Vibration on the backs of mistblower operators: is it only a (dis)comfort question?

DOI:10.1016/j.biosystemseng.2019.01.010

Vibration on the backs of mistblower operators: is it only a (dis)comfort question?

Angela Calvo[1], Christian Preti[2], Maurizio Cutini[3], Roberto Deboli[2]

[1] DISAFA (Department of Agricultural, Forest and Food Sciences and Technologies), Largo P. Braccini 2, 10095 Grugliasco, Turin, Italy

[2]IMAMOTER Institute for Agricultural and Earth-moving Machines of C.N.R (Italian National Research Council), Strada delle Cacce 73, 10135 Turin, Italy

[3] CREA Research Centre for Engineering and Agro-Food Processing, Via Milano 43, 24047 Treviglio (BG), Italy

Corresponding author: Angela Calvo, DISAFA (Department of Agricultural, Forest and Food Sciences), Largo P. Braccini4, 10095 Grugliasco, Turin, Italy. e-mail: angela.calvo@unito.it

Abstract

Mistblowers, also called powered backpack or knapsack sprayers, are found in many countries. Because of their low cost, adaptability and easy to use, they are often used in small-scale farms and in sloping fields. They are usually powered by an internal combustion engine which produces vibrations that are transmitted to the operator's body (hands, back, shoulders). In this work the vibration produced on the backs of twenty operators operating three mistblowers were studied in field, with the tank filled with 1, 5 and 10 l of pesticide with low and high engine speeds. The former occurs when the operator moves in field, the latter during the spraying. The vibration behaviour of the mistblowers was also tested in laboratory. There are no suitable standards to determine the risk of the vibration exposure to the operator’s back using backpack machines. The standard ISO 2631-1:1997 allows only a discomfort condition to be estimated. In our tests the highest Comfort Vibration Total Values (CVTV) were observed in field with the tank filled with 1 l of pesticide and at low engine speed. There were no statistically significant differences in the CVTVs among the operators, and one of the three machines (the oldest with a low level of maintenance) produced the highest CVTVs; up to 0.62 m s^{-2}. The *x*-axis (fore-and-aft direction) was the most dominant. The dominant one-third octave band centre frequency (or mid-frequency, ISO 5349-1: 2001) was 40 for the low engine speed and 100 Hz for the high engine speed.

Keywords: Back vibration; discomfort; mistblower; backpack power sprayer; whole body vibration

1. Introduction

Mistblowers consist of a two-stroke petrol engine driving a centrifugal fan and are carried on the back of the operator using a harness. They can also be termed powered knapsack or backpack sprayers. They were introduced to provide projection of spray using air-assistance to provide better penetration and coverage of the spray droplets (Jusoh, 1997) and are convenient when treating tree and bush crops since the operator does not need to manually operate a pump to obtain the necessary distribution pressure (Sutherland, 1979). Manually operating the pump lever on a standard knapsack sprayer has been shown to require the operator to expend 2 kcal min^{-1} or higher. Air-assistance from the fan also increases spray_coverage on the leaves_(Ruas, Balan, Saa, 2011). Mistblowers are relatively cheap and they have a good maintenance network (Thornhill, 1982; Matthews, 2008) and are widely available in developing countries (Kshirsagar, Dadmal, Umak, Munde, Mahale, 2016; Matanmi, Falola, Animashaun, Atanda, 2017). They are widely used in farms with a utilised agricultural areas less than 2-3 ha (Wang, Song, He, Li, Ling, 2016; Sutthiwaree, P., & Yang, M., 2015).

Mistblowers are widely used in the Mediterranean region (Hanafi, Hindy, Ghani, 2016; Maitah, Zidan, Hodrob, Malec, 2015) where many vineyards, orchards and olive groves are located in sloped terrains and in uneven grounds, where it is not possible working with a self-propelled sprayer or with a tractor-mounted sprayer. In Italy, these machines are commonly used at least 2 - 3 h per day for more than 20 - 30 days per year, depending on the crop type. But worldwide, their annual use varies with country, crop and topography. In Ghana, for example, Denkyirah et al. (2016) found that in cocoa plantations 6 pesticide sprays were applied and mistblowers were used for about 70 - 80 days per year.

Aside from pesticide contamination risks that can occur with mistblowers, physical risks related to noise and vibration transmitted to the whole body and to the hands of the operator occur. Cerruto, Manetto and Schillaci (2003) and Vilela, Malagoli, and Morrone (2005) analysed the noise produced by mistblowers and obtained values greater than 100 dB(A) at the operator's ear. Sasaki et al. (2014) obtained similar values, around 97 dB(A).

The accelerations produced by the internal combustion engine and by the moving parts of the various motorised hand-held or backpack machines used in agriculture (e.g. sprayers, pruners, olive and fruit beaters, blowers, grass trimmers, brush cutters, chainsaws) may affect different part of the operator's body (hands, wrists, elbow, shoulders, neck, back) depending on the construction of the machine. Many studies have analysed the hand-arm vibration risks caused by hand-held or pedestrian-controlled machines (Azmir & Yahya, 2017; Deboli, Calvo, Preti, 2016; Knibbs, 2014; Dewangan & Tewari, 2009; Sam & Kathirvel, 2006; Palmer, Griffin, Bendall, Pannett, Coggon, 2000; Ragni, Vassalini, Xu, Zhang, 1999; Bovenzi, Peretti, Zadini, Betta, Passeri, 1990). Piana, Marchesini, Deboli and Preti (2010) reported problems with shoulders, back, wrists and arms in more than 100 operators using backpack leaf blowers. Mallick (2008) investigated the transmission of vibration from a backpack grass trimmer to the hand-arm system (hand arm vibration, HAV) and found that the handle/hand positions and the operating parameters influenced HAV values during the grass trimming operation.

Kouchakzadeh and Beigzadeh (2015) analysed the vibration signals produced by a mistblower on the wrist, chest, head and neck of the operator using accelerometers fixed on the operator's body and found that the highest root mean square acceleration value occurred at the chest (2.5 m s^{-2}). Sasaki et al. (2014) examined noise parameters, body vibration level, energy expenditure and physical effort when using different types of mistblowers used in forestry (two with internal combustion engines, one electrically powered and one manual). When measuring vibration, they used a triaxial accelerometer housed in a structure and placed on the operator's back. The two sprayers using internal combustion engines produced vibrations with maximum values > 2 m s^{-2}.

Some studies focussed on evaluating the effect of the individual backpack components (e.g. harness) and the loads over the trunk muscle (Chow, Wang, Pope, 2014; Tang, Sun, Wang, Zhang, 2014).

International standards for measuring the vibration values of portable machines with internal combustion engines (blowers, brush-cutters, chainsaws) are available, but they only refer to the hand-arm vibration (ISO 11680-1: 2011, ISO 22867:2011, ISO 5349-1:2001). ISO 11680-1 (machines for use with backpack power source) cites the ISO 22867 for measuring HAV (paragraph 4.15.2), but at the same time the ISO 11680-2:2011 points out that a method to measure whole body vibration (WBV) from a backpack power machine is not yet available (paragraph 1, Note 1). The standard ISO 2631-1:1997, in addition to evaluating the human exposure to WBV, also permits the estimation of the vibration effects on the back using comfort coefficients to detect the discomfort that can arise (paragraph 8.1).

The discomfort produced by vibration on the back of seated or standing operators was studied by many Authors (Griffin, 1978; Griffin, Parsons, Whitham, 1982; Griffin, 2007; Thuong & Griffin, 2011), but nobody analysed the discomfort produced by backpack machines.. A set of field tests was conducted to analyse the discomfort produced by the vibration transmitted to the back of twenty operators, during their usual work in the field, when using three different mistblowers.

The goal of this work was to analyse the effects of different working conditions (machine, engine rotational speed and quantity of pesticide in the tank) and operator's body type on the vibration comfort at the operator's back. ISO 2631-1 was used only to estimate a possible operator discomfort due to the back vibration, without examining the vibration risk.

Two different set of tests were executed: the first was carried out in field, with twenty operators using three mistblowers with different tank filling (1, 5 and 10 l of pesticide) in two working situations, low engine speed (LES) and high engine speed (HES) with LES representing the engine speed when not spraying and HES representing the engine speed when spraying. The vibration comfort condition of the operators was examined using the comfort vibration total values (CVTVs) in the *x*, *y* and *z* axes, respectively the fore-and-aft, shoulder-shoulder and buttocks–head directions. A frequency analysis was carried out using the weighting curves, as required by the ISO 2631-1 standard. This test was performed in laboratory using the same running conditions as in the field, to characterise the vibratory behaviour of each machine, but without considering the comfort component.

2. Materials and methods

2.1. Tested machines

Three mistblowers were tested (Table 1). All machines used single-cylinder, two-stroke and air cooled engines. As is common practice, the engine and fan assembly was attached to the backrest metallic frame using anti-vibration mountings. The machines were equipped with padded backrests and easy-to-adjust straps (Fig. 1). Two machines were from the same manufacturer and of the same model (#1 and #2), the only difference being their year of production and condition. Machine #1 had been used for 220 h, Machine #2 used for 550 h, and Machine #3 used for 250 h.

Table 1 - Technical characteristics of the mistblowers

Machine code	Production year	Displacement cm^3	Mass kg	Rotation speed (LES) rad s^{-1} (rpm)	Rotation speed (HES) rad s^{-1} (rpm)	Power kW	Tank capacity l
1	2010	77	12.2	251.3 (2400)	645.1 (6160)	3.6	17
2	2006	77	12.2	251.3 (2400)	691.2 (6600)	3.6	17
3	2010	64.7	12.5	189.5 (1810)	748.8 (7150)	3.4	11

Fig. 1 – The tested mistblowers (from right to the left: Machine #1, Machine #2 and Machine #3)

2.2 Field tests

2.2.1 Geographic context

The tests were conducted in the vineyards located in Moncalvo, Monferrato, Italy (45°3'4"32 N latitude, 08°15'58"68 E longitude).

2.2.2 Operators

Twenty healthy men, familiar with working in the field with mistblowers, were recruited for the tests. The mean age of the subjects was 41.5 years (range 28-63 years), their mean body mass was 80.8 kg (range 68 - 90 kg) and their average height 1.79 m (range 1.72 - 1.84 m). The BMI (body mass index) was calculated for each operator (Table 2) (WHO, 1995).

Table 2 – Operators' BMI (Body Mass Index)

BMI class	Code	WHO definition	Number of operators in each class
18.5 - 22.9	1	normal range	4 (20%)
23 - 24.9	2	superior normal range	7 (35%)
25 - 27.5	3	overweight	5 (25%)
27.5 - 29.9	4	pre-obese	4 (20%)

2.2.3 Operative conditions

The mistblowers were operated in field under normal working conditions using the LES when moving among the rows of the vineyard, and the HES during spraying. Each of the twenty operators used all three machines and each test was repeated three times. Each operator properly adjusted the harness to balance the mass of the machine and to adapt the padded backpack to his back. To analyse the vibration produced by the machines with a different loads on the operator's back, different tank loads were tested; an almost empty tank with 1 l of spray liquid and with 5 and 10 l of product. A total of 1080 tests were carried out.

2.3 Laboratory tests

The machines had the empty tank during the 18 tests to establish their vibratory behaviour in laboratory, where they were suspended to a crane by a rope through their centre of gravity (Fig. 2). The runs were performed in both the LES and HES conditions.

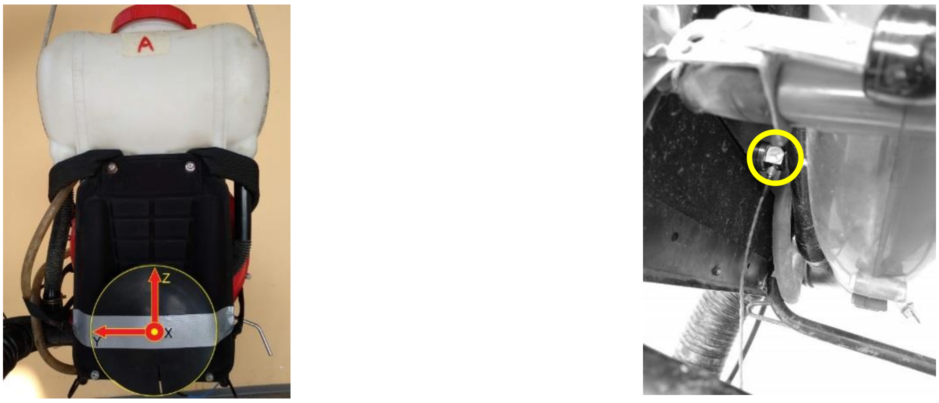
Fig. 2 – The suspended machine for analysing the vibratory behaviour in laboratory

2.4 Back measurements

2.4.1Measurement chain

A tri-axial accelerometer ICP®Model 356B4 (PCB Piezotronics, Depew, NY, USA) with a sensitivity of 100 mV g^{-1} and a 10g mass (ICP®, Integrate Current Preamplifier, PCB manufacturer, 356B41 model) was used for the real-time acquisition of the vibration values (along the three axes: x, y and z).

During the field tests the accelerometer was inserted in a rubber seat pad (ISO 10326-1: 2016), hardness 80 IRHD (International Rubber Hardness Degrees). The rubber pad was positioned on the lower part of the padded by an adhesive tape for avoiding the displacement of the measurement directions (Fig. 3a). In laboratory, the accelerometer was attached by a magnet to the central metal plate of the metal backpack frame (Fig. 3b).



(a) (b)

Fig. 3 – (a) Axes orientation with the rubber pad fixed on the padded backrest by an adhesive tape; (b) position of the accelerometer during the laboratory runs

During all the tests the accelerometer was connected to a National Instruments data acquisition card (NI 9234) with 51.2 kS s^{-1} sampling rate for each channel. Acquired data were stored on a laptop using the LabVIEW software (V.12.01f5, National Instr. Corp., Austin, TX, USA). The accelerometers and cables were calibrated by Brüel & Kjær calibrator type 4294 (standard acceleration level of 10 m s^{-2}). The measurement system was checked before and after each set of runs.

2.4.2 Back weighted vibration total values and comfort vibration total values (ISO 2631-1)

The ISO 2631-1 standard (paragraph 8.2.2.1) gives specific frequency weighting curves and multiplying factors to evaluate the health and the comfort at the back: only one weighting factor is provided for the health on the *x*-axis, whereas for comfort three weighting factors are given for the *x*, *y* and *z* axes are given (Table 3). For the *x*-axis the frequency weighting curve is W_c and the weighting factor is 0.8. The W_d curve is used for the *y* and *z*-axes with weighting factors 0.5 and 0.4 respectively.

Table 3 - Frequency-weighting curves and multiplying factors for health and comfort (source: ISO 2631-1)

Axis	Health		Comfort	
	Frequency weighting curve	Multiplying factor (k)	Frequency weighting curve	Multiplying factor (k)
x	W_c	0.8	W_c	0.8
y	-	-	W_d	0.5
z	-	-	W_d	0.4

Accelerations along the three axes were acquired for each machine, working condition (LES and HES), tank filling and operator. The acquisition time for each run was at least two minutes to obtain a steady-state signal. Each run was repeated three times.

Vibration data were processed using LabVIEW software and converted from the time domain to the frequency domain and one-third octave bands were obtained. The signals were weighted using the weighting curves W_c and W_d. The resulting data were converted to the root-mean-square (r.m.s.) acceleration.

The comfort vibration total values (CVTVs) a_{cv} were calculated as requested by the ISO 2631-1 (paragraph 6.5) (Eq. 1).

$$a_{cv} = \sqrt{k_x^2 a_{wx}^2 + k_y^2 a_{wy}^2 + k_z^2 a_{wz}^2} \tag{1}$$

where a_{cv} = comfort vibration total value, a_{wx}= acceleration along the x-axis (weighting curve W_c), a_{wy} = acceleration along the y-axis (weighting curve W_d), a_{wz} = acceleration along the z-axis (weighting curve W_d), k_x = comfort weighting factor for the x-axis (0.8), k_y = comfort weighting factor for the y-axis (0.5) and k_x = comfort weighting factor for the z-axis (0.4)

In laboratory the acquired acceleration along the three axes were weighted using the weighting curves (Table 3) and the vibration total values (VTVs) a_v were calculated as the square root of the sum of the squares of a_{wx}, a_{wy} and a_{wz}, without the comfort factors (Eq. 2).

$$a_v = \sqrt{a_{wx}^2 + a_{wy}^2 + a_{wz}^2} \qquad (2)$$

2.5 Scale of the vibration discomfort

The British Standard 6841:1987 and the ISO 2631-1 both suggest a scale of r.m.s. vibration discomfort (Table 4).

Table 4 - Scale of the vibration discomfort (adapted by ISO 2631-1)

Range		Evaluation
r.m.s < 0.315	m s^{-2}	not uncomfortable
0.315 ≤ r.m.s <0.63	m s^{-2}	a little uncomfortable
0.5≤ r.m.s <1	m s^{-2}	fairly uncomfortable
0.8≤ r.m.s <1.6	m s^{-2}	uncomfortable
1.25≤ r.m.s <2.5	m s^{-2}	extremely uncomfortable

This scale was used to compare the acquired values.

2.6 Data elaboration

Data were recorded and analysed using IBM SPSS Statistics (V. 24, International Business Machines Corporation, Armonk, New York, U.S.A.). The Pearson test was used for testing correlations between BMI and CVTV (being this the possible correlated variable that could interfere with the use of the following GLM procedures). The GLM (general linear model) is a method for analysing quantitative data and understanding how the mean response relates to a set of independent predictors. For these reasons GLM was used to assess the effects of the variables machine, operator and tank filling on the CVTVs and on the VTVs (Keppel & Wickens, 2004). When useful, the Ryan, Einot, Gabriel, and Welsch (R-E-G-W) post-hoc tests (based on the F test, as the GLM) were performed. The homoscedastic condition (assumption of equal variance) was previously tested by the Levene's test. All statistic tests used a confidence level p = 0.01.

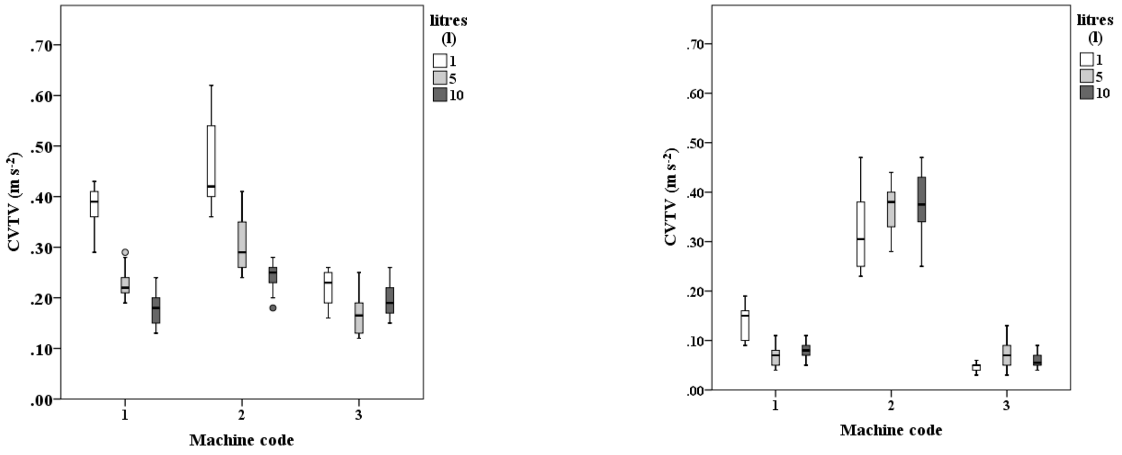
3. Results

3.1 Field

3.1.1 Comfort vibration total values (CVTVs)

The first analysis of the CVTVs in field highlighted two points (Fig. 4):

- at LES the CVTVs were usually higher (until 0.62 m s^{-2}) and the lowest tank fillings produced highest CVTVs on the operator's back
- machine #2 produced the highest CVTVs as well as more variation in the data



(a) LES

(b) HES

Fig. 4 - Box-whisker graphs of the CVTVs in function of: engine speed, machine code and tank filling

A possible correlation between the operators and the BMI classes with the CVTVs was checked, to avoid mistakes when using the GLM statistic. No correlation was found, neither for the operator, nor for the BMI classes (Pearson coefficients were between -0.02 and 0.08 with a p level = 0.001). Two GLMs were then executed (for each engine rotation speed), setting as fixed factors the machine code, the tank filling (1, 5 and 10 l) and the BMI class. While at the LES all the variables were significantly different. At HES only a likeness was detected for the variable tank filling.

In both the cases (LES and HES) the post-hoc test was performed (Table 5). As it was expected, the machine always showed CVTVs statistically different (especially the Machine #2 at the HES with a CVTV equal to 0.35 m s^{-2} against 0.06 m s^{-2} of the Machine #3 and 0.09 m s^{-2} of the Machine #1). At LES condition, average CVTVs were inversely proportional to the tank filling (0.35 m s^{-2} with 1 l of product, 0.23 m s^{-2} with 5 l and 0.20 m s^{-2} with 10 l), while at HES all the CVTVs averages were 0.17 m s^{-2}.

Table 5 -Post-hoc tests of the GLM on CVTVs in the LES and HES conditions (p = 0.01). The subset values are the means calculated for the number of data (N) in each subset.

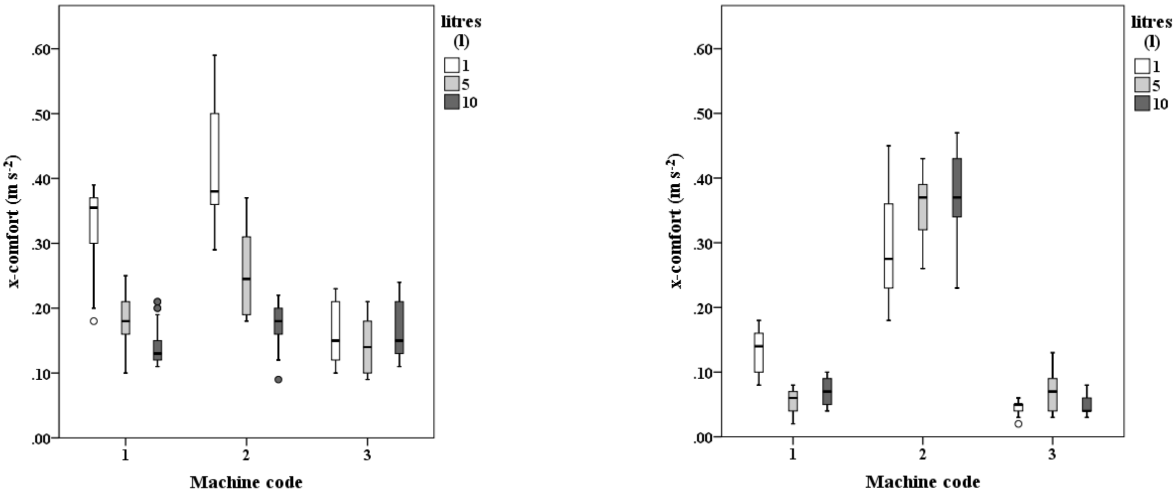
		LES (m s^{-2})					HES (m s^{-2})		
Machine	N	Subset			Machine	N	Subset		
		1	2	3			1	2	3
3	180	0.19a			3	180	0.06a		
1	180		0.26b		1	180		0.09b	
2	180			0.33c	2	180			0.35c
	Sign.	1	1	1		Sign.	1	1	1
Litres (l)	N	Subset			Litres (l)		Subset		
		1	2	3			1		
10	180	0.20a			1		0.17a		

5	180		0.23b		5		0.17a
1	180			0.35c	10		0.17a
	Sign.	1	1	1		Sign.	0.658

BMI class	N	Subset			BMI class	N	Subset			
		1	2	3			1	2	3	4
4	108	0.24a			1	108	0.14a			
1	189		0.26b		2	189		0.16b		
2	135		0.26b		4	135			0.17c	
3	108			0.28c	3	108				0.18d
	Sign.	1	0.778	1		Sign.	1	1	1	1

Note: different letters indicate different subsets

Analysis of the comfort along the *x*, *y* and *z* axes highlighted highest and floating data for the *x*-axis, oriented in the fore-and-aft direction (Fig. 4), reaching values around 0.6 m s^{-2} in the LES condition (Fig. 5). Mistblower #2 had the highest values. The GLMs performed for the *x*, *y* and *z* comfort axes gave information similar to the GLMs for CVTVs. As expected, for all machines the post-hoc test always gave different subset values along all the three axes.



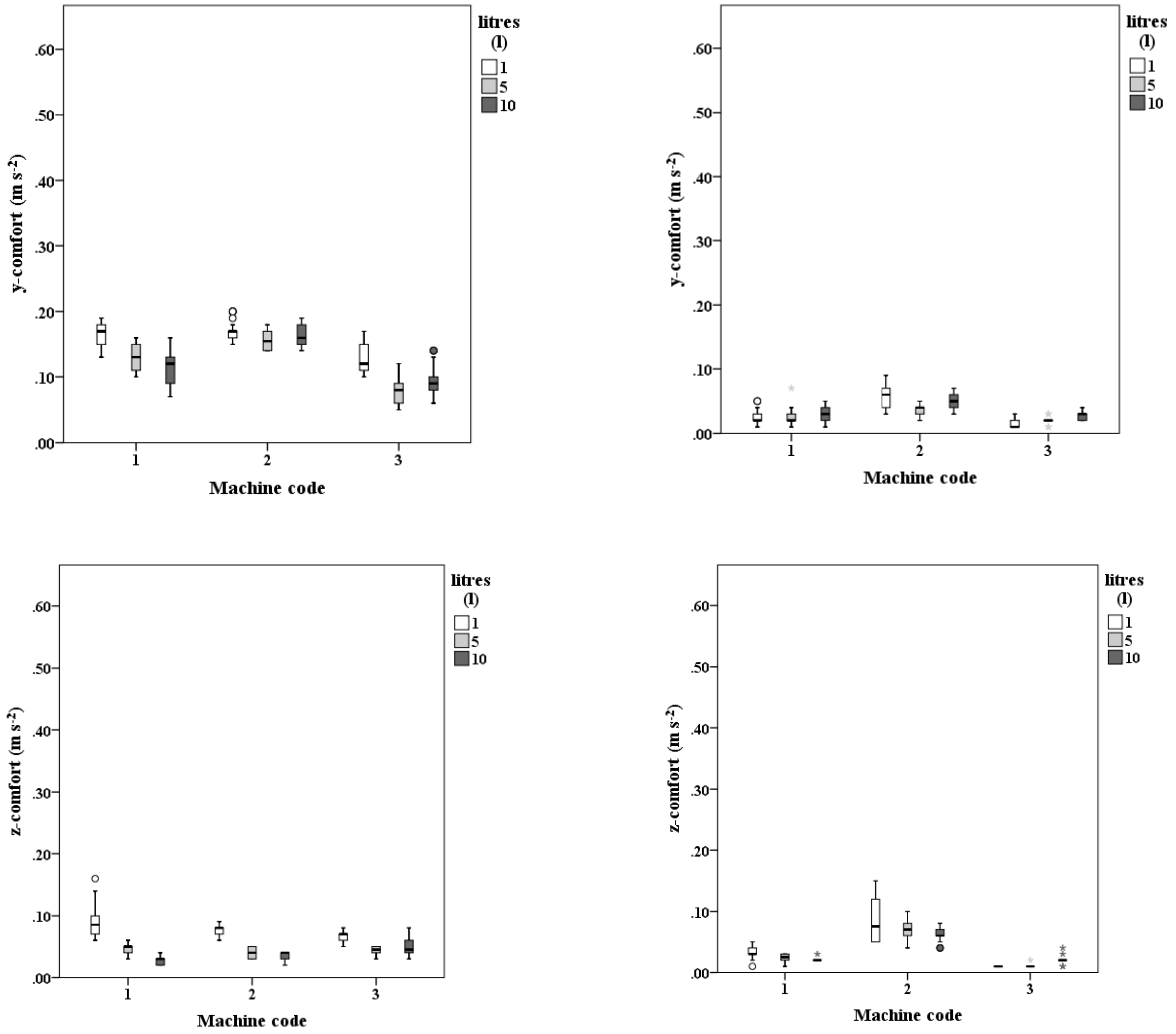


Fig. 5 - Box-whisker graphs of *x*, *y* and *z* comfort values in function of the machine and of the tank filling (left: LES; right: HES)

3.1.2 Frequency analysis

The VTVs frequency analysis was carried out considering the three machines (at LES and HES) with the tank filled with 1 and 5 l. The tanks were not filled to 10 l because the VTVs were similar at the 5 l of product.

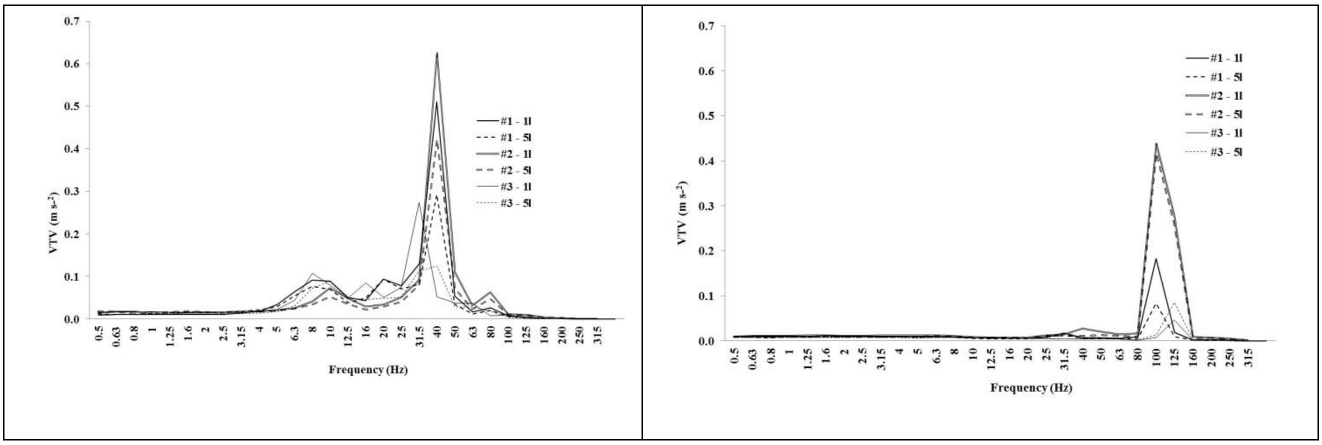


Fig. 6 - VTVs one-third octave band analysis in field of the tested machines with the tank filled with 1 and 5 l (left: LES, right: HES)

The fundamental one-third octave band centre frequency (also called the mid-frequency in ISO 5349-1: 2001) of the VTVs at LES with machines #1 and #2 was found to be 40 Hz, independent of tank filling (Fig. 6). Machine #2 registered VTVs higher than 0.6 m s^{-2} with 1 l and > 0.4 m s^{-2} with 5 l (Fig. 6). Machine #3 showed the fundamental at the one-third octave band with the centre frequency at 31.5 Hz with 1 l of product and at mid-frequency of 40 Hz with 5 l of pesticide: the curves of the Machine #3 had a shape more floating then the curves of the other machines.. The vibration energy distribution of Machines #1 and #2 at the HES condition was very similar. Both machines had the fundamental sharply defined at the one-third octave band with a centre frequency at 100 Hz (with values > 0.4 m s^{-2} with 1 and 5 l for the Machine #2 and < 0.2 m s^{-2} with 1 l and 0.1 m s^{-2} with 5 l for the machine #1). Machine #3 had a fundamental slightly greater (central frequency: 125 Hz) with data lower than 0.1 m s^{-2} (Fig. 6).

Frequency analysis of the signal along the three axes was performed with the tank filled with 5 l of spray liquid. Analysis of the acceleration along the three axes showed a more irregular trend of the curves at LES (as in the VTVs), when the engine rotational speed had greater fluctuations. For example the engine of the Machine # 2 continuously varied the speed from 233.5 rad/s to 260.7 rad/s). The highest vibration values occurred along the *x*-axis, the lowest along the *y* and *z*-axes.

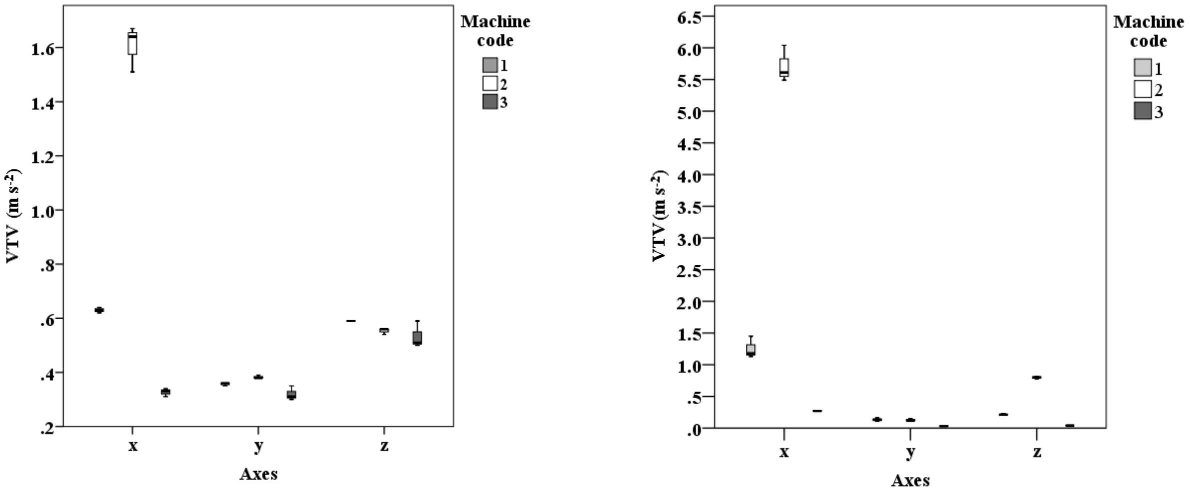
The *y* component varied the most. At HES, acceleration data concentrated near the fundamental frequencies (mid-frequency at 100 Hz for the Machines #1 and #2, at 125 Hz for the Machine #3).

3.2 Laboratory tests

3.2.1 Vibration total values

The tests conducted in laboratory with the suspended machines explained the anomalous results of the Machine #2 in field. The VTVs of the Machine #2 were around 2 times the VTVs of the other mistblowers at the LES (average of about 1.8 m s^{-2} the Machine #1, values less than 1 m s^{-2} the Machines #1 and #3) and more than 4 times at the HES (average 6 m s^{-2} the Machine #1, values lower than 1.4 and 0.5 m s^{-2} the Machines #1 and #3 respectively). As expected, the GLM procedure indicated all the subsets of the VTVs calculated per machine and per engine condition as statistically different to each other.

The analysis along the *x*, *y* and *z* axes confirmed also in this case that the x-axis was the most solicited. It was surprising the enormous difference among the values of the x-axis of the Machine #2 (average > 1.6 m s^{-2} at LES and very close to 6 m s^{-2} at HES) and the corresponding values the other machines (about 1 m s^{-2} and 0.7 m s^{-2} in the LES condition and nearly 1.3 m $s^{-2}$and 0.3 m s^{-2} at HES, respectively for the Machines #1 and #3) (Fig. 7).



(a) LES (b) HES

Fig. 7 -Box-whisker graphs of the accelerations measured in laboratory along the *x*, *y* and *z* axes

At LES the GLM procedure reported statistically significant differences along the *x*-axis, while the other axes could be considered similar. By contrast, at HES all the acceleration values obtained along the three axes were statistically different.

3.2.2 Frequency analysis

The frequency analysis of the VTVs of the three machines tested in laboratory confirmed the trends observed in field with the same dominant frequencies at LES and HES (centre frequencies of the one-third octave band respectively at 40 Hz and 100 Hz for the Machines #1 and #2 and at 31.5 Hz and 125 Hz for the Machine #3). Here, at LES the values were 0.8 m s^{-2} (Machine #1), more than 1.6 m s^{-2} (Machine #2) and about 0.37 m s^{-2} (Machine #3). At the same points they increased to more than 1 m s^{-2} (Machine #1), nearly 5 m s^{-2} (Machine #2) and less than 0.3 m s^{-2} (Machine #3) at HES.

4. Discussion

The CVTVs obtained at the operators' back appear to validate the hypothesis of the vibration being a *trifling nuisance*. In the worst case the CVTV reached 0.62 m s^{-2} with Machine #2, but it was usually < 0.40 m s^{-2} at LES and 0.20 m s^{-2} at HES. These values were similar to the results obtained by Deboli et al. (2013), who obtained averages of 0.37 m s^{-2} and 0.28 m s^{-2} respectively at LES and HES. Sasaki et al. (2014), obtained values > 2 m s^{-2}, but they did not consider the comfort.

Some of the observed values were in the *little uncomfortable* condition of the British Standard 6841 and the ISO 2631-1 scale, except for Machine #2 that was in the *fairly uncomfortable* class (Table 4).

There is, however a personal perception of the vibration discomfort, as observed by Griffin (2007). The current standard tries to translate it into procedures that consider all the vibration factors (direction, magnitude and frequency), but these actions do not always provide the desired results. The operator's discomfort may be affected by other factors than vibration (for example noise, weariness, ailment, etc.) and it may produce shifts so small as to be not perceived by the operator. A factor that may influence the operator's judgment of vibration discomfort is the noise produced by mistblowers. The literature reports sound level values never lower than 94 - 100 dB(A) (Bansal, 1998; Cerruto et al., 2003; Vilela et al., 2005; Sasaki et al., 2014). Huang and Griffin (2014) noticed that the feeling of the discomfort by operators related to WBV could be lowered by the presence of the noise, acting as 'masking effect'. In our study the operators correctly used hearing protection (in this case ear muffs) and therefore the noise at the operators' ears was lowered, but Huang and Griffin (2014) found an evidence of the masking effect also at lower noise levels (from 75 to 88 dB(A)), when the operators wore ear muffs.

The analysis of the comfort acceleration highlighted that the *x*-axis (oriented along the fore-and-aft direction) was the most prevailing. Frequency analysis showed high VTVs (without considering scaling factors), especially with the tank almost empty and at LES, reaching values between 0.3 and 0.6 m s^{-2} at the dominant mid-frequency of 40 Hz. Lower values were observed at HES; between

0.1 and 0.4 m s^2 at the dominant mid-frequency of 100 Hz. VTVs were not affected by scaling, but at several frequencies they were reduced by the W_c (x-axis) and W_d (y and z axes) weighting curves (Fig. 8). At the dominant 40 and 100 Hz mid-frequencies, for example, the W_c curve was reduced by around 14 and 25 dB respectively, while the W_d curve reduced the acquired signal by about 26 and 37 dB.

The W_c and W_d weighting curves are normally applied to the case of back vibration transmitted by a seat, or by a vibrating platform, where the operator is seated (former) or is standing (latter), but there is no evidence that these curves are suitable when the vibration is transmitted by a back-mounted power machine. This study could be useful for developing more suitable weighting curves for analysing these aspects.

The dominant mid-frequencies at 40 and 100 Hz were caused by the engine and by the fan rotation. This aspect should be studied more deeply. The vibrational behaviour of the three machines tested in the laboratory confirmed that the vertical movement of the single piston of the engine was responsible of the acceleration in the fore-and-aft direction (x axis). As discussed in section 3.1.1, operator body mass and operating mode did not appear to influence vibration. The high vibrations at HES obtained in laboratory appear to be dampened by the padding of the harness when used in the field, as observed also by other studies (Chow et al., 2014, Tang et al., 2014).

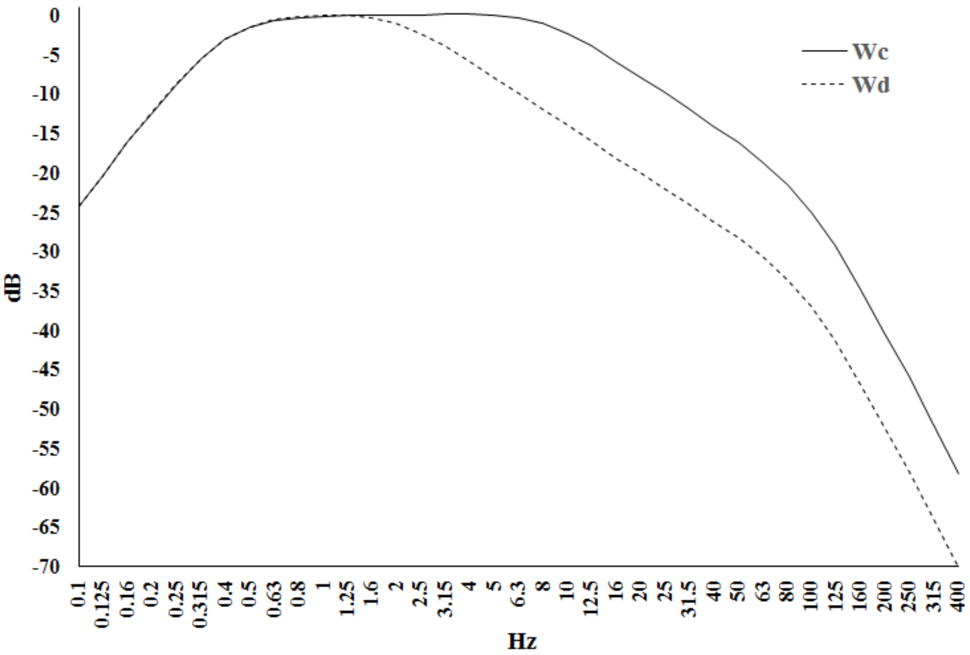


Fig. 8 -Weighting curves applied to the acquired signals along the three axes: W_c (*x*-axis) and W_d (*y* and *z* axes) (adapted from ISO 2631-1)

The vibration analysis confirmed the anomalous behaviour of the Machine #2. This machine was the oldest and poorly maintained. Machine #2 lacked correct fan balancing and maintenance of the engine and isolating mount between the frame and engine. The most important message perceived by the operators involved in the tests concerning maintenance related to the condition of the spray distribution system, because they had received specific training, as requested by the European Directive 2009/128/CE. They were less interested in the maintenance of the motorised parts of the machine, but nevertheless they all perceived a feeling of nuisance related to the lack of comfort on the back when using Machine #2. This nuisance was observed despite them correctly wearing the sprayer and balancing the harness for the best condition as observed by Bansal (1998).

Although the transmission of vibration transmitted to the backs of mistblower operators has not received much attention, the study carried out by Deboli et al. (2013) in laboratory did show sensible changes of the cutaneous temperature of the skin surface when using these types of machines. Despite the richness of medical studies carried out over many years on the back disorders produced by WBV vibration (Bovenzi & Betta, 1994; Bluthner, Seidel, Hinz, 2001; Petit & Roquelaure, 2015; Beard & Griffin, 2016; Zhou & Griffin, 2017), the literature is still lacking of medical studies on the back discomfort that can be caused by motorised back-mounted portable machines. The harness surely dampens the effects vibration on the body of the operator, but it cannot be sufficient, especially with poorly maintained machines.

5. Conclusion

The discomfort on the back produced by vibrations from by mistblowers, operating under different working conditions and different tank fillings, was investigated using a procedure suggested by the standard ISO 2631-1. The observed values usually fell inside a range of *little uncomfortable* condition as specified by the standard, although the oldest machine with the poorest maintenance of mechanical components produced increased vibration on the back.

The ISO 2631-1 standard examines operator comfort but it was developed for the case of WBV transmitted by seats or vibrating floors. The discomfort concept can be applied to the vibrations transmitted to the backs of operators of motorised backpack operators since, although it could be regarded as misleading, there is little suitable alternative data or reference standards. We were wary of using a flat weighting curve, but suitable medical and ergonomic comparisons are not available. In the case of the hand-arm vibration (HAV) from powered tools, many studies have been carried out recently and standards are available concerning osteoarticular (ISO 5349-1:2001) and vascular vibration risks (ISO/TR 18530:2017). It is clear that whilst HAV may be a serious risk, back vibrations mostly concern comfort, although attention is being placed on stress, discomfort, early fatigue and mask effects.

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

References

Azmir, N.A., & Yahya, M.N. (2017). Prevalence of Hand-transmitted Vibration Exposure among Grass-cutting Workers using Objective and Subjective Measures. *IOP Conference Series: Mathematics, Science and Engineering*, 165, 12-26. https://doi.org/10.1088/1757-899X/165/1/012026.

Bansal, A.S. (1998). Dynamic Response and Vibration Control at the Source in a Powered-backpack Sprayer. AMA, Agricultural Mechanization in Asia, Africa and Latin America, 29(3), 23-26.

Beard, G.F., & Griffin, M.J. (2016). Discomfort of seated persons exposed to low frequency lateral and roll oscillation: Effect of backrest height. *Applied Ergonomics*, 54, 51-61. https://doi.org/10.1016/j.apergo.2015.11.010.

Bluthner, R., Seidel, H., & Hinz, B. (2001). Examination of the myoelectric activity of back muscles during random vibration. Methodical approach and first results. *Clinic Biomedical*, 16(1), 25-30. PUBMED id: 11275340.

Bovenzi, M., Peretti, A., Zadini, A., Betta, A., & Passeri, A.C. (1990). Physiological reactions during brush saw operation. *International Archives of Occupational and Environmental Health*, 62(6), 445-449. https://doi.org/10.1007/BF00379061.

Bovenzi, M., & Betta, A. (1994). Low-back disorders in agricultural tractor drivers exposed to whole-body vibration and postural stress. *Applied Ergonomics*, 25(4), 231–241. https://doi.org/10.1016/0003-6870(94)90004-3.

British Standard 6841. (1987). Measurement and evaluation of human exposure to whole-body mechanical vibration and repeated shock. *BS 6841*. British Standards Institution.

Cerruto, E., Manetto, G., & Schillaci, G. (2003). Noise levels during the mechanised operations in protected crops. *Acta Horticulturae*, 614, 819-824. https://doi.org/10.17660/ActaHortic.2003.614.120.

Chow, D.H.K., Wang, C., & Pope, M.H. 2014. Effects of backpack carriage on lumbopelvic control: A dynamical systems analysis. *International Journal of Industrial Ergonomics*, 44, 493-498. https://doi.org/10.1016/j.ergon.2014.04.002.

Deboli, R., Calvo, A., Rapisarda, V., Preti, C., & Inserillo, M. (2013). Vibration transmitted to operator’s back by machines with back-pack power unit: a case study on blower and spraying machines. *Journal of Agricultural Engineering*, 44(e146), 724-729. https://doi.org/10.4081/jae.2013.(s1):e146.

Deboli, R., Calvo, A., & Preti, C. (2016). Vibration and impulsivity analysis of hand held olive beaters. *Applied Ergonomics*, 55, 258-267. https://doi.org/10.1016/j.apergo.2015.11.003.

Denkyirah, E.K., Okoffo, E.D., Taylor Adu, D., Aziz, A.A., Ofori, A. & Denkyirah, E.K. (2016). Modeling Ghanaian cocoa farmers’ decision to use pesticide and frequency of application: the case of Brong Ahafo Region. *SpringerPlus*, 5:1113. https://doi.org/10.1186/s40064-016-2779-z.

Dewangan, K.N., & Tewari, V.K. (2009). Vibration energy absorption in the hand–arm system of hand tractor operator. *Biosystems Engineering,* 3, 427-437. https://doi.org/10.1016/j.biosystemseng.2009.06.001.

European Commission (2009). Directive 2009/128/EC.

Griffin, M.J. (1978). The evaluation of vehicle vibration and seats. *Applied Ergonomics*, 9(1), 15-21. https://doi.org/10.1016/0003-6870(78)90214-4.

Griffin, M.J., Parsons, K.C., & Whitham, E.M. (1982). Vibration and comfort. IV. Application of experimental results. *Ergonomics,* 25(8), 721–739. https://doi.org/10.1080/00140138208925030.

Griffin, M.J. (2007). Discomfort from feeling vehicle vibration. *Vehicle System Dynamics*, 45(7-8), 679-698. https://doi.org/10.1080/00423110701422426.

Hanafi, A., Hindy, M., & Ghani, S.A. (2016). Effect of spray application techniques on spray deposits and residues of bifenthrin in peas under field conditions. *Journal of Pesticide Science*, 41(2), 49-54. https://doi.org/10.1584/jpestics.D15-071.

Huang, Y., & Griffin, M.J. (2014). The discomfort produced by noise and whole-body vertical vibration presented separately and in combination. *Ergonomics*, 57(11), 1724-1738. https://doi.org/10.1080/00140139.2014.943683.

Keppel, G., & Wickens, T.D. (2004). *Design and analysis: A researchers handbook*. (4th ed.). NJ: Upper Saddle River (Chapter 2).

Knibbs, L.D., 2014. Occupational hazards to the health of professional gardeners. International *Journal of Environmental Health Research*, 24(6), 580–589. https://doi.org/10.1080/09603123.2014.883594.

Kshirsagar, S., Dadmal, V., Umak, P., Munde, G., & Mahale, P.R. (2016). Design and Development of Agriculture Sprayer Vehicle. *International Journal of Current Engineering and Technology*, 4, 405-408. http://inpressco.com/category/ijcet.

Kouchakzadeh, A., & Beigzadeh, Y. (2015). Permitted working hours with a motorised backpack sprayer. *Biosystems Engineering*, 136, 1-7. https://doi.org/10.1016/j.biosystemseng.2015.05.005.

Jusoh, M.M. (1997). Spraying performance of lever-operated and motorised backpack sprayers, and motorised mistblower on rice crop. *Journal of Tropical Agriculture and Food Science*, 25(2), 239–248.

ISO 10326-1. (2016). Mechanical vibration. Laboratory method for evaluating vehicle seat vibration. Part 1: Basic requirements *International Organization for Standardization, (ISO).*

ISO 11680-1. (2011). Machinery for forestry. Safety requirements and testing for pole-mounted powered pruners. Part 1: Machines fitted with an integral combustion engine. *International Organization for Standardization, (ISO).*

ISO 11680-2. (2011). Machinery for forestry. Safety requirements and testing for pole-mounted powered pruners. Part 2:Machines for use with back-pack power source. *International Organization for Standardization, (ISO).*

ISO 22867. (2011). Forestry and gardening machinery. Vibration test code for portable hand held machines with internal combustion engine. Vibration at the handles. *International Organization for Standardization, (ISO).*

ISO 5349-1. (2001). Mechanical vibration. Measurement and evaluation of human exposure to hand-transmitted vibration. *International Organization for Standardization, (ISO).*

ISO 2631-1. (1997). Mechanical vibration and shock e Evaluation of human exposure to whole-body vibration. Part 1: General requirements. *International Organization for Standardization, (ISO).*

Maitah, M., Zidan, K., Hodrob, R., & Malec, K. (2015). Farmers Awareness Concerning Negative Effects of Pesticides on Environment in Jordan. *Modern Applied Science*, 9(2), 12-19. https://doi.org/10.5539/mas.v9n2p12.

Mallick, Z. (2008). Optimization of operating parameters for a back-pack type grass trimmer. *International Journal of Industrial Ergonomics*, 38, 101-110. https://doi.org/10.1016/j.ergon.2007.09.005.

Matanmi, B.M., Falola, A., Animashaun, J.O., & Atanda, T.O. (2017). Effect of Fadama III program on dry-season vegetable growers in Kwara Condition, Nigeria. *Kasetsart Journal of Social Sciences*, 38(2), 163-168. https://doi.org/10.1016/j.kjss.2016.04.002.

Matthews, G.A. (2008). Attitudes and behaviours regarding use of crop protection products. A survey of more than 8500 smallholders in 26 countries. *Crop Protection*, 27, 834–846. https://doi.org/10.1016/j.cropro.2007.10.013.

Palmer, K.T., Griffin, M.J., Bendall, H., Pannett, B., & Coggon, D. (2000). Prevalence and pattern of occupational exposure to hand transmitted vibration in Great Britain: Findings from a national survey. *Occupational and Environmental Medicine*, 57(4), 218-228. https://doi.org/10.1136/oem.57.4.218.

Petit, A., & Roquelaure, Y. (2015). Low back pain, intervertebral disc and occupational diseases. *International Journal of Occupational Safety and Ergonomics* (JOSE), 21(1), 15-19. https://doi.org/10.1080/10803548.2015.1017940.

Piana, E.A., Marchesini, A., Deboli, R., & Preti, C. (2010). Rischio da esposizione a vibrazioni per l'uso di soffiatori a zaino: valutazione dell'esposizione a vibrazioni trasmesse al corpo intero e alla spalla. *Atti del 37° Convegno Nazionale AIA (Associazione Italiana di Acustica),* Siracusa, Italia, 123-130.

Ragni, L., Vassalini, G., Xu, F., & Zhang L.B. (1999). Vibration and Noise of Small Implements for Soil Tillage. *Journal of Agricultural Engineering Research*, 74, 403-409. https://doi.org/10.1006/jaer.1999.0478.

Ruas, J.M.F., Balan, R., & Saa, O.J.G.A. (2011). Coverage comparison by backpack sprayers manual and engine powered. *Ciências Agrárias*, 32(4), 1417-1422. https://DOI: 10.5433/1679-0359.2011v32n4p1417

Sam, B., & Kathirvel, K. (2006). Vibration characteristics of walking and riding type power tillers. *Biosystems Engineering*, 95(4), 517–528. https://doi.org/10.1016/j.biosystemseng.2006.08.013.

Sasaki, R.S., Furtado Júnior, M.R., Leite, E.S., Souza, A.P., Teixeira, M.M., & Fernandes, H.C. (2014). Ergonomic evaluation of backpack sprayers used in forestry. *Revista Arvore*, 38(2), 331-337. http://dx.doi.org/10.1590/S0100-67622014000200013.

Sutherland, J.A. (1979). The Evaluation of Lever-operated Knapsack and Motorised Knapsack Sprayers. *PANS*, 25(3), 332-364. https://doi.org/10.1080/09670877909412112.

Sutthiwaree, P., & Yang, M. (2015). The rice production situation and mechanization level in the North Region of Thailand: Chiang Rai Province. *American Society of Agricultural and Biological Engineers Annual International Meeting*, 1, 49-56.

Tang, Z., Sun, S., Wang, J., & Zhang, K. (2014). An ergonomics evaluation of the vibration backpack harness system in walking. *International Journal of Industrial Ergonomics*, 44, 753-760. https://doi.org/10.1016/j.ergon.2014.08.004.

Thornhill, E.W. (1982). A summary of methods for testing pesticide application equipment. *Tropical Pest Management*, 28(4), 335-346. https://doi.org/10.1080/09670878209370738.

Thuong, O., & Griffin, M.J. (2011). The vibration discomfort of standing people: Relative importance of fore-and-aft, lateral, and vertical vibration. *Applied Ergonomics*, 43, 902-908. https://doi.org/10.1016/j.apergo.2011.12.011.

Vilela, R.A.G., Malagoli, M.E., & Morrone, L.C. (2005). Trabalhadores da saúdesobrisco: o uso de pulverizadores no controle de vetores. *Revista Produção*, 15(2), 263-272. http://dx.doi.org/10.1590/S0103-65132005000200010.

Wang, S., Song, J., He, X., Li, Y., & Ling, Y. (2016). Design of air-assisted electric backpack sprayer and experiment of its operation performance. *Nongye Gongcheng Xuebao/Transaction of the Chinese Society of Agricultural Engineering*, 32(21), 67-73. https://doi.org/10.11975/j.issn.1002-6819.2016.21.009.

WHO (World Health Organization). (1995). Physical status: the use and interpretation of anthropometry. *WHO Technical Report Series*, 854.

Zhou, Z., & Griffin, M.J. (2017). Response of the seated human body to whole-body vertical vibration: discomfort caused by mechanical shocks. *Ergonomics*, 60(3), 347-357. https://doi.org/10.1080/00140139.2016.1164902.

Figure captions

Fig. 1 – Tested mistblowers (from right to the left: Machine #1, Machine #2 and Machine #3)

Fig. 2 – Suspended machine for analysing the vibration behaviour in laboratory

Fig. 3 – (a) Axes orientation with the rubber pad fixed on the padded backrest by an adhesive tape; (b) position of the accelerometer during the laboratory runs

Fig. 4 - Box-whisker graphs of the CVTVs in function of: engine speed, machine code and tank filling

Fig. 5 - Box-whisker graphs of x, y and z comfort values as a function of machine and tank filling (left: LES; right: HES)

Fig. 6 - VTVs one-third octave band analysis in field of the tested machines with the tank filled with 1 and 5 l (left: LES, right: HES)

Fig. 7 -Box-whisker graphs of the accelerations measured in laboratory along the x, y and z axes

Fig. 8 -Weighting curves applied to the acquired signals along the three axes: W_c (x-axis) and W_d (y and z axes) (adapted from ISO 2631-1)