Developing Mechanical Harvesting for California Black Ripe Processed Table Olives: 2007-2010: Year 2 of 4 Progress Report

Project Leaders

Louise Ferguson, Ph.D., Extension Specialist, Department of Plant Sciences, 2037 Wickson Hall, Mail Stop II, UC Davis, 1 Shields Ave., Davis CA 95616; (O) 530-752-0507; (M) 559-737-3061; FAX: 530-752-0507; LFerguson@ucdavis.edu

Jackie Burns, Ph.D., Professor, Department of Horticulture, U. of Florida, Gainesville, FL; JKBU@ufl.edu

Jean-Xavier Guinard, Ph.D., Professor, Department of Food Science and Technology, UC Davis, Davis, CA; JXGuinard@ucdavis.edu

Uriel Rosa, Ph.D. , Assoc. Professor, Department of Bioagricultural and Mechanical Engineering, UC Davis, Davis, CA; UARosa@ucdavis.edu

Cooperating Personnel

Kitren Glozer, Ph.D., Associate Project Scientist, UC Davis; KGlozer@ucdavis.edu
William H. Krueger, MS, UC Farm Advisor, Glenn County, CA; WHKrueger@ucdavis.edu
Neil O'Connell, MS, UC Farm Advisor, Tulare County, CA; NVOConnell@ucdavis.edu
Paul Vossen, MS, UC Farm Advisor, Sonoma County, CA, PMVossen@ucdavis.edu
Rich Rosecrance, PhD, Assoc. Professor, California State University – Chico, CA, RRosecranc@CSUChico.edu
Sergio Castro, Ph.D., Associate Professor, University of Seville, Seville, Spain; SCastro@us.es
Peter Kulakow, Ph.D., Volunteer, Peter.Kulakow@Gmail.com
John Henry Ferguson, MBA, Volunteer, JohnFerguson22@SBGlobal.com

Reporting period: 15 April – 31 December 2008 (Year 2 of 4)

ABSTRACT

This is the second year of a four year project. In 2006, the project focused on adapting the DSE canopy harvester for harvesting existing Manzanillo trees with sufficient efficiency and quality to produce commercially competitive California black ripe table olives. Simultaneous research focused on identifying an abscission agent that would enhance harvest efficiency and decrease fruit damage. However, results from 2006 through 2008 have demonstrated pruning existing trees, or training new orchards for, mechanical harvesting, and evaluating these orchards with all commercially available harvesters would generate faster progress. Screening for an abscission agent and postharvest treatments for maintaining fruit quality should be secondary objectives. The 2008 research objectives and results support this redirection.

Determine if mechanical topping and hedging to make fruit more accessible for mechanical harvesting will decrease yields. Mechanically topping and hedging mature 'Manzanillo' trees did not produce statistically lower yields in the same season. Mechanically pruned trees produced 19.3 pounds per tree of fruit valued at $1,131.40 per ton versus 22.1 pounds per tree

valued at $1,151.40 per ton for conventionally pruned controls trees. However, this annual mechanical pruning should be continued for four years to determine effects on long term yields.

Determine if training method hedgerow-configured orchards affects yield. An eight year-old 'Manzanillo' hedgerow training trial has consistently produced no significant differences in annual yields or fruit values from 2004 – 2008. By 2008 the conventionally pruned control trees, those pruned to a traditional rounded canopy, at the same spacing, produced 21.00 cumulative tons per acre versus 18.85 for free standing espalier, 21.12 for a woven trellised espalier, and 20.82 tons per acre for a trellised and tied espalier hedgerows. When yields plateau, expected within 2 years, this experiment will be completed.

Evaluate the harvest efficiency and effects on fruit quality and value of the DSE 008 harvester. The DSE 008 harvester produced a significantly lower, (88.0%***) cannable percentage, and adjusted value per ton, ($1013.80***), for mechanically harvested fruit, versus 96.2% and $1137.80 per ton for hand harvested olives. However, these canning percentages and values per ton are well within normal ranges. This indicates this canopy head can produce commercially acceptable fruit. The harvester averaged 57.8% final fruit removal efficiency. This poor harvest efficiency was partially due to the configuration and manipulation of the canopy heads resulting in a swath of unharvested canopy. Our evaluation indicates the current DSE 008 harvester is too large, slow, and expensive. The catch frame is incomplete and the total machine has poor potential for successful commercialization. More progress can be made evaluating the commercially available prune, pistachio, and pomegranate harvesters that use versions of this canopy head, or trunk shaking technology, combined with the double-sided catch frames now common. In summary, the canopy head is now producing fruit suitable for processing, but the total harvester efficiency, speed, and catch frame capacity must be improved.

Evaluate the harvest efficiency and effects on fruit quality and value of trunk shaking harvesters. Four different trunk shaking harvesters were evaluated on hedgerow and smaller trees. Three shakers produced unacceptable trunk damage and had final harvest efficiencies ranging from 55.1 to 71.8%. These three shakers produced cannable percentages no lower than 91.5%, and adjusted fruit values over $872.55 per ton.

Evaluate the harvest efficiency and effects on fruit quality of the MaqTec Colossus. Trials conducted in Argentina with 'Manzanillo' and Portugal with 'Hojiblanca' table olives demonstrated that this machine removed table olives with > 95% efficiency, but bruised, mutilated or cut virtually 100% of the fruit. Colossus will need considerable reworking if it is to have potential for harvesting table olives.

Screening for abscission and postharvest treatment agents. Screening trials for both agents continued, but the few potential candidates require further testing before incorporation into harvesting trials.

Conclusions

We now need to evaluate mechanically pruned and new hedgerow orchards with the currently available commercial potential harvesters. The DSE 008 harvester has demonstrated the picking head technology is viable for table olives. Other aspects of this harvester (e.g., size, cost, speed, catch frame technology and adaptability) need to be addressed by DSE. Additionally, commercially available trunk shaking and canopy harvesters mounted on double-sided catch frames should be evaluated in conventional and mechanically pruned and hedgerow trained orchards. Screening for abscission compounds and postharvest treatments should continue, but these compounds are so far from incorporation into mechanical harvesting trials, or registration, that mechanical harvesting of olives should be developed without these chemical aids.

INTRODUCTION

Why mechanical harvesting of California black ripe table olives is needed

The California table olive industry will need to develop mechanical harvesting for economic survival. The recent decreases in harvested acres support this contention; harvested acreage has decreased by 15% since 2005. Hand harvesting costs are remaining above $350.00/ton. Using current cost study figures (http://coststudies.ucdavis.edu/files/olives-tablesprinkler_sj-valley_2005_ol-sj-05.xls), it can be seen that picking costs will become a larger problem as future gross returns per ton drop from the 2008 peak $1210.00/ton.

Further, current economics and immigration enforcement efforts suggest manual labor pools will decrease. Even if they do not, the logistics of manual labor are difficult. Thus, developing mechanical harvesting is both an economic and logistical necessity for the California black ripe processed table olive industry.

Why mechanical harvesting is difficult to develop and how we are approaching it

The limiting factor in mechanically harvesting table olives is producing commercially acceptable black ripe table olives. This requires that the product delivered to the cannery be free of bruises and cuts that decrease processed table olive quality.

Olives destined for California black ripe table processing are harvested physiologically immature; the abscission zone between the fruit and stem is undeveloped. The fruit is borne on pendulous, flexible, vertical shoots at the outer periphery of the canopy. To remove an immature individual 5-10 gram olive fruit requires at much as half a kilogram of pull force. The two major methods of fruit removal, trunk shakers and canopy contact picking heads, both have specific limitations. Trunk shakers are inefficient and damage the trunks. Canopy contact heads damage the fruit. Both are currently marginally, economically efficient in terms of % fruit removal and tons or acres per hour harvested.

Thus, logically, one primary objective of a mechanical harvesting project should be developing an effective abscission agent to accelerate the development of the fruit abscission zone that will decrease the required pull force and therefore require less forceful trunk shaking or canopy head picking force. The result would be a higher harvest percentage of cannable fruit and less tree damage. Ethylene release compounds, (ERCs), primarily ethylene, have demonstrated the best potential thus far. However, decades of abscission research with ethylene, and our recent results, have demonstrated olive leaves are more sensitive to ERCs than olive fruits. The usual result is unacceptable leaf losses (over 25%). Further, ERCs perform erratically in trials. Finally, even if an effective abscission agent is developed it will require at least five years and considerable funding to generate the efficacy, residue, and environmental impact research (EIR) required for registration.

A logical, second primary objective should be development of effective, non-damaging harvesters. Our harvester evaluations thus far, strongly demonstrated altering the tree to make fruit more accessible to the harvester would greatly increase harvest efficiency Therefore, developing and adapting olive trees suitable for mechanical harvesting should become a major objective.

Finally, pre- and post-harvest antioxidants have shown some potential for decreasing fruit damage from the harvester. However, these chemicals face the same registration requirements as an abscission compound.

In summary, when initiated in 2007 the mechanical harvesting research program focused on simultaneously developing a specific mechanical harvester, the DSE 008, and identifying an abscission agent to increase harvester efficiency and decrease harvester fruit and tree damage. However, results thus far strongly indicate that the final two years of this project should focus on two equal priorities. First, research should focus adapting trees for mechanical harvesting through pruning of existing orchards and development of new hedgerow orchards. Second, all available commercial harvesters with potential for table olives should be adapted and evaluated on these reconfigured orchards. Trials with the DSE 008 have demonstrated the canopy contact picking head can successfully harvest commercially viable fruit. As research cooperators, we gratefully thank Dave and Karen Smith of DSE for their major role in helping the olive industry reinvigorate the mechanical harvesting research program.

Development of abscission compounds for decreasing fruit removal force, and anti-oxidant pre- and post-harvest treatments for decreasing fruit damage, should both be pursued as secondary objectives. However, neither chemical can be incorporated into mechanical harvest trials until potential compounds are identified in screening trials.

The following 2008 research report supports these conclusions.

OBJECTIVES

Outline

This project had four major objectives; outlined below. Each objective will be discussed in an individual section.

I. Evaluation of Pruning and Training Methods on Tree Yield and Fruit Quality

Part A. Evaluation of Mechanical Topping and Hedging
Part B. Evaluation of Olive Hedgerow Orchards

II. Evaluation of Mechanical Harvester(s) Efficiency and Effects on Fruit Quality and Value

Part A. DSE 008
Part B. Coe. Nielsen, OMC and Spanish Wrap Around Trunk Shakers
Part C. MacTeq Colossus

III. Evaluation of Antioxidants and Preharvest Plant Growth Regulators to Reduce Physical Damage and Improve Firmness in 'Manzanillo' Olives in 2008

IV. Screening for Potential Abscission Compounds

I. Evaluation of Pruning and Training Methods for Mechanical Harvesting: 2008 Season

Part A. Evaluation of Mechanical Topping and Hedging: 2008 Season

Introduction

Preliminary work done in 2006 demonstrated that fruit on the canopy facing the row middle was mechanically harvested with the picking head type harvester significantly more efficiently than fruit on the canopy surface between the trees. This suggested that a typical orchard topped and side hedged to a hedgerow configuration could be harvested more efficiently with a picking head harvester. However, the effect of long term hedging and topping, (at least 4 years), on yield and fruit quality has not been demonstrated. Therefore this trial tests the hypothesis that a moderate, annual mechanical pruning program does not decrease yield or fruit quality over a four-year period.

The trial was also designed to test the efficiency of the DSE 008 harvester at four different ground speed (MPH) and picking head amplitude combinations (RPM). However, the DSE was delivered too late to accomplish this objective.

Procedures

Location: Block 17W: Rocky Hill Ranch, Exeter, CA

- Planted 1998
- 13 rows, 83 trees per row, 'Manzanillo' olives with 'Sevillano' pollinators
- Spaced @ 12 X 26 feet, 139 trees per acre

<u>June 16-17, 2008</u>

6 rows of 83 trees each were conventionally pruned

6 rows of 83 trees each were pruned for mechanical harvesting:

- All large, horizontal limbs extending into the row middle were pruned off
- Trees were skirted at 3 feet from the ground
- Trees were topped at 12 feet
- Trees were hedged on the west side 6 feet from the trunk

<u>September 23 – 24, 2008</u>

All of the 12 tree rows were divided into 5, 14 tree, replications with 1 buffer tree at each row end, and 2 buffer trees between each 14 tree replication:

- 1, 14 tree replication per row (12 total) was hand harvested into a separate bin
- Yield was weighed on a tared field bin scale
  - dropped fruit was collected from beneath trees and field weighed
  - fruit left in trees was hand harvested and field weighed
- Bin was reweighed at Musco receiving station
- COC sample grade pulled from each bin
- Yield per tree, % cannable, % of sizes and adjusted price/ton analyzed
- Samples were not sent for processing as this trial was to evaluate mechanical pruning effects on yield and fruit size

Results and Discussion

As can be seen in **Table 1** below, moderate mechanical topping and hedging in June, 2008 did not significantly affect yield, fruit quality, or value. In this test of six 14 tree replications the hand-pruned trees did yield 2.8 more pounds per tree than mechanically-pruned trees, but the difference was not statistically significant. There were no significant differences in % of cannable fruit, the % size distribution or the adjusted value per ton.

However, it requires at least four years of data, particularly in an alternate bearing species that produces on one year old wood, to draw conclusions about the effects of a long term pruning program on growth and annual yield. Therefore, while these results look promising this trial should be conducted for at least another three years.

The second part of this experiment was to evaluate the effect of mechanical-pruning, versus a hand-pruned control, on the harvester efficiency and effects on fruit quality, of the DSE 008 mechanical harvester. However, this trial was not able to be done because of harvester delivery delays. These trials were scheduled to begin 15 September 2008. Due to mechanical problems, the DSE 008 was not operational until 28 September. By then the fruit was seriously overripe.

Conclusion

Mechanical topping at 12 feet and hedging 6 feet from the trunk on one side of the tree in June did not affect tree yield or fruit quality and value within the same growing season. Fruit values were unaffected by the mechanical-pruning. This work will be continued for another four years to ensure there are no long term effects on tree growth or bearing.

Table 1. Yield per tree, percentage of olive sizes, culls, and trash in the sample, and adjusted price per ton. No significant differences in yield or fruit quality were found between the mechanically and hand-pruned trees.

Effect of Mechanical Topping and Hedging on Tree Yield and Value

Pruning treatment	Yield/tree (lb)	Percentage										Adjusted price/ton ($)
		Cannable	Extra large	Large	Medium	Small	Petite	Subpetite	Undersized	Culls	Trash	
Mechanical	19.3[x]	95.9	62.8	24.0	4.9	1.8	1.4	1.0	0.8	2.2	1.2	1131.50
Hand	22.1	97.4	67.9	22.2	3.1	1.6	1.4	1.0	0.8	1.1	0.8	1151.40

[x] Means separation within columns were performed with PROC TTEST procedure of SAS (SAS Institute Inc., Cary, NC); *, **, *** = 0.05, 0.01 and 0.001 level of significance. Where no symbol follows the mean values, no differences by pruning treatment were found to be significant.

I. Evaluation of Pruning and Training Methods on Tree Yield and Fruit Quality

Part B. Establishing and Training Manzanillo Table Olives for Mechanical Harvest: 2008 Season. Section written by William H. Krueger

Introduction

Table olives in California are hand-harvested. The cost of hand-harvest can be as much as 50 percent of the gross. From 1997 to 2000, the California Olive Committee (COC), the table olive marketing order, sponsored the development of a mechanical harvester for table olives. Prototype canopy shake machines were developed. Although these machines looked promising, they had two major drawbacks: 1) Efficiency of harvest - when the picking head came into close proximity of the fruit, it was removed. However, leading and trailing canopy edges and inside fruit proved to be problematic because it was difficult to get the head close to fruit located in these positions. Fruit removal was often disappointing. 2) Fruit damage - The fruit can be damaged in the removal process. While this damage may appear similar to what may occur with hand-harvest, the bruises are generally deeper and more severe. One of the major table olive processors quit accepting mechanically-harvested fruit due to concerns related to fruit damage. This temporarily stopped progress toward mechanical-harvest with this machinery. A continued and increasing need for mechanical-harvest has rekindled interest. The COC resumed funding for mechanical-harvest research in 2006 and is continuing to support this research. The focus of the research has been on improvement of the previously developed machinery to increase removal and reduce damage, the development of loosening agents to facilitate mechanical-harvest and other types of mechanical-harvesters such as trunk shakers.

If a tree canopy could be developed in which all of the fruit was accessible to the picking head, a much improved harvest efficiency with reduced force and, therefore, reduced fruit damage should be attainable. The ideal tree and orchard configuration would appear to be a close-spaced hedgerow system, which would present a flat narrow fruiting wall to the harvester with no leading, trailing edge or inside fruit. A fruiting canopy approximately 6 feet in width and approximately 12 to 15 feet high would be appear to be ideal for maximum machine efficiency. With a narrow tree canopy and tree height such as this, narrower row spacing will be necessary to achieve maximum yields. This type of tree architecture should also be more adaptable to other types of mechanical-harvesters including existing trunk type shakers and other types of machinery which could be developed.

Objectives

1. Develop a narrow canopy hedgerow to facilitate mechanical-harvest;
2. Evaluate and demonstrate the feasibility of a high density hedgerow developed specifically for mechanical-harvest; and
3. Compare different training methods for developing a narrow canopy hedgerow.

Procedures

In the spring of 2000, Manzanillo variety table olives were planted on 2 acres at the Nickel's Estate in Arbuckle with a north-south row orientation and a tree spacing of 12 feet in the row and 18 feet between rows (202 trees per acre). The selected training treatments included "conventional" and three narrow canopy hedgerow treatments. The conventional training consists of thinning out fruit wood and opening up the center of the tree. The trees will eventually have 3 to 5 primary scaffolds. With the narrow canopy hedgerow treatments, permanent limbs are being trained parallel to the row in a narrow plane (approximately 1 foot wide) with flexible temporary fruiting wood extending approximately three feet out into the row on either side. Large stiff limbs extending into the tree row are positioned into the permanent limb plane or are removed. The narrow canopy hedgerow treatments are: Free Standing - where pruning alone is used to conform the trees to the system; trellised woven - where potentially permanent limbs are woven between three wires spaced at 4, 7, and 10 feet; and trellised tied - where potentially permanent limbs are tied to the wires. In 2007 the tied treatment was not pruned because cropping potential appeared light. In 2008 this treatment was pruned, but not tied. The pruning consisted of thinning the tree canopy. This treatment will gradually be brought back to the narrow canopy system through a combination of pruning and tying. The treatments are arranged in a randomized complete block design and consist of blocks of three rows of either seven or eight trees. There are four replications of each treatment. In 2008, harvest data was collected by hand and, in some cases, mechanically with trunk shakers. In the mechanically-harvested trees, total yield was determined by weighing mechanically-harvested fruit and adding it to the weight of the fruit gleaned by hand from the same trees. At harvest, 10 to 12 lb. samples were collected from each replication of each treatment and submitted to Musco Family Olives for commercial grading. The sample results were used to assign a value to the production.

Originally six trees of the Sevillano variety were strategically placed in the planting to provide for cross pollination for the partially self-incompatible Manzanillo. Due to disappointing growth of these trees, cross pollination was inadequate. Even though there was a good bloom, the fruit set for 2003 was disappointing and did not warrant harvest. During the summer of 2003, the center row of the planting was top worked to Sevillano to provide for adequate cross pollination. During bloom in the spring of 2004 and 2005, the block was artificially cross-pollinated using Sevillano pollen. The grafted pollinators developed well and artificial pollinization was discontinued in 2006. In the spring of 2007, about two weeks after full bloom, all of the plots were chemically thinned with Napthalene Acetic Acid (NAA). In 2008, bloom appeared lighter and less uniform than in 2007 so no chemical thinning was done.

Results and Discussion

Yields for 2008 were variable from plot to plot, but were generally good with an average for all treatments of 5.35 tons per acre. There were no statistically significant differences between any of the treatments for yield per acre, value per ton or value per acre (**Table 2**).

Cumulative yields for all treatments were very similar through the first eight years and would be considered good for this area. Cumulative yield for the freestanding narrow canopy hedgerow system has been slightly less than the conventional treatment. This would be expected due to the generally more severe pruning required to conform the trees to the system. To date, plot variability has kept this difference from being statistically significant. The tied narrow canopy treatment had the lowest yield per acre in 2008. Plot variability also kept this difference from being significant. However, it is believed that this difference, if real, is due to the higher yield that this treatment had last year and reflects the alternate bearing nature of olive.

Conclusions

To date, the results indicate that olives trees can be grown and maintained in a narrow canopy hedgerow configuration with no reduction in yield or fruit value.

Table 2. Nickel's Hedgerow Olive Harvest, 2004-08

Treatment	2004	2005	2006	2007	2008			Cum. Yield
	Tons/A	Tons/A	Tons/A	Tons/A	Tons/A	$/Ton	$/Acre	Tons/A
Conventional	4.09	1.75	2.81	6.39	5.96	$1,060	$6,137	21.00
Free Standing	3.66	1.51	2.26	6.40	5.04	$948	$4,594	18.85
Trellised, Woven	4.21	1.68	2.28	6.07	5.88	$1,004	$5,875	20.12
Trellised, Tied	3.58	3.45	1.76	7.51	4.52	$1,104	$4,983	20.82
	NS	NS	NS	NS	NS	NS	NS	

Numbers followed by different letters are significantly different at the 5% level using Fischer's test.

II. Evaluation of Mechanical Harvesters

Part A. DSE 008 Picking Head Harvester

Introduction

Earlier research demonstrated that the picking head of the DSE 008 harvester removed as much as 98% of the fruit if it was accessible. However, final efficiency (the percentage of fruit that is captured in the bin) averaged 72% due to fruit being inaccessible, or removed, but not captured by an incompetent catch frame.

Mechanically harvested fruit quality in 2007, as measured by receiving station grades, % cannable and adjusted price per ton, was lowered by fruit bruising and mutilation. The 2007 fruit post-processing sensory evaluations by Dr. JX Guinard demonstrated differences between processors were more detectable than the differences between hand and mechanically-harvested fruit. The trained sensory panel found larger differences in the fruit from the two different processors than they detected in mechanically-harvested versus hand- harvested fruit. However, mechanically-harvested fruit was also evaluated as having a softer, less desirable texture.

For evaluation of the improved DSE 008 in 2008 fruit, processed fruit evaluations in March 2009 will be done on both fresh and stored processed fruit to minimize the sensory evaluation differences between the processors. The results should be available by April 2009.

Procedures

Location: Block 17W Rocky Hill Ranch, Exeter CA

- Planted 1998
- 13 rows, 83 trees per row, 'Manzanillo' olives with 'Sevillano' pollinators
- Spaced @ 12 X 26 feet, 139 trees per acre
- On 16 and 17 July 2008 the western 6 of 12 rows were mechanically topped at 12 feet, hedged 6 feet from the trunk on the west side and skirted 3 feet from the ground on both sides.

September 29 – 20, 2008

The six mechanically pruned tree rows were divided into five 14 tree replications with 1 buffer tree at each row end, and 2 buffer trees between each 14 tree replication.

- One replication was hand harvested on 24 September to provide the data for Objective I.A
- One replication per row (6 row total) was hand-harvested as a control
- Three replications per row (6 row total) were harvested with the DSE 008
  - Dropped fruit were collected and weighed; but not combined with harvested fruit
  - Each tree was hand-gleaned, and fruit weighed; but not combined with harvested fruit
- The one hand-harvested replication and three machine-harvested replications were maintained in separate bins
- The separate bins were weighed at Musco receiving station
- A COC sample grade was done for each bin
  - A 40 pound sample of extra large/large fruit was collected from the running the fruit over the sizer
  - Separated into two, 20 pound samples for Bell Carter and Musco
    - One sample will be processed fresh
    - One sample will be processed stored
    - The samples were sent to the two processors that night

2 (harvest methods) X 6 (14 tree replications) X 2 (Processors) X 2 (processing methods) = 48 samples total

These 48 samples will be:

- USDA graded by the both processors in March 2009
- Evaluated by a sensory panel under the direction of Dr. Guinard in March through June 2009

Results and Discussion

The results, below in **Table 3**, demonstrate, as expected, that harvest method has no effect on yield per tree. Mechanically-harvested trees yielded 20.3 Lbs/tree versus 17.8 Lbs/tree for hand-harvested trees. However, the method of harvest significantly affected the cannable percentage and adjusted value per ton. Mechanically-harvested fruit was valued statistically significantly lower*** at $1013.80/ton with a significantly lower cannable percentage of 88.0*** versus $1137.80/ton and a cannable percentage of 96.80% for hand-harvested control fruit. However, while significantly lower than the values for hand-harvested fruit, these average values per ton and cannable percentages are well within acceptable ranges. It is important to understand what caused these decreases in value.

The decreases in olive quality and value were, in decreasing order, a result of a significantly higher % of trash and culls, and lower % of extra large fruit, in the mechanically-harvested fruit versus hand-harvested fruit. Based on these data, the greatest decreases in value were produced by the higher trash percentage at 6.5%, six times that of the hand harvested control. This was the result of a malfunctioning blower that could have been easily repaired, and should not be a problem in the future. The higher cull percentage also decreased the fruit value; 5.1% versus 2.2 % for hand-harvested fruit. The primary reason for cullage was overripe and wrinkled fruit. Again both factors could be decreased by an earlier harvest, and should not be a problem in the future. However, these easily avoidable factors significantly affected the 2008 harvest data. The 8.6% decrease in extra large fruit harvested, from 61.4% for hand-harvested versus 52.8% for mechanically-harvested trees is interesting. It conflicts with our 2002 research demonstrating that the canopy picking head type harvest preferentially removed, the larger more mature, more easily detached fruit first. And there are no significant differences in the balance of the other fruit sizes that would suggest compensation by the other fruit sizes; all the other fruit size percentages were insignificantly different from those of the hand-harvested controls. However, the respective percentages were consistently lower. Thus, while individually no individual value was statistically significant, the summed differences could provide compensation. However, fruit size distribution was the least significant of the factors that decreased the value of the mechanically-harvested versus the hand-harvested fruit.

This data given here can also be used to determine the removal and final fruit removal efficiency of the DSE 008. These values are calculated as follows:

$$\text{Fruit Removal Efficiency} = \frac{\text{Fruit in Harvest Bin} + \text{Fruit on Ground}}{\text{Total fruit on the tree}}$$

$$\text{Final Harvest Efficiency} = \frac{\text{Fruit in Harvest Bin}}{\text{Total Fruit on the Tree}}$$

This portion of the experiment was done entirely on mechanically topped and hedged trees; a pruning treatment that, hypothetically, should have enhanced mechanical harvesting efficiency. Even with this theoretical advantage, the efficiency of removal by DSE Harvester ranged from 44.1% to 77.6%, with a mean value of 57.8%. The efficiency calculation was based on fruit left and dropped on the ground. Fruit drop from the harvester was minimal; generally less than 0.25 lbs/tree (data not shown). This average decrease in efficiency from the average 72% removal in 2007 may be partially a result of a low crop. Low crops tend to be more scattered on the tree, resulting in less efficient removal.

Conclusions

In summary, the data given here demonstrate the canopy picking head can produce commercially acceptable quality fruit if receiving station grade is the final criterion. However, processed fruit grade USDA and sensory evaluations are the limiting factor in determining the viability of any mechanical harvester. The processed fruit USDA evaluations by the two processors and sensory evaluations by Dr. Gruinard's lab will be done March 2009 and available shortly thereafter.

The two major factors that decreased fruit grade and quality in this experiment can be easily overcome. Harvesting at the right time and proper blower function would have greatly increased the cannable percentage and value per. Most likely, if these two factors had not lowered the cannable percentage and adjusted value per ton, the mechanically-harvested fruit would have received a receiving station grade as high as that of hand-harvested fruit. Therefore, based on the data available at this time, the contact canopy picking head is a viable harvester option for California black ripe processed table olives. Particularly for appropriately pruned larger and older trees.

However, the efficiency of this specific harvester, the DSE 008, suggests that we have learned as much as we can from this prototype. This DSE 008 is too slow, large, and expensive. It lacks a complete catch frame. These factors make it unlikely that the DSE 008 can be successfully developed as a commercial olive harvester within the time frame of this grant. The major contribution of Dave and Karen Smith of DSE in restarting olive mechanical harvesting research is gratefully acknowledged. Canopy contact picking head research should now be adapted using the Agright and Coe pomegranate harvesters.

Table 3. Effect of harvest method on yield, percent cannable fruit, and fruit value per ton. Harvest method had no effect on yield, but mechanical-harvest significantly lowered the percentage and value per ton of cannable fruit. The major factors causing these decreases were significant increases in the percentages of trash and culls in mechanically harvested fruit. The high percentage of trash was the result of an inoperative blower. The higher percentage of culls was the result of overripe fruit.

Evaluation of Mechanical Harvesting on Yield and Receiving Station Value												
Harvest treatment	Yield/tree (lb)	Percentage										**Adjusted price/ton ($)**
		Cannable	Extra large	Large	Medium	Small	Petite	Subpetite	Undersized	**Culls**	**Trash**	
Mechanical	20.3	**88.0*****	52.8*	25.1	5.0	2.2	1.4	1.1	0.8	**5.1****	**6.5*****	**1013.80*****
Hand	17.8	**96.2**	61.4	26.7	4.1	1.6	1.2	0.8	0.8	**2.2**	**1.1**	**1137.80**

[x] Means separation within columns were performed with PROC TTEST procedure of SAS (SAS Institute Inc., Cary, NC); *, **, *** = 0.05, 0.01 and 0.001 level of significance. Where no symbol follows the mean values, no differences by harvest treatment were found to be significant.

Efficiency of removal by DSE Harvester ranged from 44.1% to 77.6%, with a mean value of 57.8%.

II. Evaluation of Mechanical Harvester(s) Efficiency and Effects on Fruit Quality and Value: 2008 Season

Part B. Coe, Nielsen and OMC Trunk Shakers

Introduction

Trunk-shaking oil olive trees is common in Europe. In the 1960s, University of California also developed pruning methods, and an 'inertia head" shaker for mature California table olive trees. However, the technology, never widely adapted, was designed exclusively for larger trees, not younger hedgerow orchards. Because a younger hedgerow orchard, developed by Krueger and Ferguson, discussed under Objective I.B of this report, now exists, there is an opportunity to re-examine trunk shaking of table olives.

Therefore, it was proposed to compare the harvest efficiency, effects on fruit quality and long term tree health of three commercially available trunk shakers on the four different training methods on 8 year old hedgerow olives. The companies and machines selected were the ENE Inc. pistachio harvester, the Coe pistachio harvester and the Mayo Shakermaker pistachio harvester. The objective was to test the efficiency, and effects on fruit quality of these three machines on one conventional and three hedgerow training treatments.

As the data given below will demonstrate, trunk shaking of young hedgerow orchards has potential, but currently has a limiting factor that must be addressed. The trunk-shaking produced receiving station cannable grades and value equal to that of hand-harvested trees. And, as the data below show, the final harvest efficiency needs to be significantly improved. But the most severe problem is that trunk-shaking produces unacceptable trunk damage.

Procedures

Locations: Nickels Estate: Greenway Ave, Arbuckle CA; Planted 7-8-01. Tree spacing = 12'x18' or 202 trees/ac; 'Manzanillo' cultivar with Sevillano (S) pollinators; center row budded to Sevillano 07-03

Experimental Design: 4 X 4 Factorial of Tree Training and Harvest Method.

Tree Training Method

Harvester (Tx #)	Conventional (1)	Free Espalier (2)	Woven Espalier (3)	Tied Espalier (4)
Coe	20	20	13	13
ENE	19	18	11	11
OMC	18	20	11	11
Hand Harvested Control	12	9	32	35

May, 2008: Four training treatments were trained or pruned as per treatment, and thinned if necessary.

October 7- 9, 2008: Harvester companies and operators were evaluated on:

Oct. 7: ENE Inc.: Erick Nielsen
Oct. 8: Coe Harvesters: Matt Coe
Oct. 9: OMC Shakermaker: Don Mayo

Harvest Procedure:
Each harvester shook the pruning treatment replications (4) designated above.

- Catch frame was cleaned
- Fruit in bin was weighed in field using a bin scale
- Fruit on ground under tree was collected and weighed in the field using baby scale
  - Held in extra bin for the entire row
- Fruit remaining on tree was hand-harvested and weighed in the field with baby scale
  - Held in extra bin for the entire row
- Mechanically-harvested fruit in the bin were sent to Orland Musco grading station for weight and COC grade and value
- Trees were evaluated on a four point scale for trunk damage, branch damage and leaf loss:
  - 0 = no damage or loss
  - 1 = mild
  - 2 = moderate
  - 3 = severe

Results and Discussion

Preliminary trunk shaking quickly demonstrated that severe trunk barking was a limiting factor in shaking olives. This also may have been exacerbated by late rains after normal irrigation had been discontinued. As a result, a complete data set was obtained with only one, of three potential, trunk shaking harvesters. The results from the Coe pistachio harvester are given below (**Table 4**). Limited data from the ENE Inc. and OMC Shakermaker harvesters, (data not given here), produced similar results.

The Nickels hedgerow orchard 2008 experimental data was probably severely compromised by a very light and variable crop per tree that produced widely differing size distributions within the treatments. As a result no significant differences were detected among the treatments, or relative to a hand-harvested control, in fruit quality factors; percent cannable fruit and adjusted value per ton. The analyzed data for this experiment is given in **Table 4**.

The data in **Table 4** demonstrate no significant differences in harvest efficiency among the four pruning treatments. The harvest efficiency values range from 63.6 to 71.8% of the fruit removed from the tree relative to the total crop on the tree. Therefore, trunk shaking is equally efficient, or inefficient, among the four pruning treatments. However, relative to hand-harvest, at a low estimate of 95% harvest efficiency, this means an average of 30% of the fruit remained on the mechanically-harvested trees versus hand-harvested trees. Therefore, harvest efficiency of trunk-shaking does need to be improved, even with young hedgerow orchards.

Table 4. Averaged final harvest efficiency (fruit in the bin/total fruit on the tree) of the Coe pistachio harvester for the control and three training treatments. There were no significant differences in % harvester efficiency among the three training and control treatments. The % cannable fruit and adjusted price per ton were only available as averaged percentages and therefore are not statistically analyzed.

Evaluation of Coe Trunk Shaker Harvester with Four Different Hedgerow Tree Training Methods

Tree Training Method		# of Trees	Harvest efficiency (%)*NSD	Yield /tree	% Cannable	Adj. $/ton	
Control							
					95.0	*974.45*	*Machine*
	Total	**20**	**71.8**	**67.4**	*97.1*	*1,035.35*	*Hand*
					(-2.1)	**(- 60.90)**	**(Difference)**
Treatment 2 = Espalier - no trellis							
					96.4	*872.22*	*Machine*
	Total	**14**	**63.6**	**51.1**	*96.3*	*1,041.66*	*Hand*
					(+0.1)	*(-169.44)*	**(Difference)**
Treatment 3 = Espalier - trellis, no tying							
					95.3	*963.27*	*Machine*
	Total	**13**	**65.3**	**51.0**	*94.4*	*1,030.81*	*Hand*
					(+0.9)	*(-67.54)*	**(Difference)**
Treatment 4 = Espalier - trellis and tying							
					96.1	*1,130.90*	*Machine*
	Total	**13**	**69.4**	**46.8**	*92.8*	*1,100.64*	*Hand*
					(+3.3)	*(+30.26)*	**(Difference)**

* NSD; no significant differences among training treatments.

The effects on fruit quality, the percentage of cannable fruit, and the adjusted price per ton were similarly insignificant among the four pruning treatments. The canning percentages among treatments ranged from 95% to 96.4%. Adjustable prices per ton ranged from $872.22 to $1,130.90 per ton. Both ranges are well within good receiving station grades.

Canning percentage differences between the hand-harvested controls and different machine harvested pruning treatments ranged from, -2.1% to +3.3%. Adjusted values per ton relative to the hand-harvested controls ranged from - $169.44 to + $30.36 per ton. Statistics were not done on these average value differences as the replications were too limited and uneven. However, values suggest there would be no significant differences in cannable percentages or adjusted values per ton between hand-harvested and trunk-shaker harvested fruit.

The data below (**Table 5**) are from a smaller trial comparing the performance of the ENE Inc. pistachio harvester and an imported Spanish wraparound harvester. Generally, the percentage removal efficiency, percentage of cannable olives, and adjusted prices per ton are comparable to the values in the Nickels trial. Trunk damage was also sustained in this trial. Generally, this second trial reinforces the need to decrease trunk damage and increase final harvest efficiency if trunk shakers are to be successfully used for table olive mechanical harvesting.

Table 5. Comparison of the ENE Inc. pistachio harvester and the Spanish wraparound olive harvester removal efficiency and effects on receiving station values. Values in a row followed by different letters are significantly different. The Spanish wraparound harvester had significantly higher % harvest efficiency than the ENE Inc. harvester. There were no significant differences among the harvesters and control treatment in % cannable fruit. Similarly there were no significant differences between the harvesters in adjusted price per ton. However the ENE Inc. harvester did have a significantly lower adjusted price per ton than the Spanish wraparound harvester. This was a very limited experiment with uneven numbers of replications and, while statistically analyzable, this data should be treated as preliminary to larger, more completely randomized and replicated trials.

Comparison of ENE Inc and Wraparound Trunk Shaker on Young Trees*.

	ENE Inc.	**Wrap Around**	**Hand Harvest Control**
Removal efficiency (%)	55.1a	61.5b	
Cannable %	91.5a	92.3a	95.3a
Adjusted Price per Ton	879.33a	998.40ab	1072.66b
Average Yield (lb/tree)	56.9	49.83	66.0

*Numbers in row followed by different letters are significantly different at the 5% level using Fischer’s test.

Conclusions

In summary, the limited data in these two trials with trunk shaking harvesters demonstrates trunk-shaking young trees, (< 10 years), produces olive canning percentages and adjusted values per ton equal to that of hand-harvested fruit. Theses data demonstrate the strong potential trunk-shakers have for mechanically-harvesting young table olive trees. However, harvester efficiency will need to be improved for commercial adoption of trunk-shaker harvesters.

The data given here also demonstrate the major impediments to successful trunk-shaking will be eliminating trunk damage and increasing the final fruit removal efficiency. These two factors, as well as the more technical aspects of trunk-shaker performance evaluation are addressed in Drs. Uriel Rosa's and Sergio Castro's final reports.

III. Part 1. Evaluation of MacTeq Colossus

Section written by Sergio Castro

Procedures:
Date: 12 September 2008
Location: Ranch 'Rabadoa', Baleizao, Portugal
Harvester: MacTeq Colossus with rod drum modification and padded frame
Olive: 'Hojiblanca' cultivar, 5 years old, 7 x 4.8 m tree spacing

Harvesting tests in the AM:
At 12:20 pm. Five trees. Harvester used the highest drum speed, hardest conditions. Harvesting efficiency estimation (visual) = 90%.

Harvesting tests in the PM:
At 3.55 pm: Five trees. Harvester used the regular working conditions. Harvesting efficiency estimation (visual) = 60%.

Fruit removal force (FRF) was measured (cN) before and after harvesting, both in the AM and PM tests.

Collected Sample Classifications:

A = Belt.
Olives from the bottom belt; collected before fruit transport system. These olives show the damage from detachment system by canopy shaking and catch frame.

B = Belt.
Olives from the shortest conveyor belt after the transport system; collected from rear of the harvester. They came from the left bottom belt. These olives include a part of the fruit damage from the transport system.

C = Bin.
Olives from the longest conveyor belt after the transport system; collected from the rear of the harvester. They came from the right bottom belt. These olives include all fruit damage caused by the transport system.

D = Hand Control.
Hand-harvested olives.

Visual Damage Classification after 24 h.

- Sound: Fruit without damage. Fruit looks similar to those in the tree canopy.
- Bruised: Fruit with > one bruise, compression or abrasion without skin being cut. Olives from this classification could be processed. These olives have visual damage after 24 h of postharvest storage.
- Cut: Fruit with skin damage, primarily deep cuts.
- Mutilation: Fruit deformed and unsuitable for processing.

Fruit Detachment Force Evaluation:

Description of data collected. FRF is measured in centiNewton (cN)

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
FRF Control Morning Before Harvest	110	380.00	1040.00	627.55	131.97
FRF Morning After Harvest	47	200.00	880.00	565.11	171.31
FRF Control Evening Before Harvest	49	160.00	860.00	485.71	135.09
FRF Evening After Harvest	52	180.00	860.00	499.62	146.94
Valid N (listwise)	47				

T-tests with paired samples.

Differences between control measurements in AM and PM.: There were significant differences between mean values; FRF decreased from early AM through late PM.

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	FRF Control Morning Before Harvest	656.12	49	143.50	20.50
	FRF Control Evening Before Harvest	485.71	49	135.09	19.30

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	Upper			
Pair 1	FRF Control Morning Before Harvest - FRF Control Evening Before Harvest	170.41	158.34	22.62	124.93	215.89	7.53	48	0.00

Differences between FRF before and after harvesting: There are differences between the AM test when olives had a higher FRF and the harvesting process was more aggressive. However, this difference is not a good representation because the harvester removal efficiency was very high (90%) and the olives were located only on the lower branches, close to the ground. Also, FRF is less than earlier FRFs. Fruit removal doesn't depend totally on FRF; fruit location appears to be more important.

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	FRF Control Morning Before Harvest	654.68	47	143.87	20.99
	RF Morning After Harvest	565.11	47	171.31	24.99
Pair 2	FRF Control Evening Before Harvest	485.71	49	135.09	19.30
	RF Evening After Harvest	504.08	49	149.72	21.39

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	Upper			
Pair 1	FRF Control Morning Before Harvest - FRF Morning After Harvest	89.57	213.26	31.12	26.96	152.19	2.88	46	0.01
Pair 2	FRF Control Evening Before Harvest - FRF Evening After Harvest	-18.37	181.51	25.93	-70.50	33.77	-0.71	48	0.48

DAMAGE EVALUATION

AM (Hardest conditions)

Numbers (#) of fruit classified by type of damage

	SOUND	BRUISE	CUT	MUTILATION	ALL
A	75	344	26	2	447
B	66	675	52	13	806
C	53	581	119	3	756
D	830	12	9	0	851

Weights (g) of fruit classified by type of damage

	SOUND	BRUISE	CUT	MUTILATION	ALL
A	213.1	912.9	75.9	3.3	1205.2
B	183.9	1774	149.5	32.1	2139.5
C	134.9	1573.9	324.7	4.3	2037.8
D	2102.4	28.3	19.4	0	2150.1

Percentages (%) of fruit classified according with type of damage

	SOUND	BRUISE	CUT	MUTILATION
A	16.8	77.0	5.8	0.4
B	8.2	83.7	6.5	1.6
C	7.0	76.9	15.7	0.4
D	97.5	1.4	1.1	0.0

PM (Regular conditions)

Numbers (#) of fruit classified by type of damage

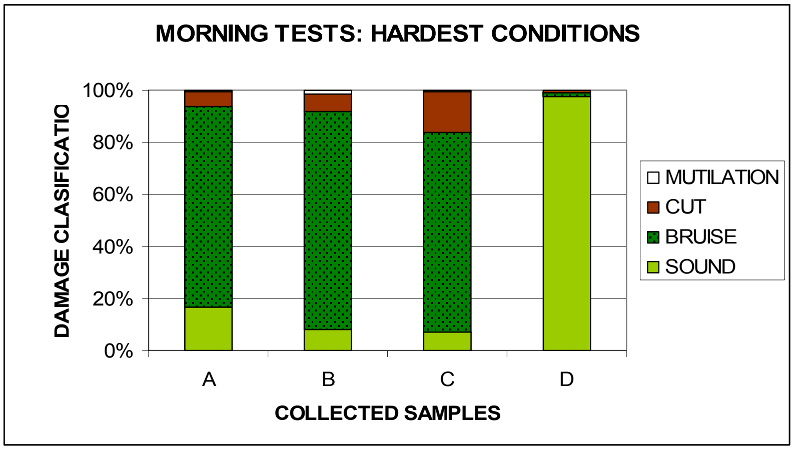
	SOUND	BRUISE	CUT	MUTILATION	ALL
A	101	494	28	1	624
B	33	680	36	4	753
C	33	797	51	3	884

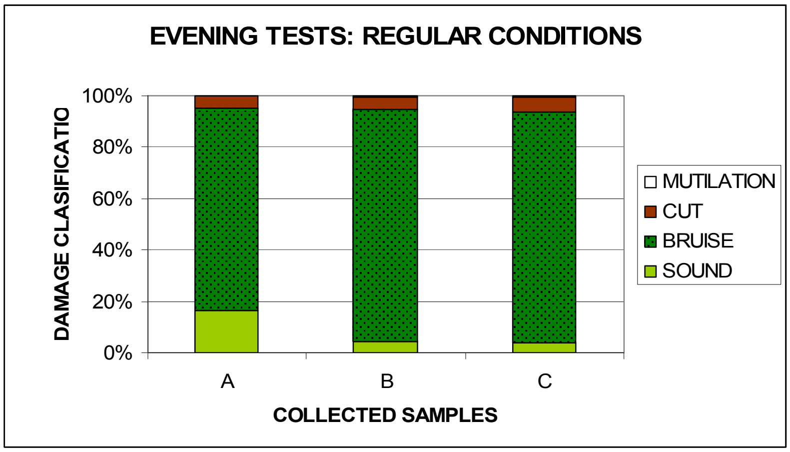
Weights (g) of fruit classified by type of damage

	SOUND	BRUISE	CUT	MUTILATION	ALL
A	265.6	1265.2	71.5	1.9	1602.3
B	91.3	1788.3	96.8	6.4	1982.8
C	83.8	2013	143.6	5	2245.4

Percentages (%) of fruit classified according with type of damage

	SOUND	BRUISE	CUT	MUTILATION
A	16.2	79.2	4.5	0.2
B	4.4	90.3	4.8	0.5
C	3.7	90.2	5.8	0.3





Conclusions

Very similar results were obtained in Argentina with 'Manzanillo' olives in February 2008. The MacTeq Colossus harvester can harvest table olives with efficiencies over 90%, but produces totally unacceptable fruit damage. The harvester will need major adaptations to its picking head, catch frame, and conveying system to be viable for table olive harvest.

III. Part 2. Evaluation of antioxidants and preharvest plant growth regulators to reduce physical damage and improve firmness in 'Manzanillo' olives in 2008

Section written by Kitren Glozer

Summary

2008 trials included testing of firmness and color instrumentation used in other fruit industries (Mitcham et al. 1996; Slaughter et al. 2005; Valero et al. 2003). These technologies are being applied to judge results from the pre- and post-harvest trials for improved quality. Tests of agents to reduce browning in 2008 included ascorbic acid, salicylic acid, sodium ascorbate, and sodium hydroxide (lye), reported to have benefit in reducing bruising in table olive (Ben-Shalom et al. 1978). Firmness in treated fruit was improved in most cases, however,

the greatest reduction in browning of bruises was found with sodium hydroxide. In 2008, we used visual versus colorimetric assessment of bruising using a colorimeter and determined that the colorimetric method will require significant modification of technique if adopted. We also implemented on a larger scale than in 2007 our use of firmness testing (FirmTech II) that has been adopted worldwide in many small fruit industries as well as research facilities.

Introduction

Enzymatic browning of fruit tissue damaged by rough handling, high pressure or machine harvest is caused by conversion of natural phenolics to quinones that are then oxidized to brown, red or black pigments (bruises). Thus, bruising results from cellular breakdown, which also often results in fruit softening. Exclusion of oxygen can reduce polymerization to colored pigments by immersion in brine or water alone. However, once fruit is removed to the air, oxidation continues.

Chemical additives can be used to reduce or prevent enzymatic browning if applied quickly enough and are appropriate to the particular type of enzymatic browning. Additives can include ascorbic acid and its analogs, sulfites (metabisulfites and bisulfites) that interact with quinones to form colorless products, and cysteine, a reducing agent. Further tests for optimum concentration, length of time prior to immersion after induced damage, temperature of lye solution, and length of immersion indicate some guidelines that may be implemented on a larger scale in future. Other treatments remain to be tested, including combinations of calcium products with bruise-inhibiting agents for improved firmness post-harvest. While Ben-Shalom et al. (1978) indicated that inhibition of enzymatic bruising in olive by polyphenol oxidase inhibitors or reducing agents is not possible due to impermeability of the whole fruit and that only dipping fruit in 0.4% NaOH (sodium hydroxide or lye) prevented bruising after mechanical injury, other procedures tested more recently on other crops show potential for reducing bruising, including calcium citrate, citric acid (Terdbaramee et al., 2003), and others. Recent research in olive characterizing the nature of the polyphenol oxidase enzyme from olive, its activity, and response to enzyme inhibitors (Segovia-Bravo et al. 2007) provides specific information that aids understanding of our own trial results and future possibilities. These authors found that the browning reaction in olive has maximum activity at pH 6, is completely inhibited below pH 3, regardless of temperature, and that pH inhibition at pH 9 is dependent on a temperature of 8EC, and at pH 11 at 25EC.

Development of instrumental techniques to assess olive fruit quality before and after processing, particularly with respect to bruising development and fruit firmness, would be beneficial to determine the effects of treatments and the comparative level of damage from different mechanical harvest techniques. In 2008, we moved from visual assessment alone of bruising to colorimetric assessment. We also implemented on a larger scale than in 2007 our use of firmness testing (FirmTech II) that has been adopted worldwide in many small fruit industries as well as research facilities. These instruments have allowed progress toward a better system of evaluation, but they are not yet optimal for use in immature olive, nor has the FirmTech been tested on processed fruit (hand- and machine-harvested) post-processing.

Objectives

1. Optimize quality measures that identify key maturity and quality parameters for table olive, using nondestructive and destructive measures, working in concert with quality researchers in

the industry processors and the USDA standards investigators, on fruit before and after processing.
2. Investigate anti-browning and plant growth regulator (PGR) potential for reduction of damage due to simulated mechanical harvest in both pre- and post-harvest applications.
3. Test treatments varying application method (preharvest spray, postharvest drench), exposure time, and concentration to maximize benefit and obtain baseline information about maximum damage reduction that might be expected of an ideal treatment.
4. Develop a strategy that would be consistent with mechanized harvest, postharvest transportation, and short-term storage, and the goals of fruit quality necessary for a high-quality processed product.

Procedures

Objective 1

Firmness, bruising and color baseline data development (Rocky Hill). Hand-harvested 'Manzanillo' fruit were obtained from the Rocky Hill commercial orchard (Exeter, CA) for testing for firmness and defect rating, to develop information on these quality measures and the instrumentation best suited to test the measures. Six replicate samples were evaluated, each a 2 lb sample from bins harvested from a 14-tree block within a tree row (each replicate was 14 consecutive trees, randomized among rows). A 50-fruit subsample was first graded by color (green-straw vs colored, showing any blush color development), then scored (yes/no) for cuts or punctures, compression (soft, flattened spots), light bruising or heavy bruising. Cuts were scored only if larger than 1 mm in length and/or 0.5 mm in width. All compressions were scored regardless of size. Bruising and overall darkening of the flesh due to oxidation were evaluated on a longitudinally cut surface, external to the pit axis. Light bruising consisted of less than 25% of the cut surface showing discoloration due to bruising, heavy bruising was 25% or more of the cut surface bruised. A second 50-fruit subsample of green-straw fruit only was tested for firmness using a FirmTech II firmness testing device (BioWorks, Inc.; http://www.bio-works.us/); this device is the standard for non-destructive firmness testing for the sweet cherry industry in California and Chile, and other fruit industries and researchers in various locations. Student's T tests were performed using SAS (SAS Institute Inc., Cary, NC) for differences in damage by color grade and means for firmness of green-straw fruit obtained for each replicate.

Color measurement methodology (used for bruise analysis). Bruising and oxidation response after mechanical damage and chemical treatment were measured on a longitudinally cut surface external to the pit with a Minolta colorimeter (Minolta, CR-200, Japan) and expressed in *LCH* color space, in which L^* = lightness, C is chroma (saturation) and H is hue angle. $L^* = 0$ is equivalent to black, $L^* = 100$ is equivalent to white. Of these measures, L and H appeared to correspond best to visual evaluation of darkening overall of the flesh with oxidation (measured as L) and darkening (browning) of bruises best measured by H. Hue angle decreases with browning (Samim and Banks, 1993); measurement of browning by reflectance is not uncommon in food quality studies (Bates, 1968; Jamieson et al., 2002). The aperture size of the colorimeter should be reduced in future tests by masking in order to reduce 'read' of tissue outside of bruised areas so as to obtain greater accuracy in measuring the bruises without measuring unbruised flesh.

Objectives 2 & 3

Antioxidant treatments. Fruit subjected to testing were bulk samples without replication, collected randomly at a uniform green-straw maturity from various mature 'Manzanillo' olive trees in the University of California, Davis, Pomology orchard (Davis, California). Fruit were treated to simulated mechanical harvest as in previous trial years by shaking a 20 to 50-fruit sample in a large closed plastic jar for 7 seconds, with external and internal damage induced in this manner similar to that of mechanically-harvested fruit under 'worse case' conditions. Fruit were evaluated after antioxidant treatment, in some cases after a several-hour delay period, simulating time delay between commercial harvest, grading at the receiving station and receipt at the processing plant. Those fruit held for an extended period were uncut and at ambient temperatures of ~75 ºF. In all trials, firmness was non-destructively measured prior to cutting fruit for bruise evaluation.

Analyses of Variance were performed with Proc GLM procedure of SAS (SAS Institute Inc., Cary, NC) and mean separations were tested by Duncan's Multiple Range Test; $P = 0.05$. PROC TTEST was used for comparison of firmness by harvest method (hand vs machine) within treatments for PGR applications in the preharvest trial.

a) *Antioxidants, survey group* -- Treatments (**Table 7**) included as controls: untreated and bruised only, as well as immersion in water with and without mechanical damage (bruising treatment). Although water immersion decreased browning initially, once fruit were allowed to air-dry, browning progressed as with bruised fruit that had not been immersed in water. Thus, water immersion gives a temporary benefit that ceases once exposure to oxygen occurs. Results from various water immersion results are omitted from the treatment lists and discussion as not being worthy of consideration.

   Antioxidants included: 0.3% ascorbic acid (AA, pH 3), 4 mM salicylic acid (SA, pH 7), 1% sodium ascorbate (SASC, pH 7), and 0.4% sodium hydroxide (lye, pH 13). Other antioxidants intended for testing included calcium citrate alone and in combination with AA or AA + SA, sodium erythorbate alone and in combination with AA. These antioxidants were not tested on fruit because of solubility problems. All immersions were in room temperature solutions, for 1.25 hr after bruising treatment, after which fruit were stored in air and ambient temperature before firmness testing and evaluation of bruise development.

b) *Sodium hydroxide series* -- This series used the results generated in the 'Antioxidant, Survey Group' test to further develop best conditions for lye reduction of bruise development, adjusting time between bruising and lye treatment (Immersion delay test), time of immersion (Immersion duration test) and Lye concentration test. There was no delay in testing for firmness and degree of bruising after treatment (no storage), other than as noted. All immersions were in room temperature solutions except as noted.

   i) Immersion delay test (**Table 8**) – Controls included: no treatment and bruised only. Lye treatments were all at 0.4% with immersion delays of 0, 1, 2, 3, 4, and 5 hours.

   ii) Immersion duration test (**Table 9**) – Controls consisted of no treatment, bruised only, bruised with immediate immersion for 15, 30 or 60 minutes. Lye treatments were all at 0.4% for the same immersion durations.

iii) Lye concentration test (**Table 10**) – Controls included untreated and bruised only. Lye treatments were all immersions for 30 minutes and varied as: 0.1% NaOH, 0.2% NaOH, 0.3% NaOH, 0.4% NaOH and 0.4% NaOH at 43EF (refrigerated).

Preharvest plant growth regulator and mechanical harvest trial. A single tree row of 'Manzanillo' olives spaced at 9' x 18' (269 trees per acre), running east-west, was pruned for mechanical harvest and utilized for this trial at the Erick Nielsen ranch, Orland, CA. Three treatments and an untreated control were randomized in a complete block design down the row in four replicate blocks. Treatments included ProGibb (30 g a.i. per acre of 4% GA_3; Valent BioSciences), Grow More LSE (4 pt/acre; seaweed foliar fertilizer; www.growmore.com), and Accel (30 g per acre of 1.8% 6-benzyladenine solution; Valent BioSciences). All treatments were applied on 29 August by handgun sprayer to runoff. No phytotoxicity was found with any treatment. Harvest occurred on 6 October; fruit were sampled from each treated tree prior to harvest (~100 fruit sample) and fruit were also sampled from the harvester bin immediately after fruit removal (~100 fruit sample). Mechanical harvest was with an ENE (Erick Nielsen Enterprises) trunk shaker. Fruit were then transported to UC Davis and a 25-fruit subsample of green-straw fruit evaluated for firmness, comparing hand-harvested and machine-harvested fruit, both treated and untreated (**Table 11**).

Results and Discussion

Objective 1

Firmness, bruising and color baseline data development (Rocky Hill). Firmness of green-straw colored fruit ranged from 622 to 1456 g/cm^2, however, mean firmness was 915-1030 (**Table 6**). When green-straw fruit were compared to colored fruit that were commercially hand-harvested into half-ton bins, green-straw fruit developed significantly more light bruising than did colored fruit (**Table 6**); heavy bruising wasn't different between treatments. Green-straw fruit were also more susceptible to cuts and punctures than colored fruit, with no significant difference in compression or soft spot development. The increased risk that green-straw fruit had toward light bruising and cuts might be due to higher tensile strength of the fruit skin than that of more mature fruit. We have not tested the firmness of colored fruit, however, it is likely that with maturity increase, fruit skin tensile strength may decrease and fruit be less prone to minor injury. Whether the same susceptibility is true under mechanical harvest conditions is not known, nor is it known what this level of damage, or the change in firmness with maturity change will affect fruit quality after processing.

Color measurement methodology (used for bruise analysis). While the colorimeter gave some indication of browning and darkening of flesh, the results were not as clear-cut as desired, possibly because the olive fruit is very hard at green-harvest stage, not allowing compression of the instrument against the flesh so as to exclude extraneous light, and because the aperture size is much larger than the typical diameter of bruises due to mechanical damage. While the second problem might be readily addressed, the first is inherent to the fruit. Other fruits that work well with the colorimeter have some 'give' to their flesh or skin, thus allowing complete contact with the instrument. Although results using the colorimeter are presented, the current system of judging visually the extent of the damage is sufficient for survey purposes, as is the case in these trials.

Objectives 2 & 3

Antioxidant treatments

A. *Antioxidants, survey group* (**Table 7**) – Firmness was least in untreated control fruit and bruised fruit with no other treatment. All antioxidant treatments improved firmness with salicylic acid, sodium ascorbate, and sodium hydroxide (lye) increasing firmness most. Any of these treatments would be acceptable for the purposes of improving post harvest fruit firmness, but sodium ascorbate showed the greatest improvement.

Lightness, or measure of darkening of cut flesh due to oxidation after cutting, was not greatly different in any treatment, especially when comparing the untreated control and the bruised control. Darkening of bruises was least in the lye-treated fruit, compared to the bruised only control, as indicated by the lowest value for hue angle. Because results for bruising were best for the lye-treated fruit, particularly as it corresponded very well to the visual assessment, lye was chosen for all other treatment series, concentrating on concentration, delay before immersion and length of immersion.

The benefit of immersion in weak solutions of lye immediately after mechanical harvest has been reported in the literature (Ben-shalom et al. 1978; Kailis and Harris 2004). Bruising consists of a local degradation of tissue combined with intracellular water exit (free water) and browning (oxidation) of phenolic compounds from released intracellular water. Shomer et al. (1979) found that browning of bruised olives is due to the enzyme catechol oxidase, which is found in chlorophyll-rich green olives. As the fruit ripens and turns black, the enzyme is released once the chloroplasts degrade. Solutions of caustic materials such as lye inactivate the enzyme, inhibiting browning associated with bruised flesh. Exclusion of the oxygen required for oxidation changes in pigments is another method of decreasing bruising, as is cold storage as soon as possible after harvest (Kader et al. 1989).

In these preliminary tests, pH of antioxidant solutions was noted, but not adjusted to fit within the pH optima found by Segovia-Bravo et al. (2007). It is to be expected that lye (pH 13) would be effective, given the alkaline nature of the treatment, less expected where pH was 7 (salicylic acid and sodium ascorbate).

B. *Sodium hydroxide series*

Immersion delay test (**Table 8**). Firmness was improved by immersion in 0.4% NaOH compared to the ‘bruised only’ control numerically by all lye treatments, however, a statistically significant difference was found only when lye immersion occurred at 1 hour after bruising treatment. All fruit discolored (reduced L or lightness) when cut compared to the untreated control, although a single lye treatment showed statistical equality to the control. This data, as well as that for bruising generated by the colorimeter, was inconclusive, however, visual inspection suggested that immersion within a short period of time after bruising treatment was better than longer delays.

Immersion duration test (**Table 9**). Firmness was significantly improved by immersion of 15 and 60 minutes in lye solution, compared to the bruised control. Lightness was significantly improved by immersion for 30 to 60 minutes compared to the bruised control, and browning was significantly less in the same immersion treatments.

Concentration test (**Table 10**). Firmness of bruised fruit was significantly improved by immersion for 30 minutes in room temperature lye at 0.3 and 0.4%, as well as 0.4% lye at 43EF, which also improved firmness compared to the untreated control. This firmness increase was not due to colder fruit at the time of measuring firmness as the fruit was allowed to come to room temperature. Thus, cold storage may provide a benefit in addition to that of lye, consistent with previous reports for table olive (Kader et al., 1989, 1990). Fruit treated in lye at 0.2 and 0.4% developed less overall flesh darkening compared to the bruised control; fruit treated with 0.4% lye in refrigeration had significantly less browning due to bruising than the bruised only control.

Results of the antioxidant tests indicate that immersion in 0.4% lye as soon as possible after mechanical harvest, for a duration of at least 30 minutes, preferably in refrigeration, would ameliorate bruising damage significantly. Other treatments that have potential for this purpose that should be tested include sodium benzoate and sodium chloride.

Preharvest plant growth regulator and mechanical harvest trial. Harvest method effects on firmness: Firmness was significantly reduced in machine-harvested fruit compared to hand-harvested fruit when untreated fruit were compared; the change in firmness due to harvest method was highly significant (0.1% level), however, fruit were still very firm after machine-harvest (more than 1 kg/cm^2), and while a greater loss of firmness may occur in processing and storage with machine-harvested fruit that were initially this firm, that remains to be tested. Firmness was also significantly different by harvest method in fruit treated with ProGibb and Accel (0.1% and 1%, respectively), but no significant difference was found due to harvest method in the Goëmar-treated fruit. All PGR treatments significantly increased firmness compared to the untreated controls, regardless of harvest method. These results indicate that a more extensive trial of these PGRs should be made with and without machine-harvest.

Table 6. Fruit quality measures of hand-harvested fruit, Rocky Hill orchard (Exeter, CA) in 2008.

Color (fruit skin)	% Light bruise	% Heavy bruise	% Cuts/punctures	% Compression, soft spot
Green-straw	35.4 a	0.6 a	23.0 a	0.6 a
Colored (exhibiting any red-purple development)	7.6 b	3.3 a	3.9 b	4.0 a

Green-straw fruit, range of firmness (g/cm^2; FirmTech II, BioWorks Inc.) minimum 622, maximum 1456; average fruit firmness 915-1030

[x] Means separation by Student's T test, $P = 0.05$.

Table 7. *Bruising reduction chemicals*: firmness and color change of 'Manzanillo' olives after bruising mechanical damage and antioxidant treatments in 2008. Immersion was for 1.25 hr; evaluation after 20 hr in air and ambient temperatures (high of ~75 ºF). Bruising measured as browning of bruises and change in lightness of cut flesh. Firmness was tested nondestructively on a FirmTech II (BioWorks, Inc.).

Treatment	Firmness (g/cm^2)	L (lightness)	Hue angle [y]
Untreated	967.3 c [x]	59.6 ab	92.3 ab
Bruised only	1002.0 c	60.4 a	92.7 a
0.3% ascorbic acid (pH 3)	1078.1 b	58.6 bc	91.5 ab
4 mM salicylic acid (pH 7)	1103.2 ab	56.9 b	91.4 ab
1% sodium ascorbate (pH 7)	1171.6 a	59.3 ab	92.8 a
0.4% sodium hydroxide (pH 11)	1108.5 ab	58.3 bc	90.4 b

Means within a column followed by the same letter do not differ at $P = 0.05$ by Duncan's Multiple Range Test.

[y]Hue is a color value in LCH color space as measured by Konica Minolta CR-10 colorimeter which decreases with browning of bruises (Samim and Banks, 1993). L = 0 is equivalent to black; L = 100 is equivalent to white. L change for cut flesh overall.

Table 8. *Immersion delay test*: firmness and color change of 'Manzanillo' olives after bruising mechanical damage and immersion in 0.4% NaOH in 2008. Immersion in NaOH followed a time course of 0-5 hours post-bruising, at hourly intervals; evaluation after ~30 min in air and ambient temperatures. Bruising measured as browning of bruises and change in lightness of cut flesh. Firmness was tested nondestructively on a FirmTech II (BioWorks, Inc.).

Treatment	Interval (hr) between bruising and immersion treatment	Firmness (g/cm^2)	L (lightness)	Hue angle [y]
Untreated		1175.1 ab[x]	70.2 a	104.7 ab
Bruised only		1125.8 b	66.0 d	104.3 ab
NaOH	0	1165.8 ab	68.2 bc	105.0 ab
	1	1201.7 a	67.0 cd	104.5 ab
	2	1158.3 ab	67.3 bcd	104.1 b
	3	1198.5 ab	68.2 bc	105.8 a
	4	1160.0 ab	68.9 ab	105.6 a
	5	1174.3 ab	66.4 d	105.6 a

[x]Means within a column followed by the same letter do not differ at $P = 0.05$ by Duncan's Multiple Range Test.
[y]Hue is a color value in LCH color space as measured by Konica Minolta CR-10 colorimeter which decreases with browning of bruises (Samim and Banks, 1993). L = 0 is equivalent to black; L = 100 is equivalent to white. L change for cut flesh overall.

Table 9. *Immersion duration test*: firmness and color change of 'Manzanillo' olives after bruising mechanical damage and immersion in 0.4% NaOH in 2008. Immersion in NaOH or water (control) followed a time course of 0-1 hours ost-bruising, at 15 minute increments; evaluation after ~30 min in air and ambient temperatures. Bruising measured as browning of bruises and change in lightness of cut flesh. Firmness was tested nondestructively on a FirmTech II (BioWorks, Inc.).

Treatment	Duration of immersion	Firmness (g/cm^2)	L (lightness)	Hue angle [y]
Untreated	0	1175.1 ab[x]	70.2 a	105.3 ab
Bruised	0	1125.8 b	66.0 d	104.7 b
NaOH	15 min	1220.5 a	67.1 cd	105.1 ab
	30 min	1151.2 ab	69.5 ab	106.4 a
	60 min	1223.4 a	68.4 bc	106.5 a

[x]Means within a column followed by the same letter do not differ at $P = 0.05$ by Duncan's Multiple Range Test.
[y]Hue is a color value in LCH color space as measured by Konica Minolta CR-10 colorimeter which decreases with browning of bruises (Samim and Banks, 1993). L = 0 is equivalent to black; L = 100 is equivalent to white. L change for cut flesh overall.

Table 10. *Concentration test*: firmness and color change of 'Manzanillo' olives after bruising mechanical damage and immersion in varying concentrations of NaOH in 2008. Immersion in NaOH was for 30 min; evaluation after ~30 min in air and ambient temperatures. A single treatment was included a 'cold' (43EF) treatment. Bruising measured as browning of bruises and change in lightness of cut flesh. Firmness was tested nondestructively on a FirmTech II (BioWorks, Inc.).

Treatment	Concentration	Firmness (g/cm^2)	L (lightness)	Hue angle [y]
Untreated		1175.1 bc[x]	70.2 a	105.3 ab
Bruised only		1125.8 c	66.0 d	104.7 b
NaOH	0.1%	1198.9 bc	67.3 cd	104.6 c
	0.2%	1206.4 bc	68.5 abc	105.5 bc
	0.3%	1216.3 b	67.7 bcd	104.7 c
	0.4%	1151.2 ab	69.5 ab	106.4 b
	0.4%, cold	1307.8 a	67.7 bcd	108.7 a

[x]Means within a column followed by the same letter do not differ at $P = 0.05$ by Duncan's Multiple Range Test.
[y]Hue is a color value in LCH color space as measured by Konica Minolta CR-10 colorimeter which decreases with browning of bruises (Samim and Banks, 1993). L = 0 is equivalent to black; L = 100 is equivalent to white. L change for cut flesh overall.

Table 11. Fruit firmness after plant growth regulator treatment preharvest, comparing hand-harvested and machine-harvested fruit in 2008. Trial location was the Erick Nielsen Ranch, Orland, California. Preharvest treatments were applied August 29 and harvest was October 6. Firmness was tested nondestructively on a FirmTech II (g/cm^2; BioWorks, Inc.).

Treatment	Hand-harvested fruit firmness	Machine-harvested fruit firmness	Significance by harvest method within treatment[y]
Untreated control	1057.8 b	1014.8 b	***
ProGibb (30 g a.i. per acre of 4% GA_3)	1088.3 a	1126.8 a	***
Goëmar BM 86 (4 pt/acre; seaweed foliar fertilizer)	1104.6 a	1103.4 a	ns
Accel (30 g per acre of 1.8% 6-benzyladenine solution)	1113.7 a	1145.1 a	**

[x]Means within a column followed by the same letter do not differ at $P = 0.05$ by Duncan's multiple range test.

[y]Significant differences by Student's ttest by harvest method (hand vs machine) for a given PGR treatment; ns, *, **, *** = non-significant, significantly different at 5%, 1% or 0.1% level, respectively.

IV. Screening Abscission Compounds for Black Ripe Table Olives: 2008 Season

Section written by Jacqueline K. Burns

Introduction

Olive abscission compound screening trials were conducted at two locations: Lindcove Research and Extension Center, Exeter, and Nichols Estate, Arbuckle, CA. Trials were conducted in September 2008. The objective of these trials was to continue olive screening with compounds from the Florida citrus fruit abscission agent library. The long-term goal of this project is to adapt table olives to mechanical harvesting. Identification of a suitable abscission agent is viewed as a key to industry adoption of mechanical harvesting, as mechanical harvesting could be performed less aggressively and fruit damage could be minimized.

Procedures

Lindcove Research and Extension Center Trial

A trial was initiated on 16 September 2008 in a block of olive trees located on the Lindcove Research and Extension Center, Exeter, CA. Four uniform 'Manzanillo' trees with good fruit load were selected, and one replicate branch on each tree was tagged for each treatment. Thus, treatments were replicated four times. Each branch contained at least eight fruit and 25 leaves. Fruit number was recorded. All treatments were randomly assigned to the branches on each tree. Abscission compounds were dissolved in water containing 0.05% Activator-90 and applied between 9:00 am and 2:30 pm with a hand-held 1.5 L pressurized sprayer until run-off. A water control containing adjuvant was included in all trials. Treatments were Ethrel (1000 and 2000 ppm); salicylic acid (SA; 1000 and 2000 ppm); 1000 ppm SA + 1000 ppm Ethrel; Embark (1000 and 2000 ppm); 1, 2 and 4 ppm LA-901; 1 and 2 mM QCR; three formulations of dikegulac at 2000 and 4000 ppm (DK-B1, BK-B2 and DK-B3); and water. Maximum, minimum, and average temperatures on the day of application were 39, 17, and 26 ºC, respectively. Fruit detachment force (FDF) in grams-force was measured 10 days after application using an Imada DPS-11 digital force gauge.

Nichols Estate, Arbuckle Trial

A trial was initiated on 20 September 2008 in a block of trees located at the Nichols Estate, Arbuckle, CA. Trees selected were trained, hedged, pruned and trellised. This trial was conducted as in Lindcove described above, and treatments were identical. Maximum, minimum, and average temperatures on the day of application were 26, 10, and 18 ºC, respectively. FDF was measured 21 days following application. Maximum, minimum and average temperatures for the duration of the trial were 28, 10, and 19 ºC, respectively.

Results

Lindcove Research and Extension Center Trial

Maximum, minimum, and average temperatures for the duration of the trial were 33, 14, and 23 ºC, respectively. No fruit or leaf drop occurred at the time of measurement (data not shown). Slight variation in FDF was measured between treatments, but no significant differences were detected (**Fig. 1**, *see page 50*, top panel). Ten days after application is not a sufficient period of time to allow loosening for olive, even at these favorable temperatures.

Nichols Estate, Arbuckle Trial

No differences in FDF (**Fig. 1**, middle panel) or leaf drop (data not shown) were measured. However, fruit drop was significantly higher in the 2000 ppm Ethephon and 4 ppm LA-901 treatments when compared to most others (**Fig. 1**, bottom panel). This behavior can be explained by the extended time period selected for loosening. Olive fruit capable of reacting to the abscission compounds dropped after 21 days, but the remaining fruit on branches either did not react or partially reacted and 'tightened' via the wound healing process.

Conclusions

1) Nine abscission compounds or combinations were screened; 2) The trial at Lindcove was inconclusive due to inadequate loosening time before measurements were made; 3) The trial at Arbuckle indicated that Ethephon and LA-901 significantly increased fruit drop when compared with most other treatments; and 4) Fruit loosening at Arbuckle was not significantly different for any treatment, due in large part to the extended loosening period.

OVERALL 2008 SEASON PROJECT CONCLUSIONS

Based on the combined results of the four objectives discussed above, further research should focus on simultaneously adapting current orchards with hand and mechanical-pruning, developing new hedgerow orchards, and evaluating these orchards with all the currently available commercial harvesters. Trials with the DSE 008 have demonstrated the canopy contact picking head can produce commercially acceptable black ripe processed table olives. The DSE 008 harvester has insurmountable problems of size, cost, head maneuverability, catch frame technology, and adaptability, and poor potential for commercial production. Research should now focus on the currently commercially available trunk shaking and picking head harvesters mounted on double sided catch frames. These should be evaluated in conventional, mechanically pruned and hedgerow trained orchards. Screening for abscission compounds and postharvest treatments should continue, but these compounds are so far from incorporation into mechanical harvesting trials, or registration, that mechanical harvesting of olives should be developed without these chemical aids.

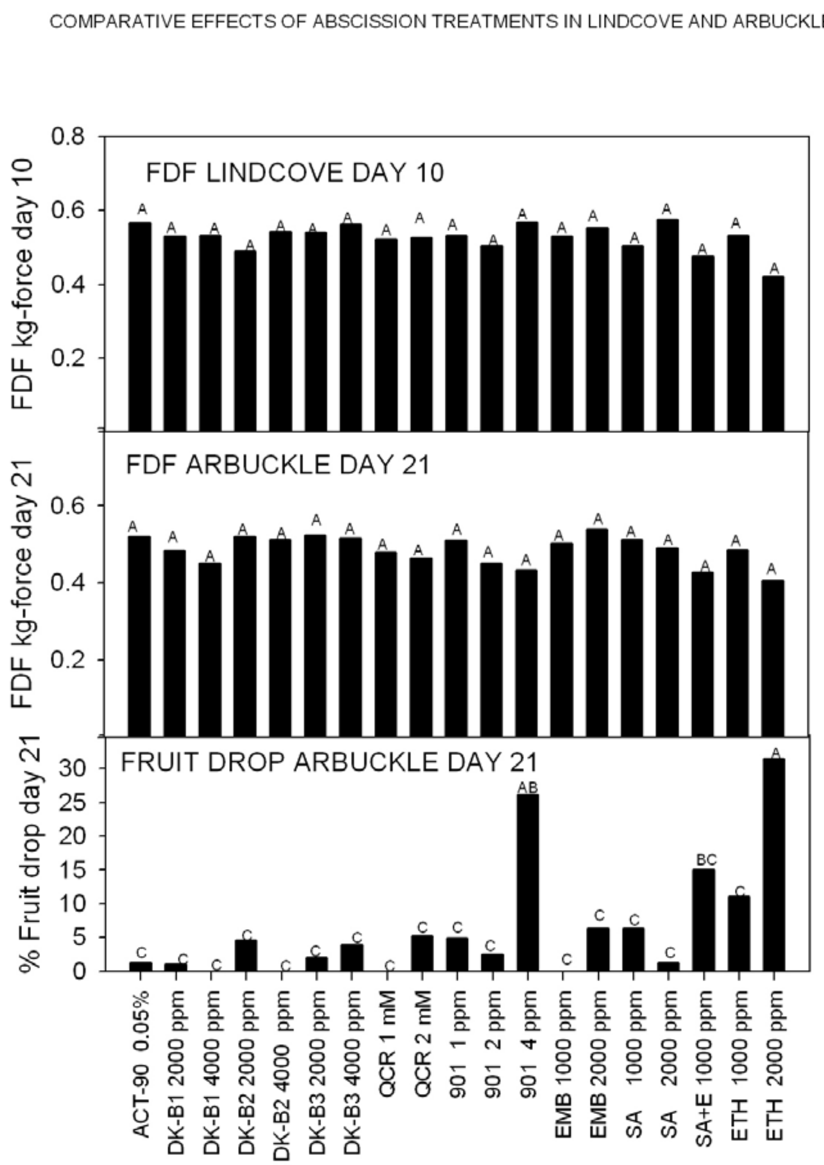


Fig. 1. Fruit detachment force and fruit drop after application of abscission compounds. See text for details.

FUNDING

The 2008 harvest research reported here was funded entirely by the California Olive Committee: $186,812.00

ACKNOWLEDGEMENTS

We gratefully acknowledge the funding support of the California Olive Committee. We gratefully acknowledge the cooperation of Musco Family Olive Company, particularly Edward Melanesio, Jesus Lopez, Dennis Burreson, Matthew Koball and Abdul Sigal and Bell Carter Olives, particularly Jane Yegge and Cody McCoy. These California experiments would not have been possible without the cooperation of Rocky Hill Ranch and Marc Pascoe and Jesse Luna, Nielsen Ranch and Erick Nielsen, and Dennis and Heath Burreson of Burreson Ranches. We wish to thank Erick Nielsen of ENE Inc., Matt Coe of Coe Harvesters and Don Mayo of OMC Shakermaker Harvesters for their patient and flexible cooperation in trunk shaking experiments. The Argentina experiments would not have been possible without the cooperation and hospitality of Nicholas and Carolina Shawnee of Finca La Bella and their ever helpful management team. The Portugal experiments would not have been possible without the cooperation and hospitality of Rabadoa Ranch, Portugal. We also wish to thank Martin Bonadeo and Jose Mourelle of MacTeq for the generous use of the MacTeq Colossus Olive Harvester. Finally, we thank volunteers John Henry Ferguson BS, MBA and Peter Kulakow PhD for their much appreciated and reliable experimental field and assistance.

REFERENCES

Agar, I.T., B. Hess-Pierce, M.M. Sourour and A.A. Kader. 1999. Identification of optimum preprocessing storage conditions to maintain quality of black ripe ‘Manzanillo’ olives. Postharv. Bio. Tech. 15:53-64.

Bates, R.P. 1968. The retardation of enzymatic browning in avocado puree and guacamole. Florida Agric. Expt. Sta. J. Ser 3149:230-235.

Ben-Shalom, N., E. Harel and A.M. Mayer. 1978. Enzymic browning in green olives and its prevention. J. Sci. Food Agric. 29:398-402.

Castro, E., D.M. Barrett, J. Jobling and E.J. Mitcham. 2007. Biochemical factors associated with a CO2 –induced flesh browning disorder of Pink Lady apples. Postharv. Biol. Techn. 48:182-191.

Jamieson, A.R., C.F. Foprney, J. Richards and K.U.K.G. Nicholas. 2002. Strawberrry fruit characteristics that contribute to postharvest quality. Proc. 4th Int. Strawberry Symp. Acta Hort 567:723-726.

Kader, A.A., G.D. Nanos and E.L. Kerbel. 1989. Responses of ‘Manzanillo’ olives to controlled atmosphere storage. In: Proc. 5th Int. Contr. Atmos. Res. Conf. vol. 2, pp. 119-125.

Kader, A.A., G.D. Nanos and E.L. Kerbel. 1990. Storage potential of fresh ‘Manzanillo’ olives. Calif. Agirc. 40(3):23-24.

Kailis, S.G. and Harris, D. (2004). Establish protocols and guidelines for table olives processing in Australia. RIRDC Publication No 04/136, Australia.

Mitcham, B., M. Cantwell and A. Kader. 1996. Methods for determining quality of fresh commodities. Perish. Handl. Newsl. 85:1-5.

Samim, W. and N.H. Banks. 1993. Color changes in apple bruises over time. Acta Hort. 343:304-306.

Segovia-Bravo, K.A., M. Jarén-Galan, P. García-García and A. Garrido-Fernandez. 2007. Characterization of polyphenol oxidase from the Manzanilla cultivar (Olea europaea pomiformis) and prevention of browning reactions in bruised olive fruits. J Agric Food Chem. 8.55(16):6515-20.

Shomer, I., N. Benn-shalom, E. Harel and A.M. Mayer. 1979. The intracellular location of catechol oxidase in the olive fruit. Ann. Bot. 44:261-263.

Slaughter, D.C., C.H. Crisosto, J.K. Hasey and J.F. Thompson. 2005. Comparison of instrumental non-descructive and destructive firmness and color measurements with human inspection in clingstone peaches. ASAE 2005 Ann. Int. Mtg. Paper 056175.

Terdbaramee, U., S. Kanlayanart and K. Ratanakhanokchai. 2003. Effect of citric acid on the control of postharvest browning of lychee fruit under cold storage. Acta Hort. 628:527-531.

Valero, C., E. Bowerman, C.H. Crisosoto, D. Garner and D. Slaughter. 2003. Introducing nondestructive flesh color and firmness sensors to the tree fruit industry. Int. Conf. on Quality in Chains. Acta Hort 604:597-600.