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Ergonomics contribution to chemical risks prevention: An ergotoxicological investigation of the effectiveness of coverall against plant pest risk in viticulture

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ABSTRACT

The purpose of this article is to present the contribution of a trans-disciplinary approach focused on ergonomics and chemical risk control. We shall more precisely discuss how such an approach carried out in the field of agricultural work has made it possible to highlight serious shortcomings in the effectiveness of the coveralls that are supposed to protect vineyard workers from pesticides. The study results, as well as the whistle-blow that followed have questioned the control and prevention measures used until then. The aforementioned trans-disciplinary approach gathers knowledge and methods from epidemiology, industrial hygiene, occupational health and safety and ergonomics. Ergonomics were central in the development of the approach as it connected task and activity analysis with contamination measurements. Lastly, the first results that were obtained have been confirmed and reused by the AFSSET (Agence Française de Sécurité Sanitaire Environnement et Travail, the French governmental agency in charge of environmental health and occupational health and safety issues) regarding the agricultural sector but also for all other situations in which workers use coveralls as protection against chemical risks.

1. Introduction

Occupational health and safety organisations have tackled chemical risks, and more precisely the risks posed by plant protection products for a number of years now. However the recommended control measures rely too heavily – if not only – on the use of Personal Protective Equipment (PPE) rather than on measures designed to reduce the risk at the source through the implementation of engineering or administrative controls. What is supposed to be, according to all risk prevention bodies, the last line of defence is often the *only* barrier between the protection products (which we shall call pesticides from now on) and the worker. A study led on French wine-growers has highlighted serious shortcomings in the efficiency of the protection equipment used by vineyard workers.

The project presented is largely based on what we shall call an ergotoxicological approach. This means that the study uses ergonomic analyses of work tasks and activities, observations of real-life working situations but also more toxicological data and measurements. Contamination levels were measured in different stages of the work such as preparing, dosing, applying and cleaning. The study shows that the coveralls usually recommended by the health and safety organisations can be ineffective.

2. The use of pesticides in French agriculture

In France, there are over 90 families of pesticides, with over 900 substances, among which 200 are used in the wine growing industry, and more than 9000 commercial products. It is thus extremely difficult to know the exact quantities of products used, their specific effects and their main routes of entry into the body. It must be noted that France is the fourth user of pesticides (see Fig. 1 below).

In France, from the farm owner and farm worker database, it is estimated that there are 1.3 million people potentially exposed to pesticides in the course of their jobs. This estimate should be doubled to take into account the agriculture pensioners. The importance of pesticide risk on public health then becomes apparent.

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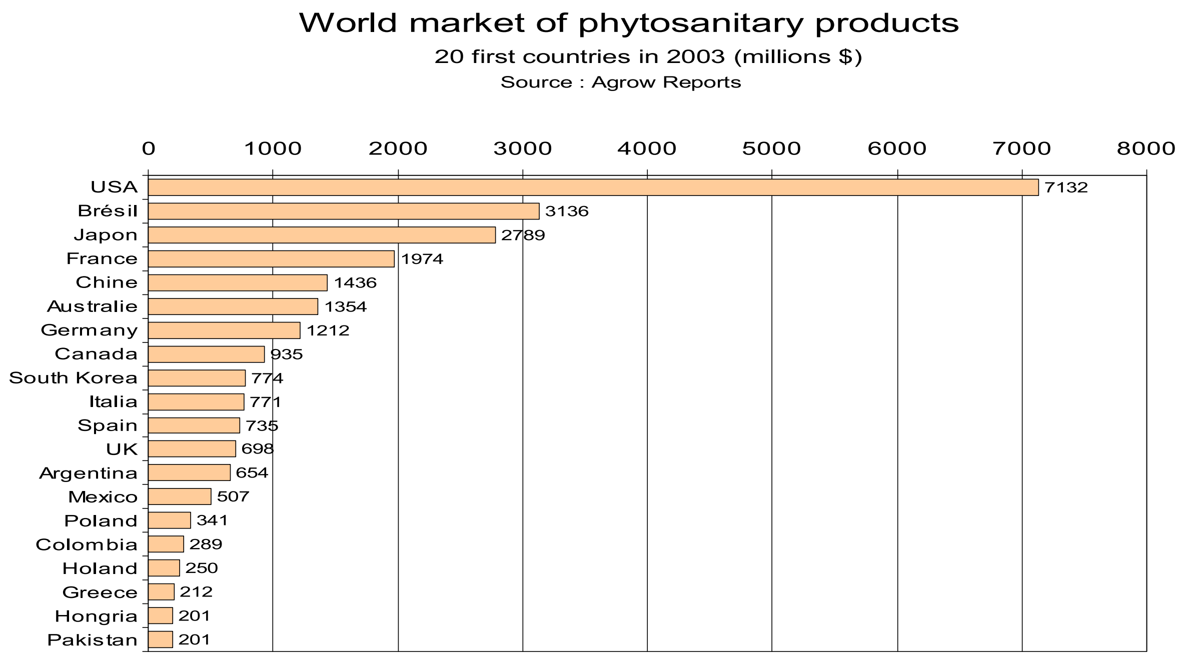

Fig. 1. World market of pesticides.

3. Effects of pesticides on health

As a result of the number of people who are exposed to pesticide substances it seems relevant to recall the different pathologies that can be caused by such exposure. Many epidemiological studies have suggested the possible role of pesticides in the occurrence of cancers (Acquavella et al., 1998; Blair et al., 1992; Dich et al., 1997), neurological diseases (Colosio et al., 2003) or reproductive disorders (Cocco, 2002).

We could detail different types of effects on health (Baldi et al., 1998, 2002, 2006; Ramwell et al., 2004; Alvania et al., 2005; Buckley et al., 2000; Garcia, 2003; Infante-Rivard et al., 1999).

3.1. Short term effects

The short term effects occur generally after poisoning, collective contamination, suicide attempts or occupational accidents. It is difficult to determine the exact number of acute, immediate effects:

- Not all pesticide poisoning cases are reported and investigated;
- Diagnosis may not necessarily identify pesticide exposure as the symptoms can be attributed to a flu or gastroenteritis;
- There is no “pharmacovigilance”, no sufficient awareness focusing on pesticides, which would aim to watch systematically for the ill effects of pesticides.

Since 1997, after an experimental stage, the MSA (French public insurance system dedicated to agriculture) has extended its surveillance network to all French departments. Incidents and accidents involving a professional use of pesticides are now monitored. The Phyt'attitude network reorganised in 2004 is implemented by the local health and safety services of each MSA which collect the incident reports. Those records are analysed by toxicologists to decide whether to link causally the effects and the suspected substances.

3.2. Long term effects

Long term effects occur either long after a peak exposure, or after moderate but frequent and prolonged exposure. Regarding those effects, three major categories have been distinguished and analysed: cancers, neurotoxicity and mutagenesis. The data that were collected mainly originate from the agricultural world.

3.2.1. Cancers

Epidemiologic data on cancers were mainly produced through American and Scandinavian studies. *The global cancer mortality rate is less important among male and female agriculturalists, but some cancers are over-represented in some studies*. These include malignant hemopathy (e.g. leukaemia, multiple myeloma), skin and lip cancers, soft tissue sarcoma, prostate and testicle cancers, intestinal cancers, brain tumours.

Several methodological problems may account for the difficulty in carrying out and interpreting the findings from such studies:

- The effects of pesticides on health are delayed; indeed, in most cases diseases do not appear until fifteen to thirty years after exposure;
- The effects are not always visible and can be cumulative;
- There are many types of pesticides and many different ways to use them, which makes it difficult to analyse them as a single category of substances;
- Individual variability may also explain why some results seem contradictory.

3.2.2. Neuro-pathologies

There are three main types of effects that can occur in the medium to long term:

- Polyneuropathies, characterized by muscular weakness and that can also cause loss of consciousness and severe respiratory failure. Nervous damage has also been observed.
- Some neuropsychological disorders have also been studied after a prolonged exposure to pesticides: for example, mood disorders, anxiety, concentration problems, memory disorders.
- Finally, pesticides could be a risk factor for Parkinson's disease. Parkinson's disease affects 1.5 percent of people of both sexes over 65. Parkinson's is accompanied by a deficit in dopamine, which generates tremor, rigidity, and slowness.

Several cases of acute Parkinsonian syndromes have been reported after exposure to a pesticide. Moreover, since the mid-1980s numerous epidemiologic studies have focused on a possible connection between exposure to pesticides and the occurrence of Parkinson's. Although some studies have brought reasons to believe in such a connection, no definite conclusion has been reached yet because of contra-indications with other studies.

3.2.3. Reproductive toxicity

Apart from dibromochloropropane (DBCP) whose use is forbidden, the role played by pesticides in reproductive troubles and congenital abnormalities is difficult to assess. Risks for male sterility, miscarriages, still born babies, delayed growth and development, or foetal abnormalities have been associated with paternal or maternal exposure to pesticides. From a toxicological point of view, it is likely that chemicals such as pesticides can interfere with hormones, growth factors or neurotransmitters and hamper the development of the nervous system at some stages of foetal life. The effects, if any, are probably moderate and cannot be highlighted by studies carried out on too few subjects or with too imprecise exposure estimates.

Regarding the prevention of health hazards induced by pesticides, the precautionary principle could be invoked. Indeed potentially adverse effects have been clearly established. On the other hand, scientific knowledge is not advanced enough yet, and it will probably take years to reach conclusive results, years that we cannot afford to wait to act. The precautionary principle is thus making the use of pesticides a major public health issue triggering toxicological and epidemiologic research and surveys.

3.3. Data on contamination in France

In France the MSA set up the Phyt'attitude network to gather and analyse the data on contamination by pesticides. The data for 2004–2005 reveal the following: 319 contamination cases were reported. 48% of the reports were made directly by the victims, 43% by farm owners, and 43% by farm employees. The cereal and wine sector represent respectively 33% and 7% of all reports.

On the whole, 80% of the cases are due to passive contamination which occurred as the victim re-entered a treated area, 20% occurred during the treatment or because of a nearby treatment. 35% of the reports involve insecticides, 27% fungicides and 27% herbicides. The most frequent types of effect are damage to the skin (24%), damage to the liver or digestive system (20%), neurological or neuromuscular damage (19%) and neurosensory (10%). Paraquat, used for weed-killing is the cause of a third of all serious burns due to pesticides in France.

The Phyt'attitude network does not make it possible to track all cases of contamination. What's more, it seriously underestimates the cases of chronic or sub-acute contamination. We should also underline that many symptoms of contamination are difficult to differentiate from "regular" pathologies or health problems (e.g. headaches, stomach aches) This makes it all the more difficult for farm workers to even be aware that they may have been contaminated, let alone to report it.

4. An ergotoxicology-driven approach to plant pest risk in viticulture

The ergotoxicological approach was originally developed by different authors: Sznelwar (1992), Mohammed-Brahim (1996, 2009), Garrigou et al. (1998, 2009), Mohammed-Brahim et al. (2003), Mohammed-Brahim and Delpuech (2009), Mohammed-Brahim and Garrigou (2009). This approach seeks to identify situations where workers are exposed to chemical hazards, and which therefore constitute a risk, based on occupational analysis of the activity. The approach then goes on to characterize the forms of *contamination*, i.e. where the product comes into contact with skin or enters into the body, in relation to the physicochemical and toxicological properties of the product and the occupational activity being performed. This makes it possible to pinpoint the Technical, Human or indeed Organisational determinants driving these exposure situations, and then to build prevention solutions designed to transform these determinants (Garrigou et al., 2004).

Among the issues addressed in ergotoxicology, the utilisation and effectiveness of protective equipment represents an important challenge for occupational health. Focusing on pesticide risk in agricultural work, researchers like Packham (2006) have raised doubts as to whether protective gloves are genuinely effective. We will take this argument further, drawing on results dealing with external contamination among wine-growers and generated by the 'Pestexpo' study led in the Bordeaux region by Isabelle Baldi (Baldi et al., 2002, 2006). This study, which used an ergotoxicological approach, attempted to characterize exposure levels and actual contamination at each phase of the work (preparation, treatment and cleaning, see Fig. 2) among wine-growers due to pesticides (dithiocarbamates) in 2001 and 2002. The most important elements of this study are presented in the following points.

4.1. Protocol of contamination measurement

The study measured actual contamination due to pesticides among wine-growers. For the treatment tasks, field observations (Baldi et al., 2006) led over 72 days (67 involving treatment applied

Fig. 2. Stages of the work.

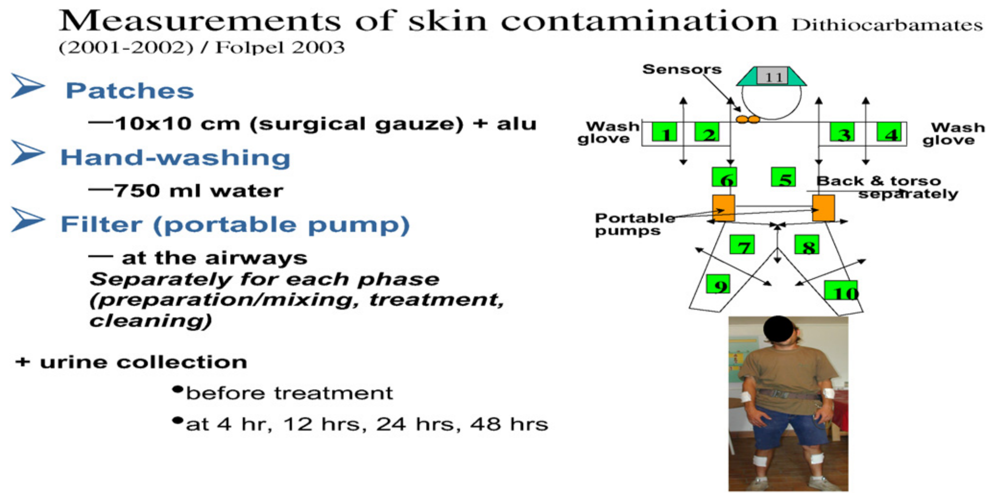

Fig. 3. Protocol of measurement.

by tractor-mounted sprayers and 5 involving backpack sprayers) generated various different data sets for each stage of the work (preparation of the spray mixture/mixing, treatment or application of the treatment, and cleaning the equipment). It should be underlined that contamination studies use the term "*actual contamination*" for contamination on the skin of the operator, as opposed to "*potential contamination*" which refers to substance deposits on coveralls, when they are being worn.

Contamination measurements were performed by analysing the quantity of pesticide agent deposited onto 10 cm^2 patches of surgical gauze. These patches were attached directly onto the skin of the wine-growers, in the different body areas, and were changed after each phase of work (see Fig. 3). The study protocol followed the Organisation for Economic Co-operation and development (OECD, 1997) guidelines for this type of field study. The patches were placed directly onto the skin, i.e. underneath the clothing, and underneath any protective coveralls being worn.

4.2. Contamination results

It should be underlined that the wine-growers were told to do their work as usual throughout the operations. Some wore protective gear, others did not. Some of those using protective gear were appropriately equipped, others were not. During the preparation phases, around 2/3 of the workers wore protective gear, a little over half of them wearing it for the treatment and over half of them wearing it for the cleaning. This being said, the simple fact that the wine-growers wore coveralls does not mean that they were fully protected, i.e. the protective gear did not prevent all contamination. The coveralls really worn by the wine-growers did not necessarily present all the characteristics of the protective coveralls recommended by the prevention management bodies. But some of them were wearing type-4 coveralls designed to protect against aerosol chemicals (see the Fig. 4 below).

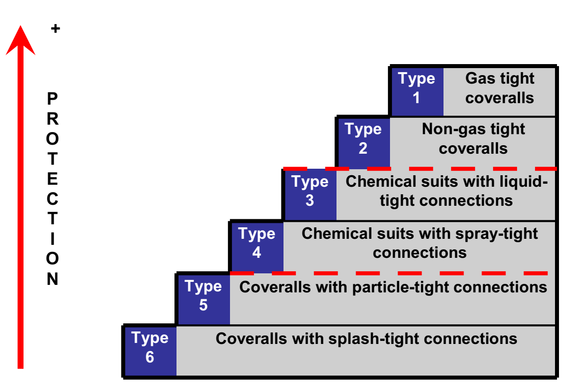

Fig. 4. Types of coveralls.

4.2.1. PPE use

The data from the 67 observations on treatment applied via tractor-mounted sprayers can be analysed to detail the frequency at which the PPE was worn:

- 50% of the wine-growers did not wear gloves, 40% wore gloves during either the preparation stage or spraying stage (2%), and only 10% wore the gloves for both of these stages;
- 58% never wore coveralls, 24% wore them for one of the two stages (of which only 4% wore them for treatment spraying) and 18% for both;
- 61% never wore a mask, 36% wore a mask for one of the two stages (of which only 4% wore one for spraying) and 3% for both stages.

4.2.2. Overview of the contamination between mixing and treatment

Based on 9 observations and contamination analysis (Baldi et al., 2002), we could underline that 50% of the contamination occurred during mixing, even though this stage accounted for only 15% of the total work time (Fig. 5).

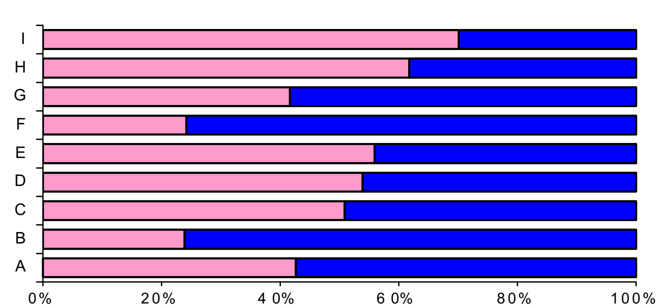

Fig. 5. Contribution of mixing (in pink) and spraying (in blue) to dermal contamination.

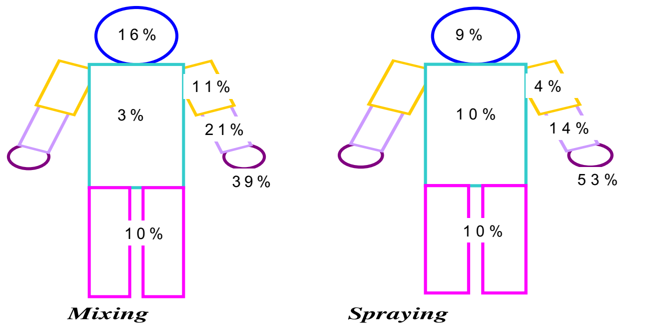

Fig. 6. Contribution of each area of the body to dermal contamination during mixing and spraying.

4.2.3. Overview of the contamination on the body area

Based on these nine observations and measurement (Baldi et al., 2002), we could point out that 71% of the contamination was at the upper limb, and in particular at the hand, with indication of greater contamination during spraying. The head represented 16% of the contamination during mixing and 9% during application (Fig. 6). They were expressed in mg of active substance deposited on the farmer's skin (after extrapolating patch size to the surface area of the body zone).

4.2.4. External contamination measurement

The results (Baldi et al., 2006) are based on 67 observations. Fig. 7 shows the median contamination level (horizontal bar) and distribution (from the bottom-to-top: minimum, 25th percentile, median, 75th percentile, maximum).

We shall now compare the contamination levels depending on the stage of activity (mixing–application or treatment–cleaning) and whether workers were wearing PPE. In these observations, we did not specify the type of PPE that had to be worn.

The most striking observation is the wide-ranging contamination distribution values for people wearing protective clothing and people not wearing protective clothing. There are cases where people wearing protective clothing presented *higher contamination values* than people not wearing protective clothing.

These results have caused disarray among the various protection management institutions, since one of the core guidelines of current prevention policy is to wear Personal Protective Equipment, and in particular class-4 coveralls designed to protect against liquid aerosols.

No attempt to correlate the contamination with ergonomic parameters was done at this stage, but we observed that wearing gloves or being in a cab did not guarantee low contamination, and that sprayed acreage did not fully explain contamination during application.

4.2.5. Comparison of the contamination measurement into two test situations

The data presented below (Fig. 8) concern two identical situations of vine spraying with a backpack sprayer. In both cases the real contamination was measured according to the protocol in 4.1 for all stages of work: preparation, applying and cleaning. Preparation lasted 5 min and spraying 20 min. In the first situation the worker prepared the mixture outside, near the vine that was going to be treated and he did not wear PPE in any of the stages. In the second situation, the worker prepared the mixture in near-perfect (according to existing good practice guidance) conditions: the mixture was made under a hood fitted with exhaust ventilation, using recommended PPE (new coverall type 4 (see Fig. 4) and gloves, dust and gas cartridge face mask). The worker carried out the same type of application as the one described above. The point of the test was to compare contamination levels depending on whether PPE was used.

The results highlight the real efficiency of the use of PPE:

—The coverall reduce the cutaneous contamination by a factor of 10 for the preparation stage and by a factor greater than 30 for application;
—In the case of the cleaning, the worker was less contaminated without wearing the coverall by a factor of 5.

It shall be noted that in this activity of applying a pesticide with a backpack sprayer the preparation and application times were respectively about 5 min and 20 min. For longer periods, we can wonder about possible pesticide accumulation inside the protective clothing, all the more so as in farm work, coveralls and suits are often reused throughout the season. In some cases, workers use the same PPE for the whole season.

4.2.6. Real efficiency of the coverall

It appears that PPE, even when adequate (recommended by experts), new and/or well maintained are not a barrier that prevents contamination completely. They do reduce it, but they do not avoid it.

This leads to several conclusions:

- Wearing protective clothing does not totally prevent contamination;
- During the preparation phase, wearing coveralls *partially protects against contamination* but does not guarantee a total barrier;

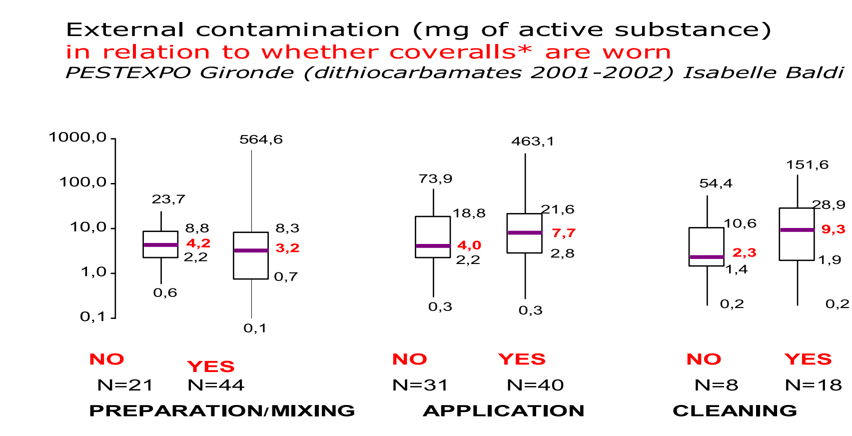

Fig. 7. External contamination measurement.

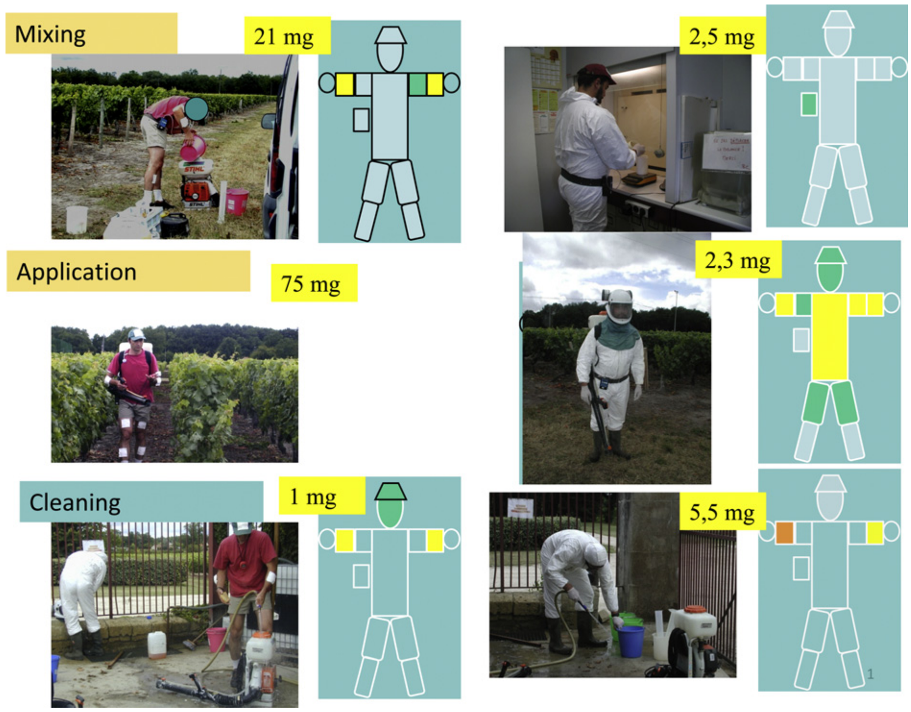

Fig. 8. Comparison of the contamination in two test situations.

- During the treatment and cleaning phases, people who wore coveralls *generally experienced higher contamination* than those who did not (see Fig. 7).

5. Several explanations of the contamination

Following discussions held with various key experts and prevention management bodies (the medical benefits fund governing the agricultural sector, the INRS (French National Institute of Health and Safety Research), the UIPP (French Federation of Pesticide Producers), the ECPA (European Federation of Plant Protection Agent Producers), the Ministries of Labour and Agricultural Affairs), we produced various explanatory hypotheses for the contamination patterns observed:

- *Individual and collective precautionary techniques or "know-hows"* developed and consolidated through experience (such as the amount of care taken when opening and pouring from sack-packed forms of powdered pesticides) are major factors of lower contamination levels. It follows that nurturing conditions for developing and communicating these kinds of "know-hows" industry-wide is a key challenge for prevention management;
- There is a lack of guidelines on choosing, using, looking after and cleaning PPE;
- *Precontamination* of PPE can occur, stemming from reuse without prior cleaning or from storage in premises that are already contaminated;
- *There can be perceived overprotection*: wearing coveralls can bolster workers' perception that they "feel protected", thus engendering a kind of sloppiness on certain precautionary measures;
- *There are false ideas among wine-growers on the contamination pathways*, ideas which are centred on respiratory pathways while strongly underestimating the skin route for contamination;
- *Contamination can stem from natural movements*: scratching your head, or wiping your face with gloves on, or with hands that have been exposed to pesticide;
- *Designers of sprayer hardware fail to engineer their equipment* for the requirements of wine-growers. Examples include the need to hold close onto the wall of tractored sprayer vats to keep them upright at the same time as emptying powder into the vats. The outer surface of the vat is often caked in deposits of pesticides left over from previous treatments, or spillage when filling the vats.

6. The permeation of the coverall: a new explanation

Since autumn 2006, we have developed a new hypothesis that challenges whether the coveralls recommended for use with pesticides are *actually effective*. While working with a manufacturer of pesticides, we raised the issue of fabric permeation in certain coveralls. This industry partner (which has a prevention department as part of its sales mission) is aware of the hazards involved with using herbicides in conditions with increased risk of exposure (with a backpack sprayer for example). This industry partner decided to commission an approved test centre to run a series of lab-based permeation tests. These tests were run on class-4 coveralls recommended for use with herbicide treatments, and the tests followed the permeation testing protocol set out in standard EN 374-3: 2004.

Permeation (Protective clothing – Terms and definitions FD CEN ISO/TR 11610) was thus defined as the process whereby a chemical product crosses through a material at molecular level (see Fig. 9).

Permeation therefore involves:

- Absorption of the chemical molecules into the contact surface (outside) of a material;
- Diffusion of the absorbed molecules through the material;
- Desorption of the molecules from the opposite (inside) surface of the material interface.

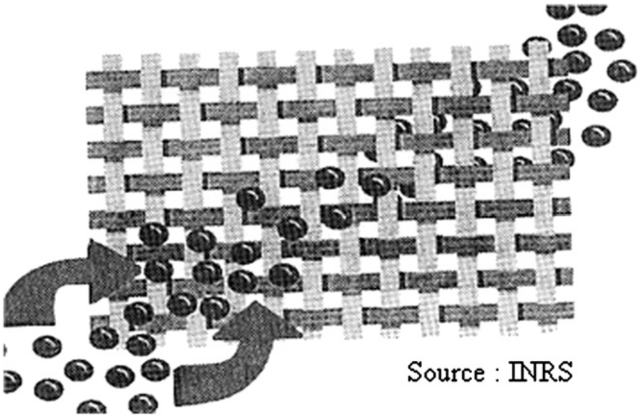

Fig. 9. The permeation process.

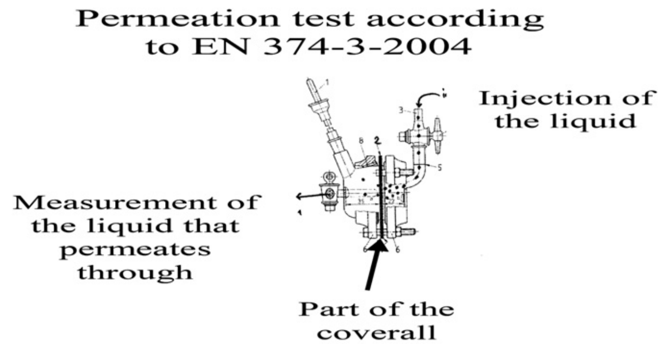

Fig. 10. The permeation test EN 374-3-2004.

- Permeation is therefore a different process from penetration, which is the movement of chemicals through zippers, pores, seams or flaws in the gloves, at non-molecular level.

For the permeation tests part of the coverall is cut out and fixed between the two elements of a test device. The test then consists in the injection of a known quantity of a liquid, here pesticides, and the measurement of the quantity of liquid that seeps through the membrane (see Fig. 10). The coverall will be ranked into 7 classes, depending on the time before permeation, from class 0 with a permeation time below 10 min through to class 6 with a permeation time of 8 h (480 min).

The tests produced *alarming* results, since they highlighted fast-action permeation effects occurring with a variety of widely used agricultural herbicides. Some pure products are able to migrate into the coveralls in less than 60 s while even diluted products can get through in less than 10 min. Fig. 11 presents the results of the permeation tests carried out according to EN 374-3-2004. Those tests were performed by the aforementioned manufacturer on a type-4 suit, which is the most frequently used type of suit. Tests were performed with 5 different herbicides in a concentrated or partially diluted solution. The tests show that all five herbicides seep very rapidly through the protection membrane, i.e. the suit. In all cases permeation occurred in fewer than 10 min (class 0).

These tests verified the permeation hypothesis and consequently the fact that the materials used for manufacturing coveralls used to protect from pesticides were not effective.

7. Technical and organisational flaws in PPE design and certification

How can it be possible that people who are *theoretically* protected are in fact getting contaminated? Discussions led with

Resistance to permeation according to EN 374-3-2004 (type 4)
Results of the tests with pure and diluted solutions of herbicides

	Concentrated	Diluted	
Herbicide 1,	Classe 0	2 %	Classe 0
Herbicide 1bis,	Classe 0	2 %	Classe 0
Herbicide 2,	Classe 0	2 %	Classe 2
Herbicide 3,	Classe 0	3,5 %	Classe 0
Herbicide 4,	Classe 0	2,5 %	Classe 0

- Class 0 : < 10 mn, non compliant
- Class 1 : 10 – 30 mn
- Class 2 : 30 – 60 mn
- Class 3 : 60 – 120 mn
- Class 4 : 120 – 240 mn
- Class 5 : 240 – 480 mn
- Class 6 : > 480 mn

Fig. 11. Results of resistance to permeation.

Resistance to liquid permeation (EN ISO 6529, migration time at 1 μg/cm²/min

Chemical	Migration time (min)	EN* class	Chemical	Migration time (min)	EN* class
Sulphuric acid (30%)	290	5 of 6	Sodium hydroxide (40%)	>480	6 of 6
Sulphuric acid (18%)	>480	5 of 6			

*In compliance with standard EN 14605/EN 14325

Resistance to liquid penetration (EN ISO 6530)

Chemical	Penetration index (%)	EN class	Repulsion index	EN class
Sulphuric acid (30%)	0.0	3 of 3	96.5	3 of 3
Sodium hydroxide (10%)	0.0	3 of 3	96.6	3 of 3
o-xylene	6.2	1 of 3	83.7	1 of 3
Butane-1-ol	3.1	2 of 3	88.4	1 of 3

Fig. 12. Coveralls instruction.

coverall manufacturers revealed that the coveralls currently recommended for use in farming were primarily developed for industry, with agriculture representing only a niche market, and indeed the effectiveness of the coveralls *has not been tested with the active substances contained in pesticides, including some of the most widely used*.

This survey highlights technical and organisational flaws (Reason, 2004) related to the assessment of the coveralls, and thus raises questions about compliance with the requirements set out in the European standard governing PPE (design, certification and commercial sale) – an issue raised previously by Mayer and Bahami (2006) but without response. Following on from Dubuc (2007), if we take an in-depth look at the manufacturer's instructions provided with each set of coveralls, it becomes clear that the information on coverall performance and limitations is highly technical and sufficiently complex to deter workers from reading it. This is demonstrated by the set of manufacturer's instructions for their coveralls given in Fig. 12.

First, users are expected to be familiar with the similar but very distinct notions of penetration and permeation, which in reality is rarely the case. Furthermore, although this is the class of coverall recommended by the prevention management institutions (Ministère de l'agriculture et CCMSA, 2007), it is clear that the tests on resistance to permeation by liquids for these coveralls are not conducted using active substances featured in pesticides but with various sulphuric acid and sodium hydroxide-based solutions.

There is currently no evidence to rule out permeation as an issue in factory settings such as the pharmaceutical industry, or more specifically the chemicals industry, with other products. Furthermore, it is highly likely that the sweat generated via physical activity and trapped within the coveralls actually promotes the penetration of plant protection agents into the coveralls. Focusing on the cleaning phase, the pressure of the water sprays together with run-off may well promote the migration of products building up on the outer shell of the coveralls.

As far as prevention solutions go, the initial response would be to recommend using type-3 or type-2 coveralls (see Fig. 4), which theoretically offer better protection. However, there is no current evidence to suggest that this would solve the permeation issue. One last point is that boosting the permeation protection level would reduce thermal comfort for workers, as the coveralls could become 'un-wearable'. This might introduce new risks related to working in hot environments by making it impossible to "wick away" sweat, thus preventing the body's homeostatic mechanisms for controlling core body temperature during work. This is likely to be one of the reasons why PPE are not being worn, because it soon becomes impossible to work in these conditions.

Therefore, it is not reasonable to expect pesticide users to be responsible for making sure that the protective gear they are supplied with is effectively compatible with the pesticides that they use, based on the information given in the manufacturer's data.

The governing guidelines (Ministère de l'agriculture et de la pêche, 2006) itself contains ambiguity, both in its authorship and in the policy statements of certain experts, that is liable to be detrimental to users' health and safety. The notified bodies, for their part, seem to believe that they are playing their role if they are applying highly technical standards that are sophisticated to implement.

According to the results presented, we have decided, to act as a whistleblower (Vaughan, 1996). For strategic reasons, a process was defined for drafting and releasing a warning notice (Garrigou et al., 2008a,b; Garrigou and Baldi, 2009) in order to mobilise as many actors as possible. This process is an integral part of a fully-managed approach fuelled by the results generated through the ergotoxicology approach. It is important not to forget that the permeation results were produced through a study led by a pesticide manufacturer whom we count as a partner. It was by cross-comparing this data (see Fig. 11) with Pestexpo data (see Fig. 7) that we were able to draw attention to the scale of the issue raised. This data nevertheless remains the property of the industry partner and as such, could not be publicly released.

The first step involved discussions with this industry partner with a view to using these results, while keeping both the company's name and the name of the protective gear manufacturer anonymous.

The second step was to test our analysis with the various stakeholders involved. Once we had enriched the results, the decision was made to draft a warning notice in scientific article format. After informal talks with all the stakeholders concerned, and notably those tasked with PPE project sponsorship roles at the various safety and health institutions, this warning notice was sent by registered mail to the managers of the institutions concerned (6 in total), and then forwarded on to various agriculture and agribusiness trade associations and labour unions (5 in total).

The final stage in this whistle blowing process consisted of working together to draft a report (Mahiou, 2007) on farmer exposure to pesticides for publication in a specialist review entitled "Santé&Travail", which enabled us to produce an in-depth, fully contextual study while at the same time reaching a wider readership in touch with prevention issues, particularly farmers and/or agricultural labour associations. This report was then relayed via mass media channels such as radio and the press, which in turn has heightened general media pressure, particularly on the institutional stakeholders. The final phase was to release the warning notice.

This relatively painstaking process showed that it was very important to create conditions whereby each stakeholder is able to use their skills and expertise and interact with others beyond the traditional boundaries.

When the ministry of labour (tasked with monitoring the implementation of directive 89/686/EEC) received this alert on the ineffectiveness of the protective coveralls worn by farmers when working with pesticides, they looked into several courses of action, all based on the principle that the findings revealed by the whistleblowers branched back to different kinds of problems. It appeared necessary to review user practices (choice of coveralls, how they are stored, looked after and disposed of) and re-examine how the coveralls are actually engineered in relation to the content of the governing standards (Garrigou et al., 2008a).

Following the warning, the ministry of labour has asked the AFSSET (Agence Française de Sécurité Sanitaire Environnement et Travail, The French Agency of environment and occupational safety and health) for support. The AFSSET then conducted research to confirm or refute the conclusions of our work.

First, they launched permeation tests for 10 class-3 and class-4 coveralls commonly sold in France (AFSSET, 2010; Le Frious and Paillat, 2010). This was to make sure that the coverall permeation performance matched the data contained in the user manual. Only two coveralls out of ten provide the level of permeation resistance displayed in the user manual. The remaining 8 coveralls vary more or less importantly with the manufacturer data, from almost immediate permeation (class 0) to a permeation resistance one class below the manufacturer data. These results have prompted the authorities to re-class some coveralls and even to forbid the sale of two sorts of coveralls. Manufacturers had to recall non-compliant coveralls that were already on the market.

Second, further tests were carried out on the best performing type-3 and type-4 suits as identified by the first series of tests. This was about testing these suits with pesticides and chemical mixtures. The tests showed that pesticides could rapidly permeate through type-4 suits. Type-3 suits had better results as they are made from materials different from those used for type-4 suits. This means that these suits are actually more resistant to permeation although their thermal comfort is poorer. It shall be noted that the study led by the AFSSET goes beyond PPE use in farming and questions their effectiveness as a means of protection against chemicals of any kind, whatever the activity and sector.

In addition, those results question the method used, in the standards (EN 374-3-2004. for example) to assess permeation resistance in the case of pesticides.

8. Conclusion

Within the scope of our study we were able to explain some of the factors that induce contamination of farm workers by pesticides. The fact that as a rule, people who used PPE were more contaminated than people who did not (Fig. 7) had been particularly strange to us. The explanation we offer lies in the very poor performance of the coveralls in terms of pesticide permeation.

That failure is due to the fact that the use of PPE in agricultural activities only results from a technology transfer (Silva et al., 1980; Wisner, 1997; Veiga et al., 2006; Palis et al., 2006) which has not been really controlled or channelled. The PPE dedicated to agriculture have been more or less directly transferred from industrial processes; so the use of PPE seems acceptable in laboratory conditions but it is much more problematic in agricultural activities where conditions are extremely diverse. Other factors, such as precautionary techniques and “know-hows” may explain the differences in contamination between PPE wearing workers and others.

Finally, the study underlines the relevance of the ergotoxicological approach (Mohammed-Brahim and Garrigou, 2009; Mohammed-Brahim, 2009; Garrigou et al. 2009) by showing how important it is to link the work activity and the work situation with a measurement of real contamination. This relies on a combination of different disciplines: toxicology, industrial hygiene and ergonomics. Ergonomics and work analysis can contribute to reducing the risks associated with the use of chemicals. This perspective makes it possible to understand the conditions and the degree of exposure in real working conditions. The effectiveness of PPE is one factor among others in the determination of exposure (Gerritsen-Ebben et al., 2007). Contrary to most methods used to reduce the occupational risks posed by chemicals, our approach does not consider PPE as the only possible measure.

Finally, the data that were gathered on pesticide exposure and real contamination levels made it possible for our research team to question the epidemiological approach generally used to analyse such issues. Given the effects of pesticides presented in Section 3, the epidemiological approach traditionally used is not sufficient. We need to also take into account real exposure situations to assess the risks posed by the use of pesticides.

This type of approach would be somewhat similar to the recent changes that have been brought about by the REACH Regulation. REACH has made it compulsory for companies that supply, produce or import hazardous chemicals to communicate more health and safety information to downstream users. Although the use of a substance may be particular to a customer, it is now the responsibility of the supplier to provide the downstream user with adequate risk prevention strategies that correspond to particular exposure scenarios, and not merely to the substance at hand.

From a practical point of view it is unreasonable, that the agricultural site managers are held responsible for the safety conditions of their employees while technical as well as organisational flaws have been identified up-stream in the prevention process.

As a conclusion, it will be necessary to change the perceptions and, often, misconceptions that stakeholders (PPE manufacturers, pesticide producers and H&S professionals) currently have on farm work. In our talks and discussions with them we often heard something which sounded to us too much like self justification, *“We’ve done something against the risks of pesticides. If it doesn’t work, it’s because farmers do not follow our advice and guidance.”*

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