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Original article

Reducing sugars, organic acids, size, color, and texture of 21 Emirati date fruit varieties (*Phoenix dactylifera*, L.)

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ABSTRACT

In this study, the variability in 23 physicochemical properties related to fruit size, color, texture, and taste (sugars and organic aids) was investigated in 21 date varieties grown in UAE. The results revealed extensive variation with some traits displaying high coefficient of variations, e.g. fruit and flesh weights (33.0% and 35.8%), red/green and yellow/blue colors (43.3% and 55.6%), organic acids (31.7–40.5%), and texture profile variables (hardness cycles 1 and 2, adhesive force, fracturability, and springiness, 27.0–68.6%). Total reducing sugars, being the main components in date fruits varied 52.1–62.8 g/100 g fruit weight with smaller variation between cultivars (6.2%). The variability observed here for the date fruits is complex and deserves more elaborate studies focussing on the link between physicochemical parameters and other chemical components especially moisture, fibers, and phenolic compounds and other pigments.

1. Introduction

The earliest evidence for the cultivation of date palm (*Phoenix dactylifera* L., Family *Arecaceae*, subfamily *Coryphoideae*) goes back to 4000 BCE in Ur, lower Mesopotamia (now Iraq), where the date palm trunks were used for the construction of the temples; while in the Nile Valley, date palm cultivation goes back to 3000 BCE [1]. Dates are an important fruit, especially in many African, Middle-Eastern, and Asian countries. Besides its local and regional commercial value, the date palm plays an important role in the diet and social life of communities across the oases of the Middle East and North Africa for the last 4000 years [1]. The tree and the fruit have been revered because of the numerous horticultural, nutritional, medicinal, economic, architectural, environmental characteristics, and their multiple uses. In recent years, this fruit has gained significant importance in global commerce as well. During the last two decades, the world production of dates has more than doubled; this trend is expected to continue as per FAO projections [1]. The date palm tree is widespread with about 100 million trees being cultivated globally and an annual yield of 7.5 million tons of date fruits [2–4]. In 2011, Egypt was the top-most producer of dates with 1.37 million metric ton (MMT) or 18.30% of total world production; followed by Saudi Arabia (1.12 MMT), Iran (1.02 MMT), United Arab Emirates (UAE) (0.90 MMT), and Algeria (0.69 MMT). Combined, these top five countries contributed a 68% share of total world production [1].

Date fruit is a single, oblong, one-seeded berry, with a terminal stigma, a fleshy pericarp and a membranous endocarp (between the seed and the flesh) [1]. The pericarp is composed of an exocarp or a thin layer of skin, a sweet mesocarp or flesh, and a thin layered endocarp surrounding the seed. The seed (also called kernel, pit, pyrene, or stone) includes the embryo, the endosperm and a hardened lignified seed coat. Genetics and environmental factors interact to cause great variation in date fruit shapes (spherical to ovoid, ovate, oblong, elliptic, or cylindrical), sizes (3–7 cm in length and 2–3 cm in diameter), and colors (yellow, brown, red, to black) [5–8]. With respect to texture, date fruits are classified into soft, semi-dry, and dry varieties on basis of moisture content and sugar types at harvest. In soft varieties, e.g. Barhee, Halawi, Khadrawy and Medjool, almost all the sucrose is converted into reducing sugars (glucose and fructose) by the enzymatic action of invertase during ripening. Dry date varieties, including Bartamoda, Gundeela, Deglet Beida, Horra, Sakoty and Thoory, contain sucrose as the major soluble sugar. Semi-dry date varieties, e.g. Amry, Dayri, Khalas, Sewy and Zahidi, mainly contain reducing sugars although some varieties like Deglet Noor may contain some sucrose [9]. The moisture contents of the three types of date varieties at harvest are approximated as follows for soft (> 30% moisture), semi-dry (20–30% moisture), and dry (< 20% moisture) but this estimation needs confirmation and correlations to sugars and texture analysis. Most of the varieties grown in United Arab Emirates and neighboring countries belong to the category

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of semi-dry dates with the varieties being largely related despite some differences between them imposed by genetics, cultivation, and environmental factors.

Date fruits are rich sources of soluble and insoluble dietary fiber, minerals, vitamins, and antioxidants [2,10,11]. The genetic pool, with possibly 2000 or more existing date varieties, is very wide and presents a great genetic diversity in the phenotypic and sensory quality of their fruits [12]. The evaluation of fruit quality is a challenging mission as it is defined either from a consumer preference and m0arket performance point of view or from a producer point of view focusing on directly measurable attributes [13]. Fruit quality evaluation includes parameters such as geometry (shape and size), color, texture, taste, and aroma, which can be evaluated by sensory assessment and/or by instrumental measurements [14]. A sensory quality scoring system for the classification of date fruits on basis of consumer surveys including 405 participants from UAE was developed [15]. Eleven quality attributes related to fruit size, color, texture, and taste were identified through questionnaires and were validated using sensory tests on five date varieties, namely Barhi, Bumaan, Eurzeiz, Fardh, and Khlas. Sensory analysis is expensive and involves great cultural subjectivity that is population dependent. On the other hand, instrumental determination of the physicochemical characteristics of fruits provides useful data for the processing and commercialization [16,17].

Date variety identification and characterization is still an empirical process dependent on the knowledge and experience of traditional inspectors and is based on fruit morphological features, which are sensitive to environmental factors. Research on date fruit identification and characterization is needed to identify potential varieties for valorization and adoption in food processing operations. Although there is considerable scattered literature on the physicochemical characteristics of selected date fruits [18], studies including larger pools of varieties and a wide range of characteristic variables are needed. The objective of this study is to characterize 21 date fruit varieties grown in UAE through quantitative measurements of 23 physicochemical parameters as major contributors to fruit quality (fruit weight and size, color, texture, total sugars and organic acids). With the wide set of information available, we also present and discuss significant correlations between variables.

2. Materials and methods

2.1. Date fruit samples

Samples of 21 date varieties grown in UAE, at the mature Tamr stage, were obtained from Al Foah Factory (Al-Ain Date Factory, Al-Saad, UAE). For each variety, three samples were collected randomly from three different locations in Abu Dhabi Emirate (Abu Dhabi, Eastern region – Al-Ain, and Western region – Al-Dhafra) without preference to size, color and appearance. Samples (total 9 samples/variety) were stored in the refrigerator until analyzed.

2.2. Physical measurements

Fruit and seed weights (g), dimensions (cm), and volumes (mL) were recorded. Date fruit weight (FW) and seed weight (SW) were determined and fruit flesh weight (FLW) was calculated as fruit weight minus seed weight. Date fruits and seeds were drawn on a millimetre paper and their lengths (FL and SL), and mid diameters (FD and SD) were measured. Fruit volumes (FV) and seed volumes (SV) were determined by displacement using mustard seeds. For fruit color, the *L, a, b* color values were measured using a Hunter Lab colorimeter (Hunter Lab Inc., Reston, VA, USA). Instrumental texture profile analysis (TPA) attributes were measured using a computerized TA-XT2i Texture Profile Analyser (Stable Microsystems, Surrey, UK). TPA involves two cycles of compression of a date fruit sample between two parallel surfaces. This is mainly used to imitate the mastication process by instrumental means. The TPA device generates a force–time curve, which is then used to define the following attributes: hardness cycle 1, the maximum force during the first compression cycle (N); hardness cycle 2, the maximum force during the second compression cycle (N); adhesive forces, the maximum force required to separate teeth after biting sample (N); resilience, the ratio of the negative area to positive area of the first compression cycle (A2/A1); springiness, the ratio between the second compression distance and the first compression distance (D2/D1) and fracturability, the load force of the first significant peak (N).

2.3. Analysis of sugars and organic acids

Sugars and organic acids were analyzed as indicators of sweet and sour taste of date fruits. For the extraction of soluble sugars and organic acids, samples (1 g) were weighed in falcon tubes, homogenized using an Ultra-Turrax homogenizer and extracted four times with 0.1% orthophosphoric acid (10 mL) with intermittent centrifugation (15 min at 4600 rpm and 4 °C). Supernatants were then filtered in HPLC vials by 0.45 μm membrane filters before analysis by high performance liquid chromatography (HPLC). Soluble sugars were analyzed on a μ-Bondapack NH2 -column (300 mm length, 3.9 mm i.d., 10 mm particle size, Waters Corporation, Milford, Massachusetts, USA). The mobile phase was acetonitrile:water (83:17, *v*/v) and the flow rate was 1.5 mL/min. Peaks were detected by a diode array detector at 190 nm and quantified against authentic standards of glucose and fructose (Sigma-Aldrich Corporation, Darmstadt, Germany). The sugars eluted as follows: fructose (6.2 min), malic acid (2.7 min), and acetic acid (6.5 min).

Organic acids were analyzed on a Shodex RSpak KC-118 model ion-exchange organic acid column (300 mm length, 8 mm i.d.) thermostated at 35 °C using 0.1% H3PO4 as a mobile phase at a flow rate of 0.8 mL/min. Peaks were detected by a diode array detector at 210 nm and quantified against authentic standards of acetic acid, citric acid, formic acid, fumaric acid, malic acid, oxalic acid, succinic acid, and tartaric acid (Sigma-Aldrich Corporation, Darmstadt, Germany). The organic acids eluted as follows: citric acid (1.8 min), glucose (7.0 min), and sucrose (10.0 min).

2.4. Statistical analysis

The differences in physicochemical properties of dates were analyzed using one-way ANOVA and Tukey's multiple range test with a statistical software program (SPSS 16, SPSS Inc., Chicago, USA). The differences were determined to be significant for p values $< .05$. The linear correlations between different physicochemical properties were measured by Pearson's correlation coefficient and were considered significant at $p < .05$.

3. Results and discussion

In this study, 21 date varieties from three locations in Abu Dhabi Emirate were investigated considering 23 different variables related to fruit and seed weight and size, fruit color, texture profile, and contents of soluble sugars and organic acids (Tables 1–3). Date fruits are known to vary in shape, size, color, texture, taste, and flavor depending on genetic factors and agro-climatic conditions [19]. Results presented in this paper are limited to variability in three locations in Abu Dhabi Emirate, UAE in one year of harvest (2012).

3.1. Fruit weight and size

Date fruits showed considerable variability between varieties with reference to fruit weight and size (Fig. 1A). Variability in weight and size was also reported within varieties, e.g. the weight of Khalas fruits covers a wide range from large (> 10 g), medium (7–9 g), and small (< 7 g) [20]. Sultanah, Saqei (Sugei/Segae), and Helali had heavier fruits compared to Barhi, Lulu, Sobo Al-Aroos, and Youwani ($p < .05$)

Table 1
Differences between date fruit varieties with respect to fruit weight volume and size.

Parameters of fruit weight, volume, size

#	Variety	Fruit weight (g)	Fruit length (cm)	Fruit mid diameter (cm)	Fruit volume (cm^3)	Flesh weight (g)	Seed weight (g)	Seed length (cm)	Seed mid diameter (cm)	Seed volume (cm^3)
1	Alrayes	7.7 ± 0.74 bcde	3.1 ± 0.17 abcdef	1.9 + 0.21 a	10.0 ± 2.00 bcde	7.0 ± 0.69 bcde	0.66 ± 0.11 ab	1.8 ± 0.06 bcd	0.67 ± 0.06 abc	0.63 ± 0.15 a
2	Anwan	6.0 ± 0.50 cde	3.2 ± 0.25 abcde	2.0 ± 0.29 a	8.7 ± 1.15 cde	5.4 ± 0.52 cde	0.60 ± 0,08 ab	2.1 ± 0.12 ab	0.60 ± 0.00 abcd	0.73 ± 0.15 a
3	Barhi	5.0 ± 0.38 e	2.4 ± 0.10 fg	1.8 ± 0.26 a	6.0 ± 1.00 e	4.4 ± 0.39 e	0.59 ± 0.10 b	1.4 ± 0.10 de	0.73 ± 0.12 ab	0.70 ± 0.20 a
4	Bumaan	7.8 ± 2.05 bcde	2.8 ± 0.42 defg	1.9 ± 0.10 a	8.7 ± 1.53 cde	7.0 ± 2.01 bcde	0.79 ± 0.12 ab	1.4 ± 0.17 de	0.53 ± 0.06 bcd	0.87 ± 0.15 a
5	Fardh	6.4 ± 1.49 cde	3.1 ± 0.21 abcdef	1.9 ± 0.12 a	6.7 ± 1.15 de	5.9 ± 1.45 cde	0.53 ± 0.05 b	1.7 ± 0.00 bcd	0.50 ± 0.00 cd	0.57 ± 0.06 a
6	Helali	11.6 ± 1.40 ab	3.3 ± 0.25 abcde	2.1 ± 0.17 a	12.7 ± 1.53 bc	10.7 ± 1.32 ab	0.88 ± 0.09 ab	1.7 ± 0.15 bcd	0.70 ± 0.00 abc	1.1 ± 0.06 a
7	Jabri	7.8 ± 0.85 bcde	2.6 ± 0.36 efg	1.9 ± 0.06 a	9.0 ± 1.00 cde	7.2 ± 0.84 bcde	0.60 ± 0.07 ab	1.5 ± 0.25 cde	0.60 ± 0.10 abcd	0.67 ± 0.12 a
9	Jesh Suweih	6.6 ± 1.24 cde	3.7 ± 0.40 abc	1.8 ± 0.11 a	7.7 ± 0.58 cde	5.7 ± 1.34 cde	0.88 ± 0.10 ab	2.4 ± 0.23 a	0.62 ± 0.10 abcd	0.97 ± 0.35 a
8	Jesh-Habash	5.4 ± 1.22 cde	2.9 ± 0.17 cdef	1.8 ± 0.17 a	5.7 ± 2.08 e	4.6 ± 1.12 de	0.75 ± 0.03 ab	2.0 ± 0.06 abc	0.73 ± 0.06 ab	1.00 ± 0.10 a
10	Khalas	7.5 ± 2.08 bcde	3.1 ± 0.25 abcdef	1.8 ± 0.35 a	9.3 ± 2.52 cde	6.9 ± 2.03 bcde	0.63 ± 0.06 ab	1.8 ± 0.06 bcd	0.53 ± 0.06 bcd	0.73 ± 0.15 a
11	Khasab	7.0 ± 0.56 cde	3.1 ± 0.15 abcdef	2.0 ± 0.10 a	8.7 ± 0.58 cde	6.4 ± 0.50 bcde	0.61 ± 0.09 ab	1.8 ± 0.10 bcd	0.63 ± 0.06 abcd	0.77 ± 0.15 a
12	Khenaizi	7.3 ± 1.30 bcde	3.2 ± 0.21 abcde	1.8 ± 0.15 a	9.0 ± 1.73 cde	6.8 ± 1.35 bcde	0.57 ± 0.06 b	1.9 ± 0.06 abc	0.43 ± 0.06 d	0.57 ± 0.06 a
13	Lulu	5.1 ± 0.53 de	2.1 ± 0.17 g	2.1 ± 0.15 a	7.0 ± 1.00 de	4.5 ± 0.51 de	0.64 ± 0.09 ab	1.4 ± 0.10 de	0.70 ± 0.00 abc	0.70 ± 0.00 a
14	Majdoul	9.7 ± 1.13 abc	3.7 ± 0.17 ab	2.2 ± 0.06 a	10.0 ± 0.00 bcde	8.7 ± 1.22 abcd	0.98 ± 0.10 a	2.0 ± 0.10 ab	0.77 ± 0.06 a	1.00 ± 0.10 a
15	Nabtat Saif	9.5 ± 2.22 abcd	3.0 ± 0.26 abcdef	2.3 ± 0.31 a	11.3 ± 2.31 bcd	9.0 ± 2.26 abc	0.50 ± +0.12 b	1.2 ± 0.26 e	0.60 ± 0.10 abcd	0.57 ± 0.15 a
16	Qattara	6.4 ± 0.55 cde	2.9 ± 0.21 bcdef	2.2 ± 0.26 a	6.7 ± 1.15 de	5.6 ± 0.58 cde	0.73 ± 0.04 ab	1.9 ± 0.06 bc	0.70 ± 0.00 abc	0.93 ± 0.12 a
17	Saqei (Sugei/Segae)	12.4 ± 3.10 a	3.7 ± 0.31 a	2.3 ± 0.30 a	14.7 ± 3.21 ab	11.7 ± 3.23 a	0.73 ± 0.13 ab	1.9 ± 0.20 bc	0.70 ± 0.10 abc	0.87 ± 0.15 a
18	Sobo Al-Aroos	5.1 ± 0.61 e	3.5 ± 0.36 abcd	1.8 ± 0.06 a	7.7 ± 0.58 cde	4.3 ± 0.57 e	0.76 ± 0.06 ab	2.1 ± 0.06 ab	0.53 ± 0.06 bcd	0.87 ± 0.12 a
19	Sultanah	13.4 ± 0.17 a	3.7 ± 0.32 a	2.3 ± 0.12 a	18.7 ± 2.08 a	12.5 ± 0.09 a	0.87 ± 0.11 ab	1.7 ± 0.10 bcd	0.72 ± 0.10 ab	0.93 ± 0.05 a
20	Youwani	5.1 ± 1.59 de	3.3 ± 0.26 abcde	1.8 ± 0.23 a	8.7 ± 2.31 cde	4.4 ± 1.21 e	0.73 ± 0.42 ab	1.9 ± 0.10 bc	0.53 ± 0.06 bcd	0.90 ± 0.44 a
21	Zahidi	6.4 ± 1.63 cde	3.0 ± 0.32 abcdef	1.9 ± 0.15 a	7.3 ± 1.15 de	5.5 ± 1.62 cde	0.88 ± 0.03 ab	1.8 ± 0.25 bcd	0.53 ± 0.06 bcd	0.83 ± 0.12 a

Values within the same column sharing a common superscrpt are not statistically differerent ($p < 0.05$).

Table 2
Differences between date fruit varieties with respect to fruit color and texture.

#	Variety	L	a	b	Hardness cycle 1 (N)	Hardness cycle 2 (N)	Adhesive force (N)	Resilience	Fracturability (N)	Springiness (mm)
	Parameters related to fruit color & texture									
1	Alrayes	30.56 ± 0.08 cde	7.84 ± 0.21 cdefg	6.9 ± 0.39 abcd	2.02 ± 0.73 a	2.97 ± 1.20 a	0.41 ± 0.05 abcd	0.09 ± 0.01 abc	1.12 ± 1.48 a	2.49 ± 0.25 cde
2	Anwan	23.04 ± 0.05 a	2.04 ± 0.07 ab	0.5 ± 0.09 a	2.94 ± 1.29 ab	4.64 ± 2.66 a	0.17 ± 0.06 a	0.08 ± 0.01 abc	1.42 ± 1.46 a	2.28 ± 0.15 bcde
3	Barhi	30.08 ± 1.94 bcde	9.03 ± 1.73 defgh	9.5 ± 1.31 cde	3.22 ± 1.20 ab	7.54 ± 3.36 a	0.46 ± 0.06 abcde	0.07 ± 0.01 ab	1.51 ± 1.84 a	2.87 ± 0.23 de
4	Bumaan	29.60 ± 1.41 bcde	10.25 ± 0.98 efgh	12.00 ± 0.18 defg	3.41 ± 0.26 ab	5.29 ± 0.66 a	0.70 ± 0.05 cde	0.07 ± 0.01 ab	1.58 ± 1.81 a	2.62 ± 0.04 cde
5	Fardh	23.06 ± 0.06 a	5.98 ± 0.04 bcde	2.24 ± 0.03 ab	2.06 ± 0.21 a	2.99 ± 0.86 a	0.63 ± 0.19 bcde	0.06 ± 0.00 ab	0.71 ± 0.06 a	0.68 ± 0.03 a
6	Helali	26.78 ± 0.13 abcd	7.77 ± 0.12 cdefg	8.50 ± 0.10 bcde	2.17 ± 0.46 ab	3.49 ± 0.87 a	0.45 ± 0.07 abcde	0.06 ± 0.01 ab	1.19 ± 1.27 a	0.75 ± 0.16 ab
7	Jabri	28.19 ± 0.15 abcde	6.78 ± 0.28 cdef	9.88 ± 0.03 cde	1.43 ± 0.33 a	2.17 ± 0.36 a	0.29 ± 0.04 ab	0.06 ± 0.01 ab	0.38 ± 0.26 a	1.26 ± 0.61 abc
9	Jesh Suweih	23.28 ± 0.07 a	1.5 ± 0.17 a	1.49 ± 0.07 a	4.59 ± 0.41 ab	4.96 ± 1.96 a	0.41 ± 0.19 abcd	0.06 ± 0.01 ab	0.48 ± 0.20 a	2.11 ± 0.09 abcd
8	Jesh-Habash	26.64 ± 2.40 abcd	7.55 ± 2.08 cdefg	6.59 ± 2.75 abcd	1.55 ± 0.42 a	3.41 ± 0.70 a	0.30 ± 0.04 ab	0.05 ± 0.01 a	0.34 ± 0.06 a	2.13 ± 0.27 abcde
10	Khalas	33.36 ± 2.40 e	10.67 ± 0.94 fghi	16.42 ± 2.82 fg	1.53 ± 0.61 a	3.06 ± 0.82 a	0.34 ± 0.06 abcd	0.06 ± 0.01 ab	0.24 ± 0.13 a	2.34 ± 0.22 cde
11	Khasab	23.38 ± 0.28 a	2.11 ± 0.09 ab	1.99 ± 0.16 a	2.12 ± 0.67 ab	2.85 ± 0.77 a	0.44 ± 0.14 abcde	0.08 ± 0.01 abc	0.98 ± 1.02 a	2.61 ± 0.33 cde
12	Khenaizi	26.19 ± 0.34 abcd	4.47 ± 0.27 abc	5.47 ± 0.12 abc	1.77 ± 0.15 a	2.43 ± 0.29 a	0.30 ± 0.11 ab	0.06 ± 0.01 ab	0.87 ± 0.73 a	2.64 ± 0.13 cde
13	Lulu	25.41 ± 1.08 abc	8.93 ± 1.79 defgh	6.69 ± 1.62 abcd	1.62 ± 0.44 a	2.07 ± 0.54 a	0.33 ± 0.08 abc	0.09 ± 0.01 abc	0.51 ± 0.19 a	2.44 ± 0.09 cde
14	Majdoul	33.17 ± 2.46 e	9.39 ± 2.28 defgh	10.28 ± 2.24 cdef	2.43 ± 0.73 ab	4.13 ± 1.07 a	0.28 ± 0.17 ab	0.09 ± 0.01 abc	1.95 ± 1.57 a	2.21 ± 0.26 abcde
15	Nabtat Saif	30.35 ± 2.91 bcde	9.68 ± 0.78 defgh	12.13 ± 3.57 defg	3.04 ± 0.72 ab	4.04 ± 0.83 a	0.62 ± 0.09 bcde	0.09 ± 0.02 bc	2.01 ± 1.16 a	3.03 ± 0.18 de
16	Qattara	24.82 + 0.09 ab	5.45 + 0.26 abcd	5.35 + 0.14 abc	1.40 + 0.54 a	2.46 + 1.04 a	0.28 + 0.09 ab	0.06 + 0.02 ab	0.31 + 0.09 a	2.31 + 0.28 cde
17	Saqei (Sugei/Segae)	29.54 ± 0.46 bcde	11.32 ± 0.25 ghi	12.76 ± 0.22 defg	4.16 ± 1.04 ab	4.94 ± 1.21 a	0.70 ± 0.20 de	0.14 ± 0.02 d	2.84 ± 2.27 a	3.33 ± 0.35 de
18	Sobo Al-Aroos	32.75 ± 4.19 e	14.79 ± 4.22 i	18.17 ± 4.98 g	4.78 ± 1.14 ab	16.46 ± 9.24 b	0.62 ± 0.24 bcde	0.08 ± 0.21 abc	2.37 ± 3.10 a	3.65 ± 1.98 e
19	Sultanah	31.53 ± 1.88 de	6.80 ± 1.87 cdef	12.54 ± 2.48 defg	3.53 ± 1.13 ab	8.23 ± 6.30 ab	0.47 ± 0.04 abcde	0.06 ± 0.01 ab	1.95 ± 2.30 a	2.20 ± 0.05 abcde
20	Youwani	30.63 ± 1.85 cde	8.93 ± 0.81 defgh	11.58 ± 2.37 cdef	1.63 ± 0.26 a	3.42 ± 1.35 a	0.28 ± 0.09 ab	0.07 ± 0.00 abc	0.69 ± 0.79 a	2.35 ± 0.15 cde
21	Zahidi	30.47 ± 3.41 cde	12.86 ± 1.56 hi	14.44 ± 3.80 efg	5.66 ± 0.69 b	9.59 ± 2.42 ab	0.81 ± 0.12 e	0.11 ± 0.01 cd	0.66 ± 0.11 a	2.85 ± 0.34 de

Values within the same column sharing a common superscrpt are not statistically differerent ($p < 0.05$).

Table 3
Differences between date fruit varieties with respect to total reducing sugars and organic acids.

Total reducing sugars and organic acids as contributors to fruit taste						
#	Variety	Total sugars (g/100 g FW)	Malic acid (mg/100 g FW)	Acetic acid (mg/100 g FW)	Citric acid (mg/100 g FW)	Total organic acids (mg/100 g FW)
1	Alrayes	60.2 ± 1.57 a	86.00 ± 5.84 a	167 ± 24 def	11 ± 2.1 a	277 ± 33 a
2	Anwan	61.1 ± 1.85 a	177 ± 5.50 bcdefg	51 ± 9.8 a	74 ± 10.6 fg	317 ± 10 ab
3	Barhi	52.4 ± 8.43 a	134 ± 10.02 abcde	63 ± 6 a	100 ± 0.6 h	321 ± 23 ab
4	Bumaan	60.2 ± 4.26 a	172 ± 11.39 bcdefg	176 ± 21 defg	40 ± 1.4 bcd	399 ± 6 bcde
5	Fardh	57.8 ± 4.84 a	213 ± 4.67 fgh	147 ± 1.6 cdef	67 ± 9.0 efg	449 ± 8 ef
6	Helali	61.5 ± 1.05 a	116 ± 15.20 abc	193 ± 15.7 fg	28.8 ± 2.5 ab	352 ± 13 abcd
7	Jabri	54.6 ± 4.61 a	148 ± 11.20 abcdef	149 ± 2.3 cdef	41 ± 9.5 bcd	348 ± 6 abcd
9	Jesh Suweih	54.0 ± 2.82 a	255 ± 4.56 h	118 ± 12 bc	78 ± 12.2 gh	456 ± 5 ef
8	Jesh-Habash	62.8 ± 2.79 a	109 ± 1.91 ab	146 ± 20 cdef	59 ± 8.8 cdefg	326 ± 22 ab
10	Khalas	52.10 ± 5.34 a	138 ± 7 abcdef	219 ± 17 g	43 ± 10.2 bcde	413 ± 5.8 cde
11	Khasab	56.50 ± 4.90 a	211 ± 18 efgh	173 ± 12 defg	33 ± 3.5 ab	432 ± 29.7 def
12	Khenaizi	67.70 ± 3.11 a	137 ± 2 abcef	153 ± 14cdef	37 ± 5.9 bc	356 ± 18.8 abcd
13	Lulu	58.10 + 5.44 a	122 ± 10 abcd	88 ± 4 ab	73 ± 1.7 fg	295 ± 4.7 a
14	Majdoul	55.50 ± 3.97 a	140 ± 15 abcdef	129 ± 7 bcd	58 ± 4.5 cdefg	331 ± 10.6 abc
15	Nabtat Saif	64.70 ± 5.96 a	343 ± 9 i	114 ± 8 bc	52 ± 8.3 bcdef	516 ± 15 f
16	Qattara	52.40 ± 1.00 a	194 ± 22 defgh	84 ± 23 ab	40 ± 15.5 bcd	335 ± 30 abc
17	Saqei (Sugei/ Segae)	61.90 ± 1.62 a	102 ± 1.6 ab	130 ± 1.4 bcd	63 ± 1.5 defg	309 ± 1.0 a
18	Sobo Al-Aroos	60.40 ± 4.62 a	117 ± 13 abcd	118 ± 17 bc	37 ± 3.8 bc	279 ± 33 a
19	Sultanah	61.70 ± 2.88 a	187 ± 8 cdefgh	185 ± 10 efg	29 ± 1.9 ab	423 ± 5.7 de
20	Youwani	58.60 ± 3.64 a	227 ± 104 gh	142 ± 36 cde	47 ± 15.2 bcde	430 ± 97.3 de
21	Zahidi	54.40 ± 7.15 a	135 ± 10 abcde	146 ± 7 cdef	67 ± 2.6 efg	352 ± 2.6 abcd

Values within the same column sharing a common superscrpt are not statistically differerent ($p < 0.05$).

(Table 1). However, this relation was not strictly followed in other parameters (i.e. length, diameter, volume, and density) because of the variation in fruit shape. Date seeds were reported to constitute 10–15% of the total fruit weight with considerable variability especially with respect to seed length (Fig. 1B).

3.2. Fruit color

Date fruit color was considered by consumers in the Gulf cooperation countries the most important fruit trait [15]. Table 2 presents the color scores for the 21 varieties on the Hunter Lab color scale; lightness (L), redness (a), and yellowness (b). The range of variation was 23.05–33.4 for (L), 1.5–14.8 for (a), and 0.5–18.2 for (b) (Fig. 1C). These results are comparable to the reported variation in the color of date varieties, i.e. L (12.12–47.05), a (1.35–15.29), and b (0.86–35.12) [21–23]. The varieties Anwan, Jesh Suweih, Khasab, and to some extent Khenaizi, which are red in the Bisr (or Khalal) stage are darker than the other varieties that are yellow at the Bisr stage. Interestingly, these varieties have less a-value (red color) and b-value (yellow color) than the other varieties. As the color of date fruits is determined by several components including anthocyanins and other phenolic compounds as well as maillard reaction products, more elaborate studies are needed to explain the variability in date fruit color and its determinants.

3.3. Fruit texture

Texture analysis provides information relevant to the mechanical properties of foods during processing as well as to sensory properties perceived by humans [24]. The different varieties displayed a typical texture profile for date fruit (Fig. 2). The date varieties revealed considerable variability in fruit texture (Fig. 1D), e.g. Zahidy fruits required more force in compression cycle 1 compared to other varieties and this difference was significant compared to Alrayes, Fardh, Jesh Habash, Khlas, Khuneizi, Lulu, Qatara, and Youwani ($p < .05$) (Table 2). Regarding hardness cycle 2 and springiness, Sobo al-Aroos showed higher values compared to other varieties ($p < .05$). The values obtained in this study are in agreement with values reported for Barhi, Bumaan, Khalas, Lulu, Saqei (Sugei/Segae), and Nabtat Seif [21,25]. Fruit texture parameters depend on anatomical cell wall structure, specifically skin cell size and shape of the underlying pericarp tissue layers [26].

Date fruits are generally different in the hardness of the edible part and are classified according to their moisture contents at fresh Tamr stage into soft (> 30% moisture), semi-dry (20–30% moisture) and dry varieties (< 20% moisture, < 0.65 water activity) [27]. Rahman et al. (2005) demonstrated that hardness of date fruit increased sharply below moisture content 21.5% (wet basis) [28]. This can be considered as the transformation of the rubbery (more easy to deform) date flesh into leathery (tough to deform) behavior. Rubbery–leathery transformation was also observed for other foods such as rice based products [29].

All sensory parameters, except gumminess, were reported to correlate with pectin, crude fiber, and moisture contents [30]. In sensory evaluation, date fruit hardness, cohesiveness, elasticity, and resilience correlated with fruit length, adhesiveness with glucose content, chewiness with fruit weight, and gumminess with fructose, glucose, and total sugar content [30].

3.4. Soluble sugars and organic acids

Sweetness of date is related to the presence of sugars while organic acids are important determinants of fruit taste contributing to sourness and modulating the sweetness of the fruit. Soluble sugars and organic acids are expected to contribute sweetness and sourness to date fruits. In agreement with other studies [31], reducing sugars (glucose and fructose) were the predominant components in the studied date varieties, where they exist as an equimixture. These invert sugars, produced by the hydrolysis of sucrose, are responsible for the sweetness of the fruits, for their softness together with moisture, and they contribute to fruit color through Maillard and caramelization reactions.

Three major organic acids were found in date fruits, mainly malic acid, acetic acid, and citric acid (Table 3) with much smaller concentrations formic, fumaric, oxalic, succinic, and tartaric acids (results not shown). Malic acid was the main organic acid in Fardh, Khasab, and Khlas dates from Oman followed by succinic, oxalic, citric, isobutyric, and formic acids [32]. Organic acids are important determinants of fruit

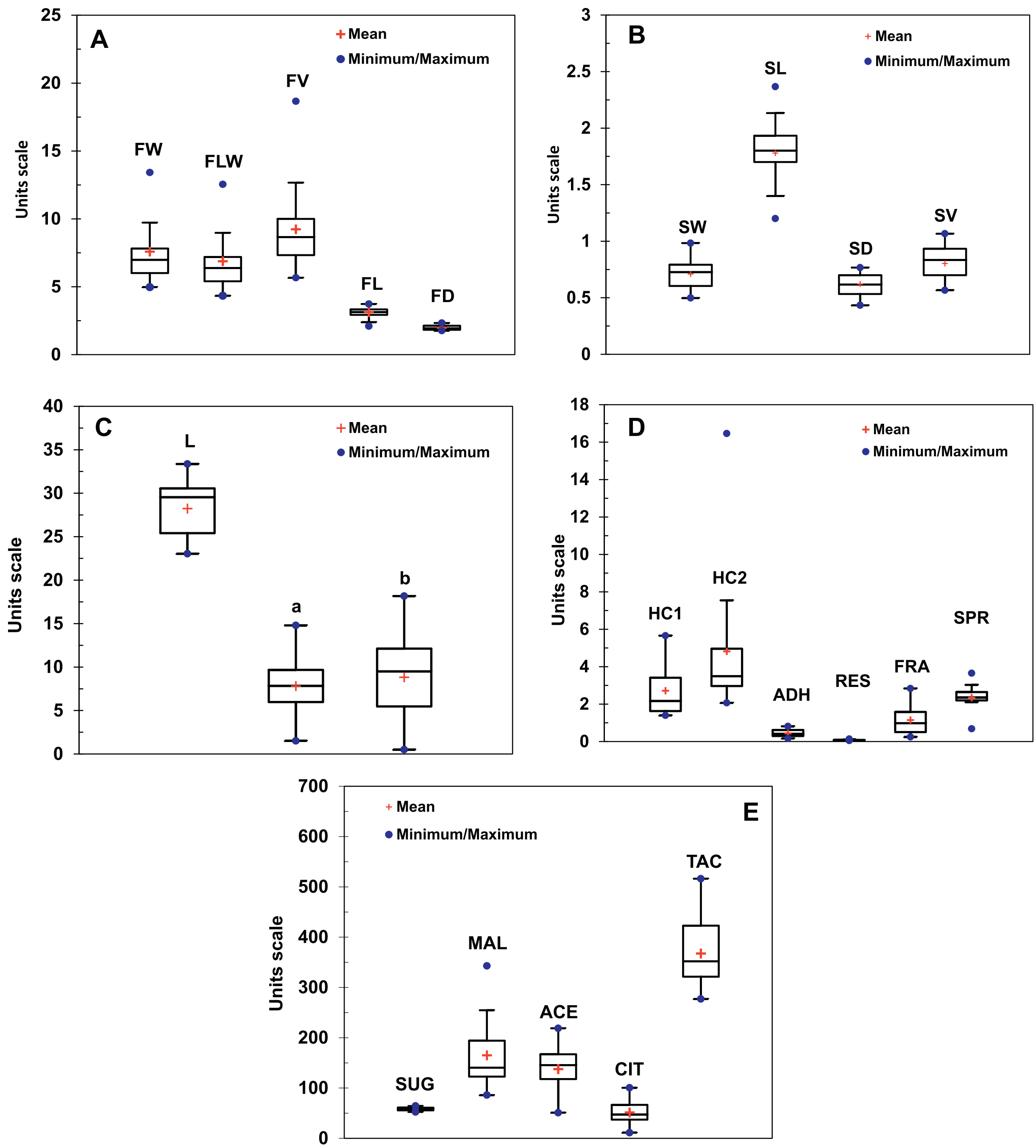

Fig. 1. Box plots showing the range of variability in the 23 variables studied in 21 date fruits. Abbreviations: FW (fruit weight), FL (fruit length), FD (fruit mid diameter), FV (fruit volume), FLW (flesh weight), SW (seed weight), SL (seed length), SD (seed lid diameter), SV (seed volume), L (lightness), a (red color), b (yellow color), HC1 (hardness cycle 1), HC2 (hardness cycle 2), ADF (adhesive force), RES (resilience), FRA (fracturability), SUG (total reducing sugars), MAL (malic acid), ACE (acetic acid), CIT (citric acid), and TAC (total organic acids).
Unit scales: A – FW (g), FLW (cm), FV (cm^3), FL (cm), FD (cm); B – SW (g), SL (cm), SD (cm), SV (cm^3); C – L(-), a (-), b (-); D – HC1 (N), HC2 (N), ADH (N), RES (–), FRA (N), SPR (mm). E – SUG (g/100 g FW), MAL, ACE, CIT & TAC (mg/100 g FW). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

taste contributing sourness and modulating the sweetness of the fruit [33]. Organic acids importance for fruit quality include their effects as preservatives and antimicrobial agents, enhancers of appetite and facilitators of digestion, stabilisation of the water-soluble vitamins B and C, and improvement of potassium, copper, zinc, and calcium absorption [34].

3.5. Correlations between variables

Significant positive Pearson correlations existed between fruit weight, flesh weight, and fruit volume were strong and highly significant ($r > 0.900$, $p < .05$) (Table 4). The correlation between fruit length and seed length is positive ($r = 0.614$, $p < .05$) but the correlation between fruit weight and seed weight is very weak although significant ($r = 0.271$, $p < .05$) partly due to the narrow range of variation in fruit weight ~5–8 g. Fruit weights of date varieties from

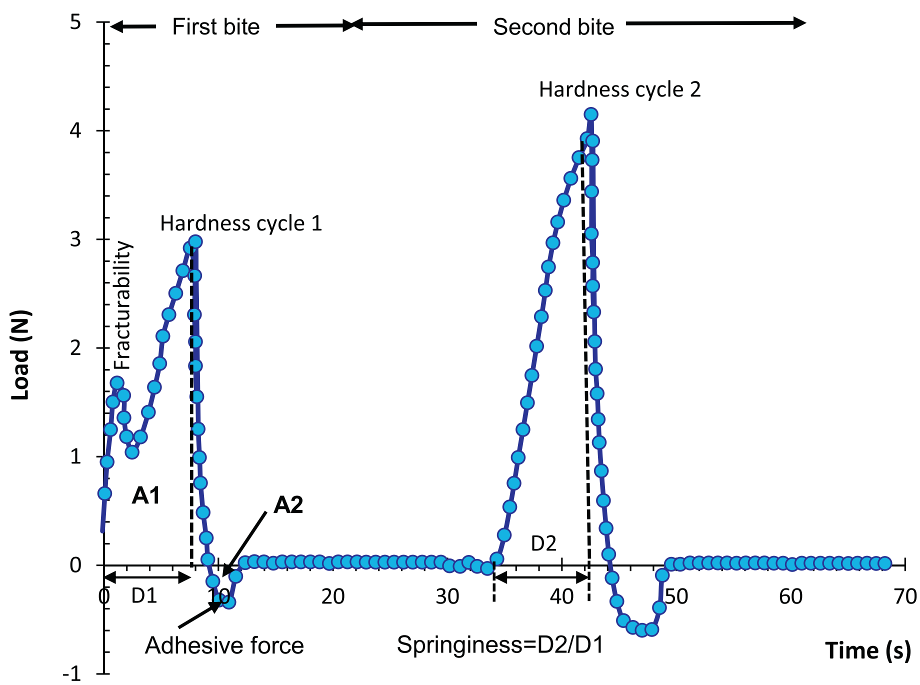

Fig. 2. Typical texture profile for date fruit. Hardness cycle 1, the maximum force during the first compression cycle (N); hardness cycle 2, the maximum force during the second compression cycle (N); adhesive forces, the maximum force required to separate teeth after biting sample (N); resilience, the ratio of the negative area to positive area of the first compression cycle (A2/A1); springiness, the ratio between the second compression distance and the first compression distance (D2/D1) and fracturability, the load force of the first significant peak (N).

Rajasthan including Hallawy, Khadrawy, Khalas, Khuneizi, Madjool, and Zahidi showed that Khunaizi had the maximum fruit weight and minimum seed weight while Halawi had the minimum fruit weight and maximum seed weight [35]. The irregularity of date fruit shape explains the weak relations between fruit weight and fruit and seed dimensions. Generally, the shape of ripe date fruits varies from spherical to ovoid, oblong, or cylindrical, with 3–7 cm length and 2–3 cm diameter [6].

Significant positive Pearson's correlations exist between the lightness of fruit color and red ($r = 0.780$, $p < .05$) and yellow colors ($r = 0.900$, p < .05) (Table 4). The darkest fruits (Anwan, Fardh, and Khasab) also have less red and yellow coloration compared to lightest fruits (Khalas and Majdoul). Date fruit color vary from yellow, brown, red, to black due to different acombinations of various pigments [6]. Similar to dried grapes, the darkness of date fruit color can be explained by non-enzymatic reactions (melanoidins and caramels), enzymatic reactions catalyzed by polyphenol oxidase (melamins), and the presence of pigments including carotenoids, anthocyanins, and tannins [36,37]. Studies on the Iranian variety Mazafati suggest that date fruits that are red in the Khalal stage turn black at Tamr stage [38]. A gene identified as VIRESCENS controls date fruit color by dominant inhibition of anthocyanin production in varieties that are yellow at the Khalal stage. Variations in anthocyanin hues are attributed to glycosylation or methylation as well as to differences in folding and stacking of molecules, copigmentation resulting from interactions with other molecules (e.g. flavonols, tannins, amino acids, pectin, certain alkaloids, and other anthocyanins), chelation of metals (e.g. Al, Fe, Sn, Mg), pigment concentration, and pH [39]. Condensed tannins (proanthocyanidins based on epicatechin) were reported in some date fruits [40] and melanin pigments may also be present in some dark varieties [41].

Hardness cycle 1 is significantly correlated ($p < .05$) to hardness cycle 2 ($r = 0.661$) and adhesive force ($r = 0.561$), resilience ($r = 0.448$), fracturability ($r = 0.375$), and springiness ($r = 0.292$) ($p < .05$) (Table 4) with hardness cycle 2 requiring about double force compared to hardness cycle 1 despite considerable variations between varieties (Fig. 3). Date fruits are characterized by varying degree of stickiness, described as tendency of a food to adhere to contact surfaces [42]. High springiness relates to cohesiveness while low springiness results in a brittle structure that can easily break into small pieces [43]. Fruit color, especially red color (a), is significantly but weakly correlated to all studied textural traits (hardness cycles 1 and 2), adhesive force, resilience, fracturability, and springiness ($r = 0.263$–0.480, p < .05).

The understanding of texture profile parameters and the correlations between color and texture require their correlation to chemical composition (sugars, moisture, fibers, and phenolic polymers), which are believed to contribute variably to the fruit texture profile. The lack of a correlation between sugars and texture in this study is explained by the restricted range of variability in total sugars [44]. Date flesh contains different levels of soluble and insoluble dietary fibers (ranging 10–17%), e.g. Tunisian varieties Deglet Noor and Allig contained *ca* 14 and 17% of total dietary fiber, respectively, with the ratio of soluble-to-insoluble fiber being 1:2 [45]. In another study, date fruits were reported to contain 0.7–7.0% cellulose, 1.28% hemicellulose, and 2% pectin [46]. Date fruit pericarp contains different phenolic compounds including polymeric tannins that are expected to contribute to date fruit color and texture [47,48]. Weak but significant Pearson's correlations were obtained between the levels of organic acids in date fruits and fruit color, e.g. the positive correlations between acetic acid and lightness ($r = 0.287$, $p < .05$) and acetic acid and yellow color ($r = 0.299$, p < .05) and the negative correlation between malic acid and red color ($r = -0.295$, p < .05) (Table 4). Organic acids may contribute to fruit color by acting as acid catalysts and buffering agents during Maillard, caramelization, and other pigmentation reactions. The contribution of organic acids to date fruit color deserves more in depth investigations.

4. Conclusions

The date varieties studied here presented considerable variation with reference to fruit size, color, texture, total soluble sugars, and major organic acids. A systematic understanding of the variability of date fruit morphology may enable the development of a reference classification system for commercial purposes. In literature, very limited studies have assessed the relationship between the sensory attributes, texture profile, and the physicochemical characteristics of date

Table 4
Pearson correlation coefficients among 23 quantitative traits in 21 date fruits[a].

Variables[b]	FW	FL	FD	FV	FLW	SW	SL	SD	SV	L	a
FW	**1**										
FL	**0.566**	**1**									
FD	**0.608**	0.174	**1**								
FV	**0.909**	**0.590**	**0.570**	**1**							
FLW	**0.998**	**0.551**	**0.608**	**0.907**	**1**						
SW	**0.271**	**0.372**	0.156	0.242	0.211	**1**					
SL	−0.055	**0.614**	−0.193	−0.016	−0.082	**0.400**	**1**				
SD	0.197	−0.034	**0.306**	0.165	0.174	**0.408**	0.055	**1**			
SV	0.147	0.217	0.161	0.120	0.099	**0.795**	**0.384**	**0.416**	**1**		
L	0.214	0.131	0.042	**0.259**	0.204	0.233	−0.198	0.023	0.077	**1**	
a	0.044	−0.062	0.023	0.044	0.032	0.192	**−0.256**	−0.014	0.063	**0.785**	**1**
b	0.177	0.066	0.029	0.235	0.168	0.202	**−0.251**	−0.089	0.093	**0.904**	**0.891**
HC1	0.171	**0.345**	0.018	0.158	0.158	0.226	0.066	−0.149	−0.009	0.192	**0.264**
HC2	−0.029	0.228	−0.102	0.071	−0.043	0.218	0.132	−0.019	0.131	**0.360**	**0.471**
ADF	0.175	0.051	0.075	0.128	0.173	0.065	−0.179	−0.113	−0.041	0.222	**0.480**
RES	**0.256**	0.155	**0.315**	0.230	**0.262**	−0.034	−0.079	−0.080	−0.086	0.209	**0.298**
FRA	0.238	0.241	0.142	**0.284**	0.240	0.031	0.017	0.195	0.002	0.231	**0.275**
SPR	−0.082	0.056	−0.010	0.025	−0.081	−0.034	0.021	−0.079	0.009	0.227	**0.263**
SUG	**0.285**	**0.286**	0.133	**0.282**	**0.291**	−0.039	0.170	−0.100	−0.001	0.034	0.092
MAL	0.009	0.108	0.146	0.043	0.017	−0.096	−0.143	−0.199	−0.062	−0.179	**−0.295**
ACE	**0.363**	0.229	−0.078	**0.325**	**0.361**	0.110	−0.035	−0.181	0.043	**0.287**	0.152
CIT	**−0.294**	−0.223	0.001	**−0.337**	**−0.299**	0.002	−0.001	0.141	0.031	−0.197	−0.029
TAC	0.152	0.173	0.071	0.154	0.158	−0.051	−0.166	**−0.278**	−0.051	−0.069	−0.223

Variables[b]	b	HC1	HC2	ADF	RES	FRA	SPR	SUG	MAL	ACE	CIT	TAC
FW												
FL												
FD												
FV												
FLW												
SW												
SL												
SD												
SV												
L												
a												
b	**1**											
HC1	**0.261**	**1**										
HC2	**0.454**	**0.661**	**1**									
ADF	**0.381**	**0.516**	**0.457**	**1**								
RES	0.229	**0.448**	0.106	**0.309**	**1**							
FRA	0.220	**0.375**	**0.526**	**0.362**	0.152	**1**						
SPR	**0.272**	**0.292**	**0.325**	0.166	**0.493**	0.142	**1**					
SUG	0.011	0.053	0.070	0.151	0.058	**0.259**	−0.047	**1**				
MAL	−0.168	0.055	−0.115	0.047	−0.078	−0.024	−0.045	−0.211	**1**			
ACE	**0.299**	−0.091	−0.072	0.196	−0.214	0.013	**−0.266**	0.219	−0.172	**1**		
CIT	−0.169	0.177	0.035	0.032	0.118	−0.022	0.058	−0.155	0.138	**−0.644**	**1**	
TAC	−0.045	0.025	−0.162	0.158	−0.205	−0.040	−0.205	−0.096	**0.863**	**0.275**	0.027	**1**

[a] Values in bold are different from 0 ($p < .05$).

[b] FW (fruit weight), FL (fruit length), FD (fruit mid diameter), FV (fruit volume), FLW (flesh weight), SW (seed weight), SL (seed length), SD (seed mid diameter), SV (seed volume), L (lightness), a (red color), b (yellow color), HC1 (hardness cycle 1), HC2 (hardness cycle 2), ADF (adhesive force), RES (resilience), FRA (fracturability), SUG (total reducing sugars), MAL (malic acid), ACE (acetic acid), CIT (citric acid), and TAC (total organic acids).

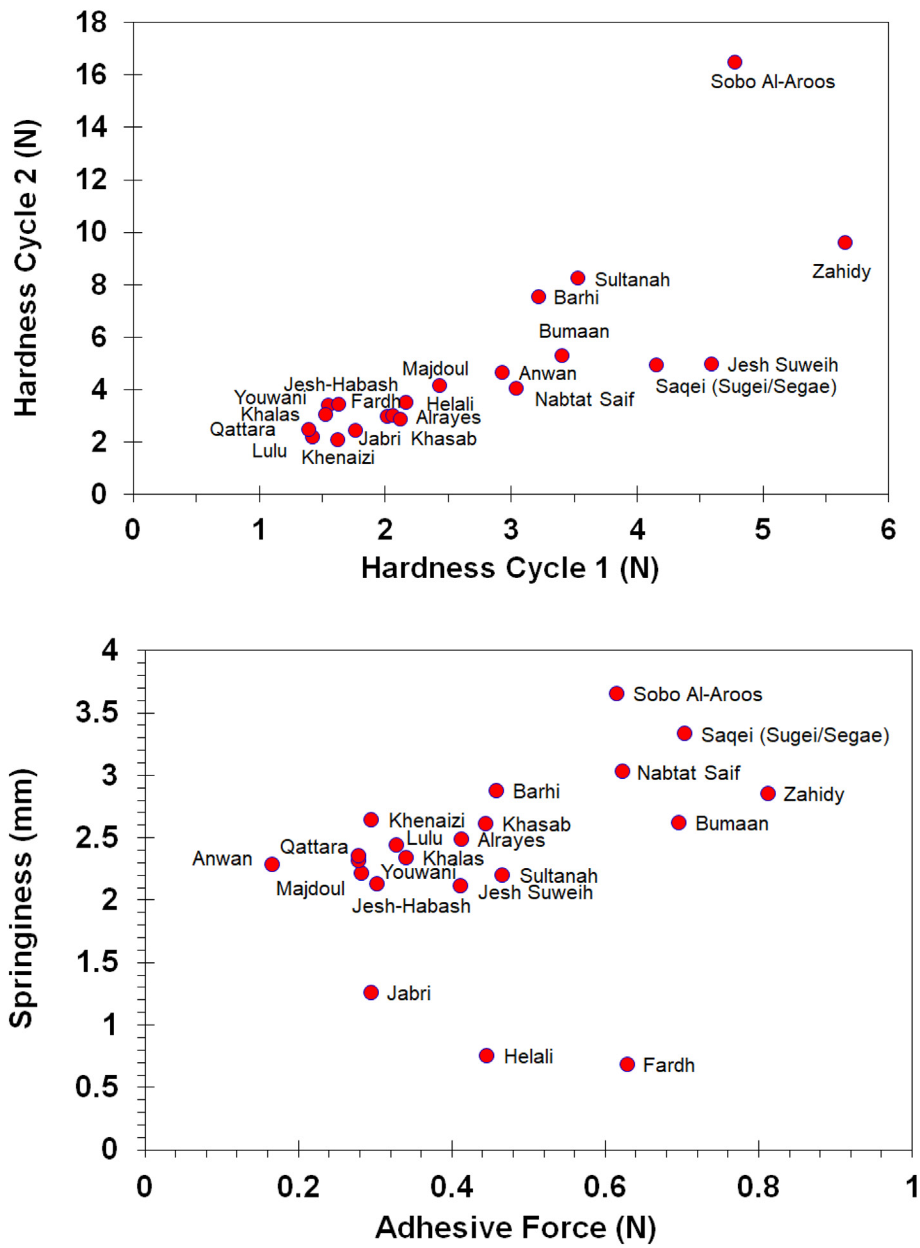

Fig. 3. Distribution of date fruits from 21 varieties with respect to fruit texture profile parameters (Hardness cycle 1 ∗ Hardness cycle 2, and Adhesive force ∗ Springiness).

fruits. A comprehensive analysis of the relationship between fruit physical properties, especially color and texture, and chemical constituents including moisture, sugars, organic acids, fibers, phenolic compounds, and other pigments is highly needed. The range of fruits may also include soft and dry fruit types from other regions.

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