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

(Article begins on next page)

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

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11

12   **Abstract**

13   Mistblowers, also called powered backpack or knapsack sprayers, are found in many countries.

14   Because of their low cost, adaptability and easy to use, they are often used in small-scale farms and

15   in sloping fields. They are usually powered by an internal combustion engine which produces

16   vibrations that are transmitted to the operator's body (hands, back, shoulders). In this work the

17   vibration produced on the backs of twenty operators operating three mistblowers were studied in

18   field, with the tank filled with 1, 5 and 10 l of pesticide with low and high engine speeds. The

19   former occurs when the operator moves in field, the latter during the spraying. The vibration

20   behaviour of the mistblowers was also tested in laboratory. There are no suitable standards to

21   determine the risk of the vibration exposure to the operator's back using backpack machines. The

22   standard ISO 2631-1:1997 allows only a discomfort condition to be estimated. In our tests the

23   highest Comfort Vibration Total Values (CVTV) were observed in field with the tank filled with 1 l

24   of pesticide and at low engine speed. There were no statistically significant differences in the

25   CVTVs among the operators, and one of the three machines (the oldest with a low level of

1

26 maintenance) produced the highest CVTVs; up to 0.62 m s^{-2}. The x-axis (fore-and-aft direction) was

27 the most dominant. The dominant one-third octave band centre frequency (or mid-frequency, ISO

28 5349-1: 2001) was 40 for the low engine speed and 100 Hz for the high engine speed.

29

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

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32

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

82   combustion engines, one electrically powered and one manual). When measuring vibration, they

83   used a triaxial accelerometer housed in a structure and placed on the operator's back. The two

84   sprayers using internal combustion engines produced vibrations with maximum values $> 2 \text{ m s}^{-2}$.

85

86   Some studies focussed on evaluating the effect of the individual backpack components (e.g.

87   harness) and the loads over the trunk muscle (Chow, Wang, Pope, 2014; Tang, Sun, Wang, Zhang,

88   2014).

89   International standards for measuring the vibration values of portable machines with internal

90   combustion engines (blowers, brush-cutters, chainsaws) are available, but they only refer to the

91   hand-arm vibration (ISO 11680-1: 2011, ISO 22867:2011, ISO 5349-1:2001). ISO 11680-1

92   (machines for use with backpack power source) cites the ISO 22867 for measuring HAV (paragraph

93   4.15.2), but at the same time the ISO 11680-2:2011 points out that a method to measure whole body

94   vibration (WBV) from a backpack power machine is not yet available (paragraph 1, Note 1). The

95   standard ISO 2631-1:1997, in addition to evaluating the human exposure to WBV, also permits the

96   estimation of the vibration effects on the back using comfort coefficients to detect the discomfort

97   that can arise (paragraph 8.1).

98   The discomfort produced by vibration on the back of seated or standing operators was studied by

99   many Authors (Griffin, 1978; Griffin, Parsons, Whitham, 1982; Griffin, 2007; Thuong & Griffin,

100 2011), but nobody analysed the discomfort produced by backpack machines.. A set of field tests

101 was conducted to analyse the discomfort produced by the vibration transmitted to the back of

102 twenty operators, during their usual work in the field, when using three different mistblowers.

103

104 The goal of this work was to analyse the effects of different working conditions (machine, engine

105 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 cm³	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

130

131

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

133

134 *2.2 Field tests*

135

136 *2.2.1 Geographic context*

137 The tests were conducted in the vineyards located in Moncalvo, Monferrato, Italy (45°3'4"32 N

138 latitude, 08°15'58"68 E longitude).

139

140 *2.2.2 Operators*

141 Twenty healthy men, familiar with working in the field with mistblowers, were recruited for the

142 tests. The mean age of the subjects was 41.5 years (range 28-63 years), their mean body mass was

143 80.8 kg (range 68 - 90 kg) and their average height 1.79 m (range 1.72 - 1.84 m). The BMI (body

144 mass index) was calculated for each operator (Table 2) (WHO, 1995).

145

7

146   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%)

147

148   *2.2.3 Operative conditions*

149   The mistblowers were operated in field under normal working conditions using the LES when

150   moving among the rows of the vineyard, and the HES during spraying. Each of the twenty operators

151   used all three machines and each test was repeated three times. Each operator properly adjusted the

152   harness to balance the mass of the machine and to adapt the padded backpack to his back. To

153   analyse the vibration produced by the machines with a different loads on the operator's back,

154   different tank loads were tested; an almost empty tank with 1 l of spray liquid and with 5 and 10 l of

155   product. A total of 1080 tests were carried out.

156

157   *2.3 Laboratory tests*

158   The machines had the empty tank during the 18 tests to establish their vibratory behaviour in

159   laboratory, where they were suspended to a crane by a rope through their centre of gravity (Fig. 2).

160   The runs were performed in both the LES and HES conditions.

161

162

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

164

2.4 Back measurements

166

<u>*2.4.1Measurement chain*</u>

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).

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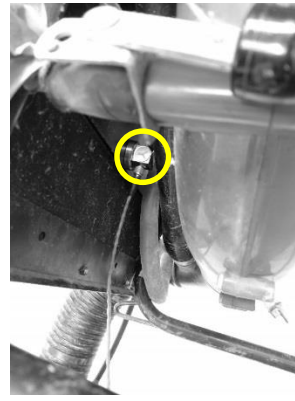
(a)   (b)

178 Fig. 3 – (a) Axes orientation with the rubber pad fixed on the padded backrest by an adhesive tape;

179 (b) position of the accelerometer during the laboratory runs

180

181 During all the tests the accelerometer was connected to a National Instruments data acquisition card

182 (NI 9234) with 51.2 kS s^{-1} sampling rate for each channel. Acquired data were stored on a laptop

183 using the LabVIEW software (V.12.01f5, National Instr. Corp., Austin, TX, USA). The

184 accelerometers and cables were calibrated by Brüel & Kjær calibrator type 4294 (standard

185 acceleration level of 10 m s^{-2}). The measurement system was checked before and after each set of

186 runs.

187

188 *2.4.2 Back weighted vibration total values and comfort vibration total values (ISO 2631-1)*

189

190 The ISO 2631-1 standard (paragraph 8.2.2.1) gives specific frequency weighting curves and

191 multiplying factors to evaluate the health and the comfort at the back: only one weighting factor is

192 provided for the health on the *x*-axis, whereas for comfort three weighting factors are given for the

193 *x*, *y* and *z* axes are given (Table 3). For the *x*-axis the frequency weighting curve is W_c and the

194 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

195 respectively.

10

196

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

198   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

199

200   Accelerations along the three axes were acquired for each machine, working condition (LES and

201   HES), tank filling and operator. The acquisition time for each run was at least two minutes to obtain

202   a steady-state signal. Each run was repeated three times.

203   Vibration data were processed using LabVIEW software and converted from the time domain to the

204   frequency domain and one-third octave bands were obtained. The signals were weighted using the

205   weighting curves W_c and W_d. The resulting data were converted to the root-mean-square (r.m.s.)

206   acceleration.

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

208   (paragraph 6.5) (Eq. 1).

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

209   (1)

210   where a_{cv} = comfort vibration total value, a_{wx}= acceleration along the x-axis (weighting curve W_c),

211   a_{wy} = acceleration along the y-axis (weighting curve W_d), a_{wz} = acceleration along the z-axis

212   (weighting curve W_d), k_x = comfort weighting factor for the x-axis (0.8), k_y = comfort weighting

213   factor for the y-axis (0.5) and k_x = comfort weighting factor for the z-axis (0.4)

11

214   In laboratory the acquired acceleration along the three axes were weighted using the weighting

215   curves (Table 3) and the vibration total values (VTVs) a_v were calculated as the square root of the

216   sum of the squares of a_{wx}, a_{wy} and a_{wz}, without the comfort factors (Eq. 2).

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

217   (2)

218   *2.5 Scale of the vibration discomfort*

219   The British Standard 6841:1987 and the ISO 2631-1 both suggest a scale of r.m.s. vibration

220   discomfort (Table 4).

221

222   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

223

224   This scale was used to compare the acquired values.

225

226   *2.6 Data elaboration*

227   Data were recorded and analysed using IBM SPSS Statistics (V. 24, International Business

228   Machines Corporation, Armonk, New York, U.S.A.). The Pearson test was used for testing

229   correlations between BMI and CVTV (being this the possible correlated variable that could

230   interfere with the use of the following GLM procedures). The GLM (general linear model) is a

231   method for analysing quantitative data and understanding how the mean response relates to a set of

232 independent predictors. For these reasons GLM was used to assess the effects of the variables

233 machine, operator and tank filling on the CVTVs and on the VTVs (Keppel & Wickens, 2004).

234 When useful, the Ryan, Einot, Gabriel, and Welsch (R-E-G-W) post-hoc tests (based on the F test,

235 as the GLM) were performed. The homoscedastic condition (assumption of equal variance) was

236 previously tested by the Levene's test. All statistic tests used a confidence level p = 0.01.

237

238 **3. Results**

239

240 *3.1 Field*

241

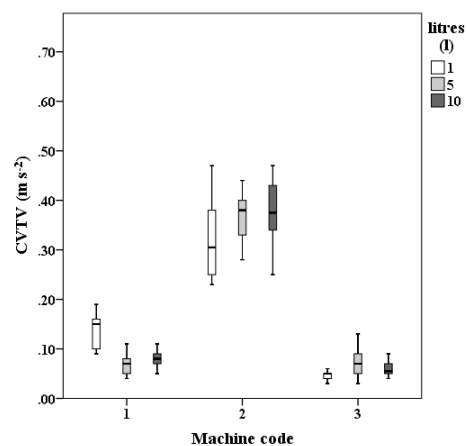242 *3.1.1 Comfort vibration total values (CVTVs)*

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

244 • at LES the CVTVs were usually higher (until 0.62 m s^{-2}) and the lowest tank fillings

245 produced highest CVTVs on the operator's back

246 • machine #2 produced the highest CVTVs as well as more variation in the data

247
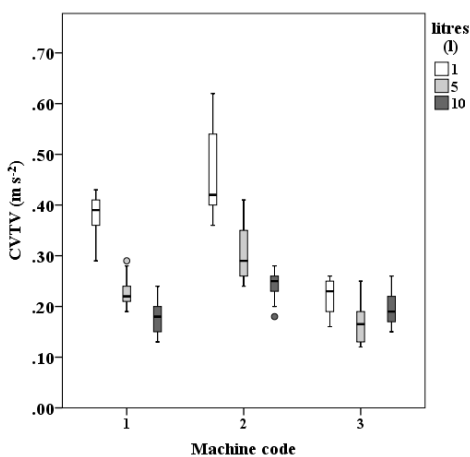
(a) LES   (b) HES

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

249 filling

250

251 A possible correlation between the operators and the BMI classes with the CVTVs was checked, to

252 avoid mistakes when using the GLM statistic. No correlation was found, neither for the operator,

253 nor for the BMI classes (Pearson coefficients were between -0.02 and 0.08 with a p level = 0.001).

254 Two GLMs were then executed (for each engine rotation speed), setting as fixed factors the

255 machine code, the tank filling (1, 5 and 10 l) and the BMI class. While at the LES all the variables

256 were significantly different. At HES only a likeness was detected for the variable tank filling.

257

258 In both the cases (LES and HES) the post-hoc test was performed (Table 5). As it was expected, the

259 machine always showed CVTVs statistically different (especially the Machine #2 at the HES with a

260 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).

261 At LES condition, average CVTVs were inversely proportional to the tank filling (0.35 m s^{-2} with 1

262 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

263 were 0.17 m s^{-2}.

264

265 Table 5 -Post-hoc tests of the GLM on CVTVs in the LES and HES conditions (p = 0.01). The

266 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		

14

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

267

268   Analysis of the comfort along the *x*, *y* and *z* axes highlighted highest and floating data for the *x*-axis,

269   oriented in the fore-and-aft direction (Fig. 4), reaching values around 0.6 m s^{-2} in the LES condition

270   (Fig. 5). Mistblower #2 had the highest values. The GLMs performed for the *x*, *y* and *z* comfort axes

271   gave information similar to the GLMs for CVTVs. As expected, for all machines the post-hoc test

272   always gave different subset values along all the three axes.

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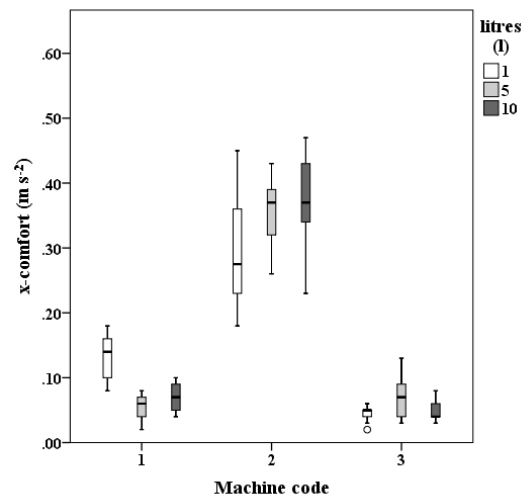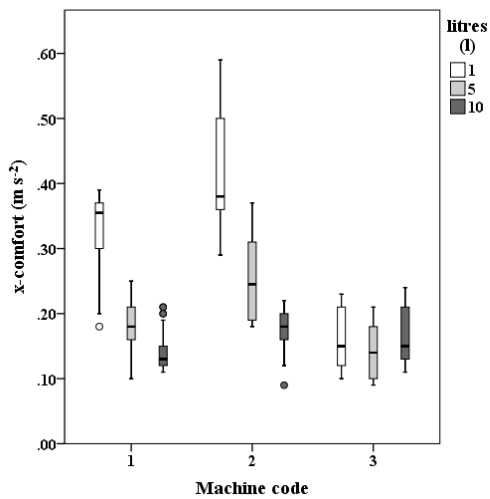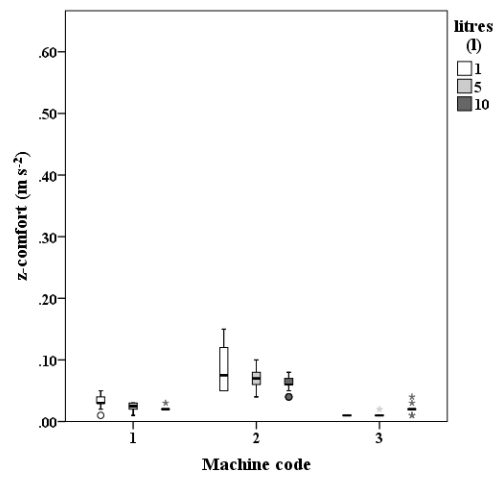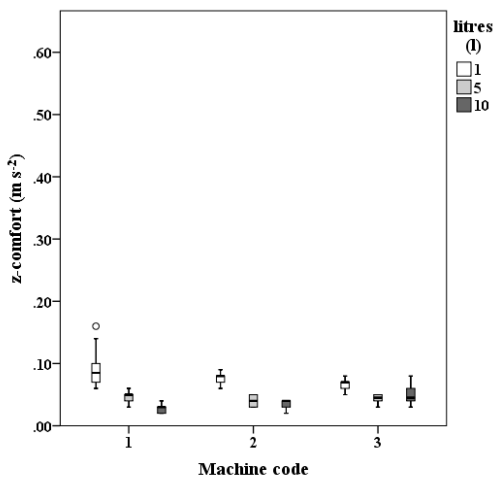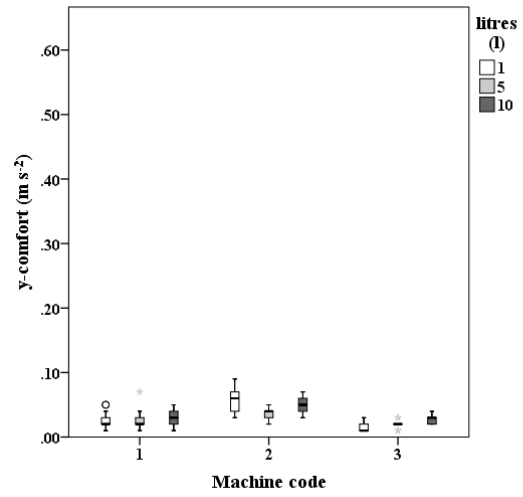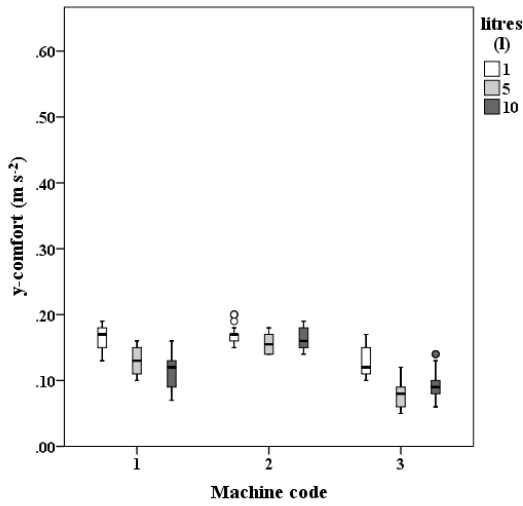
274   Fig. 5 - Box-whisker graphs of *x*, *y* and *z* comfort values in function of the machine and of the tank

275   filling (left: LES; right: HES)

276

277   *3.1.2 Frequency analysis*

278   The VTVs frequency analysis was carried out considering the three machines (at LES and HES)

279   with the tank filled with 1 and 5 l. The tanks were not filled to 10 l because the VTVs were similar

280   at the 5 l of product.

281

16
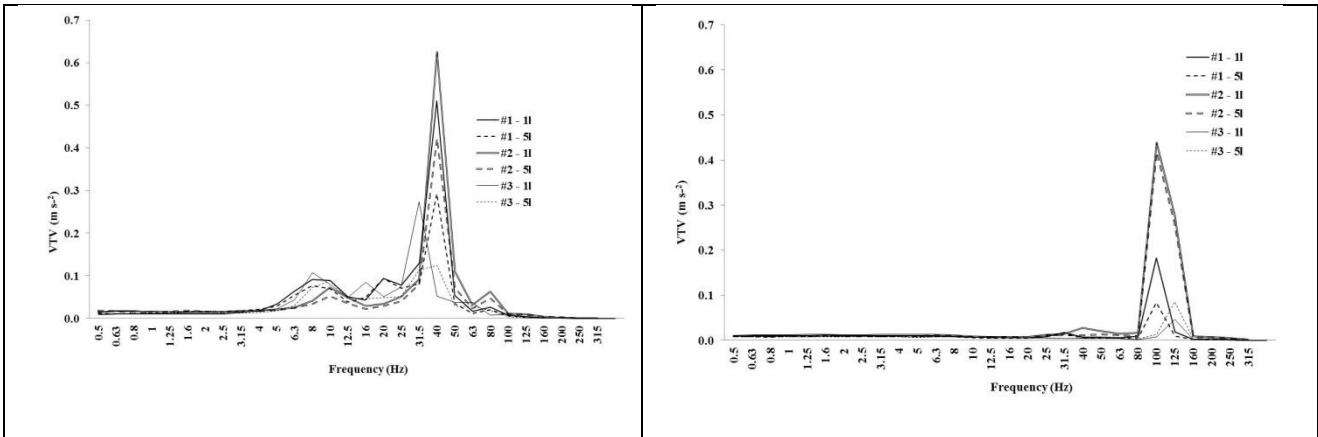
282   Fig. 6 - VTVs one-third octave band analysis in field of the tested machines with the tank filled

283   with 1 and 5 l (left: LES, right: HES)

284

285   The fundamental one-third octave band centre frequency (also called the mid-frequency in ISO

286   5349-1: 2001) of the VTVs at LES with machines #1 and #2 was found to be 40 Hz, independent of

287   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

288   5 l (Fig. 6). Machine #3 showed the fundamental at the one-third octave band with the centre

289   frequency at 31.5 Hz with 1 l of product and at mid-frequency of 40 Hz with 5 l of pesticide: the

290   curves of the Machine #3 had a shape more floating then the curves of the other machines.. The

291   vibration energy distribution of Machines #1 and #2 at the HES condition was very similar. Both

292   machines had the fundamental sharply defined at the one-third octave band with a centre frequency

293   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

294   m s^{-2} with 5 l for the machine #1). Machine #3 had a fundamental slightly greater (central

295   frequency: 125 Hz) with data lower than 0.1 m s^{-2} (Fig. 6).

296   Frequency analysis of the signal along the three axes was performed with the tank filled with 5 l of

297   spray liquid. Analysis of the acceleration along the three axes showed a more irregular trend of the

298   curves at LES (as in the VTVs), when the engine rotational speed had greater fluctuations. For

299   example the engine of the Machine # 2 continuously varied the speed from 233.5 rad/s to 260.7

300   rad/s). The highest vibration values occurred along the x-axis, the lowest along the y and z-axes.

17

301   The y component varied the most. At HES, acceleration data concentrated near the fundamental

302   frequencies (mid-frequency at 100 Hz for the Machines #1 and #2, at 125 Hz for the Machine #3).

303

304   *3.2 Laboratory tests*

305

306   *3.2.1 Vibration total values*

307   The tests conducted in laboratory with the suspended machines explained the anomalous results of

308   the Machine #2 in field. The VTVs of the Machine #2 were around 2 times the VTVs of the other

309   mistblowers at the LES (average of about 1.8 m s^{-2} the Machine #1, values less than 1 m s^{-2} the

310   Machines #1 and #3) and more than 4 times at the HES (average 6 m s^{-2} the Machine #1, values

311   lower than 1.4 and 0.5 m s^{-2} the Machines #1 and #3 respectively). As expected, the GLM

312   procedure indicated all the subsets of the VTVs calculated per machine and per engine condition as

313   statistically different to each other.

314   The analysis along the x, y and z axes confirmed also in this case that the x-axis was the most

315   solicited. It was surprising the enormous difference among the values of the x-axis of the Machine

316   #2 (average > 1.6 m s^{-2} at LES and very close to 6 m s^{-2} at HES) and the corresponding values the

317   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

318   HES, respectively for the Machines #1 and #3) (Fig. 7).
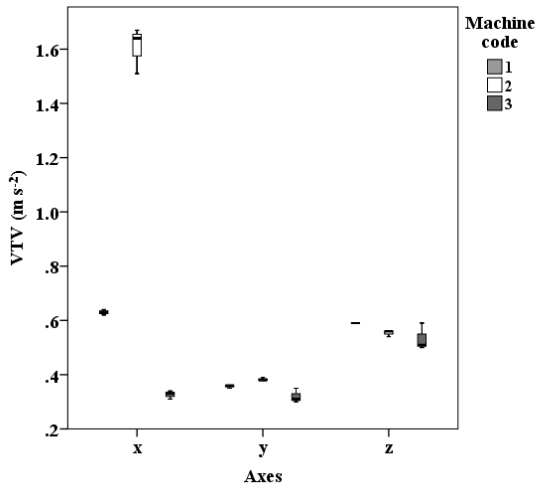
(a) LES   (b) HES
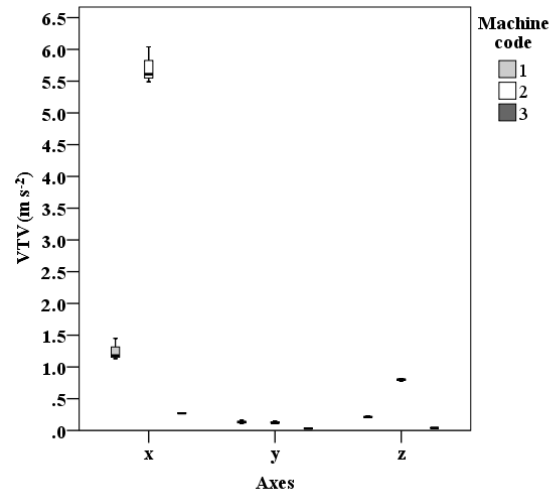
Fig. 7 -Box-whisker graphs of the accelerations measured in laboratory along the *x*, *y* and *z* axes

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

19

335 The CVTVs obtained at the operators' back appear to validate the hypothesis of the vibration being

336 a *trifling nuisance*. In the worst case the CVTV reached 0.62 m s^{-2} with Machine #2, but it was

337 usually < 0.40 m s^{-2} at LES and 0.20 m s^{-2} at HES. These values were similar to the results obtained

338 by Deboli et al. (2013), who obtained averages of 0.37 m s^{-2} and 0.28 m s^{-2} respectively at LES and

339 HES. Sasaki et al. (2014), obtained values > 2 m s^{-2}, but they did not consider the comfort.

340 Some of the observed values were in the *little uncomfortable* condition of the British Standard 6841

341 and the ISO 2631-1 scale, except for Machine #2 that was in the *fairly uncomfortable* class (Table

342 4).

343 There is, however a personal perception of the vibration discomfort, as observed by Griffin (2007).

344 The current standard tries to translate it into procedures that consider all the vibration factors

345 (direction, magnitude and frequency), but these actions do not always provide the desired results.

346 The operator's discomfort may be affected by other factors than vibration (for example noise,

347 weariness, ailment, etc.) and it may produce shifts so small as to be not perceived by the operator. A

348 factor that may influence the operator's judgment of vibration discomfort is the noise produced by

349 mistblowers. The literature reports sound level values never lower than 94 - 100 dB(A) (Bansal,

350 1998; Cerruto et al., 2003; Vilela et al., 2005; Sasaki et al., 2014). Huang and Griffin (2014) noticed

351 that the feeling of the discomfort by operators related to WBV could be lowered by the presence of

352 the noise, acting as 'masking effect'. In our study the operators correctly used hearing protection (in

353 this case ear muffs) and therefore the noise at the operators' ears was lowered, but Huang and

354 Griffin (2014) found an evidence of the masking effect also at lower noise levels (from 75 to 88

355 dB(A)), when the operators wore ear muffs.

356 The analysis of the comfort acceleration highlighted that the *x*-axis (oriented along the fore-and-aft

357 direction) was the most prevailing. Frequency analysis showed high VTVs (without considering

358 scaling factors), especially with the tank almost empty and at LES, reaching values between 0.3 and

359 0.6 m s^{-2} at the dominant mid-frequency of 40 Hz. Lower values were observed at HES; between

360   0.1 and 0.4 m s^2 at the dominant mid-frequency of 100 Hz. VTVs were not affected by scaling, but

361   at several frequencies they were reduced by the W_c (x-axis) and W_d (y and z axes) weighting curves

362   (Fig. 8). At the dominant 40 and 100 Hz mid-frequencies, for example, the W_c curve was reduced

363   by around 14 and 25 dB respectively, while the W_d curve reduced the acquired signal by about 26

364   and 37 dB.

365   The W_c and W_d weighting curves are normally applied to the case of back vibration transmitted by a

366   seat, or by a vibrating platform, where the operator is seated (former) or is standing (latter), but

367   there is no evidence that these curves are suitable when the vibration is transmitted by a back-

368   mounted power machine. This study could be useful for developing more suitable weighting curves

369   for analysing these aspects.

370   The dominant mid-frequencies at 40 and 100 Hz were caused by the engine and by the fan rotation.

371   This aspect should be studied more deeply. The vibrational behaviour of the three machines tested

372   in the laboratory confirmed that the vertical movement of the single piston of the engine was

373   responsible of the acceleration in the fore-and-aft direction (x axis). As discussed in section 3.1.1,

374   operator body mass and operating mode did not appear to influence vibration. The high vibrations at

375   HES obtained in laboratory appear to be dampened by the padding of the harness when used in the

376   field, as observed also by other studies (Chow et al., 2014, Tang et al., 2014).

377
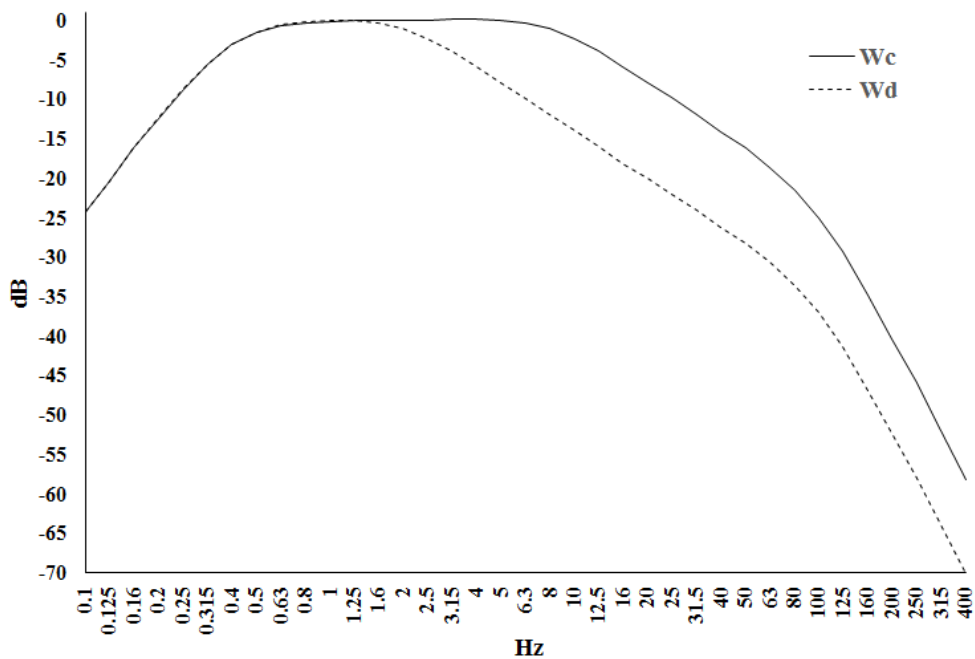
378

379 Fig. 8 -Weighting curves applied to the acquired signals along the three axes: W_c (x-axis) and W_d (y

380 and z axes) (adapted from ISO 2631-1)

381

382 The vibration analysis confirmed the anomalous behaviour of the Machine #2. This machine was

383 the oldest and poorly maintained. Machine #2 lacked correct fan balancing and maintenance of the

384 engine and isolating mount between the frame and engine. The most important message perceived

385 by the operators involved in the tests concerning maintenance related to the condition of the spray

386 distribution system, because they had received specific training, as requested by the European

387 Directive 2009/128/CE. They were less interested in the maintenance of the motorised parts of the

388 machine, but nevertheless they all perceived a feeling of nuisance related to the lack of comfort on

389 the back when using Machine #2. This nuisance was observed despite them correctly wearing the

390 sprayer and balancing the harness for the best condition as observed by Bansal (1998).

391 Although the transmission of vibration transmitted to the backs of mistblower operators has not

392 received much attention, the study carried out by Deboli et al. (2013) in laboratory did show

393 sensible changes of the cutaneous temperature of the skin surface when using these types of

394 machines. Despite the richness of medical studies carried out over many years on the back disorders

395 produced by WBV vibration (Bovenzi & Betta, 1994; Bluthner, Seidel, Hinz, 2001; Petit &

396 Roquelaure, 2015; Beard & Griffin, 2016; Zhou & Griffin, 2017), the literature is still lacking of

397 medical studies on the back discomfort that can be caused by motorised back-mounted portable

398 machines. The harness surely dampens the effects vibration on the body of the operator, but it

399 cannot be sufficient, especially with poorly maintained machines.

400

401 **5. Conclusion**

402 The discomfort on the back produced by vibrations from by mistblowers, operating under different

403 working conditions and different tank fillings, was investigated using a procedure suggested by the

404 standard ISO 2631-1. The observed values usually fell inside a range of *little uncomfortable*

405 condition as specified by the standard, although the oldest machine with the poorest maintenance of

406 mechanical components produced increased vibration on the back.

407 The ISO 2631-1 standard examines operator comfort but it was developed for the case of WBV

408 transmitted by seats or vibrating floors. The discomfort concept can be applied to the vibrations

409 transmitted to the backs of operators of motorised backpack operators since, although it could be

410 regarded as misleading, there is little suitable alternative data or reference standards. We were wary

411 of using a flat weighting curve, but suitable medical and ergonomic comparisons are not available.

412 In the case of the hand-arm vibration (HAV) from powered tools, many studies have been carried

413 out recently and standards are available concerning osteoarticular (ISO 5349-1:2001) and vascular

414 vibration risks (ISO/TR 18530:2017). It is clear that whilst HAV may be a serious risk, back

415 vibrations mostly concern comfort, although attention is being placed on stress, discomfort, early

416 fatigue and mask effects.

417

420

421 **References**

422 Azmir, N.A., & Yahya, M.N. (2017). Prevalence of Hand-transmitted Vibration Exposure among
423   Grass-cutting Workers using Objective and Subjective Measures. *IOP Conference Series:*
424   *Mathematics, Science and Engineering*, 165, 12-26. https://doi.org/10.1088/1757-
425   899X/165/1/012026.

426 Bansal, A.S. (1998). Dynamic Response and Vibration Control at the Source in a Powered-
427   backpack Sprayer. AMA, Agricultural Mechanization in Asia, Africa and Latin America, 29(3),
428   23-26.

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

432 Bluthner, R., Seidel, H., & Hinz, B. (2001). Examination of the myoelectric activity of back
433   muscles during random vibration. Methodical approach and first results. *Clinic Biomedical*,
434   16(1), 25-30. PUBMED id: 11275340.

435 Bovenzi, M., Peretti, A., Zadini, A., Betta, A., & Passeri, A.C. (1990). Physiological reactions
436   during brush saw operation. *International Archives of Occupational and Environmental Health*,
437   62(6), 445-449. https://doi.org/10.1007/BF00379061.

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

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

443   Cerruto, E., Manetto, G., & Schillaci, G. (2003). Noise levels during the mechanised operations in

444   protected crops. *Acta Horticulturae*, 614, 819-824.

445   https://doi.org/10.17660/ActaHortic.2003.614.120.

446   Chow, D.H.K., Wang, C., & Pope, M.H. 2014. Effects of backpack carriage on lumbopelvic

447   control: A dynamical systems analysis. *International Journal of Industrial Ergonomics*, 44,

448   493-498. https://doi.org/10.1016/j.ergon.2014.04.002.

449   Deboli, R., Calvo, A., Rapisarda, V., Preti, C., & Inserillo, M. (2013). Vibration transmitted to

450   operator's back by machines with back-pack power unit: a case study on blower and spraying

451   machines. *Journal of Agricultural Engineering*, 44(e146), 724-729.

452   https://doi.org/10.4081/jae.2013.(s1):e146.

453   Deboli, R., Calvo, A., & Preti, C. (2016). Vibration and impulsivity analysis of hand held olive

454   beaters. *Applied Ergonomics*, 55, 258-267. https://doi.org/10.1016/j.apergo.2015.11.003.

455   Denkyirah, E.K., Okoffo, E.D., Taylor Adu, D., Aziz, A.A., Ofori, A. & Denkyirah, E.K. (2016).

456   Modeling Ghanaian cocoa farmers' decision to use pesticide and frequency of application: the

457   case of Brong Ahafo Region. *SpringerPlus*, 5:1113. https://doi.org/10.1186/s40064-016-2779-

458   z.

459   Dewangan, K.N., & Tewari, V.K. (2009). Vibration energy absorption in the hand–arm system of

460   hand tractor operator. *Biosystems Engineering*, 3, 427-437.

461   https://doi.org/10.1016/j.biosystemseng.2009.06.001.

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

463   Griffin, M.J. (1978). The evaluation of vehicle vibration and seats. *Applied Ergonomics*, 9(1), 15-

464   21. https://doi.org/10.1016/0003-6870(78)90214-4.

465   Griffin, M.J., Parsons, K.C., & Whitham, E.M. (1982). Vibration and comfort. IV. Application of

466   experimental results. *Ergonomics*, 25(8), 721–739.

467   https://doi.org/10.1080/00140138208925030.

25

468   Griffin, M.J. (2007). Discomfort from feeling vehicle vibration. *Vehicle System Dynamics*, 45(7-8),

469   679-698. https://doi.org/10.1080/00423110701422426.

470   Hanafi, A., Hindy, M., & Ghani, S.A. (2016). Effect of spray application techniques on spray

471   deposits and residues of bifenthrin in peas under field conditions. *Journal of Pesticide Science*,

472   41(2), 49-54. https://doi.org/10.1584/jpestics.D15-071.

473   Huang, Y., & Griffin, M.J. (2014). The discomfort produced by noise and whole-body vertical

474   vibration presented separately and in combination. *Ergonomics*, 57(11), 1724-1738.

475   https://doi.org/10.1080/00140139.2014.943683.

476   Keppel, G., & Wickens, T.D. (2004). *Design and analysis: A researchers handbook*. (4th ed.). NJ:

477   Upper Saddle River (Chapter 2).

478   Knibbs, L.D., 2014. Occupational hazards to the health of professional gardeners. International

479   *Journal   of   Environmental   Health   Research*,   24(6),   580–589.

480   https://doi.org/10.1080/09603123.2014.883594.

481   Kshirsagar, S., Dadmal, V., Umak, P., Munde, G., & Mahale, P.R. (2016). Design and

482   Development of Agriculture Sprayer Vehicle. *International Journal of Current Engineering*

483   *and Technology*, 4, 405-408. http://inpressco.com/category/ijcet.

484   Kouchakzadeh, A., & Beigzadeh, Y. (2015). Permitted working hours with a motorised backpack

485   sprayer.   *Biosystems   Engineering*,   136,   1-7.

486   https://doi.org/10.1016/j.biosystemseng.2015.05.005.

487   Jusoh, M.M. (1997). Spraying performance of lever-operated and motorised backpack sprayers, and

488   motorised mistblower on rice crop. *Journal of Tropical Agriculture and Food Science*, 25(2),

489   239–248.

490   ISO 10326-1. (2016). Mechanical vibration. Laboratory method for evaluating vehicle seat

491   vibration. Part 1: Basic requirements *International Organization for Standardization, (ISO)*.

492   ISO 11680-1. (2011). Machinery for forestry. Safety requirements and testing for pole-mounted

493   powered pruners. Part 1: Machines fitted with an integral combustion engine. *International*

494   *Organization for Standardization, (ISO).*

495   ISO 11680-2. (2011). Machinery for forestry. Safety requirements and testing for pole-mounted

496   powered pruners. Part 2:Machines for use with back-pack power source. *International*

497   *Organization for Standardization, (ISO).*

498   ISO 22867. (2011). Forestry and gardening machinery. Vibration test code for portable hand held

499   machines with internal combustion engine. Vibration at the handles. *International Organization*

500   *for Standardization, (ISO).*

501   ISO 5349-1. (2001). Mechanical vibration. Measurement and evaluation of human exposure to

502   hand-transmitted vibration. *International Organization for Standardization, (ISO).*

503   ISO 2631-1. (1997). Mechanical vibration and shock e Evaluation of human exposure to whole-

504   body vibration. Part 1: General requirements. *International Organization for Standardization,*

505   *(ISO).*

506   Maitah, M., Zidan, K., Hodrob, R., & Malec, K. (2015). Farmers Awareness Concerning Negative

507   Effects of Pesticides on Environment in Jordan. *Modern Applied Science*, 9(2), 12-19.

508   https://doi.org/10.5539/mas.v9n2p12.

509   Mallick, Z. (2008). Optimization of operating parameters for a back-pack type grass trimmer.

510   *International Journal of Industrial Ergonomics*, 38, 101-110.

511   https://doi.org/10.1016/j.ergon.2007.09.005.

512   Matanmi, B.M., Falola, A., Animashaun, J.O., & Atanda, T.O. (2017). Effect of Fadama III

513   program on dry-season vegetable growers in Kwara Condition, Nigeria. *Kasetsart Journal of*

514   *Social Sciences*, 38(2), 163-168. https://doi.org/10.1016/j.kjss.2016.04.002.

515 Matthews, G.A. (2008). Attitudes and behaviours regarding use of crop protection products. A

516 survey of more than 8500 smallholders in 26 countries. *Crop Protection*, 27, 834–846.

517 https://doi.org/10.1016/j.cropro.2007.10.013.

518 Palmer, K.T., Griffin, M.J., Bendall, H., Pannett, B., & Coggon, D. (2000). Prevalence and pattern

519 of occupational exposure to hand transmitted vibration in Great Britain: Findings from a

520 national survey. *Occupational and Environmental Medicine*, 57(4), 218-228.

521 https://doi.org/10.1136/oem.57.4.218.

522 Petit, A., & Roquelaure, Y. (2015). Low back pain, intervertebral disc and occupational diseases.

523 *International Journal of Occupational Safety and Ergonomics* (JOSE), 21(1), 15-19.

524 https://doi.org/10.1080/10803548.2015.1017940.

525 Piana, E.A., Marchesini, A., Deboli, R., & Preti, C. (2010). Rischio da esposizione a vibrazioni per

526 l'uso di soffiatori a zaino: valutazione dell'esposizione a vibrazioni trasmesse al corpo intero e

527 alla spalla. *Atti del 37° Convegno Nazionale AIA (Associazione Italiana di Acustica)*, Siracusa,

528 Italia, 123-130.

529 Ragni, L., Vassalini, G., Xu, F., & Zhang L.B. (1999). Vibration and Noise of Small Implements

530 for Soil Tillage. *Journal of Agricultural Engineering Research*, 74, 403-409. https://doi.org/

531 10.1006/jaer.1999.0478.

532 Ruas, J.M.F., Balan, R., & Saa, O.J.G.A. (2011). Coverage comparison by backpack sprayers

533 manual and engine powered. *Ciências Agrárias*, 32(4), 1417-1422. https://DOI: 10.5433/1679-

534 0359.2011v32n4p1417

535 Sam, B., & Kathirvel, K. (2006). Vibration characteristics of walking and riding type power tillers.

536 *Biosystems Engineering*, 95(4), 517–528. https://doi.org/10.1016/j.biosystemseng.2006.08.013.

537 Sasaki, R.S., Furtado Júnior, M.R., Leite, E.S., Souza, A.P., Teixeira, M.M., & Fernandes, H.C.

538 (2014). Ergonomic evaluation of backpack sprayers used in forestry. *Revista Arvore*, 38(2),

539 331-337. http://dx.doi.org/10.1590/S0100-67622014000200013.

540 Sutherland, J.A. (1979). The Evaluation of Lever-operated Knapsack and Motorised Knapsack

541   Sprayers. *PANS*, 25(3), 332-364. https://doi.org/10.1080/09670877909412112.

542 Sutthiwaree, P., & Yang, M. (2015). The rice production situation and mechanization level in the

543   North Region of Thailand: Chiang Rai Province. *American Society of Agricultural and*

544   *Biological Engineers Annual International Meeting*, 1, 49-56.

545 Tang, Z., Sun, S., Wang, J., & Zhang, K. (2014). An ergonomics evaluation of the vibration

546   backpack harness system in walking. *International Journal of Industrial Ergonomics*, 44, 753-

547   760. https://doi.org/10.1016/j.ergon.2014.08.004.

548 Thornhill, E.W. (1982). A summary of methods for testing pesticide application equipment.

549   *Tropical Pest Management*, 28(4), 335-346. https://doi.org/10.1080/09670878209370738.

550 Thuong, O., & Griffin, M.J. (2011). The vibration discomfort of standing people: Relative

551   importance of fore-and-aft, lateral, and vertical vibration. *Applied Ergonomics*, 43, 902-908.

552   https://doi.org/10.1016/j.apergo.2011.12.011.

553 Vilela, R.A.G., Malagoli, M.E., & Morrone, L.C. (2005). Trabalhadores da saúdesobrisco: o uso de

554   pulverizadores no controle de vetores. *Revista Produção*, 15(2), 263-272.

555   http://dx.doi.org/10.1590/S0103-65132005000200010.

556 Wang, S., Song, J., He, X., Li, Y., & Ling, Y. (2016). Design of air-assisted electric backpack

557   sprayer and experiment of its operation performance. *Nongye Gongcheng Xuebao/Transaction*

558   *of the Chinese Society of Agricultural Engineering*, 32(21), 67-73.

559   https://doi.org/10.11975/j.issn.1002-6819.2016.21.009.

560 WHO (World Health Organization). (1995). Physical status: the use and interpretation of

561   anthropometry. *WHO Technical Report Series*, 854.

562 Zhou, Z., & Griffin, M.J. (2017). Response of the seated human body to whole-body vertical

563   vibration: discomfort caused by mechanical shocks. *Ergonomics*, 60(3), 347-357.

564   https://doi.org/10.1080/00140139.2016.1164902.

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

570

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

572

573   Fig. 3 – (a) Axes orientation with the rubber pad fixed on the padded backrest by an adhesive tape;

574   (b) position of the accelerometer during the laboratory runs

575

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

577   filling

578

579   Fig. 5 - Box-whisker graphs of x, y and z comfort values as a function of machine and tank filling

580   (left: LES; right: HES)

581

582   Fig. 6 - VTVs one-third octave band analysis in field of the tested machines with the tank filled

583   with 1 and 5 l (left: LES, right: HES)

584

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

586

587   Fig. 8 -Weighting curves applied to the acquired signals along the three axes: W_c (x-axis) and W_d (y

588   and z axes) (adapted from ISO 2631-1)

589