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Quality improvement in lemon (*Citrus limon* (L.) Burm.) through integrated management of fruit cracking

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The studies on management of fruit cracking were carried out for three consecutive years (2006 to 2008) using integrated approach. The plant material was selected from "Punjab Government Progeny Orchard and Nursery, Attari, Amritsar". The investigation comprised three sets of experiments during the fruiting years 2006 and 2007. The first experiment comprised irrigation and mulching practices; the second consisted of graded doses of farmyard manure (FYM), inorganic fertilizer and biofertilizer and in the third experiment foliar spray of 1-Naphthaleneacetic acid (NAA), K_2SO_4 and Borax were applied. The statistically best treatments accrued from three different experiments during 2007 and 2008 were combined and tested in 2008. It was revealed that the optimum utilization of different orchard cultural practices viz. proper water management, appropriate fertilizer programme and good preventive spray schedule brought profound changes in fruit cracking intensity. Hence, the consortium of intelligent management practices such as irrigation at 20% available soil moisture depletion (ASMD), mulching with black polythene, application of FYM (75 kg/tree), inorganic fertilizer (Nitrogen 350 g/tree), azotobacter (18 g/tree) and foliar spray of NAA at 40 ppm in lemon cv. Baramasi substantially reduced the cracking losses by 94.5% and resulted in impressive impact on fruit quality.

Key words: Irrigation, mulching, organic fertilizer, inorganic fertilizer, biofertilizer, growth regulator, nutrients.

INTRODUCTION

In the changing global scenario, success of citrus cultivation depends largely on the ideal quality attributes to ensure better marketability. Lemon, a leading acid citrus fruit is highly lucrative because it bears fruit in many flushes making it available throughout the year. However, the summer crop is beset with severe fruit cracking which is one of the most exasperating problems causing heavy financial losses. What is more, the summer crop has been observed to be prone to severe fruit cracking. Fruit cracking is a worldwide problem which affects a number of fruits and losses are sometimes high. Cracking is manifested as a meridian fissure of the peel, usually developing from the stylar end and reaching the equatorial zone or even extending beyond that. Irrespective to its origin, crack develops as a consequence of disruption between peel and pulp growth. It was assessed that during the phase of cell enlargement, if the peel does not restart its growth, when the pulp expansion takes place, the fruit splits.

Hoffmann (2007) explained citrus fruit splitting as one of the most serious problems experienced by citrus fruit growers. Although many studies have dealt with this complex phenomenon, the basic mechanism involved in fruit cracking remains unclear. According to Hoffmann, the split usually starts at the blossom end of the fruit, which is the weakest point in the rind. The split may be short and shallow or it may be deep and wide, exposing the segments of the juice vesicles. Splitting appears to be

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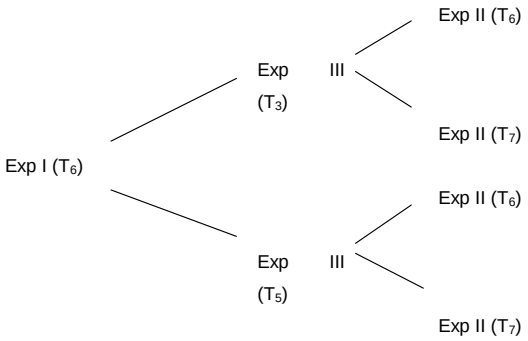

Figure 1. Treatment combinations

most closely related to extreme fluctuations in temperature, humidity, soil moisture and fertilizer levels. It is thought that the problem is caused by a combination of these factors rather than a single one. Splitting is usually observed when growing conditions become erratic such as water stress and sudden rainfall with uneven fertilizer supply. The optimal growing conditions including reasonable cultural practices, sufficient water supply with mineral nutrition and mulching can significantly reduce the occurrence of splitting. Hoffmann advocated frequent irrigation along with the use of compost and slow release fertilizers to feed the tree and foliage spray of trace elements at the most receptive time to replenish the nutrients. Therefore, for lemon cultivation to be successful, efficient management of water and nutrients is of utmost importance to produce high quality of lemon fruits free from fruit cracking. The present study is an endeavour in this direction.

MATERIALS AND METHODS

The present studies were conducted at "Punjab Government Progeny Orchard and Nursery, Attari, Amritsar" during the years 2006 to 2008. In the trial, 8 year old lemon trees, uniform in size and vigor, free from attack of diseases and pests were selected on which given treatments were applied. The investigations were planned in three sets of experiments during 2006 and 2007 and a separate one during 2008. The statistical analysis was done using RBD having four replications. The percentage data was analysed using arc sine transformation. The total number of fruits on the tree was counted on 11th June each year when fruit cracking was first observed and recorded. Cracked fruits were counted regularly at weekly interval. These were picked out and then removed. The percentage of cracked fruits was calculated on the basis of the total number of fruits initially found on the tree.

Experiment I: Effect of various irrigation and mulching treatments on fruit cracking in Baramasi lemon

Every year in April, the irrigation and mulching treatments were started, a week after fruit set and continued until the harvest. The plants received the standard fertilizer dose as recommended by PAU, Ludhiana. The treatment details were:

T_1: Irrigation at 10-15 days interval (control)
T_2: Irrigation at 40% ASMD
T_3: Irrigation at 20% ASMD
T_4: Control and mulching with black polythene sheet
T_5: Irrigation at 40% ASMD and mulching with black polythene sheet
T_6: Irrigation at 20% ASMD and mulching with black polythene sheet

Experiment II: Effect of organic manure, inorganic fertilizer and biofertilizer on fruit cracking in Baramasi lemon

The standard fertilizer dose used was as recommended by PAU, Ludhiana for 8 years old citrus trees (75 kg/tree FYM and 350 g/tree nitrogen). The whole quantity of farm yard manure was applied in December. Nitrogen dose was given in two split doses, the first part in February and the second in April after fruit set. The biofertilizer used in this experiment was Azotobacter and obtained from PAU, Ludhiana. The dose of biofertilizer used was 2 kg/acre or 18 g/tree and the applied method of application was to mix 2 kg of biofertilizer
with 200 L of water and drenching near the root zone of the plants (Indiamart, 2007). The treatment details were:

T_1: Control (Standard dose viz. 75 kg/tree FYM and 350 g/tree N).
T_2: FYM (standard dose *viz.* 75 kg/tree) + Azotobacter (18 g/tree)
T_3: Inorganic fertilizer (standard dose *viz.* 350 g/tree N) + Azotobacter (18 g/tree)
T_4: FYM (standard dose *viz.* 75 kg/tree) + inorganic fertilizer (half the standard dose *viz.* 175 g/tree N) + Azotobacter (18 g/tree)
T_5: FYM (half the standard dose *viz.* 38 kg/tree) + inorganic fertilizer (standard dose *viz.* 350 g/tree N) + Azotobacter (18 g/tree)
T_6: FYM (standard dose *viz.* 75 kg/tree) + inorganic fertilizer (standard dose *viz.* 350 g/tree N) + Azotobacter (18 g/tree)
T_7: FYM (1.25 standard dose *viz.* 94 kg/tree) + inorganic fertilizer (1.25 times standard dose *viz.* 438 g/tree N) + Azotobacter (18 g/tree)

Experiment III: Effect of foliar spray of growth regulator (NAA) and micronutrients on fruit cracking in Baramasi lemon

This experiment consisted of foliar sprays of NAA (20 ppm), NAA (40 ppm), K_2SO_4 (4%), K_2SO_4 (8%), Borax (0.5%) and Borax (1%). The whole plant spray was given with the help of knapsack sprayer during forenoon. Each year during May, 2 sprays were administered at an interval of 15 days. The first spray was given on 10th May and the second on 25th May. The treatment details were:

T_1: Control (untreated)
T_2: NAA (20 ppm)
T_3: NAA (40 ppm)
T_4: K_2SO_4 (4%)
T_5: K_2SO_4 (8%)
T_6: Borax (0.5%)
T_7: Borax (1%)

Experiment IV: Effect of treatment combinations on fruit cracking in Baramasi lemon

The best statistic results of treatments during 2006 and 2007 were combined and researched in a separate experiment during 2008. The treatment combinations are presented diagrammatically as Figure 1.

The treatment details were:

T_1: (Irrigation at 10-15 days interval + FYM (75 kg/tree) + inorganic fertilizer (350 g/tree N) + spray of plain water) Control.

Table 1. Effect of irrigation and mulching on the fruit cracking in lemon.

Treatments	Fruit cracking (%)	
	2006	2007
T_1 (Control viz. Irrigation at 10-15 days interval)	35.29 (36.40)*	36.30 (37.01)*
T_2 (Irrigation at 40% ASMD)	20.46 (26.82)	21.41 (27.49)
T_3 (Irrigation at 20% ASMD)	13.14 (21.17)	15.21 (22.90)
T_4 (Irrigation at 10-15 days interval and mulching)	29.20 (32.68)	30.09 (33.24)
T_5 (Irrigation at 40% ASMD and mulching)	15.65 (23.28)	17.53 (24.74)
T_6 (Irrigation at 20% ASMD and mulching)	7.21 (15.50)	8.28 (16.66)
CD at 5%	2.73	2.52
CV%	6.98	6.21

*Transformed values.

T_2: (Irrigation at 20% ASMD and mulching + FYM (75 kg/tree) + inorganic fertilizer (350 g/tree N) + Azotobacter (18 g/tree) + foliar spray of NAA at 40 ppm)
T_3: (Irrigation at 20% ASMD and mulching + FYM (113 kg/tree) + inorganic fertilizer (525 g/tree N) + Azotobacter (18 g/tree) + foliar spray of NAA at 40 ppm)
T_4: (Irrigation at 20% ASMD and mulching + FYM (75 kg/tree) + inorganic fertilizer (350 g/tree N) + Azotobacter (18 g/tree) + foliar spray of K_2SO_4 at 8%)
T_5: (Irrigation at 20% ASMD and mulching + FYM (113 kg/tree) + inorganic fertilizer (525 g/tree N) + Azotobacter (18 g/tree) + foliar spray of K_2SO_4 at 8%)

RESULTS AND DISCUSSION

Experiment I: Effect of irrigation and mulching on fruit cracking in Baramasi lemon

A glance over the data in Table 1 shows that during 2006, higher fruit cracking (35.29%) increased in the control treatment. T_6 proved to be the most effective treatment, significantly lower over control, by registering minimum fruit cracking (7.21%). The treatment T_6 maintained its superiority in the next trial (year 2007), also by cutting short the percentage of fruit cracking significantly over all other treatments including control. The fruit cracking in this treatment was recorded to be 8.28%, compared to 36.30% in control. Heavy losses due to fruit cracking have also been reported in Kagzi Kalan (Sharma and Shukla, 2002). The soil moisture seemed to be a major contributing factor in fruit cracking as its incidence was lowered with enhanced moisture supply. As a result of sudden increase in water content of soil and atmospheric humidity after long dry spell, the tissues of fruit skin did not cope with the rapid increase of the fruit internal tissues (Chandra, 1988), resulting in the bursting of the skin (Lu and Lin, 2011) because of internal turgor pressure of the fruit (Measham et al., 2010). The use of black polythene mulch also attributed to minimize the extent of fruit cracking in lemon. Mulching might have played an important role in plant establishment, growth and fruiting of kinnow as reported by Lal et al. (2003), which could be due to moisture conservation of soils. The frequent irrigation and mulching with black polythene would have changed the micro-climate of the trees in comparison to trees receiving irrigation at longer interval and unmulched. Hence, a reduction in fruit cracking could be attributed to better moisture regulation together with its conservation through mulching. High moisture content certainly have reduced the temperature of tree canopy, leaf, fruit and soil and increased the atmospheric humidity and created favourable conditions for continued growth of the peel for a longer period. Therefore, the texture of peel would have attained ability to resist the pressure of the expanding juice vesicles. Subsequently, it would have helped to reduce the splitting of fruit. It can be further concluded that high temperature and low humidity during the period of fruit growth rendered the peel inelastic, affecting the

Experiment II: Effect of organic manure, inorganic fertilizer and biofertilizer on fruit cracking in Baramasi lemon

Minimum percentage of fruit cracking was recorded in treatment T_7 during two years of research study giving values 18.89 and 19.93%, respectively while maximum extent of fruit cracking was evidenced in T_1 to the tune of 35.29% during first trial year and 36.30% in second year (Table 2). The extent of fruit cracking varied significantly in T_6 and T_7 as compared to control. Taking into consideration the effect of different treatments on fruit cracking, T_7 was found to be the best practice. However, the effect of treatment T_6 was found to be statistically at par with the best treatment. Thus, the treatment T_6 proved to be most judicious fertilizer application practice from an economic point of view. When all three nutrient sources viz. FYM, inorganic fertilizer and biofertilizer (Azotobacter) were applied, it reduced the fruit cracking percentage. This can be attributed to improved nutrient and water availability as result of application of required nutrient sources, leading to vital plant and fruit growth,

Table 2. Effect of organic and inorganic nutrient sources on the fruit cracking in lemon.

Treatments	Fruit cracking (%)	
	2006	2007
T_1 {Control (75 kg/tree FYM + 350 g/tree N)}	35.29 (36.40)*	36.30 (37.01)*
T_2 {FYM (75 kg/tree) + Azotobacter (18 g/tree)}	33.15 (35.11)	34.26 (35.78)
T_3 {Inorganic fertilizer (350 g/tree N) + Azotobacter (18 g/tree)	31.55 (34.15)	32.82 (34.93)
T_4 {FYM (75 kg/tree) + inorganic fertilizer (175 g/tree N) + Azotobacter (18 g/tree)}	28.75 (32.40)	30.00 (33.19)
T_5 {FYM (38 kg/tree) + inorganic fertilizer (350 g/tree N) + Azotobacter (18 g/tree)	26.60 (31.03)	27.77 (31.78)
T_6 {FYM (75 kg/tree) + inorganic fertilizer (350 g/tree N) + Azotobacter (18 g/tree)}	20.28 (26.72)	21.37 (27.49)
T_7 {FYM (94 kg/tree) + inorganic fertilizer (438 g/tree N) + Azotobacter (18 g/tree)}	18.89 (25.72)	19.93 (26.47)
CD at 5%	2.32	2.61
CV%	4.94	5.43

*Transformed values.

Table 3. Effect of foliar spray of growth regulator (NAA) and nutrients on the fruit cracking in lemon.

Treatments	Fruit cracking (%)	
	2006	2007
T_1 (control) untreated	35.29 (36.40)*	36.30 (37.01)*
T_2 {NAA (20 ppm)}	17.06 (24.34)	17.57 (24.72)
T_3 {NAA (40 ppm)}	11.86 (20.04)	12.65 (20.75)
T_4 {K_2SO_4 (4%)}	17.60 (24.69)	18.40 (25.30)
T_5 {K_2SO_4 (8%)}	12.39 (20.49)	13.09 (21.11)
T_6 {Borax (0.5%)}	18.03 (25.08)	18.80 (25.67)
T_7 {Borax (1%)}	19.68 (29.30)	19.88 (26.44)
CD at 5%	3.38	3.41
CV%	9.00	8.90

*Transformed values.

because of the development of better root system along with increase in number of rootlets. This is corroborated with the findings of Prahraj et al. (2002). Bio-fertilization helps a better proliferation of roots, which ultimately results in sturdy and healthy plants showing resistance to biotic and abiotic stresses. These results conform with that of Sharma and Thakur (2001). The biofertilizers produces nitrate substances along with auxins. The presence of both promoted the deposition of the exogenous calcium in the cell walls of pericarp. Higher concentration of structural calcium in cell wall of pericarp provided cracking resistance. The higher capacity in binding exogenous calcium in the cell wall of pericarp suggests higher concentration of negatively charged structural component, that is, glacturonic acid residues which can be one of the material bases for cracking resistance (Zhong et al., 2006). It was further suggested that availability of such nutrients in the early stage of fruit ontogeny is important for cracking resistance. Azotobacter is capable of elaborating small qualities of growth promoting substances like B-vitamin and phyto-hormones like IAA, and with inorganic N and FYM might have improved the physiology of the plants (Nair and Najachandra, 1995), thereby, reducing fruit cracking. The increase in auxin status in plants could have increased peel thickness as the auxins have the tendency of faster and prolonged cell division in peel (Amiri et al., 2012). The optimized standards of fertilizer application might also have played role in keeping pace between the growth of the cell wall and the cortex leading in increase in elasticity of peel which in turn have helped to cut short fruit cracking.

Experiment III: Effect of foliar spray of growth regulator (NAA) and nutrients (K_2SO_4 and Borax) on fruit cracking in Baramasi lemon

The data presented in Table 3 revealed that maximum fruit cracking was increased in control (untreated) trees, with a rate of 35.29% in 2006 and 36.30% in 2007. The treatment T_3 (NAA at 40 ppm) proved to be most effective in minimizing the fruit cracking in lemon in two consecutive years of research trial, with records of 11.86% in first year and 12.65% in second year. The treatment T_5 was statistically at par with T_3. All the spray treatments had a profound effect on the fruit cracking percentage and the elastic and plastic properties of the citrus rind are thought to be involved in resistance to puncture. Application of auxins caused enlargement of cells by increasing the elasticity or permeability of cell wall (Cline and Trought, 2007). Thus, the peripheral tissues of the fruit would keep pace with the growth of cortex resulting in the control of fruit cracking, given that one of the main reasons for fruit cracking is attributed to the differential growth rates of the peripheral and cortex tissues. Low level of potassium was thought to be responsible for splitting of Hamlin orange (Morgan et al., 2005). Earlier findings of Bar-Akiva (1975) in Valencia orange also lend support to the present results, who further reported that reduction of splitting may be a potassium mediated effect, via strengthening of the fruit rind as seen from the increasing rind thickness of fruits in potassium treated trees. The decline in fruit cracking

Table 4. Effect of various treatment combinations on the fruit cracking in lemon.

Treatments	Fruit cracking (%)
	2008
T_1 (Irrigation at 10-15 days interval + FYM (75 kg/tree) + inorganic fertilizer (350 g/tree N) + spray of plain water) control	34.54 (35.97)*
T_2 (Irrigation at 20% ASMD and mulching + FYM (75 kg/tree) + inorganic fertilizer (350 g/tree N) + Azotobacter (18 g/tree) + foliar spray of NAA at 40 ppm)	1.89 (7.82)
T_3 (Irrigation at 20% ASMD and mulching + FYM (113 kg/tree) + inorganic fertilizer (525 g/tree N) + Azotobacter (18 g/tree) + foliar spray of NAA at 40 ppm)	4.42 (12.12)
T_4 (Irrigation at 20% ASMD and mulching + FYM (75 kg/tree) + inorganic fertilizer (350 g/tree N) + Azotobacter (18 g/tree) + foliar spray of K_2SO_4 at 8%)	7.27 (15.62)
T_5 (Irrigation at 20% ASMD and mulching + FYM (113 kg/tree) + inorganic fertilizer (525 g/tree N) + Azotobacter (18 g/tree) + foliar spray of K_2SO_4 at 8%)	9.35 (17.78)
CD at 5%	1.62
CV %	5.89

*Transformed values.

due to boron treatments may be attributed to its physiological role in synthesising of pectin substances in cells. Boron is responsible for increasing the elasticity of the cell membranes and prevents the breakdown of vegetative tissues. Boron also improved the translocation of sugar and synthesis of cell wall material. Thus, this decrease in fruit cracking might be the result of borate bridging with cell wall constituents, thus giving it elasticity, response to it as advocated by Singh et al. (2005) in litchi.

Experiment IV: Effect of treatment combinations on fruit cracking in Baramasi lemon

The minimum fruit cracking to the rate of 1.89% was registered in fruits obtained from T_2 trees kept under optimum orchard management practices. The highest cracking of fruit during experimentation in year 2008 was recorded in control to the rate of 34.54% which is considered a huge loss to fruit growers. The reduction in fruit cracking to maximum extent in treatment T_2 (Table 4) giving negligible loss (1.89%) could have been anticipated due to efficient management of water, nutrients and optimum level of PGRs. The absence of even a single practice in various treatment combinations intensified the fruit cracking percentage. In the present experimentation, the increase of inorganic N and FYM in T_3 negated the proper orchard management leading to increase of fruit cracking over treatment T_2. This may be due to ill-effects of excessive fertilization which caused a burning effect of the citrus rind resulting in a weak rind susceptible to crack. The moisture regulation and conservation created favourable conditions for continued growth of peel for a longer span, making it sufficiently elastic to keep pace with the internal growth of pulp thereby, resisting pressure to split or crack. The optimized fertilizer application in the form of organic manure, inorganic nitrogen and biofertilizer resulted in higher nutrient uptake partly due to higher nutrient composition in soil and better availability of water as a result of root proliferation. The foliar spray of growth regulator (NAA at 40 ppm) reduced the fruit cracking to a great extent. Thus, the maintenances of adequate soil moisture and nutrients reduced this problem (Measham, 2011). If a single component is avoided, it directly or indirectly influences the cracking percentage.

Conclusion

From the foregoing discussion, it can be concluded that efficient management of water and nutrients is essential to increase the quality of lemon fruits and to prevent the fruit from cracking. Generally, multiple applications consisting of proper water management, good fertilizer programme and good preventive spray programme are necessary. Hence, intelligent management practices such as irrigation at 20% available soil moisture depletion (ASMD), mulching with black polythene, application of FYM (75 kg/tree), inorganic fertilizer (Nitrogen 350 g/tree), azotobacter (18 g/tree) and foliar spray of NAA at 40 ppm in lemon, substantially reduced the cracking losses and resulted in better fruit quality. Thus, to combat this serious problem the consortium of different appropriate treatments is of utmost importance. Therefore, it can be further concluded that fruit cracking can be controlled by a combination of treatments, and inadequate water and nutrient management practices at a critical stage of fruit development adversely affect the

fruit quality.

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