Hand arm vibration generated by a rotary pick-up for table olives harvesting

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Abstract: The manual harvest of olives is one of the most expensive operations in the table olives production, but the use of the electric hand-guided machines triples the productivity. The development of these new machines leads to changes in the harvesting methodologies and in the operator's working behavior. These items may also affect the hand-arm vibration (HAV) transmitted to the operators during the work. Aim of this study is to evaluate the hand-arm vibration transmitted to the operator using an experimental electric labor saving machine with rotary combs with teeth of different dimensions covered by silicon to minimize the damage to the drupes. Moreover, the olives removal forces have been analyzed to understand if the force necessary to detach the drupes is correlated to the vibration levels transmitted to the operator's hand arm. With this type of hand held olive harvester, it has been found that higher is the fruit removal force, higher are the measured vibration levels.

Keywords: HAV, portable olive shakers, rotary pick-up, table olives

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1 Introduction

Olives are a strategic product in all the Mediterranean countries: among them the table olives are of great importance. In Italy, for example, according to the latest data on commerce (ISTAT, 2010), in the three-year period from 2006 to 2008 the production of table olives was 68,453 tons. This production is not sufficient: in this country the import of table olives is around 70,000 tons per year, chiefly coming from Spain and Greece, whereas the export is about 5,000 tons per year.

Table olives are currently harvested with large shaking self-propelled machines (Fridley et al., 1973; Ferguson, 2006; Sessiz and Özcan, 2006; Amirante et al., 2007; Ferguson et al., 2010; Jiménez-Jiménez et al., 2013), but in many Mediterranean countries olive groves are located in sloped areas, where it is impossible to work with this type of harvesters. Harvesting operations are therefore manually executed and the olive branches are beaten with sticks (or canes), causing all the mature green olives to fall off the tree. Many fruits are however damaged by the effect of the direct impact of the sticks on the olives: the result is a later formation of more or less extensive superficial browning and injuries at different depths. To avoid a huge quantity of rejected product, it is necessary to minimize the quantity of damaged fruits.

The manual harvesting is moreover an operation with low productivity and with costs which reach the 50%-70% of the cultivation revenue (Hester, 2006; Vieri and Sarri, 2010): when necessary it is therefore convenient to use hand held harvesters (pneumatic, electric or with knapsack engine). Among these machines, the most suitable harvester for the table olives

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is the rotary pick up. While the shaker olive harvester (flap type or hook type) produce the falling of the olives by means of impacts (produced by motor driven sticks) or branches shaking (produced by a little two-cycle engine), the rotary pick up 'combs' the branches instead of hitting them. The combing, moreover, avoids the violent hit of the machine elements over the fruit, limiting their damages.

Paschino et al. (2010) carried out a preliminary study on the use of electric hand held harvesters, equipped with titanium undulating teeth coated with silicone, while Gambella et al. (2013) analyzed the damages produced to the drupes by different sets of an electric harvesting comb with six tungsten undulating teeth, coated with different elastic materials.

This type of harvester is a low weight machine, around 2 kg: for this reason its working tools generate high vibration levels which are transmitted to the operator hands. Prolonged exposures to hand-transmitted vibration are associated with an increased occurrence of symptoms and signs of disorders in the vascular, neurologic, and osteoarticular systems of the upper limbs (Griffin, 1990). These disorders are called hand-arm vibration syndrome (HAVS) and the vascular component of the HAV is represented by the white finger (VWF) (Bovenzi, 1998; Bovenzi, 2005). Neuropathy of the hand often occurs at an early stage (before white fingers) and may appear with cold intolerance, i.e. discomfort at exposure to a cold environment, without true blanching of the fingers (Lundborg et al., 1998). This fact is important, because olives are manually harvested in cold seasons (autumn or winter), when outdoor temperatures are low (from 2°C to 10°C).

Vibration levels produced by hand guided machines for olive harvesting are around 15-20 m/s^2, as reported by Cerruto et al. (2009), Çakmak et al. (2011) and Manetto et al. (2012). These data are comparable with the levels obtained by portable tools (as rotary and demolition hammers) used in building and industry (Vergara et al., 2008).

To correctly evaluate the hand arm vibration exposure, also the exposure time must be considered (Gerhardsson et al., 2005). As reported in the standard CEN/TR 15350, a rotary or demolition hammer is normally used for a maximum time of one hour per day (in intensive industry application), while fruit and olive harvesters are used until 3 h per day (Table 1).

Table 1 Typical exposure durations for the use of single machines during an eight-hour working day (CEN/TR 15350)

Machine	Typical or normal daily exposure duration time	Industry applications
Rotary hammer > 4 kg	0.5 h	1 h
Demolition hammer > 12 kg	0.5 h	-
Fruit harvester (flap type)	3 h	-
Olive harvester (hook type)	3 h	-

On the other hand, olive harvesters may be used in field also 4-5 h per day, in a period of three, four months long. The same operator who harvests the olives, moreover, during the year uses many machines which produce high vibration levels (brush cutters, chainsaws, pneumatic or electric scissors and rotary tillers).

Aim of this study was to evaluate the hand-arm vibration transmitted to the operator using an experimental electric comb machine with rotary teeth covered by a plastic coating material (silicon) to minimize the damage to the drupes.

2 Materials and methods

2.1 Field site and cultivar

Harvesting was carried out in a farm specialized in table olive production, located in the plain of Ozieri (40°35'00"N - 9°00'00"E), northern Sardinia, Italy. The “Nera di Gonnos”, “Nocellara del Belice” and “Tonda di Cagliari” (*Olea europea L.*) were the traditional cultivar. Olives were harvested in the last ten days of October 2012 during the green maturation stage.

The drupes were harvested from five year old trees with the same amount of growth as potted trees. The trees had a maximum height of 2.5 m, and the lower branches were 70 cm above the ground, which allowed under-crown catching nets to be correctly positioned.

2.2 The olive comb harvester

The used machine was an experimental electric comb for the mechanical harvesting of table olives. The machine had one handle and it was gripped by one operator’s hand only (Figure 1). A telescoping pole up to a maximum height of 2.9 m could be mounted on, but in this work it was not used.

Figure 1 The electric comb machine at work

The main characteristics of the tested harvester are in Table 2.

Table 2 Technical characteristics of the hand held olive harvester

Technical data	Model 105C
Teeth, rotations per minute, r/min	3360
Silicon tooth mass, 13.9 mm diameter, g	36.90
Silicon tooth mass, 19.2 mm diameter, g	54.64
Machine (without teeth) mass with 2 m of electrical cable, g	1205
Sticks length, mm	155
Plastic covered length sticks, mm	125
Stick diameter, mm	14 - 19
Supply voltage, V	12
Current consumption in work, A	5

The comb had five titanium undulating teeth (4 mm diameter), coated with silicone and driven by an electrical engine powered by a battery pack (12 VDC). During the tests the harvester was equipped with two series of undulating teeth with whole diameters of 14 mm and 19 mm (Figure 2). The coating elastic material was silicone with hardness value of 50 Shore A (EN ISO 868). The use of undulating teeth of different thicknesses did not change the inter-axis distance (2 cm), and a constant space was maintained between the contiguous undulating teeth. With the machine unloaded, the rotational teeth speed was 3,360 r/min and it was monitored by a mechanical tachometer (Deumo 2, Deuta-Werke, Bergisch Gladbach, Germany).

Figure 2 The two coated teeth
(diameter: 14 mm left, 19 mm right)

2.3 HAV measurements

2.3.1 Procedure of measurements

Accelerations along the three perpendicular axes (a_x, a_y, a_z) were simultaneously measured, following the recommendations of the EN ISO 20643/A1 standard. Signals from accelerometers were frequency weighted using the weighting curve *Wh* as described in the ISO 5349-1 standard. The acquisition time during each test was from two to four minutes, to obtain a signal related to a complete working session.

The evaluation of vibration was based on the vibration total value (a_{hv}), defined as the square root of the sum of the squares (r.m.s.) of the frequency-weighted accelerations a_{hwx}, a_{hwy} and a_{hwz} along the individual axes (Equation (1)):

$$a_{hv} = \sqrt{a_{hwx}^2 + a_{hwy}^2 + a_{hwz}^2} \quad (1)$$

2.3.2 Measurement chain in field

A tri-axial accelerometer ICP (Integrate Current Preamplifier) by PCB (SEN020 model, 1 mV/g sensitivity, 10 g mass) was oriented according to the EN ISO 20643 standard and secured to the harvester handle by means of metal supports wrapped with metallic screw clamp, as suggested by Ainsa et al. (2011) to reduce the uncertainty of hand-arm vibration measurements.

The output signals from the accelerometers were processed in real time through a NI (National Instruments, Austin, Texas, U.S.) 9402 (six channels), while the software Sound and Vibration Assistant (National Instruments) was used to post-process the data. The measurement chain was previously calibrated. The position of the accelerometer was on the top of the grip, the same position in which it is possible to measure the vibration entering inside the hand. It was maintained the resilient material which envelops the handle grip. Axis directions are reported in Figure 3.

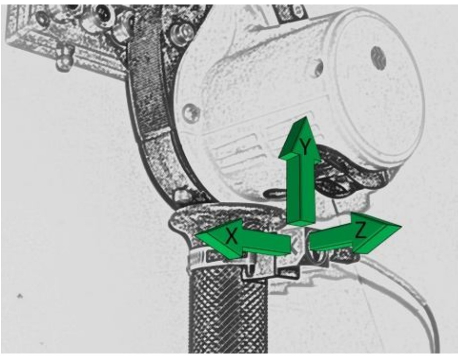

Figure 3 Directions of axis for vibration measurement on the harvester handle

2.4 Operators

Three operators, according to the EN ISO 20643, were involved in field tests. The operators were right-handed, skilled and able to properly operate the machine, because it was important to correctly analyze different comb coats types on olive fruits damage. Inside this activity the study concerning the operators' exposure to hand arm vibration was also considered. Operators' anthropometric data are collected in Table 3.

Table 3 Operators data

Operator code	Height/cm	Mass/kg
0	180	80
1	173	80
2	170	85

After holding the harvesting tree branch with the left hand and inserting the comb teeth inside the secondary branches, each operator 'combed' them downwards: if the drupes did not detach, the same combing operation was repeated. The arms position was sometimes over the shoulder, in function of the branches height.

Figure 4 The branches combing to detach the olives

2.5 Measurement of the olives removal forces

The olives removal forces were analysed to understand if the force necessary to detach the drupes was correlated to the vibration levels transmitted to the operator's hand arm.

A dynamometer Imada, DPS model (Imada Inc.3100 Dundee Rd, Northbrook, IL 60062, USA) with a load cell of 0-2000 N capacity and ±0.2% resolution full scale, was used to determine the removal forces.

A small hook was built to better adapt the machine to the drupes characteristics. The measurement of the removal force occurred with the operator positioning the drupe inside the hook and keeping the branch stretched with the hand free: a controlled strain followed until the detach of the drupe.

The removal forces of 100 olives were measured for each cultivar and each olive was then weighted. The fruits weights were determined with a digital balance with a capacity of 1.2 kg reading to 0.01 g.

2.6 Tests procedure

Tests were conducted by three operators (see 2.4) and each of them used the same rotary pick up. Each operator worked with the comb equipped with teeth of different dimensions (Table 2) on three different cultivar of olive tree (see 2.1). Unloaded (teeth out of olive branches) and full load (teeth in olive branches) conditions were always performed.

The unloaded state was tested with the harvester handle in two positions: horizontal and vertical.

During the harvesting, at full load, the foliage density sometimes blocked the engine: also in these cases the acceleration measurements were correctly registered and therefore analyzed.

Only a_{hv} values were studied.

2.7 Data analysis

The acceleration values were processed using the IBM SPSS Statistics 20 software package. To compare data, the ANalysis Of VAriance (ANOVA) procedure was used, because the normal distribution of the data was always detected. The confidence interval was always 95%. When necessary, the post processing Tukey test was applied.

3 Results and discussion

3.1 Olive detachment forces

Table 4 reports the main characteristics of the harvested olives: the mass (g), the necessary force to detach each drupe, called fruit removal force (N) and the ratio between the removal force and the fruit mass (N/g), used for comparing the suitability of the olive cultivar with the mechanical harvesting.

Table 4 Some properties of harvested olives fruits

	Nera di Gonnos	Nocellara del Belice	Tonda di Cagliari
100 fruit mass (g)	604.4	509.3	463.7
Fruit removal force average (N)	1.40	2.68	5.87
Standard deviation (N)	0.90	1.74	2.48
Min (N)	0.16	0.11	1.373
Max (N)	7.65	9.48	11.56
Ratio removal force to weight (N/g)	0.23	0.53	1.27

During this harvesting season the "Tonda di Cagliari" is the cultivar which has the major detachment problems related to the comb vibration: their removal only occurs by direct impact and not by shaking the branch.

As explained in the materials and method chapter, while combing the branches the teeth hit them transmitting vibratory energy for the fruit detachment: if the olive does not fall, it is necessary to directly impact it.

It should be noted, however, that the natural FRF (Fruit Removal Force) cannot be the sole indicator for the response of a cultivar to shaking for fruit removal. This is because the fruit mass might respond to the vibration during branch shaking to a different extent than the degree of the attachment force due to the thickness of the fruit stalk (Lavee et al., 1982).

3.2 HAV results

3.2.1 Unload state

The first analysis (which considered all the unload states data) underlined differences between the rotary pick up with the teeth of 19 mm diameter and the 14 mm diameter (Table 5), establishing that the harvester with the teeth with inferior diameters produced higher acceleration values (14 mm teeth diameter registered an average a_{hv} higher than 20 m/s^2, against 13.5 m/s^2 for the 19 mm).

Table 5 Descriptive analysis of the acceleration values a_{hv} in unload conditions in function of the teeth diameter

Teeth diameter/mm	Average a_{hv}	St.dev.	Min	Max
	m s^{-2}			
14	20.33	0.73	19.71	21.38
19	13.48	2.62	9.5	16.39

The ANOVA analysis therefore established that neither the harvester position (horizontal or vertical) nor the operator influenced the vibration data (because the main differences were detected by the diameter size).

3.2.2 Full load state

3.2.2.1 All tests

At full load condition (considering the 14 mm diameter's data together with the 19 mm), the first analysis concerned the olive variety and the operator influence on the acceleration recorded: the ANOVA established that any of these two conditions was cause of a_{hv} differences (Table 6).

Table 6 ANOVA of operators and varieties a_{hv}

Operator		Variety	
	Average a_{hv} ± st. error/m s^{-2}		Average a_{hv} ± st. error/m s^{-2}
0	13.97±0.60	Nera di Gonnos	13.24±0.56
1	13.66±0.94	Nocellara del Belice	14.89±0.60
2	14.94±0.59	Tonda di Cagliari	15.08±1.16

The different diameters were subsequently tested and differences were revealed by the ANOVA procedure (Table 7). The teeth with lower diameter (14 mm) vibrate significantly more than the 19 mm, with an average difference of 5.6 m/s^2, with an increase of 48.4% from 11.57 to 17.17 m/s^2.

Table 7 ANOVA for teeth diameters (mean followed by different letters are statistically different, p>0.05)

Teeth diameter/mm	Average a_{hv} ± st. error/m s^{-2}
14	17.17 a ±0.28
19	11.57 b ±0.22

From this moment on, all the analysis were conducted separately for the 14 and 19 mm teeth.

3.2.2.2 14 and 19 mm teeth analysis

The analysis of the 14 mm teeth harvester concerned both the operators and the variety. Regarding the operators, no differences among the a_{hv} were detected by the ANOVA procedure, while for the variety "Tonda di Cagliari", a_{hv} were statistically different (Table 8).

Table 8 ANOVA of operators and varieties a_{hv} using the harvester with 14 mm teeth diameter (mean followed by different letters are statistically different, $p > 0.05$, Tukey test)

Operator		Variety	
	Average a_{hv} ± st. error/m s^{-2}		Average a_{hv} ± st. error/m s^{-2}
0	16.89 a ±0.48	Nera di Gonnos	16.20 a ±0.17
1	17.42 a ±0.71	Nocellara del Belice	17.70 ab ±0.45
2	17.35 a ±0.37	Tonda di Cagliari	18.87 b ±0.92

Differences were revealed among the operators and the varieties using the 19 mm teeth harvester (Table 9).

Table 9 ANOVA of operators and varieties a_{hv} using the harvester with 19 mm teeth diameter (mean followed by different letters are statistically different, $p > 0.05$, Tukey test)

Operator		Variety	
	Average a_{hv} ± st. error/m s^{-2}		Average a_{hv} ± st. error/m s^{-2}
0	10.73 a ±0.43	Nera di Gonnos	10.68 a ±0.29
1	11.43 ab ±0.31	Nocellara del Belice	12.09 b ±0.25
2	12.53 b ±0.22	Tonda di Cagliari	12.80 b ±0.22

The operator number 2 registered higher acceleration values than the other two operators (with lower variability), probably due to a higher grip force of his hand.

With the Nera di Gonnos variety, instead, the lowest vibration data were recorded (10.68 m/s^2). The highest values of the acceleration for the Tonda di Cagliari variety (12.80 m/s^2) are probably connected to their high fruit removal force (5.87 N against 1.4 N of the Nera di Gonnos variety, Table 4).

The graph in Figure 5 shows the direct correlation between the average fruit removal force and the average acceleration a_{hv} registered for the different olive varieties: higher is the fruit removal force, higher are the vibration levels measured.

3.2.3 Engine blockage analysis

For both the teeth diameters, the ANOVA revealed uniform values of a_{hv} considering the harvester engine blockage due the high quantity of leaves present, at the same time, between the teeth (Table 10).

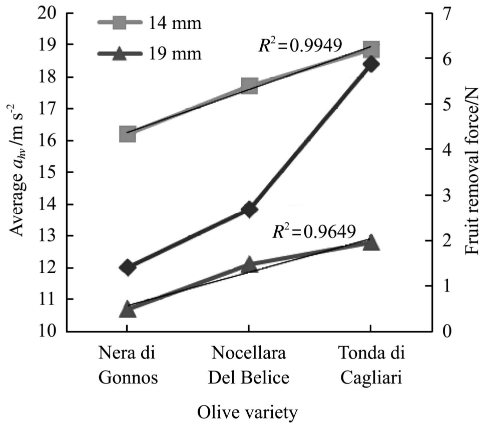

Figure 5 Average a_{hv} and corresponding average fruit removal force for olive varieties

Table 10 ANOVA of the number of engine blockages and a_{hv} for the 14 and 19 mm teeth diameters

Number of engine blockages	14 mm teeth average a_{hv} ± st. error/m s^{-2}	19 mm teeth average a_{hv} ± st. error/m s^{-2}
0	17.28±0.37	11.65±0.30
1	17.02±0.52	11.12±0.36
2	16.70±1.05	12.27±1.08
3	-	12.09±0.09

4 Conclusions

In the table olive, the quality of the harvested fruits is the most important factor limiting the use of mechanical harvesting, due to the high probability of damaged fruits, but in these crops an important profitability factor is to improve the mechanical harvesting to reduce field time and costs (Ferguson et al., 2010).

The harvest productivity of the hand held machines (pneumatic combs and electrical beater, for example) is as much as 5 and 4.5 times that of using the hands but, very few studies are actually available concerning their produced vibration, both on the branches and on the operator's hand-arm system. Çakmak et al. (2011), using one operator only, observed that vibration levels depended on the operating system of the flap type olive harvesters and the operator received the vibration in his hands at the grip of the handle: the vibration total values were almost similar for all the harvesters except for one and varied from 2.23 and 42.9 m/s^2 (including the idle state). Saraçoğlu et al. (2011) obtained similar results on hook type olive harvesters (vibration total values ranged from 5.52 and 39.14 m/s^2), but nobody already analyzed the comb type harvester (described in this paper) which, as the others, produces high vibration levels to the hand arm system (averages from 11.6 to 17.2 m/s^2).

Some differences were however highlighted between the two teeth types used, because the diameters influence the acceleration data. The harvester equipped with the 14 mm diameter teeth vibrated more than the same when the 19 mm teeth were mounted on. It must be however considered that this is a prototype: for this reason an explanation of the different recorded acceleration values can be in an irregular teeth coating in the 14 mm teeth.

At the unload condition, moreover, the machine vibrated more (averages from 13.5 to 20.3 m/s^2), because there was not the breaking effect of leaves and branches.

A good correlation was found between the fruit removal force and the acceleration values: this is due to the system work of this machine, which does not detach the fruit through direct impact (as for some beater harvesters) or branch oscillation. The fruit detachment, instead, is caused by the most slight teeth action. This fact could however cause damages to the fruits, as observed by Gambella et al. (2013), who obtained a percentage of damaged fruits around the 34% with the same type of machine.

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