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Variation in fruit chemical and mineral composition of Kenyan guava (*Psidium guajava* L.): Inferences from climatic conditions, and fruit morphological traits

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Summary

There is limited knowledge about the impact of climatic conditions and fruit morphological traits on the nutritional composition of the guava fruit. Fruits were gathered from 128 guava trees across four geographically diverse regions of Kenya. The fruits were morphologically characterized and analysed for their chemical and mineral composition. The ascorbic acid content correlated positively only with total annual precipitation, while total soluble solids (TSS) correlated positively with mean annual temperature. TSS correlated negatively with pulp weight and was higher in white-fleshed fruits than in the red-fleshed types. The mineral content of the fruits correlated negatively with most of the fruit weight- and size-based morphological traits, as well as with the total annual precipitation, but positively with fruit seed proportion. This information could act as a guide in the selection of specific regions for upscaling guava production and aid in the selection of accessions for improvement programmes that enhance guava fruit nutritional composition.

Key words: ascorbic acid, fruit minerals, guava, *Psidium guajava* L., pulp colour, TSS

Introduction

Tropical fruits have considerable importance for developing countries from both nutritional and economic perspectives, with about 90% of these fruits being consumed in their countries of origin, while 10% are traded internationally as fresh fruits and processed products (Available: http://www.fao.org/docrep/meeting/028/ma937e.pdf – Accessed 22.02.2019). Despite some efforts seen in the production of tropical fruits such as mangoes and avocados, the opportunities to grow, consume, and export more fruits from tropical regions remain under-exploited compared to those in temperate regions (Griesbach, 2007). For instance, the supply of fruits and vegetables in lower-income countries fall on average 58% short based on nutritional recommendations (Siegel et al., 2014). Consequently, low-quality nutritionally unbalanced diets are common in these regions, leading to high risks of nutrient deficiencies (Arimond et al., 2010). Research to improve fruit production, therefore, offers tremendous opportunities for raising the incomes of small-scale farming families in these regions while also improving their nutritional status, as observed by Keding et al. (2017).

Guava (*Psidium guajava* L.) is an important tropical fruit tree grown mainly for its edible fruits which are eaten raw or made into purée (pulp), jam, jelly, paste, juice, syrup, chutney, among other products (Leite et al., 2006). The guava tree is cultivated in orchards and in home gardens in many tropical countries (CABI, 2013). In Kenya, for example, the guava tree exists in all regions of the country (HCD, 2014) and mainly grows unattended. Despite the lack of attention to guava tree husbandry, guava fruit production in Kenya has recently seen an increase (HCD, 2014). However, most of these guava fruits are collected from the wild, and not much effort is put to improve tree husbandry and the production potential (Mbuvi and Boon, 2009).

Recent studies have reported an appreciable amount of antioxidant phytochemicals including ascorbic acid, carotenoids, flavonoid compounds and polyphenols in the guava fruit (Araújo et al., 2015, Flores et al., 2015; Gull et al., 2012), which are essential dietary components (Flores et al., 2013). Besides, guava has been reported to contain substantial amounts of minerals such as K, P, and Ca (Ogoloma et al., 2013; Natale et al., 2007), which could significantly contribute to meeting a person's daily dietary requirements. Detailed nutritional evaluation of guava for other mineral nutrients such as Fe and Zn is still needed.

The nutritional composition of a fruit reflects the geographic region where the fruit tree grows and the mineral composition of the soil there (Wall, 2006; Forster et al., 2002). The traits also vary with climate (Rodriguez-Amaya et al., 2008), fruit maturity (Gull et al., 2012), and cultivar (Burlingame et al., 2009; Toledo and Burlingame, 2006a). Soil quality determines the sustainability and productivity of any agro-ecosystem (Forster et al., 2002). Hence, the growth and development of a plant is a function of the soil-plant interaction and the prevalent weather conditions (Haque et al., 2009). The nutritional composition of fruits may thus vary from continent to continent, from country to country, as well as from region to region within the same country due to changes in climatic conditions (Haque et al., 2009) and soil quality parameters. However, there is limited data on the nutrient content of the guava fruit in relation to these variables (Natale et al., 2007).

The objectives of this study were as follows: (1) to characterize and correlate the variation in the fruit chemical and mineral composition of guava with climatic variables (temperature and precipitation), and (2) to determine if the fruit morphological traits (flesh colour, and size- and weight-based traits) influence the chemical and mineral composition of the guava fruit and if they could be correlated. It is assumed that variations in fruit chemical and mineral composition are correlated to climatic and fruit morphological traits, which lead to their differences in guava fruits. The information would help establish the species' actual and potential contributions to nutritional security, especially in relation to these factors.

Materials and methods

Sampling

The regions for sampling in Kenya were chosen based on their high guava fruit production trends (HCD, 2014). Fruit sampling was carried out between September and November 2015. This was when the fruits were available and ready for harvesting in the specific regions. With the help of key informants and field guides, the main guava-producing locations within the regions were identified. Households

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and institutions were randomly selected within these locations, and trees with ripe fruits were targeted for fruit collection. The geographical locations of the trees were recorded with a handheld Global Positioning System (GPS) (Tab. S1). The latitudes and longitudes also enabled the retrieval of the mean annual temperature and annual precipitation data from WorldClim—Global Climate Data: http://www.worldclim.org/bioclim (FICK and HIJMANS, 2017) for individual accessions (Tab. S1). Fig. S1 shows the monthly meteorological data (temperature, relative humidity [RH], and precipitation) based on the nearest meteorological station within the regions. Healthy and clean fruits from 128 trees were collected from the Coast (36 trees), Eastern (12 trees), Rift Valley (19 trees), and Western (61 trees) regions (Fig. 1).

Fruit morphological characterization

A descriptor list for mango (IPGRI, 2006) was modified to accommodate guava fruit traits for characterization. The modification also considered the results of other guava characterization studies (e.g. SINGH et al., 2015; MEHMOOD et al., 2014; NASUTION and HADIATI, 2014; SHARMA et al., 2010) and the authors' own observations. Twenty fruits per tree were randomly collected for measurements in the laboratory at the World Agroforestry Centre (ICRAF), Nairobi. During morphological fruit characterization, fruits that were found to be infested by maggots and could only be discovered after longitudinal dissection were not characterized. This reduced the number of accessions for morphological characterization. As the minimum number of fruits for size- and weight-based fruit morphological characterization was set to be at least 20, the characterization was eventually carried out for fruits from 105 trees (Coast = 23, Eastern = 12, Rift Valley = 17, and Western = 53), except for the characterization of fruit flesh colour, for which at least one fruit per tree was used. Therefore, all the 128 trees were used for the determination of flesh colour. Fig. 2 depicts the fruit and the various fruit parts which were measured.

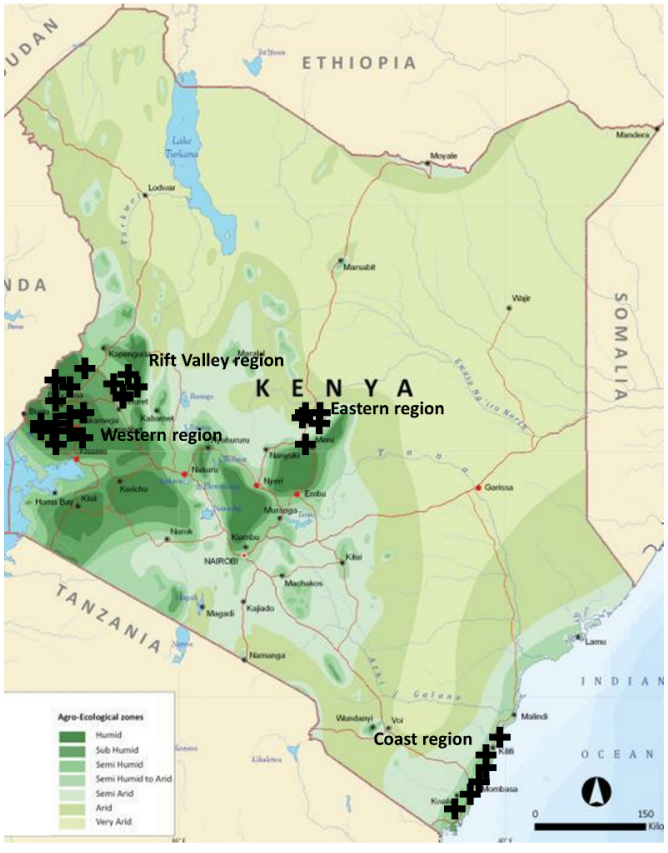

Fig. 1: Sample collection locations for guava accessions (crosses) from four regions of Kenya with Coast = 36, Eastern = 12, Rift Valley = 19, and Western = 61.

Determination of fruit chemical and mineral composition

Since the chemical and mineral characterization of the fruits considered between five to 20 healthy and undamaged ripe fruits, fruits from all the 128 trees were characterized for their chemical and mineral content. The ripeness of the fruits was determined as the yellow colour of the skin based on the colour chart of the Royal Horticultural Society besides the softness of the fruits to touch (ARAÚJO et al., 2015; GULL et al., 2012). The fruits were cleaned and separated into skin, pulp, and seeds, while the edible portion (pulp plus skin) was divided into two sub-samples. One fresh sample was used for the analysis of ascorbic acid content, TSS, and titratable acidity (TA) immediately after processing. The other sub-sample was weighed and then freeze-dried. The freeze-dried sample was weighed again to determine the percentage of water loss. The sample was later used to analyse the protein, sugar (glucose and fructose), phenolic compounds, and mineral contents. All the results were expressed in fruit fresh weight (FW).

Fruit chemical analyses based on fresh weight

The content of ***ascorbic acid*** was determined in fresh samples by reduction with 2,6-dichloroindophenol solution to a colorless dye using the titration method according to the procedure developed by PUWASTIEN et al. (2011). For better precision, the samples were measured titrimetrically.

TSS was measured by placing a few drops of guava juice squeezed from fresh fruits on a handheld refractometer. The values were read directly as % brix.

TA was determined on the extracted guava juice from fresh fruits by titrating to a pH of 8.1 by adding 0.1N NaOH according to the method by LMBG (1983). The result was expressed as mg of citric acid per 100 g of sample.

Fruit chemical and mineral analyses based on freeze-dried weight

The ***phenolic compounds*** were extracted from 0.25 g of freeze-dried sample by adding 5 ml of 80% ethanol in a falcon tube. The tube was thoroughly vortexed and then centrifuged at 5,000 g for 10 minutes. The supernatant was transferred to a 10-ml flask. The extraction was repeated and the supernatants combined. The flask was then filled up to the 10-ml mark with 80% ethanol. The amount of the phenolic compounds was estimated in triplicate photometrically at 735.8 nm, immediately after extraction with the Folin-Ciocalteu reagent and expressed as mg per gallic acid equivalent (mg/GAE), following the protocol developed by SINGLETON and ROSSI (1965).

Sugars (glucose and fructose) were extracted from 200 mg of freeze-dried and milled guava fruit samples by adding 8 ml of pure water, vortexing, and then shaking the samples for one hour. Thereafter, 0.5 ml of 0.25 M Carrez I (containing potassium hexacyanoferrate (II) trihydrate, $K_4[Fe(CN)_6]\cdot 3H_2O$) and 0.5 ml of 0.09 M Carrez II (containing zinc sulphate heptahydrate, $ZnSO_4\cdot 7H_2O$) were added to each sample and mixed by vortexing. The tubes were then centrifuged at 5,000 rpm for 20 minutes and the supernatant transferred into 25 ml volumetric flasks. The extraction was repeated by adding 7 ml of pure water. The volumetric flasks were then filled up to the 25-ml level and the extract filtered into scintillation vessels. Soluble carbohydrates were separated according to the procedure used by KEUTGEN and PAWELZIK (2008), and the sugar content (glucose and

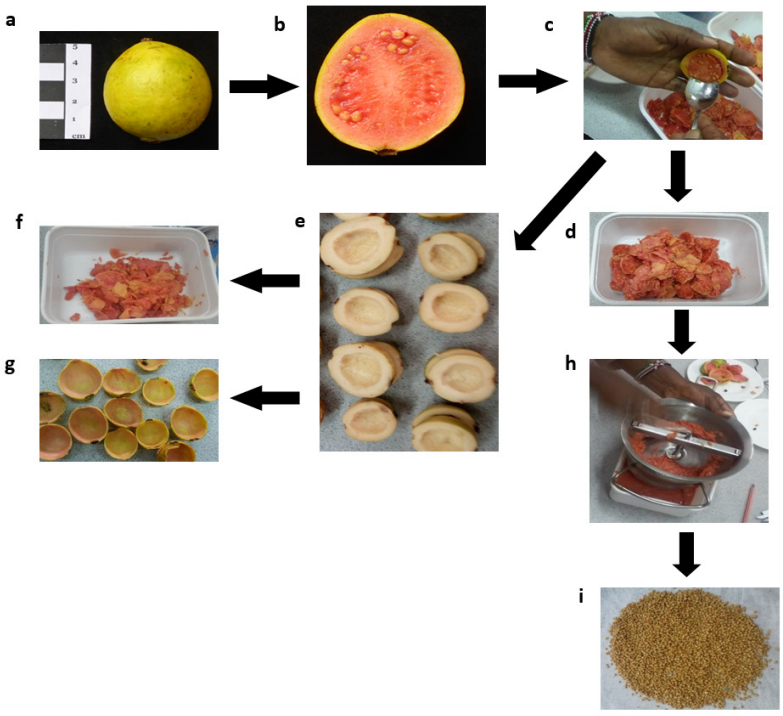

Fig. 2: Guava fruit and fruit parts used in morphological characterization: **(a)** entire guava fruit, **(b)** fruit longitudinally cut into two parts, **(c)** pulp and seed removed with a spoon, **(d)** seed and pulp, hence their combined weight measured **(e)** pericarp, hence pericarp thickness and weight measured, **(f)** mesocarp removed from pericarp with a spoon and weight measured, **(g)** fruit exocarp/skin after removing the mesocarp, thickness and weight measured, **(h)** seed and pulp separated by a fruit mill and pulp weight measured, and **(i)** guava seeds washed and dried for weighing.

fructose) detected by High-Performance Liquid Chromatography (HPLC) (Jasco, 26600 Mary's Court Easton, MD 21601).

Proteins were extracted using the phenol protocol developed by FAUROBERT et al. (2007) on 200 mg of milled freeze-dried samples. The proteins were measured photometrically, each in three replications, according to BRADFORD (1976).

Fruit mineral contents – namely calcium (Ca), magnesium (Mg), potassium (K), sodium (Na), phosphorus (P), sulphur (S), iron (Fe), boron (B), zinc (Zn), and copper (Cu) – were extracted from 100 mg of each milled freeze-dried sample according to the procedure developed by WHEAL et al. (2011), and determined using inductively coupled plasma atomic emission spectroscopy (ICP-AES) (Vista-RL ICP-OES, Varian Inc., USA).

Data analysis

Analysis of variance, mean separation, and correlation analyses for fruit traits were conducted using SPSS (version 20.0) (IBM, 2011). The test for normality and the resulting histograms showed that the data for morphological traits and fruit chemical composition was slightly skewed to the right. Therefore, these datasets were log transformed to make the distribution normal. The data was thus analysed by analysis of variance (ANOVA), followed by either a post hoc Tukey test or independent sample t-test for mean separation. Regarding the fruit chemical and mineral composition, analysis was first done per region to check for regional variations. Next, mean annual temperature and annual precipitation data obtained from WorldClim–Global Climate Data: http://www.worldclim.org/bioclim (FICK and HIJMANS, 2017) for individual accessions was correlated to the fruit chemical and mineral composition data. Furthermore, the fruit chemical and mineral composition data was again tested for variation based on the colour of the fruit pulp and also correlated with the fruit morphological traits.

Results

Fruit chemical and mineral composition and morphological traits based on region and climate

The chemical and mineral composition and important morphological fruit traits of guava from the four mentioned regions of Kenya are provided in Tab. 1. The ascorbic acid content ranged between 10 mg/100 g FW and 360 mg/100 g FW, and was on average, highest in the Eastern region and lowest in the Rift Valley region. The Eastern region had 58% of the trees recording the ascorbic acid content of more than 100 mg/100 g FW, followed by Western (36%), Coast (19%), and Rift Valley (11%). On the other hand, TSS ranged between 6-20% brix with the highest mean value recorded at the Coast. Consequently, higher fructose values were also recorded in samples from the Coastal region, with the other regions recording similar lower values. However, the glucose content was higher and similar for the Rift Valley, Western, and Coastal regions. More than 79% of trees in each region had TSS values above 9% brix. The least TA values were recorded in fruits from the Rift Valley region, while the highest was in the Eastern region, although high variations were observed within regions. With regard to protein, mineral, and water content of the fruits, a significant variation among regions was observed, but also high variations were noted within regions.

Fruit weight was fairly uniform and did not differ among regions, but other fruit components like proportion of pulp and seed varied. The pulp proportion ranged between 11-48% of the total fruit fresh weight with the highest value being recorded in the Eastern region. Fruits from the Coastal and Western regions were seedier while those from the Rift Valley region were less seedy.

Tab. 2 shows a correlation of fruit chemical and mineral composition of individual accessions, with mean annual temperature and annual precipitation at their growth location. The ascorbic acid content correlated positively with annual precipitation (Fig. S2) but negatively with mean annual temperature. Similarly, the fruit water content cor-

Tab. 1: Fruit chemical and mineral composition, and morphological traits of 128 guava accessions sampled from four regions of Kenya

	Region of collection					
Fruit chemical and mineral composition	**Rift Valley (n=19)**	**Western (n=61)**	**Coast (n=36)**	**Eastern (n=12)**	**Mean (n=128)**	***p*-value**
Ascorbic acid (mg/100 g FW)	43.7^{c} (19%)	79.3^{ab} (13%)	48.5^{bc} (21%)	128.1^{a} (11%)	66.1 (18%)	< 0.001
Total Phenolic compounds(mg/100 g FW)	141.1^{a} (2%)	148.6^{a} (4%)	148.2^{a} (4%)	157.9^{a} (3%)	148.2 (4%)	0.425
TSS (% brix)	8.98^{c} (9%)	11.0^{b} (6%)	13.0^{a} (7%)	9.47^{c} (5%)	11.0 (9%)	< 0.001
TA (mg/100 g FW)	0.77^{c} (60%)	0.93^{bc} (55%)	0.98^{ab} (53%)	1.14^{a} (75%)	0.94 (64%)	< 0.001
Fructose (g/100 g FW)	2.42^{b} (20%)	2.62^{b} (22%)	3.64^{a} (15%)	2.25^{b} (17%)	2.81 (21%)	< 0.001
Glucose (g/100 g FW)	1.05^{ab} (28%)	0.99^{ab} (43%)	1.43^{a} (36%)	0.87^{b} (20%)	1.11 (39%)	< 0.004
Protein (mg/100 g FW)	1.42^{b} (18%)	1.48^{b} (27%)	1.68^{a} (19%)	1.38^{b} (16%)	1.52 (28%)	< 0.001
Ca (mg/100 g FW)	14.4^{a} (13%)	12.5^{a} (15%)	15.0^{a} (13%)	9.27^{b} (16%)	13.1 (15%)	0.001
K (mg/100 g FW)	259.1^{b} (6%)	267.7^{b} (7%)	393.3^{a} (4%)	239.3^{b} (4%)	293.7 (7%)	< 0.001
Mg (mg/100 g FW)	7.64^{b} (18%)	8.96^{b} (17%)	12.7^{a} (9%)	8.36^{b} (11%)	9.60 (17%)	< 0.001
Na (mg/100 g FW)	3.58^{a} (48%)	1.57^{b} (141%)	5.44^{a} (28%)	1.15^{b} (172%)	2.44 (91%)	< 0.001
P (mg/100 g FW)	17.5^{a} (11%)	11.3^{b} (17%)	18.1^{a} (10%)	10.7^{b} (12%)	13.7 (16%)	< 0.001
S (mg/100 g FW)	10.2^{b} (15%)	10.1^{b} (17%)	16.5^{a} (10%)	9.93^{b} (8%)	11.6 (17%)	< 0.001
Fe (mg/100 g FW)	0.45^{a} (11%)	0.27^{b} (6%)	0.37^{ab} (7%)	0.36^{ab} (9%)	0.33 (8%)	< 0.001
B (mg/100 g FW)	0.15^{c} (25%)	0.21^{b} (33%)	0.27^{a} (26%)	0.18^{bc} (18%)	0.21 (33%)	< 0.001
Zn (mg/100 g FW)	0.09^{ab} (0.8%)	0.04^{b} (0.9%)	0.11^{ab} (1.9%)	0.13^{a} (0.8%)	0.08 (1.3%)	0.006
Cu (mg/100 g FW)	0.13^{a} (12%)	0.11^{ab} (9%)	0.10^{ab} (4%)	0.07^{b} (4%)	0.11 (8%)	0.062
Water content (%)	86.3^{a} (0.7%)	85.1^{a} (1.2%)	78.4^{b} (1.5%)	88.4^{a} (0.5%)	83.6 (1.5%)	< 0.001
Fruit morphological trait	**Rift Valley (n=17)**	**Western (n=53)**	**Coast (n=23)**	**Eastern (n=12)**	**Mean (n=105)**	***p*-value**
Fruit weight (g)	46.4^{a} (8%)	48.9^{a} (10%)	41.9^{a} (10%)	51.9^{a} (9%)	47.2 (9%)	0.283
% Pulp	31.4^{ab} (10%)	27.5^{bc} (6%)	24.0^{c} (7%)	34.4^{a} (6%)	28.0 (8%)	0.001
% Seed	7.43^{b} (22%)	10.4^{a} (10%)	10.1^{a} (15%)	8.21^{ab} (20%)	9.52 (15%)	< 0.001

Values within the same row show the geometric mean (antilog of the transformed means), followed by the percent standard deviation of the log transformed means in parenthesis. The mean values in the same row followed by the same letter are not significantly different at $p < 0.05$ according to ANOVA followed by Tukey HSD pairwise comparisons. Ascorbic acid, TSS, and TA were determined on extracted juice from edible portion of the fruit, total phenolic compounds were determined from 0.25 g of freeze dried sample, fructose, glucose, and proteins were determined from 200 mg of freeze-dried sample, while minerals were determined from 100 mg of freeze-dried sample. Water content was determined as the difference between freeze-dried and fresh sample weights. Pulp proportion (% pulp), and seed proportion (% seed) are based on the weight of the entire fresh fruit (g).

related positively with annual precipitation, but it had a negative correlation with the mean annual temperature. However, TSS (see also Fig. S2), fructose, protein, and most of the fruit minerals (e.g. K, Mg, Na, P, S, and B) correlated positively with the mean annual temperature but negatively with annual precipitation.

Fruit chemical and mineral composition, and morphological traits based on pulp colour

The chemical and mineral composition of the fruits based on fruit pulp colour is depicted in Tab. 3. There was no variation in the ascorbic acid content of the fruits. However, the content of phenolic compounds of the red-fleshed fruits (151.0 mg/100 g FW) was significantly higher than that of the white-fleshed fruits (137.6 mg/100 g FW).

The TA did not vary with the fruit pulp colour, but the TSS of the rather few fruits with white pulp was significantly higher than that of fruits from the red-fleshed group (12.6% vs 10.7%). Similar to TSS, the fructose content was also higher in the white-fleshed fruits than in the red-fleshed fruits. There was no variation in the glucose content with regard to fruit pulp colour.

There was no variation in the fruit mineral contents of Ca, Fe, Zn, and Cu with respect to the fruit flesh colour. However, interestingly, the white-fleshed fruits were superior to the red-fleshed ones with regard to their protein content and the content of K, Mg, Na, S, P, and B. In contrast, the water content was higher in the pulpier red-fleshed group (84.4%) than in the less pulpy white-fleshed group (80.7%).

Correlation of fruit morphological traits and fruit chemical and mineral composition

Results of a correlation analysis of fruit chemical and mineral composition traits vs fruit morphological traits are presented in Tab. 4. Fig. S3 specifically depicts the correlation between pulp proportion and TSS, as well as seed proportion and fruit water content. The contents of ascorbic acid, TA, fructose, and glucose, as well as the fruit mineral concentrations of Zn and Cu, showed no correlation with the fruit morphological characteristics; hence, they are not depicted in Tab. 4.

Fruit weight generally correlated negatively with most fruit minerals and protein, but positively with fruit water content. The pericarp proportion correlated positively with TSS, but negatively with K. The proportion of the exocarp (fruit skin) correlated positively with TSS, fructose, Ca, and B, but negatively with the fruit water content. However, the percent mesocarp negatively correlated with the content of phenolic compounds, K, and B. The proportion of pulp negatively correlated with TSS, protein, Mg, Na, and B, but was found to have a positive correlation with the fruit water content. Seed proportion of the entire fruit positively correlated with TSS, fructose, protein and most minerals such as Ca, K, Mg, S, B, and Cu. Seed proportion however negatively correlated with the fruit water content.

Discussion

The effect of temperature and precipitation on fruit chemical and mineral composition

The mean ascorbic acid content of fruits from the 128 guava trees

Tab. 2: Pearson correlation coefficients between fruit chemical and mineral composition traits with annual mean temperature and annual precipitation based on the individual accession climatic data (Tab. S1) of 128 guava accessions

Fruit chemical and mineral composition	Climatic data	
	Mean annual temperature	Annual precipitation
Ascorbic acid	-0.22*	0.37***
Total phenolic compounds	ns	ns
TSS	0.36***	-0.31***
TA	ns	ns
Fructose	0.18*	-0.36***
Glucose	ns	-0.30***
Protein	0.35***	-0.47***
Ca	ns	-0.25**
K	0.30***	-0.45***
Mg	0.27**	-0.40***
Na	0.44***	-0.71***
P	0.21*	-0.54***
S	0.32***	-0.51***
Fe	ns	-0.32***
B	0.28**	-0.28**
Zn	ns	-0.24**
Cu	ns	ns
Water content	-0.38***	0.52***

***Correlation is significant at $p \leq 0.001$ level. **Correlation is significant at $p \leq 0.01$ level. *Correlation is significant at $p \leq 0.05$ level. ns = correlation was not significant at $p \leq 0.05$ level. Ascorbic acid, TSS, and TA were determined on extracted juice from edible portion of the fruit, total phenolic compounds were determined from 0.25 g of freeze dried sample, fructose, glucose, and proteins were determined from 200 mg of freeze-dried sample, while minerals were determined from 100 mg of freeze-dried sample. Water content was determined as the difference between freeze-dried and fresh sample weights.

from four Kenyan regions was 66.1 mg/100 g FW. According to food composition tables, the ascorbic acid content of guava is estimated to be 228.3 mg/100 g edible portion (LUKMANJI et al., 2008), which is higher than the observed value in our sample. The observed differences could be due to variation in the determination methods and the state of the sample at the time of analysis. The samples used in this study were partly transported over long distances to the laboratory and could only be analysed for ascorbic acid content the following day. However, variations ranging from 11% to 21% of the mean values were observed within the regions. Based on mean annual temperature and total annual precipitation data from WorldClim-Global Climate Data: http://www.worldclim.org/bioclim (FICK and HIJMANS, 2017) for individual accessions, annual precipitation correlated positively with the ascorbic acid content of the fruits in this study, while the mean annual temperature correlated negatively with the ascorbic acid content.

The effect of precipitation on the ascorbic acid content of guava has so far not been reported. However, GULL et al. (2012) determined the ascorbic acid content in the pulp and peel of fully ripe guava fruits from three diverse regions of Pakistan as ranging between 129.5 mg/100 g and 247.9 mg/100 g. The ascorbic acid composition of the fully ripe fruits was found to vary regionally, with higher values recorded in the higher-temperature regions (mean max./min. air temperature: 35/24 °C) than in moderate and colder areas (mean max./min. air temperature: 33/21 °C and 33/18 °C). The variation was attributed to climatic and soil factors. Contrarily, THAIPONG and BOONPRAKOB (2005) found higher contents of ascorbic acid in the slightly colder winter season (mean max./min. air temperature: 31.8/20.8 °C) rather than in the hot summer season (mean max./min. air temperature: 33.6/24.5 °C) in guava fruits grown in Thailand. The authors concluded that the effect of lower temperatures in winter during fruit development could not only retard the excessive loss of respiratory substrates but also increase the translocation of photosynthates to other parts of the plant, including the fruits. It should be noted that the mean annual temperature for individual accessions in the present study (21.2 °C), the mean minimum (16 °C), and the mean maximum (23.7 °C) are far below that reported by GULL et al. (2012) and THAIPONG and BOONPRAKOB (2005), making a comparison of the results difficult. However, it can be assumed that the cooling effect and slightly lower temperatures associated with precipitation are a possible reason for the positive correlation between the ascorbic acid content and precipitation. Thus in this study, an increase in precipitation was found to be important as it resulted in an increase in the ascorbic acid content of guava fruits.

The observed TSS value in the present study (mean = 11.0% brix) is similar to that reported by EL-SISY (2013) in eight-year-old guava genotypes growing under uniform conditions for two seasons (ranging from 9.4% to 14.07%). EL-SISY (2013) recorded higher values in the first season than in the second season, although both were under a uniform irrigation scheme, which highlights the variation in temperature as one of the factors influencing TSS. The TSS in the present study positively correlated with mean annual temperature but negatively with annual precipitation.

These results partly agree with those of THAIPONG and BOONPRAKOB (2005), where lower TSS values during the summer season were attributed to the higher moisture content. However, the findings of THAIPONG and BOONPRAKOB (2005) contrast with the positive correlation observed between temperature and TSS in the present study. A possible explanation for the negative correlation of TSS with precipitation could be the dilution effect, which is a result of a higher soil moisture content leading to more water uptake and, hence, to water accumulation in the fruits, as also shown by the positive correlation between fruit water content and precipitation (Tab. 2). In line with the observations of the present study, and using a ^{14}C tracer to compare the effects of elevated temperature on sugar and acid accumulation in mandarin fruit grown under tunnel house experiments, MARSH et al. (1999) reported a positive correlation between temperature and TSS. Fruit labelling with ^{14}C showed that rising canopy temperatures reduced the amount of incoming photosynthates partitioned to citrate and increased the amount allocated to sugars. A likely scenario could also have occurred in our study with guava.

The mean protein content of the guava fruit samples of the present study was 1.52 g/100 g FW, which is slightly lower than that reported in the food composition tables (2.6 g/100 g edible portion; LUKMANJI et al., 2008). Similar to TSS, the protein content also positively correlated with the mean annual temperature but negatively with the total annual precipitation. This trend was also observed with regard to most of the fruit minerals, which were also lower than that given in the food composition tables (except for Na and Fe) for Ca (18 mg/100 g), K (417 mg/100 g), Mg (22 mg/100 g), Na (2.0 mg100 g^{-1}), P (40 mg/100 g), Fe (0.3 mg/100 g), Zn (0.2 mg/100 g), and Cu (0.2 mg/100 g) (LUKMANJI et al., 2008). The state of the sample at the time of determination, the method of determination and possibly genetic differences among the accessions are the likely reasons for the observed variations. There is presently no report on the relationship between climatic conditions and guava fruit protein and mineral composition for comparison. However, the dilution effect as a result of higher moisture content is also the likely reason for the negative correlation between precipitation and these fruit components. This can also be confirmed by the positive correlation between the fruit water content and annual precipitation. The observed positive correlation of protein and some fruit minerals with temperature requires further investigation.

Tab. 3: Chemical and mineral composition, and morphological traits of fruits from 128 guava accessions based on the fruit pulp colour irrespective of the region of collection

	Fruit pulp colour			
Fruit chemical and mineral composition	**White (n = 26)**	**Red (n = 102)**	**Mean (n = 128)**	***p*-value**
Ascorbic acid (mg/100 g FW)	67.6[a] (17%)	65.7[a] (18%)	66.1 (18%)	0.860
Total phenolic compounds (mg/100 g FW)	137.6[b] (3%)	151.0[a] (4%)	148.2 (4%)	0.020
TSS (% brix)	12.6[a] (8%)	10.7[b] (8%)	11.0 (9%)	<0.001
TA (mg/100 g FW)	0.92[a] (58%)	0.94[a] (65%)	0.94 (64%)	0.681
Fructose (g/100 g FW)	3.29[a] (20%)	2.70[b] (21%)	2.81 (21%)	0.018
Glucose (g/100 g FW)	1.28[a] (36%)	1.06[a] (40%)	1.11 (39%)	0.120
Protein (g/100 g FW)	1.60[a] (26%)	1.50[b] (28%)	1.52 (28%)	0.007
Ca (mg/100 g FW)	12.9[a] (17%)	13.1[a] (14%)	13.1 (15%)	0.852
K (mg/100 g FW)	346.2[a] (7%)	281.7[b] (6%)	293.7 (7%)	0.011
Mg (mg/100 g FW)	11.8[a] (13%)	9.11[b] (17%)	9.60 (17%)	0.002
Na (mg/100 g FW)	3.44[a] (74%)	2.24[b] (95%)	2.44 (91%)	0.016
P (mg/100 g FW)	16.0[a] (16%)	13.2[b] (16%)	13.7 (16%)	0.036
S (mg/100 g FW)	14.1[a] (16%)	11.0[b] (16%)	11.6 (17%)	0.006
Fe (mg/100 g FW)	0.31[a] (6%)	0.34[a] (9%)	0.33 (8%)	0.368
B (mg/100 g FW)	0.24[a] (29%)	0.21[b] (34%)	0.21 (33%)	0.030
Zn (mg/100 g FW)	0.07[a] (1.1%)	0.08[a] (1.3%)	0.08 (1.3%)	0.780
Cu (mg/100 g FW)	0.09[a] (4%)	0.11[a] (9%)	0.11 (8%)	0.248
Water content (%)	80.7[b] (1.8%)	84.4[a] (1.4%)	83.6 (1.5%)	0.002
Fruit morphological trait	**White (n = 18)**	**Red (n = 87)**	**Mean (n = 105)**	***p*-value**
Fruit weight (g)	49.5[a] (12%)	46.7[a] (9%)	47.2 (9%)	0.545
% Pulp	23.6[b] (8%)	29.0[a] (7%)	28.0 (8%)	0.002
% Seed	9.29[a] (17%)	9.57[a] (15%)	9.52 (15%)	0.745

Values within the same row show the geometric mean (antilog of the transformed means), followed by the percent standard deviation of the log transformed means in parenthesis. The mean values in the same row followed by the same letter are not significantly different at $p < 0.05$ according to independent sample t-test. Ascorbic acid, TSS, and TA were determined on extracted juice from edible portion of the fruit, total phenolic compounds were determined from 0.25 g of freeze dried sample, fructose, glucose, and proteins were determined from 200 mg of freeze-dried sample, while minerals were determined from 100 mg of freeze-dried sample. Water content was determined as the difference between freeze-dried and fresh sample weights. Pulp proportion (% pulp), and seed proportion (% seed) are based on the weight of the entire fresh fruit (g).

Tab. 4: Pearson correlation coefficients between fruit morphological characteristics and fruit chemical and mineral composition from 105 guava trees summarized for all the regions

Fruit morphological characteristics	**Fruit chemical and mineral composition**													
	Total phenolic compounds	**TSS**	**Fructose**	**Protein**	**Ca**	**K**	**Mg**	**Na**	**P**	**S**	**B**	**Fe**	**Cu**	**Water**
Fruit weight	ns	ns	ns	-0.23*	-0.49***	-0.28**	-0.23*	-0.23*	-0.19*	-0.26**	-0.20*	-0.33***	ns	0.26**
% Pericarp	ns	0.22*	ns	ns	ns	-0.21*	ns	ns	ns	ns	ns	ns	ns	ns
% Exocarp	ns	0.32***	0.19*	ns	0.20*	ns	ns	ns	ns	ns	0.30**	ns	ns	-0.19*
% Mesocarp	-0.22*	ns	ns	ns	ns	-0.25*	ns	ns	ns	ns	-0.20*	ns	ns	ns
% Pulp	ns	-0.45***	ns	-0.31**	ns	ns	-0.27**	-0.22*	ns	ns	-0.25**	ns	ns	0.28**
% Seed	ns	0.42***	0.28**	0.49***	0.37***	0.61***	0.48***	ns	ns	0.45***	0.59***	ns	0.25**	-0.48***

***Correlation is significant at $p \leq 0.001$ level. **Correlation is significant at $p \leq 0.01$ level. *Correlation is significant at $p \leq 0.05$ level. ns = correlation was not significant at $p \leq 0.05$ level. Total phenolic compounds were determined from 0.25 g of freeze dried sample, TSS was determined on extracted juice from edible portion of the fruit, Fructose and proteins were determined from 200 mg of freeze-dried sample, while minerals were determined from 100 mg of freeze-dried sample. Water content was determined as the difference between freeze-dried and fresh sample weights. Pericarp proportion (% pericarp), exocarp proportion (% exocarp), mesocarp proportion (% mesocarp), pulp proportion (% pulp), and seed proportion (% seed) are based on the weight of the entire fresh fruit (g).

Pulp colour influences chemical and mineral composition of guava fruits

The findings related to the fruit flesh colour depicted red-fleshed fruits as having a higher phenolic content than the white-fleshed types. The results of this study were in agreement with those of SANTOS and CORRÊA (2012), in which the pink- and red-fleshed guava accessions recorded greater values for phenolic compound concentrations. In contrast, HASSIMOTTO et al. (2005) found a higher phenolic content in white guava pulp than in red guava pulp (160 vs. 124 mg/100 g FW, respectively). Phenolic compounds have been reported to be

affected by many other factors such as variety, cultivation, species, area, and climatic conditions (IQBAL and BHANGER, 2006; WANG and LIN, 2000). The total phenolic compounds have been reported to also vary with the cultivars (FLORES et al., 2015; WANG and LIN, 2000) and thus could indicate genotypic variation among accessions of guava. Accordingly, we found that the white-fleshed guavas accumulated more TSS and fructose than the red-fleshed types, which is in agreement with the findings of CHOUDHARY et al. (2012), who studied the chemical composition of four guava cultivars under similar cultural conditions and found variations in TSS and non-reducing sugars, which were attributed partly to the variety of the fruit. Moreover, we also observed that the white-fleshed guava fruits accumulated more protein and some minerals (K, Mg, Na, S, and B) than the red-fleshed ones. The variation in the accumulation of minerals in the fruit, such as K, Mg, S, and B, support the observation by NATALE et al. (2002, 2007) that different guava cultivars vary in their nutrient uptake.

Larger and heavier fruits negatively correlate with their chemical and mineral composition

Fruit weight correlated negatively with protein and with most fruit mineral contents. Fruits with higher pulp weight negatively correlated with TSS, protein, and a few minerals as Mg, Na, and B. In this regard, the results of the present study were similar to those of THAIPONG and BOONPRAKOB (2005) – larger fruits resulted in lower TSS and total sugar content in guava. MEHMOOD et al. (2014) and SINGH et al. (2015) also reported poor accumulation of chemical compounds in large guavas, including TSS. Similarly, negative observations of fruit size and weight with TSS were observed during guava selection and breeding (DINESH and YADAV, 1998), where the genotypic correlation was lower than the phenotypic correlation for TSS, indicating a greater effect of fruit size- and weight-based traits, along with external factors such as soil and environment, on TSS. Accordingly, pulp weight positively correlated with the fruit water content – an indication that much of the juicy pulp core in large fruits mainly consisted of water. This could be confirmed by the positive correlation between the pericarp and exocarp proportions with TSS, implying a higher dilution effect of TSS in the pulp core but no or less effect in the peel portion.

In addition, the pulp proportion of the fruits negatively correlated with the fruit protein content and some of the minerals (Mg, Na, and B). Similarly, negative correlations were also observed between the mesocarp proportion and some fruit minerals, mainly K and B. These negative correlations could still be attributed to the dilution effect of increasing fruit size on fruit mineral accumulation, as was also observed by SINGH et al. (2015), MEHMOOD et al. (2014), and DINESH and YADAV (1998) in guava. However, the peel part of the fruit (exocarp) is not likely to be affected by the dilution effect as evidenced by the positive correlation between the exocarp proportion with TSS, fructose, Ca and B. It was notable that seed proportion correlated positively with most of the fruit mineral and chemical constituents, but negatively with fruit water content. One may assume that increased seed proportion is likely to take up the position of water in the fruit pulp, thus reducing water accumulation in the pulp core of the guava fruit, as evidenced by the negative correlation observed between seed proportion and fruit water content. Reduced water in the pulp core implies a reduced dilution effect for the fruit minerals and chemicals in the pulp.

The fruit qualities of guava define their uses and vary by genotype, developmental stage, and growing environment (MOON et al., 2018). Qualities preferred for industrial/commercial production are outlined in POMMER and MURAKAMI, (2009). For instance, preferred pulp colour for industrial production is dark rose, rosy or red. In our study, the red-fleshed fruits were more frequent, comprising of 80% of the total sample collected and were found in all the sampled regions. Despite significant variations in important traits such as TSS, the preferred threshold for industrial processing of at least 9% brix was met by most trees in all the regions, such as Western (100%), Coastal (97%), Eastern (83%), and Rift Valley (79%). Similarly, the preferred TA range of 1.25-1.5 mg/100 g FW was observed in fruits from 64% of trees in Western region, 55% from Coastal region, 50% from Eastern region, and 32% from the Rift Valley region. Substantial amount of ascorbic acid of at least 100 mg/ 100 g FW was found in fruits from 58% of the trees in Eastern region, 36% in the Western region, 19% at the Coast, and 11% in the Rift Valley region. This implies that despite some regions having low mean values for certain traits, individual trees superior in these traits could be targeted for breeding and commercial production. For the Kenyan guava, the similar low values observed with regard to fruit size of 47.2 g against the preferred size of 200-300 g, and pulp yield of 48% against the preferred >70% for industrial processing could be improved through agronomic practices. Quantification of these traits in each production area to identify the best genotypes for specific markets and selection of superior parents for breeding is vital.

Conclusions

The ascorbic acid content positively correlated with annual precipitation. TSS positively correlated with temperature, and was found to be higher in white-fleshed fruits and fruits having lower pulp weight and more seeds. Red-fleshed fruits had a higher content of phenolic compounds than the white-fleshed types, while the white-fleshed fruits had more TSS, protein, and some minerals. Larger fruits were generally observed to have a dilution effect on the fruit mineral content. Generally, most of the correlations were not strong, implying that more than just the studied factors influence the nutritional and chemical content of guava.

The relationship between climatic data on fruit traits such as ascorbic acid and TSS could aid in the choice of guava production regions that are rich in these chemical components. The flesh colour of fruits provides the information necessary for the selection of fruits for various purposes – for example, sweeter white-fleshed fruits with a higher mineral content could be preferred for fresh consumption; larger, less sweet fruits with a lower mineral content could be preferred for industrial processing.

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References

ARAÚJO, H.M., RODRIGUES, F.F., COSTA, W.D., NONATO, C., RODRIGUES, F.F., BOLIGON, A.A., ATHAYDE, M.L., COSTA, J.G., 2015: Chemical profile and antioxidant capacity verification of *Psidium guajava* (Myrtaceae) fruits at different stages of maturation. EXCLI J. 14, 1020-1030.

ARIMOND, M., WIESMANN, D., BECQUEY, E., CARRIQUIRY, A., DANIELS, M.C., DEITCHLER, M., FANOU-FOGNY, N., JOSEPH, M.L., KENNEDY, G., MARTIN-PREVEL, Y., 2010: Simple food group diversity indicators pre-

dict micronutrient adequacy of women's diets in 5 diverse, resource-poor settings. J. Nutr. 140(11), 2059-2069.

Bradford, M.M., 1976: A rapid and sensitive method for the quantitation of microgram quantities of protein utilizing the principle of protein-dye binding. Analytic. Biochem. 72(1-2), 248-254.

Burlingame, B., Charrondiere, R., Mouille, B., 2009: Food composition is fundamental to the cross-cutting initiative on biodiversity for food and nutrition. J. Food Compos. Anal. 22(5), 361-365.

CABI, 2013: Invasive species compendium. CAB International. Wallingford, UK.

Choudhary, M.L., Dikshit, S., Neeraj, S., Saxena, R., 2012: Studies on physico-chemical properties of different guava varieties under agro-climatic conditions of Chhattisgarh plains. Progressive Horticulture 44(2), 340-341.

Dinesh, M., Yadav, I., 1998: Half-sib analysis in guava (*Psidium guajava*). Indian J. Horticulture 55(1), 20-22.

El-Sisy, W.A.A.Z., 2013: Evaluation of some genotypes of guava trees grown under Alexandria Governorate condition I. Vegetative growth, flowering and fruit quality. World Appl. Sci. 28(4), 583-595.

Faurobert, M., Pelpoir, E., Chaïb, J., 2007: Phenol extraction of proteins for proteomic studies of recalcitrant plant tissues. Plant Proteomics: Methods and Protocols 9-14.

Fick, S.E., Hijmans, R.J., 2017: WorldClim 2: new 1-km spatial resolution climate surfaces for global land areas. Int. J. Climatology 37(12), 4302-4315.

Flores, G., Dastmalchi, K., Wu, S.-B., Whalen, K., Dabo, A.J., Reynertson, K.A., Foronjy, R.F., Kennelly, E.J., 2013: Phenolic-rich extract from the Costa Rican guava (*Psidium friedrichsthalianum*) pulp with antioxidant and anti-inflammatory activity. Potential for COPD therapy. Food Chem. 141(2), 889-895.

Flores, G., Wu, S.-B., Negrin, A., Kennelly, E.J., 2015: Chemical composition and antioxidant activity of seven cultivars of guava (*Psidium guajava*) fruits. Food Chem. 170, 327-335.

Forster, M.P., Rodríguez, E.R., Martín, J.D., Romero, C.D., 2002: Statistical differentiation of bananas according to their mineral composition. J. Agric. Food Chem. 50(21), 6130-6135.

Griesbach, J., 2007: Growing temperate fruit trees in Kenya. World Agroforestry Centre, Nairobi.

Gull, J., Sultana, B., Anwar, F., Naseer, R., Ashraf, M., Ashrafuzzaman, M., 2012: Variation in antioxidant attributes at three ripening stages of guava (*Psidium guajava* L.) fruit from different geographical regions of Pakistan. Molecules 17(3), 3165-3180.

Haque, M.N., Saha, B.K., Karim, M.R., Bhuiyan, M.N.H., 2009: Evaluation of nutritional and physico-chemical properties of several selected fruits in Bangladesh. Bangladesh Journal of Scientific and Industrial Research 44(3), 353-358.

Hassimotto, N.M.A., Genovese, M.I., Lajolo, F.M., 2005: Antioxidant activity of dietary fruits, vegetables, and commercial frozen fruit pulps. J. Agric. Food Chem. 53(8), 2928-2935.

HCD, 2014: Horticultural Crops Directorate. Horticulture validated report (2014), 68. Available: http://www.agricultureauthority.go.ke/wp-content/uploads/2016/05/Horticulture-Validated-Report-2014-Final-copy.pdf. (Accessed 30 Nov 2017).

IBM, 2011: IBM SPSS statistics for Windows, version 20.0. New York: IBM Corp.

IPGRI, 2006: Descriptors for Mango (*Mangifera indica* L.) International Plant Genetic Resources Institute, Rome, Italy.

Iqbal, S., Bhanger, M., 2006: Effect of season and production location on antioxidant activity of *Moringa oleifera* leaves grown in Pakistan. J. Food Compos. Anal. 19(6), 544-551.

Keding, G.B., Kehlenbeck, K., Kennedy, G., McMullin, S., 2017: Fruit production and consumption: practices, preferences and attitudes of women in rural western Kenya. Food Security 9(3), 453-469.

Keutgen, A.J., Pawelzik, E., 2008: Quality and nutritional value of strawberry fruit under long term salt stress. Food Chem. 107(4), 1413-1420.

Leite, K.M.S.C., Tadiotti, A.C., Baldochi, D., Oliveira, O.M.M.F., 2006: Partial purification, heat stability and kinetic characterization of the pectinmethylesterase from Brazilian guava, Paluma cultivars. Food Chem. 94(4), 565-572.

LMBG, 1983: Bestimmung des Gesamtsäuregehaltes von Tomatenmark (Potentiometrische Methode). L.26.11.03-4.

Lukmanji, Z., Hertzmark, E., Mlingi, N., Assey, V., Ndossi, G., Fawzi, W., 2008: Tanzania food composition tables. MUHAS-TFNC, HSPH, Dar es Salaam Tanzania.

Marsh, K., Richardson, A., Macrae, E., 1999: Early-and mid-season temperature effects on the growth and composition of satsuma mandarins. J. Hortic. Sci. Biotechnol. 74(4), 443-451.

Mbuvi, D., Boon, E., 2009: The livelihood potential of non-wood forest products: the case of Mbooni Division in Makueni District, Kenya. Environ. Dev. Sust. 11(5), 989-1004.

Mehmood, A., Jaskani, M.J., Khan, I.A., Ahmad, S., Ahmad, R., Luo, S., Ahmad, N.M., 2014: Genetic diversity of Pakistani guava (*Psidium guajava* L.) germplasm and its implications for conservation and breeding. Scientia Hortic. 172, 221-232.

Moon, P., Fu, Y., Bai, J., Plotto, A., Crane, J., Chambers, A., 2018: Assessment of fruit aroma for twenty-seven guava (*Psidium guajava*) accessions through three fruit developmental stages. Scientia Hortic. 238, 375-383.

Nasution, F., Hadiati, S., 2014: Characterization and clustering of some guava germplasm collections based on leaf and fruit characters. Agrivita 36(1), 91.

Natale, W., Coutinho, E., Pereira, F., Boaretto, A., 2002: Nutrients foliar content for high productivity cultivars of guava in Brazil. Acta Hortic., 383-386.

Natale, W., Prado, R., Quaggio, J., Mattos Junior, D., 2007: Guava. In: Johnston, A.E. (ed.), Fertilizing for high yield and quality tropical fruits of Brazil, 103-122. International Potash Institute, Horgen, Switzerland 1.

Ogoloma, M., Nkpaa, M., Akaninwor, J.O., Uwakwe, A.A., 2013: Proximate, phytochemical and mineral elements compositions of some edible fruits grown in oil producing community of rivers state, Nigeria. IOSR-JESTFT 5, 38-46.

Pommer, C.V., Murakami, K.R.N., 2009: Breeding guava (*Psidium guajava* L.). In: Breeding plantation tree crops: Tropical species, 83-120. Springer.

Puwastien, P., Siong, T., Kantasubrata, J., Caven, G., Felicionoand, R., Judprasong, K., 2011: Asean manual of food analysis. Regional centre of Asean network of food data system, institute of nutrition, Mahidol University Thailand, 1-190.

Rodriguez-Amaya, D.B., Kimura, M., Godoy, H.T., Amaya-Farfan, J., 2008: Updated Brazilian database on food carotenoids: Factors affecting carotenoid composition. J. Food Compos. Anal. 21(6), 445-463.

Santos, C., Corrêa, L., 2012: Antioxidant and biochemical content in Brazilian guava germplasm with white, red and pink pulps. III International symposium on guava and other Myrtaceae 125-130.

Sharma, A., Sehrawat, S.K., Singhrot, R.S., Ajinath, T., 2010: Morphological and chemical characterization of *Psidium* species. Notulae Botanicae Horti Agrobotanici Cluj-Napoca 38(1), 28-32.

Siegel, K.R., Ali, M.K., Srinivasiah, A., Nugent, R.A., Narayan, K.V., 2014: Do we produce enough fruits and vegetables to meet global health need? PloS one 9(8), e104059.
DOI: 10.1371/journal.pone.0104059

Singh, D., Gill, M., Boora, R., Arora, N., 2015: Genetic diversity analysis in guava (*Psidium guajava*) on the basis of morphological and physico-chemical traits. Indian J. Agric. Sci. 85, 678-683.

Singleton, V.L., Rossi, J.A., 1965: Colorimetry of total phenolics with phosphomolybdic-phosphotungstic acid reagents. Am. J. Enol. Vitic. 16(3), 144-158.

Thaipong, K., Boonprakob, U., 2005: Genetic and environmental variance components in guava fruit qualities. Scientia Hortic. 104(1), 37-47.

Toledo, Á., Burlingame, B., 2006a: Biodiversity and nutrition: A common

path toward global food security and sustainable development. J. Food Compos. Anal. 19(6), 477-483.

WALL, M.M., 2006: Ascorbic acid, vitamin A, and mineral composition of banana (*Musa sp.*) and papaya (*Carica papaya*) cultivars grown in Hawaii. J. Food Compos. Anal. 19(5), 434-445.

WANG, S.Y., LIN, H.-S., 2000: Antioxidant activity in fruits and leaves of blackberry, raspberry, and strawberry varies with cultivar and developmental stage. J. Agric. Food Chem. 48(2), 140-146.

WHEAL, M.S., FOWLES, T.O., PALMER, L.T., 2011: A cost-effective acid digestion method using closed polypropylene tubes for inductively coupled plasma optical emission spectrometry (ICP-OES) analysis of plant essential elements. Analytical Methods 3(12), 2854-2863.

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Supplementary information

Tab. S1: Geographical coordinates, altitude, mean annual temperature, and annual precipitation of the 128 guava accessions collected from four regions of Kenya*Accessions used for fruit morphological characterization.

Accession number	Accession code	Region	Latitude [N°/S°]	Longitude [E°]	Altitude (m)	Mean annual temperature (°C)	Annual precipitation (mm)
1	KIL001	Coast	03.69568 °S	039.72340 °E	208	23.7	425
2	KIL002*	Coast	03.69580 °S	039.72343 °E	199	23.7	425
3	KIL003*	Coast	03.69679 °S	039.72604 °E	202	23.7	425
4	KIL004*	Coast	03.69518 °S	039.72219 °E	200	23.7	425
5	KIL009*	Coast	03.92239 °S	039.74352 °E	23	23.7	410
6	KIL010*	Coast	03.92240 °S	039.74314 °E	25	23.7	410
7	KIL011*	Coast	03.92226 °S	039.74282 °E	22	23.7	410
8	KIL012*	Coast	03.92228 °S	039.74283 °E	22	23.7	410
9	KIL013*	Coast	03.91339 °S	039.74015 °E	18	23.7	410
10	KIL014	Coast	03.91348 °S	039.74015 °E	17	23.7	410
11	KIL015*	Coast	03.91338 °S	039.73997 °E	18	23.7	410
12	KIL016*	Coast	03.91332 °S	039.73999 °E	21	23.7	410
13	KIL017*	Coast	03.91347 °S	039.73988 °E	20	23.7	410
14	KWA001	Coast	04.16923 °S	039.59783 °E	23	22.7	458
15	KWA002	Coast	04.16853 °S	039.59749 °E	19	22.7	458
16	KWA003	Coast	04.16856 °S	039.59748 °E	19	22.7	458
17	KWA005*	Coast	04.16494 °S	039.57737 °E	104	22.5	475
18	KWA006*	Coast	04.16495 °S	039.57743 °E	97	22.5	475
19	KWA007*	Coast	04.16496 °S	039.57764 °E	119	22.5	475
20	KWA008*	Coast	04.16782 °S	039.56780 °E	108	22.7	458
21	KWA009	Coast	04.16837 °S	039.56796 °E	92	22.7	458
22	KWA010*	Coast	04.16860 °S	039.56822 °E	94	22.7	458
23	KWA011*	Coast	04.34928 °S	039.53458 °E	22	22.3	469
24	KWA014	Coast	04.34318 °S	039.51459 °E	35	22.3	469
25	KWA015*	Coast	04.33752 °S	039.44971 °E	117	22.1	491
26	KWA016*	Coast	04.33753 °S	039.44975 °E	118	22.1	491
27	KWA017*	Coast	04.49746 °S	039.25124 °E	39	21.6	518
28	KWA018	Coast	04.49765 °S	039.25125 °E	45	21.6	518
29	KWA019*	Coast	04.49763 °S	039.25131 °E	41	21.6	518
30	KWA020*	Coast	04.49715 °S	039.25139 °E	45	21.6	518
31	KWA021	Coast	04.60348 °S	039.18504 °E	25	21.7	505
32	KWA023	Coast	04.60352 °S	039.18509 °E	20	21.7	505
33	KWA024	Coast	04.60323 °S	039.18452 °E	21	21.7	505
34	MOM006	Coast	03.96482 °S	039.73122 °E	15	23.7	410
35	MOM007*	Coast	03.96493 °S	039.73089 °E	14	23.7	410
36	MOM008	Coast	03.96229 °S	039.73233 °E	16	23.7	410
37	MER001*	Eastern	00.17234 °S	037.64283 °E	1564	20.5	1149

38	MER002*	Eastern	00.17239 °S	037.64275 °E	1545	20.5	1149
39	MER005*	Eastern	00.17249 °S	037.65120 °E	1479	20.5	1149
40	MER009*	Eastern	00.08721 °S	037.66675 °E	1455	20.5	1382
41	MER010*	Eastern	00.08726 °S	037.66695 °E	1452	20.5	1382
42	MER012*	Eastern	00.08564 °S	037.66451 °E	1478	16.8	1582
43	MER013*	Eastern	00.08536 °S	037.66438 °E	1481	16.8	1582
44	MER014*	Eastern	00.11461 °S	037.69637 °E	1384	20.5	1382
45	MER016*	Eastern	00.18701 °S	037.69572 °E	1290	20.8	1335
46	MER017*	Eastern	00.18693 °S	037.69600 °E	1288	20.8	1335
47	MER018*	Eastern	00.12048 °S	037.72087 °E	1393	20.5	1382
48	MER019*	Eastern	00.12024 °S	037.72074 °E	1385	20.5	1382
49	ELG001*	Rift Valley	00.64776 °N	035.51977 °E	2089	21.2	950
50	ELG002*	Rift Valley	00.64203 °N	035.52221 °E	2064	21.2	950
51	ELG003*	Rift Valley	00.64265 °N	035.52145 °E	2077	21.2	950
52	ELG004*	Rift Valley	00.64264 °N	035.52150 °E	2071	21.2	950
53	ELG005*	Rift Valley	00.67029 °N	035.51809 °E	2214	20.3	954
54	ELG007*	Rift Valley	00.64350 °N	035.51839 °E	2104	21.2	950
55	ELG008*	Rift Valley	00.64349 °N	035.51843 °E	2104	21.2	950
56	ELG009*	Rift Valley	00.64338 °N	035.51852 °E	2102	21.2	950
57	ELG010*	Rift Valley	00.64505 °N	035.51627 °E	2132	21.2	950
58	ELG011*	Rift Valley	00.63185 °N	035.52095 °E	2024	21.2	950
59	ELG012	Rift Valley	00.63469 °N	035.52243 °E	2031	21.2	950
60	ELG013*	Rift Valley	00.63766 °N	035.51977 °E	2079	21.2	950
61	ELG014*	Rift Valley	00.57152 °N	035.30377 °E	2142	17.1	1055
62	ELG015*	Rift Valley	00.57151 °N	035.30377 °E	2150	17.1	1055
63	ELG016*	Rift Valley	00.58574 °N	035.46054 °E	2317	16	1104
64	ELG019*	Rift Valley	00.58788 °N	035.46055 °E	2322	16	1104
65	ELG020	Rift Valley	00.66651 °N	035.53149 °E	1972	21.2	950
66	ELG021*	Rift Valley	00.66682 °N	035.53004 °E	1985	20.3	954
67	UAG018*	Rift Valley	00.64256 °N	035.52145 °E	2067	21.2	950
68	HOM001*	Western	00.59582 °N	034.57717 °E	1308	20.8	1659
69	HOM003*	Western	00.59585 °N	034.57596 °E	1307	20.8	1659
70	HOM004*	Western	00.59594 °N	034.57690 °E	1306	20.8	1659
71	HOM006*	Western	00.59596 °N	034.57690 °E	1306	20.8	1659
72	HOM007*	Western	00.59593 °N	034.57692 °E	1307	20.8	1659
73	HOM009*	Western	00.59600 °N	034.57698 °E	1305	20.8	1659
74	HOM010*	Western	00.59596 °N	034.57703 °E	1307	20.8	1659
75	HOM011*	Western	00.59603 °N	034.57717 °E	1302	20.8	1659
76	HOM012*	Western	00.60963 °N	034.58897 °E	1329	20.8	1659
77	HOM013*	Western	00.60974 °N	034.58366 °E	1335	20.8	1659
78	HOM014*	Western	00.60961 °N	034.58369 °E	1339	20.8	1659
79	HOM016*	Western	00.60961 °N	034.58374 °E	1337	20.8	1659
80	HOM017*	Western	00.60984 °N	034.58377 °E	1336	20.8	1659
81	HOM018*	Western	00.60610 °N	034.63214 °E	1463	20.8	1659
82	HOM019*	Western	00.60611 °N	034.63223 °E	1456	20.8	1659
83	HOM020*	Western	00.61762 °N	034.64497 °E	1498	20.8	1659

84	HOM021*	Western	00.61760 °N	034.64495 °E	1502	20.8	1659
85	HOM022*	Western	00.53904 °N	034.50943 °E	1242	20.8	1659
86	HOM023*	Western	00.53907 °N	034.50946 °E	1238	20.8	1659
87	HOM024*	Western	00.53907 °N	034.50945 °E	1240	20.8	1659
88	HOM025*	Western	00.53907 °N	034.50941 °E	1237	20.8	1659
89	HOM026*	Western	00.53908 °N	034.50942 °E	1238	20.8	1659
90	HOM027	Western	00.53906 °N	034.50946 °E	1242	20.8	1659
91	HOM028*	Western	00.53905 °N	034.50951 °E	1239	20.8	1659
92	HOM029*	Western	00.53893 °N	034.50956 °E	1240	20.8	1659
93	HOM030*	Western	00.53880 °N	034.50989 °E	1239	20.8	1659
94	HOM032*	Western	00.53987 °N	034.50855 °E	1246	20.8	1659
95	HOM035*	Western	00.72481 °N	034.45610 °E	1289	21.1	1526
96	HOM036*	Western	00.72479 °N	034.45597 °E	1290	21.1	1526
97	HOM039*	Western	00.72471 °N	034.45581 °E	1292	21.1	1526
98	HOM042*	Western	00.72455 °N	034.45533 °E	1283	21.1	1526
99	HOM043*	Western	00.72442 °N	034.45531 °E	1283	21.1	1526
100	HOM045*	Western	00.72436 °N	034.45530 °E	1285	21.1	1526
101	HOM046*	Western	00.72439 °N	034.45518 °E	1283	21.1	1526
102	HOM047*	Western	00.72412 °N	034.45534 °E	1265	21.1	1526
103	HOM048*	Western	00.72412 °N	034.45539 °E	1275	21.1	1526
104	KAK001*	Western	00.27951 °N	034.67358 °E	1419	20.6	1917
105	KAK002*	Western	00.27863 °N	034.67363 °E	1409	20.6	1917
106	KAK003	Western	00.27861 °N	034.67367 °E	1420	20.6	1917
107	KAK004*	Western	00.27791 °N	034.69564 °E	1447	20.6	1917
108	KAK005*	Western	00.27700 °N	034.69589 °E	1441	20.6	1917
109	KAK006*	Western	00.27777 °N	034.69579 °E	1443	20.6	1917
110	KAK007*	Western	00.24446 °N	034.82470 °E	1571	20.6	1917
111	KAK008*	Western	00.24442 °N	034.82479 °E	1572	20.6	1917
112	SIA001	Western	00.19481 °N	034.34081 °E	1297	21.8	1774
113	SIA002*	Western	00.19376 °N	034.33390 °E	1286	21.8	1774
114	SIA003*	Western	00.19423 °N	034.33385 °E	1280	21.8	1774
115	SIA004*	Western	00.13007 °N	034.42597 °E	1358	21.6	1740
116	SIA005	Western	00.13003 °N	034.42687 °E	1357	21.6	1740
117	SIA006*	Western	00.12687 °N	034.42089 °E	1340	21.6	1740
118	SIA007	Western	00.12680 °N	034.42102 °E	1342	21.6	1740
119	SIA008*	Western	00.12804 °N	034.42337 °E	1347	21.6	1740
120	SIA009*	Western	00.12810 °N	034.42309 °E	1347	21.6	1740
121	SIA010*	Western	00.13046 °N	034.42354 °E	1348	21.6	1740
122	SIA011*	Western	00.13008 °N	034.42255 °E	1349	21.6	1740
123	UNK001	Western	00.84360 °N	034.79930 °E	1684	16.8	1455
124	UNK002	Western	00.08413 °N	034.79875 °E	1688	20.3	1864
125	VIH001*	Western	00.08540 °N	034.79936 °E	1680	20.3	1864
126	VIH002	Western	00.08539 °N	034.79936 °E	1679	20.3	1864
127	VIH003*	Western	00.08532 °N	034.79938 °E	1682	20.3	1864
128	VIH004*	Western	00.84470 °N	034.79931 °E	1683	16.8	1455

*Accessions used for fruit morphological characterization.

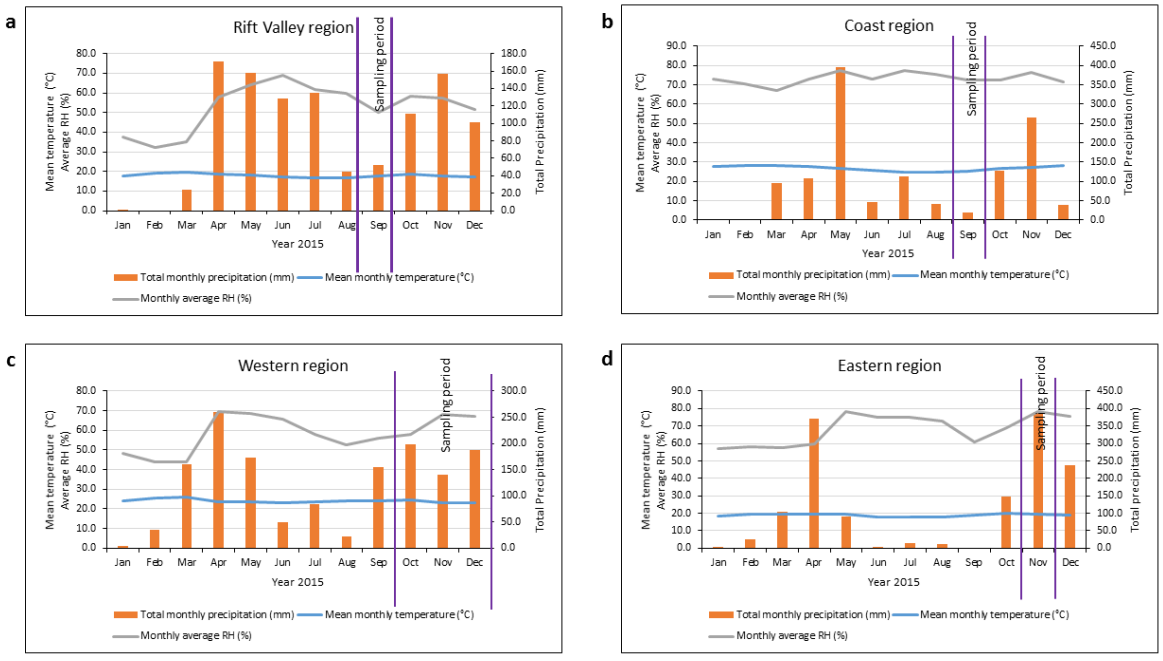

Fig. S1: Mean monthly temperature, precipitation, and relative humidity (RH) of the four regions (a) the Rift valley, (b) Coast, (C) Western, and (d) Eastern of guava fruit collection based on data from the nearest meteorological station for the year 2015. The period when sampling was carried out is indicated.

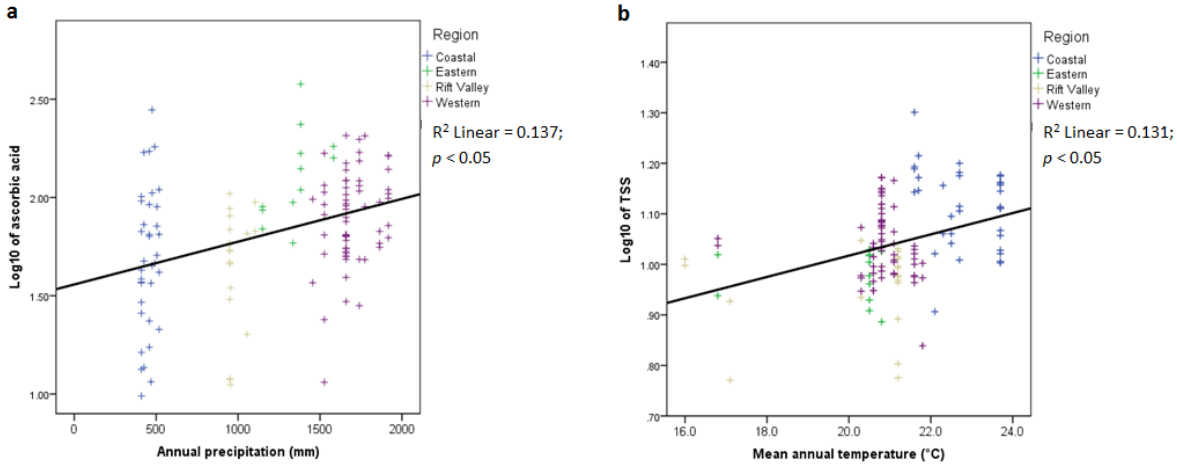

Fig. S2: Pearson correlation between **(a)** annual precipitation and ascorbic acid content in 128 guava fruit samples from four regions of Kenya, and between **(b)** mean annual temperature and TSS in 128 guava fruit samples from four regions of Kenya. Ascorbic acid and TSS were determined on extracted juice from edible portion of the fruit.

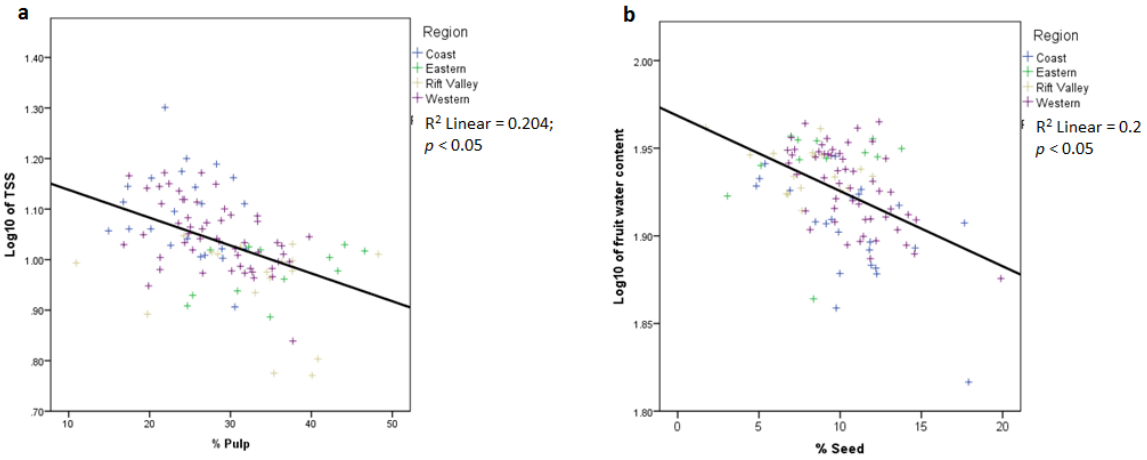

Fig. S3: Pearson correlation between **(a)** pulp proportion and TSS of 105 guava fruit samples from four regions of Kenya, and between **(b)** seed proportion and fruit water content of 105 guava fruit samples from four regions of Kenya. TSS was determined on extracted juice from edible portion of the fruit, and water content was determined as the difference between freeze-dried and fresh sample weights. Pulp proportion (% pulp), and seed proportion (% seed) are based on weight of the entire fresh fruit (g).