Turkish Journal of Agriculture and Forestry

Volume 36 | Number 5 Article 4

1-1-2012

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Recommended Citation

RAB, ABDUR and HAQ, IHSAN-UL (2012) "Irrigation intervals affect physicochemical quality attributes and skin cracking in litchi fruit," *Turkish Journal of Agriculture and Forestry*: Vol. 36: No. 5, Article 4.
https://doi.org/10.3906/tar-1108-11
Available at: https://journals.tubitak.gov.tr/agriculture/vol36/iss5/4

Research Article

Turk J Agric For
36 (2012) 553-562
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doi:10.3906/tar-1108-11

Irrigation intervals affect physicochemical quality attributes and skin cracking in litchi fruit

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Received: 06.08.2011 ● Accepted: 03.03.2012

Abstract: The influence of irrigation intervals on the physicochemical quality attributes and fruit cracking of litchi cultivars was investigated by irrigating 4 litchi cultivars at intervals of 3, 6, and 9 days. It was found that cultivars Gola and Bedana had the highest and lowest fruit weight (21.90 g and 14.31 g), pulp weight (16.478 g and 10.85 g), total soluble solids (22.16% and 16.37%), total sugars (21.22% and 15.28%), and fruit cracking (41.60% and 10.40%). While cultivar Gola also had the highest reducing sugars (18.01%) but the lowest nonreducing sugars (3.80%), cultivar Bedana had the lowest reducing sugars (5.68%) and the highest nonreducing sugars (10.02%). Similarly, cultivar Bedana had the highest skin strength (3.33 kg cm^{-2}) compared to the lowest (2.16 kg cm^{-2}) in cultivar Gola. The highest skin calcium content (4.916 mg 100 g^{-1} DW) was recorded in cultivar Surahi, while boron was the highest (0.112 mg 100 g^{-1} DW) in cultivar China. In contrast, Bedana had the lowest calcium (3.976 mg 100 g^{-1} DW) and boron (0.10 mg 100 g^{-1} DW) contents. The fruit and pulp weight decreased significantly with an irrigation interval of 9 days but the fruit cracking percentage increased significantly from 20.48% at a 3-day irrigation interval to 27.55% and 31.45% at irrigation intervals of 6 and 9 days, respectively. Increasing irrigation intervals decreased the skin strength and calcium content of the fruit but increased the reducing sugars and ion leakage from skin disks. The data suggest that both pulp and skin characteristics of litchi fruit may determine fruit cracking susceptibility and that increasing the irrigation intervals promotes the incidence of cracking.

Key words: Cracking, irrigation, litchi skin strength, quality

Introduction

Litchi is an emerging fruit of Pakistan (Rajwana et al. 2010). The litchi fruit is a good source of food and nutrition (Paull et al. 1984; Jiang et al. 2006), especially vitamin C and antioxidant compounds (Hu et al. 2010). Though grown in a relatively small acreage, the litchi is in high demand due to its taste and health benefits (Rajwana et al. 2010). The litchi fruit is generally marketed fresh in domestic markets. A small percentage is processed (Ghosh et al. 1988), while a negligible quantity is exported (Rajwana et al. 2010).

The cultivation of litchi fruit could not be increased due to its yield, and fruit quality is highly sensitive to water deficit (Spreer et al. 2007), which may also aggravate the fruit cracking and shorten the postharvest life (Mitra and Pathak 2010). Further complexities in optimizing irrigation emerge due to different cultivars, plant sizes, and fruit developmental stages (Li et al. 2001; Khurshid et al. 2004). The

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litchi flowers in March and the fruit matures during the month of June, a season characterized by high temperatures and relatively low rainfall (Khurshid et al. 2004). Thus, water deficit is a major limiting factor in litchi fruit production. The litchi plants may need irrigation every 2-3 days to avoid water deficit (Singh 1986), ensure normal plant growth (Nakata and Suehisa 1969), and maximize yield and quality (Spreer et al. 2007). Excess water is also undesirable (Chandel and Sharma 1992) and may trigger fruit cracking (Underhill and Simons 1993; Li et al. 2001; Huang et al. 2004). Irrigation management has been shown to decrease fruit cracking and enhance fruit quality (Kumar et al. 2001). Therefore, this study was started to investigate the influence of irrigation intervals on the quality of litchi fruits and identify the relationship between irrigation and fruit cracking.

Materials and methods

Plant material and treatment

The study was carried out during 2007 and 2008 at the Litchi Fruit Farm, Agriculture Extension Department, Haripur, and Hazara of Khyber Pakhtunkhwa Province, Pakistan. Four cultivars of litchi, China, Gola, Surahi, and Bedana, were irrigated at intervals of 3, 6, and 9 days. The soil under the canopy was covered with transparent plastic sheeting during the cloudy weather to avoid accidental rainfall between successive irrigation intervals. All other agronomic practices were kept uniform throughout the experiment.

Experiment site

The soil at the experimental site was silt loam in texture, slightly alkaline in reaction (pH 7.51), moderately calcareous (1.5%), and deficient in organic matter (1.77%), with total usable water for effective rooting depth for each soil layer of 0-30 (60%), 30-60 (48%), and 60-90 (32%) cm (Tariq et al. 2011) and a bulk density of 1.35 Mg m^{-3}. The average daily evapotranspiration of the experiment site was 2.7-3.55 mm during the fruiting season.

Physical quality parameters

Fruit and pulp weight

The fruit weight of 10 fruits from each treatment in each replication was measured to 3 decimal places using an electronic scale. The pulp weight was recorded by removing the skin and stones of 10 randomly selected fruits from each treatment in each replication and weighing the pulp with an electronic scale to 3 decimal places. The weight of the selected fruits from the tagged branches was recorded in grams.

Fruit cracking

Fruit skin cracking percentage was recorded by visually observing and counting the number of total and cracked fruits on the tagged branches and converting the differential into a percentage. Fruits with even the slightest of cracks were counted as cracked fruits.

Specific gravity

The specific gravity was recorded from the selected fruits by measuring their weight (g) in air and in water and then applying the following formula:

$$\text{Specific gravity} = \frac{\text{Weight in car}}{(\text{Weight in air - Weight in water})}$$

Fruit skin strength

The firmness of the fruit skin was measured using a penetrometer (FT 011, Facchini SRL, Alfonsine, Italy; equipped with 4-mm probe) from the selected tagged fruits and the data were recorded in kg cm^{-2}. The sample size consisted of 10 fruits, from which readings were taken on the 2 opposite sides of the equatorial area of the fruit and then averaged to represent a treatment.

Chemical quality parameters

Total soluble solids

The fruit juice was extracted from the mature fruits and the total soluble solids (TSS) were measured using a handheld refractometer (KRÜSS HRN-16, KRÜSS, Hamburg, Germany) after prior calibration using distilled water. One drop per sample was put on the refractometer prism plate, and the readings from the prism plate were recorded to 1 decimal place. After each test, the prism plate was cleaned with distilled water and wiped with a soft tissue. The data were averaged and recorded as percent TSS.

Total, reducing, and nonreducing sugars

Total and reducing sugars in the litchi fruit juice were determined as described by AOAC International (1995). For this purpose, 10 fruits from each treatment in each replication were taken at random. The juice was extracted from the fruit using a locally made juice extractor and filtered through filter paper (Whatman No. 4). Twenty-five grams of filtered juice was then transferred to a 250-mL volumetric flask; 100 mL of water was added to it and the solution was neutralized with 1 N NaOH. Next, 2 mL of lead acetate solution was added. The solution was shaken and left to stand for 10 min. The required quantity of potassium oxalate was added to remove the excess lead and the volume was replenished with water.

Sugars were calculated as follows:

reducing sugars (%) = 6.25 × (X/Y),

where X = milliliters of standard sugar solution used against 10 mL of Fehling's solution and Y = milliliters of sample aliquot used against 10 mL of Fehling's solution. Total sugars were first estimated by taking 25 mL of an aliquot in a 100-mL volumetric flask into which 20 mL of distilled water and 5 mL of concentrated HCl were added, and the solution was kept overnight to convert the nonreducing sugars into reducing sugars. The solution was neutralized with 50% concentrated NaOH solution and the volume was filled to 100 mL with distilled water. The solution was transferred to a burette and titrated against 10 mL of Fehling's solution to a brick red end point using methylene blue as an indicator. Total sugars were calculated with the following formula:

total sugars (%) = 25 × (X/Z),

where X = milliliters of a standard sugar solution used against 10 mL of Fehling's solution and Z = milliliters of a sample aliquot used against 10 mL of Fehling's solution. Nonreducing sugars (%) = (total sugars % – reducing sugars %) × 0.95.

Calcium content of fruit skin

The fruit skin was peeled and washed with distilled water, oven dried at 70 °C, and weighed periodically until a constant weight was reached. After oven drying, the plant samples were ground using a Tema mill (Tema, Northamptonshire, UK), which was cleaned thoroughly with a brush and acetone before each treatment. The ground plant materials were dry ashed. The mineralization was done by adding 4 mL of nitric acid (65% aqueous solution) and then heating. The calcium percentage of the fruit skin was determined using an atomic absorption spectrophotometer (GBC AA 932, Analitica, Sao Paulo, Brazil) for elemental determination of Ca, as suggested by Isaac and Kerber (1971). The spectrophotometer was calibrated with a 5 µg mL^{-1} standard solution, as recommended by the manufacturer.

Boron content of fruit skin

The peeled skins of the selected fruits were washed thoroughly, first with tap water and then with distilled water. From each sample, 10 g was taken, dried for 12 h at 75 °C in an oven, and ashed for 3 h. Ashes were extracted with 10 mL of 2 M HNO_3 and were heated on a hot plate. Filtered contents after dissolution were diluted to a final volume of 50 mL with 50 mL of distilled water. This solution was used for determination of boron content in the fruit skin using the azomethine-H method (Harp 1997) with a Shimadzu double beam UV-VIS spectrophotometer (UV-2101 PC, Shimadzu, Kyoto, Japan).

Ion leakage

Ion leakage was recorded by excising 1-cm^2 skin disks from the equatorial regions of the selected fruits. Copolymer polypropylene vials with 20 mL of doubly distilled water were used for estimating ion leakage. First, the baseline conductivity of the double distilled water was recorded in µS cm^{-1} using an HI 9813 portable conductivity meter (Hanna Instruments, Inc., Woonsocket, RI, USA). Each vial containing double distilled water had 3 disks placed in it, and the vials were then fixed on a stand and vibrated for 30 min on a rotary shaker. At the end of 30 min, the conductivity of the water, representing ion leakage from the cell walls, was recorded (Saltveit 2005). The vials were then put through 3 freeze/thaw cycles to determine the total conductivity as described earlier (Saltveit et al. 2004). The ion leakage from the cell was determined by the formula:

$$\%\ \text{Ion leakage} = \frac{(\text{Conductivity of water with disks after 30 min}) - (\text{Conductivity of water})}{\text{Total conductivity after 3 freeze thaw cycles}} \text{ x } 100$$

Statistical procedure

The experiment was designed in a randomized complete block design with 2 factors. The cultivars were in the main blocks and irrigation intervals were in subplots. There were 3 trees in each treatment with 4 replications. Data on physicochemical quality attributes were recorded and analyzed using MSTAT-C software.

Results

Fruit and pulp weight

The highest fruit (21.90 g) and pulp weights (16.47 g) were recorded in cultivar Gola, while the lowest fruit and pulp weights were recorded in cultivar Bedana at 14.31 g and 10.85 g, respectively. While irrigation intervals of 3 and 6 days had no significant influence on fruit and pulp weight, fruit weight decreased significantly from 20.01 g to 16.86 g and pulp weight decreased significantly from 15.67 g to 12.92 g with an irrigation interval of 9 days (Table 1).

Table 1. The influence of irrigation intervals on quality attributes of litchi fruit.

Cultivars	Fruit weight (g)	Pulp weight (g)	TSS (%)	Total sugars (%)
China	20.51 a	15.52 b	20.54 b	19.50 b
Gola	21.90 a	16.47 a	22.16 a	21.22 a
Surahi	19.17 b	15.85 ab	19.77 c	18.22 c
Bedana	14.31 c	10.85 c	16.37 d	15.28 d
LSD	0.126	0.749	0.431	0.467
03	20.01 a	15.67 a	19.61	18.42
06	20.06 a	15.38 a	19.70	18.53
09	16.86 b	12.97 b	19.83	18.72
LSD	0.376	1.281	ns	ns
C × I	ns	ns	ns	ns

Means sharing the same letter in a column do not differ significantly at P = 0.05;
ns = nonsignificant.

Total soluble solids and total sugars

The total soluble solids (TSS) and total sugar content of the litchi fruit were significantly different among the cultivars, but were not affected by irrigation interval or the interaction of cultivars and irrigation intervals. The highest TSS (22.16%) and total sugars (21.22%) were recorded in cultivar Gola, while the lowest TSS (16.37%) and total sugars (15.28%) were found in cultivar Bedana. The influence of the irrigation interval on TSS and total sugar content of the fruit was not significant (Table 1).

Fruit cracking

The fruit cracking of litchi was significantly affected by cultivar, irrigation interval, and the interaction of cultivars and irrigation intervals (Table 2). The highest fruit cracking (41.60%) was recorded in cultivar Gola, followed by 31.60% and 22.37% in cultivars Surahi and China, respectively; the least cracking (10.40%) was seen in cultivar Bedana (Table 2). The mean fruit cracking incidence increased significantly with increasing irrigation intervals from 20.48% to 27.55% and 31.45% when the irrigation interval was extended from 3 to 6 and 9 days, respectively (Table 2). The interaction of cultivars and irrigation intervals revealed that cultivar Gola was the most susceptible to fruit cracking. It had significantly higher cracking at all irrigation intervals than the other 3 cultivars under study. With a 9-day irrigation interval, the incidence of fruit cracking in cultivar Gola was 77.61%, 46.15%, and 28.5% higher than in cultivars Bedana, China, and Surahi, respectively (Figure 1).

Reducing and nonreducing sugars

The reducing sugars were the highest (18.01%) in cultivar Gola, followed by cultivars China and Surahi at 14.25% and 13.70%, respectively; they were the lowest (5.68%) in cultivar Bedana (Table 2). In contrast, the nonreducing sugars were highest

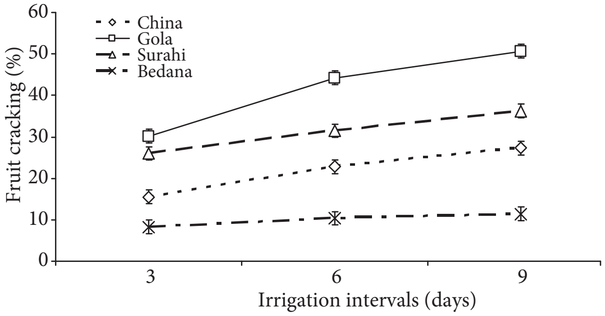

Figure 1. The influence of irrigation intervals on the fruit cracking percentage of litchi cultivars. The error bars represent LSD at P > 0.05.

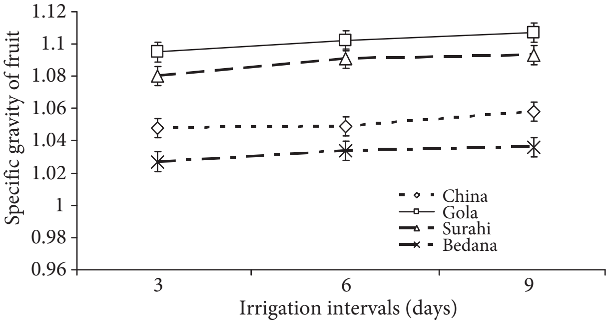

Figure 2. The influence of irrigation intervals on the specific gravity of litchi fruit. The error bars represent LSD at P > 0.05.

(10.02%) in cultivar Bedana, followed by cultivars China and Surahi at 5.66% and 4.93%, respectively; they were the lowest (3.80%) in cultivar Gola (Table 2). Reducing sugars increased from 12.85% to 12.97% from a 3-day to a 9-day irrigation interval, while the influence of irrigation intervals on nonreducing sugars was not significant (Table 2).

Specific gravity

The specific gravity of the fruit was the highest (1.101) in cultivar Gola, followed by 1.088 in cultivar Surahi. The fruits of cultivars China and Bedana had a specific gravity of 1.052 and 1.032, respectively, which were significantly lower than that of Surahi (Table 2). The specific gravity of the litchi fruit increased significantly from 1.063 to 1.069 and 1.074 with irrigation intervals of 3, 6, and 9 days (Table 2). The interaction of irrigation intervals and cultivars was also significant, with the lowest specific gravity in cultivar Bedana at an irrigation interval of 3 days and the highest (1.107) in cultivar Gola at an irrigation interval of 9 days (Figure 2).

Table 2. Fruit cracking, reducing and nonreducing sugars, and specific gravity of fruit of litchi cultivars at different irrigation intervals.

Cultivars	Cracking (%)	Reducing sugars (%)	Nonreducing sugars (%)	Specific gravity
China	22.37 c	14.25 b	5.66 b	1.052 c
Gola	41.60 a	18.01 a	3.80 d	1.101 a
Surahi	31.60 b	13.70 c	4.93 c	1.088 b
Bedana	10.40 d	5.68 d	10.02 a	1.032 d
LSD	0.54	0.69	0.14	0.02
Irrigation intervals (days)				
03	20.48 c	12.85 b	6.13	1.063 c
06	27.55 b	12.91 a	6.12	1.069 b
09	31.45 a	12.97 a	6.07	1.074 a
LSD	4.81	0.049	ns	0.005
Cultivar × irrigation				
significance	*	ns	ns	*
LSD	1.650			0.006

Means sharing the same letter in a column do not differ significantly at P = 0.05;
ns = nonsignificant.

Table 3. The influence of irrigation intervals on skin strength (kg cm^{-2}), calcium and boron content (mg 100 g^{-1} DW) of fruit, and ion leakage from skin disks of litchi fruits.

Cultivars	Skin strength	Ca	Boron	Ion leakage
China	2.29 c	4.722 b	0.112 a	30.04 c
Gola	2.16 d	4.817 ab	0.109 b	39.99 a
Surahi	2.50 b	4.916 a	0.101 c	36.26 b
Bedana	3.33 a	3.976 c	0.109 b	25.14 d
LSD (5%)	0.0314	0.114	0.002	0.541
Irrigation intervals (days)				
03	2.79 a	4.747 a	0.111 a	26.63 b
06	2.49 b	4.570 b	0.108 ab	33.58 a
09	2.44 b	4.506 b	0.105 b	38.6 a
LSD (5%)	0.166	0.108	0.003	5.10
Cultivar × irrigation				
Significance	ns	ns	ns	*

Means sharing the same letter in a column do not differ significantly at P = 0.05;
ns = nonsignificant.

Calcium content of litchi fruit skin

The calcium content of the litchi fruit skin varied significantly in different cultivars and was significantly affected by irrigation intervals, but the interaction of cultivars and irrigation intervals was not significant. The highest calcium content (4.916 mg 100 g^{-1} DW) was in cultivar Surahi, followed by cultivar Gola with 4.817 mg 100 g^{-1} DW, with the difference being nonsignificant. Cultivar Bedana had the least calcium content in the fruit skin (3.976 mg 100 g^{-1} DW) (Table 3). The highest calcium content at an irrigation interval of 3 days (4.747 mg 100 g^{-1} DW) declined significantly to 4.570 and 4.506 mg 100 g^{-1} DW for irrigation intervals of 6 and 9 days, respectively. However, the difference in calcium content between the 6-day and 9-day irrigation intervals was not significant (Table 3).

Boron concentration in litchi fruit skin

The highest fruit skin boron content (0.112 mg 100 g^{-1} DW) was in cultivar China, followed by cultivars Gola and Bedana with 0.109 mg 100 g^{-1} DW each. Cultivar Surahi, with 0.101 mg 100 g^{-1} DW, had the lowest boron content among the cultivars under study (Table 3). The boron content of the fruit skin also significantly decreased from 0.111 mg 100 g^{-1} DW at an irrigation interval of 3 days to 0.108 and 0.105 mg 100 g^{-1} DW at irrigation intervals of 6 and 9 days, respectively (Table 3).

Skin strength

The fruit skin strength was the highest (3.33 kg cm^{-2}) in cultivar Bedana while it was the lowest in cultivar Gola (2.16 kg cm^{-2}), and it decreased significantly across cultivars from 2.79 kg cm^{-2} to 2.49 and 2.44 kg cm^{-2} as the irrigation interval was increased from 3 to 6 and 9 days (Table 3). The interaction of irrigation intervals and cultivars also significantly affected the fruit skin strength, with the highest skin strength (3.54 kg cm^{-2}) recorded in cultivar Bedana irrigated at a 3-day interval as compared to 2.04 and 2.05 kg cm^{-2} recorded in cultivar Gola irrigated at 6-day and 9-day intervals, respectively (Figure 3).

Ion leakage

The ion leakage from the fruit skin disks was the highest (39.99%) in cultivar Gola while it was lowest in cultivar Bedana (25.14%), and it increased from the lowest value of 26.63% at an irrigation interval of 3 days to 33.58% and 36.60% when the irrigation interval was extended to 6 and 9 days (Table 3). The interaction of cultivars and irrigation interval revealed the greatest increase in ion leakage in

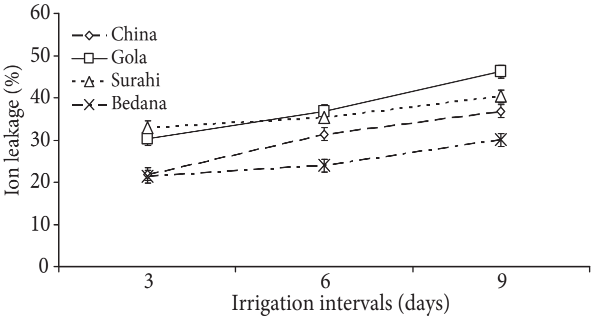

Figure 3. The influence of irrigation intervals on ion leakage from skin disks of litchi fruit. The error bars represent LSD at P > 0.05.

cultivar China (40.57%), while the lowest was seen in cultivar Surahi (18.26%). Bedana and Gola had 28.92% and 34.48% increases in ion leakage with a 9-day irrigation interval, respectively (Figure 3).

Discussion

The litchi cultivars varied significantly in physical and chemical quality attributes, which decreased with increasing irrigation intervals. Fruit weight was the highest in cultivar Gola, which was statistically at par with cultivar China, while cultivar Bedana had the lowest fruit weight (Table 1). In contrast, the highest pulp weight in cultivar Gola was at par with that of cultivar Surahi, while cultivar Bedana had the lowest pulp weight (Table 1). Despite having a lower fruit weight than cultivars Gola and China, cultivar Surahi had a comparable pulp weight to Gola, which was higher than in China. This shows that cultivar Surahi is characterized by higher pulp content (Islam et al. 2003; Khurshid et al. 2004). An irrigation interval of 9 days significantly decreased the mean fruit and pulp weight by 15.74% and 16.46%, respectively, but the difference for the 3-day and 6-day irrigation intervals was not significant (Table 1). This may be the reason why relatively longer irrigation is sometimes employed in litchi orchards (Jones and Corlett 1992; Batten et al. 1994).

The litchi fruit cultivar Gola had the highest TSS and total sugar content, while these were lowest in cultivar Bedana (Table 1). The TSS and total sugars depend on the genetic makeup of a cultivar (Waseem et al. 2002; Islam et al. 2003). Thus, significant variations are commonly observed in different cultivars (Islam et al. 2003; Khurshid et al. 2004). While an increase in TSS is observed with increasing water deficit (Reich 1974), the influence of the irrigation interval on TSS and total sugar content of litchi fruit was not significant in this study.

The fruit cracking was the highest in cultivar Gola, while it was the lowest in Bedana (Table 2). The cracking of litchi fruit is a serious quality and marketing problem (Singh 1986). Fruit cracking in litchi depends on both genetic and environmental factors (Singh 1986; Li et al. 2001; Huang et al. 2004). Thus, different cultivars may show considerable variation in susceptibility to fruit cracking (Islam et al. 2003). Increasing irrigation intervals increased the fruit cracking (R^2 = 0.972). There was a 1.53-fold increase in fruit cracking when the irrigation interval was increased from 3 to 9 days (Table 2). The interaction of cultivars and irrigation intervals revealed that the fruit cracking increased from the lowest in cultivar Bedana at an irrigation interval of 3 days to the to the highest in cultivar Gola with a 9-day irrigation interval (Figure 1). The enhanced fruit cracking with a longer irrigation interval could be due to pericarp desiccation (Mitra and Pathak 2010), or the lowered skin strength could result from lowered solute transport for the cell wall synthesis in skin tissue (Zhang et al. 2007).

An interesting observation was made regarding the reducing and nonreducing sugar contents of the litchi fruit. Cultivar Gola had the highest reducing sugars while cultivar Bedana had the lowest. In contrast, nonreducing sugars were the lowest in Gola and highest in Bedana (Table 2). Furthermore, while reducing sugars increased with increasing irrigation intervals (R^2 = 0.973), the nonreducing sugars were not significantly affected (Table 2). It has been reported that litchi cultivars vary considerably in their sugar contents (Waseem et al. 2002; Khurshid et al. 2004) or that the ratio varies between reducing and nonreducing sugars (Jiang et al. 2006). Generally, the reducing sugar content of the fruit plants increases with increasing water deficits (Drake et al. 1981). The variations in relative amounts of reducing and nonreducing sugars are due to differences in the activity of certain key enzymes (Paull et al. 1984) and may be related to the incidence of fruit cracking in litchi fruit (R^2 = 0.972). High reducing sugars may increase the influx of water into the aril and subsequently increase the outward turgor pressure on the fruit skin, leading to higher fruit cracking (Li et al. 2001). In contrast, the high nonreducing sugars in the pulp may lower the outward pressure. Furthermore, since some of the nonreducing sugars may be structural components of the cell walls (Ghosh and Misra 2010), this may cause stronger cell wall assembly in the skin tissue, hence decreasing fruit cracking ($R^2 = 0.972$). According to this model, the lower level of fruit cracking in cultivar Bedana could be attributed to low reducing sugars (Islam et al. 2003), which leads to low turgor pressure and high nonreducing sugars, and thus a stronger cell wall assembly. Consequently, the interaction between low turgor pressure and a stronger skin cell wall may be a major reason for the low fruit cracking in cultivar Bedana (Yamamoto et al. 1990).

The specific gravity of the fruit also varied considerably among the cultivars and was higher with longer irrigation intervals ($R^2 = 0.997$). The specific gravity of the fruit was 3.314% higher with an irrigation interval of 9 days as compared to 3 days. The interaction of cultivars and irrigation intervals revealed the lowest specific gravity in cultivar Bedana with 3-day and 6-day irrigation intervals as compared to the highest specific gravity in cultivar Gola with a 9-day irrigation interval (Figure 2). The specific gravity of the fruit depends on its sugar and TSS contents (Zaltzman et al. 1987). Since the litchi cultivars varied in TSS and sugar contents (Islam et al. 2003; Khurshid et al. 2004), they also had significant variation in specific gravity. It has been determined that water deficit decreases the synthesis of sugars (Batten et al. 1994). Thus, the increased specific gravity at longer irrigation intervals could be attributed to an increased concentration of solutes already present in the fruit or the conversion of nonreducing sugars to reducing sugars (Kramer and Boyer 1995).

The calcium content of litchi fruit skin was the highest in cultivar Surahi, while the lowest was observed in cultivar Bedana (Table 3). The calcium content of the skin decreased with increasing irrigation intervals ($R^2 = 0.931$). It decreased by 3.57% and 6.25% with an increase in irrigation intervals from 3 days to 6 days and 9 days, respectively (Table 3). Calcium plays an important role in cell wall and membrane structure (Hepler 2005). Thus, a regular supply of calcium is needed to ensure vigorous growth (del Amor and Marcelis 2006). Litchi varieties may have significant differences in their calcium content. A negative correlation between the calcium content in litchi leaves and the rate of fruit cracking was reported by Li et al. (1999). It has been reported that cracking-resistant variety Huauzhi had high calcium (Huang et al. 2004) and the pericarp of the cracked litchi fruit had significantly lower calcium levels than those of the uncracked fruit within the same cultivars (Sanyal et al. 1990; Lin 2001). Furthermore, cracking has been shown to decrease with foliar calcium application (Hasan and Jana 2000; Ruby et al. 2001). It is observed that a higher calcium content of the fruit skin resulted in lower fruit cracking ($R^2 = 0.972$). The decrease in calcium content with increasing irrigation intervals illustrates that calcium uptake depends on water availability and transpiration (Kumar et al. 2001), hence explaining the cracking incidence with longer irrigation intervals.

The boron content of litchi fruit skin was highest in cultivar China while it was lowest in cultivar Bedana (Table 3). The boron content of the fruit skin also decreased with increasing irrigation intervals ($R^2 = 0.999$), such that it was 3.72% and 5.07% lower at irrigation intervals of 6 and 9 days, respectively, compared to 3 days (Table 3). Boron may be important in Ca metabolism in the cell wall (Yamaguchi et al. 1986). Its deficiency results in fruit discoloration and cracking (Dale and Krystyna 1998), and application of boron decreases fruit cracking (Brahamchari et al. 1997; Ruby et al. 2001). Decreasing the boron content in litchi fruit skin may contribute to the fruit cracking ($R^2 = 0.972$). Thus, the increased fruit cracking with increasing irrigation intervals may in part be attributed to low boron and a subsequent decrease in calcium metabolism in the cell wall (Yamaguchi et al. 1986) or lower borate ester formation with hydroxyl groups of cell wall carbohydrates and glycoproteins (Blevins and Lukaszewski 1998).

The fruit skin strength of cultivar Bedana was 35.0%, 33.13%, and 24.70% higher than that of cultivars Gola, China, and Surahi, respectively (Table 3). The fruit's skin strength, highest at a 3-day irrigation interval, decreased significantly by 10.87%

and 12.69% at increasing irrigation intervals of 6 days and 9 days ($R^2 = 0.854$). The fruit cracking in litchi is inversely related to the fruit skin strength ($R^2 = 0.972$). Since the turgor pressure of the expanding aril may contribute to fruit cracking in litchi (Joubert 1986; Yamamoto et al. 1990), the lower skin strength (Table 3) and high reducing sugars (Table 1) of cultivar Gola may be responsible for its greater susceptibility to fruit cracking (Huang and Huang 1998; Hasan and Jana 2000; Ruby et al. 2001). The decrease in skin strength with longer irrigation intervals may be due to poor nutrient uptake and incorporation in skin cell walls (Li and Huang 1995).

Ion leakage from the skin disks correlated with skin strength and was highest in cultivar Gola but lowest in cultivar Bedana. There was a linear increase in ion leakage from the skin disks with increasing irrigation intervals ($R^2 = 0.988$). Compared to an irrigation interval of 3 days, ion leakage increased by 20.70% and 31.01% with irrigation intervals of 6 and 9 days, respectively (Table 3). Ion leakage was relatively lower in all the cultivars under study at a 3-day irrigation interval. At the same irrigation interval, however, cultivars Gola and Surahi had significantly higher ion leakage from their skin disks. Ion leakage increased with increasing irrigation intervals to the highest (40.57%) in cultivar China at a 9-day irrigation interval (Figure 3). Water deficit decreases the relative water content of the plant and fruit (Chen et al. 2001), which may promote pericarp desiccation (Hardie and Considine 1976), thereby increasing the electrolyte leakage (Chen et al. 2001) and subsequently encouraging fruit cracking ($R^2 = 0.972$).

Conclusions

This study suggests that litchi cultivars vary significantly in different quality attributes and the incidence of fruit cracking. Increasing the irrigation interval to 9 days decreased the fruit and pulp weight significantly. However, an irrigation interval of 6 days resulted in a significant decline in skin calcium and boron content with a concomitant increase in the percentage of fruit cracking. This suggests that fruit cracking is more sensitive to irrigation interval than the other quality attributes.

Acknowledgment

The authors acknowledge the financial support for chemicals and lab equipment for this research provided by the HEC-Citrus Project, AUP, and funding provided by the Higher Education Commission, Pakistan.

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