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PJBS

ISSN 1028-8880

Pakistan Journal of Biological Sciences

ANSInet
Asian Network for Scientific Information
308 Lasani Town, Sargodha Road, Faisalabad - Pakistan

Pakistan Journal of Biological Sciences, 2 (3): 969-973, 1999 Research Article

Effect of Interstock Bridge Grafting on Fruit Quality at Harvest and During Storage of Four Apple Cultivars

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Abstract

Fruit from interstock bridge grafted trees had significantly higher brix and seed number in both seasons. Bridge grafted trees had significantly smaller fruit and reduced L:D ration in the second season only. Fruit from M9 bridge grafted trees were significantly firmer in both seasons. In the second season (95/96) fruit from trees with M9 interstock were significantly smaller and had a higher flesh firmness, brix value and seed number. Fruit from interstock bridge grafted trees had significantly higher Ca levels and lower K and Mg levels. In both seasons storage for 40 or 60 days at 10°C significantly increased weight loss, flesh colour and reduced flesh firmness for all fruit. There was a non-significant increase in fruit brix after 40 days storage which was partially reversed at 60 days after storage. In both year the same significant effect was present for weight loss, flesh firmness and flesh colour. There was no significant interaction between treatment and storage duration in the first season while in the second season there was a significant interaction between treatment and storage duration for weight loss and a significant interaction between rootstock and treatment for brix value and flesh colour.

Introduction

Fertile soils and a favourable climate produce apple trees with excessive vegetative growth in New Zealand. Excessive vegetative growth can be detrimental to fruit quality and yield (Casper and Taylor, 1989). Furthermore, excessive vegetative growth can be difficult and expensive to control. While dwarfing rootstocks are available for apples, orchardists may have increased vigour problems by planting apple tree without adequately matching site characteristics with scion and rootstock vigour. Once mature, the orchardist may find that trees are too vigorous for the allotted space. Several techniques can be employed by the orchardist for controlling vigour. These techniques include the use of appropriate rootstocks, pruning, manipulating branch angles and root restriction. However, all of these methods can have both desirable and undesirable secondary effects on fruit productivity, quality and tree growth (Jackson *et al.*, 1982) and (McKenzie and Rae, 1978).

Interstock bridge grafting is also a procedure that may be used to control vigour in mature trees. This study examines the effect of interstock bridge grafting on vegetative vigour and its resultant effect on productivity and fruit quality. Samad *et al.*, 1998) demonstrated significant positive effects of interstock bridge grafting on reducing tree vigour and improving reproductive status of the tree.

Morgan *et al.* (1984) reported that light exposure level determines fruit size under New Zealand summer conditions, fruit size in Gala apple was most severely reduced by inadequate light level. Jackson *et al.* (1971) reported that apple fruit from the inner parts of the tree differed from those from the outer portions in size, colour and storage behaviour. Light and shade also have an effect on the physiology of plants. Various physiological processes like stomatal conductance, photosynthesis and carbohydrate synthesis have been investigated by various researchers in different plant species and these have been shown to respond to light levels (Smart *et al.*, 1988).

Interstock bridge grafting may also have direct or indirect effects on other factors e.g., mineral concentrations that affect quality. Many physiological disorders are likely to develop during storage in fruits deficient in calcium and/or too rich in potassium and magnesium (Marcelle, 1984).

The main purpose of this study is to see the effect of interstock bridge grafting on apple fruit quality at harvest and after storage for 40 and 60 days in order to better understand both the physiology of apples in storage and the economic potential of interstock bridge grafting.

Materials ad Methods

Ten year old apple tree of the cultivar "Granny Smith", "Cox,s Orange Pippin", "Oregon Red Delicious" and "Gala" on rootstock MM106, M793 and Northern Spy were used in this experiment. This experiment was started in August 1994. The trees were located at the Horticulture Research Area, Lincoln University Canterbury, New Zealand (latitude 43°39' S and longitude 172°28'E). The soil type was Wakanui silt loam on a sandy loam weakly mottled phase (New Zealand Soil Bureau, 1968). The trees used in this study were grown with a between row spacing of 5 m and a between tree spacing of 3.5m (570 tree/hectare). The trees were unpruned during the course of the study. Previously they had been pruned and managed as centre axis trees. The tree were irrigated three times during the season i.e., late December, January and late February for 6 to 8 hours with sprinklers which provided an irrigation capacity of 12 mm per hour.

A ring of bark about 8 cm wide was removed from the trunk at about 30 cm from the ground level, and at the same time grafting was done. At about 25 mm intervals completely around each bridge a 1 cm wide split interstock with cambial matching. After completing bridge grafting the graft was tightly wrapped with plastic tape and then with adhesive tape in order to prevent water loss and insect pests entering. A control was also kept untreated.

Data collection and fruit quality measurements: The fruit were harvested from interstock bridge grafted trees during the specified commercial harvest period for each cultivar (specified by the New Zealand Apple and Pear Marketing Board). Sound fruit of each cultivar were selected for the storage experiments. Fruit were taken from two branches from opposite sides of the tree for each tree. Fruit were selected from each branch portion namely the basal, mid and distal portions. Fruit fresh weight and colour were taken after picking using Minolta refractometer (Chromameter CR-100). The fruit were divided in three sets with each set consisting of 6 fruit one from each of the tree locations listed above from every tree in the trial. Two of the sets of fruit were weighed individually and then put into storage, for 40 and 60 day intervals, at 10^0 C respectively. Fruit quality was measured at the end of this storage. Quality measurements were taken on the third set at harvest. Juice expressed from one side of the apple was measured for soluble solids (%) using an automatic compensation refractometer (ATC-1; Atago, Tokyo). Flesh firmness was measured with a penetrometer (Model FT 327; Alfosine, Italy) mounted on a drill stand with a lever to apply a constant and even pressure. Each apple was assessed on opposite sides, by pushing an 11.1 mm diameter probe 10 mm into the apple at 90^0 angle to the surface and recording the maximum force required. Fresh fruit weight was measured at harvest and following storage so that weight loss after storage could be determined. Fruit length to diameter (L/D) ratio was measured with callipers (Model Dial-15. Tajima Carbon Fibre Digital Fibre). Finally fruit were cut transversely with the help of a sharp knife and the number of seeds per fruit were counted. This storage experiment was conducted in 1995 and was repeated in 1996. Tissue samples were taken from fruit of "Gala" and "Cox's Orange Pippin" which has been stored for 40 days at 10^0 C. Samples were taken with the help of a 10 mm diameter hollow probe by pushing it into the fruit at a 90^0 angle longitudinally from the side of fruit. Approximately 15-20 cm^3 fresh apple pulp was taken, and put in the glass vail for analyses. Before placing the fresh apple pulp into the vail the empty glass vail weight was recorded. The filled glass vial were put in oven at 70^0C till the pulp was fully dried, than the full glass vail weight (vail+dry pulp) was also recorded. Fruit dry weight was derived by subtracting empty glass vail weight from full glass vail weight. The level of Ca, Mg, and K presence was determined for the same fruit using a (Shimadzu Model AA 670 Atomic Absorption Spectrophotometer).

Experimental design and statistical analyses: A split split plot design was used with cultivars as the main plots a treatment and rootstock as sub plots and different stora periods, (0, 40 and 60) as sub sub-plots, For Ca, K and M a split plot design was used for analysis, with cultivar the main plot and treatment and rootstock as sub plot. F most quality parameters, data were analysed separately each year while for Ca, K and Mg only 2nd year data we analysed for two cultivars ("Gala" and "Cox's Oran Pippin"). Analysis of variance was performed with the GL procedure in SYSTAT[R] (Statistical Analysis Package), a then mean separations were tested by Fisher's LSD.

Results

Effect of bridge grafting at harvest: Treatment effects we observable in the first growing season. Data are present in (Table 1) for the 1994/95 growing season. Mean fru weight, L/D ratio and flesh colour at harvest were n influenced by the bridge grafting treatments. Observab but non-significant decreases in mean fruit weight a slight decreases in flesh colour were noted for the "sam bridge" treatment. "M9 bridge" treatments significant increased flesh firmness while the "same bridge" treatme only slightly increased flesh firmness compared to t control "no bridge". Highly significant brix and seed numb increases were observed for both bridge grafting treatmen in the first growing season. Brix values were 9.1 per ce and 14.6 per cent greater for the "same bridge" and "M bridge", respectively. A comparison of "same bridge" a "M9 bridge" treatments shows the "M9 bridge" treatme tended to produce greater differences from the control. the second growing season, similar effects were observ with bridge grafting. There were no significant decrease the mean fruit weight by both bridge grafting treatmen while fruit L/D ratio show significant differences by bo treatment compared to the control. The "M9 bridg produced the greatest difference in fruit L/D ratio compar to the control. The "M9 bridge" gave a significant fles firmness difference compared to the control while th "same bridge" value was non-significant. "M9 bridge" fru were 8.1 per cent higher in brix value and 11.1 per ce higher in seed number. There was no significant differen observed in fruit flesh colour gave a greater difference fro the control whereas the "same bridge" gave less seve changes in the same direction.

Effect of interstock treatment on storage: Highly significa storage duration effects were observed for fruit weight los flesh firmness and flesh colour. There was no significa effect on brix. Fruit weight loss increased, flesh firmne decreased and flesh colour became creamy with duration storage. The same trend occurred in both years. In bo seasons the trend in brix value was to show an increas brix at 40 days (14 and 13 per cent in each respecti season) and a decreased brix at 60 days (13.9 and 12.7 p cent). However, the values at 40 and 60 days were n significantly different when compared to the brix at harve

Table 1: The main effects of interstock bridge grafting treatments (m9 dwarfing interstock bridge, and same cultivar cutting bridge) on apple quality parameters on different apple cultivars scion by rootstock combinations one (1994/95) and two (1995/96) years after treatment.

Treatment	Mean fruit weight (gm)	L/D Ratio	Flesh Firmness (Kg/cm^2)	^{0}Brix Value	Flesh @ Colour	Seed Number
1994/95 Growing Season						
Control	135.5	0.90	4.2	13.2	1.4	7.1
Same Cultivar Bridge	142.0	0.90	4.4	14.4*	1.5	7.7*
M9 Bridge	126.4	0.90	4.6*	14.6**	1.4	7.6*
1995/96 Growing Season						
Control	133.4	0.93	3.9	12.3	1.5	7.2
Same Cultivar Bridge	114.1	0.91*	4.1	13.0**	1.5	7.9**
M9 Bridge	127.0	0.90***	4.3**	13.3***	1.5	8.0***

Values followed by *, **, *** represent, in order, probabilities of P= 0.05, 0.01 and < 0.001 from Fisher's LSD. Comparisons against control; @ 1 = White 2= Yellow.

Table 2: The main effects of storage treatment (0, 40, and 60 days) on apple quality parameters for different apple cultivars, scion by rootstock combination and interstock bridge grafting treatments, one (1994/95) and two (1995/96) years after interstock treatment.

Treatment	Weight Loss (gm)	L/D Ratio	Flesh firmness (Kg/cm^2)	^{o}Brix Value	Flesh @ Colour	Seed Number
1994/95 Growing Season						
0 days	0	0.91	5.6	13.7	1.2	7.4
40 days	5.8***	0.90	3.9***	14.6	1.6***	7.7
60 days	7.1***	0.90	3.7***	13.9	1.5***	7.2
1995/96 Growing Season						
0 days	0	0.92	5.1	12.8	1.3	7.4
40 days	2.9***	0.91	3.4***	13.0	1.6***	8.0**
60 days	4.0***	0.91	3.9***	12.7	1.7***	7.3

Values followed by *, **, *** represent, in order, probabilities of P= 0.05, 0.01 and < 0.001 from Fisher's LSD. Comparisons against control; @ 1 = White 2= Yellow.

(Table 2). Storage had therefore modified the characteristics of the fruit and provided an opportunity to test the effects of the bridge grafting treatments on apple storage behaviour. No significant interactions were found in the 1994/95 season but in the second season several significant interactions were observed. An interaction between bridge grafting treatment and storage duration was observed for fruit weight loss. A significant rootstock and bridge grafting interaction was obtained for brix and fruit flesh colour. However, it can be seen that there appeared to be few interaction effects on the quality and storage behaviour of apples with the main treatment effects accounting for most of the differences (Table 4).

Bridge grafting significantly increased calcium concentrations and significantly reduced K and Mg level (Table 3). There were significant differences between bridge grafting treatments. Fruit were examined for storage disorders. Very few fruit from control or treated trees were found to have any disorders making any evaluation of treatment effects redundant.

Table 3: The effect of interstock bridge grafting treatments (m9 dwarfing rootstock and same cultivar cutting) on mineral composition after harvest across two apple cultivars.

Treatment	Potassium	Calcium	Magnesium
Control	8934.8	334.8	250.5
Same cultivar bridge	7652.0**	388.9*	242.3
M9 Bridge	8050.9	393.0**	215.2

Values followed by *, **, *** represent, in order, probabilities of P= 0.05, 0.01 and < 0.001 From Fisher's LSD. Comparisons against control.

Discussion

Controlling vigour in apple trees is a common problem in New Zealand because of fertile soils and the favourable climate. In another study (Samad *et al.*, 1998) bridge grafting was reported to be an effective means of controlling vegetative vigour in an overgrown, established orchard across a wide range cultivar, rootstocks and scions. With the removal of the bark from the tree trunk the movement of carbohydrates from the leaves and branches to the root system was restricted. There was, therefore, an accumulation of carbohydrates above the bridge graft. The decrease in the mean fruit weight observed in the second year is in agreement with work by Greene and Lord (1983). However Elfving *et al.* (1991) found no effect with trunk ringing and Murneek (1940) found ringing increased apple size. Many factors can alter the size of fruit. Girdling the tree may raise the concentration of carbohydrates in the upper canopy and reduce movement to the root system (Greene, 1937) thereby potentially providing more assimilates for fruit growth. The increase in the (CHO) concentration in the upper canopy can affect the reproductive status of the tree (previous paper) and fruit set. Increased fruit set may reduce the overall size of the fruit because of crop density. A further influence on fruit size might be the restricted movement of root sourced plant growth regulators past the trunk girdle into the canopy of the tree (Cutting and Lyne, 1993) potentially all these factors may effect the quality of the fruit and it was to ascertain the level of this potential effect that these data are presented.

Quality was affected to some degree by the bridge grafting treatment, generally increasing brix levels, firmness and seed number while reducing L/D ratio's of the fruit. As a consequence it may be necessary to modify harvesting time in particular to optimise it for bridge grafted trees. However, these changes are generally in the direction of higher quality, rather than lower quality fruit. Highly significant changes were found for several variables after 40 and 60 days storage (Table 2). Fruit undergo a complex series of enzymatically controlled biochemical changes prior to and after harvest. These changes include the conversion of starch to sugars, the use of carbohydrates in respiration, a decrease in inorganic acids and changes in pectic composition-changing pectic composition is part of the process of fruit softening (Westwood, 1988). Any or all these changes also have an opportunity to interact with the bridge grafting treatments. A significant fruit weight loss and decrease in fruit firmness was observed with 40 and 60 days storage in both seasons. The weight loss and loss of firmness was expected as fruit removed from the tree have no further access to water or nutrients. In spite of these many opportunities, there were few significant interactions between the grafting treatment and fruit quality during storage. The consequences of this are that while there were treatment effects they were readily comprehensible main effects, generally in the direction of improved quality. This indicates bridge grafting produces generalized effects on fruit quality, rather than complex interaction with oth factors, which should simplify the need for modifie management practices.

The calcium content of apple has been linked as a important factor in determining the storability of fruit an the susceptibility of apples to numerous physiologic disorders (Tomala and Dilley, 1989). Calcium appears t have an important regulating role in the metabolism of fru and maintaining the integrity of fruit tissue. In this stud the elemental composition of fruit has been affected b bridge grafting treatments. Magnesium and potassium we generally lower in fruit from grafted trees compared to fru from untreated tress. Calcium was higher in fruit fro bridge grafted trees. The results concerning Mg and K agre with work by Greene and Lord (1983) and Elfving *et a* (1991). There are conflicting reports about calcium statu with girdling treatments in the literature. Greene and Lor (1983) found no effect of ringing on fruit calcium level Ferree and Palmer (1982) showed low concentration o calcium with girdling. This study found increased levels o calcium with girdling treatment. It seems reasonable t expect the increased Ca concentration in the fruits resulting from girdling, may have improved the storability o the apples. This was not observed though there was generalized improvement of the overall level of fruit qualit in terms of sugar and firmness in the apples from treate trees which is consistent with the benefits of better C nutrition.

Tomala and Dilley (1989) show calcium accumulation developing apple fruits associated with polar auxin transpo and that seed were found to play an important role in thi Parthenocarpic fruit tend to have lower calcium levels th seeded fruit and Bangerth (1976) suggested that aux derived from seed played a role in calcium transport to t fruit. Other studies showed that calcium is transported the fruit throughout the fruit growing period (Jones *et a* 1989; Tomela *et al.* 1989). Further, calcium concentratio expressed as a percentage of fresh or dry fruit weig decreases as a function of fruit growth. In our study, found a significant increase in seed number with brid grafting. Our study supports Tomala and Dilley (1989) suggesting a positive effect of seed number on calci accumulation and this requires further investigation.

Table 4: The level of significance for rootstock, treatment, and days interaction for different apple cultivars with intersto bridge grafting treatment.

Treatment Interaction	Mean.F. Weight	Fruit Wt.	L/D Ratio Loss	Flesh Firmness	°Brix	Flesh Colour	Seed Numbe
1994/95 Growing Season							
RS* Treat	N.S	N.S	N.S	N.S	N.S	N.S	N.S
RS* Day	N.S	N.S	N.S	N.S	N.S	N.S	N.S
Treat* Day	N.S	N.S	N.S	N.S	N.S	N.S	N.S
RS* Treat*Day	N.S	N.S	N.S	N.S	N.S	N.S	N.S
1995/96 Growing Season							
RS*Treat	N.S	N.S	N.S	N.S	*	*	N.S
RS*Day	N.S	N.S	N.S	N.S	N.S	N.S	N.S
Treat* Day	N.S	*	N.S	N.S	N.S	N.S	N.S
RS* Treat*Day	N.S	N.S	N.S	N.S	N.S	**	N.S

Significance level; N.S, *, **: represent nonsignificant, $P< 0.05$, 0.01, respectively RS = rootstock, Treat = Treatm present there is no convincing explanation of how the girdling treatment exerted its effect on seed number. Other trials looking at vigour control however, have observed similar benefits of vigour control on seed number and Ca levels (Khan *et al.*, 1998).

The purpose of this trial was to determine the effect of bridge grafting treatments on fruit quality at fruit harvest and after storage time at 10°C. The most noticeable effects were reduced fruit size, lower L/D ratio, increased flesh firmness and brix value and increased seed number at harvest, while flesh firmness was reduced with increasing storage time and flesh colour showed a significant increase. The reduction in fruit size with bridge grafting treatments could be eliminated by developing appropriate management practices for fruit load. In this trial we found increased calcium concentration and reduced potassium and magnesium concentration in fruit from treated trees. Overall it appear that the bridge grafting treatment need not be precluded from use in existing vigorous apple orchards,on the basis of concern for fruit quality.

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