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Classifying Criteria for Major Fruit Traits in *Prunus persica* and Correlation Analyses Among the Traits

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Abstract

To develop classification criteria for major fruit traits of peaches and nectarines (*P. persica* [L.] Batsch.), fruits from more than 800 accessions and 700 cultivars were analyzed for several quantitative fruit traits. Each trait was then converted to five categories spanning the range observed for fruit development period, fruit mass, soluble solids content, soluble sugars, titratable acidity, Vitamin C content and the ratio of soluble solids to titratable acidity. Correlations among these traits were also evaluated. Fruit development period was correlated with fruit mass, concentration of soluble solids, soluble sugars, titratable acidity and Vitamin C content. Positive correlations were also found between fruit mass and Vitamin C, soluble solids content and soluble sugars, Vitamin C and the ratio of soluble solids to titratable acidity. These results, obtained from a large number of accessions with different characteristics, measured in multiple locations and multiple years, can effectively provide researchers with practical, universal, valuable information for breeding and cultivation of peaches and nectarines.

Peaches and nectarines (*P. persica* [L.] Batsch.), native to China, have been cultivated for at least three to four thousand years (22). From its center of origin, cultivation has been extended into many other countries in temperate and subtropical zones with commercial production between 30º and 45º North and South latitudes (14). In 2006, the total area and production of cultivars in *P. persica* in the world reached 1,435,909 ha and 17.1 million MT, respectively. The top three countries ranked by area and production were China, Italy and Spain (7). More than 5000 cultivars exist (1), of which 1000 or so are in China (22) and about 700 are in the USA (20).

In China, germplasm preservation of peaches and nectarines is the task of three national repositories, with many smaller ones in local areas. Many fruit traits have been recorded for years, but acceptable scales to be used for classifying fruit criteria have not been established. The International Institute of Plant Genetic Resources (IPGRI) published an evaluation system for peach and nectarine germplasm in the 1980s (19), and "descriptive symbols of pomological germplasm", including those for peaches and nectarines, were published in 1990 in China (17). The former listed 3, 5, 7 and 9 as classes but without giving any corresponding values for quantities, and the latter barely mentioned classification scales. Neither gave complete information about fruit traits of peaches and nectarines. Good criteria should cover different geographic areas and large numbers of accessions/cultivars to guarantee spanning the extensive range of quantitative fruit traits in peach.

Correlations among fruit yield, total soluble solids, total acidity, and the mass of fruit, pit, and kernel were studied in apricot (2). In peach, studies have shown correlations between total acidity and malic, citric and quinic acid contents, and also glucose and fructose contents (5); sucrose, sorbitol and quinic acid contents (23); the concentrations of sucrose and malic acid with citric acid concentration, flesh firmness and the concentration of reducing sugars (10); soluble sugars and FM (fruit mass) (11); FDP (fruit development period) and date of ripening, fruit blush, soluble sugars and TA (titratable acidity) (21); soluble sugars, Vc (Vitamin C) and TA (12). Some important traits like SSC (soluble solids concentration), and the ratio of SSC to TA have not been stud-

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ied, and correlations amongst several of these traits have not yet been completely analyzed. Besides the above-mentioned factors, there are unresolved problems such as contradictions in the literature, and the number of genotypes used for past analyses was generally below 200 accessions or 100 cultivars, except for Guo et al. (12) who studied 253 accessions. Moreover, all these experiments used data only from one site, so it is difficult to apply the results to numerous cultivars and geographic locations.

In order to address these questions, we developed quantitative classification criteria by analyzing FDP, FM, SSC, soluble sugars, TA, Vc, and ratio of SSC to TA, and analyzed relationships among the traits using data from more than 800 accessions and 700 cultivars of peaches and nectarines from different geographical locations. The objective was to provide universal, practical criteria and correlation analyses for guiding breeding and cultivation of peaches and nectarines of numerous genotypes in diverse environments.

Materials and Methods

The experiment used 837 accessions of peaches and nectarines obtained primarily from three national repositories and several other locations in China as recorded previously (8, 9). Of these, 546 accessions were originally from China and 291 were from other countries. The genotypes included: 1) various cultivar groups [crisp peach, honey peach, juicy peach, yellow peach, flat peach, nectarine]; 2) different ecological types of cultivars originating in Northern China, Central China and Europe; and 3) types with different qualitative traits such as presence/absence of pubescence, skin and flesh color, melting/non-melting flesh, freestone/ clingstone pits and pollen viability. These data for the 837 genotypes are available as supplementary information in an Excel file from the author upon request by e-mail (chenzp@rose.whiob.ac.cn or chenzp2000@hotmail.com).

All accessions were managed according to local recommendations for the regions. FDP was recorded as the period from blossom to fruit maturity. FM was measured by weight, SSC by refractometer, soluble sugars by the Tollens reagent method (13), TA by titration (15) and Vc by the 2,6-dichloro-indophenol titration method (4). Ten to twenty representative fruits were randomly collected from 3 to 4 trees to conduct analyses for each accession. The values reported for each variable are the averages of data measured in two or three years. The data were stored and processed using Microsoft Excel and edited into a data bank of *P. persica* germplasm (8, 9). FDP, FM and SSC were measured on 837 accessions, soluble sugars and TA on 826 accessions, and Vc on 821 accessions. The measured values were then divided into fifteen sections [except for TA (20 sections) and SSC to TA ratio (13 sections)], with reference to Liu et al. (16). Classes were calculated from values between the maximum and minimum divided by the number of sections. Besides the six traits already mentioned, the ratio of SSC to TA was also analyzed. To obtain reliable classifying criteria for major fruit traits, we combined the middle sections (with enormous numbers of samples) to define the intermediate values for the categories. Exceptions were made for TA and ratio of SSC to TA due to a severely asymmetrical distribution of data for these traits. Correlations among fruit traits were analyzed in Microsoft Excel, and significance was determined by comparing calculated correlation coefficients with standard values (16).

Results and Discussion

Of the 837 accessions, 375 representing 159 cultivars were grown in two or three locations. When comparing data for accessions of the same cultivar in different locations, we observed that qualitative traits such as shape, flesh color, melting/nonmelting flesh, adherence of pit to flesh and pollen viability were consistent, but data for quantitative traits like FM, SSC, soluble sugars, TA, Vc displayed valuable variation (data available from author as a supplementary Excel file). These facts affirmed that our approach of using data from numerous accessions and various locations to make universal criteria is likely to eliminate errors or bias introduced by using only a few accessions growing in a single location.

Values for FDP, FM and SSC of the 837 accessions were divided into 15 individual sections, following which we determined the classifying criteria according to both the middle sections and the range observed for each trait. Five categories were designated to cover the 15 sections of the frequencies; each category contained three sections (Tables 1 to 3). The three highest frequencies were considered as "intermediate" on the scale. For soluble sugars and Vc, the methodology was the same, but the number of accessions differed (Tables 4 and 5).

For FDP, the three highest frequencies, at 15.29%, 13.38% and 13.02% of the 837 accessions sampled, were in the sections of 101-110 d, 111-120 d and 121-130 d, respectively (Fig. 1), so the intermediate category was set as 101-130 d, and the other four categories were set as noted in Table 1. Likewise, for FM, the three highest frequencies (at 16.23%, 22.43% and 18.85%) were in the sections of 90.1-110.0 g, 110.1-130.0 g and 130.1-150.0 g, respectively (Fig. 2), so the "intermediate" category was set as 90.1-150.0 g, and the others were established as noted in Table 2. For SSC, the three highest frequencies, at 18.64%, 21.63% and 15.05% of the accessions, were in the sections of 10.1-11.0%, 11.1-12.0% and 12.1-13.0%, respectively (Fig. 3). Hence, the "intermediate" category was 10.1% -13.0%, and the other four were set as shown in Table 3.

Although the data for soluble sugars were divided into fifteen sections, only 11 sections contained accessions, one of which had only a single accession. Therefore, the five scales were chosen with reference to ten sections, with each category containing two sections; the fifth category contained the extra section with only one accession in it. The two intermediate frequencies for soluble sugars, at 23.46% and 21.04% of the accessions, were found in the sections 8.1-9.0% and 9.1-10.0%, respectively (Fig. 4), so the intermediate category was set at 8.1%-10.0%, and the other four as noted in Table 4.

For Vc, the three highest frequencies (at 26.03%, 19.83% and 18.01% of accessions) contained 6.01-8.00 mg/100g, 8.01-10.00 mg/100g and 10.01-12.00 mg/100g, respectively (Fig. 5). "Intermediate" was set at 6.01 mg/100g -10.00 mg/100g, and the other four categories as in Table 5.

The three highest frequencies for TA (at

Table 1. Classification categories, the percentage frequency distribution among the 837 accessions, and description for fruit development period (FDP).

Category	FDP (days)	Frequency (%)	Description
1	≤ 70	4.78	Extremely short
2	71-100	32.98	Short
3	101-130	41.70	Intermediate
4	131-160	19.48	Long
5	> 160	1.20	Extremely long

Table 2. Classification categories, the percentage frequency distribution among the 837 accessions, and description for fruit mass.

Category	Fruit mass (g)	Frequency (%)	Description
1	≤ 30	0.11	Extremely small
2	30.1-90	14.08	Small
3	90.1-150	57.51	Intermediate
4	150.1-210	22.43	Large
5	> 210	5.85	Extremely large

Table 3. Classification categories, the percentage frequency distribution among the 837 accessions, and description for soluble solids content (SSC).

Category	SSC (%)	Frequency (%)	Description
1	≤ 7.0	0.36	Extremely low
2	7.1-10.0	21.98	Low
3	10.1-13.0	55.32	Intermediate
4	13.1-16.0	20.19	High
5	> 16.0	2.15	Extremely high

Table 4. Classification categories, the percentage frequency distribution among the 826 accessions, and description for soluble sugars.

Category	Soluble sugars (%)	Frequency (%)	Description
1	≤ 6.0	3.87	Extremely low
2	6.1-8.0	33.86	Low
3	8.1-10.0	44.50	Intermediate
4	10.1-12.0	15.36	High
5	> 12.0	2.42	Extremely high

Table 5. Classification categories, the percentage frequency distribution among the 821 accessions, and description for Vitamin C.

Category	Vitamin C (mg/100 g)	Frequency (%)	Description
1	≤ 2.0	0.12	Extremely low
2	2.01-6.00	14.96	Low
3	6.01-10.00	45.86	Intermediate
4	10.01-14.00	28.59	High
5	> 14.00	10.46	Extremely high

18.86%, 13.91% and 13.06% of accessions) were in the sections of 0.20-0.30%, 0.51-0.60% and 0.61-0.70%, respectively (Fig 6). For this variable, the 826 accessions were divided into 20 sections. A severely asymmetrical distribution of data was observed, which may be attributable to past selection of cultivars for sweet flavor (with less acidity) and canned peaches (with higher acidity), and perhaps preference differences between Asian and Western people. The two highest frequencies, with 0.51%-0.70%, were considered as "intermediate" on the scale (Table 6).

For the ratio of SSC to TA, 821 accessions were analyzed. The three highest frequencies at (17.52%, 34.55% and 13.99%) occurred in the sections 5.01-15.00, 15.01-25.00 and 25.01-35.00, respectively (Fig. 7). These accessions were divided into 13 sections because of the biased distribution of TA. Values from 35.1 to 55.0 were considered as "intermediate" (Table 7). Although the ratio of SSC to TA is associated with each individual factor, it is greatly affected by the biased distribution of TA.

It is quite valid to establish fruit classification criteria based on data collected from more than 800 accessions and more than 700 cultivars of peaches and nectarines from more than three places. The intermediate categories that we have determined for FDP, FM, SSC, soluble sugars and Vc contained 40-60% of

Table 6. Classification categories, the percentage frequency distribution among the 826 accessions, and description for titratable acidity (TA).

Category	TA (%)	Frequency (%)	Description
1	≤ 0.30	31.32	Extremely low
2	0.31-0.50	22.01	Low
3	0.51-0.70	26.97	Intermediate
4	0.71-0.90	11.73	High
5	> 0.90	7.98	Extremely high

Table 7. Classification categories, the percentage frequency distribution among the 821 accessions, and description for ratio of soluble solids content (SSC) to titratable acidity (TA).

Category	SSC:TA ratio	Frequency (%)	Description
1	≤ 15.0	17.52	Extremely low
2	15.1-35.0	48.54	Low
3	35.1-55.0	19.22	Intermediate
4	55.1-75.0	8.15	High
5	> 75.0	6.57	Extremely high

Table 8. Correlation matrix for fruit traits in this study.

Character	FM[z]	SSC[z]	SS[z]	TA[z]	Vitamin C	SSC:TA ratio
FDP[z]	0.18**[y]	0.52**	0.45**	0.17**	0.19**	-0.06
FM		0.01	-0.04	-0.02	-0.10*[y]	-0.02
SSC			0.58**	-0.02	0.17**	0.30**
SS				-0.06	0.43**	0.20**
TA					0.23**	-0.78**
Vitamin C						-0.24**

[z]FM: fruit mass; SSC: soluble solids content; SS: soluble sugars; TA: titratable acidity; FDP: fruit development period
[y]*, **: significant at 5% and 1% respectively

the accessions analyzed.

Correlation coefficients were calculated among FDP, FM, SSC, soluble sugars, TA, Vc, and the ratio of SSC to TA (Table 8). FDP was positively correlated with FM, SSC, soluble sugars, TA and Vc. These results are in agreement with previously reports, e.g. correlations between FDP and SSC (r = 0.62) and TA (r = 0.64) in 108 peach seedlings (21), and FDP with soluble sugars in sweet cherry (3). FM tended to correlate positively with SSC or negatively with soluble sugars, TA, Vc and SSC to TA ratio, respectively, but only the negative correlation of FM with Vc was statistically significant. Previous results for similar analyses showed some differences from our results. Giovannini et al. (11) pointed out that FM and soluble sugars were associated positively in 54 peach and nectarine cultivars, but it is not true that the larger the fruit, the sweeter it tastes. Schroder et al. (18) found no correlation between FM and Vc in tests of 156 accessions and 8 cultivars. SSC was positively correlated with soluble sugars, Vc and SSC to TA ratio, confirming the good correlation between soluble sugars and SSC reported previously in apricot (r = 0.83) by Fabrizio (6). Here soluble sugars were significantly correlated with Vc or SSC to TA ratio, but not TA. These results agree with correlations between

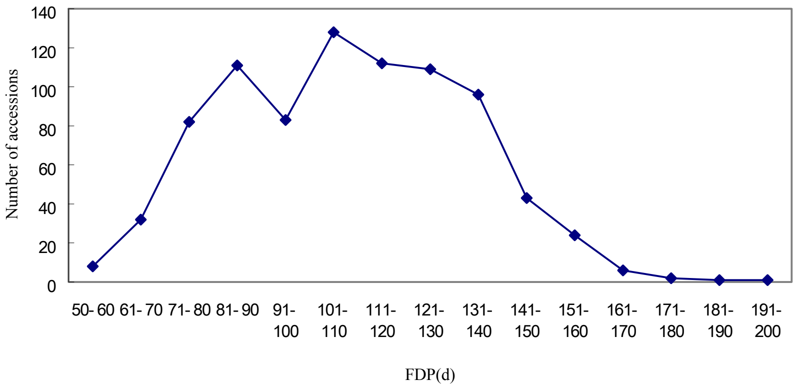

Figure 1. Frequency distribution of fruit development period (FDP, in days) of 837 *Prunus persica* accessions grown in China.

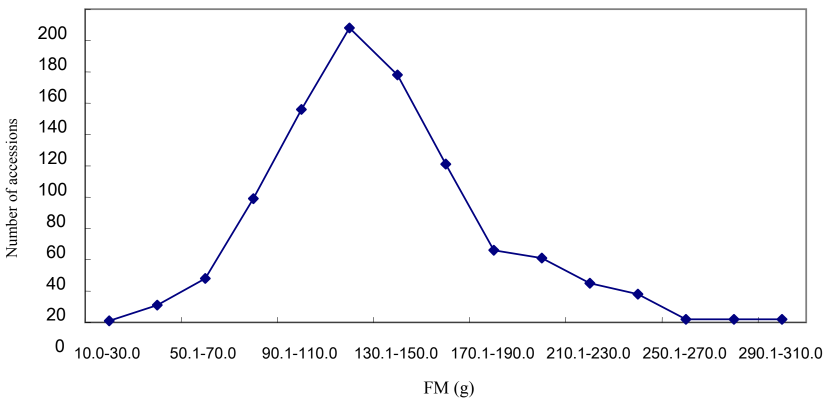

Figure 2. Frequency distribution of fruit mass (FM, in grams) of 837 *Prunus persica* accessions grown in China.

soluble sugars and Vc in Guo et al. (12), but disagree with the correlations between soluble sugars and TA, and soluble sugars and Vc in 42 cultivars studied by Valdomiro et al. (21), or 253 accessions studied by Guo et al. (12). TA had a significant negative correlation with the ratio of SSC to TA, but was positively correlated with Vc content; the latter finding was slightly different from Guo et al.'s observation of a non-significant trend for positive correlation between TA and Vc (12). Vc was negatively correlated with SSC to TA, although it was positively correlated with SSC and TA separately, implying that Vc was more affected by TA. This is logical since Vc is an acid. The other above-mentioned discrepancies between our results and others may be attributable to the limited sample of cultivars or accessions in other studies. In addition, their data were from only one location, and the traits in question interact with environment.

In summary, we conducted assessments of fruit traits on a large number of genotypes originating from inside and outside of China, comprising different cultivar groups, different ecological types, different biological traits and more than three locations, and determined the correlations among the various measured

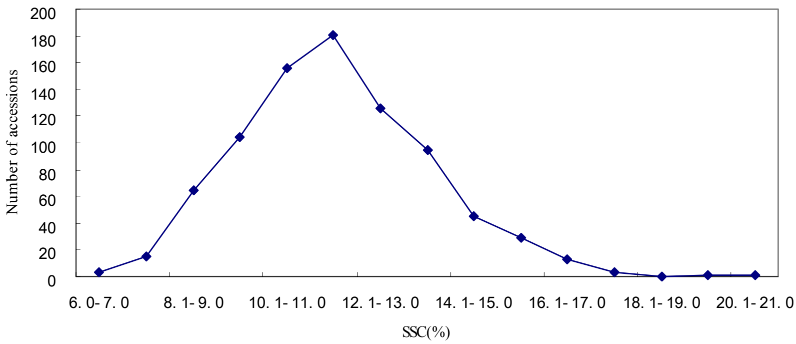

Figure 3. Frequency distribution of soluble solids content (SSC) of 837 *Prunus persica* accessions grown in China.

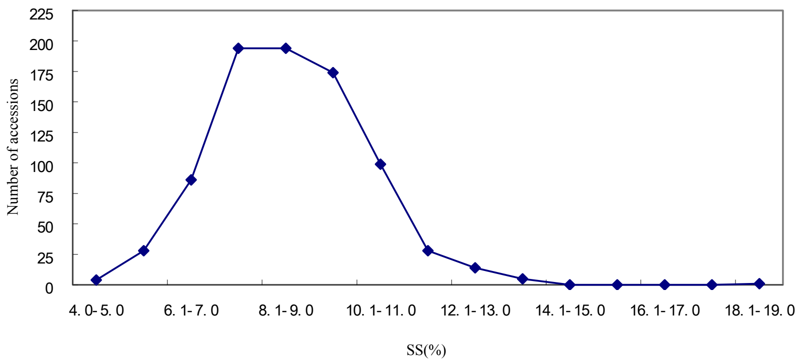

Figure 4. Frequency distribution of soluble sugars (SS) of 826 *Prunus persica* accessions grown in China.

traits. The results are certainly representative, universal and valuable, and will provide some guidance for screening breeding resources and improving fruit quality. Correlations among some fruit traits can be used as additional information for breeding. Although some of these results contradict previous reports, we think that our results should be more reliable and accurate than studies with fewer accessions and data from only one site.

Acknowledgements

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Literature Cited

1. Association for Agriculture and Culture. 1985. Pp. 83-91. In: Encyclopedia of fruits —*Prunus persica*. Agriculture Mountain and Fish Village Association in Japan, Tokyo.
2. Bayram, M.A. and O. Kadir. 2005. Analysis of morphological, pomological and yield characteristics of some apricot germplasm in Turkey. Genetic Resources and Crop Evolution 52:305–313.
3. Cai, Y.L., S. Li, Y.P. Chen, G.F. Zhao and R.M. Fu. 2005. Determination and analysis of main fruit inclusions of different varieties of *Prunus avium*. Acta Bot. Boreal. Occident. Sin. 25:304-310.
4. Comprehensive Laboratory of Jiangsu Provincial Academy. 1989. GB 6159 (Standard of the People's

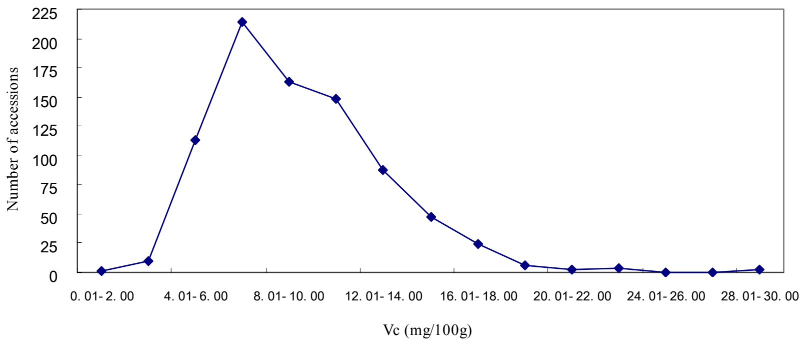

Figure 5. Frequency distribution of vitamin C ontent (Vc) of 821 *Prunus persica* accessions grown in China.

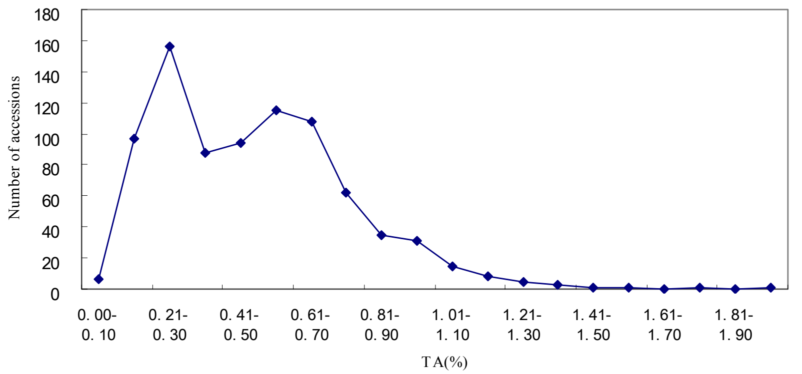

Figure 6. Frequency distribution of titratable acidity (TA) of 826 *Prunus persica* accessions grown in China.

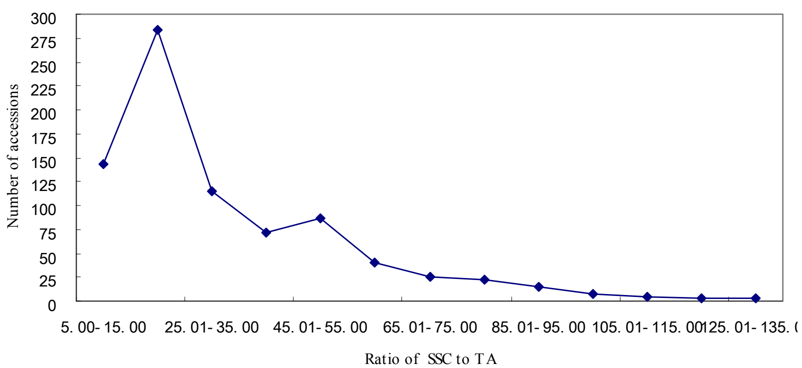

Figure 7. Frequency distribution of the ratio of soluble solids content to titratable acidity (SSC to TA) of 821 *Prunus persica* accessions grown in China.

Republic of China). In: Determination of vitamin C in vegetable and fruits. Standards Press of China, Beijing.
5. Dirlewanger, E. A., Moing, C. Rothan, L. Svanella, V. Pronier, A.Guye, C. Plomion and R. Monet. 1999. Mapping QTLs controlling fruit quality in peach (*Prunus persica* (L.) Batsch). Theor. Appl. Genet. 98:18–31.
6. Fabrizio, G., J.M.Audergon, A. Guy and R. Maryse. 2001. Use of principal component analysis to characterize apricot fruit quality. Euphytica 117:183–189.
7. Food and Agriculture Organization of the United Nations. Area harvested and production quantity. http://faostat.fao.org/site/567/default.aspx. <Accessed 22 April 2008>
8. Fruit Research Institute, Chinese Academy of Agricultural Sciences. 1993. Pp. 56-89. In: Catalog of resource of fruit germplasm (Vol.1). Agricultural Publishing House, Beijing.
9. Fruit Research Institute, Chinese Academy of Agricultural Sciences. 1998. Pp. 24-31. In: Catalog of resource of fruit germplasm (Vol.2). Agricultural Publishing House, Beijing.
10. Génard, M., M.Souty, S. Holmes, M. Reich and L. Breuils. 1994. Correlations among quality parameters of peach fruit. J. Sci. Food Agric. 66:241-245.
11. Giovannini, D., A. Liverani, F. Brandi. 2002. Quality of peach and nectarine fruit commercialized in Romagna (Italy): a two-year survey. Acta Hort. 592:485-492.
12. Guo, H., M.Z Zhao, Z.X. Lu and J.T. Zhou. 1992. Sugar, acid and vitamin C of peach fruits. Deciduous Fruit 24:22-23.
13. Heinongjiang Provincial Agricultural Academy. 1986. GB 6194 (Standard of the People's Republic of China). In: Determination of soluble sugar in vegetable and fruits. Standards Press of China, Beijing.
14. Hesse, C.O. 1975. Peaches. Pp. 285-335. In: J. Janick and J.N. Moore (eds.) Advances in fruit breeding. Purdue University Press, West Lafayette.
15. Institute of Vegetable and Flower, Chinese Academy of Agricultural Sciences. 1990. GB 12293 (Standard of the People's Republic of China). In: Fruits and vegetable products determination of titratable acidity. Standards Press of China, Beijing.
16. Liu, C., B.Q. Ma and Z.Z.Chu. 1990. Statistics and experiment design of fruit trees. China Forestry Publishing House, Beijing.
17. Pu, F.S. 1990. Pp. 64-77. In: Descriptors of fruits genetic resources. Agricultural Press, Beijing.
18. Schroder, G.M. G.H. Satterfield and D. Holmes. 1943. The influence of variety, size, and degree of ripeness upon the ascorbic acid content of peaches. J. Nutrition 25:503-509.
19. Secretariat of International Institute of Plant Genetic Resources. 1984. Peach descriptors. IBPGR, Rome.
20. United States Department of Agriculture. 1998. Handbook of peach and nectarine varieties. Agricultural Research Service, Byron, Georgia.
21. Valdomiro, A.B., H.B. David and F.T. Jeremy. 1998. Heritability, genetic and phenotypic correlations, and predicted selection response of quantitative traits in peach: II. An analysis of several fruit traits. J. Amer. Soc. Hort. Sci. 123:604-611.
22. Wang, Z.H. and E.J. Zhuang (eds). 2001. Fruit annals in China--scroll of peach and nectarine. China Forestry Publishing House, Beijing.
23. Wu, B.H., B. Quilot, J. Kervella, M..G´enard and S.H. Li. 2003. Analysis of genotypic variation of sugar and acid contents in peaches and nectarines through the principle component analysis. Euphytica 132:375–384.