GRASAS Y ACEITES, 57 (1),
ENERO-MARZO, 9-15, 2006,
ISSN: 0017-3495

Trends in olive fruit handling previous to its industrial transformation

Trends in Olive Harvesting

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RESUMEN

Tendencias actuales en la recolección mecánica de las aceitunas

Las aceitunas se recogieron a mano hasta los años cuarenta, cuando la necesidad de reducir costes de producción y la escasez de mano de obra comenzaron ya a hacer inviable tal sistema. A pesar de la investigación realizada durante los últimos 60 años, la recolección mecánica no es todavía una práctica común. Hay dos razones principales para ello. La primera es que los árboles de más de 20 años de antigüedad son demasiado altos y no están adecuadamente estructurados para aplicar dichas técnicas. La segunda es que la investigación sobre la recolección mecánica para las aceitunas de mesa no se ha enfocado adecuadamente dándole el peso suficiente al objetivo final de obtener frutos elaborados de calidad. Para el caso de las aceitunas destinadas a la obtención de aceite, cuyos frutos están fisiológicamente maduros en el momento de la recolección y requieren menos fuerza para desprenderles del árbol, se han producido, sin embargo, importantes avances tanto en cuanto a los vibradores como a los sistemas de recogida. También, a medida que el aceite de oliva esta extendiéndose alrededor del mundo, las nuevas plantaciones están realizándose de manera que faciliten la recolección mecánica. Por el contrario, en el caso de las aceitunas de mesa, las técnicas de recolección mecánica están todavía en fase de desarrollo. En contraposición con los trabajos realizados con anterioridad, la investigación que se está realizando actualmente en este campo va encaminada a obtener simultáneamente los objetivos de un desprendimiento eficaz de los frutos y de la obtención de un fruto elaborado de calidad. Dentro de los próximos diez años, la mayoría de los olivares de tamaño y formas adecuadas dedicados a aceite se recolectarán mecánicamente. No obstante, no es posible aún predecir cuando las aceitunas destinadas a mesa se recogerán de la misma forma.

PALABRAS-CLAVE: Aceite de oliva - Aceituna - Aceituna de mesa - Recolección mecánica.

SUMMARY

Trends in olive harvesting

Until the 1940s, when production economics and labor shortages became pressing, olives around the world were hand harvested. Despite 60 years of research, mechanical olive harvesting is still not a common commercial practice. There are two major reasons for this. First, trees over 20 years old are too tall and poorly structured for mechanical harvesting. Second, mechanical harvesting research for table olive production has not been sufficiently focused on the final goal, processed fruit quality. For oil olives, which are physiologically mature at harvest and require less removal force, advances in both trunk shaking and picker head technology are advancing rapidly. Also, as olive oil is enjoying a renaissance around the world new orchards are being planted in the hedgerows that facilitate mechanical harvesting. For table olives however, mechanical harvesting is still in the developmental stage. The research being done now, unlike earlier work, focuses on the parallel goals of efficient fruit removal and final processed product quality. Within 10 years most olive oil orchards of suitable tree size and shape will be mechanically harvested. When table olives will be routinely harvested mechanically cannot be predicted.

KEY-WORDS: Mechanical harvesting - Olive - Olive oil - Table olive.

1. INTRODUCTION

When and how the olives are harvested are among the most important factors in both the quantity and quality, and therefore value of processed table olives and olive oil. Efficiency of harvest, the percent of fruit removed from the total crop on the tree, is the first component of total processed product value. Quality of the fruit, partially a function of maturity for table olives and oil, and size for table olives, and condition when delivered to the processing facility is the second component of total processed oil or table value. Harvesting is the final step in field production of an olive crop, but if done at the wrong time or in the wrong way it can markedly affect net return to the grower. However, within limits, depending upon the use of the harvested fruit, the two factors are ranked differently. Efficiency of harvest removal and collection is the more important factor in developing mechanical harvesting for olives destined for olive oil. Fruit quality and condition, within limits, is secondary. Fruit quality and condition, the potential for producing an acceptable table fruit when delivered to the processing plant, is the more important factor in developing mechanical harvesting in olives destined for table fruit. Efficiency of harvest is secondary. Given the relative size of the world's olive oil and table olive industries, and the relative difficulty of developing mechanical harvest for oil or table fruit, successful harvesting of olives for oil will be developed sooner and more easily than successful harvesting of olives for table fruit processing.

The major reason for developing mechanical olive harvesting is the high cost of hand harvest; currently the single most expensive cost in olive production worldwide. In California's San Joaquin Valley the 2005 average hand harvest cost per ton was 65% of the gross return per ton. (Hester, 2006) Other major olive producing countries report similar percentages. Further, in most olive producing countries adequate harvest labor is becoming less available.

These two factors, the potential for olive harvesting methods to affect the quantity and quality of the final processed product, and harvest costs, means efforts to develop mechanical harvesting for olives must be dictated by both the quality of the table olives or oil produced and by the reduction in harvest costs. Though, as discussed above these factors, within limits, rank differently depending upon the final use of the harvested fruit. However, reducing the cost of olive harvest is of no advantage if the harvested olives cannot be successfully processed into high quality table olives or oil.

2. HISTORY OF OLIVE HARVESTING

The first method of harvesting olives was to collect fruit from the ground late in the growing season when the physiologically mature fruit abscises naturally. Or the fruit may have been diseased or infested with insects which hastened abscission. On the ground fruit can be further degraded, infected and infested. The result was a decrease in olive oil or table fruit quality. Thus harvesting fully mature olives from the ground for table or oil processing was abandoned early in olive production and replaced with hand harvesting, a method still used extensively. Hand harvested fruit removed directly from the tree is stripped with a downward motion and placed into baskets, bags or boxes. If the olives are destined for table fruit processing the laborers often wear knitted cotton gloves. Hand reach can be extended with hand held wooden or metal toothed devices resembling coarse combs or rakes, used with the same downward motion. Poles have also been used to beat the branches. The latter method is only effective with mature fruit for oil extraction. These methods of extending hand harvest have improved efficiency of removal, but poling results in tree damage, and all methods are inefficient and slow, and require fruit to be picked up from the ground. The first harvest innovation was to string plastic nets under the trees or spread them on the ground. As interest in improving harvest efficiency grew harvest aids, platforms that positioned pickers were investigated. However, Fridley (1969) soon demonstrated that these only improved the speed of the slowest laborers and actually slowed the more efficient ones. In the 1940s in California, USA and in the 1960s in Europe both universities and the commercial sector began investigating adapting the mechanical harvesting methods used in other tree, bush and vine crops for olive harvest. Among the technologies investigated have been ground sweeping, hand held combing and limb shaking devices, trunk shakers, both orbital and multidirectional, inertia or impact shakers, double or single sided picking head mechanisms, and straddle type harvesters adapted from bush and vine harvesters. While the body of research has been wide ranging it has not been, as with most applied field work, systematic or thorough. Trials have been conducted in most of the major olive growing countries, on the major cultivars with trees of different ages, with and without abscission agents. The results, as a body, are extremely variable. None the less, the commercial sector has used this data to develop harvesters. As a result olive mechanical harvesting of olives is slowly gaining in most of the major production areas of the world.

The first mechanical harvesting investigations were conceived in the 1940s through the 1960s and conducted in all the major olive producing countries. Though the technologies investigated have differed the goal has remained the same; a mechanical harvester that economically and efficiently harvests olives capable of producing quality table fruit and oil. Unfortunately, not all investigations have incorporated investigations of final processed product quality, a serious experimental deficiency, particularly for table olives as flesh bruises and cuts will produce an unacceptable processed fruit. Further, in the early experiments, and even now, it is difficult to integrate all the factors that affect final processed olive quality; cultivar, orchard spacing, production practices, particularly irrigation and canopy shape as a result of pruning, fruit maturity, the machine itself, how, when and by whom it is operated, and the final use of the olive. The last factor complicates the mechanical harvesting experimentation further as the physiologically immature olives required for some table processing cures do not have a fully developed abscission zone and therefore require more force to detach the olive. This precipitated the thus far unsuccessful attempts to develop abscission agents to aid olive harvest. In this review the fruit, tree, and other parameters affecting mechanical harvest will be discussed followed by a review of the currently most promising mechanical harvesting technology.

3. TREE AND FRUIT PARAMETERS OF HARVESTING OLIVES

Olive fruits are borne in groups of one to three, laterally on paniculate inflorescences in the axils of oppositely arranged leaves, on one year old wood. The natural growth habit of the mature tree produces long cascades of pendulous, weeping, branches with these one year old fruit bearing shoots at the extremities. Thus the bearing surface of a mature olive tree allowed to grow naturally is a 0.5 to 1 m shell around the tree's periphery. Mature trees are generally 3-6 m tall. Depending upon variety the mature olive fruits have a wide size range, designated by weight. Most olive fruit cultivars weigh between 1.0 to 15 g. Fruit under 1 g are difficult to mechanically harvest with any method. Fruit weighing 3 g and above are more amenable to mechanical harvest. Visco *et al.,* (2004) has demonstrated fruits with a shorter puduncle are more amenable to mechanical harvest.

It is the combination of tree height, pendulous, apical bearing habit, far from the tree trunk, and light fruit weight that generates, particularly for table olive production, the major problem of mechanical olive harvesting technology; generating sufficient fruit removal force, (FRF) properly transmitted to the olive abscission zone, to remove the olive fruit without damage. Generally, when fruit is still green the FRF is 800 – 1000 g or 1000 cN. It drops markedly as the olive matures at maturity and much more slowly thereafter. Research done by Martin, (1994) in California and others in Spain, as summarized by Kouraba *et al*., (2004) demonstrates the not only does FRF affect the efficiency of mechanical harvest but it can also be used as an indicator of when to begin, and terminate, mechanical harvest.

4. FACTORS AFFECTING MECHANICAL OLIVE HARVEST

Cultivar

Olive cultivars vary greatly in fruit weight and FRF, and therefore in the ratio of the two. However, in all cultivars there is a decline of this ratio through full maturity, and then it plateaus. Fridley (1971) and Tombesi (1990) have demonstrated, and Kouraba *et al.,* (2004) recently summarized, the importance of this ratio, in assessing the suitability of specific cultivars for mechanical olive harvest. However, though fruit weight and FRF can be measured directly, and the ratio calculated, fruit color development is used often used as the indicator, or proxy, for maturity. Most olive producing regions have developed maturity indices, based upon color development for the different cultivars, often different for different regions, which indicate when to harvest (Kouraba *et al*., 2004). However, while the FRF/fruit weight ratio is useful experimentally, and the color maturity indices useful in production, neither has played a major role in cultivar selection when planting an orchard even if mechanical harvesting is planned. Only recently, with the introduction of Arbequina IRTA-i-18, Arbosana i-43 and Koroniki i-38 have olive cultivars been recommended or selected for their ability to be mechanically harvested. Further, it appears the reason for their selection is that the tree stature and growth habit of these cultivars make them more suitable for high densities and straddle type comb mechanical harvesters, as opposed to fruit weight and FRF, or the ratio of the two. Probably, because mechanical harvesting technology is still being developed, it has not yet become a major factor in cultivar selection, nor is cultivar a limiting factor for mechanical harvest.

However, efforts are being made to evaluate the relative merits of different cultivars for mechanical harvest under specific conditions, and why. For example, Visco *et al*., (2004) ranked Leccino, Frantoio, Pendolino and Dritta, from best to worst, as suitable for mechanical harvest when trained to a vase with a cubic volume of 29-39 cubic m and using a trunk shaker. Similarly, Kouraba *et al.,* (2004), have ranked 19 varieties for the efficiency of unidirectional branch shaking. Among the 19 they tested Datilero and Temperano were best suited unidirectional branch shaking and Sevillenca and Chemali were least suited. Further they determined fruit weight and fruit maturity were the primary factors in producing the efficiency of this harvest method. Interestingly, and unlike trunk shakers, FRF was a less important factor than fruit weight in determining harvest efficiency with branch shakens.

Tree Shape, Canopy Density and Pruning

The tree trunk and branch architecture and height, shape and density of a canopy can markedly affect mechanical harvesting efficiency and harvested olive quality for two reasons. Tree and canopy structure affects first, the ability of the shaker to remove the fruit, and second, the potential to damage the fruit as it drops through the canopy after detachment. The latter factor is particularly important for olives destined for table processing as bruised or cut olives cannot be successfully processed into marketable table olives Tree and canopy shape best for specific harvesters differs somewhat for different machines but some factors are common to all.

Generally, tree height is the first limitation. As with hand harvesting, tree height is an impediment to all forms of mechanical harvesting. If the technology is hand held, or requires contact with the canopy as with picking head technology the problem is simply the physical ability to make canopy contact. With hand held shaker technology the length and diameter of the branch, as well as the angle of shaker attachment, affects efficiency of removal (Kouraba *et al*. 2004). Tree height is an obvious limitation for over the row harvesters. If the harvester uses trunk shaking or impact technology the impediment is the ability to transmit the force to the fruit bearing surface (Martin, 1994).

Canopy shape, width and length, and density also affect mechanical harvesting (Tombesi *et al.,* 2002). Generally, canopy shape and density are less limiting for hand held branch shakers or combs but dense canopies slow the operator and can damp the efficiency of the shaker or comb. Similarly, canopy density can damp the efficiency of trunk shaking (Martin *et al.*, 1994). Dense canopies will also decrease the efficiency of picking head harvesters when the dense sections of the canopy overlap onto adjacent sections of the canopy impeding picking head's access to unharvested fruit. Shaking technology, whether hand held, or self propelled and mounted, requires skirt pruning for trunk or branch access. Mounted, self propelled shaking and combing harvesters, both single and double sided, and over the row harvesters with catching frames all require a tree below a certain height, width, and with trunk access or clearance below the canopy for the fruit catching frame. Single sided and double sided combing harvesters are more efficient if the fruiting wall of the tree is flat, not rounded, and continuous (Ferguson *et al.* 1999).

Collectively, these requirements suggest the ideal olive orchard for efficient mechanical harvest will be a hedge row of limited width and height with trunk access and clearance below the canopy. The ideal way to achieve this shape is with mechanical topping, hedging and skirting combined with some selective hand pruning (Ferguson *et al.* 1999) to produce a tree that is roughly no more 4 m high, 2 m from row to row middle, and 1.5 from trunk to trunk. Figure 1 is a picture of a traditional, formerly hand harvested olive orchard pruned for mechanical harvest.

However, because olives bear their crop on a 1 m shell of one year old shoots in a cascade, mechanical hedging can greatly reduce crop, particularly on existing trees at commercial densities of 300 trees per hectare (Ferguson *et al.* 1999). In the collective research trials investigating mechanical harvesting it is well demonstrated per tree yields will be decreased by the mechanical and hand pruning necessary to shape a tree for efficient mechanical harvest (Camerini *et al.,* 1999; Ferguson *et al.,* 1999). However, collectively the accumulating data is also suggesting higher tree densities, combined with reduced pruning and harvesting costs, will offset the yield decreases produced by the pruning. Most experimental trials, and most commercial orchards, integrating high densities, and mechanical harvesting and pruning, have not reached full bearing but economic projections indicate they will be economically viable at maturity (Klonsky *et al.*, 2005; Vossen *et al.*, 2004).

Figure 1
Trees on the left have been hedged, topped and skirted for mechanical harvest

Orchard Density

As the preceding discussion suggested, as mechanical harvesting is incorporated into olive production, tree densities in olive orchards will decrease from the very wide spacing of dry land production or from the 7-8 m by 5-6 m spacing in unirrigated orchards to 1.25-1.5 m in row by 3.75-4.0 m between row spacing of hedge row orchards. This is an increase from as few as 125 trees to the hectare to as many as 2225 trees to the hectare.

These high density orchards will, due to between tree competition, naturally limit tree size, facilitating tree harvesting and fruit collection with most mechanical harvesters. The orchards will also have the added benefit of producing higher yields earlier. Initial trials of high density orchards for olive oil production are confirming the ability to produce higher yields earlier and be successfully harvested mechanically. However, most of these high density orchards are too young to fully demonstrate if annual economical crop production can be achieved while maintaining the tree size required for successful mechanical harvesting, particularly with the over the row harvesters. It has not been fully demonstrated that the topping, hedging and hand pruning required to maintain the adequate tree size will produce annual economic crops. However, as an increasing number of trials, and commercial orchards are being planted at these densities this data will be generated within ten years (Vossen *et al.,* 2004). Figure 2 is a four year old hedgerow olive orchard.

Fruit Loosening Agent

In the late 1960s, when it became obvious mechanical harvesting the physiologically immature olives destined for table production required a fruit removal force that damaged the fruit investigations of abscission compounds were initiated. The collective results thus far have not produced any reliable fruit

Figure 2
Four year old hedgerow orchard

loosening agents. Early research by Martin *et al*., (1994), Ben-Tal and Woodner (1994), Metzdakis, (1999) and Gerasopoulos *et al*., (1999) focused on ethylene releasing compounds (ERC) and how to apply them. Though many of the ERCs successfully promoted development of the abscission zone between the fruit and pedicel they failed to loosen fruits, damaged the fruit, or produced unacceptable leaf loss. In 1993 Banno *et al.* demonstrated phosphates enhanced the performance of ERCs. Arquero *et al.* (1997) later produced promising results in a number of trials using monopotassium phosphate (MPK). Currently MPK, with and without Ethephon, and surfactants, is being investigated by Barranco *et al*. (2002) as a fruit loosener for the oil cultivars Arbequinqa and Picual. Among the results thus far the most interesting finding is that MPK and Ethephon appear to produce abscission in different zones of the fruit attachment. MPK produced more abscission in the peduncle - branch zone. With the addition of Ethephon, abscission was greatest in the pedicel – peduncle zone. Their experimental results appear promising in that FRF is reduced to 300 – 400 cN and leaf loss is limited, but mechanical harvesting efficiency was only 60% with a vibrating type harvester. In summary, currently there are no reliable fruit abscission agents for oil or table olives which could be successfully used in commercial olive harvesting.

Figure 3
Traditional olive harvest using ladders and picking bag

Figure 4
Pneumatic hand held vibrating combing rake harvesting aid

5. MECHANICAL OLIVE HARVESTERS

Harvest Aids

Olive harvest technology can be broadly divided into hand held machines and larger machines mounted on tractors or on self propelled units. Technically, hand held harvesting units are harvest aids and serve a function in smaller, particularly hilly, orchards, but cannot be considered mechanical harvesting because the speed and efficiency of the unit is determined by the operator, and there is no collection mechanism. The units are usually pneumatic, can extend an operator's reach by 4 m and remove fruit with a vibrating motion of the comb, or by clamping on the branch and shaking. Using either a pneumatic, hand held combing unit, or a clamping shaking unit a single operator can harvest 300–450 kilos per day, before fruit collection. This is at least 50 kilos per day better than the best hand harvest laborers. However, collection of the dropped fruit onto nets, as opposed to already being deposited in the picker's bag, can eliminate some of the efficiency of removal. Figure 3 is a laborer hand harvesting olives in the traditional manner. Figure 4 is a pneumatic branch shaker.

Mechanical Olive Harvesters

Most olive harvesters fall into two general categories based upon the principal of removal. They either clamp and shake the trunk or branches, or picking heads connect directly with the canopy. The shaker technology for other nut and tree fruit crop harvesters could not be adapted for table olive harvest so scientists at the University of California Davis developed a new harvester for table olives in the 1960s (Martin *et al*. 1994). The harvest head technology was adapted from grape harvesters in California in the 1990s (Ferguson *et al.* 1999). The most modern versions of both are self propelled with catch frames incorporated in the machine and are therefore capable of continuous operation. Each technology has advantages and disadvantages.

For a shaker harvester to achieve a 90% removal efficiency when harvesting table olives either a short stroke, less than 2.5 cm and a frequency above 2500 cycle per minute, or a long stroke, 10 cm and low frequency, 1000 cycles per minute, is required. Efficiency would probably be higher when harvesting mature olives for oil. With the latter combination limb breakage is a problem and with the former leaf loss is a problem. The most efficient versions have an integrated catching frame with a mechanism for downloading that allows continuous operation. This type of shaker can be used with traditional trees pruned to an upright vase with vertically oriented scaffolds. Bark damage to the trunk can occur if the clamping strength is too great. Fruit damage, both bruising and cutting can result from the fruit falling through the canopy into the catch frame. Figure 5 is an example of a shaker with a catch frame.

Picking head type harvesters were adapted from grape harvesters. The picking head consists of ranks of meter long graphite or fiberglass rods radiating from a cylinder. The cylinder rotates passively on its central axis when the rods connect with the hanging shoots. The rods have a 30 cm horizontal whipping motion, and as they connect with the shoots this motion removes the fruit. This harvester can achieve 90% fruit removal efficiency if the tree is properly configured and the canopy does not overlap on itself as the picking head moves forward. The major problem with this harvester is the fruit bruising and cutting when harvesting immature olive for table processing. The harvesting head has been mounted on other units for harvesting olives for oil processing. Figures 6 and 7 demonstrate picking head harvesters harvesting olives for table fruit processing.

Figure 5
Shaker type olive harvester with a catch frame attached

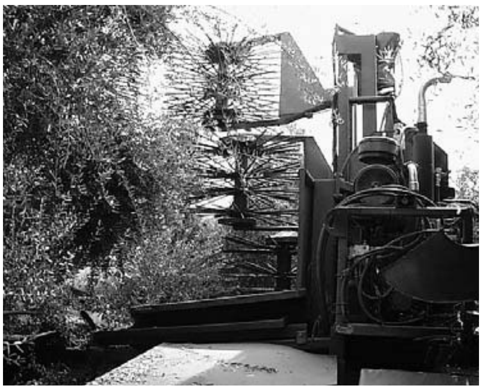

Figure 6
Picking head harvester harvesting table olives

Over the row harvesters were adapted from grapes and bush harvesters are used for harvesting oil olives in hedgerow plantings. Figure 8 is an example of one of these harvesters.

Figure 7
Paired picking head harvesters harvesting table olives

Figure 8
Gregoire over the row harvester for oil olives

6. CONCLUSION

Interestingly, though olives are one of the oldest crops produced the technology of production has remained unchanged through even the industrial revolution, a revolution that had a greater impact on farming than any other sector. Now however, the changes in olive harvesting technology are bringing this traditional crop into the twenty first century.

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Recibido: Septiembre 2005
Aceptado: Noviembre 2005