dates and plunger surface, resilience (RE, ratio of the area of first positive peak after the maximum point to base line divided by the area of first positive peak from the initiation to the maximum point, A_x and A_y) as the capacity of the sample to fight back to regain its original position. Cohesiveness 1 (CO1, ratio of A_2 and A_1) was defined as the ratio of the areas of first and second compressions while cohesiveness 2 [CO2, ratio of (A_2–A_3) and (A_1–A_4)] was determined from the ratio after excluding negative areas for first and second decompression. Springiness 1 (SP1 = y, s) was defined as the distance from the start of second compression to the peak, while springiness 2 (SP2 = y/x) was defined as ratio of the distance from the start of second compression to its peak and the distance from the start of first compression to its peak. The gumminess (GU1, N) is defined as the multiplication of HA and CO1, while chewiness (CH1, N s) as the multiplication of GU1 and CO1. GU2 (N) is defined as the multiplication of HA and CO2, CH2 (N s) is the multiplication of GU2 and CO2, respectively. Modulus 1 (E1, N/s) was defined as the first linear portion (initial slope) of the force–deformation curve and modulus 2 (E2, N/s) was defined as the second linear portion before failure point in the first compression cycle. All attributes were first measured and then selected only the improved ones (i.e., SP1, CO1, GU1, CH1, E1) if they provide better correlations with the physico-chemical properties. Toughness index (TI) was defined as the ratio of the total sugar and water content (Besbes et al., 2009).

2.6. Multivariate analysis

Multivariate analysis including Pearson's (i.e. linear) and Spearman's correlation matrix, cluster analysis (CA) and principal component analysis (PCA) were run using all textural attributes and physico-chemical properties. Linear and Spearman's correlations were used to determine the relationships between each variable and the results were summarized for the p values $\leq$0.05 and $\leq$0.1. PCA was used for classifying and characterizing the products. Data of TPA attributes and physico-chemical properties were standardized to bring all variables in same scale range. All PCA loading values were multiplied by 5 in order to spread the data points in the biplot of Principal components (PC). The formula used for the standardization is written below:

$$y = \frac{x - x_{\min}}{\sigma} \qquad (1)$$

where, y is the standardized data for variable, x is the measured variable, $x_{\min}$ is the lowest value measured across the different batches, σ is the standard deviation of the data for this variable. Data were statistically analyzed using PAST software. Correlations matrix, principal component and cluster analysis were conducted using the PAST software (Hammer et al., 2001). Multiple linear and non-linear regressions of TPA attributes as a function of physico-chemical properties were developed using SAS glm procedure (SAS, 2002). Model selection was performed considering Akaike information criterion (AIC) (Akaike, 1973).

3. Results and discussion

3.1. Physico-chemical properties

Moisture content of dates varied from 16.1 to 22.4 g/100 g sample (Table 1). These results are within the range reported by Ahmed

Table 1
Physico-chemical characteristics of different date samples.

CP[a]	XW	MA	LT	WD	pH	CF[b]	Sugar			Color			PE[c]	TI
							FR[b]	GL[b]	SU[b]	*L*	*a*	*b*		
A	17.9(0.1)	9.1(1.7)	34.6(4.0)	21.2(2.4)	6.0(0.1)	3.5(0.1)	34.9(3.1)	25.7(2.4)	1.4(0.1)	21.9(1.7)	7.9(1.0)	9.0(1.5)	39.6(0.1)	3.5
B	20.6(0.3)	8.1(0.9)	33.8(2.3)	19.2(1.7)	5.9(0.1)	3.7(0.1)	34.3(0.1)	25.1(0.1)	1.3(0.1)	19.4(2.5)	8.0(1.4)	4.5(1.4)	43.7(0.2)	3.0
C	17.9(0.2)	5.5(1.2)	31.0(4.0)	19.0(2.4)	5.7(0.2)	4.0(0.1)	34.1(1.7)	25.4(1.6)	1.7(0.3)	22.3(2.6)	8.5(2.6)	8.0(3.5)	46.8(0.1)	3.4
D	16.1(0.3)	7.8(1.6)	36.0(4.4)	20.0(2.0)	5.4(0.1)	3.2(0.1)	32.5(0.2)	23.9(0.1)	1.6(0.1)	23.1(1.7)	12.7(0.7)	10.3(2.1)	50.3(0.1)	3.6
E	22.4(0.6)	6.2(1.2)	32.0(4.3)	20.5(3.2)	5.0(0.3)	3.5(0.1)	34.2(0.2)	25.1(0.1)	1.4(0.1)	20.4(1.3)	8.2(0.6)	5.9(0.4)	42.9(0.1)	2.7
F	19.5(0.2)	6.9 (1.4)	33.0(4.4)	23.3(3.1)	5.3(0.1)	3.6(0.1)	28.5(0.1)	21.3(0.2)	0.8(1.1)	18.4(1.1)	8.7(0.8)	5.1(0.7)	40.3(0.2)	2.6
G	17.7(0.3)	4.5 (0.8)	27.0(2.0)	18.9(2.3)	5.9(0.1)	3.4(0.1)	34.0(0.1)	26.0(0.3)	0.3(0.1)	15.0 (0.9)	6.0(0.3)	2.1(0.2)	46.5(0.3)	3.5
H	16.1(0.1)	9.1(1.2)	40.6(2.6)	19.6(1.6)	5.9(0.1)	3.3(0.1)	34.7(0.1)	26.0(0.3)	0.7(1.0)	22.1(1.7)	6.8(1.1)	4.2(1.0)	50.7(0.2)	3.8
I	16.5(0.2)	10.5(2.1)	40.7(2.9)	21.7(2.0)	5.3(0.1)	2.9(0.2)	30.9(0.1)	23.8(0.1)	1.4(0.1)	18.8(2.2)	7.2(1.0)	3.9(1.5)	55.6(0.3)	3.4

[a] CP: commercial products, XW: moisture content, LT: length of whole date fruit, MA: mass of whole date fruit, WD: width of whole date fruit, CF: crude fiber, FR: fructose, GL: glucose, SU: sucrose, PE: pectin, TI: toughness index. *Note*: Values in parentheses are the standard deviation.
[b] (g/100 g sample).
[c] (mg/100 g sample).

et al. (1995) and Hasnaoui et al. (2011) for Omani and Moroccan dates, respectively. The length, width and mass of whole date fruits varied from 27.0 to 40.7 mm, 18.9 to 23.3 mm and 4.5 to 10.5 g, respectively and are consistent with those reported by Jahromi et al. (2008). The pH values varied from 5.0 to 6.0 and are within the acidic range reported earlier (Al-Hooti et al. 1997; Besbes et al., 2009; Borchani et al., 2010; Rastegar et al., 2012; Haider et al., 2012). Crude fiber varied from 2.9 to 4.0; these values are similar to those reported in FAO Report (1993) for various varieties of dates. Major sugars in dates flesh at *tamar* stage of maturity consisted of the reducing sugars, glucose (21.3–32.6 g/100 g total sugars) and fructose (28.5–34.9 g/100 g total sugars) similar to results reported by Ahmed et al. (1995), Rastegar et al. (2012), Al-Hooti et al. (1997) and Al-Farsi and Lee (2008). The color *L*, *a* and *b* values varied from 15.0 to 23.1, 6.0 to 12.7, 2.1 to 10.3, respectively. Toughness index of the different batches of date fruits varied from 2.6 to 3.8. Besbes et al. (2009) reported toughness index for *Deglet Nour*, *Allig* and *Kentichi* as 5.52, 5.15 and 24.16, respectively depending on the moisture content.

3.2. Correlations between TPA attributes

Physico-chemical properties and instrumental TPA attributes of different dates are presented in Tables 1 and 2 respectively. Initial statistical analysis showed that SP2, CO2, GU2, CH2 and *E*2 did not improve correlation with the physico-chemical properties ($p > 0.05$), thus original definitions of SP1, CO1, GU1, CH1 and *E*1 were only used in this study. Linear correlation showed that hardness was negatively correlated with moisture content, crude fiber and positively correlated with pectin content ($p < 0.05$) and toughness index ($p < 0.10$) (Table 3). Spearman's correlations did not improve the relation between the hardness and physico-chemical properties ($p < 0.05$ or $p < 0.1$). Similarly, a positive correlation between hardness and pectin content in pear was observed (Ying et al., 2011). In contrast, hardness of extruded corn starch increased with an increase in fiber content and decreased with an increase in pectin content (Yanniotis et al., 2007). The variation of hardness with fiber and pectin content was possibly the result of the effect of these materials on the cell wall thickness. Moreover, water is well-known as a plasticizer of the amorphous regions of starch granules and promotes rupture of hydrogen bonds and formation of new hydrogen bonds between water molecules and associated starch chains. However, presence of non-starch polysaccharides like pectin hydrates itself and competes with other components, thus restricted plasticization and gelatinization due to unavailability of water. A negative correlation was also observed between hardness and moisture content in the case of date fruits (Rahman and Al-Farsi, 2005), cheese with resistant starch (Noronha et al., 2007), sausage (Herrero et al., 2008), goat meat patties (Das et al., 2008), sandesh (Khamrui and Solanki, 2010), vegetables (Yee et al., 2012), and Omani halwa (Rahman et al., 2012). Rahman and Al-Farsi (2005) also showed that hardness of date flesh increased sharply below the moisture content of 21.5% (wet basis). This could be due to transformation of the rubbery (easy to deform) state of date flesh to a leathery (tough to deform) behavior. Similar transformation of rubbery to leathery state was also observed for rice based products (Seow and Thevamalar, 1988). Water molecules act as a plasticizer of the solids component of food, and makes food products less elastic and more vulnerable to fracture upon compression (Fox et al., 2000; Rahman et al., 2012).

Adhesiveness was linearly correlated with color *a* and *b* ($p < 0.05$) and with color value *L* ($p < 0.1$). Spearman's analysis did not improve the correlation between the adhesiveness and physico-chemical properties ($p < 0.1$). Adhesiveness of dates remained constant upto the solids content of 18.5 g/g fruit and then increased with the further increase in solids content (Rahman and

Table 2
Texture profile analysis as a function of moisture content of different date sample.

CP[a]	XW	HA (N)	AD (N s)	SP1 (s)	SP2	CO1 (s)	CO2	RE	GU1 (N)	GU2 (N)	CH1 (N s)	CH2 (N s)	*E*1 (N/s)	*E*2 (N/s)
A	17.9(0.1)	30(7)	4.5(1.1)	5.3(0.8)	1.00(0.02)	0.17(0.02)	0.16(0.02)	0.08(0.01)	4.9(1.1)	4.7(1.1)	26(7)	4.7(1.1)	6.5(2.7)	4.8(3.6)
B	20.6(0.3)	19(3)	4.7(1.5)	4.4(0.2)	0.99(0.03)	0.24(0.07)	0.26(0.10)	0.08(0.01)	4.6(1.5)	5.1(2.3)	21(7)	5.1(2.3)	4.3(1.1)	2.1(1.4)
C	17.9(0.2)	29(7)	4.8(2.7)	3.8(0.3)	1.19(0.41)	0.22(0.05)	0.24(0.08)	0.11(0.04)	6.6(2.4)	7.1(3.1)	25(8)	8.4(4.1)	7.3(2.3)	6.0(2.7)
D	16.1(0.3)	40(9)	5.3(1.4)	3.7(0.2)	0.98(0.01)	0.20(0.03)	0.21(0.03)	0.12(0.02)	7.9(2.1)	8.1(2.1)	30(8)	8.0(2.1)	8.8(2.6)	7.2(5.4)
E	22.4(0.6)	32(8)	4.9(1.8)	3.6(0.2)	0.99(0.01)	0.23(0.04)	0.25(0.05)	0.13(0.04)	7.6(3.1)	8.1(3.5)	27(9)	8.0(3.5)	8.1(2.6)	7.0(6.3)
F	19.5(0.2)	31(4)	4.1(1.3)	3.7(0.3)	0.99(0.01)	0.22(0.03)	0.22(0.03)	0.11(0.01)	6.7(1.2)	6.8(1.4)	25(6)	6.7(1.4)	8.9(1.9)	7.4(4.2)
G	17.7(0.3)	46(4)	3.7(1.3)	2.6(0.3)	0.99(0.01)	0.24(0.01)	0.25(0.01)	0.17(0.02)	10.9(0.9)	11.2(0.8)	28(5)	2.8(0.2)	17.4(2.8)	19.3(10.6)
H	16.1(0.1)	53(3)	3.9(1.3)	3.1(0.1)	1.00(0.01)	0.20(0.03)	0.21(0.03)	0.18(0.04)	10.9(2.0)	11.1(2.3)	34(7)	11.1(2.3)	17.8(2.1)	11.8(9.5)
I	16.5(0.2)	51(6)	4.7(0.9)	3.4(0.3)	0.99(0.01)	0.21(0.02)	0.22(0.02)	0.14(0.01)	10.5(1.2)	10.7(1.1)	36(6)	10.7(1.1)	16.7(1.9)	7.1(4.8)

[a] CP: commercial products, XW: moisture content, HA: hardness, CO: cohesiveness, AD: adhesiveness, SP: springiness, RE: resilience, CH: chewiness, E: elasticity.

Table 3
Linear and Spearman's correlation between textural attributes and physico-chemical properties of dates.

Attributes	List of significant variables	
	Linear correlation	Spearman's correlation
HA	SP1, RE, GU1, CH1, *E*1, *E*2, XW, CF, PE ($p < 0.05$); TI ($p < 0.1$)	SP1, RE, GU1, CH1, *E*1, *E*2, XW, CF ($p < 0.05$); PE ($p < 0.1$)
AD	*E*2, *a*, *b* ($p < 0.05$); *E*1, *L* ($p < 0.1$)	*a*, *b* ($p < 0.05$); *L* ($p < 0.1$)
SP1	HA, RE, GU1, *E*1, *E*2 ($p < 0.05$); *b* ($p < 0.1$)	HA, RE, GU1, CH1, *E*1, *E*2, *b* ($p < 0.05$)
CO1	MA ($p < 0.1$)	XW, LT ($p < 0.1$)
RE	HA, SP1, GU1, CH1, *E*1, *E*2, ($p < 0.05$)	HA, SP1, GU1, CH1, *E*1, *E*2 ($p < 0.05$); CF, PE ($p < 0.1$)
GU1	HA, SP1, RE, CH1, *E*1, *E*2, PE ($p < 0.05$); CF ($p < 0.1$)	HA, SP1, RE, CH1, *E*1, *E*2, CF ($p < 0.05$); XW, CF, PE ($p < 0.1$)
CH1	HA, RE, GU1, *E*1, XW, LT, CF, PE ($p < 0.05$)	HA, SP1, RE, GU1, *E*1, XW, CF, PE ($p < 0.05$); *E*2, LT, TI ($p < 0.1$)
*E*1	HA, SP1, RE, GU1, CH1, *E*2, PE ($p < 0.05$); AD, CF, *b* ($p < 0.1$)	HA, SP1, RE, GU1, CH1, *E*2 ($p < 0.05$); XW, CF, *b* ($p < 0.1$)

Al-Farsi, 2005). Springiness 1 was linearly correlated with color *b* value ($p < 0.1$). This correlation was improved in spearman's correlation ($p < 0.05$). Linear correlation showed that cohesiveness 1 was negatively correlated with mass of whole date fruit only ($p < 0.1$), while it was positively correlated with moisture content and length of whole date fruit ($p < 0.1$) in Spearman's analysis. In contrast to our results, Leick et al. (2012) observed, in the case of raw goat meat patties, no correlation of springiness and cohesiveness with moisture, fat or protein contents; however they found significant correlations between hardness, moisture and fat contents (Fig. 1).

Resilience did not show linear correlation with any physico-chemical properties ($p > 0.05$), however it was correlated with crude fiber and pectin in Spearman's correlation ($p < 0.1$). It was reported that resilience was positively influenced by moisture content and ash content in the case of sandesh, milk based sweet (Khamrui and Solanki, 2010). Gumminess 1 was linearly correlated with pectin content ($p < 0.05$) and with crude fiber ($p < 0.1$), while Spearman's correlation showed that gumminess 1 was correlated with crude fiber ($p < 0.05$), and with moisture and pectin ($p < 0.1$). In this case, moisture content and crude fiber were negatively correlated while pectin content was positively correlated. Similarly, gumminess 1 was significantly correlated with moisture content in Omani halwa (Rahman et al., 2012), in cheese (Saint-Eve et al., 2009) and in milk based sweet (Khamrui and Solanki, 2010). Further, gumminess 1 was positively correlated with fat content and negatively correlated with moisture and ash content in milk based sweet (Khamrui and Solanki, 2010) and with C16:0 in Omani halwa (Rahman et al., 2012).

Chewiness 1 was linearly and negatively correlated with moisture content and crude fiber; and positively correlated with pectin content and length of whole date fruit ($p < 0.05$). This correlation did not improve in Spearman's correlation except for the toughness index at $p < 0.1$. Similarly, in case of Omani halwa, chewiness 1 was significantly correlated with moisture content however, in case of sandesh sweets only chewiness 1 showed negative correlation with moisture content and positive correlation with fat content (Khamrui and Solanki, 2010). Elasticity 1 was linearly correlated with pectin content ($p < 0.05$), crude fiber and color *b* value ($p < 0.1$). However, Spearman's analysis showed correlation with moisture content, crude fiber and color *b* value ($p < 0.1$). In this case, moisture content, crude fiber and color *b* value were negatively correlated while pectin content was positively correlated.

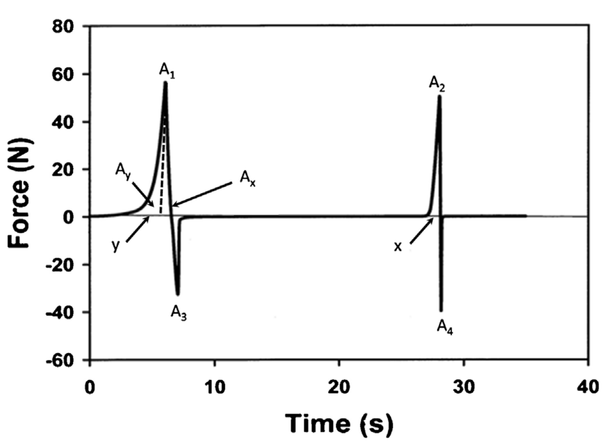

Fig. 1. A typical force–time graph of two-cycle instrumental TPA for different date samples [A_1: first compression (N s); A_2: second compression (N s); A_3: first decompression (N s); A_4: second decompression (N s); *x*: distance from start of second compression to the peak (s); *y*: distance from start of second compression to the peak (s); A_x: first positive peak after the maximum point to base line (Ns); A_y: area of first positive peak from the initiation to the maximum point (N s)

3.3. Cluster (CA) and principal component analysis (PCA)

A CA of dates based on Ward's method (Ward, 1963) revealed 3 groups named Group 1, Group 2, and Group 3, at a level of similarity/distance 8 (Fig. 2). Hannon et al. (2005) used PCA and CA to classify cheeses based on their key chemical indices and grouped them into 5 clusters. In the cases of 12 commercial custard desserts, DeWijk et al. (2003) identified 4 cluster groups of vanilla custard desserts based on sensory and instrumental mouth feel. Using PCA, Al-Hinai et al. (2013) identified 5 PC (i.e., 5 factors: plasticity, elasticity, hydrocolloids' concentration, resilience, cohesiveness) affecting the characteristics of each date-tamarind fruit leather. Using CA they identified 4 classes of the fruit leathers and bi-plot (i.e., including all products and their characteristics), generated through PCA and recognized these classes as hard-chewy, soft-springy, hard-fragile and soft-resilient leathers.

The PCA analysis of the same groups identified by CA shows six principal components (96.2% of total variance) had an Eigen values close to 1 (Kaiser criterion; Rahman and Al-Farsi, 2005). These PC explained 36.7, 23.6, 15.7, 10.7, 5.5 and 4.0 of total variance, respectively. The first axis well correlated with moisture content, pectin, crude fiber, toughness index and hardness, and corresponds

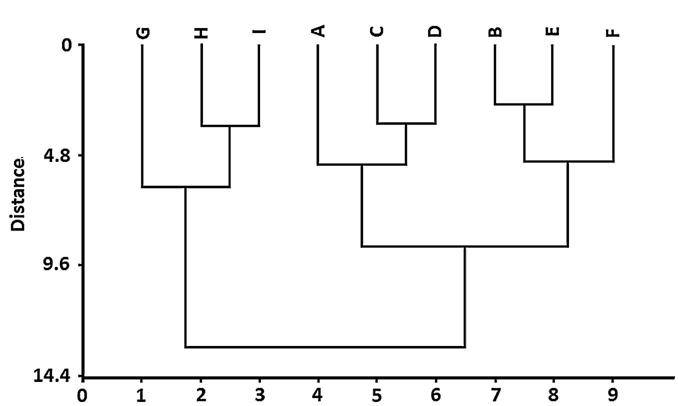

Fig. 2. Dendogram of the cluster analysis for different date samples [GR 1: group 1 (G, H, I); GR 2: group 2 (D, A, C); GR 3: group 3 (B, E, F)]

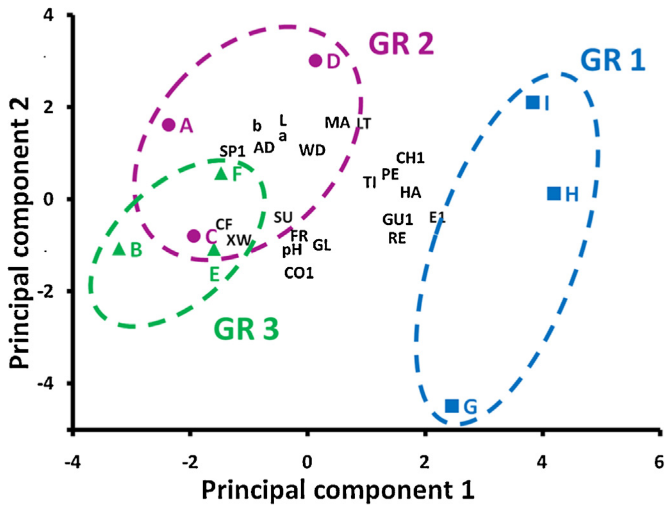

Fig. 3. Bi-plot of principal component 2 and principal component 1 [■: group 1 (GR 1); ●: group 2 (GR 2); ▲: group 3 (GR 3); HA: hardness; CO1: cohesiveness; RE: resilience; SP1: springiness; GU1: gumminess; CH1: chewiness; AD: adhesiveness; *E*1: elasticity 1; XW: moisture content, MA: mass, LT: length, WD: width, CF: crude fiber, FR: fructose, GL: glucose, SU: sucrose, PE: pectin, TI: toughness index].

to a descriptor of strength (i.e., force required to deform during first compression). The second axis was strongly correlated to size (i.e. mass and length) and sucrose, and corresponds to the size of fruits. The third axis was strongly correlated to width of whole date fruit, fructose, and pH (i.e. pH). The fourth axis correlated with adhesiveness, color *L*, glucose, and cohesiveness 1 (i.e., strength of the internal bonding and surface stickiness) (Fig. 3). The fifth axis correlated with color *a* and *b*, and elasticity 1 (i.e. degree of non-elastic deformation). The sixth axis correlated with springiness 1, gumminess 1, and resilience (i.e. structural regain ability after damage). Rahman and Al-Farsi (2005) reported that the PCA of mechanical characteristics for dates (i.e. same variety and batch) at different moisture content showed that two factors "plastic nature" and "elastic nature" of the dates are affecting the process. In this case, the sample contained same chemical composition with varied moisture, thus only two factors could explain the instrumental texture. The six PC observed in this study indicated the complexity of the instrumental texture with varied physico-chemical properties. Similarly 5 PC (explained 84.1% of total variance) were required to explain the instrumental texture of dates-tamarind fruit leather with varied moisture contents as well as hydrocolloids used. The types and concentration levels of hydrocolloids caused the complexity (Al-Hinai et al., 2013).

Fig. 3 presents the bi-plot including all date fruits and their composition and physico-chemical characteristics. In Fig. 3, the products and attributes are the plotted considering PC 2 versus PC 1. The group 1 on the right hand side of the PCA plot includes hard and resilient (i.e., hard-resilient) dates. On the direction of the springy component, the group 2 includes dates that are soft and springy (i.e., soft-springy). The group 3 medium-hard (i.e. firm) and adhesive dates (i.e., firm-adhesive). Therefore, this type of classification based on texture and physico-chemical properties could guide to identify different types of dates in the market and it could be matched to the consumer preference. Similarly commercial halwa, a dessert (i.e., sweet jelly) made up mainly of starch, sugar, water, ghee, and flavored with saffron, nuts and/or rose water, was grouped into four classes as soft-resilient, soft-springy-cohesive, soft-springy, and hard-chewy (Rahman et al., 2012). The date-tamarind fruit leathers developed with varied hydrocolloid types and its concentration were classified into four classes (hard-chewy, soft-gummy, hard-adhesive, and soft-adhesive) (Al-Hinai et al., 2013). Classification was also performed based on chemical compositions and nutrient contents. For example, Hazir et al. (2012) classified oil palm ripeness based on flavonoids and anthocyanin contents.

It is important to address the effects of storage conditions on the changes of the physico-chemical and textural properties of dried fruits or dates. Although this aspect is outside the scope of this paper, it could be explained little from other literatures. In the cases of mango fruit leather at moisture content 17.2 g/100 g sample (water activity: 0.62) stored at room temperature, water activity increased and hardness decreased while there was no significant changes in color and pH when stored up to 6 months (Azeredo et al., 2006). The sensory color, taste, texture and overall acceptability scores of dried dates stored at room temperature decreased significantly ($p < 0.05$) (Kulkarni et al., 2008). Sugar composition in sultana fruit bar affected the texture (i.e. stiffness) of sultana fruit bar during storage at 20 and 40 °C. The addition of malto dextrin lowered the rate of the structure loss during storage. The sultana bars with higher glucose concentrations were extremely hard. The samples got softer as the storage temperature increased (Ozilgen, 2011). Ismail et al. (2008) studied the physico-chemical and sensory characteristics of dates (two varieties, *tamar* stage) during storage at 25 and −3 °C (2 months and one year). They observed that physico-chemical properties and texture deteriorated during storage. Firmness increased after 2 months followed by a decline until 1 year. This was due to the breakdown of the cellulose with enzyme activity during long storage. All these results indicated that it could be important to consider the storage conditions when classifying dates. The authors are targeting their future works in this direction.

3.4. Regression models

Most of the TPA related papers reported in the literature, analyzed data considering correlations with moisture or other selected physico-chemical properties, or through PCA. Limited attempts were made to explain some of the TPA characteristics through multiple regression models of physico-chemical properties or processing conditions (DeWijk et al., 2003; Dimitreli and Thomareis, 2007; Lobato et al., 2009; Herrero et al., 2008; Zhu et al., 2013). TPA attributes of 8 block type cheese formulations were correlated with multiple linear regression as a function of water, fat and protein contents (Dimitreli and Thomareis, 2007). Considering 9 starch based desserts, multiple correlations with interaction terms were also developed as a function of milk, starch and inulin contents (Lobato et al., 2009). In the case of meat sausage, correlations were developed as a linear function of dry solids and fat contents and water activity (Herrero et al., 2008). In this study, 7 most significant properties were considered for developing multiple linear and non-linear (quadratic and log transformation of the independent variables) regression models (Table 4). It was observed that r^2 increased and mean square error (MSE) decreased with the increase of the number of independent variables included in the models. In order to select the best possible model, AIC was applied to the set of linear and non-linear models (Akaike, 1973). AIC was originally designed to be an approximately unbiased estimator of the expected Kullback–Leibler information of a fitted model (Hurvich and Tsai, 1989). AIC criterion ranks available models according to the "fit" of the models to data but also to the complexity of the model reducing thus the risk of over fitting (Hurvich and Tsai, 1989). It was evident that most of the cases only one physico-chemical property was good enough for the selection of the best model but this variable differed among TPA attributes (Table 4). The relative simplicity of the best model may be due to the simplicity of the functional relationship between TPA attributes and physico-chemical properties but also to the number of data points (9) which taxes heavily models with larger number of

Table 4
Selected linear and non-linear regression models for the TPA attributes as a function of physico-chemical properties.

TPA attribute	Linear and non-linear models	AIC	r^2
Hardness	HA = 57.5 − 16.83(CF) + 517.7(PE) − 0.43(XW) + 6.54(TI)	0.00	0.73
	HA = 131.1 − 27.3(CF)	0.43	0.56
	HA = 153.7 − 94.4[log(CF)]	0.52	0.57
Adhesiveness	AD = 2.39 + 0.13(a) + 0.033(b) + 0.041(L)	0.00	0.61
	AD = 2.8 + 0.2(a)	0.93	0.54
	AD = −0.37 + 0.91(a) − 0.04(a^2)	0.17	0.63
Springiness 1	SP1 = 2.71 + 0.18(b)	0.19	0.37
	SP1 = 2.7 + 0.18(b)	0.19	0.37
	SP1 = 2.0 + 1.0(log b)	0.58	0.44
Cohesiveness 1	CO1 = 0.094 − 0.014(MA) + 0.00499(XW) + 0.00389(LT)	0.00	0.55
	CO1 = 0.29 − 0.0068(MA) − 0.0044(b)	0.74	0.64
	CO1 = 0.55 − 0.094[log(LT)]	0.05	0.28
Resilience	RE = 0.021 − 0.0149(CF) + 3.358(PE)	0.17	0.33
	RE = −0.058 + 3.94(PE)	0.37	0.32
	RE = 0.71 + 0.19[log(PE)]	0.45	0.34
Gumminess 1	GU1 = 4.737 + 241.71(PE) − 2.239(CF) − 0.0174(XW)	0.01	0.57
	GU1 = −7.64 + 334.6(PE)	0.79	0.51
	GU1 = 29.3 − 17.3[log(CF)]	0.14	0.42
Chewiness 1	CH1 = 36.54 − 7.40(CF) + 284.1(PE) − 0.201(XW) + 0.12(LT) + 1.0(TI)	0.00	0.83
	CH1 = 37.64 − 8.28(CF) + 408.9(PE)	0.27	0.80
	CH1 = 83.47 − 44.9[log(CF)]	0.39	0.72
Elasticity 1	E1 = 47.46 + 80.80(PE) − 3.38(CF) − 1.19(b) − 1.19(XW)	0.00	0.84
	E1 = −19.6 + 653.2(PE)	0.85	0.44
	E1 = 107.3 − 45.3(CF) + 5.0$(CF)^2$	0.02	0.43

variables. Furthermore, each of the 9 data points corresponds to the averages for all measured variables resulting in loss of specificity of the models. This illustrates the complexity of the relationships of the TPA attributes and physico-chemical properties. However data from different sources when available could be complied for further development of the prediction model.

4. Conclusion

Instrumental TPA of different batches of date fruits with different quality level as a function of their physico-chemical properties were analyzed. Based on physico-chemical properties and TPA attributes, dates fruits available in the market can be classified into three different groups namely hard-resilient, soft-springy and firm-adhesive. The results in this study could be used to explore which physico-chemical properties contribute to the texture, helps to select fruits with desired textural attributes and should offer a basis for the development of a clear classification of dates to facilitate local and international trade of dates. Attempts were made to develop multiple regressions to predict the TPA attributes as a function of physico-chemical properties.

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