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Effects of two different water sources used for irrigation on the soil geochemical properties and the quality of the Lohan guava (*Psidium guajava* L. Lohan)

Dominic Soloman George, Kelvin Kiran Anthony, Vicknesha Santhirasegaram, Nadiah Mohd Saruan, Hasvinder Kaur, Zuliana Razali and Chandran Somasundram

ABSTRACT

The effect of two different water sources (treated waste water and lake water) used for irrigation on the soil geochemical properties and the fruit quality parameters of the Lohan guava were studied. The fruits' physical attributes, physicochemical attributes, nutritional attributes, mineral content as well as consumers' acceptance were evaluated. The properties of the different water sources and their effect, on both the soil and the quality of the fruits, were evaluated. Analysis of the irrigation water revealed that treated waste water was of acceptable quality with reference to irrigation water quality guidelines, while the lake water used for irrigation fell short in several aspects. The different water sources used for irrigation in the farms affected the soil geochemical properties significantly. The quality of guavas harvested from the farms that were irrigated with different water sources was significantly different. Irrigation water qualities were observed to have positive effects on the quality of the fruits and consumers' acceptance as observed from the results of quality analysis and the consumers' acceptance test.

Key words | fruit quality, irrigation water, Lohan guava, soil properties

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INTRODUCTION

The guava (*Psidium guajava* L.) belongs to the genus *Psidium* and the *Myrtaceae* family (Joseph & Priya 2011). It is native to Mexico, Central America, and northern South America but is now extensively cultivated throughout the tropics and subtropics, including Africa, South Asia, Southeast Asia, the Caribbean, subtropical regions of North America, Hawaii, New Zealand, Australia and Spain. Guava is known to contain high amounts of vitamins, minerals and antioxidant properties and is frequently exploited for traditional medication purposes by certain cultures (Hassimotto *et al.* 2005). The guava is often referred to as a 'superfruit' due to its high antioxidant capacity (Sanda Grema & Bukar-Kolo 2011). Furthermore, according to previous reports, it has been proven that guava contains four times more vitamin C than an orange and contains various biologically active secondary compounds such as flavonoids and triterpenoids (Hassimotto *et al.* 2005). Besides the fruit, different parts of the plant have been actively used to treat diseases such as diabetes, caries, wounds, diarrhoea, inflammation and hypertension (Gutierrez *et al.* 2008). Moreover, previous researches have reported on the anti-plasmodial, anti-inflammatory, hepatoprotective, anticancer and antioxidant activities of the guava fruit (Salib & Michael 2004; Ojowole 2006; Roy *et al.* 2006; Flores *et al.* 2013).

In Malaysia, guavas are cultivated primarily for fresh consumption. Secondary uses of guava are for export and processing. The total area for guava plantation in Malaysia was estimated to be 1,440 hectare in 2011 with an annual production of 18,880 metric tons. In 2011, guavas were actively grown in Muar, Johor (213 ha), Perak (185 ha) and Segamat, Johor (68 ha). Currently, there are 14 registered guava clones in Malaysia since 1951 according to the Malaysian Department of Agriculture. The latest variety introduced in Malaysia is the 'Lohan Guava' or 'Giant Guava', which is the variety of interest in this present study. This variety is larger in size compared to its counterparts, averaging from 600 to 800 grams per fruit. Unlike the other varieties in Malaysia, the 'Lohan Guava' is known for its unique ability

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of flowering without the need for heavy pruning. The 'Lohan Guava' is also known to be the most fragrant among the 14 cultivars in Malaysia (Anem 2013).

Despite the widespread cultivation of guava, its productivity and quality are affected by various factors (Mishra 2005). For instance, the effect of fertilizers on the quality of fruits has been extensively studied and there have been reports on chokeberry, persimmon, dates, apricot, pomegranate and tomato (Jeppsson 2000; Hossain & Ryu 2009; Marzouk & Kassem 2011; Milošević *et al.* 2013; Parvizi *et al.* 2014; Watanabe *et al.* 2015).Besides fertilizers, the quality of water used for irrigation in agriculture is also known to have an effect on the quality of fruits as a whole (Bauder *et al.* 2004; Al-Omran *et al.* 2010; Almeelbi *et al.* 2014). A common problem faced by the guava industry is the scarcity of quality fresh water for agriculture due to the adverse effects of climate change and increasing competition from other sectors, which has led to the use of alternative sources for irrigation such as treated wastewater (Mesa-Jurado *et al.* 2012; Milano *et al.* 2012). Previous reports suggest that treated wastewater has high nutritive value, which improves plant growth and the subsequent quality of the fruits produced (Al-Lahham *et al.* 2003; Pedrero & Alarcón 2009). Accordingly, the aim of this present study is to investigate the effects of the different water sources used for irrigation on the quality of the fruits, taking into consideration the various aspects for quality parameters. In this present study, two farms with similar practices, with the only difference being the water source that is used for irrigation, were used to study the effects of irrigation water quality on fruit quality. Both farms practice the drip irrigation method from the onset, with one farm using treated waste water and another using lake water respectively. The farm that uses treated waste water for irrigation of crops is referred to as TWW, while the farm that uses lake water as its water source for irrigation of crops is referred to as LW in this present research.

MATERIALS AND METHODS

Sample collection and preparation

Water samples were collected from nine different points at the water source used for irrigation of the guava farms at three separate times, which made up composite samples. The pH and electrical conductivity (EC) were measured immediately using portable Hanna meters. Water samples were collected in sampling bottles, transferred to the laboratory and stored at 4 °C for dissolved oxygen (DO) and nutrient analysis. Soil samples were collected from nine points via an auger sampler (AMS regular soil auger; AMS Inc., USA). Soil samples included two layers of soil that made up the composite sample (topsoil layer and eluviation layer). Soil samples collected were sieved and allowed to dry before pH, EC and nutrient analysis were carried out. Mature guava (*Psidium guajava* L. Lohan) fruits of uniform size and free from external defects were harvested from the two guava farms. The fruits were rinsed under running water, dipped in a 5% benomyl (fungicide) solution for 1 minute, rinsed again with water, air dried and used for analysis.

Analytical methods and measurements

Irrigation water quality analysis

The pH, EC and turbidity of the two water sources used for the irrigation of the guava crop were determined using a pH meter (Hanna HI 991001 extended range portable pH meter; Hanna Instruments Inc., MI, USA), an EC meter (Hanna HI 9835 portable EC meter; Hanna Instruments Inc., MI, USA) and a turbidity meter (Hanna HI 93703C portable turbidity meter; Hanna Instruments Inc., MI, USA), respectively according to the manufacturers' protocol. Dissolved oxygen (DO), chemical oxygen demand (COD) and biochemical oxygen demand (BOD_5) were determined by the American Public Health Association (APHA) 5220, 5210 and 5220B methods respectively. Total nitrogen was determined via persulfate digestion, followed by the colorimetric measurement of nitrate (APHA 4500-N C method), whereas total phosphorus was determined via orthophosphate digestion followed by colorimetric measurement (APHA 4500-P B method) (APHA 1998). Calcium, magnesium and potassium were determined according to the APHA 3120 B method. Heavy metals (Ni, Cd, Cr, Cu, Pb, Zn) were determined by inductively coupled plasma atomic emission spectrometry (ICP–AES, Interprid II XDL). As for microbial analysis, 100 ml of each water sample was filtered with a vacuum system using 0.45 μm membrane filters (Millipore). These filters were placed in Chromocult coliform agar (Merck, Darmstadt, Germany) and incubated at 37 °C for 24 hours for *Escherichia coli* growth and at 44.5 °C for 24 h to obtain the faecal coliforms. Helminth eggs were measured according to the method described by Bailenger (1979).

Soil geochemical properties and mineral content analysis

Soil samples were mixed in a ratio of 1:2 with deionized distilled water prior to analysis (Barman *et al.* 2015). The pH

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and EC of soil samples were measured using the soil suspensions as described previously for water analyses. Calcium, magnesium, potassium and phosphorus were determined according to the AOAC 990.8 method. Total nitrogen was determined according to AOAC 2001.11. Heavy metals were determined by ICP after nitric-perchloric acid (2:1) digestion. As for microbial analysis, soil samples were diluted 1:10 in sterile 0.1% peptone water and homogenized by hand in sterile laboratory stomacher bags. The microbiological analyses of these dilutions were done as described previously for water analyses.

Guava fruit samples

Physical analysis (length, diameter, fresh weight and volume)

Fifty fruits from both the different farms were selected for fruit physical analysis. Fruit length was measured from the top to the bottom of the fruit using a measuring tape. Fruit diameter was measured using a digital caliper (Digimatic CDC-30; 1–300 mm; Mitutoyo, Japan). Fruit fresh weight was determined by an electronic balance (A & D GR-200) while the volume of the fruit was determined using the water dispersion method (Bozokalfa & Kilic 2010).

Physicochemical analysis (moisture, firmness, pH, total soluble solids and titratable acidity)

Ten grams of sample were allowed to dry in an oven at 100 °C for 7 days. After 7 days, the samples were weighed again, and the moisture content was calculated with the following equation: moisture content (%) = [10 g (fresh weight) – dried weight/10 g] × 100%. The firmness was determined using a fruit hardness tester (Mitutoya HR-200). The pH of samples was determined using a pH meter (Hanna HI 991001 extended range portable pH meter; Hanna Instruments Inc., MI, USA) at 25 ± 1 °C. Total soluble solids (TSS) were determined using a digital refractometer (Atago PR-1 digital refractometer, Tokyo, Japan) at 25 ± 1 °C according to the manufacturer's protocol, and results were expressed in standard °Brix unit. As for the determination of titratable acidity, juice was extracted from the samples using a juice extractor and titrated with standardized 0.1 N sodium hydroxide to a definite faint pink end point using phenolphthalein as an indicator. The titratable acidity (% TA) was calculated according to the method of Sadler & Murphy (2010), where results were expressed in grams of citric acid per 100 ml of juice sample.

Ascorbic acid content

The ascorbic acid content in samples was determined based on the 2,6-dichlorophenol-indophenol (DCPIP) visual titration method (Ranganna 1977).

Antioxidant activity

Preparation of extract. The extraction was performed according to the method by Xu *et al.* (2008) with modifications. Crude extracts were prepared using 80% methanol with a sample to methanol ratio of 1:1. The mixture was placed in a shaking incubator (Shellab Orbital Shaking Incubator S14, OR, USA) at 250 rpm for 30 min at room temperature, and then centrifuged at 5,000 rpm for 20 minutes at 5 °C using a Beckman J2-MI refrigerated centrifuge. The resultant supernatant was used as sample extracts for antioxidant activity analysis.

Total polyphenol content. Total polyphenol content of the sample extracts was determined using a Folin–Ciocalteu assay modified to a microscale (Bae & Suh 2007). Following extraction, 0.79 ml of double-distilled water (ddH_2O), 0.01 ml sample and 0.05 ml Folin–Ciocalteu reagent was added into a 1.5 ml Eppendorf tube and mixed. Then 0.15 ml of sodium carbonate was added to the solution after 1 minute and mixed well. The mixture was then allowed to stand for 2 hours at room temperature (25 °C). The absorbance was measured at 750 nm using a Shimadzu MRC UV-200-RS spectrophotometer. A standard curve of gallic acid (y = 0.0052x, $R^2 = 0.9913$) was prepared by substituting samples with different concentrations of gallic acid, and the results were reported as milligrams of gallic acid equivalent (GAE) per 100 ml of fruit juice.

DPPH radical scavenging assay. The 2,2-diphenyl-1-picrylhydrazyl (DPPH) assay was based on the method described by Bae & Suh (2007). The radical scavenging activity was calculated accordingly:

$$\%\,\text{DPPH inhibition} = (A_{\text{control}} - A_{\text{sample}}/A_{\text{control}}) \times 100$$

where A_{control} is the absorbance reading of the control and A_{sample} is the absorbance reading of the sample.

Total antioxidant capacity. The total antioxidant capacity of the guava fruits harvested from the different farms was measured via a spectrophotometric method described by Prieto *et al.* (1999). A standard curve of ascorbic acid (y = 0.0020x, $R^2 = 0.9931$) was prepared and results were reported as micrograms of ascorbic acid equivalent (AAE) per ml fruit extract.

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Mineral, heavy metals and microbial analysis

Calcium, magnesium, potassium and phosphorus were determined according to the AOAC 990.8 method. Total nitrogen on the other hand was determined according to AOAC 2001.11. Results were expressed in milligrams per kilograms of sample. Heavy metal and microbial analysis were carried out as described in the water analysis.

Sensory analysis

A panel of 90 untrained panelists was used to evaluate consumer's acceptance of the guava samples. The samples were evaluated individually in partitioned booths under fluorescent light at room temperature. Acceptance test were performed using a 1 to 9 hedonic scale (1 = dislike extremely; 5 = neither like nor dislike; 9 = like extremely) to evaluate the acceptability of the guava's attributes (appearance, texture, aroma and taste/flavor). The panelists were provided with mineral water and unsalted crackers to cleanse their palate between samples to prevent carry over taste.

Statistical analysis

The data obtained were subjected to statistical analysis using SPSS 19.0 software (SPSS Inc., IBM). In this study, data were represented as mean values ± standard error (SE) for nine replications ($n = 9$) for water and soil analysis, 30 replications ($n = 30$) for quality analysis of guavas and 90 replications ($n = 90$) for sensory evaluation of guavas. The significant differences between mean values of samples were determined by analysis of variance (one-way ANOVA) using Tukey's Honestly Significant Difference test at a significance level of $p < 0.05$.

RESULTS AND DISCUSSION

Irrigation water quality

The average values of physicochemical, mineral, heavy metal and microbial properties of the two water sources met irrigation water quality standards according to FAO guidelines (Ayers & Westcot 1985), as shown in Table 1. The pH of both the water sources was acidic and was lower than that of the quality guidelines. However, it is suggested that a variation of 10% to 20% above or below the guideline value has little to no significant effects on the yield or quality if considered in proper perspective with other factors (WHO 2012). The EC of both water sources were well within the threshold, with the lake water having a significantly higher EC compared to the treated waste water. Both COD and BOD_5 levels were significantly higher in the lake water compared to treated waste water. However, COD and BOD_5 levels in both water sources were lower than that of the quality guidelines. There were no significant differences between the water sources with respect to DO. Both water sources tested contained levels of DO that were higher than the minimum limit. DO is an important attribute when it comes to irrigation water, as an increased level of DO is perceived to increase root mass and fine root hairs, which eventually leads to increased growth, better fertilization and overall plant health (Becker 2014). The nutrient content of the different water sources was observed to impact the nutrient content of the guava fruits. As for the treated waste water used for irrigation, the content of calcium, magnesium and potassium was well within the range of the irrigation water quality guidelines. Total nitrogen in treated waste water, however, was higher than the guideline level. Lake water used for irrigation on the other hand contained calcium and magnesium levels that were within the acceptable range, while total nitrogen and phosphorus levels were higher than the level of the irrigation water quality guidelines. An excess of nitrogen may prove to be detrimental to highly sensitive crops. However, most crops are relatively unaffected until nitrogen levels exceed 30 mg/l (Hassan 1990). The total nitrogen content of the treated waste water did not exceed the 30 mg/l threshold, while the content of total nitrogen in the lake water was above the level that is perceived to have adverse effects on crops. The nutrients present in irrigation water are vital for plant growth: calcium and magnesium are essential plant nutrients and cations responsible for good soil structure; potassium influences rooting, drought, heat, cold and disease tolerance; nitrogen is one of the main chemical elements required for plant growth and reproduction; phosphorus is known to play vital roles in photosynthesis and plant growth (Uchida 2000). Results from the microbial analysis revealed that both water sources had faecal coliform, *E. coli* and helminth egg values that were below the recommended values set by WHO (1989). Treated waste water, which may be a carrier of a variety of bacteria and viruses when used for irrigation purposes, could cause diseases through contamination of crops. However, in our study, relatively low microbial values were obtained, which could be attributed to the use of chlorine as a disinfectant. Heavy metals (Ni, Cd, Cr, Cu, Pb, Zn) levels in both water sources were observed to be well within the respective recommended range. This reduces the potential accumulation

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Table 1 | Physicochemical and mineral analysis of the two different water sources used for the irrigation of the Lohan guava crops

	TWW	LW	Irrigation water quality guidelines
Physicochemical parameters			
pH	5.83 ± 0.18^a	5.52 ± 0.23^b	6.50–8.40
EC (ppm)	53.15 ± 3.51^a	138.61 ± 1.98^b	<448
COD (mg/L)	205.4 ± 3.14^a	232.7 ± 2.88^b	<300
BOD_5 (mg/L)	95.3 ± 1.92^a	102.5 ± 1.32^b	<150
DO (mg/mL)	5.4 ± 0.2^a	5.6 ± 0.3^a	>5
Turbidity (NTU)	1.54 ± 0.33^a	5.55 ± 0.22^b	0–5
Macroelements			
Calcium (mg/l)	4.58 ± 0.42^a	16.3 ± 0.53^b	0–20
Magnesium (mg/l)	1.18 ± 0.19^a	4.81 ± 0.23^b	0–5
Potassium (mg/l)	1.81 ± 0.09^a	13.5 ± 0.11^b	0–2
Total nitrogen (mg/l)	26.5 ± 1.07^a	39.3 ± 1.19^b	0–10
Phosphorus (mg/l)	ND (<0.01)	ND (<0.01)	0–2
Heavy metals			
Nickel, Ni (ppm)	0.16 ± 0.03^a	0.20 ± 0.04^a	0–2
Cadmium, Cd (ppm)	0.03 ± 0.02^a	0.05 ± 0.03^a	0–0.05
Chromium, Cr (ppm)	0.07 ± 0.03^a	0.09 ± 0.02^a	0–1
Copper, Cu (ppm)	0.04 ± 0.01^a	0.03 ± 0.01^a	0–3
Lead, Pb (ppm)	0.02 ± 0.02^a	0.03 ± 0.01^a	0–1
Zinc, Zn (ppm)	0.07 ± 0.01^a	0.08 ± 0.02^a	0–1
Microbiological parameters			
Faecal coliforms (CFU/100 ml)	<10	<10	0–200
E. coli (CFU/100 ml)	<10	<10	0–100
Helminth (eggs/10 l)	<10	<10	<1

Values followed by different letters within the same column are significantly different for each fruit ($p < 0.05$) ($n = 9$). TWW: treated waste water; LW: lake water.

of toxic heavy metals in the soil that will lead to adverse effects on plant growth (Rattan *et al.* 2005). Through comparison of the different water sources' properties against irrigation water quality guidelines, it is evident that the treated waste water was of better quality for irrigation purposes.

Effects of the irrigation treatments on the soil geochemical properties and mineral content

The soil geochemical properties and mineral content were evaluated to assess the effects of different water sources used for irrigation on the soil (Table 2). The pH and EC of the soil were significantly different, whereby soil irrigated with water of higher pH and EC resulted in soil with higher pH and EC and vice versa. Irrigation water was observed to affect soil in this present study. The pH of soil irrigated with treated waste water was higher than that of soil irrigated with lake water, while the EC of soil irrigated with treated waste water was observed to be significantly lower than that of soil irrigated with lake water. However, previous research has reported no significant impact of irrigation on the soil (Rusan *et al.* 2007). The mineral content of the soils irrigated with different water sources were also observed to be correlated with the mineral content of the water used for irrigation. Calcium, magnesium and potassium levels in soil correlated with levels of irrigation water, whereby irrigation water with higher levels of these nutrients resulted in soil with higher levels as well. No correlation was observed between total nitrogen, phosphorus and heavy metals of the irrigation water and the soil.

Effects of the irrigation water on the physical and physicochemical attributes of the guava fruit

Table 3 shows the effects of the different water sources used for irrigation of guava crops on the physical and

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Table 2 | Effects of the different water sources used for irrigation of guava crops on the soil properties

	TWW	LW
Physicochemical parameters		
pH	5.47 ± 0.03[a]	5.34 ± 0.04[b]
EC (ppm)	4.19 ± 0.45[a]	5.67 ± 0.55[b]
Macroelements		
Calcium (mg/l)	440 ± 15[a]	1294 ± 28[b]
Magnesium (mg/l))	116 ± 13[a]	227 ± 22[b]
Potassium (mg/l)	60.1 ± 2.7[a]	103 ± 3.12[b]
Total nitrogen (mg/l)	0.04 ± 0.01[a]	0.06 ± 0.02[a]
Phosphorus (mg/l)	137 ± 5[a]	127 ± 8[a]
Heavy metals		
Nickel, Ni (ppm)	0.06 ± 0.03[a]	0.09 ± 0.04[a]
Cadmium, Cd (ppm)	0.02 ± 0.02[a]	0.04 ± 0.03[a]
Chromium, Cr (ppm)	0.03 ± 0.03[a]	0.05 ± 0.02[a]
Copper, Cu (ppm)	0.98 ± 0.11[a]	1.07 ± 0.09[a]
Lead, Pb (ppm)	3.66 ± 1.23[a]	4.13 ± 1.09[a]
Zinc, Zn (ppm)	3.34 ± 0.13[a]	4.23 ± 0.15[b]
Microbiological parameters		
Faecal coliforms (CFU/100 ml)	<10	<10
E. coli (CFU/100 ml)	<10	<10
Helminth (eggs/10 l)	<10	<10

Values followed by different letters within the same column are significantly different ($p < 0.05$) ($n = 9$). TWW: treated waste water; LW: lake water.

Table 3 | Effects of different water sources used for irrigation of guava crops on the physical and physicochemical attributes of the guava fruit

	TWW	LW
Length (cm)	11.65 ± 0.3[a]	11.71 ± 0.2[a]
Diameter (cm)	11.33 ± 0.25[a]	10.58 ± 0.2[b]
Fresh weight (g)	679.4 ± 27.9[a]	580.35 ± 26.7[b]
Volume (cm3)	752.75 ± 57.25[a]	620.25 ± 45.5[b]
Firmness (kgf)	0.78 ± 0.01[a]	0.75 ± 0.01[b]
TSS (°Brix)	8.17 ± 0.21[a]	7.02 ± 0.3[b]
pH	3.73 ±0.05[a]	3.93 ±0.09[b]
TA (%)	0.51 ± 0.04[a]	0.31 ±0.03[b]
Moisture content (%)	92.69 ± 0.41[b]	90.82 ± 0.52[a]

Values followed by different letters within the same column are significantly different for each fruit ($p < 0.05$) ($n = 30$). TWW: treated waste water; LW: lake water.

physicochemical properties of the fruits. There was a significant difference in all the physical and physicochemical properties, with only the fruit length being an exception. Larger fruits are generally preferred both by harvesters and consumers. Irrigation of crops with treated waste water resulted in fruits that were larger with respect to diameter, fresh weight and volume. The guava fruits were up to 17% higher in fresh weight and up to 21% higher in volume compared to those that were irrigated with lake water. It has been reported that wastewater affects the plant nutrient source and may contribute to the accumulation of organic matters in soils, which results in improved growth in both trees and fruits (Pedrero & Alarcón 2009). As for the physicochemical attributes, guava fruits harvested from the farm that uses treated waste water for irrigation of crops were observed to possess higher firmness, TSS, titratable acidity and moisture content. Higher amounts of these attributes in fruits are highly preferred by consumers. The firmness of fruits is related to the texture of fruits, and a higher firmness equates to fruits that are crunchier in nature. A higher firmness of the fruits also correlates to a higher moisture content of the fruits, where the higher the moisture content, the firmer the fruits (Rashidi *et al.* 2010). The TSS, on the other hand, is used to indicate the percentage of soluble solids and is one of the important factors for grading the quality of fruits (Beckles 2012). Besides being more desirable for consumption, fruits with high TSS content are desirable for processing (Ercisli 2007). In addition, previous research also suggests that TSS are often associated with the eating quality of ripe fruits (Mitchell *et al.* 1991). As for titratable acidity, it is often times responsible for the distinct taste and flavors in most fruits (George *et al.* 2016) and the guava is no exception. A higher amount of TA results in a more distinct flavor in the guava fruits. Guava crops irrigated with treated waste water resulted in fruits that were of better quality with regards to physical and physicochemical attributes. Results from this study are in agreement with previous studies, whereby irrigation with treated waste water was observed to result in fruits with higher quality compared to irrigation with other water sources, due to the ability of waste water to supply the crops with enough nutrients (Al-Lahham *et al.* 2003; Jun-feng *et al.* 2007). The physicochemical properties of the fruits ultimately affect the sensory attributes of the fruits, and the effects of the water sources used for irrigation on the sensory attributes of the fruits will be further discussed in the following sections.

Effects of the irrigation water on the nutritional properties of the guava fruit

The effects of the different water sources used for irrigation of guava crops on the nutritional properties of guava crops

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are shown in Table 4. Guava crops harvested from the farm that uses treated waste water for irrigation of guava crops were observed to contain higher ascorbic acid content, total polyphenols content and total antioxidant activity. Ascorbic acid content was observed to be higher by up to 21% in the guava crops. Ascorbic acid (vitamin C) is one of the most abundant antioxidants in plants and is a cofactor of many plant dioxygenases, and hence is an important factor in grading the quality of fruits (Mahieddine *et al.* 2011). Guavas with higher ascorbic acid content are therefore given higher preference. Besides a higher ascorbic acid content, guavas harvested from the farm irrigated with treated waste water were also observed to contain significantly higher total polyphenols and total antioxidant activity. The total polyphenol content was up to 12% higher, while total antioxidant activity was higher by up to 18%. There were no significant differences in the DPPH scavenging activity of the guavas irrigated with different water sources. Polyphenols are yet another attribute that is highly desired by consumers, which contributes to the quality of fruits. Polyphenols are known to possess biological properties and exhibit anticancer, antioxidant, antiviral and anti-inflammatory actions (Borchardt *et al.* 2008), whilst playing an important role in plants by acting as a chemical defence of plants against predators and in plant-plant interferences (Bhattacharya *et al.* 2010). As for the mineral content, lower calcium, magnesium and potassium contents were observed in guavas harvested from the farm that uses treated waste water for irrigation. This corresponds with the lower level of minerals in the treated waste water used for irrigation. Accordingly, calcium, magnesium and potassium contents were higher by up to 7%, 41% and 2% respectively in guavas irrigated with lake water. No significant differences were observed between the total nitrogen and phosphorus content of the guavas irrigated with different water sources.

Effects of the irrigation water on heavy metal uptake and microbial contamination of the guava fruit

Table 5 shows the effects of different water sources used for irrigation of guava crops on the heavy metal and microbial content of the guava fruit. As shown in Table 5, the heavy metals Ni, Cr and Pb were not detected in either of the guava samples. On the other hand, heavy metals Cd, Cu and Zn were detected at levels that were lower than the safe recommended values by WHO. This observation could be a result of the low concentrations of heavy metals found in both the water sources used for irrigation. Besides that, a previous report has suggested that heavy metals taken up by plants tend to remain in the roots, and only a fraction of the heavy metals absorbed is translocated to other parts of the plants such as the fruit (Al-Lahham *et al.* 2007). Translocation of heavy metals to other parts of the plants has also been reported to be attributed to the tendency of different parts of the plant to accumulate certain amounts of metals (Fazeli *et al.* 1991). This explains the phenomenon whereby minimal uptake of heavy metals from soil and water was

Table 4 | Effects of different water sources used for irrigation of guava crops on the nutritional properties of the guava fruit

	TWW	LW
Ascorbic acid content (mg AA/100 g)	6.8 ± 0.31^a	5.6 ± 0.21^b
Total polyphenol content (mg GAE/100 ml)	122.82 ± 3.01^a	110.06 ± 2.74^b
DPPH scavenging activity (μg AAE/ml)	9.51 ± 0.04^a	9.55 ± 0.02^a
Total antioxidant activity (mg AAE/g)	1240.06 ± 49.06^a	1047.65 ± 40.14^b
Calcium (mg/g)	15.5 ± 0.1^a	16.6 ± 0.2^b
Magnesium (mg/g)	12.8 ± 0.93^a	18.1 ± 0.75^b
Potassium (mg/g)	177 ± 0.15^a	180 ± 0.25^b
Total nitrogen (mg/g)	0.08 ± 0.01^a	0.08 ± 0.01^a
Phosphorus (mg/g)	9.8 ± 0.23^a	8.9 ± 0.18^b

Values followed by different letters within the same column are significantly different for each fruit ($p < 0.05$) ($n = 30$). TWW: treated waste water; LW: lake water.

Table 5 | Effects of different water sources used for irrigation of guava crops on the heavy metal and microbial content of the guava fruit

	TWW	LW	WHO permissible level
Heavy metals			
Nickel, Ni (ppm)	ND	ND	<0.01
Cadmium, Cd (ppm)	0.03 ± 0.01^a	0.04 ± 0.01^a	<0.1
Chromium, Cr (ppm)	ND	ND	<0.01
Copper, Cu (ppm)	0.05 ± 0.01^a	0.03 ± 0.01^a	<1
Lead, Pb (ppm)	ND	ND	<2
Zinc, Zn (ppm)	0.06 ± 0.02^a	0.05 ± 0.01^a	<5
Microbiological parameters			
Faecal coliforms (CFU/100 ml)	ND	ND	<1000
E. coli (CFU/100 ml)	ND	ND	<1000

Values followed by different letters within the same column are significantly different for each fruit ($p < 0.05$) ($n = 30$). TWW: treated waste water; LW: lake water; ND: not detected.

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observed in the guava fruits. Results from Table 5 also showed that guava fruits from plants irrigated with both the different water sources were completely uncontaminated. This could be a result of the low microbial levels in both the water sources used for irrigation. Guavas are fruits that are mostly eaten raw, and therefore there are regulations for the quality of water that should be used for irrigation of this particular crop (WHO 1989). With regards to heavy metal uptake and microbial contamination, both the water sources used for irrigation in this study resulted in fruits that do not pose a public health risk.

Effects of the irrigation water on the consumers' acceptance of the guava fruit

Guavas harvested from farms using different water sources for irrigation were evaluated through a consumers' acceptance test and the results are shown in Figure 1. Guavas harvested from the farm that were irrigated with treated waste water resulted in scores that were higher than those of guavas harvested from the farm irrigated with lake water. Higher scores were received for all attributes including appearance, aroma, taste, texture as well as overall acceptability. Results from the consumers' acceptance test correlated with the results of the physicochemical analysis. Guavas that were higher in physicochemical properties such as TSS, titratable acidity and pulp firmness scored higher in the consumers' acceptance test. It has been reported that titratable acidity and TSS affect the taste of fruits (Kader 2008), while firmness and moisture content both affect the texture of the fruits (Jha *et al.* 2005). The texture can be considered as one of the most important quality characteristics of edible fruits and vegetables (Waldron *et al.* 2003) and is often evaluated based on attributes that include crispness, hardness and juiciness or moisture release (Meilgaard *et al.* 1999). Aroma and taste of fruits on the other hand are affected by volatile compounds and TSS (Kader 2008). As for appearance, it has been reported that darker looking fruits are less desirable to consumers (George *et al.* 2015). In this present study, guavas harvested from the farm irrigated with treated waste water resulted in fruits that were more desired by consumers in comparison with guavas harvested from the farm that was irrigated with lake water.

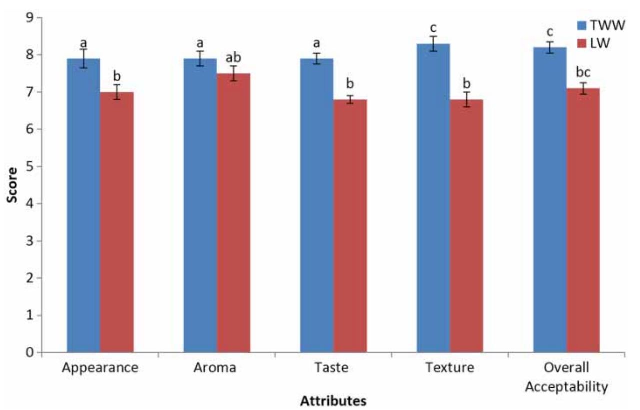

Figure 1 | Effects of different water sources used for irrigation of guava crops on consumers' acceptance of the guava fruit. Values followed by different letters are significantly different ($p < 0.05$) ($n = 90$). TWW: treated waste water; LW: lake water.

CONCLUSIONS

Analysis of the irrigation water revealed that treated waste water was of better quality with reference to irrigation water quality guidelines, while the lake water used for irrigation fell short in several aspects. The different water sources used for irrigation in the farms affected the soil geochemical properties as well as the quality of the guava fruits significantly. The quality of water used for irrigation had a direct effect on the quality of the fruit. The treated waste water, which fell within the guidelines, resulted in fruits with higher quality with respect to physical attributes, physicochemical attributes nutritional attributes and consumers' acceptance. Although the use of treated wastewater in irrigation remains a public concern, this study suggests that it might be a feasible alternative because of its high nutritive value, which may improve plant growth. Therefore, water used for irrigation that falls within the guideline is important in ensuring better quality fruits produced.

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REFERENCES

Al-Lahham, O., El Assi, N. M. & Fayyad, M. 2003 Impact of treated wastewater irrigation on quality attributes and contamination of tomato fruit. *Agricultural Water Management* **61**, 51–62.

Al-Lahham, O., El Assi, N. M. & Fayyad, M. 2007 Translocation of heavy metals to tomato (*Solanum lycopersicum* L.) fruit

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irrigated with treated wastewater. *Scientia Horticulturae* **113**, 250–254.

Almeelbi, T., Ismail, I., Basahi, J. M., Qari, H. A. & Hassan, I. A. 2014 Hazardous of waste water irrigation on quality attributes and contamination of citrus fruits. *Biosciences Biotechnology Research Asia* **11** (1), 89–97.

Al-Omran, A. M., Al-Harbi, A. R., Wahb-Allah, M. A., Nadeem, M. & Al-Eter, A. 2010 Impact of irrigation water quality, irrigation systems, irrigation rates and soil amendments on tomato production in sandy calcareous soil. *Turkish Journal of Agriculture and Forestry* **34**, 59–73.

Anem, M. 2013 *Guava Clones in Malaysia.* Department of Agriculture, Muar, Johor, Malaysia. Available from: http://animhosnan.blogspot.com/2010/12/guava-clone-in-malaysia.html (accessed 27 September 2014).

APHA 1998 *Standard Methods for the Examination of Water and Wastewater,* 20th edn. American Public Health Association, Washington, DC.

Ayers, R. S. & Westcot, D. W. (eds) 1985 *Water Quality for Irrigation.* FAO, Rome.

Bae, S. H. & Suh, H. J. 2007 Antioxidant activities of five different mulberry cultivars in Korea. *LWT – Food Science and Technology* **40**, 955–962.

Bailenger, J. 1979 Mechanisms of parasitological concentration in coprology and their practical consequences. *The American Journal of Medical Technology* **41**, 65–71.

Barman, M., Datta, S. P., Rattan, R. K. & Meena, M. C. 2015 Chemical fractions and bioavailability of nickel in alluvial soils. *Plant Soil Environment* **61** (1), 17–22.

Bauder, T. A., Cardon, G. E., Waskam, R. M. & Davis, J. G. 2004 Irrigation water quality. Colorado State University. Cooperative Extension Agriculture 506.

Becker, K. 2014 *Gromax Sees Yield Increases and Grade Improvement From Clean Water, Increased Dissolved Oxygen.* DRAMM corporation. Available from: http://www.hortidaily.com/ (accessed 20 October 2014).

Beckles, D. M. 2012 Factors affecting the postharvest soluble solids and sugar content of tomato (*Solanum lycopersicum* L.) fruit. *Postharvest Biology and Technology* **63** (1), 129–140.

Bhattacharya, A., Sood, P. & Citovsky, V. 2010 The roles of plant phenolics in defence and communication during *Agrobacterium* and *Rhizobium* infection. *Molecular Plant Pathology* **11**, 705–719.

Borchardt, J. R., Wyse, D. L., Sheaffer, C. C., Kauppi, K. L., Fulcher, R. G., Ehlke, N. J., Biesboer, D. D. & Bey, R. F. 2008 Antioxidant and antimicrobial activity of seed from plants of the Mississippi river basin. *Journal of Medicinal Plants Research* **2**, 81–93.

Bozokalfa, M. K. & Kilic, M. 2010 Mathematical modeling in the estimation of pepper (*Capsicum annuum* L.) fruit volume. *Chilean Journal of Agricultural Research* **70** (4), 626–632.

Ercisli, S. 2007 Chemical composition of fruits in some rose (*Rosa* spp.) species. *Food Chemistry* **104**, 1379–1384.

Fazeli, M. S., Sathyanarayan, S. & Satish, P. N. 1991 Effect of paper mill effluents on accumulation of heavy metals in coconut trees near Ninjangud, Mysore District, Karnataka, India. *Environmental Geology and Water Sciences* **17** (1), 47–50.

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

George, D. S., Zuliana Razali, Z., Santhirasegaram, V. & Somasundram, C. 2015 Effects of ultraviolet light (UV-c) and heat treatment on the quality of fresh-cut chokanan mango and josephine pineapple. *Journal of Food Science* **80** (2), S426–S434.

George, D. S., Zuliana Razali, Z. & Somasundram, C. 2016 Physiochemical changes during growth and development of pineapple (*Ananas comosus* L. Merr. cv. Sarawak). *Journal of Agricultural Science and Technology* **18**, 491–503.

Gutierrez, R. M., Mitchell, S. & Solis, R. V. 2008 *Psidium guajava*: a review of its traditional uses, phytochemistry and pharmacology. *Journal of Ethnopharmacology* **117** (1), 1–27.

Hassan, S. A. 1990 *Effects of Excess Nitrogen on Growth, Flowering and Fruit set of Bell Pepper (Capsicum annuum L.)*. University of Illinois at Urbana-Champaign, Illinois, USA.

Hassimotto, N. M., Genovese, M. I. & Lajolo, F. M. 2005 Antioxidant activity of dietary fruits, vegetables, and commercial frozen fruit pulps. *Journal of Agricultural Food Chemistry* **53** (8), 2928–2935.

Hossain, M. B. & Ryu, K. S. 2009 Effect of foliar applied phosphatic fertilizer on absorption pathways, yield and quality of sweet persimmon. *Scientia Horticulturae* **122** (4), 626–632.

Jeppsson, N. 2000 The effects of fertilizer rate on vegetative growth, yield and fruit quality, with special respect to pigments, in black chokeberry (*Aronia melanocarpa*) cv. 'Viking'. *Scientia Horticulturae* **83** (2), 127–137.

Jha, S. N., Chopra, S. & Kingsly, A. R. P. 2005 Determination of sweetness of intact mango using visual spectral analysis. *Biosystems Engineering* **91** (2), 157–161.

Joseph, B. & Priya, R. 2011 Review on nutritional, medicinal and pharmacological properties of Guava (*Psidium guajava* Linn.). *International Journal of Pharmacy and Biological Sciences* **2** (1), 53–69.

Jun-feng, W., Gen-xu, W. & Hua, W. 2007 Treated wastewater irrigation effect on soil, crop and environment: wastewater recycling in the loess area of China. *Journal of Environmental Sciences* **19** (9), 1093–1099.

Kader, A. A. 2008 Perspective: flavor quality of fruits and vegetables. *Journal of the Science of Food and Agriculture* **88**, 1863–1868.

Mahieddine, B., Faouzi, S. M., Hedjer, S., Moussa, H., Aïssa, B. & Mahmoud, S. 2011 Heat treatment effect on the technological quality of processed tomato paste. *Canadian Journal of Chemical Engineering Technology* **2** (3), 27–40.

Marzouk, H. A. & Kassem, H. A. 2011 Improving fruit quality, nutritional value and yield of Zaghloul dates by the application of organic and/or mineral fertilizers. *Scientia Horticulturae* **127**, 249–254.

Meilgaard, M., Civille, G. V. & Carr, B. T. 1999 *Sensory Evaluation Techniques, Third Edition.* CRC Press, Boca Raton, FL, pp. 195–208.

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Mesa-Jurado, M. A., Martin-Ortega, J., Ruto, E. & Berbel, J. 2012 The economic value of guaranteed water supply for irrigation under scarcity conditions. *Agricultural Water Management* **113**, 10–18.

Milano, M., Ruelland, D., Fernandez, S., Dezetter, A., Fabre, J. & Servat, E. 2012 Facing climatic and anthropogenic changes in the Mediterranean basin: what will be the medium-term impact on water stress? *C. R. Geoscience* **344**, 432–440.

Milošević, T., Milošević, N. & Glišić, I. 2013 Tree growth, yield, fruit quality attributes and leaf nutrient content of 'Roxana' apricot as influenced by natural zeolite, organic and inorganic fertilizers. *Scientia Horticulturae* **156**, 131–139.

Mishra, A. K. 2005 Important diseases of guava in India with special reference to wilt. In: *Proceeding of Ist International Guava Symposium* (R. Kishun, A. K. Mishra, G. Singh & R. Chandra, eds). CISH, Lucknow, India, pp. 75–90.

Mitchell, F. G., Mayer, G. & Biasi, W. 1991 Effect of harvest maturity on storage performance of 'Hayward' kiwifruit. *Acta Horticulturae* **297**, 617–625.

Ojowole, J. A. O. 2006 Anti-inflammatory and analgesic effects of *Psidium guajava* Linn (Myrtaceae) leaf aqueous extract in rats and mice. *Methods and Findings in Experimental and Clinical Pharmacology* **28** (7), 441–446.

Parvizi, H., Sepaskhah, A. R. & Ahmadi, S. H. 2014 Effect of drip irrigation and fertilizer regimes on fruit yields and water productivity of a pomegranate (*Punica granatum* (L.) cv. Rabab) orchard. *Agricultural Water Management* **146**, 45–56.

Pedrero, F. & Alarcón, J. J. 2009 Effects of treated wastewater irrigation on lemon trees. *Desalination* **246**, 631–639.

Prieto, P., Pineda, M. & Aguilar, M. 1999 Spectrophotometric quantitation of antioxidant capacity through the formation of a phosphomolybdenum complex: specific application to the determination of vitamin E. *Analytical Biochemistry* **269**, 337–341.

Ranganna, S. 1977 Chapter 5: ascorbic acid. In: *Manual of Analysis of Fruit and Vegetable Products* (S. Ranganna, ed.). Tata McGrawHill Publishing Company, New Delhi, pp. 94–96.

Rashidi, M., Ranjbar, I., Gholami, M. & Abbassi, S. 2010 Prediction of carrot firmness based on carrot water content. *American-Eurasian Journal of Agricultural & Environmental Science* **7** (4), 402–405.

Roy, C. K., Kamath, J. V. & Asad, M. 2006 Hepatoprotective activity of *Psidium guajava* Linn. leaf extract. *Indian Journal of Experimental Medicine* **44** (4), 305–311.

Rusan, M. J., Hinnawi, S. & Rousan, L. 2007 Long term effect of waste water irrigation of forage crops on soil and plant quality parameters. *Desalination* **215**, 143–152.

Rattan, R. K., Datta, S. P., Chhokar, P. K., Suribabu, K. & Singh, A. K. 2005 Long-term impact of irrigation with sewage effluents on heavy metal content in soils, crops and groundwater – a case study. *Agriculture, Ecosystem & Environment* **109**, 310–322.

Sadler, G. D. & Murphy, P. A. 2010 pH and titratable acidity. In: *Food Analysis,* 4th edn (S. S. Nielsen, ed.). Springer, New York, pp. 231–233.

Salib, J. Y. & Michael, H. N. 2004 Cytotoxic phenylethanol glycosides from *Psidium guajava* seeds. *Phytochemistry* **65** (14), 2091–2093.

Sanda, K. A., Grema, H. A. & Bukar-Kolo, Y. M. 2011 Pharmacological aspects of Psidiumguajava: an update. *International Journal of Pharmacology* **7** (3), 316–324.

Uchida, R. 2000 Essential nutrients for plant growth: nutrient functions and deficiency symptoms, plant nutrient management in Hawaii's soils, approaches for tropical and subtropical agriculture. In: *College of Tropical Agriculture and Human Resources* (J. A. Silva & R. Uchida, eds). University of Hawaii at Manoa, Honolulu, HI.

Waldron, K. W., Parker, M. L. & Smith, A. C. 2003 Plant cell walls and food quality. *Comprehensive Reviews in Food Science and Food Safety* **2**, 101–119.

Watanabe, M., Ohta, Y., Licang, S., Motoyama, N. & Kikuchi, J. 2015 Profiling contents of water-soluble metabolites and mineral nutrients to evaluate the effects of pesticides and organic and chemical fertilizers on tomato fruit quality. *Food Chemistry* **169**, 387–395.

WHO (World Health Organization) 1989 *Health guidelines for the use of wastewater in agriculture and aquaculture*. Technical Report No. 778, WHO, Geneva, p. 74.

Xu, G., Liu, D., Chen, J., Ye, X., Maa, Y. & Shi, J. 2008 Juice components and antioxidant capacity of citrus varieties cultivated in China. *Food Chemistry* **106**, 545–551.

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