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Effect of compost tea and partial root zone drying on tomato productivity and quality

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All relevant data are within the paper and its Supporting Information files.

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The authors declare no competing interests.

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Abstract: To evaluate the effect of partial root zone drying in combination with compost tea on growth, morpho-physiological traits, yield and quality attributes of tomato (*Lycopersicon esculentum* Mill), a greenhouse experiment was conducted. The ultimate aim of this study was to evaluate the effect of partial root zone drying (PRD) and conventional drip irrigation (CDI) incorporated with compost tea (CT) on tomato productivity and quality. The results of this study indicated positive and significant effect of CT in combination with PRD on fruit size, fruit weight, fruit firmness, cluster per plant, fruit per cluster, fruit lycopene content, pH, TSS and TSS/TA. The PRD treated plant's fruits exhibited better appearance, higher lycopene content, fruit firmness, total soluble solid (TSS), and TSS/titratable acidity (TA) ratio than fruits plants treated with CDI (conventional drip irrigation). Combined treatment with CDI and CT had positive effect on plant height, leaf area, chlorophyll and water content in fruits. But they exhibited the negative effect on fruits blossom end rot, weight loss, chilling injury, and TA content. The results of this study indicated that CT improve more significantly tomato yield and quality under PRD than CDI. Combining PRD and CT led to the maximization of crop water productivity.

1. Introduction

The consumption of fresh fruits and vegetables has been increasing because of their vitamin, mineral, and antioxidant contents. With the increasing consumption of fresh vegetables especially for tomatoes (Consumption Census, 2015) there has been a corresponding rise in concern about the inorganic chemical fertilizer and pesticides residues linked to tomato fruits (Ware, 2017). Besides that, the increasing public concern about negative environmental effects of agricultural practices like conventional chemical fertilization has promoted the evaluation of alternatives like the use of organic fertilizers. Compost is considered as an organic fertilizer. It is made with substance such as organic crop residues, animal wastes, food garbage, organic municipal and industrial wastes. Pane *et al.* (2013) highlighted the beneficial effects of agricultural utilization of compost, which include improvement on physical, chemical, biochemical and biological properties of the soils. But compost can be heavy and bulky to transport and spread. As an alternative, compost tea (CT) offers the benefits of compost in a lighter-weight package. It is a liquid version of compost, obtained through a liquid-phase of compost and extraction ranging from few hours to two weeks with or without active aeration and the addition of nutrients such as molasses. It is easier to apply to plants and the soil.

The effectiveness of compost teas may vary due to the differences in types of compost, management and procedures used for its preparation (Egwunatum and Lane, 2009; Pant *et al.*, 2012). According to Martin *et al.* (2012), the best results were obtained when aerated compost teas rather than non-aerated teas were used. Most probably dissolved oxygen supports microbial activity (Arancon *et al.*, 2007). Reeve *et al.* (2010) reported that the potential of compost teas for supplementing or substituting other types of fertilizers also seems promising. In a study, Moretti *et al.* (2015) indicated that composted green wastes are advantageous when compared to other organic wastes since they present a lower risk of toxicity due to the presence of heavy metals, pollutants, aromatic hydrocarbons, hormones, pharmaceuticals as well as viruses, fecal coliforms and salmonella (Benito *et al.*, 2005). These materials exhibit excellent biological activity (Ros *et al.*, 2005).

Hatam *et al.* (2015) and Mavity (2016) reported that compost tea is an effective, low-strength, all-natural fertilizer for plants, seedlings, and gardens. They also assert that compost tea reduces salt accumulation in soils that come from commercial fertilizers, improves the ability of soil to hold nutrients, retain water and facilitates the soils pH buffering ability through microbe diversity.

The use of compost tea as a foliar spray or soil drench has been demonstrated to improve plant health, yield and nutritional quality by: enhancing beneficial microbial communities and their effects on agricultural soils and plants. It also enhances mineral nutrient status of plants and induces the production of plant defense compounds that may have beneficial bioactivities in humans (Weltzien, 1991; Hoitink *et al.*, 1997; Diver, 2002; Scheuerell and Mahaffee, 2002; Carpenter-Boggs, 2005; Ingham, 2005). The potential benefits of compost tea are substantial and particularly relevant to crop production in low-input agricultural systems, e.g. minimize water use. Less water input is now one of the globally used modern practice of sustainable agriculture and sustainable food production system.

Indeed, throughout the world, water supplies are limited and water crises are a top global risk. As irrigation of agricultural lands accounts for 70% of water usage worldwide (Khokhar, 2017), even a slight reduction in irrigation water could substantially increase the water available for other purposes. Therefore, there is an urgent need to identify effective irrigation management strategies. Partial root-zone drying irrigation (PRD) is one of the new efficient and productive water-saving irrigation methods that can conserve irrigation water up to 50% in processing tomatoes (Casa and Rouphael, 2015). This technique has the potential to significantly reduce crop water use (El-Sadek, 2014), minimize canopy vigor, but able to maintain crop yields and quality of crops (Sun *et al.*, 2014) when compared to conventional irrigation methods. It is expected that plants under PRD condition will maintain high water saving potentials while adequately watering plants.

In this context, the aim of this study was to check the use of CT in combination with less water use to improve tomato production sustainability. Accordingly, the use of compost tea combined with PRD was checked as a possible management system for promoting tomato growth and decrease need for chemical fertilizer which might lead to sustainable agriculture.

Most of the previous studies were focused on the application of compost as a soil supplement or foliar application for tomato plant or tomato fruit disease control (Vawdrey and Stirling, 1997; Gutierrez-Miceli *et al.*, 2007; Segarra *et al.*, 2009; Souleymane *et al.*, 2010). No information is available on the combined effect of compost tea and PRD on morpho-physiological traits, yield and quality attributes of "Vibelco" tomato grown in closed environments. Thus some investigations are required to provide clear information about the effects of compost tea and partial root zone drying in growth promotion, yield and quality among the worldwide consumed vegetables such as tomatoes. Therefore, this work was focused on the effects of compost tea combined with PRD on the growth, yield and main quality parameters of tomatoes grown in closed environments. Based on the initial observations, we hypothesized that the applied compost based tea with deficient water supply may exert a suitable bioactivity on the tomato plants as related to the stimulation of growth, yield and quality parameters of the fruits.

2. Materials and Methods

Experimental conditions

The experiment was conducted in a greenhouse setting at approximately 22°C during daytime temperature and 15°C at night, Relative Humidity (RH) of 67%, 14 hour's photoperiod and ambient light condition at the Chateau Fresno Nursery, 13505 South Fresno, California 93609, USA, from April to September 2017. Seeds of a fresh market tomato (*Lycopersicon esculentum* Mill cv. Vibelco) were sown on March 1, 2017. Thirty three days after seeding, uniform plants were transplanted into 24 wooden boxes (2.53 m length × 0.65 m width × 0.20 m height each). Each box had 4 compartments (0.50 m length × 0.50 m width × 0.20 m height) with one experimental plant per compartment. To avoid lateral water movement, a small piece of plastic (0.50 m length × 0.025 m width × 0.04 m height) was placed centrally on the base of each compartment. The plants were grown in a vermicast and coconut fiber mixture (60:40 v/v). Bees were used for pollination (Fig. 1).

Compost tea preparation

First, a large plastic bin (25 gallons, about 95 l) was filled almost to the brim with water and allowed it to stand overnight to rid it of chlorine, which will otherwise would kill the soil biota in the compost. A close fitting lid was used to exclude mosquitoes and limit odor. Then, to make up a compost "tea-bag", a Hessian sack was used. A measured amount of compost (homemade compost prepared from organic tree leaves) with organic cow manure, that is approximately one-tenth of the volume of water, was placed inside the tea-bag. For every 25 liter bucket, we used about 2.5 liter of compost. The "tea-bag" was tied and securely closed and immersed it in the water for three weeks. The mixture was frequently dunked to speed up the process and obtain better results. After three weeks the mixture was filtered. The whole process was done at ambient temperature. Then the tea was applied to the plant by incorporating it to the irrigation water used for with drip irrigation at the ratio of 1:4 (1 part tea and 4 part water) (Fig. 2).

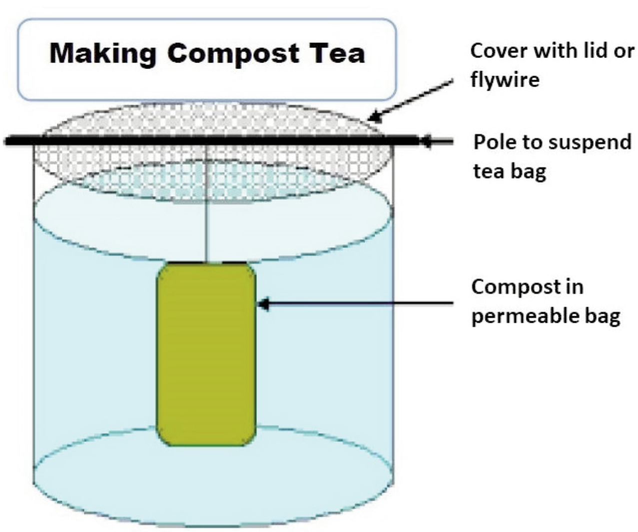

Fig. 1 - Schematic diagram of compost tea production.

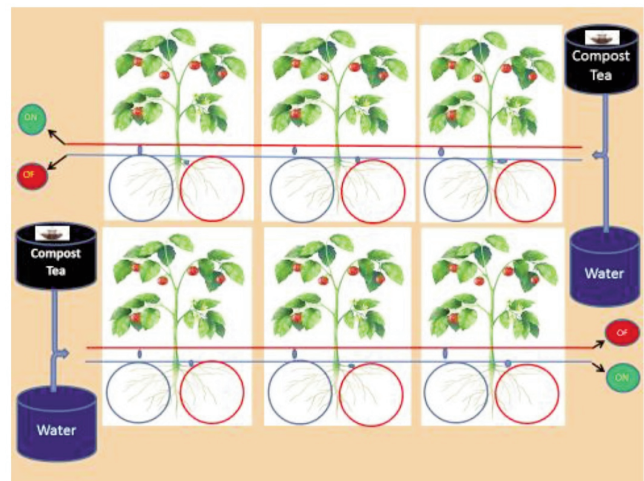

Fig. 2 - Schematic diagram of drip irrigation treatments incorporated with compost tea.

Irrigation treatments incorporated with compost tea

Two weeks after transplanting, irrigation treatments incorporated with compost tea were tested. Treatments were: 1. conventional drip irrigation (CDI) to both sides of the root system, 2) half of irrigation water, in drip irrigation given alternately only to one side of the root system with each irrigation (PRD), 3) CDI plus compost tea, and 4) PRD plus compost tea. In the CDI the irrigation treatment was given 0.10 meter away from the main stem and on both sides of the row. The irrigation (CDI) covered a total area and soil volume of 0.24 m^2 and 0.048 m^3, respectively. The amount of water was given in two equal doses at 10:00 h and at 16:00 h by drip irrigation system with emitters. Two irrigation lines were set up and operated separately for the PRD treatment. Two sprinklers per plant (one on each line) each emitters 4 l/h were placed 0.15 m away from the main stem of each plant. The irrigation in PRD treatment covered a total area and soil volume of 0.018 m^2 and 0.004m^3, but half of irrigated area and soil volume was wetted in PRD treatment. There was some drainage in all treatments, but it was not measured. However, water loss by drainage was minimized by adjusting the amount of water as the crop developed. The values of the irrigation efficiency presented here might have been underestimated, considering no water loss.

Plant and fruit growth performance

Growth, yield, yield components and blossom-end rot were measured in 12 randomly selected plants/fruits from each treatment. The plant heights were measured with a tape from the base to the tip of the plant. Plant growth and development data were documented in the sampled and tagged plants monthly for three months. Leaf area was measured using a destructive method. Total leaf area (cm^2) was measured by leaf area meter (Model: Delta-T, Cambridge, U.K.). The numbers of clusters were counted per plant from the first to the last cluster during the growing period. The number of fruits was counted when the plants started fruiting. The fruit weights were determined after harvesting the tomato using a weighing balance. After 150 days, one plant per treatment per replication was destroyed and the total vegetative fresh weight was assessed and expressed as kg/plant. Mature green tomato fruit firmness was measured using an Instron Universal Testing Machine with a 0.5 cm^2 plunger. The measurement was taken at the mid-section of the fruit. Water content of fruit was expressed on a dry weight basis. Fruit blossom-end rot incidence was recorded and calculated in percentage of fruits affected per plant.

Fruit quality at harvest or postharvest

For postharvest quality evaluation, 6 replicates of 5 mature green (Cascio, 2017) fruits from each treatment were randomly chosen approximately 125 days after transplanting and were stored in a dark refrigerated room at 4°C with 94% RH. After a storage period of 2 weeks, all fruits were moved to a ventilated room without supplemental light at 24°C with 66% RH and held for 7 days. The following attributes were checked for quality measurements: weight loss, chilling injury, decay, appearance/color change, total soluble solids (TSS), pH, titratable acidity (TA), chlorophyll and lycopene content.

Fruit weight loss was determined prior to and after storage. It was calculated as the percentage of initial fresh weight. Color development was observed visually using a subjective scale with mature green (MG) = 1, breaker (B) = 2, pink (P) = 3, light red (LR) = 5 and red (R) = 6 (USDA, 2005). Chilling injury (surface pitting) was rated visually by estimating the percentage of the injured fruits. Decay (unidentified) was rated visually and calculated as a percentage of fruit affected.

Chlorophyll and lycopene content were determined from three randomly selected fruits from each treatment by grinding pericarp tissue (about 5 g) in 15 ml acetone. The extract was taken for centrifugation at 35,000 rpm for 10 minutes. Before centrifugation, the tubes were covered with aluminum foil to prevent light-induced lycopene oxidation. After centrifugation, the supernatant was decanted and adjusted to 20 ml with acetone. Absorbance of the extracts at 664 nm for chlorophyll and 503 nm for lycopene was measured with a spectrometer (Model 160 A). Total chlorophyll content in milligram per 100 grams of tissue was calculated according to the formula developed by Holden (1976). Lycopene content was calculated using the molecular extension coefficient of 3240 (Davis, 1976) and expressed as micrograms per gram of fresh weight.

Total soluble solid (TSS), pH and titratable acidity (TA) were measured on juice extracted from fruits. The TSS content was determined with a digital refractometer (Atago, Model 1, Tokyo, Japan). The TA was determined by a Metler Auto titrator (Model V 20) and pH was measured with an autocal pH meter (Model PHM 83).

Experimental design and data analysis

A completely randomized design was used with the four treatments replicated six times with four plants per replication for each treatment. Data were analyzed by a complete randomized model using the ANOVA procedure of SAS software version 8.2 (SAS Institute, Cary, NC, USA). Treatment effects on tomato growth, yield and quality components were analyzed using Duncan's Multiple Range Tests to determine significant effects at p = 0.05 among four treatment means.

3. Results and Discussion

Figure 3 illustrates the mean plant height over a period of 3 months. Bars represents standard deviations. Plants height increased gradually within 3 months. The different letters in the columns at the same month showed significant differences. The maximum height was obtained from those tomato plants which were irrigated with CDI/full water regime plus compost tea and the difference was significant during the whole experiment. On second and third month, CDI plus CT treated plans exhibited higher height than PRD plus CT treated plans and the difference was significant. On third month, The PRD treated plants resulted in the significantly lowest height among the four treatments. Similar results were reported by Pal *et al.* (2016), who grew tomato plants under deficit irrigated conditions. Among the four treatments in this study, the growth of CDI treated plants exhibited moderate growth compared to other treated plants.

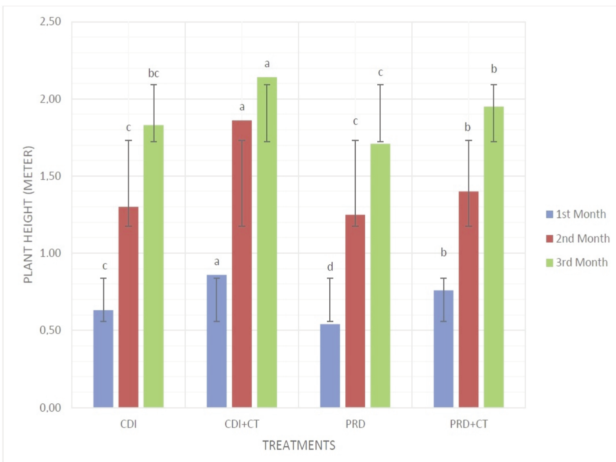

Fig. 3 - Effect of CDI (conventional dripping irrigation) and PRD (partial root-zone irrigation) with compost tea (CT) on plant height over 3 months. Bars represents standard deviations; means followed by different letters at the same month are significantly different at 5% probability level using Duncan's Multiple Range Test (DMRT).

Combined treatment with CDI and CT had positive (+) and significant effect on fruit fresh weight and leaf area of the plant, respectively. The PRD had a negative (-) effect in shoot fresh weight and leaf area of plant. However, PRD had positive (+) effect on the number of fruits per cluster as well as in fruit production in comparison to the CDI treatment (Table 1). Combined treatment with PRD and CT exhibited the positive (+) and significant effect on cluster per plant and number of fruits per cluster. The difference between CDI and PRD treated plants' shoot fresh weight, leaf area, and fruit production were significantly different at 0.05 % level. The CDI treated plants appeared to have excess moisture in the root zone (didn't investigated moisture in root zone in this study), which may have caused root inactivity contributing to lower yield and delayed maturity of the crop as compared to the PRD treated plants. Therefore, this study demonstrates that the deficit of irrigation water with compost tea can induce biological activity of tomato plant which ultimately increased the number of clusters per plant and number of fruits per cluster.

Table 1 illustrates that among the four treatments, partial root zone drying (PRD) plus compost tea (CT) treated plant fruits exhibited the highest percentage blossom end rot. Table 1 also illustrated that the PRD treated plant's fruits showed significantly higher percentage (%) of blossom-end rot as compared to the CDI treated ones. Mathew and Salvadore (2007) reported that the blossom-end rot is a physiological disorder of tomato fruit caused by calcium deficiency or excessive soil moisture fluctuation, which reduce uptake and movement of calcium into the plant. The higher percentage (%) of blossom-end rot in the PRD treated fruits might be due to the reduced movement of calcium to in the PRD treated plants. However, no calcium was analyzed either in the leaves or fruits in this experiment.

Both PRD and CT treatments influenced the fruit size, water content and fresh fruit weight (Table 1). Among the four treatments, fruit size showed significant difference and the largest size of fruits were produced by those plants irrigated with deficit (PRD) water mixed with compost tea. There were some differences in fresh fruit weight and water content in

Table 1 - Effect of CT and PRD on tomato fruit size, total fresh weight, water content, fruit weight, fruit firmness, cluster/plant, fruit/cluster, shoot fresh weight, leaf area, and blossom-end rot

Plant yield parameter	Treatment			
	CDI	PRD	CDI + CT	PRD + CT
Fruit size, diameter (mm)	65.40 d (x)	68.30 c	70.27 b	72.03 a
Total fresh weight of fruit (kg/plant)	5.11 d	6.47 c	7.53 b	9.34 a
Fruit water content (%)	95.17 a	96.1 a	92.17 c	94.07 b
Fruit weight (g)	94.4 b	97.33 a	94.57 b	95.5 b
Fruit firmness after harvest (kg/cm^2)	9.97 a	9.13 b	8.30 c	8.17 c
Cluster/plant	8.03 d	9.10 c	10.40 b	11.23 a
Fruit/cluster	5.03 d	5.60 c	6.40 b	6.80 a
Shoot fresh weight (Kg)	10.60 b	11.53 a	8.97 d	9.30 a
Leaf area (cm^2)	453 b	419 d	478 a	432 c
Bloom end rot (%)	5.50 a	6.00 c	6.50 b	8.27 a

(x) Means followed by different letters in a row are significantly different at 5% probability level using Duncan's Multiple Range Test (DMRT).

PRD and CDI treated plants' fruits; and the differences were statistically significant (Table 1).

The results of this study indicates that, during conservation, combined CDI and CT treated plant fruits lost more weight than combined PRD and CT treated plant fruits (Table 2). The results of this study also confirm that PRD treated plant fruits lost less water compared to the CDI treated ones. Reduced weight loss in the PRD treated tomatoes during the storage is a positive quality attribute in tomato fruits, especially for distant markets. According to Yadav and Singh (2014) the weight loss of fruits in storage condition is mainly from water loss and from solid constituents. The lower water loss in PRD treated fruit might be due to lesser incidents of micro-cracks in the skin. However, no skin micro-cracks were examined in this investigation.

As demonstrated in this study, chlorophyll and lycopene contents were influenced by irrigation and compost tea treatment (Table 2). Combined treatment with PRD and CT postulated higher lycopene and lower chlorophyll contents compared to the plants treated with a combination of CDI and CT. When compared to the fruits from CDI treated plants, fruits from PRD treated plants exhibited significantly lower chlorophyll and higher lycopene content on the 7th day at 24°C. This was followed by a 2-week storage period at 4°C (Table 2). Klunklin and Savage (2017) also detected significantly higher lycopene content in PRD treated tomato fruits.

Gindi *et al.* conducted a survey in 2016 and concluded that 63 percent of consumers' purchase interest depends on the color of fruits. Fruit colors were affected by irrigation and compost tea treatment. The best color (tone of red) was observed on plants fruit those treated with PRD plus CT. Fruits from PRD treated plants exhibited less visible chilling injury (fruit surface pitting) and decay, but faster color change than the fruits treated with CDI. The less visible chilling injury, decay and faster color changes in PRD treated plants fruit might be due to less water content compared to CDI treated plants fruits.

Tomato flavor is generally determined by the content of soluble solids (TSS) and titratable acidity content (TA).

According to Hong *et al.* (2014), sweetness of the most fruits is closely related to the TSS content. According to Baldwin *et al.* (2015), the sourness in most of the fruits is governed by TA content.

Valero *et al.* (2005), reported that changes in sugar content and organic acid metabolism occur during the ripening process of tomato fruits. Aoun *et al.* (2013) examined that tomato flavor is co-related to the total sugar and acid contents in the fruit. The results of this study demonstrated that the total soluble solid (TSS), TA and pH were affected by the treatment of PRD and CT individually and in combined treatments. Fruits from PRD plus CT treated plant exhibited significantly higher content of TSS, and pH values, but lower TA than fruits from CDI and CT treated plants. The total soluble solid (TSS), TSS/TA and pH increased, while TA decreased in PRD treated fruits than CDI treated ones (Table 2). In an earlier study, Sun *et al.* (2014) also detected higher TSS levels in tomato fruits produced under a PRD condition. The higher TSS and the lower TA in fruits from PRD treated plants were probably due to the less retained water in fruit from PRD treated plant than the fruits from CDI treated plants. The higher pH in fruits from PRD treated plants was compatible with the lower TA

Table 2 - Effect of CT and PRD on tomato fruit weight loss, chilling injury, decay, chlorophyll and lycopene content, fruit color change, pH, TA, TSS content and TSS/TA ratio, 7th day at 24°C followed by a 2-week storage period at 4°C

Phylogical parameter	Treatment			
	CDI	PRD	CDI + CT	PRD + CT
Weight loss (%)	2.18 b [X]	1.88 c	2.93 a	2.03 bc
Chilling injury (%)	14.66 b	9.00 d	17.00 a	10.70 c
Decay (%)	13.67 a	7.50 d	12.30 b	10.20 c
Chlorophyll (mg/100 g fresh weight)	3.80 a	3.30 bc	3.53 b	3.60 b
Lycopene (µg/g fresh weight)	7.00 d	7.80 b	7.43 c	8.10 a
Color change	4.36 c	4.76 b	4.63 bc	5.23 a
pH	4.30 d	4.63 b	4.50 c	4.80 a
TA (% citric scid)	0.49 c	0.45 d	0.53 b	0.56 a
TSS	4.27 d	4.80 b	4.56 c	5.10 a
TSS/TA	8.61 c	10.67 a	8.60 c	9.11 b

(X) Means followed by different letters in a row are significantly different at 5% probability level using Duncan's Multiple Range Test (DMRT).

in fruits from PRD treated plants than in the fruits from CDI treated plants.

4. Conclusions

The results of this study demonstrates the significant effect of PRD on biometric variables such as number of cluster per plant, number of fruit per cluster, fruit weight, and fruit size in combination with CT treatments. The results of the study also shows that the plants treated with a combination of PRD, a cost effective water saving method, and CT exhibited slower plant growth, but produced higher yield, and better postharvest quality attributes of fruits.

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