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Developing Mechanical Harvesting for California "Black Ripe" Table Olives (*Olea europea* cv. "Manzanillo")

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Abstract: The *Olea europaea* cv. "Manzanillo" fruits destined for "California Black Ripe" table olive processing are harvested before fully mature where fruit detachment forces are over 5.0 N. Superficial bruises that has not extended into the flesh, are masked by the processing methods as the immature fruit is oxidized to black during processing. A jatropha canopy contact harvested was modified to adapt the density and length of the radiating rods to extend into the 1.0 m olive canopy depth. Preliminary studies determined a head speed of 300 rpm, a displacement of 125 mm and a tine length of 910 mm are the most suitable parameters for table olive harvest. In the first of two field experiments, a 19 year old 4x8 m hedgerow orchard mechanically pruned with a production of 18.5 ton/ha was harvested with 92% average efficiency versus 81% of efficiency for a hand pruned conventional control orchard with a production of 32.58 ton/ha.

Key words: Olive, olive harvest mechanization, olive harvest machine, black ripe table olives

INTRODUCTION

Olive is of the main tree crops grown in California. Virtually all are processed into black ripe (99%) or California style green olives (less than 1%).

The table olive industry in California is based upon the 'Manzanillo' cultivar, which is harvested when the fruits are still green and not fully mature yet. The harvested fruits become the "California Black Ripe" table olive through an oxidation process.

The traditional California black ripe table olive production is not sustainable, because its current combination of increasingly expensive and less available labor and stagnant per ton returns to the grower.

Hand harvesting costs are volatile often exceeding 50 – 75% of gross return, crop value has not increased in tandem with harvest labor costs, and competition for pickers has also increased. Segovia-Bravo et al. (2007), reported that traditionally, the harvesting of olives is done by hand using a technique known as "milking the tree", and the cost of this operation accounts for 50–70% of the total production cost. Mechanical harvesting, using big machines that shake the olive tree or smaller machines that move the branches of the tree, is carried out only on cultivars with low susceptibility to bruising.

The high cost and time consumption of hand harvesting make mechanical harvesting desirable.

Currently, most olive harvesters are designed, developed and marketed, for oil olive harvesting. Oil olives are physiologically mature and have a low fruit removal force which results in a highly efficient harvest.

However, most table olives are harvested before they are physiologically mature and have high fruit removal forces. Therefore the harvesters designed for table olive harvesting must use more force to achieve the same efficiencies. Therefore, the main objective should be achievement of the same mechanical harvesting efficiency that on oil olive without compromising quality.

Recently, some studies have been developed in California about mechanical table olive harvest. For example, the canopy contact head technology was adapted from grape harvesters (Ferguson et al., 1999). But still, nowadays, mechanical olive harvest is not common treatment among the table olive growers.

As with most of California's horticultural crops, if the table olive industry continues to rely on hand harvesting, it is only a matter of time before table olives are no longer produced here. Even if the labor is readily available, it is not economically feasible, and is declining in skill and efficiency.

Harvesting is the final step in field production of an olive crop, but it can markedly affect net return to the grower if done at the wrong time or in the wrong way.

Previous studies showed that efficiency is most important factor for mechanical harvest of "Black Ripe" table olive. The harvest efficiency varies and depends on different factors such as species, characteristics, tree size, density of canopy, harvest time, topographic situation of orchard, machine operator and harvest machine. Tombesi et al. (2002) declared that canopy shape, width and length, and density also affect mechanical harvesting.

Tree and canopy structure affect first, the ability of the harvest machine to remove the fruit, and second, the potential to damage the fruit after it drops through the canopy after detachment (Ferguson et al., 2010)

To increase the efficiency of mechanical harvesting, trees must be fit to machine. For this reason, pruning is one of the most important parameters to consider. But, pruning done by hand requires extra labor. To prevent this, mechanical pruning is being applied in some olive orchards. Although, there aren't much research related to olive tree pruning; Giametta and Zimbalatti (1997), reported that mechanical pruning required 4 man h/100 trees as compared with 128 man h/100 trees for hand pruning; a reduction was also obtained over hand pruning, to 21 man h/100 trees, when mechanical pruning was followed by selective hand pruning. Negligible differences in harvest yields were found in the three years following pruning, between any of the three methods.

On this study was aimed to design, improve and evaluate a canopy contact harvester, as well as to analysis the pruning effect on harvest efficiency.

MATERIAL and METHODS

This research was conducted in two stages; firstly, the prototype machine was developed and secondly, orchard experiments were conducted.

Design and improvement of a prototype machine

The machine system described in this study was not designed to harvest olives. It was designed and modified extensively as a research tool to develop information which would be useful to design a new harvest system based in this technology.

This experimental machine was designed as a canopy shaker to evaluate harvest parameters for a variety of crops. The harvest head allows the stroke and frequency to be changed to suit the particular crop. The modification also applied to the rods of shaking head, which reach into the canopy during harvesting. Some of the characteristics of the rods could be changed to suit the particular crop. The notes here pertain to harvest table olives. This machine has allowed to identify some important harvest parameters which should be useful for anyone who might design a machine to harvest table olives. Therefore, this machine in this study, will be referred to as "experimental olive shaker" (EOS).

Figure 1. Experimental olive shaker (EOS)

As shown in Figure 1, the shaking head was mounted on a track laying tractor (Bobcat 337G Excavator). This rubber tracked machine provides a stable base for the shaking head as well as the control system for moving and powering the head. The conventional boom was removed and replaced by a short telescoping boom. The main lift cylinder from the standard boom was retained to lift the telescoping boom. The control which moved the bucket on the standard boom now is used to tip the head forward and back. The auxiliary power circuit provides the hydraulic fluid to the hydraulic motor which now powers the shaker.

Approximately 450 kg of counter weights were added to excavator to improve shaker control and stability when the boom was at near maximum extension.

The telescoping boom was mounted using the same pins that were used for the original boom. It consists of two sections of telescoping square steel tubing with a 1220 mm double acting hydraulic cylinder mounted on top to power the telescoping function. In addition to telescoping, a second hydraulic cylinder was attached to the boom to tilt the shaking head. At one time in the development of this EOS, a third cylinder was used to roll the head from side to side.

The telescoping boom was partially raised and partially extended. The telescoping function is controlled by the 1220x25 mm hydraulic cylinder which is located on top of the boom. The 610x25 mm tilt cylinder is attached near the end of the boom and is connected to a pivot point near the top of the "C" frame.

Figure 2. EOS from the right side of the Bobcat excavator

The shaker head is has a counter balanced vertical crank turning in a substantial "C" frame. A hydraulic motor has been placed at the top of the crank mechanism. A pair of bearings at the top and bottom of the crank provide the center about which the crank turns (This is conceptually similar to the crank shaft in a single cylinder engine. Instead of a piston attached to a counter balanced crank, it was a set of rods attached to the crank). On this machine, the displacement of the center of the crank can be varied in 13 mm increments, and the displacement of the counter balances are also variable to compensate for the weight and offset of the crank. A shaft (25.4 mm diameter) connects the top and bottom of the crank. A steel sleeve (65 mm diameter) is connected to this shaft by bearings so that the sleeve is free to rotate independent of the internal drive shaft.

Figure 3. The "C" frame which holds the crank

Figure 4. The crank mounted in the "C" frame

A bearing mounted sleeve fits over the crank shaft and the aluminum rod holders are fitted loosely over the sleeve. Collars were attached to the sleeve to maintain approximately 300 mm spacing between the rod holders in use. A number of rod holders are not being used and simply go along for the ride.

Figure 5. The top of the crank

In the Figure 5, the small yellow spot has shown the center of rotation. The crank is offset in one direction, and the counter balance is offset in the other direction. It can be also seen the two part aluminum rod holders which clamp together to hold the rods in place.

Figure 6. The bottom of the crank

The bottom of the crank is identical to the top except that it is mostly covered to keep fruit from being damaged by the mechanism.

A hydraulic motor sits on top of the "C" frame and is attached to a Lovejoy coupling, which is, in turn, attached to the top of the crank. Two steel mounted brass bearings hold the top of the crank in alignment.

There is no motor on the bottom. The bottom of the crank shaft rides on a brass plate, which is held in place by a steel plate.

Figure 7. Hydraulic motor

Rods were used during the field trials, which were about 32 mm in diameter and 910 mm long. A steel tubing (200 mm length of 20 mm diameter) was attached to one end of the rod to allow it to be clamped to the crank. The main structure of the rod was either a fiberglass rod or a fiberglass tube. In each case the outside of rod was covered by rubber tubing with a wall thickness of 3 mm.

Orchard Trials

The experimental orchard was located in Tulare County in California's Central Valley. The 19-year-old 'Manzanillo' orchard with irregularly placed 'Sevillano' pollinators had 13.83 tree, experimental rows spaced at 4x8 m (335 trees per ha).

The mechanical pruning treatments were done June 6th 2013 in a split plot with 6 hand-pruned and 6 mechanically pruned rows as replications. Half of the rows were mechanically topped at 3.5 m at hedged 1.5 m from the trunk on the west side. The trees had been pruned at the same distance from the trunks on the east side the in 2012. All rows were skirted 1 m from the ground.

Both fruit removal force and individual fruit weight were determined on 100 individual fruits/row before and after harvest. At harvest all rows were hand harvested for fruit yield and quality evaluations from the local receiving station. Due to time constraints and technical problems 20 mechanically pruned trees and 5 hand pruned trees were harvested with the mechanical harvester. Harvester final efficiency for both machine and hand pruned treatments was calculated as follows:

$$HE = \left(\frac{K_1}{K_1 + K_2} \right) \times 100 \qquad \text{..........(1)}$$

where;

HE: Percentage of harvested product (efficiency) (%),
K_1: Mechanically harvested product (kg/tree),
K_2: The product weight left in the tree after mechanical harvest (kg/tree).

RESULTS and DISCUSSIONS

Design issues

At the end of the orchard trials tests showed that the machine needs to undergo some significant design changes. The first of these changes is to improve operator visibility. Ideally, the boom would be most efficient if it could be positioned perpendicular to the row of trees. Since it was still needed to reach the top of trees and between trees, a more efficient method of telescoping is desirable. Also, the actual head is longer than it needs to be. The "C" frame was designed for 1220 mm rods. But in this research, 910 mm rods have been used.

A new design of the shaker head was conducted by modifying from the original shaker head for different shrubs and trees. The original shaker head has 12 rods in each circle, while it was found that we could reduce rod breakage by changing to 6 rods per circle in the new design.

The height of the head (1220 mm) seems about right to conform to the various shapes of the trees. In very uniform trees the height might be increased.

Orchard experience showed that the roll function was not necessary and thus was not used in later trials. The tilt function was necessary for this design to allow the head to "fit" the particular tree structure.

The major problem with the current design was the very short life of the rods. It is a problem which demands the attention of anyone who pursues this design concept.

In this test, an offset radius of either 65 or 75 mm was used for shaker head, corresponding to a rotational diameter (stroke) of 130 or 150 mm. The 130 mm diameter was used in the later tests, which was as effective as the 150 mm diameter. It was not attempted to operate the machine with less than 130 mm rotational diameter, though a smaller stroke diameter could work and provide for longer rod life. However, the impact on harvest efficiency is unknown.

There have been significant problems due to the vibration in the crank bearing. To overcome to these problems, brass sleeves were used to replace the bearings with pressed 25 mm steel plates. For intermittent use and relatively slow speeds (300 rpm) these fixed bearings were acceptable. In the experiments, there was no any shaft failure. However, according to observations, a larger diameter (approximately 25%) crank shaft and strong bearing could be used. Ball bearings may have better potential performance than brass sleeves.

Initially all of the rods were rigidly attached to the sleeve so that if one rod turned, all of the other rods had to turn as well. This was determined to be a cause of rod breakage and did not improve fruit removal. Later versions of the machine allowed each ring of rods to rotate about the sleeve independently. The 19 mm diameter rods were attached to the crank by clamping them between two aluminum plates. Each plate was allowed to freely rotate about the sleeve. Each set of plates could hold as many as 12 rods. In later tests, six rods were used in each row which reduced the amount of rod breakage and did not have obvious effect on the harvest efficiency. Collars were placed at one foot intervals along the length of the crank shaft. These collars supported the rods which actually extended into the tree to remove olives. The inertia moment of the individual rod vibrating in the foliage causes fruit removal.

In all cases, the end of the rods were capped by super sealed end caps of the type used in underground electrical circuits. We did not experience any difficulty with damage to the end of the rods.

This machine was designed for another crop (Jathropha). Major modification or redesign should be done on this machine for olive harvesting. The bulky design irritated the operator due to the difficulty of locating the shaking head. The "C" shape frame has a 1500 mm opening, and could accommodate rods of 1220 mm long. The rod breakage could be reduced by shortening the rods to 910 mm, and this does not reduce our ability to remove fruit from the trees. Whereas, a smaller C frame designed to use with 910 mm rods could improve visibility of the operator, reduce the weight of the shaking head, and perhaps even eliminate the need for a counter balance on the Bobcat.

Operational Issues

The machine did not successful at moving continuously down a row of trees, but step by step. The best fruit removal was obtained by positioning the head in the various portions of the tree and pushing the head into the foliage and then activating the vibration. After about ten seconds, the head was repositioned in the tree and another cycle was started. This technique requires the ability to position the head in the various portions of the tree and is enhanced if the operator can see both the head and the tree. The telescoping boom along with the excavator's ability to move forward and back and also rotate addresses some of the flexibility and visibility issues. A redesigned "C" frame could help as well. A three section telescoping boom would provide additional flexibility, and a scissors mechanism could provide even more.

Figure 8. The shaking head presses into the tree compressing the canopy

When the foliage hangs freely and is not compressed, very little fruit is removed by the rods. By compressing the foliage, the vibration is transmitted to the fruit causing the olives to separate from the tree. Compressing the foliage can have the negative effect of forcing rods into contact with larger limbs, resulting in broken rods.

Figure 9. The interaction between the tines and larger limbs

This research was concentrated on fruit removal, with fruits being collected on tarps. A less labor intensive method of fruit handling would be highly desirable in a new harvest system.

Orchard Trials

The results for individual fruit removal force before harvest, individual fruit weight, yield per ha and harvester efficiency are given in Table 1 below.

Table 1 demonstrates mechanical pruning had no effect on individual olive fruit removal force or individual fruit size but did have a significant effect on yields per hectare and mechanical harvester efficiency. However, statistics could not be done on harvesting efficiency as there was no replication due to time constraints and technical problems. The trees in each harvester efficiency trial were within a single row.

The results given above demonstrate mechanical pruning did not significantly affect individual olive fruit removal force or weight but significantly lowered the yield ton per hectare. The mechanical pruning treatment also improved the efficiency of mechanical harvester. It is important to note these harvester efficiency results are preliminary results as we were not able to produce replicated data due to time constraints and technical problems. However, the efficiencies produced are well within the ranges needed for economically feasible mechanical harvesting. Based on these preliminary results, it appears that a combination of mechanical pruning and mechanical harvesting with a canopy contact head harvester will produce economically feasible mechanical harvesting. The mechanical pruning produces a smaller canopy with a lower crop load and the fruit borne on the exterior in a flat fruiting surface that allows more efficient mechanical harvesting with a canopy contact harvester.

Table 1. Fruit removal force, individual fruit weight, yield and harvester efficiency

Pruning treatment	Fruit Removal Force (N)	Individual Fruit Mass (g)	Yield (ton/ha)	Harvester Efficiency (%)
Mechanical	6.1	4.91	18.5b	92%
Hand Pruned Control	5.7	4.76	32.6a	81%
Significance	NSD	NSD	$P \leq 0.01$	Not applicable

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