Vibration operator exposure during olive harvesting

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Abstract

The paper reports the results of some experimental tests aimed at measuring the vibrations transmitted to the hand-harm system by electric portable harvesters for olives. One flap-type harvesting head was applied to three bars, different for diameter (35 and 40 mm), length (2010 and 2210 mm) and material (aluminium and carbon fibre), so assembling three harvesters. The vibrations were measured in two points, next to the hand-grips. Measurements were carried out both in laboratory, during idle running, and in field, during the harvesting of "Nocellara Etnea" olive variety, under ordinary working conditions.

The results of the laboratory tests showed that the bar material had the greatest influence in reducing the vibration level: the average RMS value was about 12 m/s^2 for the carbon fibre bar and about 21 m/s^2 for the aluminium ones, without significant differences between the two diameters. The in field tests proved that the tree canopy had a negative effect on the vibrations transmitted to the hand-arm system: in fact, the average RMS value increased from 16 (laboratory) up to 20 m/s^2 (in field). The greatest difference between laboratory and in field tests was observed when using the 35-mm aluminium bar.

Key words: safety, electric portable harvesters, hand-arm system.

Introduction

The use of hand-held portable harvesters for olives is very widespread to increase the work productivity, mainly when full mechanisation is not possible (Famiani *et al*., 2008). Unfortunately, they expose operators to several sources of risk, as noise, vibrations, and fatigue (Iannicelli and Ragni, 1994; Blandini *et al*., 1997; Deboli *et al*., 2008), that only after proper design or optimal selection of the operating parameters can be reduced (Monarca *et al*., 2007; Pascuzzi *et al*., 2008; Mallick, 2010). A significant reduction in noise level exposure has been achieved by using machines powered by electric motors (Biocca *et al*., 2008), so increasing in the same time the operator's comfort.

Vibration is probably the most important risk connected with the use of these portable harvesters. The effects of vibrations on the hand-harm system can lead to the well-known Raynaud syndrome, a disease which requires attention from the medical point of view (Chetter *et al*., 1998). Moreover, workers, when operate with hand-held power tools, in most of the cases do not perceive acceleration levels as being too high, so increasing the exposure risk (Vergara *et al*., 2008). This aspect is often underestimated by agricultural farmers, mainly interested at the harvest capacity.

The factors influencing the biodynamic response of the hand-arm system are multiple, depending on the vibration (acceleration, direction, frequency), the operator (mass, posture,

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grip force), the operating tool (mass, material, handle sizes), and the use of anti-vibrating equipment (Buström, 1997; Monarca *et al*., 2003; Dong *et al*., 2005; Aldien *et al*., 2006; Dewangan and Tewari, 2008; Tewari and Dewangan, 2009).

This research intends to evaluate the vibrations transmitted to the hand-arm system by electric portable harvesters at varying bar features (material, diameter and length), but keeping the same harvesting head. First studies, presented in (Cerruto *et al*., 2009) and (Cerruto *et al*., 2010), dealt with laboratory tests only, while in this paper the results of both laboratory and in field tests, under ordinary working conditions, are reported.

Materials and Methods

The portable harvesters

Experimental tests were carried out by using three portable harvesters, assembled by applying the same flap-type harvesting head to three bars, different for material, diameter, length and mass as reported in Table 1. The use of carbon fibre is mainly aimed at reducing the weigh of the equipment and then the fatigue of the operators, but it is expected to have influence on vibrations too.

The harvesting head presents an aluminium-made box and 12 teeth (the small bars that beat branches and olives during the harvest). The teeth, all in carbon fibres and of the same size (diameter = 5 mm, length= 370 mm), are connected to a 36-centimetre arm parallel to the motor shaft, and are arranged in the classical flap-type shape (Figure 1), widely used in pneumatic harvesters.

Table 1. Portable harvester features.

Harvesting head		Bars			
			B1	B2	B3
Mass, kg	1.365	Material	Aluminium	Carbon fibre	Aluminium
Teeth:		Diameter, mm	35	40	40
Number	12	Length, mm	2010	2210	2210
Material	Carbon fibre	Thickness, mm	2	2	2
Diameter, mm	5	Mass, kg	1.356	1.342	1.416
Length, mm	370				

The harvesters are powered by an electric motor (maximum power of 900 W and rotating speed of around 6000 rpm, fixed by an electronic card), feed by means of an external 12 V battery. The motor shaft is connected to a gear that, with a gear ratio of 10:58, gets the arm carrying the teeth moving with frequency of around 18 Hz.

Measuring equipment

Vibrations were measured by using three mono axial accelerometers DJB, model A/123/S, screwed on to the mutually orthogonal faces of a small cube tied to the bar by means of a metallic clamp (Figure 2). The reference axes were selected according to the basicentric coordinate system defined by the UNI EN ISO 5349-1:2004 regulation: x-axis perpendicular to the palm surface area, y-axis parallel to the longitudinal axis of the grip, and z-axis directed along the third metacarpus bone of the hand.

Figure 1. The harvesting head.

Figure 2. Positioning of the accelerometers on the bar.

The accelerometer signals were recorded on the hard disk of a notebook by using a PC based recording and analysis system made up of a four-channel USB-II data acquisition unit (dB4), a PC, and the dBFA Suite software (01 dB-Metravib). The software allows for several post-processing analyses, among which narrow band analysis (FFT), 1/3 octave analysis, and frequency weighting according to the ISO 5349 regulation.

The research activity

The experimental activity was aimed at evaluating the vibrations transmitted to the hand-arm system at varying bar features (material and geometry) and operating mode (idle and harvesting running). To this end, the research was developed in two steps, the former in laboratory and the latter in field.

Laboratory tests were conducted by operating the three portable harvesters idle running by the same person. To take into account possible influences of the bar angle, three inclinations (vertical, inclined at about 45 degrees, and horizontal), were considered. Vibrations were measured, at different times, in two points, next to the hand positions in working conditions (Figure 3). Each measuring session lasted about 5 minutes.

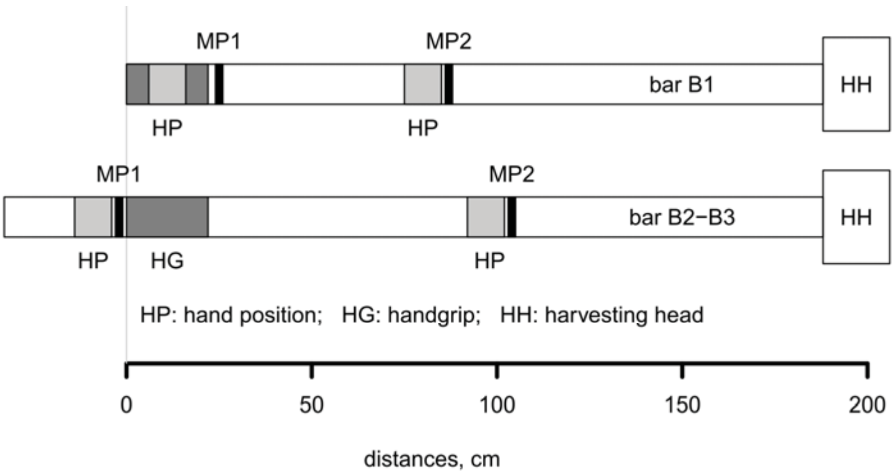

Figure 3. Measurement point position (MP1 and MP2).

The in field tests were conducted while harvesting "Nocellara Etnea" olive variety. The tree were irregularly spaced, vase pruned, and with canopy diameter of about 4 m. Again, vibrations were measured in two points as during the laboratory tests and the harvesters were operated by the same person, but different by the previous one. Each measuring session ranged from about 4 up to 13 minutes, so to complete the harvesting of one tree during each run.

All considered, laboratory tests required 18 measuring sessions (3 harvesters × 3 bar angles × 2 measurement points), whereas those in field 6 (3 harvesters × 2 measurement points).

Data analysis

Sub-samples lasting 1 minute (4 from the laboratory tests and ranging from 4 to 13 from the in field tests) were extracted from each signal recorded during the measuring sessions, so to simulate pseudo-replications. They were analysed in the range 5.6–1400 Hz (third of octave bands from 6.3 to 1250 Hz) by applying the FFT and the 1/3 octave analysis, computing the frequency weighted accelerations (RMS values) for each axis (a_{hwx}, a_{hwy}, and a_{hwz}). Finally, the global acceleration a_{hw} was calculated according to:

$$a_{hw} = \sqrt{a_{hwx}^2 + a_{hwy}^2 + a_{hwz}^2} \; .$$

All a_{hw} acceleration values were statistically analysed to ascertain significant differences related to bar type and/or bar inclination (laboratory tests) and/or operating mode (idle and harvesting running). The 1-minute sub-sample signals, being pseudo-replicates only, selected without a true randomisation, were analysed via the more robust Kruskal-Wallis non parametric test rather than the analysis of variance. Statistical analyses and graphical representations were carried out by using the open source software *R*.

Results and Discussions

Global weighted acceleration

Comparing global weighted acceleration values for bar type, bar inclination, measurement point, and operating mode, the plot design reported in Figure 4 was obtained. It shows that the mean value of the global weighted acceleration is quite high (17.7 m/s^2) and comparable with that measured when using mechanic or pneumatic machines (Blandini *et al*., 1997; Çakmak *et al*., 2011). Moreover, the Kruskal-Wallis test shows that there are statistical significant differences among the levels of the factors included in the experimental design.

In detail, the in field tests were more stressing than the laboratory ones: in fact, the global weighted acceleration values increased from 16.3 up to 19.6 m/s^2, so denoting that the tree canopy had a negative effect on the vibrations transmitted to the hand-arm system.

Looking at the bars, the lowest acceleration was measured when using the carbon fibre (B2) bar: 12.0 m/s^2 vs. 20.1 m/s^2 (B3) and 21.1 m/s^2 (B1). These first results show a positive effect of the carbon fibre in reducing the vibrations transmitted to the hand-arm system with respect to the aluminium, keeping constant bar diameter and material thickness. However, different results could be obtained when using carbon fibre of different features and/or aluminium with different alloy and thickness. Therefore, other bars of other manufacturers should be tested in order to study more in depth the effect of the material on the vibrations.

When comparing the measurement points, it emerged that the acceleration values were higher in MP2 and lower in MP1: 21.1 m/s^2 vs. 14.5 m/s^2. Therefore, the hands are differently stressed: that which holds the bar in MP2 is more exposed to the vibrations than that in MP1. Probably the lower vibrations measured in MP1 are due to the greater distance from the source of vibration (the harvesting head) and/or to the vibrating mode with a node near the measurement point MP1.

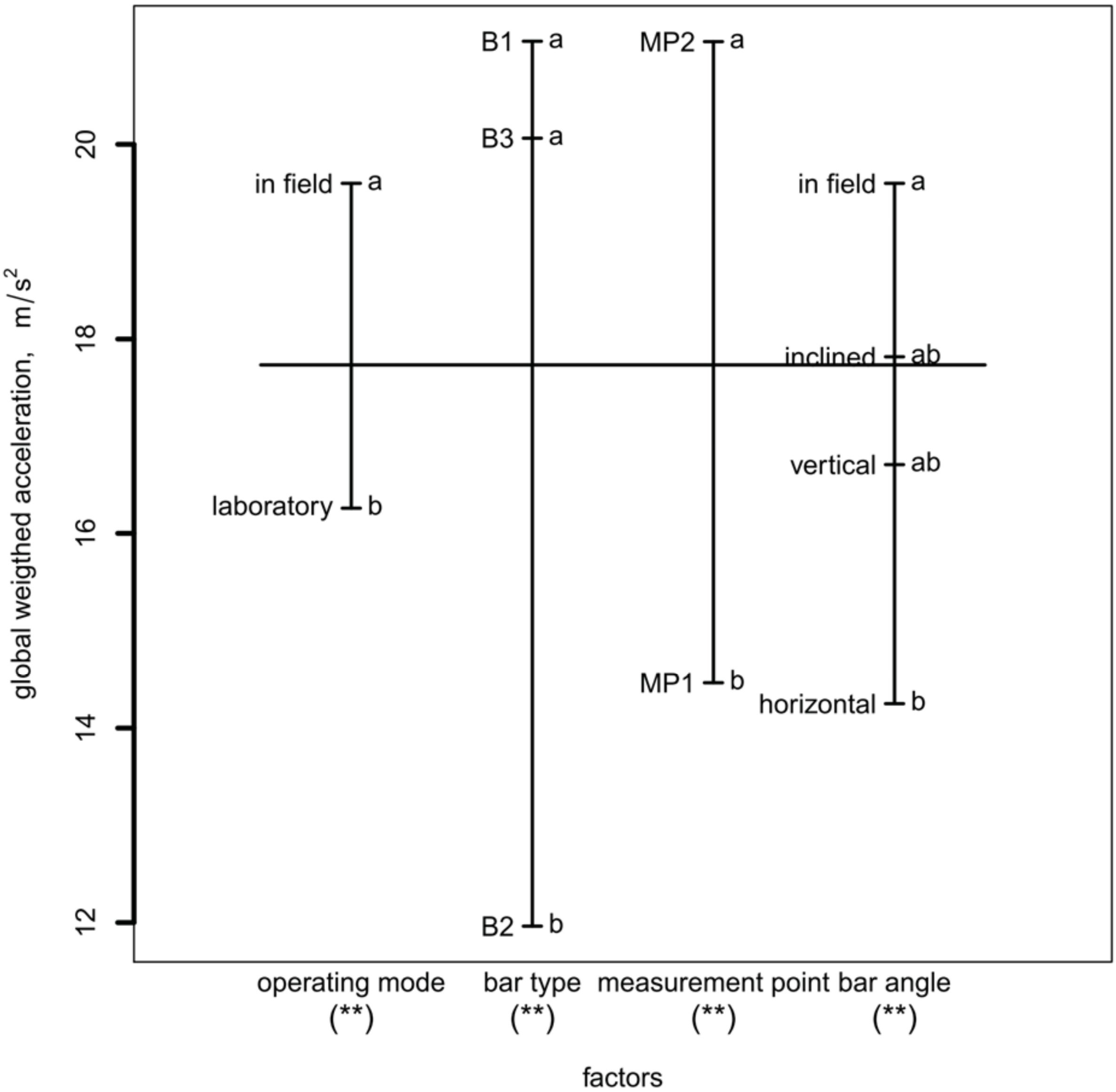

Figure 4. Plot design (mean values) of the global weighted accelerations (group separation by Kruskal-Wallis test at p=0.05).

Finally, the differences among the bar angles during the laboratory tests were not statistically significant: the acceleration values ranged from 14.3 (horizontal) up to 17.8 m/s^2 (inclined).

These acceleration values lead to daily exposure levels much higher than the daily limit value of 2.5 m/s^2 and the daily action value of 5.0 m/s^2 established by the European directive 2002/44/CE. With reference to the mean value of acceleration (17.7 m/s^2) and supposing a daily exposure of 4 h (obtained considering a work-day of 7 h and that operators attend also to positioning of nets on the ground and to the recovery the olives), the corresponding A(8) values becomes:

$$A(8) = \sqrt{\frac{T}{T_0}} a_{hw} = \sqrt{\frac{4}{8}} 17.7 \text{ m/s}^2 = 12.5 \text{ m/s}^2 .$$

Conversely, by imposing $A(8) = 5.0$ m/s^2 or $A(8) = 2.5$ m/s^2, the daily exposure times should be 0.64 h and 0.16 h respectively, clearly incompatible with the length of a standard work-day in agriculture, so the use of appropriate personal protection equipment should be mandatory.

The first order interactions involving the operating mode (operating mode × bar and operating mode × measurement point), are reported in Figure 5. They show that the carbon fibre bar (B2) produced the lowest accelerations both in field and in laboratory and that the differences between laboratory and in field tests were progressively increasing when going from carbon fibre bar (B2, 11.7 vs. 12.3 m/s^2), to 40 mm aluminium bar (B3, 19.1 vs. 21.1 m/s^2), to 35 mm aluminium bar (B1, 18.0 vs. 25.7 m/s^2).

These results lead to the conclusion that, keeping constant the harvesting head, the bar material plays the most important role in reducing the acceleration values, both during idle and harvesting running.

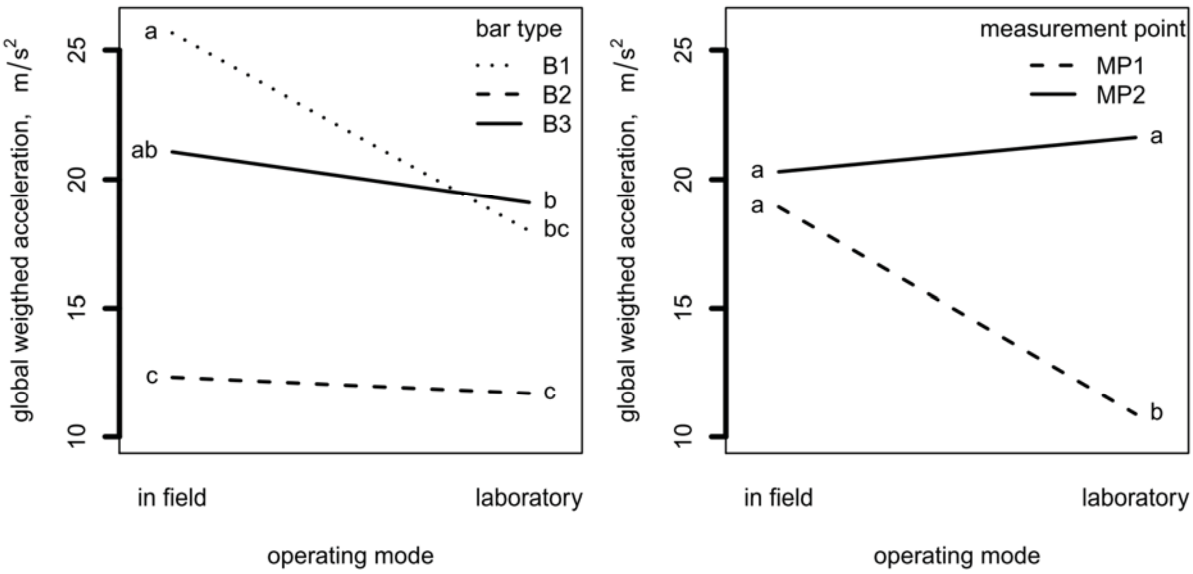

Figure 5. Interaction plot (mean values) of the global weighted accelerations (group separation by Kruskal-Wallis test at p=0.05).

When comparing the measurement points, it emerges that the differences between MP1 and MP2 were not statistically significant in field, whereas they were in laboratory. This result could be due to the fact that the tree canopy, differently from the idle running, interferes with the flap oscillations and requires a greater force from the operator, so modifying the transmission of the vibrations through the bar.

Acceleration components

The box plots of the weighted acceleration values for each axis and operating mode are reported in Figure 6. They show that the lowest accelerations were measured along the bar axis (*y* direction) in both operating modes (laboratory and in field). Moreover, during the laboratory tests, carried out in controlled conditions, the highest vibrations were always measured along the *x* axis: they were 2–3 times those measured along the other two axes. On the contrary, during the in field tests, due both to the canopy reaction and the necessity to move and rotate the bar according to the harvesting needs, it was observed a large increase in the *z* component, mainly for B1 and B3 bars.

This implies that, given the influence of canopy and operating mode, laboratory tests are need to characterise materials and machines in standard and controlled conditions, while operator's exposure should be evaluated in field.

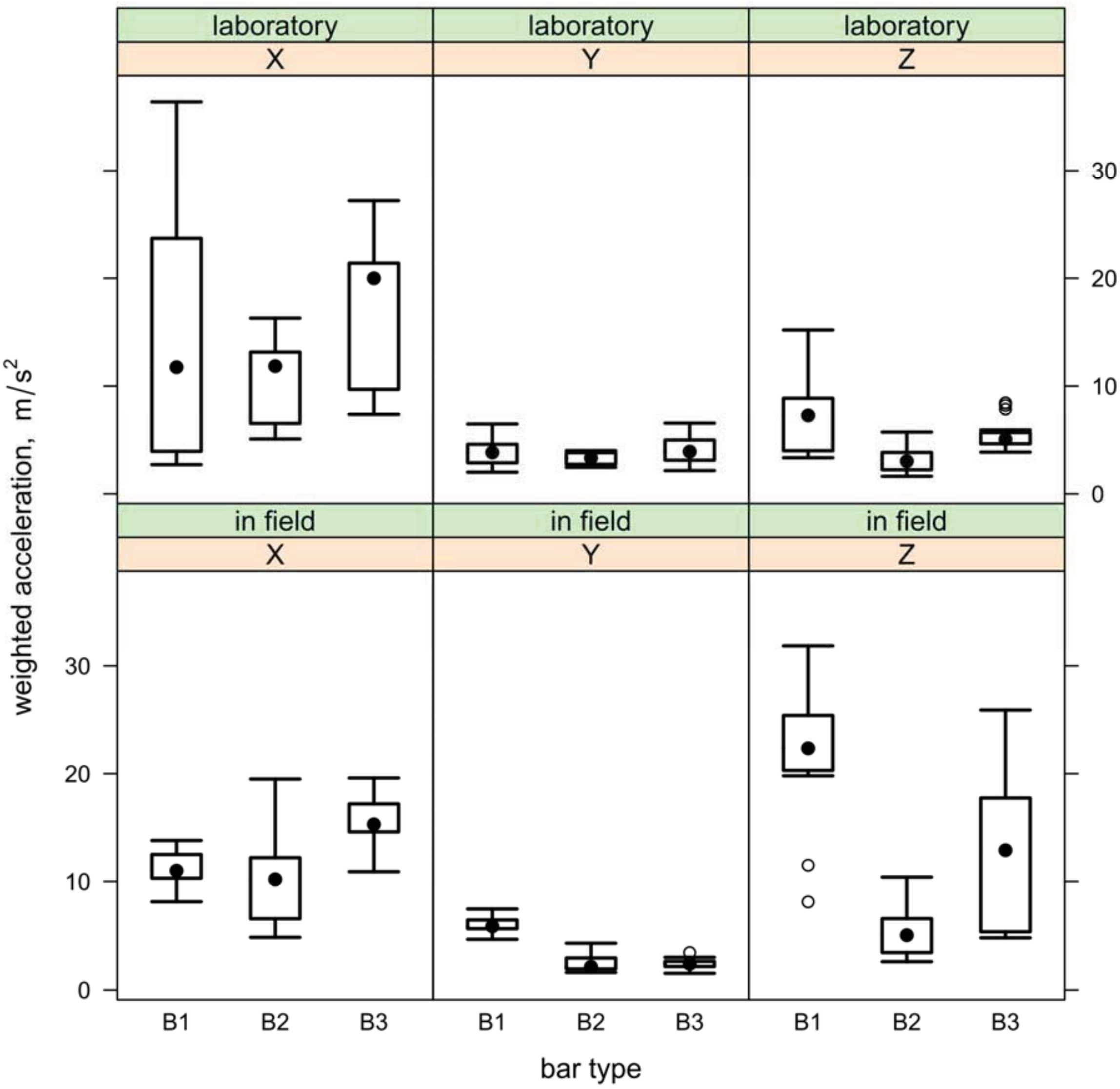

Figure 6. Weighted acceleration components for bars and operating modes.

Conclusions

The study, even if preliminary, allows for the following conclusions, to be integrated by further investigations:

- The measurement procedure proved to be effective in ascertaining the vibration level of the portable harvesters. Global weighted accelerations were quite high for all the harvesters: this means that the vibration level is mainly affected by the kinematic system that activates the harvesting head. Probably this is the key aspect to be investigated to reduce vibrations at the source. Actually, electric systems increase the operator's comfort by reducing weight and noise with respect to mechanic or pneumatic systems.
- Comparisons between laboratory (idle running) and in field tests (harvest in ordinary working conditions) showed that the tree canopy had a negative effect in vibration transmission. Acceleration values, in fact, increased from 16.3 up to 19.6 m/s^2 (from 18.0 to 25.7 m/s^2 for the aluminium low diameter bar). This implies that laboratory tests are need to characterise materials and machines, ensuring standard and controlled conditions and keeping constant all the external factors (operator's influence, operating modes, load parameters), whereas the effective daily operator's exposure should be measured during harvesting tests.
- Carbon fibre ensured a significant reduction in the vibrations transmitted to the hand-arm system with respect to the aluminium: 12.0 m/s^2 vs. 20.1 m/s^2, keeping constant the bar diameter (40 mm). This has also a positive effect on the comfort of the operators as reduce the global weight of the machinery. However this result should be investigate more in depth, as different results could be obtained when using carbon fibre of different features and/or aluminium with different alloy and thickness, so other bars of other manufacturers should be tested to evaluate the effect of the bar material on the vibrations.
- Given the quite high vibration level, operators should take into great consideration not only the harvest capacity of the portable harvesters, but also the health and safety aspects and take all the precautions to reduce vibration exposures.

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