Evaluation of respirable dust exposure during hazelnut and chestnut mechanized harvesting

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Abstract
Atmospheric dust is defined in different ways but the most used classification are "total suspended dust" (T.S.D) and "particulate matter" (P.M.). A further distinction within the T.S.D. is about inhalable and respirable dust. Inhalable dust has an aerodynamic diameter between 5 and 10 μm, while respirable dust presents a diameter between 0,5 and 5 μm.
Beside the dimension, the danger about dust regards other factors, like: concentration, chemical composition, individual absorption characteristics and exposure time.
The mechanized harvesting of nuts, like hazelnuts and chestnuts, is carried out with specific machines that can be classified in three different types: pulled vacuum harvesters with aspirating tubes; pulled or tractor mounted harvesters with automatic picking system; self-propelled harvesters (aspirating or picking). In spite of installation of dust limitation devices, some studies have shown that dust concentration is still more elevated (up to 10 times) than the maximum limits indicated by the American Conference of Governmental Industrial Hygienists (A.C.G.I.H.).
The objective of the present study is to evaluate the level of risk at which operators, during nut mechanized harvesting and using modern machines, are really exposed.
In order to carry out this survey the data have been collected among some farms of the province of Viterbo (Italy); the farms selected have heterogeneous characteristics so that it is possible to obtain representative results for each type of working site and ground.

Keywords: health at work, dust exposure, respirable dust.

Introduction

The agriculture, despite all the transformations and technological evolutions, has preserved peculiar and well differentiated characteristics from all the other productive sectors. The multiplicity and the heterogeneity of the different cultural operations, the variety of the forms of management of the firms, the pulverization and dispersion of these in the territory, the variability of the ground (especially in reference to slope and physical-chemical characteristics), the land setups, the working age of the employees, constitute the principal determinants of the multiplicity and heterogeneity of the situations of risk for the agricultural operators.

The laws about operational safety and health impose the assessment of the risks for the operators who are exposed and the realization of prevention and protection measures to improve working conditions. Besides, the whole process of prevention, from the identification of the dangers to the measures of improvement, must be based on the consultation and the share of all the working subjects in the work place.

The present study intends to analyze one of the principals risks derived by the mechanized harvesting of hazelnuts and chestnuts, that is the workers' exposure to inorganic breathable air-spread particles [3-7].

It talks, in substance, of the dust that is absorbed during the respiration and that can not be expelled through cough or secretion of mucous, which is composed by particles that are not intercepted to the level of the first respiratory ways and which, therefore, reach the bronchial and pulmonary hollows.

The nature of these pollutants can be the most varied: silicium, zinc oxide, carbonaceous particles, combustion smokes, radioactive substances, asbestos, insecticides, organic substances as well as those that derive from the cereals, etc. With concentration is meant the quantity of particles in suspension in one cubic meter of air: it is generally expressed in mg/m^3, in $\mu g/m^3$ and in ppm (parts per million: volume of the contained particles in 10^6 volume unit).

The granulometry points out the dimensions of the particles: a diameter *d* is defined, expressed as the arithmetic average of the three dimensions of the particle (length *l*, width *b* and thickness *s*).

In the study of the dangerousness for inhalation, great importance however has the subdivision between breathable dust and non breathable dust, depending on the aerodynamic diameter.

This represents the diameter of a sphere of unitary density (1 g/cm^3) that has the same terminal speed of sedimentation of the particle in examination. The well known PM10 (particulate matter, with an aerodynamic diameter inferior to 10 μm) represents the dust able to penetrate into the superior part of the respiratory apparatus; while the PM 2,5 represents the dust able to penetrate into the inferior part of the respiratory apparatus (pulmonary alveoluses).

These last ones are the most dangerous because they are able to deposit themselves in the pulmonary system provoking inflammations, fibrosis and neoplasms.

The dusts with pathological action in humans are classified in two categories: pneumoconiogenic dusts and not pneumoconiogenic dusts [8].

The first ones are those that expound their action to the level of the respiratory apparatus provoking pneumoconiosis which consists of an accumulation of dusts in the lungs and consequent reaction of the pulmonary tissue.

The pneumoconiogenic dusts, in their turn, can be divided in inactive and fibrogenic dusts. The first ones don't alter the structure of the respiratory apparatus causing reactions that can modify the tissue in a potentially reversing way; the second ones can provoke more serious alterations modifying the structure of the alveoluses and provoking a fibrogenic reaction of the tissue [4].

These pathologies are subject to further worsenings, even after the exposure, up to the appearance of illnesses as silicosis (provoked by dusts of dioxide of silicium), asbestosis (provoked by asbestos dusts) and bissinosis (provoked by cotton dusts).

Also the not pneumoconiogenic dusts however can result as harmful because they bring particular substances or active principles able to pass into the circulation of the organism through the emo-lymphatic system. Given the dangerousness of the aforesaid dusts, in the last years (and it is predictable also for the next ones) there has been an increase of studies, researches, normative with the purpose to avoid, to prevent or to reduce the harmful effects on the health and on the environment.

The threshold limit values (TLV) find their application in the sector of the work hygiene.

They are fixed and annually adjourned by the A.C.G.I.H. (American Conference of Governmental Industrial Hygienists) and indicate the atmospheric concentrations of the

principal harmful substances to which workers can repeatedly be exposed to, without negative effects.

There are three categories of TLV:

- threshold limit value - time-weighed average (TLV-TWA): the average concentration under which most people can work consistently for eight hours, day in, day out, with no harmful effects. Gas or vapors are expressed in *parts per million* (ppm), while solids, mist or floating dust particles are expressed in milligrams per cubic meter (mg/m^3);
- threshold limit value - short-term exposure limit (TLV-STEL): is the maximum concentration permitted for a continuous 15-minute exposure period. There may be a maximum of four such periods per day, with at least 60 minutes between exposure periods, and provided the daily TLV-TWA is not exceeded;
- threshold limit value - ceiling exposure limit (TLV-C) - an exposure limit which should not be exceeded under any circumstances.

Material and methods

The tests have been effected near different hazelnut and chestnut farms in the center of Italy (province of Viterbo), and have currently concerned the harvest with all the principals models of harvesting machines in use.

Pulled harvesters are equipped with one or two aspirating tubes from 100 to 140 mm in diameter. The harvesting is executed by walking operators, which pass the tubes over fruits that are usually piled or aligned in rows. Aspired fruits arrive in a sedimentation chamber where the heaviest particles (small clods, pebbles, twigs), carried together with fruits by blown air, fall on the bottom and are expelled. A further cleaning is provided by another fan and by a rotating sieve. Fruits are transported on a conveyer belt to a sack or directly to a pulled trailer.

The traditional system need a lot of workers, at least 1 operator at the tractor and 3 alternating operators at the two tubes, besides other workers responsible for carrying in and out the empty and full trailers. In the earliest models, the fan-blown air was expelled directly outside. The dust concentration in the air was so elevated that in 1986, in order to limit health risks for operators and even for residents, the use of hazelnut harvesters without dust limitation devices was forbidden.

In the late 80's, some Italian designers started to plan self-propelled harvesters. These machines are produced in different models where the harvesting technique (aspirating or picking) varies together with the engine power [3].

The samplings of dust have been effected using personal samplers built by the English SKC: particularly the model Sidekick© has been used at constant flow during the samplings (figure 1), with its pump set to a flow of 1,9 l/minute through a bubble flowmeter and cyclone SKC (figure 2) for the selection of the respirable convention as defined by the EN 481 standard "Workplace atmospheres. Size fraction definitions for measurement of airborne particles".

Figure 1. SKC Sidekick Pump™

The cyclone is realized in conductive plastics and it exploits a system of removable and reusable cassette sampling; inside the cassette the filter is supported on a homogeneous grilled surface, to exploit in a uniform way the filtering surface and at the same time to facilitate the manipulation of the filter before and after the sampling.

Filters have been employed in cellulose nitrate with a porosity of 0,8 μm and a diameter of 25 mm. The filters have been weighted, before and after the reliefs, through an analytical Gibertini scale mod. E42-B, with precision equal to 0,1 mg and a maximum of 120 g (figure 3).

Before weightings, for every filter a conditioning of 24 hours in a checked environment has been anticipated.

Figure 2. SKC cyclone for respirable fraction

The samplers have been submitted to the workers during the normal harvesting job, positioning the orifice of entrance of the sampler parallel to the body and at the same height of the respiratory zone.

Figure 3. Analytical Gibertini scale

The times of sampling have been timed and verified with the times pointed out by the counter in endowment to the pump. The choice of the duration of the samplings is founded on the observation of the membranes filtering there: particularly the sampling was concluded when on the membranes a light visible layer of dust resulted, without reaching excessive accumulations of particles that during the transport of the filters would have been able to cause a loss of part of the samples and consequent under-estimation of the concentration values.

For the transport of the samples a stuffed handbag has been used, to guarantee an elevated protection against the bumps that would have been able to provoke the separation of the particles sampled by the membranes (events that would have distorted the results of the tests); the handbag was maneuvered with particular attention.

Given the time of sampling t_c (min), the volume flow rate of sampling Q (m^3/min), the initial mass of the filter M_i (mg) and the mass of the dust-filled filter M_f (mg) (values gotten after the conditioning of the membranes) the value of the concentration of dust Ct_c is gotten through the formula [9]:

$$Ct_c = \frac{(M_f - M_i)}{Q \times t_c} \qquad (mg/m^3) \qquad (1)$$

The dust samplings, for the following analyses of the concentrations and exposures of the workers, have been effected during the harvest of hazelnuts and chestnuts in different farms in the province of Viterbo, using different models of machines.

Particularly the study has been effected on different fields in which the following harvesters were used:

- pulled vacuum harvester Cimina 300, produced by the firm Facma;
- self-propelled vacuum harvester Cimina 160 S, produced by the firm Facma;
- self-propelled vacuum harvester Cimina 180 S, produced by the firm Facma;
- self-propelled vacuum harvester Cimina 200 S, produced by the firm Facma;
- self-propelled vacuum harvester Cimina 300 S, produced by the firm Facma;
- self-propelled vacuum harvester Cimina 380 S, produced by the firm Facma;
- pulled vacuum harvester Facma Cimina 200 T, produced by the firm Facma;
- tractor mounted picker Jolly 2800, produced by the firm GF;
- self-propelled picker Perla 55, produced by the firm Agrintem.

Regarding the times of exposure (to the aerodisperse dusts) of the workers employed in the harvest, a fundamental factor for the evaluation of the risk, it's necessary to underline that these are influenced by the dimensions of the surfaces to be picked up, the orografic characteristics, the conditions of the ground and the order of orchards.

Nevertheless in all the examined farms an exposure time practically coincident with the whole working shift is noticed, (equal to the 8 daily hours). This has allowed to be able to directly compare the average values of concentration noticed with the limits defined by the ACGIH.

Results

The values of concentration noticed, as said, coincident with the values of respirable dusts exposure of the workers employed to the harvest, is brought in table 1.

The aforesaid values have been compared with the limit values defined by the A.C.G.I.H. in 2007.

The A.C.G.I.H. identifies specific limits for coal dust, dust of cereals, dust of glass fibers, wood dust and cotton dusts. Other dusts are gathered under the name "(insoluble) particles not otherwise classified" (P.N.O.C.) and for these the A.C.G.I.H. nowadays speaks of "guidelines", rather than of TLV; in the past, TLVs fixed for the P.N.O.Cs have been used wrongly and applied to any non available particle in the lists.

Table 1. Concentrations of the respirable dusts found in the different examined firms, defined for every single machine (rate flow of sampling: 1,9 l/min) (TWA-A.C.G.I.H. limit value = 3 mg/m^3)

Tested Machine	Sampling time [min]	Volume aspirated [l]	Dust concentration [mg/m^3]
Species: hazelnut			
pulled vacuum harvester Facma Cimina 300	124	236	**21,8**
self-propelled vacuum harvester Facma Cimina 160 S	82	156	**13,4**
self-propelled vacuum harvester Facma Cimina 180 S	65	124	**14,6**
self-propelled vacuum harvester Facma Cimina 200 S	83	158	**20,5**
self-propelled vacuum harvester Facma Cimina 300 S	90	171	**24,7**
self-propelled vacuum harvester Facma Cimina 380 S	62	118	**25,0**
tractor mounted picker GF Jolly 2800	47	89	**21,3**
tractor mounted picker GF Jolly 2800	69	131	**18,8**
Species: chestnut			
pulled vacuum harvester Facma Cimina 200 T	52	99	**4,6**
self-propelled picker Agrintem Perla 55	52	99	**0,98**

The A.C.G.I.H., today, specifies that the recommended limits for the P.N.O.Cs are applied to particles that:

- have not a specific applicable TLV;
- are insoluble or poorly soluble in water (or, preferably, in the pulmonary fluids if available data have been given);
- have low toxicity.

For the aforesaid particles (in 2007) limits of air concentration of 3 mg/m^3 in the case of the respirable particles and 10 mg/m^3 in the case of the inhalable particles are recommended.
From the analysis of the data gathered in table 1 it is noticeable that in all the 8 fields of hazelnut harvest dust concentrations expose the workers to values above the limits of

respirable dusts defined by the ACGIH.

Conclusions

From the data shown in table 1, a constant trespassing of the limit values defined by the ACGIH is deduced, for hazelnuts harvesting, although the technologies used for the mechanized harvest of these shell fruits result to be characterized by a high degree of innovation [1].

The average concentration of dusts found in the tests is equal to 20 mg/m^3 (with a standard deviation equal to 4,25 mg/m^3), against a value defined by the "guidelines" recommended by the ACGIH equal to 3 mg/m^3.

The situation improves for chestnut harvesting, generally effected in the month of October, when the grounds are mostly damp (besides it needs to be underlined that generally chestnut orchards present well more grass covered grounds in comparison to those of the hazelnuts): in fact values of exposure are also gotten below the limits suggested by the ACGIH. Nevertheless the results related to chestnut harvesting cannot be considered indicatives, because the bad meteorological conditions during the harvesting season have not allowed the execution of a sufficient number of samplings.

Besides this the research has also analyzed the importance of the variables in play during a typical harvest: particularly the dampness of the ground assumes a notable influence, while other variables as the order of the orchards, the dimension of the fields, the organization of the work, primarily affect on the exposure times to the specific agent of risk.

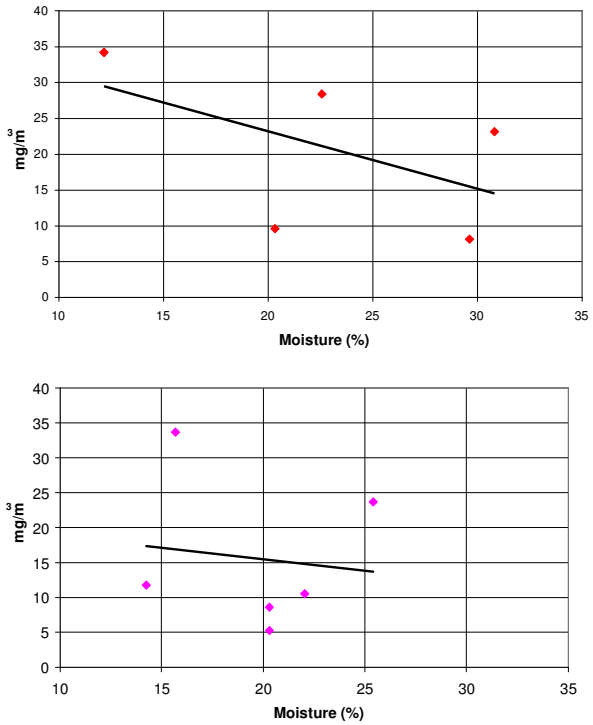

Figure 4. Course of the concentration of breathable dusts in relation to the moisture of the ground [6]

Previous researches, as it is deduced by the graphics brought in figure 4, underline the relationship between the ground moisture and concentrations of the aerodisperse dusts (Cecchini et al. 2005): obviously a great quantity of water in the ground reduces the concentration of particles, but this would seem more evident for the picking machines in comparison to the vacuum machines.

Anyway, in the hazelnuts harvesting, to avoid the onset of possible illnesses of the respiratory apparatus of the workers the use of individual protection devices (IPD - instruments of protection of the respiratory ways) is fundamental.

The choice of a fit individual protection device of the respiratory ways necessarily has to keep different factors in mind: the only criterion of choice in fact cannot be only the evaluation of the level of protection offered. Other aspects not to be underestimated are: the convenience, above all if the device must be worn for long periods, and the correct use.

For the choice of the IPD the norm EN 529:2005 "Respiratory protective devices - Recommendations for selection, use, care and maintenance - Guidance document." is adopted [9].

To be protected by the inorganic dusts the adoption of respirators is enough to filter against particles: facial anti-dust filters, or facial filtering.

The anti-dust filters (characterized by the white color code) and the respirators with anti-dust filter are divided in the following classes:

- low efficiency (filters P1 - respirators FFP 1, THP 1, TMP 1);
- medium efficiency (filters P2 - respirators FFP 2, THP 2, TMP 2);
- high efficiency (filters P3 - respirators FFP 3, THP 3, TMP 3).

The "nominal factor of protection" of a device (NPF) is the relationship between the concentration of the contaminant in the environment (C_{ext}) and its concentration inside the facial (C_{int}) one. The simple formula that ties the factor of protection to the filtering efficiency is the following:

$$NPF = \frac{C_{ext}}{C_{int}} \qquad (2)$$

The factor of nominal protection declared by the producer is given by measurements in the laboratory. In a work environment the conditions of use of the device can be very different: insofar, to the practical goals, more than the factor of nominal protection interests the "operational factor of protection". This last one can be considered, for devices with average efficiency, equal to 10.

From the results of the present study, therefore, considering that the workers' exposures during hazelnut harvesting are always revealed ten times above the TWA limit of the ACGIH, they would result to be fit facial filtering FFP 2 or P 2 filters fitted on masks.

However, for the reduction of the risks it seems evident the benefits brought by solutions like for instance: the substitution of the technique of the tilled soil with that of the natural cover crop, the reduction of the number of employees (with passage from the traditional system with hauled machines and three or four employees to the harvest, to the self moving ones usable by a single operator), while the employment of picking machines rather than vacuum machines doesn't appear as an evident system of prevention anymore [5].

More drastic solutions to the problem such as the adoption of semi-cab machines, even though desirable, result difficult as an application for the peculiarities of the work (necessity to pick up under the tree).

References

[1] ACGIH (2007), Valori limite di soglia. Indici Biologici di Esposizione, ACGIH 2007. Giornale degli Igienisti Industriali, AIDII, Milano, luglio 2007.
[2] Biondi P., Monarca D., Maraziti F. (1997), Il rischio da polvere in campo agricolo. Rivista di Ingegneria Agraria 4/1997: 226-236.
[3] Biondi P., Monarca D., Zoppello G. (1992), Il problema delle polveri nella raccolta delle nocciole con macchine aspiratrici. Rivista di Ingegneria Agraria 23 (4), 228-236.
[4] Biondi P., Monarca D., Zoppello G. (1993), Il problema delle polveri nella raccolta delle nocciole. Macchine e Motori agricoli, 50 (4), 63-69.
[5] Biondi P., Monarca D., Zoppello G. (1994), Dust control in hazel harvesting with vacuum harvesters. Atti III International Congress on Hazelnut, Alba 14-18 settembre 1992. Acta Horticulturae, gennaio, 351, 513-519.
[6] Cecchini M., Monarca D., Biondi P., Colantoni A., Panaro A. (2005), Il rischio da esposizione a polveri per gli addetti alla raccolta delle nocciole. Convegno AIIA2005: l'ingegneria agraria per lo sviluppo sostenibile dell'area mediterranea. Catania, 27-30 giugno 2005.
[7] Monarca D., Cecchini M., Antonelli D. (2005). Innovations in harvesting machines. Acta Horticulturae. vol. 686, pp. 343-350 ISSN: 0567-7572.
[8] Monarca D., Zoppello G. (1993), Il problema delle polveri e dei rumori in ambiente agricolo. Atti del V Convegno nazionale AIGR. Maratea 7-11 giugno 1993, (4) 383-390.
[9] EN 529:2005 "Respiratory protective devices - Recommendations for selection, use, care and maintenance - Guidance document"

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