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GENOTYPIC AND SEASONAL VARIABILITY IN GUAVA FRUIT QUALITY AND IMPLICATIONS FOR BREEDING

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Guava (*Psidium guajava* L.) fruit physical and chemical characterization was performed across six distinct summer and winter seasons (Year I-III) in two elite cultivars (Round and Pyriform) to assess genotypic and seasonal variations and their correlations with the key environmental components. A strong negative correlation was found between in temperature with ratio fruit length to fruit diameter (FL:FD), total sugars (%) and rain fall with fruit weight, seed cavity weight and total sugars (%). Relative humidity (%) and sunshine (hrs) were positively correlated to fruit weight and ratio TSS:TA suggesting existence of a higher genotype × environment interplay which regulated contrasting changes in fruit traits. Most of the physical and chemical traits were higher in cv. Pyriform compared with cv. Round. Fruit produced in winter seasons had markedly better physical and chemical attributes compared with that of summer seasons. However, acid contents were higher during summer seasons. Traits like reducing sugars and ratio flesh weight and seed cavity weight (FlW:SCW) remained stable across contrasting summer and winter seasons over the years in both cultivars. Assessment of guava fruit physico-chemical traits across multiple seasons provided precise estimates of genetic, seasonal and annual variations which could be useful in selection of parental material for future guava breeding and biotechnology applications.
Keywords: Environmental components, fruit traits, seasonal variations, round, pyriform.

INTRODUCTION

Tree fruit crops have long juvenile phase and it is difficult to maintain large number of seedlings for further field evaluations. Replicating measurements over samples in the same genotype across multiple seasons could provide valuable data sets. Interplay of genetic and environmental elements is significant in regulation of blooming patterns, fruit growth and fruit quality which vary across seasons and localities (Wei *et al*., 2002; Shiraishi *et al*., 2012). The evaluation of effects of these key components on quantitative traits has key role for success in a breeding program. Genetic and environmental variation had been reported in few fruit crops for one or two seasons including peach (De Souza *et al*., 1998), blueberry (Connor *et al*., 2002), guava (Thaipong and Boonprakob, 2005), grape (Shiraishi *et al*., 2012) and strawberry (Aguero *et al*., 2015). In guava, genotypic and environmental variance was estimated under mild summer and winter conditions (Thaipong and Boonprakob, 2005). Stable expression of quantitative traits in relation to contrasting environmental components across multiple seasons in guava is lacking.

Guava (*Psidium guajava* L.) is amongst the most nutritious fruit crops of Myrtaceae family. It is popular fruit due to its year-round availability, better crop production economics, low and stable prices and consumer preference including medium to large fruit size, white and reddish skin colors, less number of seeds or soft seeds and more juice content. Guava is commercially produced in countries like Thailand, Pakistan, India, Colombia, South Africa, Brazil and New Zealand (Yadava, 1996; Usman *et al*., 2012). Guava tree can bloom and produce fruit throughout the year under tropical conditions. In Pakistan, about 80% fruit (448 thousand tons) is being produced in Punjab having sub-tropical conditions mainly for fresh consumption. (MINFAL, 2019) In Punjab, major fruit production seasons are summer (April–August) and winter (September–March). However, 'Sadabahar' selections continue bearing fruit 8-9 months a year (Usman *et al*., 2012). During these seasons remarkable differences have been found in fruit size and quality. Early and frequent flowering habit of guava among major sub-tropical tree fruits make it a robust candidate tree for future crop improvement programs (Usman *et al.*, 2013).

The guava selection and breeding project to develop new cultivars with better fruit quality, less seeds and resistance to environmental stress was initiated in 2005-06 in University of Agriculture, Faisalabad and first report of metaxenial effects in inter-varietal crosses was presented (Usman *et al*., 2012). Guava producing belt in Pakistan is also facing seasonal shifts, higher temperatures and a 15% higher rain fall intensity leading to a highly variable crop production patterns in future (Rasul *et al.*, 2012). Information on relationship of the key environmental components with economically important fruit traits is lacking in Pakistan and information available elsewhere is outcome of short-term studies. The wide variation in environmental conditions across seasons and localities limit generality of the available genetic information. Thorough knowledge on genotypic variability and impact of environmental conditions across multiple seasons could increase our understanding towards the relationships of fruit quality traits with environmental components and help improving selection and breeding strategies (Thaipong and Boonprakob, 2005). Availability of genotypic and environmental relationship patterns could enhance prediction efficiency in expression of the fruit quality traits. Such data could also be helpful to underpin key environmental components responsible for trait expression and developing an efficient breeding program. Hence, the aims of this study were to assess genotypic variations in economically important fruit traits across multiple seasons and their correlations with key environmental components to enhance efficiency of the breeding programs.

MATERIAL AND METHODS

Plant materials: These investigations were carried out during summer and winter seasons for three years at the Institute of Horticultural Sciences, University of Agriculture, Faisalabad, Punjab-Pakistan. The Faisalabad city is in central part of the Punjab province having latitude and longitude 31.43° N, 73.06° E, respectively. The average environmental conditions prevailing during study period (2010-2012) are presented as yearly, seasonal and annual means (Table 1). Six uniform bearing trees (7-8 years age) of white fleshed dessert type commercial cultivars including 'Round' (Gola) and 'Pyriform' (Surahi) were randomly selected from experimental fruit garden of the institute. Trees were planted in the field at 7.0 m x 7.0 m spacing under square system of layout. Trees were uniformly fertilized with 1 kg NPK (16%-16%-16%) fertilizer per tree in two split doses (one each in summer and winter seasons) and 50-60 Kg rotten farmyard manure annually during winter season. Trees were irrigated using canal water weekly during summer and fortnightly during winter seasons.

Fruit quality analysis: Samples of five market mature fruits per tree were collected randomly in summer and winter seasons during years I-III. Guava fruit were analysed for seven physical traits including: fruit size comprising of length (FL) and diameter (FD), ratio FL:FD, fruit weight (FW), flesh weight (FlW), seed cavity weight (SCW), ratio FlW/SCW and seven chemical traits: total soluble solids (TSS), titratable acidity (TA), ratio TSS/TA, ascorbic acid (AA), total sugars (TS), reducing sugars (RS), and non-reducing sugars (NRS).

Physical traits: Fruit size including FL and FD were measured using digital vernier caliper (KBD-MT 0014) in mm and ratio FL/FD was computed by dividing FL by FD. Digital balance (UX320G, SHIMADZU, Japan) was used to measure FW and SCW in grams while FlW was calculated using formula, FlW= (fruit weight – seed cavity weight). Average of five fruits per tree was calculated and data were subjected to statistical analysis.

Chemical traits: Total soluble solids (TSS) of guava juice was measured at harvest using digital refractometer (RX 5000, ATAGO, Japan) and were expressed as °Brix. Fruit samples were prepared for further chemical analysis following Usman *et al*. (2012). Titratable acidity (%) was determined by titration with 1N NaOH and phenolphthalein 1% as an indicator (Hortwitz, 1970). Ratio TSS:TA was computed by dividing TSS values by corresponding TA values. Fruit pulp sugars were determined following Hortwitz (1970). Ascorbic acid was determined as mg $100mL^{-1}$ juice using oxalo-acetic acid solution and titration with 2,6-dichlorophenolindophenol dye solution (AOAC, 1990). The experiment was laid out in randomized complete block design.

Statistical analysis: The measurements of fruit from three different plants per replicate per cultivar for each season were statistically analysed using Student's t-test ($P < 0.05$). Pearson's correlation coefficients were used to determine correlations between environmental components and physical and chemical fruit traits for each genotype across seasons (Steel *et al.*, 1997).

RESULTS

Seasonal and yearly climatic variability and correlations among environmental components: To develop a correlation amongst the key environmental components and fruit traits

Table 1. Average seasonal and annual climatic conditions (Year I-III)

Seasons /years	Environmental components					
	Temperature (°C)			Relative Humidity (RH) %	Rainfall (RF) mm	Sunshine (SS) h
	Max.	Min.	Avg.			
Year I	30.30±7.47	17.41±7.84	24.75±6.76	54.20±7.90	25.43±14.8	8.21±1.05
Year II	31.56±6.81	18.67±7.32	24.24±6.19	54.21±10.6	24.61±19.9	7.60±1.14
Year III	29.95±6.17	17.08±6.96	23.61±6.64	55.19±10.5	25.09±19.6	7.11±0.14
Summer	37.43±0.66	25.10±0.57	30.70±0.40	44.88±0.78	43.15±1.47	8.42±0.61
Winter	23.80±0.56	10.30±0.53	17.70±0.35	64.20±1.07	6.90±1.87	6.90±0.21
Annual	30.62±0.48	17.72±0.49	24.20±0.33	54.53±0.33	25.04±0.24	7.64±0.32

Data are means of values of environmental components during years I, II, III, 3 summer (S) seasons (March-August), 3 winter season (W) (September-February) and mean annual (January-December).

across different seasons, it is important to track seasonal and yearly climatic conditions and variability. Contrasting seasonal and annual climatic variations were observed (Table 1). Both temperature and sunshine significantly decreased from Year I to Year III whereas RF patterns showed variable response. Less RF was noted in years II and III compared with year I, however, RH sharply increased in Year III. (Table 1). During summer seasons, mean temperature (30.7°C), RF (43.15 mm) and SS (8.42 hrs) were higher compared with winter seasons which showed higher RH (64.2%) and lower values for the other environmental components. Correlation analysis revealed that RH had a negative correlation (r = -0.892) with the temperature and RF (r = -0.969) whereas SS had no significant correlation (Table 2).

Correlations of environmental components with genotypes for fruit physical and chemical traits: Temperature had a strong negative correlation to fruit size (FL:FD, r = -0.890) and TS (r = -0.908) while RF was highly negatively correlated with SCW (r = -0.895) and TS (r = -0.916) in cv. Round. RH was positively correlated with FW (r = 0.881) while RF had a strong negative correlation with FW (r = -0.897) in cv. Pyriform. SS had a strong positive correlation (r = 0.976; r = 0.920) with TSS:TA in both cultivars (Table 3). Other fruit traits were least affected by these environmental components.

Correlations in fruit physical and chemical traits: In fruit traits, physical traits like FD was positively correlated to FL (r = 0.881) while FLW was correlated to FL, FD (r = 0.755; r = 0.742) and SCW (r = 0.667). In chemical traits, TSS was more correlated to FD and FlW (r = 0.406; r = 0.430). Ratio TSS:TA were negatively correlated (r = -799) to TA. AA content had a negative correlation (r = -0.414) with FW. Total sugars were correlated to NRS (r = 0.897) as shown in Table 4.

Genotypic variability for fruit traits: Physical traits (FL, FL:FD, FW) and chemical traits (TSS:TA, NRS and RS) remained consistently higher in cv. Pyriform while TA and AA contents were higher in cv. Round suggesting that these traits were more genotype dependent and less influenced by the environmental changes (Table 5).

Seasonal and yearly variability for fruit traits: Most of the physical traits (FL, FD, ratio FL:FD, FlW, SCW and FW) and chemical traits (TSS, TA, RS and TS) remained higher across winter seasons compared with summer seasons in both

Table 2. Pearson's correlation coefficients among environmental components

Variables	Temperature (°C)	RH (%)	Rainfall (mm)	Sunshine (h)
Temperature	1.000			
RH	-0.892*	1.000		
Rainfall	0.820^{NS}	-0.969**	1.000	
Sunshine	0.554^{NS}	-0.223^{NS}	0.009^{NS}	1.000

^{NS} = Non-significant; * = Significant (P<0.05); ** = Highly significant (P<0.01)

Table 3. Pearson's correlation coefficients among environmental components, physical and chemical traits in Round (R) and Pyriform (P) cultivars

Traits		Temperature (°C)		RH (%)		Rainfall (mm)		Sunshine (h)	
		R	P	R	P	R	P	R	P
Physical Traits	FL	-0.749^{NS}	-0.797^{NS}	0.685^{NS}	0.705^{NS}	-0.637^{NS}	-0.596^{NS}	-0.445^{NS}	-0.625^{NS}
	FD	-0.691^{NS}	-0.790^{NS}	0.670^{NS}	0.691^{NS}	-0.621^{NS}	-0.595^{NS}	-0.395^{NS}	-0.601^{NS}
	FL:FD	**-0.890***	-0.735^{NS}	0.697^{NS}	0.701^{NS}	-0.662^{NS}	-0.514^{NS}	-0.541^{NS}	-0.721^{NS}
	FW	-0.570^{NS}	-0.802^{NS}	0.722^{NS}	**0.881***	-0.781^{NS}	**-0.897***	0.077^{NS}	-0.145^{NS}
	FlW	-0.536^{NS}	-0.811^{NS}	0.685^{NS}	0.871^{NS}	-0.728^{NS}	-0.855^{NS}	0.038^{NS}	-0.250^{NS}
	SCW	-0.635^{NS}	-0.677^{NS}	0.782^{NS}	0.808^{NS}	**-0.895***	**-0.916***	0.216^{NS}	0.185^{NS}
	FlW:SCW	-0.009^{NS}	-0.198^{NS}	0.021^{NS}	0.012^{NS}	0.082^{NS}	0.225^{NS}	-0.328^{NS}	-0.844^{NS}
Chemical Traits	TSS	-0.651^{NS}	-0.465^{NS}	0.785^{NS}	0.416^{NS}	-0.688^{NS}	-0.431^{NS}	-0.340^{NS}	-0.215^{NS}
	TA	-0.487^{NS}	-0.548^{NS}	0.374^{NS}	0.306^{NS}	-0.140^{NS}	-0.222^{NS}	-0.842^{NS}	-0.650^{NS}
	TSS:TA	0.401^{NS}	0.485^{NS}	-0.103^{NS}	-0.104^{NS}	-0.128^{NS}	-0.057^{NS}	**0.976****	**0.920***
	AA	-0.176^{NS}	0.582^{NS}	0.166^{NS}	-0.629^{NS}	-0.045^{NS}	0.431^{NS}	-0.435^{NS}	0.623^{NS}
	RS	0.709^{NS}	0.020^{NS}	-0.645^{NS}	-0.295^{NS}	0.637^{NS}	0.510^{NS}	0.213^{NS}	-0.807^{NS}
	NRS	-0.828^{NS}	-0.774^{NS}	0.800^{NS}	0.487^{NS}	-0.843^{NS}	-0.360^{NS}	-0.115^{NS}	-0.832^{NS}
	TS	**-0.908***	-0.709^{NS}	0.868^{NS}	0.494^{NS}	**-0.884***	-0.370^{NS}	-0.223^{NS}	-0.755^{NS}

^{NS} = Non-significant; * = Significant (P<0.05); ** = Highly significant (P<0.01); Abbreviations: FL, fruit length; FD, fruit diameter; FL:FD, ratio fruit length to fruit diameter; FW, fruit weight; FlW, flesh weight; SCW, seed cavity weight, FlW/SCW, ratio flesh weight to seed cavity weight; TSS, total soluble solids; TA, titratable acidity, TSS/TA, ratio total soluble solids to titratable acidity; AA, ascorbic acid, TS, total sugars; RS, reducing sugars and NRS, non-reducing sugars.

Table 4. Pearson's correlation coefficients among fruit physical and chemical traits

Traits		**Physical traits**								**Chemical Traits**				
		FL	**FD**	**FL:FD**	**FlW**	**SCW**	**FlW:SCW**	**FW**	**TSS**	**TA**	**TSS:TA**	**AA**	**RS**	**NRS**
Physical traits	FD	**0.881****												
	FL:FD	0.512**	0.050											
	FlW	**0.755****	**0.742****	0.238**										
	SCW	0.467**	0.421**	0.213**	**0.667****									
	FlW:SCW	0.373**	0.403**	0.062	0.434**	-0.337**								
	FW	0.128	0.044	0.173*	0.287**	0.367**	-0.060							
Chemical traits	TSS	0.383**	0.406**	0.049	**0.430****	0.371**	0.094	0.014						
	TA	0.246**	0.339**	-0.107	0.178*	-0.045	0.232**	-0.341**	0.409**					
	TSS:TA	-0.177*	-0.206*	0.002	-0.001	0.204*	-0.211**	0.336**	0.013	**-0.799****				
	AA	-0.086	0.032	-0.224**	0.013	-0.060	0.069	**-0.414****	0.189*	0.383**	-0.262**			
	RS	-0.012	0.104	-0.207*	-0.014	-0.173*	0.189*	-0.178*	0.020	0.051	-0.005	0.123		
	NRS	0.382**	0.307**	0.259**	0.249**	0.239**	0.057	0.310**	0.197*	-0.021	-0.022	-0.296**	0.024	
	TS	0.360**	0.308**	0.216**	0.234**	0.194*	0.092	0.251**	0.199*	-0.026	-0.008	-0.222**	0.284**	**0.897****

^{NS} = Non-significant; * = Significant (P<0.05); ** = Highly significant (P<0.01); Abbreviations: FL, fruit length; FD, fruit diameter; FL:FD, ratio fruit length to fruit diameter; FW, fruit weight; FlW, flesh weight; SCW, seed cavity weight, FlW/SCW, ratio flesh weight to seed cavity weight; TSS, total soluble solids; TA, titratable acidity, TSS/TA, ratio total soluble solids to titratable acidity; AA, ascorbic acid, TS, total sugars; RS, reducing sugars and NRS, non-reducing sugars.

Table 5. Genotypic variation for physical and chemical traits among Round (R) and Pyriform (P) cultivars in summer and winter seasons

Traits		**Cultivars**	**Summer**	**Winter**	**Means**
Physical traits	**FL (mm)**	R	50.72±1.29	66.26±2.04	60.04±1.59
		P	55.70±1.13**	71.07±1.70^{NS}	64.92±1.41*
	FD (mm)	R	51.96±1.07^{NS}	63.14±1.68^{NS}	58.67±1.26^{NS}
		P	50.58±1.04	62.78±1.54	57.90±1.22
	FL:FD	R	0.97±0.01	1.05±0.02	1.02±0.11
		P	1.10±0.01**	1.14±0.01**	1.12±0.01**
	FW (g)	R	84.05±4.30^{NS}	94.49±7.44	72.19±4.89
		P	78.79±4.12	109.32±3.10*	97.11±3.02**
	FlW (g)	R	63.69±3.47^{NS}	80.55±3.45^{NS}	73.81±2.41^{NS}
		P	58.33±3.41	82.50±2.49^{NS}	72.83±2.43
	SCW (g)	R	20.36±0.99	25.27±0.79	23.31±0.68
		P	20.46±1.12^{NS}	26.82±0.96^{NS}	24.28±0.58^{NS}
	FlW:SCW	R	3.17±0.11^{NS}	3.21±0.11^{NS}	3.20±0.81^{NS}
		P	2.99±0.16	3.17±0.09	3.09±0.08
Chemical traits	**TSS (Brix)**	R	8.64±0.22^{NS}	9.98±0.21^{NS}	9.44±0.17^{NS}
		P	8.57±0.24	9.46±0.22	9.10±0.17
	TA (%)	R	0.45±0.03**	0.71±0.04**	0.61±0.03**
		P	0.34±0.01	0.44±0.02	0.40±0.01
	TSS:TA	R	23.67±2.46	15.63±0.83	18.85±1.18
		P	26.61±1.28^{NS}	22.51±0.80**	24.15±0.73**
	AA (mg)	R	186.89±5.41^{NS}	193.26±3.36**	190.71±2.96**
		P	176.60±3.46	155.71±4.20	164.07±3.09
	RS (%)	R	2.92±0.07*	2.78±0.07	2.84±0.05^{NS}
		P	2.71±0.07	2.72±0.06^{NS}	2.72±0.04
	NRS (%)	R	2.74±0.09	3.75±0.09	3.35±0.08
		P	2.95±0.15^{NS}	4.62±0.15**	3.95±0.14**
	TS (%)	R	5.73±0.10	6.65±0.10	6.28±0.09
		P	6.21±0.143**	7.51±0.18**	6.99±0.14**

Values are means of three biological replicates (n=30) ± standard error in each cultivar; NS = Non-significant (P>0.05); * = Significant (P<0.05); ** = Highly significant (P<0.01); Abbreviations: FL, fruit length; FD, fruit diameter; FL:FD, ratio fruit length to fruit diameter; FW, fruit weight; FlW, flesh weight; SCW, seed cavity weight, FlW/SCW, ratio flesh weight to seed cavity weight; TSS, total soluble solids; TA, titratable acidity, TSS/TA, ratio total soluble solids to titratable acidity; AA, ascorbic acid, TS, total sugars; RS, reducing sugars and NRS, non-reducing sugars.

cultivars, however, ratio TSS:TA was more during summer seasons (Table 6). AA content was higher during summer seasons in cv. Round and during winter season in cv. Pyriform. Overall, physical traits like fruit size (FL, FD, FL:FD), fruit weight (FlW and SCW) and chemical traits including TSS, TA, NRS and TS remained consistently higher

Table 6. Seasonal variability among summer (s) and winter (w) seasons for fruit physical and chemical traits in guava cultivars

Traits		Seasons	Round	Pyriform	Means
Physical traits	FL (mm)	S	50.72±1.29	55.70±1.13	53.21±0.91
		W	69.46±2.04**	74.83±1.70**	68.67±1.35**
	FD (mm)	S	51.96±1.07	50.58±1.04	51.27±0.74
		W	66.26±1.68**	65.56±1.54**	62.96±1.13**
	FL:FD	S	0.97±0.01	1.10±0.01	1.04±0.01
		W	1.05±0.02**	1.14±0.01^{NS}	1.09±0.01**
	FW (g)	S	83.78±4.30	78.79±4.12	81.42±2.97
		W	92.98±7.44*	112.35±3.10**	107.57±4.66**
	FlW (g)	S	63.69±3.47	58.33±3.41	61.01±2.44
		W	85.57±3.45**	86.26±2.49**	81.53±2.12**
	SCW (g)	S	20.36±0.99	20.46±1.12	20.41±0.74
		W	24.84±0.79**	26.09±0.96**	26.05±0.62**
	FlW:SCW	S	3.17±0.11	2.99±0.16	3.08±0.10
		W	3.21±0.11^{NS}	3.38±0.09*	3.19±0.07^{NS}
Chemical traits	TSS (Brix)	S	8.64±0.22	8.57±0.24	8.60±0.16
		W	10.57±0.21**	9.72±0.22**	9.72±0.15**
	TA (%)	S	0.45±0.03	0.34±0.01	0.39±0.02
		W	0.87±0.04**	0.46±0.02**	0.58±0.02**
	TSS:TA	S	23.67±2.46**	26.61±1.28**	25.14±1.39**
		W	12.31±0.83	21.81±0.80	19.07±0.68
	AA (mg)	S	186.89±5.41	176.60±3.46**	181.75±3.25^{NS}
		W	203.45±3.36*	144.82±4.20	174.48±3.33
	RS (%)	S	2.92±0.07	2.71±0.07	2.82±0.05^{NS}
		W	2.84±0.07^{NS}	2.75±0.06^{NS}	2.75±0.04
	NRS (%)	S	2.74±0.09	2.95±0.15	2.85±0.09
		W	3.45±0.09**	4.79±0.15**	4.18±0.10**
	TS (%)	S	5.73±0.10	6.21±0.14	5.97±0.09
		W	6.47±0.10**	7.81±0.18**	7.08±0.11**

Values are means of three biological replicates (n = 90 samples) ± standard error in each cultivar; NS = Non-significant (P>0.05); * = Significant (P<0.05); ** = Highly significant (P<0.01); Abbreviations: FL, fruit length; FD, fruit diameter; FL:FD, ratio fruit length to fruit diameter; FW, fruit weight; FlW, flesh weight; SCW, seed cavity weight, FlW/SCW, ratio flesh weight to seed cavity weight; TSS, total soluble solids; TA, titratable acidity, TSS/TA, ratio total soluble solids to titratable acidity; AA, ascorbic acid, TS, total sugars; RS, reducing sugars and NRS, non-reducing sugars.

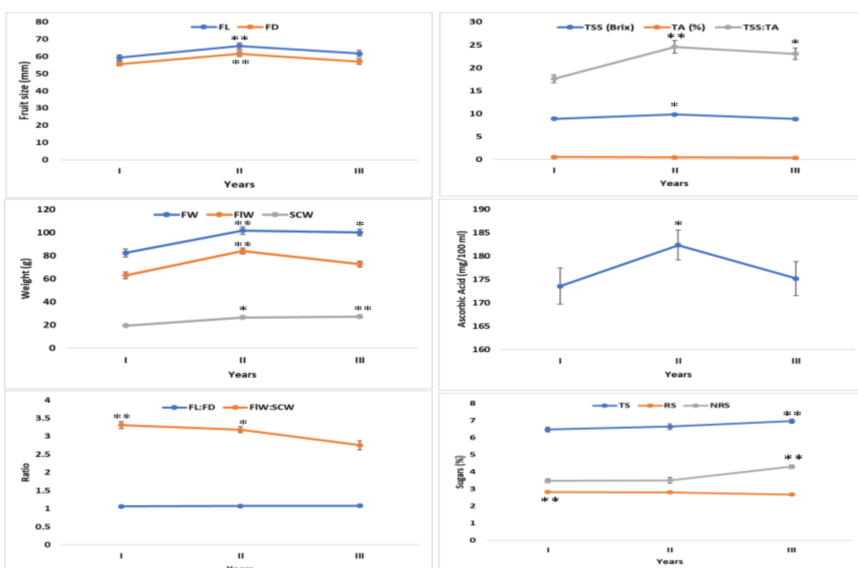

Figure 1. Yearly variability in fruit physico-chemical traits in guava cultivars

Values are means of three biological replicates (n = 90 samples). Error bars show standard error in each parameter. Abbreviations: FL, fruit length; FD, fruit diameter; FL:FD, ratio fruit length to fruit diameter; FW, fruit weight; FlW, flesh weight; SCW, seed cavity weight, FlW/SCW, ratio flesh weight to seed cavity weight; TSS, total soluble solids; TA, titratable acidity, TSS/TA, ratio total soluble solids to titratable acidity; AA, ascorbic acid, TS, total sugars; RS, reducing sugars and NRS, non-reducing sugars. * = Significant (P<0.05); ** = Highly significant (P<0.01).

during winter seasons while TSS:TA remained higher during summer seasons suggesting this trait may be regulated with higher SS, temperature, RF and low RH conditions prevailing during summer seasons (Table 6).

Among yearly variations, physical traits including fruit size (FL, FD), fruit weight (FW and FlW) and chemical traits (TSS, TSS:TA, AA) were greater during year II and FL:FD was higher in year I whereas FlW:SCW remained stable with no significant variation. Traits including SCW, TS and RS were greater in Year III compared with years I and II (Fig. 1).

DISCUSSION

Like other fruit crops, guava is also heterozygous, hence genotype x environment interaction has been high. Stable genotypes shall be preferred which can withstand diverse agro-climatic conditions (Dinesh and Reddy, 2012). Genotypes and environmental components altered fruit quality attributes in crops like peach (De Souza *et al*., 1998), blueberry (Connor *et al*., 2002) and grape (Shiraishi *et al*., 2012). The behavior of different crops was different under diverse climatic conditions. The data available in literature for guava comprised of two seasons having mild climatic conditions thus limiting its generality and precision in prediction of crop behavior under contrasting climates. Hence, data generated in the current study under distinct climatic conditions appeared better in precision and usefulness.

Guava fruit quality attributes were more likely to be affected by change in the environmental components like temperature, RF patterns and RH across seasons and were least affected by the seasonal variation in SS or day length. Generally mild temperatures result in better quality fruit however, higher temperatures could be deteriorating. In the present study, temperature inversely affected fruit size (FL:FD) and total sugars in cv. Round indicting its higher sensitivity to temperature variations compared with cv. Pyriform. Similarly, low temperature induced increase in FS and TS was found during years I-III. Similar inverse relationship of temperature to TSS and dry mass (%) was reported in grapes. Fruit quality was positively related to warm and dry weather (Hoppula and Karhu, 2006). In guava, high temperature and moisture developed higher TSS like mango and papaya (Dinesh and Reddy, 2012). In contrast, TSS was not correlated to temperature, RF and RH in this study. Rather, TSS:TA was positively correlated to SS.

Higher moisture content decreases TS in fruit crops. Higher irradiance enhances transpiration rate leading to enhanced influx of water and essential nutrients to fruit that enhances rate of fruit growth (Naizaque *et al*., 2014). In guava, traits like SCW and TS were inversely correlated to RF. This demonstrates that variable development of SCW across seasons and years is regulated by changing RF patterns and its interplay with the temperature. SCW showed genotypic independence, however, it varies across seasons and years. Decrease in RF and increase in RH enhanced FW in cv. Pyriform and overall in year I and II, indicating existence of a strong environment x genotype interaction. Contrary to this study, higher RF and RH enhanced FW in pineapple guava (Parra-Coronado *et al*., 2015) which may be attributed to differences in specie and climatic conditions. Similar genotype to environment interaction was reported by Aguero *et al*. (2015) in strawberry where temperature was negatively correlated to FW. Fruit size and weight were more at higher altitudes with high radiation and low temperatures in grapes (Regina *et al*., 2010) and Cape gooseberry (Fischer *et al*., 2007). Conclusively, low temperature enhanced fruit size and TS while low RF increased FW, SCW and TS. Higher RH and more SS also enhanced FW and TSS:TA. The interplay and correlations of the key environmental components to fruit quality attributes underpin the key fruit growth regulating factors across seasons and years. Like our findings, FW, TSS and TA were higher in different fruits grown at low temperatures (Benkeblia and Tennant, 2011). TSS of pineapple guava produced in areas with low temperature and RH was higher (Parra-Coronado *et al*., 2015). Acidity (TA) was influenced by cumulative radiation during fruit growth (Martinez-Vega *et al*., 2008). Highest TSS was recorded corresponding to the lowest RF and RH and highest radiation (Benkeblia and Tennant, 2011). In contrast, RF was highly associated with variation in TS than TSS in the current study. Traits like FD, FlW, SCW, TSS and RS remained highly stable and genotype independent across contrasting multiple summer and winter seasons. Similarly, yearly data depicted FlW:SCW and TA as relatively stable traits suggesting more usefulness of these traits for selection and varietal characterization for fruit quality attributes. In contrast, higher genotypic effects were reported for FLW, SCW, TSS, TA and AA in dessert type white flesh guava cultivars based on two season's data (Thaipong and Boonprakob, 2005). Genotypic variability in FW, TSS and TA was also reported in Strawberry (Aguero *et al*., 2015). In present study acid contents (TA, AA) were consistently higher in cv. Round while other fruit quality attributes remained higher in cv. Pyriform across seasons. These findings suggest that genetic gain could be achieved through classical breeding for genotype dependent traits showing considerable variation across seasons.

Guava fruit showed higher seasonal and yearly variability and fruit physico-chemical traits were highly affected by the seasonal and annual climatic shifts. Most of the physical and chemical traits were higher during winter seasons compared with the summer seasons. Similarly, most of the physical traits and TSS:TA and AA contents were higher in year II whereas SCW, TS and RS were greater in year III. During winter seasons, guava fruit growth remained slow due to prevalence of low temperature, less RF, higher RH and shorter day length however, fruit size, weight, quality and yield were higher. In contrast, a rapid fruit growth accompanied with low yield was observed during summer seasons owing to higher temperature, long days and higher RF.

Strong negative correlations of temperature with FL:FD, TS and RF with FW and SCW observed in this study demonstrates why fruit growth and quality was better in winter compared with summer season. Greater fruit size and FW during winter seasons could also be attributed to low temperature and less SS that reduces excessive loss of respiratory substances and increases translocation of photosynthates to other parts of plant particularly in fruits leading to better quality fruit. Similarly, a negative correlation of higher summer temperature with low fruit yield was reported in black currant (Woznicki *et al*., 2015). SCW was negatively correlated to RF patterns and remained higher during winter seasons having low seasonal RF. Relative humidity showed a positive correlation with FW and was higher during winter seasons compared with summer seasons. Chemical traits were higher in winter season (mean max/min air temperature 31.8/20.8°C) and physical traits were higher in summer season (mean max/min air temperature 33.6/24.5°C) in guava based on one-year data (Thaipong and Boonprakob, 2005). In contrast, mean temperatures in the present study were contrastingly much higher under summer conditions (warmer) and much lower under winter conditions (cooler). Similar variability of annual mean temperature was found in the yearly data. Hence, these differences in physical and chemical traits of the two studies on guava could be attributed to contrasting seasonal conditions and differences in the cultivars used.

Seasonal and yearly variability for FW, TSS and TA was also reported in Strawberry (Aguero *et al*., 2015). However contrary to our findings, FW was higher with early ripening during summer season due to higher temperature compared with winter season. Similar faster fruit development was also reported in pineapple guava during summer season due to higher temperatures compared with winter season (Parra-Coronado *et al*., 2015).

Acid contents (TA and AA) were higher during summer seasons and did not show correlation with any environmental component. Ratio TSS:TA remained higher during summer seasons and showed strong positive genotype independent correlation with SS. In contrast, ascorbic acid concentration was negatively related to temperature and positively related to precipitation in black currant during summer season (Woznicki *et al*., 2015). Total sugars (TS) were higher during winter seasons and were negatively correlated to temperature and RF suggesting rise in temperature and RF decreases TS in fruit. Likewise, a low total sugar content was reported in grapes under high temperature and higher rain fall during summer seasons (Shiraishi *et al*., 2012). Warm and dry summer season enhances TS accumulation compared with warm and wet summer season. Chemical trait, RS was highly stable across seasons and genotypes suggesting this trait could be useful for selection in breeding programs.

Conclusions: Higher correlations of different genotypes, key fruit traits and environmental components revealed existence of a higher genotype x environment interplay which contributed to contrasting changes in fruit size, shape and quality. Most of the physical and chemical traits were higher in cv. Pyriform compared with cv. Round except TA. Among seasons, most of the physical and chemical traits remained consistently higher during winter seasons compared with summer seasons excluding acid contents. Traits like FD, FLW, SCW, TSS remained highly stable across genotypes and RS was least affected across contrasting summer and winter seasons. In yearly evaluations, most of the physical and chemical traits were variable whereas FlW:SCW and TA remained stable. Evaluation of guava fruit quality attributes across several seasons provided precise estimates of genotypic and seasonal variations in fruit quality. These findings in elite indigenous varieties could be highly useful for identification of the fruit traits that remain stable or variable in contrasting environmental conditions for utilization in guava breeding programs.

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