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Effects of a manual harvesting device on the quality of the fermented green olives (cv. Manzanilla)

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Abstract: In order to make harvesting table olives profitable, mechanical harvesting has become an absolute necessity. Many small Andalusian producers face structural and financial constraints in implementing the mechanisation of harvesting and, as a consequence, the fruit is still harvested manually. A manual inverted umbrella (MIU), initially designed for harvesting oil olives, was evaluated in order to determine the extent in which this device can optimise the harvesting without jeopardising the fruit quality. Simultaneously, the effects of a diluted lye treatment, applied to prevent the proliferation of brown spots caused by bruising during mechanical harvesting, was also studied. The quality of the harvested fruit was evaluated after complete fermentation. The results indicate that when no diluted lye treatment was applied, using the MIU resulted in a slightly inferior fruit quality. However, when the amount of heavily damaged fruit is taken as a standard, the MIU presented results comparable to those obtained by manual harvesting. The MIU does, therefore, offer small producers an efficient alternative, given that manual harvesting costs are up to three times higher than the costs incurred during MIU harvesting.

Keywords: fruit damage; harvesting; manual device; small producers; table olives

Table olive production in Spain covers an area of approximately 150 000 ha, 84% of which is located in Andalusia. The province of Sevilla has the largest area of table olive cultivation (67%), followed by Cordoba (25%) and Huelva (5%) and majority of these olive groves (57.5%) contain fewer than 200 trees·ha^{-1} (Gobierno de España 2016). The overall figures for the area occupied by Spanish olive production, including both oil and table olives, indicate that 80% of olive groves cover less than 10 ha each (Junta de Andalucía 2015). The Manzanilla and Hojiblanca cultivars account for more than half of the total production – approximately 400 000 t·year^{-1} for the 2019–2020 growing season (Junta de Andalucía 2019). While the Manzanilla cultivar is used almost exclusively for table olive production, Hojiblanca is also used for oil production (Gobierno de España 2016).

Table olive production requires numerous man-hours of labour (Vega Macias et al. 2005; Ferguson 2006; Ferguson et al. 2010; Zipori et al. 2014). For the 2019–2020 growing season, the total man-hours for the Andalusian region was estimated at 1.75 million (Junta de Andalucía 2019). A breakdown of the direct costs related to table olive production in Spain reveals that in groves with less than 200 trees·ha^{-1}, harvesting costs were 50% of the total production costs (Gobierno de España 2016). The harvest costs per kg of olives were estimated at between 0.33 and 0.38 €·kg^{-1} in olive groves with a density

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of fewer than 200 irrigated and rain-fed trees·ha^{-1}, respectively (Gobierno de España 2016). Mechanising the harvest is seen, therefore, as being essential for reducing these costs. Various factors, however, hamper its straightforward introduction: trees over 20 years old are not adapted to this harvesting method while the bruising on the fruit that occurs during the harvesting process compromise its quality and economic value (Ferguson et al. 2010; Jiménez-Jiménez et al. 2013).

The inevitable bruising that occurs during the harvesting process produces brown marks on the fruit due to the oxidation of phenolic compounds (García et al. 2008; Segovia-Bravo et al. 2009; Sánchez et al. 2013). As well as the intrinsic genetic factor, the onset of bruising is directly related to the impact energy level and the time after impact before treatment with lye (Jiménez-Jiménez et al. 2013). Cushioning materials and the umbrella's angle of inclination significantly influence the damage caused by bruising (Zhou et al. 2016). The Manzanilla cultivar was shown to be highly susceptible to bruising when compared with Hojiblanca (Ferguson 2006; Jiménez-Jiménez et al. 2013; Zipori et al. 2014). The differences in the propensity to suffer bruising between the cultivars show the relationship between their skin and pulp properties (Zipori et al. 2014). Degradation can be inhibited by immediately immersing the harvested olives in a cooled, diluted NaOH solution (Ben-Shalom et al. 1978; Rejano Navarro et al. 2008; Zipori et al. 2014). In economic terms, producing undamaged fermented olives is crucial, as the presence of brown spots is one of the official parameters that define the quality of the product and, therefore, its economic value (IOC 2004).

In the Spanish context, the above-mentioned land parcelling, combined with the ageing farming population's (70% are over 45 years old) disinclination to undertake substantial investments, further limit the full-scale mechanisation of harvesting (Junta de Andalucía 2009). Consequently, the traditional method of manually harvesting olives for fermentation persists. This ensures a very good end product, but seldom is it profitable. To a large extent, these structural and financial factors also apply to small oil olive producers. Until now, however, the fruit quality has not been seen as being such a critical factor among the producers, as fruit quality has had no immediate economic consequences for them. Most small producers continue to beat olive trees with sticks while nets spread on the ground catch the detached fruit. Both dragging the nets to the next tree and the unavoidable stepping on fallen olives during the beating process compromise the quality of the harvested fruit (Plasquy et al. 2021).

Over the last decade, and in effort to produce premium oils, small-scale producers have started to develop small, but handy, devices to avoid fruit bruising during harvesting. These devices were soon followed by industrially produced ones (Plasquy et al. 2019). The manual inverted umbrella (MIU) is an inclined tarpaulin that catches the detached fruit and funnels it directly into a plastic box placed beneath it. Made of a resistant tarpaulin stretched over hollow aluminium rods, this movable device has an inverted umbrella structure with a maximum diameter of 6.85 meters. The outer ends of the tarpaulin are attached to the umbrella by an elastic band running inside the rods, emerging at their outer end. This band moves over a small internal roller and enables the branch vibrator operator to access the tree easily. At the lowest part of the umbrella, opening funnels the fruit into a 20-kg capacity plastic box which is removed and replaced by a system of ropes and pulleys, thus avoiding any contact between the olives and the ground and also preventing damage caused by the subsequent dragging to the next tree.

A prototype of such an MIU was tested using branch shakers instead of sticks to detach the fruit. This revealed that the novel harvesting method did not require a significantly longer harvesting time than the traditional one, while the impact on the quality of the fruit was significant, especially when dealing with a more delicate cultivar such as Arbequina (Plasquy et al. 2021). Using the farm labourer's salary table for the 2016–2017 season, the cost of the harvesting with an MIU fell within a range of 0.12 and 0.14 €·kg^{-1}. The number of operators (2 or 3) and branch shakers used (1 or 2), explains the small differences between the calculated values (Plasquy et al. 2019). This implied that, when compared with manual harvesting, the MIU harvesting costs were three times lower (Gobierno de España 2016).

While it is obvious that harvesting with an MIU and trunk shakers is quicker than manual olive harvesting, the extent to which this more aggressive method, compared with manual harvesting, jeopardises the final quality of the table olives, is not so clear. To this end, an experiment comparing the effects of both methods, as well as the effect of the diluted NaOH solution on the harvested fruit with the MIU, was designed and performed.

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MATERIAL AND METHODS

Fruit of the Manzanilla cultivar was harvested in an olive grove in Bollullos par del Condado (Huelva, Spain). The trees were on average 8 years old, planted at 250 trees·ha^{-1}, and deficit irrigated.

Harvesting took place at the beginning of October 2018, when the olives' green-yellow colour indicated their optimum harvesting condition. The fruit on the tree was healthy and unmarked by pests or diseases.

Manual harvesting was performed by two workers who placed the picked olives in a small basket, known as a macaco, slung on the waist (Figure 1A). The baskets were emptied into a plastic box until 15 kg had been harvested.

Mechanical harvesting was performed with a prototype MIU as described in Plasquy et al. (2019). In our case, a single operator detached the fruit with a 2.1-kW SP-471 branch vibrator (Stihl, Waiblingen, Germany) (Figure 1B–C). Two boxes of olives were harvested in this way and the harvested fruit was inspected for damage. Any detached leaves and small twigs were also removed at this stage.

A 10 L bottle of NaOH (0.3%) was prepared in a laboratory at the Spanish National Research Council (CSIC)'s Instituto de la Grasa the day before harvesting. It was then taken to the farm, where it was refrigerated at 4 °C until use on-site.

Two plastic containers, specifically designed to be used as fermenters, were each filled with 8 kg of the mechanically harvested olives and the diluted solution and left to steep for 3 hours (samples BL1 and BL2). During this time, they were transported to the Instituto de la Grasa's laboratory in Sevilla. After 3 h, the liquid was replaced with a 2% solution of NaOH (lye).

The boxes with the cleaned olives from both harvesting methods, manual and mechanical, were transferred to the laboratory and kept for 24 h at room temperature to prevent fruit skin blistering, a problem specific to the Manzanilla cultivar during the lye treatment (Rejano Navarro 2008). After that time, they were placed in four fermenters and filled with lye (samples BT1 and BT2 being the manually harvested olives and BM1 and BM2 being the mechanically harvested fruit). All the experiments were performed in duplicate.

The lye penetration was monitored over 7 h in all the samples until the alkali reached two-thirds of the way into the pit. Once this point was reached, the liquid was removed, the fruit was washed with tap water for 8 h before being finally covered with a 12% NaCl solution where spontaneous lactic acid fermentation occurred over a period of several months. Due to the cold room temperature, the fermenters were placed in an incubator at 25 °C from day 23 to day 58. The fermenters were inoculated with a combination of lactic bacteria (*Lactobacillus plantarum*), as well as 25 mL of Espanufer and 1.0 g of Epsaferm starter cultures (Epsa, Valencia, Spain)on day 63. On day 155, the brines were adjusted with lactic acid (90%) to attain the desired acidity and pH values with the aim of ensuring the correct final conservation.

The brine pH, salt, and acidity, both free and combined, were measured weekly for 12 weeks using a Metrohm 670 Titroprocessor (Herisau, Switzerland).

Colorimetric measurements of the fruit were taken with a 9 000 colour-view spectrophotometer (BYK-

Figure 1. Harvesting methods: Manual harvesting using a macaco (A); and the manual inverted umbrella prototype (B) and a branch vibrator (C)

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Gardner, Germany) equipped with software for calculating the CIE L* (lightness), a* (redness), and b* (yellowness) parameters. The data from each measurement are the average of twenty olives.

The firmness was measured using a Kramer shear compression cell coupled to a Texture Analyser TA.XT plus (Stable Microsystems, Godalming, UK). The crosshead speed was 200 mm·min^{-1}. The firmness was the mean of ten replicate measurements, each of which was performed on five pitted olives, and expressed as N·g^{-1} of pitted olives.

After 8 months the fermented olives were visually assessed by a panel of table olive experts. The appearance of brown spots was estimated by measuring the area of spotting on each olive in a 1-kg sample. The olives were classified into one of the following categories: A (olives free of any brown spots in an area larger than 3 mm^2), B (olives free of any brown spots larger than 9 mm^2), C (olives with brown spots covering areas larger than 9 mm^2) and D (olives with extended softened or broken tissue). The international standard for table olives establishes defective fruit as The international standard for table olives establishes defective fruit when there are marks on the skin that excede 9 mm^2 in surface area (IOC 2004).

A statistical data analysis of the physicochemical parameters was performed using PASW Statistics version 18.0 (IBM SPSS Statistics). A one-way analysis of variance (ANOVA) was performed within the same quality categories and Tukey's test was applied to differentiate the mean values ($P < 0.05$) between the different treatments. The chi-square (χ^2) was calculated to analyse the difference between the treatments.

RESULTS AND DISCUSSION

The follow-up of the fermentation of the different samples demonstrated an overall profile in line with the three-phased evolution as described by De la Borbolla and Rejano Navarro. (1981). Due to the low ambient temperature in the laboratory, the first phase, in which the pH of the brine descends to a value of approximately 6 in 2 to 3 days, was extended to more than a week (Figure 2A). Consequently, the second phase, in which lactobacilli and yeasts develop and the Enterobacteriaceae disappear completely, set in later and took up to 4 weeks. In the third phase, the pH remained at around 4 until the point at which the fermentable material was exhausted, the final values for all the samples being 3.8. Olives from the BM samples presented higher values during the whole fermentation process until a correction was performed at day 157 and the final values ended up being equal. In the case of BM, 47.1 mL of 90% lactic acid was added while 23.9 mL and 26.1 mL of 90% lactic acid were added to BT and BL samples, respectively.

The same trend was present in the free acidity. Until the correction, higher values were reported for the BT and BL samples. After the correction, the BM values started to increase until they reached the same level (0.77–0.80%) as the others (Figure 2B). The combined acidity values fluctuated between values of 0.08 and 0.11 N (data not shown).

In terms of the calculated colour index (data not shown), no significant differences were observed between the different treatments. This was in line with published results that focussed on the post-harvest storage of olives (Sanchez et al. 2013; Ramírez et al. 2015).

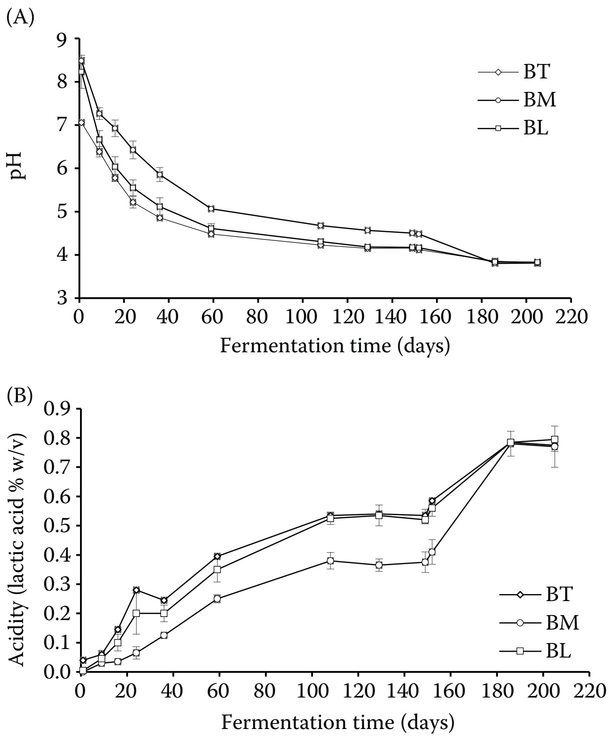

Figure 2. Evolution of the pH (A) and titratable acidity (B) throughout the fermentation process

The points are the means of duplicate fermenters of three treatments: BT – manually harvested and 24 h dry storage; BM – picked with the MIU and 24 h dry storage; BL – picked with the MIU and the with diluted lye treatment (0.3%); MIU – manual inverted umbrella. Error bars express ± SD

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Compared with the samples kept dry for 24 h, the firmness values of the pitted olives demonstrated that the pre-treatment with diluted NaOH (BL) had a significant effect. The effect, however, was more pronounced in BM than in BT (Figure 3). Ramírez et al. (2015) reported similar results with regard to the stronger post-fermentation firmness of fruit that had undergone a diluted lye treatment.

The distribution of the quality categories differed over the three treatments (Figure 4). A goodness-of-fit chi-square test determined a significant effect when the treatments were compared: χ^2 (degrees of freedom = 6, N = 12) = 25.76, $P < 0.001$. The differences within each quality category, presented as percentages, were significant in categories A, B, and C; olives with broken tissue (cat. D) were not present in any of the samples (Figure 5). Most of the fermented olives presented no defects (cat. A). There was, however, a significantly lower percentage between the MIU harvested fruit kept at room temperature for 24 h (BM) and the two others, namely the manually harvested olives (BT) and those harvested using the MIU and treated with diluted lye (BL). The same distinction was observed regarding cat. B, where the BM stood out significantly when compared with the two others. Finally, the presence of olives with the largest spots (cat. C) was significantly greater in the BM samples when compared with the BT and BL samples. Indeed, in the latter, the category was absent.

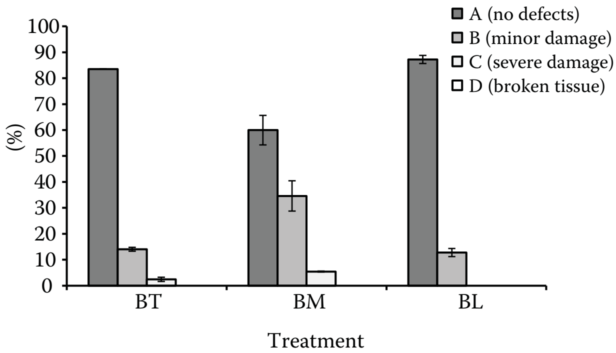

Figure 4. Distribution of the type of damage in the three treatments

BT – manually harvested and 24 h dry storage; BM – picked with the MIU and 24 h dry storage); BL – picked with the MIU and with the diluted lye treatment (0.3%). Values are the means of the percentage of the duplicate fermenters; MIU – manual inverted umbrella Error bars express ± SD

The results indicate that using an MIU does indeed have a negative impact on the overall quality of the harvested fruit when compared to the manual harvesting and to when the fruit is harvested with an MIU when a resting period of 24 h is applied. However, when it is assumed that slightly damaged olives are considered suitable for commercialisa-

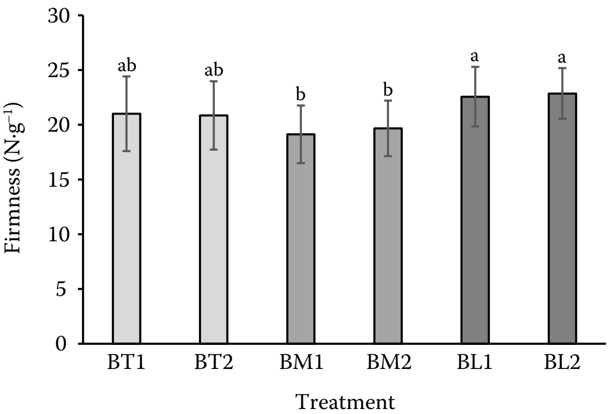

Figure 3. Firmness of the fruit expressed as $N \cdot g^{-1}$

Each treatment represents the mean of ten replicates of five pitted olives each. Three different treatments (BT, BM, BL) were applied in duplicate (1, 2). BT –manually harvested and 24 h dry storage; BM – picked with the MIU and 24 h dry storage; BL – picked with the MIU and with the diluted lye treatment (0.3%); MIU – manual inverted umbrella. Error bars express ± SD. Different letters on the bars mean significant differences according to Tukey's test ($P < 0.05$)

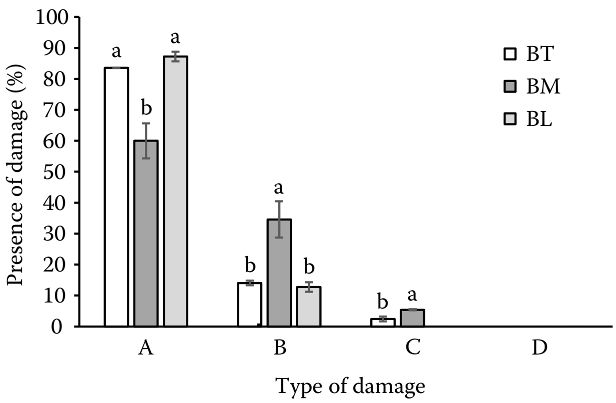

Figure 5. Quality level of the olives harvested under different harvesting conditions and post-harvest treatment

A – no defects; B – minor damage; C – severe damage; D – broken tissue; BT – manually harvested and 24 h dry storage; BM – picked with the MIU and 24 h dry storage; BL – picked with the MIU and with the diluted lye treatment (0.3%); MIU – manual inverted umbrella. Different letters on the bars within each quality level mean significant differences according to Tukey's test ($P < 0.05$)

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tion together with the undamaged ones in the same jar, the differences between the three treatments disappear (Rejano et al. 2008; Zipori et al. 2014). Interpreted in this way, none of the treatments results in more than 5% of heavily damaged fruit. These results are in line with the those obtained by Rejano et al. (2014) who reported ≈ 6% of heavily damaged fruit (subjective evaluation) for the Manzanilla cultivar when comparing manual harvesting with a 24-h rest and mechanically harvested olives (trunk shaker with and without the application of an abscission agent) with a treatment of diluted lye (0.3%). Zipori et al. (2014) reported higher values regarding the manually harvested Manzanilla cultivar of olives: ≈ 12% with severe damage, while the mechanically harvested ones even reached ≈ 50%. Therefore, the results obtained with the MIU can be evaluated as being far better than those published thus far regarding mechanical harvesting. The specific design of the device – and especially the type of tarpaulin, its inclination, and its slacker tension – reduces the impact-induced damage. A possible explanation could be the use of a branch shaker instead of a more aggressive trunk shaker, given that bruising is causally related to the impact energy level (Jiménez et al. 2013). Using boxes with a maximum capacity of 20 kg further contributes to preserving the integrity of the fruit to the greatest possible extent.

The effect of the diluted lye treatment is obvious when the values obtained regarding the two types of mechanically harvested olives are compared. As such, the results again demonstrate the usefulness of the above treatment as a means of preventing the formation of brown spots. However, using the MIU resulted in only 25% less undamaged fruit compared with using a non-protective treatment (*BM*), while almost 90% of the fruit is only slightly damaged and, thus, perfectly suited for commercialisation. These results indicate that, although the effect of diluted lye is beneficial, its use is not critical when an MIU is used, and the harvesting of fruit of a commercially acceptable quality is foreseeable.

CONCLUSION

This present study confirms the beneficial effects of using diluted lye to prevent the formation of brown spots due to bruising during harvesting. Compared with the published results of mechanical harvesting, the results also indicate that using the MIU in combination with a branch shaker provoked far less fruit damage. The fact that the observed damage was almost exclusively minor raises the possibility of harvesting fruit with an acceptable quality range and without the need for any infrastructure to store and transport a large volume of diluted lye. Taking into account that using the MIU already offered a substantial reduction in the labour costs-calculated as being less than a third of that required for manual harvesting – and in the other costs as well, these data confirm that cheap and simple devices and procedures of this kind can offer small producers an efficient harvesting solution without jeopardising the desired fruit quality.

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