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Quality traits of date palm fruits in a center of origin and center of diversity

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Abstract

Multivariate statistical analyses procedures were employed in data reduction of six fruit qualitative traits in addition to economic value and a final score of fruit quality, scored at the "*tamr*" fruit ripening stage of 203 date palm cultivars grown in 20 ecogeographical regions in six countries in the Arabian Peninsula. Phenotypic diversity indices varied tremendously among (0.885 to 1.122) and within (0.086 to 0.998) countries. These cultivars represent a complex gene pool within which historical movements of germplasm, recent introductions and human selection are shaping their genetic structure. The relatively low amount of variation (49%) explained by the first three principal components, and the portion of total diversity (0.761) partitioned among ecogeographical regions (32%), among populations (45%) and among cultivars (23%) indicate the presence of a highly diverse germplasm among and within countries. Discriminant analysis correctly assigned 55 to 88% of the germplasm to its country of origin; fruit color, ripening and shape provided the basis for this level of discrimination. Anthropogenic factors were reflected on the number of traits forming two-, three- or four-trait log-linear models for each country. However, fruit color, shape, size and ripening and their interactions predominantly reflected differences in consumer preferences in these countries. "Hot spots" were identified in some ecogeographical regions where unique variants of quality traits are found with high frequencies.

Key words: Date palm, *Phoenix dactylifera*, diversity, fruit quality, Arabian Peninsula.

Introduction

Date palm *(Phoenix dactylifera*) cultivation is centered in a rainless belt of the deserts south of the Mediterranean Sea and in the southern fringes of the Middle East, from south Iran in the east to the Atlantic coast of North Africa in the west. All over these hot deserts, a date palm oasis still is a welcome sight, where water and shade are available, and the sugar-rich fruits (60-70% sugar, mainly glucose and fructose) serve as an important food[1].

Countries in the Arabian Peninsula are both part of the center of origin and constitute a major part of the center of diversity of date palms[2]; they are the home to the world's highest production and consumption of dates[3]. Date palm trees were, and still are, integral components of the farming systems in arid and semi-arid regions, especially in the oases of the Middle East whether in small farm units or as large scale plantations[4]. Most date plantations are intercropped with vegetables, cereals or fodder crops in the first few years and subsequently with low growing fruit trees and grapevines. The tremendous advantage of the date palm tree is its resilience, its long term productivity, and its multipurpose attributes[1]. The fruits, depending upon the cultivar and its growing conditions vary in size, weight, color, shape, texture, softness and maturity, thus offering wide scope for selection[5].

Date palm trees are very productive and the fruit yield may be as high as 100-200 kg per tree per year, however, some researchers[3,4] reported yields as high as 400 kg/tree/year. Estimates vary as to the number of date palm cultivars in the world and in each major date-producing country. According to recent report[4] there are approximately some1,500 known date palm cultivars around the world. However, Bashah[6] quoted a number as high as 5,000 cultivars. Each cultivar is derived from a unique single seed, cloned and multiplied vegetatively[1]. More recently, however, an increasing number of date palm cultivars are being propagated through tissue culture[7]. Cultivars throughout the oases of the Middle East derive their importance from their local adaptation to climatic, edaphic and socio-economic conditions[8] and quality of their fruit[9]. Of the estimated 120 million date palms in the world, over two-thirds are in Arab countries[3]. Approximately, 800 different kinds of dates are available in the Arab countries; these account for 60% of the world's production[4,9]. In addition to 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[3,10].

Some of the desirable quality traits in the fruits of date palm include: glossy black fruit, late maturity, firm texture, moisture tolerance, superior quality and long fruitstalk[11]. Bedouin Arabs, who eat dates on regular basis, show an extremely low incidence rate of cancer and heart disease[3]. Dry or soft dates are eaten out-of-hand, or may be seeded and stuffed, or chopped and used in a great variety of ways: on cereal, in pudding, bread, cookies, ice cream, or candy bars. The fruit is a one-seeded berry consisting of a fleshy mesocarp covered by a thin pericarp; a hard endocarp surrounds the seed or pit[1]. The fruits are arranged on spikelets bearing 20-60 individual fruits, and the spikelets are attached to a stalk to form a bunch. The number of bunches per tree varies from 5 to 30, depending on the cultivar, nutrition, management and age of the tree[3].

Table 1. Number of date palm cultivars by country and region within six countries of the Arabian Peninsula.

Country	Regions within country	Number of cultivars: Ecogeographical region	Country
Bahrain	Manamah	4	
	Budiaya	3	
	Janabiya	13	
	Jesra	2	
			22
Kuwait		18	
			18
Oman	Dakhlia	6	
	Dhahra	10	
	Batinah	18	
	Shargia	5	
	Musandam	4	
			43
Qatara	Doha North	14	
	Doha South	12	
			26
Saudi Arabia	Western Region	15	
	Eastern Region	14	
	Central Region	16	
			45
United Arab Emirates	Ras Al Khaymah (RAK)	12	
	Al Dhaid	11	
	Masfoot	10	
	Western Region	6	
	Central Region	10	
			49
Total			203

The fruit is a high energy food of high sugar content, as well as a good source of iron and potassium[12]. Surplus dates are made into cubes, paste, spread, powder (date sugar), jam, jelly, juice, syrup or vinegar. Cull fruits are dehydrated, ground and mixed with grain to form a very nutritious stockfeed[13], whereas low quality dried dates are fed to camels and horses in the Sahara desert[14].

Threats to the millions of date palms in the Arabian Peninsula have been highlighted recently in a number of reports and workshops[4,9]. The red palm weevil [(*Rhynchophorus ferrugineus* (Olivier)] is threatening the region's multimillion dollar date industry and the very survival of the date palm trees. On the other hand, drought, due to a lengthy rainless period and drying up of many water wells, and as a consequence, increased water and soil salinity, are two serious threats to the expanding date palm plantations in most parts of the Arabian Peninsula. Due to economic and social factors, the diversity of date palm groves in most countries in the Arabian Peninsula[15] and North Africa[16] is declining and the composition of these groves as to the number of cultivars witnessed a sharp decline in recent years.

For a successful date palm industry, accurate estimates of genetic diversity and its partitioning, especially for fruit quality traits, within and among gene pools in this center of origin and center of diversity, are important considerations. This is particularly important for date palm due to its long generation time and, in particular, due to the associated costs of maintaining mature female date palms[17,18]. The objectives of this study were to characterize a representative sample of date palm cultivars as to the quality and economic value of their fruits, quantify available diversity in fruit quality and identify ecogeographical regions rich in one or more desirable variants of quality traits.

Materials and Methods

Field surveys were conducted in six countries of the Arabian Peninsula to collect data and information on date palm cultivars being grown throughout each country (Table 1) with the objective of characterizing cultivars as to the quality and economic value of their fruits. A questionnaire was developed by a panel of experts, pre-tested on 10 farms in the United Arab Emirates and, after verification it was distributed to cooperators in 20 ecogeographical regions in six countries in the Arabian Peninsula. Specific information on local names of date palm cultivars, their distribution, economic value and quality of their fruit were collected. A descriptor list of fruit shape, ripening, softness, quality, and consumption stage (Table 2) was provided in the questionnaire. Participants in each country and ecogeographical region within country were requested to classify typical fruits of each cultivar according to these descriptors. Records on a total of 203 date palm cultivars with unique names were collected and entered into a database by country, ecogeographical region within country and cultivars within ecogeographical regions (referred to hereafter as populations).

Table 2. Qualitative traits scored on fruit of 203 date palm cultivars grown in six countries in the Arabian Peninsula and their description.

Qualitative trait	Levels of qualitative trait and their description
Economic value	Commercial (C), Semi-commercial (SC), Non-commercial (NC)
Fruit color	Yellow (Y), Red (R), Light red (LR), Dark red (DR), Yellowish red (YR), Reddish Yellow (RY), Light yellow (LY), Yellow orange (YO).
Fruit shape	Ovate (O), Obovate (OB), Ovate elongated (OE), Obovate elongated (OBE), Cylindrical (C), Spherical (S), Global (G).
Fruit ripening	Early (E), Medium (M), Late (L).
Fruit size	Small (S), Medium (M), Big (B), Very big (VB).
Fruit softness	Dry (D), Semi-dry (SD), Soft (S).
Fruit quality	Low (L), Medium (M), Good (G), Excellent (E).
Consumption stage	Bisr (B), Tamr (T), Rutab (R), Tamr & Rutab (TR).

Table 3. Number of observed trait variants (NA), trait variant (TV) with the highest frequency (*f*), effective number of trait variants (NE) and estimates of Shannon's Information Index (I) for 6 quality traits, in addition to an overall quality score and economic value, scored on 203 date palm cultivars in six countries in the Arabian Peninsula.

Qualitative trait	NA	TV	*f*	NE	I
Economic value	3	Non- commercial	0.422	1.95	1.128
Fruit color	7	Yellow	0.495	3.25	1.508
Fruit shape	7	Ovate	0.389	3.69	1.510
Fruit ripening	3	Medium	0.622	1.18	0.947
Fruit size	4	Medium	0.57	2.42	1.060
Fruit softness	3	Semidry	0.503	2.23	0.875
Fruit quality	4	Good	0.438	2.86	1.138
Consumption stage	3	Tamr	0.578	2.08	0.820
Mean	4.25			2.71	1.123
Standard deviation					0.264

Data Analysis

The overall objective of the data analysis was to utilize fruit descriptors of date palm to assess the level of diversity in fruit quality traits, quantify intra- and inter-country diversity among cultivars, and utilize results of this analysis to formulate a regional project for the assessment of diversity of date palm genetic resources in the participating countries. Relative phenotypic frequencies of categorical traits, based on random fruit samples at the tamr maturity stage, of a minimum of 5 typical trees per cultivar were used to calculate a polymorphic diversity index (*I*) for each country and ecogeographical region within country as described by Zhang and Allard[19]. Total diversity (H_T) and its components for each country was calculated and the proportion due to each of ecogeographical regions within countries, populations within ecogeographical regions and cultivars within populations were calculated using frequencies of all categorical data[20]. Principal components analyses (PCA) were performed on the variance matrices[21] for germplasm from each country. Correlations between the first three PCs and the initial eight traits were calculated to aid in interpretation of the analysis. Discriminant functions for the whole collection were calculated to mathematically predict the country of origin based on fruit quality traits. The *a priori* probabilities were set to be proportional to the sample size from each country in relation to the whole collection[21]. Discriminant loadings and their univariate F-ratios were used to rank traits according to their discriminating power among countries. Frequency data per ecoregeographical region and country were used to calculate squared Euclidean distances between ecogeographical regions and between countries for subsequent unweighted pair group method with arithmetic average (UPGMA) clustering of all 20 ecogeographical regions and six countries[21]. The multi-trait organization of phenotypic variation within the whole germplasm collection and within germplasm form each country for all six fruit quality traits was analyzed with log-linear models. The most parsimonious models with best goodness-of-fit to the frequency tables of the observed data sets, were obtained by model selection procedures[22] based on the partitioning of likelihood-ratio statistics (G^2). Multiple regression analyses were used to identify quality traits that can be used to predict economic value in each country, and the trait variant of the highest frequency was identified for each trait and country of origin. Finally, "hot spots" for specific variants of quality traits were identified based on the frequency of these variants and the level of polymorphic variation within each ecogeographical region and country of origin. All statistical analyses were conducted using several modules in the statistical packages STATISTICA[23], unless otherwise specified.

Results

Polymorphism: Basic statistics for fruit quality traits, along with the economic value and a fruit quality grade are presented in Table 3. A large portion (42.2%) of date palm cultivars were classified as non-commercial with a high diversity index of 1.128. Not all trait variants contributed equally to the phenotypic diversity indices as suggested by the discrepancy between the number of variants (NA) and number of effective variants (NE) for each trait, and by the trait variant with the highest frequency. These frequencies indicate that cultivars producing medium size, semidry, yellow and ovate fruits consumed at the tamr stage of maturity are predominant in the date palm germplasm surveyed in this study.

The overall phenotypic diversity index averaged over the whole germplasm collection was 1.123 (Table 4) with a high coefficient of variation (23%) as indicated by the standard deviation. However, phenotypic diversity indices for germplasm varied tremendously among (1.122 in the UAE to 0.885 in Saudi Arabia) and within (0.086 in the Western region of the UAE to 0.998 in Masfoot in the UAE) countries. Nevertheless, the standard deviations associated with most phenotypic diversity index estimates were extremely high (>0.3) and approached, and sometimes exceeded, the value of the phenotypic diversity

Table 4. Within country polymorphism (mean and standard deviation, s.d. of Shannon's Information Index, I) based on frequencies of categorical data for six quality traits scored on203 date palm cultivars grown in six countries in the Arabian Peninsula.

Country	Regions within country	I Mean	s.d.
Bahrain	Manamah	0.443	0.396
	Budiaya	0.318	0.340
	Janabiya	0.834	0.454
	Jesra	0.260	0.358
	Mean	**0.866**	**0.438**
Kuwait		0.989	0.189
	Mean	**0.989**	**0.189**
Oman	Dakhlia	0.571	0.434
	Dhahra	0.686	0.260
	Batinah	0.898	0.353
	Shargia	0.516	0.455
	Musandam	0.454	0.286
	Mean	**0.962**	**0.302**
Qatar	Doha North	0.813	0.380
	Doha South	0.669	0.354
	Mean	**0.772**	**0.369**
Saudi Arabia	Western Region	0.848	0.202
	Eastern Region	0.789	0.253
	Central Region	0.775	0.265
	Mean	**0.885**	**0.127**
United Arab Emirates	RAK	0.975	0.386
	Al Dhaid	0.893	0.367
	Masfoot	0.998	0.413
	Western region	0.086	0.245
	Central Region	0.929	0.416
	Mean	**1.122**	**0.364**
Region		**1.123**	**0.263**

index (e.g., Budiaya and Jesra in Bahrain).

Mean separation among country-based phenotypic diversity indices (Tukey HSD for unequal number of observations) indicated that although there were highly polymorphic cultivars from UAE (I=1.122), Kuwait (0.989) and Oman (0.962), they were not significantly different from cultivars from Saudi Arabia (0.885), Bahrain (0.866) and Qatar (0.772) due to the high standard deviations associated with these estimates.

Genetic diversity analysis: Total diversity (H_T) was estimated as 0.761 for the whole region (Table 5), however, it ranged from 0.55 in Bahrain to 0.934 in the UAE. Components of total diversity based on the whole germplasm collection indicated that 32, 45 and 23% of H_T are partitioned among ecogeograhical regions, among populations and among cultivars, respectively. These ratios varied widely when total diversity for each country was partitioned into its hierarchical components. Kuwait was the only country to be considered as one ecogeographical region, with 40 and 60% of total diversity partitioned among populations and among cultivars, respectively. The portion of diversity component partitioned among ecogeographical regions was highest in Oman (48%), followed by UAE (45%), Saudi Arabia (42%), Bahrain (28%) and Qatar (21%). On the other hand, the portion of diversity component partitioned among populations was highest in Kuwait (40%), followed by UAE (30%), Bahrain (29%), Qatar (27%), Saudi Arabia (21%), and Oman (20%). Diversity among cultivars within populations, in most countries, accounted for >25% of total diversity, with Kuwait being the highest (60%), and UAE being the lowest (23%).

Principal components analysis: Six principal components were needed to explain 82.5% of total diversity in the whole germplasm collection; this is a quantitative indicator of the high level of diversity available for the quality traits in the whole germplasm collection. The first three principal components (Fig. 1) explained, on average, 49% of total variance in the whole germplasm collection, however, percent variance explained in germplasm from individual countries was 68% in Bahrain, 72% in Kuwait, 58% in Saudi Arabia, 56% in Oman, 71% in Qatar and 52% in UAE. When all germplasm was considered, fruit color (0.69) and fruit size (0.73) loaded high on PC1 which explained 18% of total variance. Fruit economic value (0.56), fruit ripening (0.51) and fruit softness (0.45) loaded high on PC2 which explained 18% of total variance, whereas fruit shape (-0.62) and fruit quality (0.75) loaded high on PC3 which explained 13% of total variance.

Visual comparisons among countries, based on trait loadings on PC1, PC2 and PC3 axis indicate that germplasm from almost each country has a unique pattern of trait association and loading on the first three PCs. However, relatively similar patterns were observed among germplasm from Bahrain, Kuwait and Qatar, on the one hand, and among germplasm from Oman, UAE, and to some extent Saudi Arabia, on the other.

A minimum of one (economic value, Oman) and a maximum of four traits (e.g., Qatar and Saudi Arabia) were associated in any one PC in this germplasm. Fruit color and shape were associated in one PC in germplasm from Bahrain, Qatar and UAE but not in the remaining countries. Similarly, fruit size and ripening were associated in one PC in germplasm from Bahrain, Saudi Arabia and UAE. Economic value loaded high on one PC with one or more traits; it was associated with fruit quality in Bahrain and Saudi Arabia; with fruit softness in Oman; with fruit shape, fruit size and fruit quality in Kuwait; with fruit color, fruit shape and fruit quality in Qatar; and with fruit quality in UAE.

Cluster analysis: UPGMA separated UAE germplasm from the rest at the maximum relative distance (100%) in the dendrogram (Fig 2). The remaining germplasm was separated at successive distances from the origin, with germplasm from Saudi Arabia joining UAE germplasm at 45% of maximum

Table 5. Partitioning of genetic diversity (GD) into its components at the regional and country levels based on eight qualitative traits scored on fruits of 203 date palm cultivars in the Arabian Peninsula.

GD components	Bahrain	Kuwait	Oman	Qatar	Saudi Arabia	UAE	Region
Total diversity	0.550	0.760	0.875	0.623	0.823	0.934	0.761
Ecogeographical regions %	28	0.0	48	21	42	45	32
Populations %	29	40	20	27	21	30	45
Cultivars %	42	60	32	52	37	25	23

Table 6. Classification matrix (%) of 203 date palm cultivars grown in six countries of the Arabian Peninsula and based on discriminant analysis of 8 qualitative traits.

Country	**Bahrain**	**Kuwait**	**Oman**	**Qatar**	**Saudi Arabia**	**United Arab Emirates**
			Percent correct classification (diagonal in bold)			
Bahrain	**63.0**	0.0	17.0	0.0	8.0	12.0
Kuwait	0.0	**88.0**	6.0	0.0	6.0	0.0
Oman	4.0	2.0	**75.0**	2.0	10.0	7.0
Qatar	0.0	0.0	25.0	**55.0**	7.0	13.0
Saudi Arabia	5.0	2.0	18.0	5.0	**70.0**	0.0
United Arab Emirates	0.0	0.0	15.0	2.0	4.0	**79.0**

Table 7. Log-linear models describing non-random association of quality traits scored on fruits of 203 date palm cultivars from six countries in the Arabian Peninsula.

Country	**Two-trait model**	**Three-trait model**	**Four-trait model**
All	[Color*Shape]; [Color*Ripening*Size* Softness]		[Color*Shape*Ripening* Softness]; [Ripening*Size]
Bahrain	[Color*Shape]		
Kuwait	[Color*Shape]; [Color*Size]		
Oman	[Color*Shape]; [Ripening*Softness]		
Qatar	[Color*Shape]; [Color*Ripening]; [Shape*Ripening]		
Saudi Arabia	[Color*Shape]; [Color*Ripening]		
United Arab Emirates	[Ripening*Softness]	[Color*Ripening *Softness]	[Color*Shape*Ripening*Size]; [Color*Ripening*Size*Softness]

Table 8. Predictors of fruit economic value for date palm cultivars (R^2=0.655), along with trait variant of highest frequency (*f*) in each of six countries in the Arabian Peninsula.

Predictor traits	**Bahrain**	**Kuwait**	**Oman**	**Qatar**	**Saudi Arabia**	**United Arab Emirates**
Fruit color	Dark red	Light red	Red	Yellow	Yellow	Yellow
	61%	55%	58%	64%	70%	70%
Fruit softness	Soft	Soft	Semi-dry	Soft	Semi-dry	Dry & Semi-dry
	100%	72%	72%	60%	60%	44, 49%
Consumption stage	Rutab	Rutab,Tamr	Rutab	Rutab	Rutab, Tamr	Rutab, Tamr
	78%	38, 33%	70.5%	100%	47, 45%	45, 53%

distance, followed by germplasm from Kuwait (30%) and Qatar (5%). Germplasm from Bahrain and Oman were the last to cluster and were closest to each other. A cluster model (Fig. 2) based on squared Euclidean distances separated the six countries into four significantly different clusters at the 20% linkage distance. Germplasm from three countries (Bahrain, Qatar and Oman) clustered in one, whereas germplasm from Kuwait, Saudi Arabia and UAE each formed a single cluster.

An intricate hierarchical nested cluster of ecogeographical regions was revealed by the UPGMA clustering procedure indicating that the relationships among germplasm from different ecogeographical regions are complex (Fig. 3). Except for Kuwait which was considered as one ecogeographical region, ecogeographical regions from the remaining countries displayed different patterns of clustering within and among countries.

Germpalsm from the Manamah ecogeographical region was totally separated from the remaining three ecogeographical regions in Bahrain; it differed drastically from the rest by having high frequency (50%) of the unique global fruit shape. In addition, germplasm from Janabiya was closer to germplasm from Qatar, a geographically close country to Bahrain. Germplasm from three ecogeographical regions in Oman (Dhahrah, Batinah and Musandam), geographically closer to the western part of the UAE than to other parts of Oman, clustered closer to germplasm from the Western and Central ecogeographical regions in the UAE. The remaining two ecogeographical regions in Oman (Dakhlia and Shargia) clustered close to the germplasm from the western part of Saudi Arabia. A cluster model (Fig. 3) based on squared Euclidean distances separated the 20 ecogeographical regions into 11 significantly different clusters at the 20% linkage distance. A maximum of three ecogeographical regions from one (e.g., Saudi Arabia) or two (e.g., Bahrain and Qatar) countries were clustered in one, whereas ecogeographical regions from the same country (e.g., Oman and UAE) were clustered in two

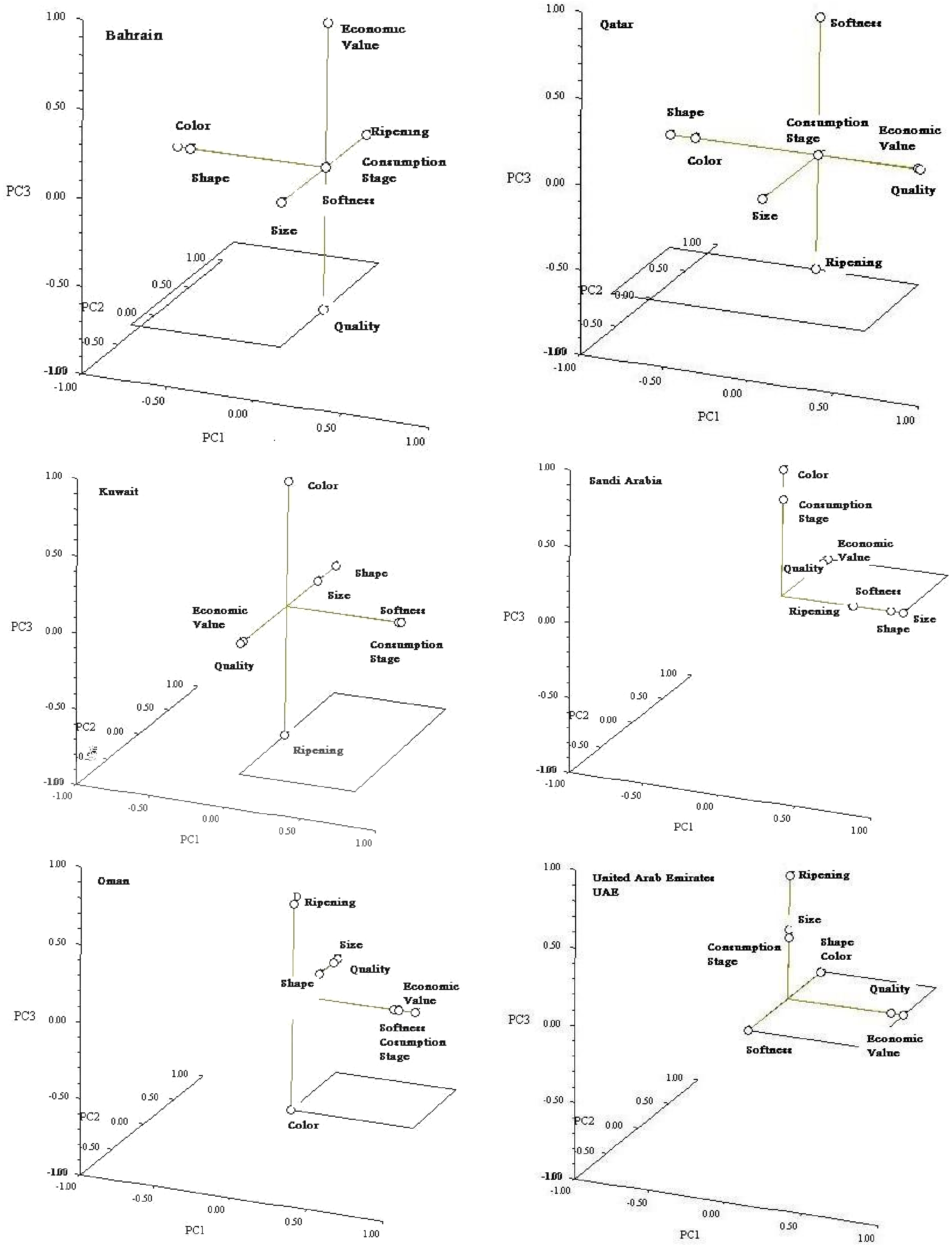

Figure 1. Quality trait loadings on the first three principal components for date palm germplasm from six countries in the Arabian Peninsula.

significantly different clusters.

Discriminant analysis: Linear discriminant function analysis was employed to test the hypotheses that the country means of the six fruit quality traits for the germplasm from all six countries are equal. Percent correct classifications of the country of origin, based on classification functions, ranged from 55% in germplasm from Qatar to 88% for the germplasm from Kuwait (Table 6). Consequently, misclassification of cultivars ranged from 12 to 45% in germplasm from Kuwait and Qatar, respectively. The highest portion of misclassified germplasm (25%) from Qatar was classified as part of the Omani germplasm.

Discriminant analysis correctly predicted country of origin of date palm cultivars (55 to 88%) using a small number of variables measured on numerous individual plants, with an overall ratio of 1 trait to 25.5 date palm cultivars. Discriminant analysis was useful in identifying the most influential traits and their discriminating power. This is indicated by the discriminant loading (DL) and the univariate F-ratios[21], the joint ranking of which suggests that fruit color (DL= 0.89, F=22.6), fruit ripening (DL=0.67, F=12.8), fruit shape (DL=0.62, F=10.9), fruit softness (DL=0.58, F=10.4, fruit size (DL=0.58, F=9.2) and consumption stage (DL=0.42, F=9.6), in decreasing order, provided the basis for discrimination among fruits of date palm cultivars across the region. All F-ratios were highly ($P<0.01$) significant.

Log-linear models: Two log-linear models described quality trait associations of date palm cultivars for the whole region (Table 7). The first was a two-term, two-trait model and the second was a two-term, four-trait model. Fruit color, shape, ripening and size were common to both models, whereas fruit softness appeared in the four-trait model.

Log-linear models for individual countries shared four quality traits, however, in different combinations. The most interactive trait was fruit color, with 11 trait combinations, followed in decreasing order by fruit ripening (eight combinations), fruit shape (six combinations), fruit softness (four combinations) and fruit size (three combinations). A two-term, two-trait log-linear model fully described fruit quality in all countries, except for Bahrain (one-term, two-trait model) and UAE (one-term, two trait model, one-term, three-trait model and two-term, four-trait model).

The pronounced non-random associations among two or more traits in the whole collection and in germplasm from each country may reflect either farmers' conscious selection, or an association between phenotype and utility of the fruit (i.e., ripening, softness, consumption stage).

Prediction of economic value: Variation in three quality traits (fruit color, softness and consumption stage) explained 65.5% of the variability in the economic value for date palm cultivars in this study (Table 8). However, trait variants with the highest frequency for each predictor trait varied among countries, thus reflecting consumer preferences in each country. Red fruit color and its variants (i.e., light or dark) predominate in germplasm from Bahrain, Kuwait and Oman, whereas yellow fruit color predominates in germplasm from Qatar, Saudi Arabia and UAE. The soft fruit variant in germplasm from each of Bahrain, Kuwait and Qatar, and the dry or semidry fruit variant in germplasm from Oman, Saudi Arabia and UAE were most predominant. A large portion of the fruit is consumed at the rutab stage in each of Qatar (100%), Bahrain (78%) and Oman (70.5%), whereas fruit is consumed almost equally at the rutab and tamr stages in each of Kuwait, Saudi Arabia and UAE.

"Hot spots" for specific quality variants: Ecogeographical regions that can be described as "hot spots" for certain variants of quality traits are presented in Table 9. Unique variants of quality traits are present with high frequencies in certain ecogeographical regions (e.g., semi-dry fruit in Shargia, Oman, and red fruit color in Western region, Saudi Arabia) but not in others, whereas a highly desirable trait variant (e.g., ovate fruit shape in seven ecogeographical regions in six countries) is found in several ecogeographical regions with moderate frequencies. The high frequency of global fruit shape (50%) in Manamah is the predominant variant notwithstanding the high level of polymorphism (I=1.039) for this trait in Bahrain. Similarly, large fruit size, characteristic of the cultivar Anbarah[9] from Medina (Western region, Saudi Arabia) is a unique variant found with a relatively low frequency (28.9%) and was associated with a high polymorphic index (I=1.059).

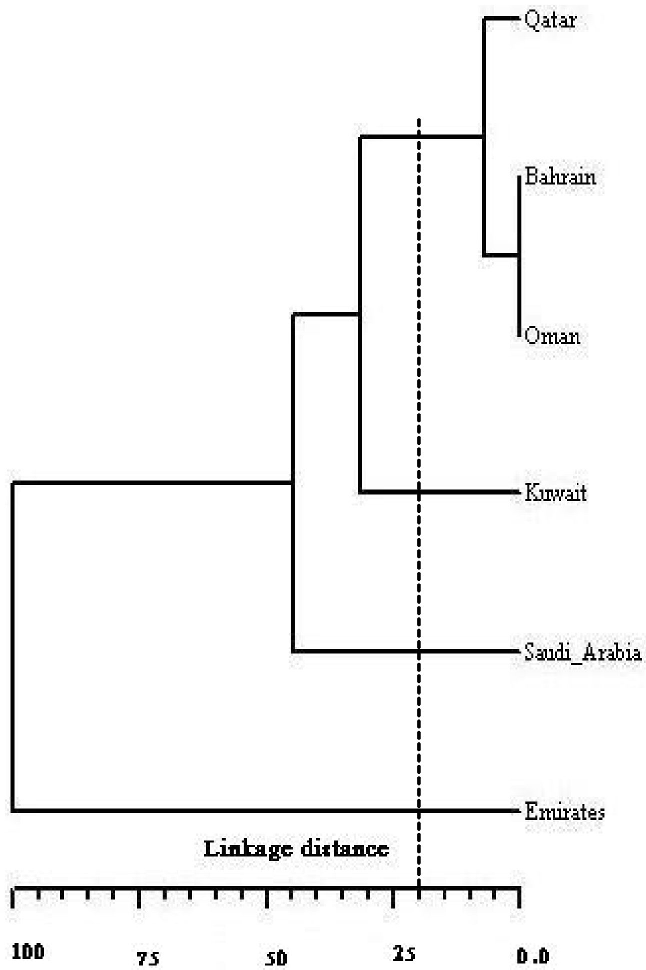

Figure 2. UPGMA clustering of date palm germplasm from six countries in the Arabian Penensula. The dashed line indicates the linkage distance at which differences among clusters are significant ($P<0.05$).

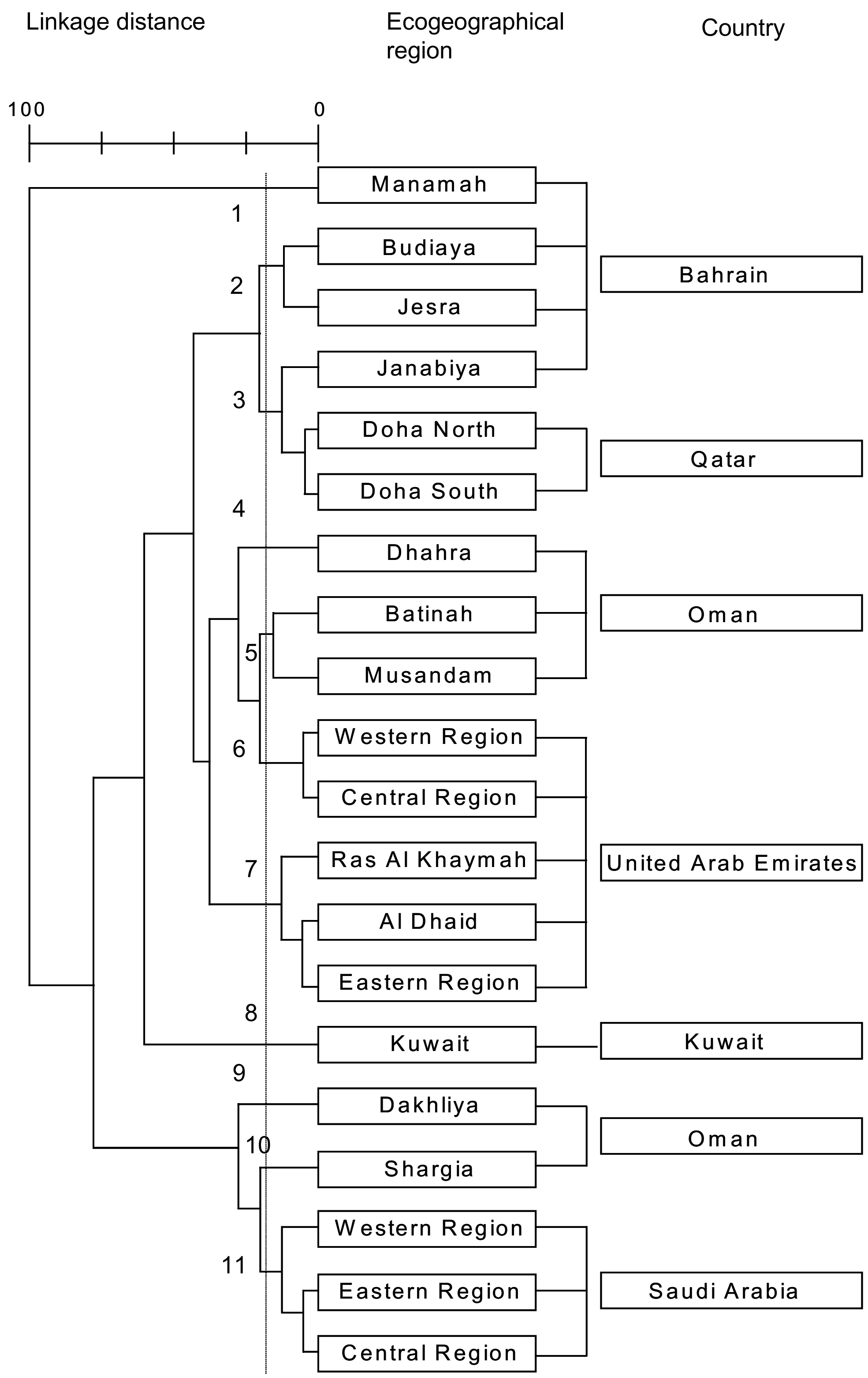

Figure 3. UPGMA clustering of date palm germplasm from 20 ecogeographical regions in six countries in the Arabian Penensula. The dashed line indicates the linkage distance at which differences among clusters are significant (P<0.05).

Table 9. Quality traits with the highest frequency (*f*) and their Shannon's Information Index (I) values for date palm cultivars grown in six countries in the Arabian Peninsula.

Country	Eco-geographical region	Quality trait with highest frequency	*f*	I
Bahrain	Manamah	Global fruit shape	0.50	1.039
	Budiaya	Ovate fruit shape	0.667	0.637
	Janabiya	Late ripening fruit	0.357	1.272
	Jesra	Ovate-elongated fruit	0.500	0.693
Kuwait		Ovate fruit shape	0.440	1.215
Oman	Dakhlia	Medium/late fruit ripening	0.375 each	1.082
	Dhahra	Ovate fruit shape	0.539	1.157
	Batinah	Ovate fruit shape	0.372	1.711
	Shargia	Semi-dry fruit	1.000	0.000
	Musandam	Semi-dry fruit	0.750	0.562
Qatar	Doha North	Yellow fruit color	0.688	1.037
	Doha South	Ovate-elongate fruit shape	0.667	0.824
Saudi Arabia	Western	Very big fruit size	0.286	1.059
	Eastern	Ovate/ Ovate-elongate fruit	0.39 each	1.223
	Central	Late ripening fruit	0.350	1.094
United Arab Emirate	RAK	Light-yellow fruit color	0.334	1.724
	Al Dhaid	Ovate fruit shape	0.400	1.255
	Masfoot	Yellow fruit color	0.360	1.507
	Western	Red fruit color	1.000	0.000
	Central	Medium fruit size	0.607	1.061

Discussion

Traditional date palm production in the Arabian Peninsula[9,10] and North Africa[7], two major date palm production regions, is based on thousands of distinct cultivars exhibiting a wide range of adaptation, growth habits and fruit characteristics[24,25]. Fruit morphology and quality traits of date palm were the subject of descriptive[5] and often incomplete studies[25] in countries of the Middle East and North Africa. However, more recent studies in the United Arab Emirates[12] described chemical composition of a limited number of date palm cultivars as influenced by the ripening stage and other studies in North Africa[24] presented multivariate fruit descriptors for a small number of cultivars. Varietal differences as to fruit ripening and quality are largely unknown or not documented for the large number of date palm cultivars in the Arabian Peninsula. This study was the first attempt at quantifying the phenotypic variation and partition genetic diversity into its components for a representative sample of date palm cultivars from the Arabian Peninsula.

The survey and study were undertaken to evaluate the extent and range of genetic diversity available for fruit quality traits in germplasm of 203 date palm cultivars, *Phoenix dactylifera* from six countries in the Arabian Peninsula. Reports are conflicting as to the number of date palm trees and varieties in each country in the Arabian Peninsula. Al-Farisi[13] reported that Oman has 12 million trees, 7.3 million of which are fruit-bearing. Moreover, he indicated that there are 230 date palm varieties 20 of which are grown commercially. Bashah[6] reported a total of 450 date palm cultivars in Saudi Arabia. However, the Medina date market, alone contains about 150 varieties, the most popular and most expensive of which is Anbarah[9]. The United Arab Emirates, being the lead country in date production, was reported[10] to have 40 million date palm trees and a minimum of 200 cultivars, 68 of which are the most important commercially.

At a regional level, low quality dates constitute 42.2% of all cultivars, however, they occupy about 60% of total area planted to date palm in Oman[13] and almost none in Kuwait[4]. These dates are of poor quality, small in size and unsuitable for human consumption. However, the cost of maintaining and irrigating these large numbers of un-productive trees is high[15]. Nevertheless, some of these non-commercial varieties are high in sugar content which makes them suitable for industrial uses for a wide range of products[9,13].

The high levels of polymorphism displayed by germplasm form individual countries and ecogeographical regions within countries were associated with relatively high values of standard deviations (e.g., in Budiaya, Bahrain and western region, UAE), hence the low level of statistical significance among countries and among ecogeographical regions. It is postulated[7,17] that the long-term intra- and inter-country selection for specific traits resulted in the highly diverse germplasm in this center of origin and center of diversity of date palm.

The overall partitioning of genetic diversity based on fruit traits suggests that the surveyed date palm cultivars represent a complex gene pool within which historical movement of germplasm, recent introductions and human selection are shaping the genetic structure. The date palm, as a clonally-propagated perennial crop is unique in that it is composed of genetically discrete clones representing cultivars without the benefits of a dynamic mutation-recombination system[1]. Although most variation at the regional level (45%, Table 5) was found to reside among populations, however, substantial differences were found in genetic diversity components among and within populations. In addition, a substantial portion of genetic diversity was found within populations in at least two countries (e.g., 60% in Kuwait and 52% in Qatar), thus confirming an important genetic characteristic of clonally-propagated perennial crops[17]. The data in Table 5 confirms the suggestion[17] that the strong artificial selection and clonal propagation of perennials such like date palms, greatly alters their original genetic structure.

Results of the multivariate analyses, including PC analysis (Fig. 1), the different groupings associated on the country- (Fig. 2) and the ecogeographically-based (Fig. 3) UPGMA tree, the relatively low (55-88%) correct classification of germplasm (Table 6) and the different log-linear models describing trait association in germplasm from individual countries (Table 7) complement each other and confirm the complex multidimensional nature of relationships among different quality traits among and within countries.

The first three principal components accounted for only 49%of total variation in the whole germplasm collection, and the first six principal components were needed to account for 82.5% of total variation indicating the high level of variation in the germplasm[17]. The nature and level of organization of genetic diversity in this germplasm are graphically displayed on the agroecologically-based UPGMA tree (Fig. 3). We identified 11 clusters (numbered at the dotted line, Fig. 3) significantly different from each other at 20% of the maximum linkage distance. This suggests that a sizable amount of variation is available among populations within these clustered ecogeographical regions[17,24].

Anthropogenic factors were reflected on the number of traits forming two-, three- or four-trait log-linear models (Table 7). Undoubtedly, fruit color, shape and ripening stage and their two- and three-way interactions predominantly reflect differences in consumer preferences in different countries[9,10]. Additionally, the long-term intra- and inter-country selection[6,18] for specific fruit quality traits is reflected on the level of polymorphism and the portion of genetic diversity apportioned in the regional, ecogeographical, population and cultivar hierarchy.

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