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Scientia Horticulturae 104 (2005) 37–47

SCIENTIA HORTICULTURAE

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Genetic and environmental variance components in guava fruit qualities

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Accepted 21 July 2004

Abstract

The proportion of genetic and environmental variances for fruit weight (FW), flesh thickness (FLT), flesh weight (FLW), fruit firmness (FF), seed cavity weight (SCW), total soluble solids (TSS), titratable acidity (TA), juice acidity (pH), and ascorbic acid (AA) in guava were estimated with eight genotypes, four trees per genotype, and five fruits per tree for two seasons. The variance components of the fruit traits were consisted of genotypic variance (4.2–65.1%), seasonal variance (0–61.0%), genotype by season interaction variance (2.0–17.0%), among trees within genotype variance (0–4.2%), tree by season interaction variance (0–7.4%), and among fruit within tree variance (19.0–50.7%). A high proportion of genotypic variance was found with FW, FLT, FLW, SCW, and AA indicating that genetic improvement for these traits through breeding and selection was achievable. Seasonal variance was high for pH, while among fruits within tree variance was greatest for FF, TA, and TSS. The traits which were high in either season were more difficult to improve genetically.
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Keywords: Fruit breeding; Quantitative traits analysis; Heritability; *Psidium guajava* L.

1. Introduction

Most economically significant fruit traits show quantitative variation which is controlled by a combination of genetic and environmental factors. In order to improve quantitative traits successfully in any breeding program, genetic and environmental effects

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doi:10.1016/j.scienta.2004.07.008

need to be evaluated. Estimation of genetic and environmental variance has been made in many fruit crops such as sweet cherry (Hansche and Beres, 1966), almond (Kester et al., 1977), Japanese persimmon (Yamada et al., 1993), strawberries (Shaw, 1991; Sacks and Shaw, 1994), peach (De Souza et al., 1998), grape (Sato et al., 2000), and blueberry (Connor et al., 2002). These studies were typically parts of an ongoing breeding program. Knowledge of the expression of quantitative traits helps in selecting an efficient breeding strategy including optimal sample size and evaluation method.

Guava (*Psidium guajava* L.) is the most valuable cultivated species of the Myrtaceae family. It is native to tropical America and presently found distributed in many tropical and subtropical countries (Cobley, 1976; Samson, 1986; Morton, 1987). Guava fruit is commercially important in India, South Africa, FL, Hawaii, Egypt, Brazil, Colombia, West Indies, Cuba, Venezuela, New Zealand, Philippines (Wilson, 1980; Yadava, 1996), Vietnam (Le et al., 1998), and Thailand (Tate, 2000).

In Thailand, though a guava tree can produce flowers and fruits throughout a year, major production seasons are summer (March–June) and winter (November–February) during which fruit qualities show remarkable differences. Annual production was reported to be over 155,000 metric tonnes from a production area of 9600 ha located mainly in the central part of the country (http://www.doae.go.th/plant/faung.htm). More than 90% of the production was for fresh consumption. Lower grade fruit was processed to juices, pickled, dried, or canned.

Guava is a popular tropical fruit due to its year round availability, affordable price, durable for transportation and handling, and overall consumer preference. The guava breeding program aimed to develop new cultivars with superior fruit qualities and resistance to biotic/abiotic stress was initiated in 1998 by Kasetsart University. A genetic study on guava fruit traits has not been done in Thailand and little information is available elsewhere. Moreover, environmental differences among locations limit any generalization of available genetic information. Knowledge on genetic variability and environmental effect could help in designing crosses, evaluation methods and breeding strategies.

The objectives of this study were to estimate the genetic and environmental variances and to provide the optimal sample size, seasonal repetition, and number of tree replications required for efficient evaluation of guava fruit qualities in a breeding program under Thailand conditions.

2. Materials and methods

2.1. Experimental materials

These investigations were conducted during the winter and summer season of 2001 at the Department of Horticulture, Kasetsart University, Kamphaengsaen Campus, Nakhon Pathom, Thailand. Nakhon Pathom province is located in the central part of Thailand. Its longitude and latitude are 99°58′E and 14°01′N, respectively. The environmental conditions in the winter and summer season had mean max/min air temperature of 31.8/20.8 and 33.6/24.5 °C, mean max/min RH of 95/50 and 95/58%, total precipitation of 9 and 265 mm, and mean saturated light duration of 7.5 and 6.5 h day^{-1}, respectively. Eight clones were randomly selected from the collection of breeding materials. These consisted of six white flesh dessert types (‘Klom Salee’, ‘Yensong’, ‘Pan Seethong’, ‘Khao Um-porn’, ‘Pan Yuk’, and ‘Nasuan’), one red flesh dessert type (‘Philippines’), and one pink flesh processing type (‘Pijit 12-102’). All white flesh types are commercial cultivars in Thailand, and three cultivars (‘Klom Salee’, ‘Yensong’, and ‘Pan Seethong’) are presently produced on a large scale. None of pink flesh processing types are commercialized. ‘Philippines’ genotype is a selected red leaf seedling introduced from Philippines. ‘Pijit 12-102’ is an advanced selection from an open pollinated population of ‘Beaumont’. Their fruit development period (90–105 days) is shorter than that of the white flesh (126–140 days) cultivars. Four air layering propagated trees of each were planted randomly in an experimental field at 4.0 m $\times$ 4.0 m spacing in December 1999.

2.2. Fruit quality evaluation

A random sample of five fruits per tree was collected in winter and summer seasons when the trees were 14 and 18 months old, respectively. The guava fruit traits evaluated were five physical traits: fruit weight (FW), fruit firmness (FF), flesh thickness (FLT), flesh weight (FLW), seed cavity weight (SCW), and four chemical traits: total soluble solids (TSS), titratable acidity (TA), juice acidity (pH), and ascorbic acid (AA).

FW and SCW were measured with digital balance (SK-5001, A&D, Japan). FF was determined on one side of fruit with fruit hardness tester (N.O.W., Japan) using 0.5 cm diameter probe after 0.3 cm skin was sliced off. FLT was measured at equatorial plane cut with a standard caliper. FLW was computed using the formula, FLW = (fruit weight − seed cavity weight). TSS was measured with a temperature compensated hand refractometer (ATC-1E, Atago, Japan). TA was determined by titration with 1.0N NaOH and 1% phenolphthalein as an indicator using a digital burette (Burette digital III, Brand, Germany). Extracted juice from a fruit was used for determining the pH using a pH meter (pHScan 2, Eutech, Singapore) and AA was estimated according to the method described in Association of Office Analytical Chemists (1990) using oxalo-acetic acid solution and titration with 2,6-dichlorophenolindophenol dye solution.

2.3. Statistical analysis

The statistical model used to describe the phenotypic value of a trait was $P_{ijkl} = \mu + g_i + t_{ij} + s_l + (gs)_{il} + (ts)_{ijl} + f_{ijkl}$, where P_{ijkl} was the phenotypic value of the k fruit of the j tree of the i genotype in the l season, μ the overall mean, g_i was a random effect contributed by the i genotype, t_{ij} a random effect of the j tree of the i genotype, s_l a random effect of the l season, $(gs)_{il}$ the interaction between the i genotype and the l season, $(ts)_{ijl}$ the interaction between the j tree of the i genotype and the l season, and f_{ijkl} was a random effect of the k fruit of the j tree of the i genotype in the l season.

PROC ANOVA and PROC VARCOMP statements in statistical analysis system program (SAS, 1988) were used for statistical testing and for estimating the variance components.

3. Results and discussion

From the results of analysis of variance (ANOVA), the total variance (σ_T^2) of each fruit traits was partitioned into the variance components associated with genotype (σ_g^2), season (σ_s^2), genotype by season interaction (σ_gs^2), trees within genotype (σ_t^2), tree by season interaction (σ_ts^2) and fruit samples within tree (σ_f^2) and their expected mean squares (EMS) are shown in Table 1.

3.1. Genotypic variance (σ_g^2)

The dessert type, especially white flesh genotypes had larger fruit size (FW, FLT, FLW, and SCW) but was lower for TA than those of the processing type (Table 2). The differences reflected habits of Thais who prefer a large size and sweet flavor for any dessert type fruits. Interestingly, the flavor of all dessert cultivars was sweeter but the TSS was lower than those of the processing cultivars (Table 2) indicating that the components in TSS of the processing type may be metabolites other than sugars. Therefore, when measuring TSS in guava to evaluate its sweetness, one should be concerned about the type of guava as well. The results of ANOVA showed that the main effect of genotype was significant for FW, FLT, FLW, SCW, TSS, TA, and AA but not for FF and pH (Table 3) indicating that there are genetic differences between the genotypes. The Genotypic variance component (σ_g^2) or broad-sense heritability (H^2) of the traits with significant genotypic effect was between 21.2 and 65.1% (Table 4). These traits showed considerable genetic variation suggesting that genetic gain through breeding was practical assuming additive genetic variance contributed significantly to phenotypic variance.

3.2. Seasonal variance (σ_s^2)

All guava fruit traits, except FLT and FLW, were significantly influenced by the season (Table 3). Most chemical traits in the winter season were higher than those in summer, while most of physical traits were higher in summer season (Table 5). This result is in agreement with Rathore (1976) that winter-season fruits were higher in chemical composition than spring season. The important factor contributing to higher chemical

Table 1
Expected mean squares (EMS) in ANOVA for calculating F values and variance components using eight genotypes, four trees per genotype, and five fruits per tree for two seasons

Source	d.f.	EMS
Genotype	7	$\sigma_\mathrm{f}^2 + 5\sigma_\mathrm{ts}^2 + 20\sigma_\mathrm{gs}^2 + 10\sigma_\mathrm{t}^2 + 40\sigma_\mathrm{g}^2$
Season	1	$\sigma_\mathrm{f}^2 + 5\sigma_\mathrm{ts}^2 + 20\sigma_\mathrm{gs}^2 + 160\sigma_\mathrm{s}^2$
Genotype × season	7	$\sigma_\mathrm{f}^2 + 5\sigma_\mathrm{ts}^2 + 20\sigma_\mathrm{gs}^2$
Among trees within genotype	24	$\sigma_\mathrm{f}^2 + 5\sigma_\mathrm{ts}^2 + 10\sigma_\mathrm{t}^2$
Tree × season	24	$\sigma_\mathrm{f}^2 + 5\sigma_\mathrm{ts}^2$
Among fruits within tree	256	σ_f^2
Total	319	

Table 2
Mean and S.D. of fruit quality traits in eight guava varieties

Name	Type	FW (g)	FLT (cm)	FLW (g)	FF (N)	SCW (g)
Klom Salee	Dessert	655.5 ± 204.2	2.63 ± 0.42	546.6 ± 170.7	30.4 ± 6.8	108.9 ± 40.2
Khao Um-porn	Dessert	669.3 ± 112.5	2.92 ± 0.49	570.9 ± 102.7	31.7 ± 6.5	98.3 ± 23.4
Yensong	Dessert	622.7 ± 155.5	2.39 ± 0.48	503.8 ± 123.9	32.7 ± 6.3	118.8 ± 39.9
Pan Yuk	Dessert	641.5 ± 188.6	2.45 ± 0.36	528.7 ± 153.7	32.8 ± 4.9	112.8 ± 43.6
Pan Seethong	Dessert	703.2 ± 191.4	2.60 ± 0.43	577.8 ± 164.1	30.8 ± 4.6	125.4 ± 47.0
Nasuan	Dessert	496.8 ± 104.2	2.33 ± 0.40	407.20 ± 95.81	30.94 ± 7.35	90.1 ± 22.2
Philippines	Dessert	306.7 ± 76.1	1.79 ± 0.26	243.70 ± 62.36	25.50 ± 6.30	62.6 ± 22.1
Pijit 12–102	Processing	114.4 ± 37.6	1.26 ± 0.23	92.38 ± 31.44	24.58 ± 13.06	22.0 ± 9.0

Name	Type	TSS (°Brix)	TA (%)	pH	AA (mg/100 g fresh wt.%)
Klom Salee	Dessert	6.5 ± 0.8	0.33 ± 0.15	4.3 ± 0.2	104.4 ± 27.2
Khao Um-porn	Dessert	6.7 ± 1.0	0.34 ± 0.12	4.2 ± 0.2	108.2 ± 26.7
Yensong	Dessert	7.0 ± 1.6	0.34 ± 0.13	4.2 ± 0.3	109.6 ± 37.1
Pan Yuk	Dessert	7.3 ± 1.2	0.30 ± 0.09	4.3 ± 0.2	68.4 ± 23.1
Pan Seethong	Dessert	7.3 ± 1.5	0.34 ± 0.13	4.2 ± 0.3	68.8 ± 24.9
Nasuan	Dessert	7.2 ± 1.4	0.32 ± 0.13	4.2 ± 0.3	104.6 ± 30.3
Philippines	Dessert	7.8 ± 1.3	0.34 ± 0.11	4.4 ± 0.2	78.9 ± 23.4
Pijit 12–102	Processing	9.3 ± 1.7	0.64 ± 0.20	4.0 ± 0.2	201.9 ± 66.2

Table 3

Analysis of variance showing mean squares (MS) and probabilities (*P*) of test statistics (*F*-test) for guava fruit traits

Source	d.f.	FW		FLT		FLW		FF	
		MS	*P*	MS	*P*	MS	*P*	MS	*P*
Genotype	7	1770165.84	<0.001	11.207	0.001	1254910.80	<0.001	395.15	0.330
Season	1	377575.20	0.037	0.300	0.466	160742.45	0.083	2910.68	0.015
Genotype × season	7	56944.90	0.078	0.506	0.077	39344.12	0.117	284.76	0.003
Trees within genotype	24	42583.15	0.128	0.219	0.570	29005.28	0.214	52.41	0.682
Tree × season	24	26567.70	0.034	0.236	0.014	20910.15	0.017	63.73	0.020
Fruits within tree	256	16204.27		0.131		11842.80		36.69	
Total	319	2290041.06		12.599		1516755.60		3743.42	

Source	d.f.	SCW		TSS		TA		pH		AA	
		MS	*P*	MS	*P*	MS	*P*	MS	*P*	MS	*P*
Genotype	7	47787.28	0.001	31.10	0.024	0.4788	0.002	0.4227	0.104	72,869.02	0.011
Season	1	45481.95	0.013	133.00	0.002	1.0963	0.001	9.4453	<0.001	66808.71	0.047
Genotype × season	7	4182.11	0.001	6.00	0.007	0.0376	0.074	0.1426	0.006	11,506.74	<0.001
Trees within genotype	24	2311.97	0.005	1.68	0.463	0.0189	0.415	0.0719	0.056	1,874.55	0.004
Tree × season	24	781.47	0.462	1.62	0.150	0.0173	0.176	0.0371	0.004	609.35	0.622
Fruits within tree	256	778.80		1.22		0.0135		0.0184		688.31	
Total	319	101323.58		174.62		1.6624		10.1380		15,436.68	

Table 4
Estimates of variance components of guava fruit traits and their percent contribution to the total variance

Variance components	FW		FLT		FLW		FF		SCW	
	Variance	Percentage	Variance	Percentage	Variance	Percentage	Variance	Percentage	Variance	Percentage
σ_g^2	42430.14	64.5	0.268	61.8	30186.79	65.1	30.4	4.2	1051.87	43.6
σ_s^2	2003.94	3.0	0[a]	0	758.74	1.6	16.41	22.5	258.12	10.7
σ_{gs}^2	1518.86	2.3	0.014	3.2	921.70	2.0	11.05	15.2	170.03	7.01
σ_t^2	1601.54	2.4	0[a]	0	809.51	1.8	0[a]	0	153.05	6.3
σ_{ts}^2	2072.69	3.2	0.021	4.8	1813.47	3.9	5.41	7.4	0.53	0
σ_f^2	16204.26	24.6	0.131	30.2	11842.80	25.6	36.91	50.7	778.80	32.3
σ_T^2	65831.37	100.0	0.434	100.0	46333.01	100.0	72.82	100.0	2412.40	100.0

Variance components	TSS		TA		pH		AA	
	Variance	Percentage	Variance	Percentage	Variance	Percentage	Variance	Percentage
σ_g^2	0.626	21.2	0.011	33.4	0.006	6.3	1502.42	46.8
σ_s^2	0.794	26.9	0.007	20.6	0.058	61.0	345.64	10.8
σ_{gs}^2	0.219	7.4	0.001	2.9	0.005	5.3	544.87	17.0
σ_t^2	0.006	0.2	0[a]	0	0.004	4.2	126.52	3.9
σ_{ts}^2	0.078	2.7	0.001	2.9	0.004	4.2	0[a]	0
σ_f^2	1.225	41.6	0.014	41.2	0.018	19.0	688.79	21.5
σ_T^2	2.948	100.0	0.034	100.0	0.095	100.0	3208.24	100.0

[a] Negative values were assumed to be zero.

Table 5
Mean, S.D. and probabilities (P) of test statistics (F-test) for guava fruit traits in two seasons

Fruit traits	Season		P
	Winter	Summer	
FW (g)	491.9 ± 234.7	560.6 ± 248.8	<0.001
FLT (cm)	2.3 ± 0.6	2.3 ± 0.7	0.162
FLW (g)	411.5 ± 198.4	456.3 ± 210.2	0.083
FF (N)	32.9 ± 6.6	26.9 ± 7.9	<0.001
SCW (g)	80.5 ± 41.1	104.3 ± 48.2	<0.001
TSS (°Brix)	8.0 ± 1.6	6.7 ± 1.2	<0.001
TA (%)	0.4 ± 0.2	0.3 ± 0.1	<0.001
pH	4.1 ± 0.2	4.4 ± 0.2	<0.001
AA (mg/100 g fresh wt.%)	120.0 ± 61.6	91.2 ± 37.4	<0.001

composition in the winter season may be the effect of lower temperature during the period of fruit development. Low temperature not only retards the excessive loss of respiratory substrates but also increases the translocation of photosysthates to other parts of a plant, particularly in fruits (Crane, 1969). Kliewer and Lider (1970) working with grapes grown under controlled conditions found an increase of total acidity and malate in berries which matured at low compared with high day temperatures. In addition, light duration of winter (7.5 h day^{-1}) in this study was longer than that of summer (6.5 h day^{-1}). It could be that guava plants have higher net photosynthesis in winter, which leads to more accumulation of food reserves within plants. The lower TSS, TA, AA and higher pH traits in summer might also be partly due to higher moisture content (data not presented) and larger fruits (Table 2). Kushman and Ballinger (1975) reported that larger fruits of blueberries had lower TSS and total sugar. FW was significantly influenced, while, FLT and FLW were not. This implied that the change in FW between seasons was a result of corresponding change in SCW.

Significant seasonal variance component (σ_s^2) of fruit traits was between 10.7 and 61.5% (Table 4). The pH, the only chemical trait that had an opposite seasonal effect in which the summer season had a higher value (Table 5), showed the greatest seasonal variation (Table 4). The σ_s^2 was high among the variance components for pH and moderately high for FF, SCW, TSS, and TA, revealing that one season evaluation was inadequate. Therefore, evaluation of these traits should be done for several seasons to accurately estimate the genetic expression.

3.3. Genotype by season interaction variance (σ_{gs}^2)

The genotype by season interaction was significant for FF, SCW, TSS, pH and AA but not for FW, FLT, FLW and TA (Table 3). The spearman rank correlation coefficient (r_s) among genotypes between winter and summer for FF, SCW, TSS, pH and AA was only significant for SCW (0.71, $P = 0.05$) and AA (0.76, $P = 0.03$). The significant genotype by season interaction for FF and pH was due to a change in ranking among genotypes between two seasons, while that of SCW, TSS and AA was mainly due to a change in the magnitude of the differences among genotypes between two seasons with little ranking change.

Genotype by season interaction variance component (σ_{gs}^2) was small for all the traits studied except for FF (15.2%) and AA (17.0%) (Table 4). Since interaction of AA was mainly due to a change in magnitude rather than a ranking change among genotypes as mentioned earlier, therefore, a one season evaluation would be efficient for selection. For FF, the large variance component associated with σ_s^2 and σ_{gs}^2 indicated that for effective measurement of this trait evaluation should be repeated for more than a season.

3.4. Trees within genotype variance (σ_t^2)

The effect of trees within genotype was only significant for SCW and AA (Table 3) and their variance component (σ_t^2) was about 6.3 and 3.9%, respectively while those for FLT, FF and TA could not be estimated and were given a zero value (Table 4). The results indicated that fruits of the same genotype harvested from different trees had similar qualities. A relatively small value of all σ_t^2 implied that effective field evaluation of the fruit traits could be based on a single tree rather than several trees.

3.5. Tree by season interaction variance (σ_{ts}^2)

The tree by season interaction effect was significant for FW, FLW, FLT, FF and pH, but not for SCW, TSS, TA and AA (Table 3). However, the variance component for the traits with significant interaction effects was relatively low (3.2–7.4%) compared to the other variance components (Table 4). Therefore, a single tree evaluation as previously mentioned could be efficiently used.

3.6. Fruits within tree variance (σ_f^2)

The fruits within tree was an error component in the model. The fruits within tree variance component (σ_f^2) was between 19.0 and 50.7% (Table 4). In general, the σ_f^2 was relatively high for all fruit traits and highest among other components for FF, TSS, and TA. This showed a great sampling variability within a tree. The harvesting index for guava is the skin color changing because of its most obvious parameter. The skin color index was correlated to maturity, but it did not yield fruits with the same level of maturity. This may cause the variation of fruit qualities. In addition, fruits were randomly chosen from different position from the guava plants; therefore, the variation of fruit qualities could be occurred. Peiris et al. (1998) showed that TSS varied from 11.9 to 15.4% for fruit samples taken from different locations on a medium size peach.

The large σ_f^2 and small σ_t^2 suggested that increasing number of fruits per tree was more effective than increasing number of trees per genotype for accurate genetic estimation. This practice would allow a breeding program to operate more economically and efficiently for field evaluation.

4. Conclusion

High genetic variance components of fruit quality traits in guava indicated that genetic gain through breeding and selection was feasible. All chemical fruit qualities were greatly influenced by seasonal variation; therefore, evaluation should be done in several seasons to precisely estimate their genetic parameters. The change in fruit weight (FW) between seasons was mainly due to a corresponding change in seed cavity weight (SCW) without changes in flesh thickness (FLT) or weight (FLW). Although the genotype by season interaction was significant for FF, SCW, TSS, pH and AA, there were significant genotype ranking changes for only FF and pH. Low variances of the trees within genotype and high variances of the fruits within tree indicated that increasing the number of fruits sampled was more effective approach to minimizing environmental variance than increasing number of trees per genotype for genetic evaluation.

Acknowledgements

This research was financially supported by The Kasetsart University Research and Development Institute, and a grant from The Graduate School of Kasetsart University.

References

Association of Office Analytical Chemists (AOAC), 1990. Official Method of Analysis, 15th ed. George Banta, Washington, DC.

Cobley, L.S., 1976. An Introduction to the Botany of Tropical Crops, 2nd ed. Longman, New York (revised by W.M. Steel).

Connor, A.M., Luby, J.J., Tong, C.B.S., Finn, C.E., Hancock, J.F., 2002. Genotypic and environmental variation in antioxidant activity, total phenolic content, and anthocyanin content among blueberry cultivars. J. Am. Soc. Hort. Sci. 127, 89–97.

Crane, J.C., 1969. The role of hormones in fruit set and development. HortScience 4, 108–111.

De Souza, V.A.B., Byrne, D.H., Taylor, J.F., 1998. Heritability, genotypic and phenotypic correlations, and predicted selection response of quantitative traits in peach. II. An analysis of several fruit traits. J. Am. Soc. Hort. Sci. 123, 604–611.

Hansche, P.E., Beres, V., 1966. An analysis of environmental variability in sweet cherry. Proc. Am. Soc. Hort. Sci. 88, 167–172, http://www.doae.go.th/plant/faung.htm.

Kester, D.E., Hansche, P.E., Beres, V., Asay, R.N., 1977. Variance components and heritability of nut and kernel traits in almond. J. Am. Soc. Hort. Sci. 102, 264–266.

Kliewer, W.M., Lider, L.A., 1970. Effect of day temperature and light intensity on growth and composition of *Vitis vinifera* L. fruits. J. Am. Soc. Hort. Sci. 95, 766–769.

Kushman, L.J., Ballinger, W.W., 1975. Effect of season, location, cultivar and fruit size upon quality of light sorted blueberries. J. Am. Soc. Hort. Sci. 100, 564–569.

Le, H.T., Hancock, J.F., Trinh, T.T., 1998. The fruit crop of Vietnam: introduced species and their native relatives. Fruit Var. J. 52, 158–168.

Morton, J.F., 1987. Fruits of Warm Climates. Julia F. Morton Publishers, Miami.

Peiris, K.H., Dull, G.G., Lefler, R.G., Kays, J.J., 1998. Near-infared spectrometric method for nondestruction of soluble solids content of peaches. J. Am. Soc. Hort. Sci. 123, 898–905.

Rathore, D.S., 1976. Effect of season on the growth and chemical composition of guava (*Psidium guajava* L.) fruits. J. Hort. Sci. 51, 41–47.

Sacks, E.J., Shaw, D.V., 1994. Optimum allocation of objective color measurements for evaluating fresh strawberries. J. Am. Soc. Hort. Sci. 119, 330–334.

Samson, J.A., 1986. Tropical Fruits. Tropical Agricultural Series, 2nd ed. Longman, New York.

SAS, Institute, 1998. SAS User's Guide: Statistics. SAS Institute, Cary, NC.

Sato, A., Yamda, M., Iwanami, H., Hirakawa, N., 2000. Optimal spatial and temporal measurement repetition for reducing environmental variation of berry traits in grape breeding. Sci. Hort. 85, 75–83.

Shaw, D.V., 1991. Genetic variation for objective and subjective measures of flesh fruit color in strawberries. J. Am. Soc. Hort. Sci. 116, 894–898.

Tate, D., 2000. Tropical Fruit of Thailand. Asia Books Co. Ltd., Bangkok, Thailand.

Wilson, C.W.III., 1980. Guava. In: Nagy, S., Shaw, P.E. (Eds.), Tropical and Sub-tropical Fruits: Composition, Properties, and Uses. AVI, Westport, CT, pp. 279–299.

Yadava, U.L., 1996. Guava (*Psidium guajava* L.): an exotic tree fruit with potential in the southeastern United States. HortScience 31, 789–794.

Yamada, M., Yamane, H., Yoshinaga, K., Ukai, Y., 1993. Optimal spatial and temporal measurement repetition for selection in Japanese persimmon breeding. HortScience 28, 838–841.