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Robert-Sauvé en santé
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ABSTRACT

There are close to 29,000 farm operations in Québec, and they employ some 125,000 farm workers (2007). Pesticides are used on these farms to control crop pests, but they can have short-term as well as long-term health effects on farm workers exposed to them, mainly through the skin. Pesticide use is thus controlled and risk prevention measures are recommended. Personal protective equipment (PPE) plays a key role in reducing the risks of exposure. Because of the lack of data on occupational illnesses and injuries caused by pesticides in Québec, however, the current prevention message is not getting across. This multidisciplinary study presents a status report on the use of personal protective equipment (PPE) to shield workers from agricultural pesticides, describes the contexts and practices of pesticide use in Québec's apple industry and offers a preliminary priority list of the top pesticides necessitating protective measures. Possible courses of action are also suggested and discussed.

In Canada, the Pest Management Regulatory Agency (PMRA) is responsible for pesticide regulation. The PMRA carries out risk assessments and determines the mitigation measures necessary to ensure safe working conditions. The assessments are based on studies of exposure scenarios in which PPE use is considered by applying a protection factor (%) for each type of equipment. PPE use recommendations, which appear on virtually all pesticide labels, have the force of law and compliance is supposed to guarantee an acceptable risk.

Recommended respiratory protective equipment must be certified, but skin protective equipment is described generically. Standards that can help to clearly identify protective clothing needed and give minimum performance requirements exist throughout the world. CSA standard Z16602 on chemical protective clothing suggests a classification system based on the nature of the potential risk, but chemical resistance to pesticides is not considered. ISO standard 27065 specifically addresses protective clothing for application of pesticides, defining performance requirements for three levels of protective clothing, which can then be selected according to the potential risk in a given situation.

Measurements of the protective efficacy of clothing under real working conditions can supplement the information provided in standards. About 20 scientific studies of protective clothing used in the agricultural sector were identified. The protection factors measured are comparable to those applied by the PMRA in its risk assessments, but the reliability of the comparisons is undermined by the small amount of data available, the substantial methodological and experimental variability of the studies and various difficulties or shortcomings that make it impossible to be certain that the anticipated protective efficacy of the PPE is attained.

This study of Québec apple growers provided a better understanding of the realities of the industry and made it possible to contextualize the findings of the status report. More than 500 apple-growing operations, most of them small, were identified in Québec. The growers report strong economic pressure, stemming in particular from the cost of land, equipment, trees and pesticides. Environmental issues, new parasites, frost, hail, and the concentration and proximity of the orchards are additional challenges. To deal with these and ensure an adequate return, growers experiment with different types of plantations, apple varieties, tree training practices and pesticides.

Apple producers have witnessed changes in the industry over the past 15 years. Most expressed agreement with the objectives and practices of integrated fruit production (IFP): new insecticides are replacing older ones, with preference given to lower-risk pesticides, and an application strategy based on regular monitoring has been widely adopted. These changes have been supported by independent agronomists as well as agronomists from Québec's ministry of agriculture, fisheries and food (MAPAQ) and from technical clubs—key stakeholders whose opinions are valued by growers.

Economic constraints and pressure from pests, however, sometimes lead growers to choose the pesticides that are most effective—and less compatible with IFP goals. Most growers prefer selling to wholesalers, because that is how they get the best prices for their fruit. This, coupled with consumer demand for "perfect" fruit, can affect the number of applications and contribute to apple-grower exposure to pesticides.

An exploratory analysis of farm operations and exposure situations has also demonstrated that site layout, pesticide formulation and packaging, and equipment design determine exposure when mixing and applying pest control products. In these situations and others, PPE can play a significant role in protecting against exposure, but it is not always used, or used correctly—as repeatedly reported in other studies. Growers say there is not enough clear information about the risks of pesticides or the best methods of protection against them. Perception of the risk and lack of information about it, coupled with time and financial constraints, are additional factors in the failure to systematically use PPE.

A variety of measures can be suggested for better prevention against pesticide-related risks in agriculture, specifically among apple growers. Initiatives to raise awareness among apple producers, through training, for example, could help to convince them of the need for a systematic and rigorous approach to the protection of their current and future health. Concerted efforts by concerned institutions and the agricultural and scientific communities could support growers' efforts to reduce pesticide use. A preliminary list of pesticides, based on risk indices developed in this study for the products most commonly used by apple growers, may help guide prevention and research efforts. Standardization and better design of equipment used by growers could help to reduce exposure. In addition, clear identification of recommended PPE on pesticide labels and better characterization of PPE performance would be worthwhile. Also, the necessary PPE training and information should be jointly developed by stakeholders and disseminated through a network of key partners trusted by growers.

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SYMBOLS AND ABBREVIATIONS

AAC	Agriculture and Agri-Food Canada
ACGIH	American Conference of Governmental Industrial Hygienists
ADE	Actual dermal exposure, that is, the amount of pesticide collected under PPE (mg)
ADI_{HC}	Acceptable daily intake according to Health Canada (mg/kg/day)
ADI_{WHO}	Acceptable daily intake according to the World Health Organization (mg/kg/day)
AERU	Agriculture and Environment Research Unit, University of Hertfordshire, U.K.
AFNOR	*Association française de normalisation* (French standards organization)
AHED	Agricultural Handler Exposure Database
AHS	Agricultural Health Study
ANSES	*Agence nationale de sécurité sanitaire de l'alimentation, de l'environnement et du travail* (French agency for food, environmental and occupational health and safety)
ANSI	American National Standards Institute
AOEL	Acceptable operator exposure level (mg/kg/day)
AOHS	Act respecting occupational health and safety
aRfD, cRfD	Acute and chronic reference doses for ingestion exposure (mg/kg/day)
ASABE	American Society of Agricultural and Biological Engineers
ASTM International	International standards organization formerly known as the American Society for Testing and Materials
BHSE	British Health and Safety Executive, now called the Health and Safety Executive
BRI	Orchard beneficials risk index
CAPQ	*Centre antipoison du Québec* (Québec poison control centre)
CCOHS	Canadian Centre for Occupational Health and Safety
CEN	European Committee for Standardization
CFIA	Canadian Food Inspection Agency
CNESST	*Commission des normes, de l'équité et de la santé et la sécurité du travail*, formerly the CSST (Québec's workplace safety and insurance board)
CPC	Chemical protective clothing
CSA Group	Formerly the Canadian Standards Association
DFG	*Deutsche Forschungsgemeinschaft* (German research foundation)
DRASS	*Direction régionale des affaires sanitaires et sociales* (French regional directorate of health and social affairs)
E	Efficacy or protection factor (%)
EFSA	European Food Safety Authority
ERI	Environmental risk index
f_i	Frequency of application of commercial preparation containing active ingredient *i* (%)
FAO	Food and Agriculture Organization of the United Nations
FIFRA	US Federal Insecticide, Fungicide and Rodenticide Act
HRI	Health risk index

HSDB	Hazardous Substances Data Bank
IDHL	Immediately dangerous to health and life (mg/m^3) (30 min)
IFP	Integrated fruit production
INRS	*Institut national de recherche et de sécurité pour la prévention des accidents du travail et des maladies professionnelles* (France's national occupational health and safety research institute)
INSERM	*Institut national de la santé et de la recherche médicale* (France's national institute of health and medical research)
INSPQ	*Institut national de la santé publique du Québec* (Québec's national public health institute)
IRDA	*Institut de recherche et de développement en agroenvironnement* (Québec institute of agro-environmental research and development)
IRSST	*Institut de recherche Robert-Sauvé en santé et en sécurité du travail* (Québec occupational health and safety research institute)
ISO	International Organization for Standardization
ISQ	*Institut de la statistique du Québec* (Québec statistics institute)
K_{ow}	Octanol-water partition coefficient
K_p	Skin permeability coefficient (cm/h)
LC_{50}	Concentration that kills 50% of the test population (mg/m^3)
LD_{50}	Dose that kills 50% of the test population (mg/kg)
LOAEL	Lowest observed adverse effect level
M	Molar mass (g/mol)
MAK	*Maximale Arbeitsplatz-Konzentration* (8 h) (mg/m^3) (maximum allowable concentration)
MAPAQ	*Ministère de l'Agriculture, des Pêcheries et de l'Alimentation du Québec* (Québec department of agriculture, fisheries and food)
$MAX(ri_x)$	Maximum calculated ri_x
MDDELCC	*Ministère du Développement durable, de l'Environnement et de la Lutte contre les changements climatiques* (Québec's ministry of sustainable development, the environment and the fight against climate change)
MOE	Margin of exposure
MRL	Maximum residue limit (mg/kg)
MSHA	US Mine Safety and Health Administration
MSSS	*Ministère de la Santé et des Services sociaux* (Québec department of health and social services)
NIOSH	US National Institute for Occupational Safety and Health
NOAEL	No observed adverse effect level
OECD	Organisation for Economic Co-operation and Development
OEL	Occupational exposure limit (8 h) (mg/m^3)
OHS	Occupational health and safety
OSHA	US Occupational Health and Safety Administration
OSHS	Occupational safety and health standard
OWC	Ordinary work clothes
PCPA	Pest Control Products Act (Canada)
PDE	Potential dermal exposure, or amount of pesticide collected on PPE (mg)

PEL	Permissible exposure level, or permissible exposure limit (8 h) (mg/m^3)
PF	Penetration factor (%)
PHED	Pesticide Handlers Exposure Database
PMRA	Pest Management Regulatory Agency (Canada)
PPDB	Pesticide Properties Database
PPE	Personal protective equipment
PPQ	*Producteurs de pommes du Québec* (Québec apple growers' association)
PRDD	Proposed Regulatory Decision Document (Canada)
Q	Mass of active ingredient *i* applied per hectare, per application (kg/ha)
QPeRI	Québec pesticide risk index
RED	Reregistration Eligibility Decision (Canada)
REL	Recommended exposure limit (mg/m^3) (8 h)
ri_a	Risk index per pesticide application
ri_f	Risk index for commercial formulation
ri_i	Risk index for active ingredient
RI_x	Normalized risk index x ($x = f, i$ or a)
ROHS	Regulation respecting occupational health and safety
RPE	Respiratory protective equipment
RTECS	Registry of Toxic Effects of Chemical Substances
SAgE	Québec information tool on health risks, environmental risks and agricultural use of pesticides, developed to promote judicious pesticide management
SE	Small enterprises
SOFAD	*Société de formation à distance des commissions scolaires du Québec* (Québec school boards' distance education commission)
SPQA	*Stratégie phytosanitaire québécoise en agriculture* (Québec crop protection strategy)
TLV-STEL	Threshold limit value - short-term exposure limit (15 min) (mg/m^3)
TLV-TWA	Threshold limit value - time-weighted average (8 h) (mg/m^3)
TRI	Toxicological risk index
TWA	Time weighted average (8 h) (mg/m^3), mean exposure concentration for a conventional 8-hour workday
UdeM	*Université de Montréal*
UPA	*Union des producteurs agricoles* (Québec farmers' association)
URCAM	*Union régionale des caisses d'assurance maladie* (French regional association of health insurance funds)
USEPA	US Environmental Protection Agency
WGPETC	Pesticide Education, Training and Certification Working Group (Canada)
WHO	World Health Organization
WPS	Worker protection standard

1. APPLE PRODUCTION AND PESTICIDES

The bio-food industry is strategic for Québec (1), putting resources to work to further the economic development of the province and its regions and contributing to the health of Québecers through food (2). It includes agricultural production, fishing and commercial aquaculture, the processing and marketing of food and beverages, and the hotel, restaurant and institutional sector, and it employs some 475,000 men and women. In the agricultural sector alone, there were close to 29,000 operations in Québec in 2007, providing employment for 125,000 workers (3). In Québec, as in Canada, apples are the most popular fruit, second only to bananas, with berries (blueberries, cranberries and strawberries) in third place. It is thus not surprising that there are more apples grown in Québec than any other fruit, including blueberries and cranberries (4).

Like any other tree fruit, apples require considerable pest control, no matter what the production system—conventional or biological. Van Drooge et al. (5) estimated the average number of pesticide applications on an apple orchard in the Netherlands in 1997 at about 50. Sauphanor et al. (6) estimated at 25 to 30 the number of applications per season in France in 2002 to 2007 and in 1990, an apple orchard in Québec required 18 applications per season (7). A more recent estimate suggests over 12 applications per season may be required (4). Given the application frequency, there is pesticide residue in the fruit: in 2012-2013, there was pesticide residue in 88% of the apples tested in Canada (8), and in 2007-2009, pesticide residue was found in 56% to 82% of Québec apples. In addition, residues from seven to ten different pesticides were identified in the samples analyzed during this period (9). For 2012-2013, the Canadian Food Inspection Agency (CFIA) reports recurrent presence of ethylenediamine (associated with use of fungicides such as mancozeb and captan) in apples grown in Canada (8). Though residue levels very rarely exceed maximum residue limits in Québec, Canada and European Union (MRL) (<1%), all of the data available confirms that apple production relies on use of a wide range of pesticides.

1.1 Apple production in Canada

1.1.1 Overview

Canada has a long history of growing apples. First brought over by European settlers in the 17th century, apples were a pillar of the developing national economy (10). With the development of Canadian agriculture, however, the total planted acreage for apples, as for peaches, pears and plums, declined steadily between 1941 and 2011. However, though the acreage in apples shrank from 53,820 to 18,243 ha during this time, yield per hectare increased by a factor of 4.3, partially compensating for the drop in acreage. Nonetheless, annual per capita production declined from 23.5 kg to 11.8 kg (11).

The downward trend has continued in Canada, with area harvested dropping to 15,494 ha in 2013 (12). In 2014, apple growing accounted for 18.6% of the area devoted to fruit production in Canada—less than that devoted to blueberries (47.6%) and more than that used to grow grapes (13.7%) (12). For the years 2009-2013, average yield in Canada was 23.0 tonnes per hectare

(T/ha) (13). For the year 2011, Canada ranked eighth in the world for imports of apples and 33rd for exports.

1.1.2 Comparison between provinces

The decrease in planted acreage for apples occurred in the five provinces responsible for the bulk of Canada's apple production: Ontario, Québec, British Columbia, Nova Scotia and New Brunswick. Between 2002 and 2010, the planted acreage for apples declined respectively in these provinces by 28%, 10%, 39%, 27% and 45% (12). The downward trend is due to a shift to other tree fruits and to high-density apple planting methods and new apple varieties in an effort to up returns (10).

In 2014, Ontario, Québec and British Columbia accounted for 37%, 28% and 23% respectively of the total acreage devoted to apples in Canada. Nova Scotia and New Brunswick accounted for 11% and 1% of the total acreage of apples (12).

Yields (T/ha) were 25.1 in Ontario, 24.8 in Québec, 26.8 in British Columbia and 21.3 in Nova Scotia in 2013-2014 (12). Lastly, Québec is Canada's second largest apple-producing province, with 29.1% of the country's production and 26.8% of its farm gate value, ahead of British Columbia (20.9% and 25.3%) and behind Ontario (39.1% and 37.9%).

1.1.3 Apple production in Québec

In 2014, 18% of the total fruit cultivated area in Québec was devoted to apples, after blueberries (60%) but ahead of cranberries (14%) (12). However, apple-growing operations accounted for 26% of all fruit-growing farms in the provinces, 578 in 2012 (14), compared to 588 in 2010. In 2012, 37 of the 578 operations were growing biological apples on 1% of the area in apples (4).

However, the number of agricultural operations identified depends on the method used to count or estimate them. According to the 2011 Census of Agriculture, there were 692 agricultural operations in Québec (15), but according to 2011 data extrapolated to 2013 of the registry of agricultural operations of Québec's ministry of agriculture, fishing and food (MAPAQ, Ministère de l'Agriculture, des Pêcheries et de l'Alimentation du Québec), there were 802 agricultural operations in Québec, 66 of them with less than 0.2 ha in crops.[1] As not all orchard owners surveyed were necessarily active every year, Québec's apple growers' association (*Les Producteurs de Pommes du Québec*, PPQ) counts the number of active producers: according to the PPQ there were 522 active producers in 2013.

Table 1 gives a breakdown of agricultural operations in Québec based on 2010 data from MAPAQ's profile of Québec's horticulture industry (14), and data from Québec's statistics institute (Institut de la statistique du Québec) (16).

[1] Tuduri L, Ministère de l'Agriculture, des Pêcheries et de l'Alimentation du Québec. Personal communication. 2015.

Table 1. Number and size of agricultural operations in Québec's apple-growing regions (14, 16)

	Size		Number	
	ha	%	n	%
Province of Québec	5,837	100	588	100
Bas-Saint-Laurent	23	0.4	16	2.7
Saguenay – Lac-St-Jean	6	0.1	9	1.5
Capitale-Nationale	**193**	**3.3**	**54**	**9.2**
Mauricie	12	0.2	6	1.0
Estrie	70	1.2	21	3.5
Montréal	12	0.2	1	0.2
Outaouais	29	0.5	14	2.4
Abitibi-Témiscamingue	6	0.1	3	0.5
Côte-Nord	0	0	0	0
Nord-du-Québec	0	0	0	0
Gaspésie – Iles-de-la-Madeleine	6	0.1	9	1.5
Chaudière-Appalaches	**140**	**2.4**	**41**	**7.0**
Laval	23	0.4	5	0.9
Lanaudière	6	0.1	4	0.6
Laurentides	**1,325**	**22.7**	**105**	**17.9**
Montérégie	**3,806**	**65.2**	**282**	**47.9**
Centre-du-Québec	181	3.1	18	3.1

The Montérégie and Laurentides administrative regions alone include 88% of Québec's acreage in apples and 66% of its apple-growing operations, with the Capitale-Nationale and Chaudière-Appalaches regions a distant second and third. In other words, Québec orchards are heavily concentrated in two regions. In addition, as Table 2 shows, small apple-growing operations are the rule.

Table 2. Breakdown of Québec orchards by size[2] (17)

	Area (ha)				
Year	**0-5**	**5-10**	**10-15**	**15-20**	**> 20**
2008	52%	19%	11%	8%	10%
2013	59%	17%	9%	5%	10%

Most of the apple-growing operations were orchards of 5 ha or less. Average orchard size was 9.3 ha in 2004, 8.7 ha in 2008 and 8.4 ha in 2013 (4, 17).

Four apple varieties (McIntosh, Spartan, Cortland and Empire) dominate Québec's apple-growing industry (4). Exports are few, and 43% of Québec apples are destined for processing, a less profitable market than the fresh fruit market (4).

[2] Tuduri L, Ministère de l'Agriculture, des Pêcheries et de l'Alimentation du Québec. Personal communication. 2015.

1.2 Pesticides and occupational health and safety (OHS) in agriculture

The use of pesticides (that is, substances meant to control pests) has a long history, dating back thousands of years to when sulfur was used as a fumigant. The extraction and use of plant-derived insecticides, such as rotenone and nicotine, are described starting in the 17th century. Later, the use of arsenic- and copper-based compounds developed. It was only after World War II, however, thanks to industrial research and development initiatives, that synthetic insecticides became widely available and massively applied in agriculture (18). The goal was to improve crop productivity to feed the world's population. This is still a real issue today, but the quality criteria (colour, size, shape, shelf life) of today's consumers as well as economic sustainability criteria for agricultural systems must also be considered (19).

1.2.1 Pesticide use

1.2.1.1 Definitions

Crop protection products are regulated in Canada, with responsibility shared by federal, provincial and municipal authorities (see Section 3.1.1.2). They are called "pest control products" in Canadian legislation and regulations and "pesticides" in Québec legislation and regulations:

- Canada's Pest Management Regulatory Agency (PMRA) defines a pest control product as "a product, an organism or a substance, including a product, an organism or a substance derived through biotechnology, that consists of its active ingredient, formulants and contaminants, and that is manufactured, represented, distributed or used as a means for directly or indirectly controlling, destroying, attracting or repelling a pest or for mitigating or preventing its injurious, noxious or troublesome effects" (20).

- Québec's ministry of sustainable development, environment and the fight against climate change (MDDELCC) defines a pesticide as "any substance, matter or microorganism intended to directly or indirectly control, destroy, mitigate, attract or repel any organism that is injurious to or noxious or troublesome for humans, animal life, vegetation, crops or any other object, or intended for use as a plant growth regulator, except a vaccine or a medication other than a topical medication for external use on animals" (21).

1.2.1.2 Pesticide sales estimates

In 2011, for the 6,161 pest control products registered in Canada, 90.3×10^6 kg of active ingredient (kg a.i.), including bleach and creosote, were sold (22). In Québec, a total of 3.9×10^6 kg a.i., including bleach and creosote, were sold (23). Whereas only 69% of the pesticides sales in Canada were agricultural sector products, 84% were agricultural sector products in Québec.

These agricultural sector products can be grouped by their main target pest (Figure 1). Note that herbicides were used far more than any other product type in Canada as well as in Québec, and that fungicides are used more often in Québec than they are in Canada as a whole.

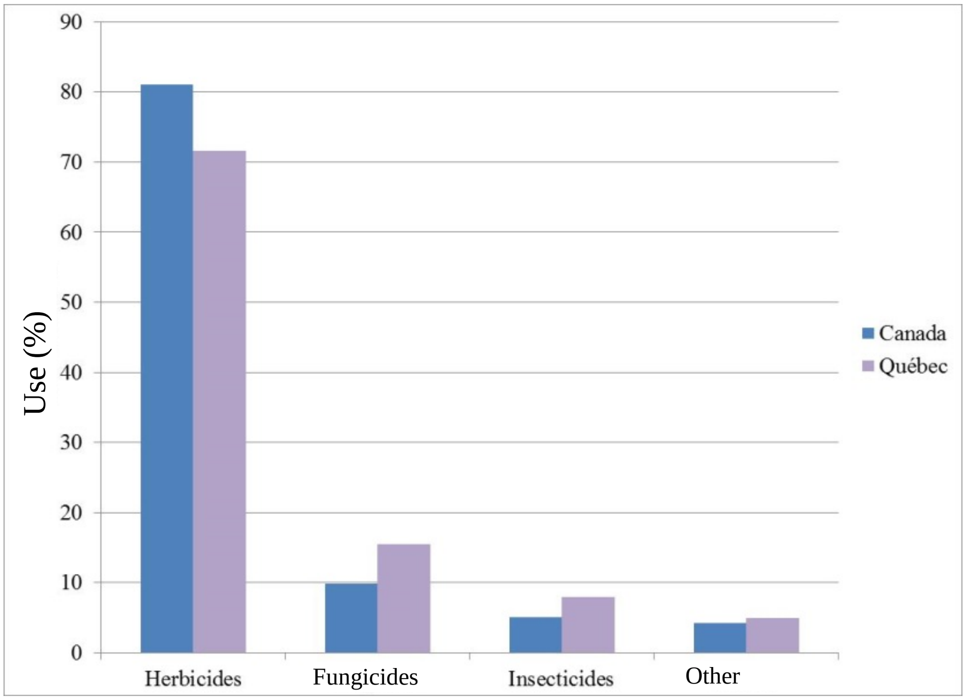


Figure 1. Use of agricultural pesticides Québec and Canada (22, 23).

Table 3 shows the top active ingredients sold in Canada and Québec in 2011.

Table 3. Top active ingredients sold in Canada and Québec (22, 23)

Canada (all sectors)	Canada (agricultural sector)	Québec (all sectors)
2,4-D	1,3-dichloropropene	Atrazine and related triazines
Chlorothalonil	2,4-D	Chlorothalonil
Creosote	Bromoxynil	Glyphosate
Corn gluten meal	Chlorothalonil	Mancozeb
Glufosinate ammonium	Glufosinate ammonium	Metiram
Glyphosate	Glyphosate	S-metolachlor
Mineral oil	Mineral oil	
Hypochlorite de sodium	Mancozeb	
MCPA	MCPA	
Surfactant blend	Surfactant blend	

Given the confidentiality of census data, a more detailed ranking of sales by sector and active ingredient is not possible. Québec data indicate that sales of each of the ingredients listed in Table 3 totalled more than $0.1x10^6$ kg and that sales of each of those listed as sold in Canada (all sectors) also totalled more than $1x10^6$ kg.

1.2.1.3 Estimated pesticide use by apple growers

In 2001, 73.2% of Canadian agricultural operations (plant production) used herbicides, insecticides or fungicides (24). The figure was 68.1% in Québec. Data extraction from the Census of Agriculture of 2001, 2006 and 2011 (15, 25, 26) gave further details about the practices of Québec farmers who reported they produce apples (some produce only apples, other produce other products as well). Table 4 shows these findings.

Table 4. Pesticide use among Québec apple growers (15, 25, 26)

	Percentage of operations using pesticide		
	2001	**2006**	**2011**
Herbicide	56.9	50.3	50.1
Insecticide	74.7	69.4	64.6
Fungicide	73.6	69.1	65.3

The figures reported show a decrease over time in the rate of pesticide use by apple growers, with fungicides and insecticides remaining the product types most frequently used. A breakdown of the 2011 findings by size of operation shows variability among apple growers (Table 5).

Table 5. Pesticide use among Québec apple growers by size of operation (15, 25, 26)

	Percentage of operations using pesticide		
Size of operation (ha)	**Herbicide**	**Insecticide**	**Fungicide**
All	50.1	64.6	65.3
< 2.4	34.0	41.8	41.8
2.4-4.9	47.2	72.6	76.4
4.9-10.1	58.3	81.5	80.6
10.1-20.2	68.8	85.3	87.2
> 20.2	78.7	88.0	88.0

In fact, the rate of use of all three types of pesticide increases with the size of the operation. Table 6 lists the products most commonly used by Québec apple growers as reported in the 2005 Statistics Canada survey (27).

Table 6. Pesticides most commonly used in Québec apple production (27)

Herbicides	**Insecticides**	**Fungicides**
Glyphosate	Mineral oil	Metiram
Paraquat	Phosmet	Captan
2,4-D	Azinphos methyl	Mancozeb
Simazine	Phosalone	Copper*
Glufosinate	Carbaryl	Dodine

* Different compounds

To our knowledge, these are the most recent published data. However, the growing conversion to integrated fruit production (IFP) and the re-evaluation of certain active ingredients (azinphos methyl and metiram [28, 29]) may have altered pesticide use in apple production since the 2005 survey.

1.2.2 Pesticide exposure, a risk factor in agriculture

1.2.2.1 Pesticide toxicity

While the role of pesticides is to control crop pests, they can have an impact on organisms in fields or orchards that are not targeted and on the workers who handle them. Their release to the environment and residues on food may also pose a risk for the general population.

In other words, there are concerns about pesticide use. The effects of pesticides on workers, as documented, can be chronic or acute, local or systemic. Certain toxicological properties can be characterized through in vivo or in vitro testing of laboratory animals. Such tests make it possible to establish or characterize the potential risks of each pesticide. This type of data is used in the pesticide registration processes and makes it possible to determine permissible exposure limits for workers and consumers. Epidemiological studies are an additional important source of information that make it possible to associate pesticide exposure and effects in a given population. For example, it has been reported that working with pesticides is associated with an increase in respiratory symptoms, such as dyspnea (30) and wheezing (31), as well as an increased risk of developing respiratory diseases such as asthma and rhinitis (32, 33) or skin diseases, particularly irritant or allergic contact dermatitis and urticaria (34, 35). Pesticides have also been associated with neurotoxic, reprotoxic and carcinogenic effects (36-38). The Institut national de la santé et de la recherche médicale (INSERM, France’s national institute of health and medical research) recently published a comprehensive review of the topic, *Pesticides: effets sur la santé*, the source of the information in Table 7 (39).

Table 7. Presumed association between occupational pesticide exposure and pathologies (39)

Pathology	Association*
Non-Hodgkin lymphoma	++
Multiple myeloma	++
Prostate cancer	++
Parkinson’s disease	++
Leukemia	+
Alzheimer’s disease	+
Impact on fertility	+
Hodgkin disease	±
Testicular cancer	±
Brain tumour	±

*Strong association (++); Moderate association (+); Weak association (±)

As the table shows, the presumed association with pesticide exposure is stronger with some pathologies that others. In addition to the number of epidemiological studies available, the size of the study population, the selection of the control group (group used for comparison) and the adjustments made for confounding factors (risk factors of the disease studied) can alter the strength of the association. Weakness in characterizing exposure in the epidemiological studies also diminishes the robustness of the association between exposure and pathology, especially in the case of chronic diseases for which exposure over decades must be documented. Sometimes data specific to a particular active ingredient are obtained. Often, however, a rough estimate of exposure intensity is obtained from metrics such as number of years of experience or type of job held and an inventory of the active ingredients to which the target population might have been exposed.

Characterization of exposure is thus crucial, not only for precision in epidemiological studies but also to characterize any given situation and to measure the effectiveness of risk mitigation measures introduced.

1.2.2.2 Pesticide exposure in agriculture

1.2.2.2.1 Exposure conditions

Agricultural producers can be exposed to pesticides directly or indirectly during a variety of tasks they perform:

- Preparation of spray mixtures (mixing-loading): concentrates are handled in different physical forms (liquid, powder, pellets).
- Spraying (application): diluted products are delivered to the target to be treated in the form of fine droplets. Pesticides can be applied using a tractor-mounted sprayer (tractor with or without cab) or a hand-held sprayer. In arboriculture, the spray is directed upward (skyward), meaning the potential for exposure is greater than when the spray is directed towards the ground.
- In addition to the tasks mentioned that are directly related to crop protection, exposure can also occur on re-entry into sprayed areas for observation, monitoring, thinning or pruning purposes or to dispose of pesticide waste. Skin can also come in contact with splashes when equipment used for spraying is cleaned.

In addition, the commercial formulation, the size of the area sprayed, the duration and number of applications, the method of application, the weather, and worker behaviour can all have an impact on the level of exposure (40-45).

Under normal conditions of use, exposure can be dermal (including through the eyes) or respiratory (through inhalation). The digestive route can become a key entry route if basic rules of hygiene are not followed (do not eat or smoke before washing hands, for example), if work practices are dangerous (using the mouth to clear a contaminated hose or a blocked sprayer nozzle, for example) or in case of accident. There is consensus that the skin is a major route of human exposure to pesticides (46-48). Worksafe BC, for example, mentions that more than four out of five accepted pesticide-related compensation claims involved exposure of the skin (49).

For guidance in developing preventive measures and reducing risks, a thorough assessment of exposure determinants is crucial. This involves not only a knowledge of exposure levels in the workplace but also an understanding of pesticide use practices and contexts.

1.2.2.2.2 Measuring exposure

There are a number of ways of measuring occupational exposure to pesticides. The first is to quantify potential external exposure. This involves measuring pesticides in breathable air and then pesticide residues on the skin. An advantage of this method is that it differentiates between routes of exposure and between exposure levels of different body areas, but it does not consider the amount of pesticide actually absorbed (see Section 3.1.3.2 for further information). A second method is to quantify internal exposure by sampling biological fluids, such as urine or blood. This method takes the amount of pesticide actually absorbed into account, it but does not differentiate a priori between routes of exposure.

To our knowledge, the only Canadian study of exposure of apple growers to pesticides was conducted in Québec in 1997 (50). Though a correlation was established between number of hours spent applying pesticides and level of urinary metabolites of organophosphate insecticides, the exposure levels recorded remained below the lowest observed adverse effect level.

Other studies of pesticide exposure in apple production have been published in the scientific literature. These are summarized in Table 8.

Table 8. Published scientific studies of pesticide exposure in apple production

Year	Location	Pesticide	Exposure measured	Task*	Reference
2015	South Korea	Flonicamid	Dermal and inhalation	M-L/Ap	(51)
2013	South Korea	Fenvalerate	Dermal and inhalation	M-L/Ap	(52)
2013	South Korea	Imidacloprid	Dermal and inhalation	M-L/Ap	(53)
2013	South Korea	Acetamiprid	Dermal and inhalation	M-L/Ap	(54)
2012	South Korea	Methomyl	Dermal and inhalation	M-L/Ap	(55)
2012	Switzerland	Captan	Biological monitoring	M-L/Ap/T/P	(56)
2008	United States	Captan	Dermal, inhalation and biological monitoring	Ap	(57)
2003	United States	Azinphosmethyl	Biological monitoring	T	(58)
1999	United States	Azinphosmethyl	Dermal	T	(59)
1999	United States	Azinphosmethyl	Biological monitoring	T	(60)
1998	Netherlands	Captan	Dermal and inhalation	M-L/Ap/T/P/H	(61)
1992	United States	Organophosphates	Biological monitoring + fluorescence	M/Ap	(62)
1983	United States	Captan	Dermal and inhalation	M/Ap	(63)
1978	United States	Azinphosmethyl Captan	Dermal	M/Ap	(64)
1975	United States	Parathion	Dermal and inhalation	T	(65)

* M-L: mixing-loading; Ap: application; T: thinning; P: pruning; H: harvest

As the table shows, the bulk of the research addresses the mixing-loading and application stages. In addition, the results do not necessarily distinguish between exposure during mixing-loading and exposure during application. Thinning has also been studied, with measurement of exposure to organophosphate insecticide residues. The substances most frequently measured in these publications are organophosphate insecticides and the fungicide captan.

In other words, there is still not much data on pesticide exposure in apple production and the conditions under which published results were obtained are quite variable:

- The substances selected for study reflect the substantial time span covered by the studies, indicated by the dates of publication. The variability in methods of application, and their efficacy is also likely a reflection of this time span.
- Methodologies for measuring exposure vary from one study to the next. Some researchers measure absorption (biological monitoring), whereas others measure external exposure (dermal and air contamination measurements).
- The experimental conditions for measuring exposure also vary. For example, Moon et al. (52) measured dermal exposure to fenvalerate at 13 different body locations in an unknown number of applicators during 20-minute applications in an experimental orchard in a research institute, whereas Hines et al. (41) measured dermal exposure to captan at 10 different body locations in 74 pesticide applicators during applications of unknown duration under real working conditions.

1.2.2.2.3 Social perspectives on pesticide exposure

The establishment, epidemiologically and toxicologically, of causal relationships between pesticide exposure and health effects in applicators is progressing slowly. Social science studies target use practices and contexts to understand exposure situations and provide guidance for preventive measures. Rather than quantification of the effects of pesticide exposure, these studies are based on observations, interviews and surveys of target agricultural populations with the specific goal of documenting real working conditions, the multiple determinants of activities contributing to exposure and the factors that play a role in the decisions pesticide users make about how to use products and protect themselves (66-71). Looking at real working situations makes it possible to document the constraints on producers, the compromises they make, the information available to them, their perception of the risk and the key characteristics of PPE (57, 72, 73). This type of data is sometimes also collected for subsampling in large-scale epidemiological studies such as the Agricultural Health Study (AHS) (57, 74), making it possible to explain quantitative results and possibly improve risk measurement by identifying other variables to be considered (75, 76).

Small businesses are a key component of the Québec apple industry. According to the most recent data, many Québec apple-growing operations are small (59% are ≥ 5 ha),[3] belong to a single owner (45%) (15), produce only apples (47%) (77) and are worked mainly by family members. International research has documented typical characteristics of small businesses (including isolation, lack of information, reduced capacity due to lack of resources and underestimation of OHS hazards) that are associated with less investment in OHS and a poorer OHS performance (78-80). The difficulties that small businesses face in managing chemical risk have also been documented (81). In agriculture, there are other specific conditions and cultural

[3] Tuduri L, Ministère de l'Agriculture, des Pêcheries et de l'Alimentation du Québec. Personal communication. 2015

arrangements associated with small operations—lack of separation between work and family life, family home on the site of operations, work hours spread over the entire day for owner-operators and participation of family members in production activities (76, 82-84)—that can impact exposure. Operation size is thus a variable to be considered in trying to understand and prevent pesticide exposure situations.

1.2.3 Prevention approaches

Mitigation strategies have been developed to reduce the level of risk to which apple growers may be exposed. These strategies are based on the general approach used in occupational health and safety, which is to incorporate a hierarchy of controls that gives priority to prevention at the source, or primary prevention, then to secondary prevention through use of collective protective equipment and last to tertiary protection through use of personal protective equipment (PPE). These preventive measures are especially important in that there are virtually no data in Québec on occupational diseases and injuries with pesticides as the etiological agent. Underestimation of the actual number of cases is a real possibility given the following:

- There seems to be evidence of under-reporting of minor occupational illnesses and injuries in agriculture (85, 86).
- Only 11,000 agricultural establishments were registered with the Commission des normes, de l'équité, de la santé et de la sécurité du travail. (CNESST), Québec’s workplace safety and insurance board)[4] in 2009, though more than 30,000 producers were documented (87). Family farms and those that have no employees are not required to contribute to the CNESST, which means that a large part of the agricultural labour force is not included in the documentation of occupational injuries. Furthermore, the Québec OHS system takes few preventive actions in agriculture, which is not considered a priority industry.
- The annual average number of calls to Québec’s poison control centre (CAPQ) between 1989 and 2010 in the category of “occupational exposure” to pesticides[5] was about 100. It is reasonable to think that the total number of cases of exposure to pesticides that might have had minor or major effects was greater than the number of calls received by the poison control centre. At any rate, pesticide poisonings remain commonly under-diagnosed (88).

1.2.3.1 Prevention at the source through elimination, substitution and reduction of pesticide use

There are a number of primary prevention approaches. The approval or registration process (by the PMRA in Canada) for use of a pesticide on particular crops is a regulatory measure that serves as a first line of defence against undue risk. Registration (equivalent to marketing authorization) is granted to products of agricultural benefit and “acceptable risk” to human health and the environment provided prescribed conditions of use are respected (20). This process thus eliminates the products that pose the greatest risk and encourages use of other products.

[4] The CSST became the CNESST in January 2016.

[5] Tuduri L, Lebel G, Centre antipoison du Québec. Personal communication. 2012

Other government measures can also help to prevent risks at the source. In 1992, for example, Québec introduced a crop protection strategy, the *Stratégie phytosanitaire québécoise en agriculture* (89), with the goal of cutting pesticide use in agriculture in half by the year 2000. The goal has since become to reduce, replace and re-think the use of pesticides in agriculture in order to lessen the risks to human health and the environment.

Lastly, certain farming methods (organic production and integrated fruit production (IFP), for example) are re-thinking pest control and encouraging agronomic practices that respect the environment and the health of pesticide users as well as citizens. IFP uses a formula known as the Environmental Impact Quotient (EIQ) that rates and ranks pesticides so the most desirable or least toxic pesticide choices can be made (90). The IPF program conducted in Québec by the Institut de recherche et de développement en agroenvironnement (IRDA, a Québec agri-environmental research and development institute) has been using other indices to classify pesticides since 2011: a health risk index (HRS), an environmental risk index (ERI) and an orchard beneficials risk index (BRI) (91). The health risk index and the environmental risk index are based on the Québec pesticide risk index (QPeRi) developed by the INSPQ, Québec's institute of national health (92), and the orchard beneficials risk index is based on a database maintained by *Réseau-pommier du Québec*. These indices were developed from a variety of data (on toxicity, half-life in soil and bioaccumulation, for example) and make it possible to assess the potential health and environmental risks of pesticide use and to estimate the impact of IFP on crop protection practices in apple production. Figure 2, for example, tracks changes in the average environmental impact of pesticide use in Québec orchards between 1978 and 2008.

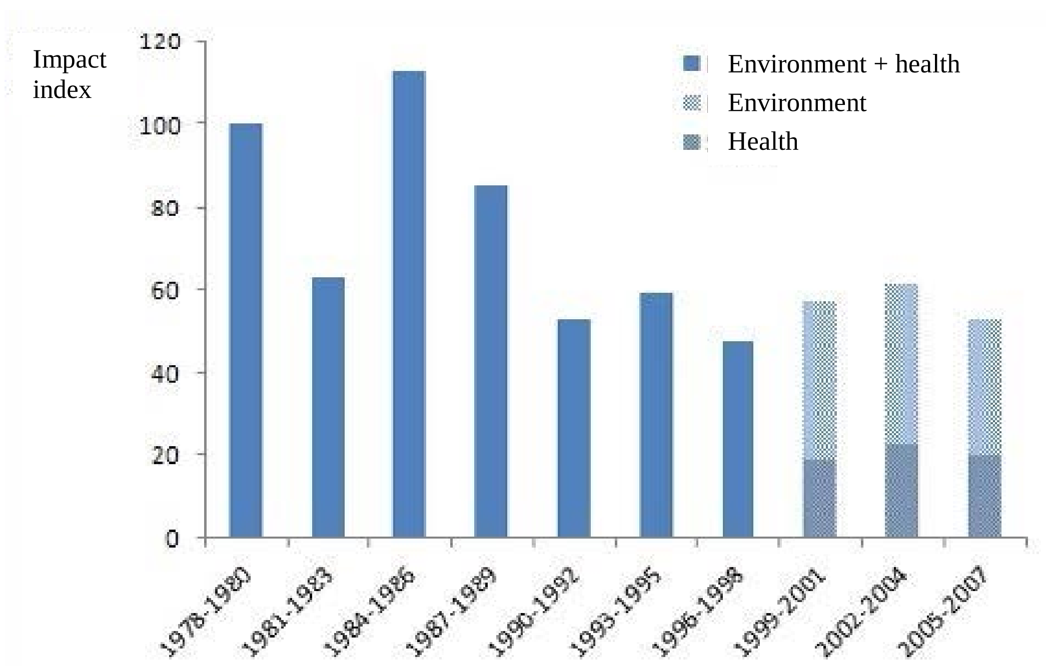


Figure 2. Mean environmental impact (health and environmental risks) of pesticides used in Québec orchards, 1978 to 2007, from Chouinard et al. (93)

1.2.3.2 Prevention through administrative and engineering controls

When a product becomes commercially available, certain administrative controls may be imposed by law to reduce the risks of its use. For example, re-entry intervals (also called restricted entry interval or re-entry time) are indicated on the labels of certain PMRA-registered pesticides to reduce indirect exposure in areas where the pesticide has been applied. An INSPQ study also lists re-entry intervals (94). In addition, the Regulation respecting permits and certificates for the sale and use of pesticides (95) requires that pesticides be applied by or under the supervision of a person who has obtained a certificate authorizing him or her to do so. A course, which is not mandatory, facilitates obtaining such a certificate.

Engineering controls also help to reduce risks. Sites used for storage and preparation of pesticides are thus organized to minimize the risk of spills and limit the number of times products must be handled. They must also have adequate ventilation. An example of a well-designed setup is described in a document published by IRDA (96).

The formulation of a pesticide and its packaging can also help reduce risk. Packaging powder formulations in water-soluble bags, for example, reduces direct risks of inhalation. Using gel formulations instead of powder in such bags reduces the possibility of leaks and of contamination of the environment in addition to reducing the direct risk of inhalation and the risk of indirect skin exposure.

A number of systems can be used to reduce product handling when preparing spray mixtures and product contact when loading the sprayer (98):

- A closed transfer systems can be used to move the pesticide from the original shipping container to the sprayer tank.
- Induction hoppers can be fitted to the side of the sprayer tank. The commercial formulation is then poured into the hopper and water is added to flush it into the tank.
- A direct pesticide injection system immediately upstream of the sprayer can be used, so the tank of the sprayer holds clean water only.

Tractors with enclosed cabs (cab tractors) help reduce exposure:

- They reduce direct deposit of aerosols/droplets on the body (43, 62).
- If the cab is equipped with a suitable air filtration system, the air inside the cab is free of particles and vapours.

Two-thirds (67%) of Québec apple growers have cab tractors, and 84% of these are equipped with carbon filters (99). A study by Coffman et al. of 702 pesticide applicators in the states of New York, Iowa and Michigan showed 72% of the applicators used cab tractors, of which 33% were equipped with carbon filters (100). Closed transfer systems, induction hoppers and injection systems were used by 33%, 33% and 17% respectively of the participants in this study.

Use of collective protective measures always takes precedence over use of PPE. Use of enclosed cabs reduces the need to wear PPE during pesticide application, according to the Worker Protection Standard (WPS), the US occupational health and safety regulation for agricultural workers (101). A number of standards describe enclosed cab performance requirements with respect to filtration and airtightness (102, 103). It seems that for optimal performance in the field, careful cleaning and maintenance is required (104, 105).

1.2.3.3 Prevention and personal protective equipment (PPE)

Despite the pre-eminence of elimination and replacement approaches and administrative and engineering controls, it is widely documented that PPE is very frequently required when pesticides are used in agriculture. An examination of the labels on registered pest control products, the content of which is prescribed by law, makes this quite clear. Failure to comply with the requirement that PPE be worn is nonetheless a reality among agricultural populations, as repeatedly reported in the literature (57, 72, 99, 106-109).

Hines et al. (57), for example, in a study of 216 fruit-growers (apples and peaches) in Iowa and North Carolina, reported that chemical-resistant coveralls/spray suits were worn by 36% (mix) and 37% (apply) of pesticide applicators and respirators by 45% (mix) and 49% (apply). Another study, of farms in British Columbia growing tree fruits, berries or grapes and practicing Integrated Pest Management (IPM) (72), reports that 77% use protective clothing and 75% use respirators. A recent Québec report on Integrated Pest Management gives a snapshot of the situation in the province (99). Table 9 shows some of the statistics from this report.

Table 9. PPE use (%) in Québec when mixing-loading and applying pesticides (99)

	Always		Usually		Rarely		Never	
PPE	Mix	Apply	Mix	Apply	Mix	Apply	Mix	Apply
Rubber gloves	72	69	11	9	2	3	15	19
Respiratory protection	47	47	13	12	11	9	29	32
Rubber boots	51	52	12	12	10	8	27	28
Protective clothing[1]	42	42	13	13	13	11	32	34
Safety glasses	45	43	11	12	11	9	33	36

[1]Ex.: Tyvek® coverall or apron

These data must, however, be interpreted with some reservations. Firstly, it is most likely that the different PPE mentioned (in Table 9, for example) are not all required at the same time by regulation. Secondly, the terms “respiratory protection” and “rubber gloves” are broad terms that cover a variety of very different types of PPE, including some that would be satisfactory in given exposure situations and others that would not. A respondent, for example, might consider disposable nitrile gloves acceptable when they are not. A respirator is required in some situations, but not in others. In other words, an applicator wearing gloves and respiratory protection is not necessarily well protected in the meaning of the law.

Discomfort, loss of dexterity, costs, insufficient knowledge and perceptions of risk are the reasons commonly given to explain these rates of PPE use (108, 110, 111). The suitability of PPE for agricultural tasks has also been raised in European studies (112).

A recent report by the French Agency for Food, Environmental and Occupational Health and Safety (ANSES) showed that some types of recommended chemical protective clothing were not chemically resistant to certain commercial pesticides, particularly organic solvent-based pesticides (113). In a study of wine-growers, agricultural workers wearing protective clothing were not systematically better protected than those who were not (112). Such studies raise questions about the chemical resistance of PPE evaluated in a laboratory, the suitability of such PPE for agricultural work and the impact on the safety or risk-taking practices of workers ("I am protected, therefore I can take risks").

Compliance with regulations for using PPE and recommendation of the "right" PPE, that is, equipment that is resistant and suited to the task, seem to still be a problem today. To correct the situation, a number of guides have been published in Québec, complementing the regulations with concrete recommendations. These include, *Pesticides et agriculture: bons sens, bonnes pratiques*, a joint publication of MAPAQ, the MDDELCC and the ministry of health and social services (MSSS) (114) and *Pesticides en agriculture*, published by the MSSS, the CNESST and the Union des producteurs agricoles (UPA) (115).

1.3 Summary and research objectives

Agriculture today relies on the use of pesticides not only to protect crops and maintain/increase production but also to ensure the nutritional and esthetic quality of the crops. Apple production, in Québec, as elsewhere, requires many applications to achieve these goals. Given the inherent toxicity of pesticides, their demonstrated and potential human health effects and the lack of administrative data on compensated injuries in Québec, reducing occupational exposure to pesticides should be a constant goal of all stakeholders.

The implementation of integrated fruit production (IFP) helps in making wise and informed pest control choices, thus limiting the risks of undue occupational exposure to the most harmful products. Engineering controls, such as the use of cab tractors, are recommended but their adoption by farm operators is not optimal. In addition, having a cab tractor on a farm is not enough: it must be equipped with the proper filters and rigorously maintained for effective protection. In addition, a cab tractor can be used for only some of the agricultural tasks associated with pesticide exposure. Though PPE is the last resort and the least effective option for reducing risks, it is a key component of most safety recommendations for farm operators. It thus plays a key role in the risk management options of competent authorities.

The substantial variation in compliance with PPE use recommendations, still poorly documented, and recent doubts about PPE efficacy under real working conditions have prompted interest in assessing the current situation with respect to prevention of the chemical risks of pesticide use by Québec apple producers.

The main objective of this study was thus to document the risks of pesticide use by Québec apple growers. To do this, and to suggest credible solutions for reducing pesticide exposure, a multidisciplinary approach was taken. The data collection was geared to documentation of exposure determinants using a variety of data and from a number of complementary perspectives—sociological, ergonomic, chemical and toxicological. Specific objectives were as follows:

1. Develop a status report on PPE use and chemical protection in agriculture.

Canadian regulation of PPE was studied and compared to US and European regulation. International standards for PPE chemical resistance performance criteria and requirements in agriculture were also examined. Lastly, a summary assessment of the field efficacy of PPE, chemical protective clothing (CPC) in particular, was made based on the scientific literature.

2. Draw a portrait of work contexts and practices in Québec's apple-growing industry

   Based on interviews, observations and a questionnaire survey, this portrait made it possible to get a clearer picture of the reality of the apple-growing industry and a better assessment of the pesticide-related risks in the industry and the protective measures actually used.

3. Draft a list of pesticides to be prioritized for protection efforts.

   Based on pesticide use data obtained from questionnaires completed by apple producers and relevant toxicological data, a risk index was developed to guide future studies on occupational pesticide exposure.

2. METHODS

A variety of sources and methods were used to generate the complementary findings of the status report presented in this study. The methods used in each section are described below.

2.1 PPE for pesticide use in agriculture

To get a complete picture of the regulations and standards governing the use of PPE and to investigate the field efficacy of certain PPE, a document search by French and English keywords was performed. Scientific databases and Internet sites were consulted. Table 10 lists the keywords and variants used for this search.

Table 10. Search keywords and variants

Keyword	Variants
Pesticide	*Produits phytopharmaceutiques, produits phytosanitaires, produits de protection des plantes, produits antiparasitaires*, chemical, chemosterilant, fungicide, herbicide, insecticide
Équipement de protection individuelle	*Équipements de protection individuelle*, personal protective equipment, *appareil de protection personnel*, *protection respiratoire, protection cutanée*, PPE
Vêtement de protection chimique	Personal protective clothing, chemical protective clothing, protective clothing chemical barrier, coverall, protective apparel, work clothing, chemical protective suit, liquid splash protective clothing, *vêtements de protection chimique*, protective clothing, protective device, garments, *ensembles*
Méthode d'essai des matériaux	Penetration resistance, permeation resistance, permeation index, materials testing, chemical resistance test, liquid penetration test, chemical penetration
Efficacité	Effectiveness, efficiency, performance, efficacy, penetration factor

2.1.1 Regulations governing PPE

Websites of European, Canadian and US government departments and agencies were consulted to develop an inventory of relevant effective legislation. The legislation was consulted on dedicated sites, such as the Government of Canada's Justice Laws Website,[6] the EUR-Lex website giving access to European Union law,[7] the U.S Government Publishing Office's Keeping America Informed website [8] and the website of Publications Québec.[9]

[6] http://laws-lois.justice.gc.ca/eng/

[7] http://eur-lex.europa.eu/homepage.html?locale=en

[8] http://www.gpo.gov

[9] https://www.publicationsduquebec.gouv.qc.ca/cspq/en/

The websites of the CNESST,[10] and SAgE pesticides[11] were also visited, as Québec workers often consult these resources to obtain information about regulations.

2.1.2 Standards for PPE

To develop an inventory of standards on PPE, a search of sites of standards-setting organizations was performed using the following keywords and their variants (listed in Table 10): *vêtements de protection chimique*, *méthodes d'essai des matériaux*, and pesticides. Sites consulted included those of AFNOR, the French standardization association,[12] the CSA Group,[13] the International Organization for Standardization (ISO),[14] the American National Standards Institute,[15] and ASTM International.[16] In addition, each of the standards examined cited others as references, and those that were pertinent were also consulted.

2.1.3 Field efficacy

The databases Embase, PubMed and Toxline were searched for scientific studies published between 1980 and 2014 that deal with assessment of the effectiveness of protective clothing in agriculture. The following keywords and their variants (listed in Table 10) were used for this search: *vêtements de protection chimique, efficacité* and pesticides.

2.2 Collection of primary data from Québec apple growers

The data collection was designed to document exposure determinants with multiple data from a variety of complementary perspectives (sociological, ergonomic, chemical and toxicological). Three sources of primary data were used to document work contexts and practices related to pesticide and PPE use in apple production: interviews, workplace observations and a questionnaire survey.

2.2.1 Role of the project monitoring committee

A monitoring committee composed of representatives from the occupational health and safety (OHS) and agricultural communities was established when the project was launched. The committee members (from the UPA, PPQ, CNESST, Montérégie public health department, MAPAQ and MDDELCC, as well as an apple producer who is a member of the board of directors of the PPQ) were asked to disseminate information about the study and facilitate access for the field work. The PPQ was of particular help with the questionnaire survey, mailing a hardcopy of the questionnaire to all its members and encouraging them to complete it.

[10] http://www.cnesst.gouv.qc.ca/publications/Pages/listepublications.aspx?ChoixLangue=Fran%u00e7ais&tri=date

[11] http://www.sagepesticides.qc.ca/

[12] http://www.boutique.afnor.org

[13] http://shop.csa.ca/fr/canada/produits/icat/publications

[14] http://www.iso.org/iso/fr/home/standards.htm

[15] http://webstore.ansi.org

[16] https://www.astm.org

2.2.2 Research ethics

A certificate of ethics approval was granted for the project by the health research ethics committee of the Université de Montréal (UdeM). Issued on April 24, 2013, this certificate (No. 13-025-CERES-D) provides oversight specifically for the two phases of the primary data collection from apple growers: the semi-structured interviews and observations in a sample of farm operations; and the questionnaire survey of all Québec apple producers.

2.2.3 Preparatory meetings with industry informants

Informal interviews were conducted with 10 informants familiar with apple production to give members of the research team an opportunity to acquire basic information about the industry, become familiar with the vocabulary and build a rapport with those who work in the industry. The informants were apple producers, sellers of pesticides and agricultural equipment, agronomists and technical consultants. Meetings were also held with the *Réseau-pommier* and a day was spent in an orchard. The knowledge acquired was used to prepare the data collection tools and organize the data collection.

2.2.4 Observations and interviews with a sample of apple producers

This first phase of the data collection involved interviews and observations at a sample of apple-growing operations. These qualitative data were used to explain the context of pesticide use and the work and preventive practices in words used by the growers themselves and from concrete situations documented by observation. This data collection also served to guide the development of the questionnaire for the survey.

2.2.4.1 Recruitment

The PPQ did not want to give the names and contact information of its members to the research team, citing their obligation to protect the privacy of this information. Volunteer apple growers could not as a result be recruited randomly. Instead, a snowball and trial-and-error sampling method was used. The process was started by the members of the monitoring committee passing on the information, by reaching out to contacts in the apple-growing community and by Internet searches of sites where producers advertise their products. A small number of growers were met in trips to target areas, where members of the research team went to meet growers on their farms, distribute flyers and ask producers in person if they would be willing to participate.

A summary of the project and a flyer explaining its objectives and what participation involved was handed out or sent by e-mail to addresses provided by growers. Each grower was thus well aware that participation in the data collection involved the following:

- A brief visit to the orchard and to sites where operations are carried out
- Taking photographs and recording videos during mixing-loading and application operations
- An interview of about 20 minutes

The data collection took place during the 2013 and 2014 production seasons. Just over 45 growers were contacted from April to June 2013 and from May to June 2014. Fifteen of these eventually agreed to participate. In some cases, the interviews and the observations were carried out in separate visits. In all, interviews were conducted with 15 producers and observations were made at 12 operations. There seemed to be three main reasons for the difficulty recruiting participants: the growers are subject to severe time pressures; there was reluctance to disclose information for fear that new regulations or administrative controls would be imposed; apple growers were already surveyed in the spring of 2013 for a MAPAQ study.

2.2.4.2 Representativeness

The sample of apple producers was not random; it was voluntary. The possibility of selection bias cannot therefore be eliminated: many of the participants were active in regional or provincial organizations and others were reached through technical club. The average age of the interview participants was close to the average age of the population of apple growers. The two main apple-growing regions were targeted for recruitment, Montérégie and Basses-Laurentides, given the large number of apple producers in these regions and their proximity to Montréal. A breakdown of participants by the size of their operations, compared to the MAPAQ data on Québec orchard sizes, shows the smallest operations are underrepresented in the study sample (Table 11).

Table 11. Operation size: study participants and MAPAQ data (17)

	Participants		MAPAQ 2008
Operation size (ha)	%	n	%
0-5.0	20	3	52
5.1-10.1	20	3	19
10.2-15.1	7	1	11
15.2-20.2	20	3	8
> 20.3	33	5	10
Total	100	15	100

2.2.4.3 Procedures for interviews and observations

The study objectives were recapped on meeting with the participating apple grower. A consent form specifying terms of privacy protection and participant anonymity was signed in duplicate, with the participant retaining one of the two signed forms.

The semi-structured interviews were conducted either outside or in one of the farm buildings before or after the observations, at the producer's convenience. All of the participating apple growers agreed to be recorded, filmed and photographed. A guide was used for all the interviews and observations. Lasting an average of 90 minutes, the interviews covered a wide variety of topics, making it possible to characterize the operations (region, size, ownership, production, etc.), the producers/operators themselves (age, experience, training, resources, services and sources of information, etc.), pesticide use (products, controls, concrete practices, etc.), equipment and PPE, safety rules and precautions, work tasks during the main operations, risk perception and accidents/incidents/health experience. The purpose of the observation of the work activity during mixing-loading and application of pesticide was to get a preliminary overview of exposure situations (average duration = two hours).

2.2.4.4 Analysis

All of the interviews were transcribed in their entirety. Coding and qualitative analysis were performed by two researchers with the help of the NVivo 10 program. Key themes related to the research objectives were identified: site layout, economic constraints, environmental constraints, operations, physical demands, mental demands, personal protective equipment (information, trends, choices, use, cleaning and maintenance), equipment (tractor, sprayer), the industry, risk perception, pesticides (information, trends, strategies, choice, use, the pesticide trap, producer, main tasks, secondary tasks, time, health, occupational health and safety, and regulations.

The videos and photographs taken for exploratory purposes were not systematically analyzed. A visual analysis was performed, consisting in identifying and summarily describing the main exposure situations associated with the activities that were the target of the observation and the main associated exposure determinants. The information thus generated was treated as qualitative data.

2.2.5 Questionnaire survey

The second phase of the data collection comprised a questionnaire survey targeting all Québec apple growers. The goal was to generate representative data to contextualize and document certain agricultural practices involving pesticide use in apple production and the implementation of collective and personal protective measures.

2.2.5.1 Development of the questionnaire

A number of sources were used in developing the content of the questionnaire, including meetings with the experts at *Réseau-pommier*, collection of data at the apple-growing operations, documents from MAPAQ (17) and Agriculture and Agri-Food Canada (AAC) (116), studies by Statistics Canada (27), surveys such as the Agricultural Health Study,[17] the questionnaire for agricultural advisors developed by INSPQ, the health risks perception survey of pesticide users conducted by Bretagne's *Union régionale des caisses d'assurance maladie* (URCAM) and *Direction régionale des affaires sanitaires et sociales* (DRASS) (71) and a British Colombian study of fruit-growing farms (72).

To keep the estimated amount of time required to answer the questionnaire down to 30 minutes, the number of questions was limited to 50. There were six sections to the questionnaire: producer, operation, choice and use of pesticides, preventive and protective measures, risk perception and health. A preliminary version of the questionnaire was submitted for validation in the fall of 2013 to a number of experts associated with concerned organizations: the PPQ, the INSPQ, MAPAQ, the CNESST, the UPA, IRDA, the Université de Montréal and the IRSST.

[17] http://aghealth.nih.gov

An English as well as a French version of the questionnaire [18] was produced. A paper version was created in addition to an online version that was developed with the online survey software SurveyMonkey®. The Université de Montréal parameterized and saved the online survey responses. The online version was pretested with five apple growers (four in French and one in English) in November 2013. The final version of the questionnaire was placed online on December 3, 2013.

2.2.5.2 Data collection

The questionnaire survey was conducted from early December 2013 to mid-April 2014. The apple-growing community was informed of the survey by an article that appeared in the *Bulletin des pomiculteurs*, sent by the PPQ to all its members, by bulletins posted on the *Réseau-pommier* website and at meetings organized in the community in November and December 2013 and January 2014. At public meetings in the farming community in late 2013, paper versions of the questionnaire together with a self-addressed postage-paid envelope were available. The URL for access to the French and English online versions of the questionnaire was also provided in a flyer distributed to growers; the URL was for a page on the IRRST website.

Preference was given to participation through SurveyMonkey, to facilitate processing of the survey responses. Reminders were issued by *Réseau-pommier*, regional unions of apple growers and several technical clubs that had agreed to ask their members to participate. In mid-February 2014, the PPQ included the paper version of the questionnaire in a mailing of the *Bulletin des pomiculteurs* sent to all its members. A self-addressed postage-paid envelope was included with all questionnaires.

A total of 195 completed questionnaires were collected, about 35% of them online and 65% by mail (paper version). Nine apple growers answered the questionnaire in English, only one of whom used SurveyMonkey. As all answers were precoded, all of the questionnaires were processed together in French. The data collected by SurveyMonkey were exported and saved in Excel. All data from the hardcopy questionnaires were double entered, and both input files were then converted to Excel files and compared using an Excel procedure to identify entry errors. A total of 27 questionnaires were unusable. The two Excel data files were then merged to constitute a complete database including 168 cases (Table 12). This file was then converted for use with the SPSS statistics software package and saved as the questionnaire survey database.

Table 12. Online and paper questionnaires received and used

	Received		Unusable		Used	
	n	%	n	%	n	%
SurveyMonkey	75	38.5	17	63.0	58	34.5
Paper version	120	61.5	10	37.0	110	65.5
Total	195	100	27	100	168	100

[18] Available on request.

2.2.5.3 Response rate and representativeness

One year prior to our data collection, the PPQ counted 522 active apple growers among its members. Based on this information, the response rate to our survey was 32%, a rate not uncommon in social studies (117) and considered adequate. The apple growers' distrust of the survey, coupled with their busy schedules and the constant demands they face for information of all sorts, worked against our efforts to obtain greater participation in the survey. The relevance and importance of the topic for growers, and the support expressed by a considerable number of industry experts and stakeholders seems however to have promoted adequate participation.

Without access to the PPQ's membership list, it was not possible to obtain a stratified, random sample. The sample of Québec apple growers who completed the questionnaire survey was a voluntary sample. A comparison of the survey sample data to data on the Québec apple-producing population made it possible to determine the representativeness of the sample.[19] The comparison showed that with respect to age, the sample was perfectively representative, but women were underrepresented. As for geographic region, the representation was quite good, but the main region, the Montérégie, was slightly overrepresented. With respect to legal status, an overrepresentation of partnerships and companies and an underrepresentation of farms owned by individuals was noted. In the case of grower-owned operations, size was not well represented: small operations of less than 5.0 ha were decidedly underrepresented (43% compared to 52%) and operations larger than 5.1 ha were overrepresented (see Table 11). Lastly, with respect to percentage of earnings stemming from apple-growing, the middle categories (51% to 75%, and 76% to 99%) were overrepresented and the two categories on either side (1% to 50% and 100%) were underrepresented. In other words, there are reservations about the representativeness of the survey sample, and caution should be exercised in interpreting the data.

2.2.5.4 Impact of data collection method

The entire active population of apple growers is the subject of the questionnaire survey. All growers who are members of the PPQ received information about the survey, and all were able to choose one of the two methods of data collection.

The population of apple growers is, however, diversified, and familiarity with the Internet probably varies and is undoubtedly significantly associated with age. Thus the average age of the producers who decided to use SurveyMonkey was 48.3, compared to an average age of 54.8 among those who opted for the paper version of the questionnaire. A choice of data collection method, very clearly offered from the start to the entire population of apple producers in this case, is a documented way of countering bias caused by data collection method (118). The way the data collection proceeded and the response rate seem to confirm the usefulness of the strategy: SurveyMonkey participation was slow to get started and remained weak. There was a big hike in participation in the days following the systematic mailing of the paper questionnaire to all apple growers, and the response rate was twice as high with this method of collection.

Using two different modes of survey distribution, mail (paper) and online, can have other effects on the data. The online version of the questionnaire, for example, required that the participant

[19] Document available on request.

answer all of the questions in a single sitting. In other words, an apple grower could not answer some of the questions and come back to the questionnaire at another time—which definitely discouraged some potential participants and lowered the response rate of the online version. The paper version gave participants more flexibility, allowing them to complete it at their own pace. The higher percentage of incomplete and unusable questionnaires collected by SurveyMonkey seems to confirm this (117). The concern with anonymity may also have favored the paper questionnaire, even though the guaranties of anonymity and confidentially were the same for the two modes. Lastly, the graphic design of the presentation of the questionnaire was identical for the two modes and could not have resulted in a participant selection bias.

A posteriori, it is possible that the organization of the data collection may have had an effect on the response rate and the representativeness of the sample. The survey targeted the entire Québec population of apple growers, but growers in the two main regions, Montérégie and Basses-Laurentides probably received more information than other regions and this may have caused some selection bias and influenced the overall response rate and the representativeness of the sample.

2.2.5.5 Analyses

The survey data were processed with SPSS survey software. Simple distributions are presented in the report.

2.2.5.6 Scope and limitations

The 32% response rate for the questionnaire survey satisfies recognized validity criteria, and the sample size is large enough to perform statistical analyses. The sample's representation of the target population is not ideal but considered adequate. Though the overall profile was validated by the members of the monitoring committee, the results should be interpreted with caution.

Thanks to the combination of three types of complementary data, the profile of pesticide and PPE use practices among Québec apple growers is broad and yet gives an in-depth picture of documented practices—an appropriate approach for a status report. In addition, the qualitative data collected from the subsample of growers who were interviewed provided new insight on the practices of apple growers and how they describe themselves and their work.

The smallest apple-growing operations are underrepresented in both the survey data and the interviews and observation of the small voluntary sample. The survey findings are nonetheless deemed to be representative enough of the population of owner/operators for a preliminary status report. However, the study does not address working conditions and OHS of wage earners in the apple industry, limiting the scope of the findings. The difficulties organizing data collection that would include agricultural labourers must not be underestimated and were considered when developing the objectives of this study.

2.3 Prioritizing pesticides used in apple production

2.3.1 Pesticides used

Pesticides used in apple production were first inventoried by consulting the list of pesticides authorized for IFP (91) and through discussions with the experts at *Réseau-Pommier*. The list constituted in this way was then submitted to apple growers in the questionnaire survey (see Section 2.2.5) to assess application frequency (%) of the pesticides listed.

In this study, the term “pesticides used” refers to commercial formulations and/or active ingredients actually used in the apple-growing industry in Québec. Herbicides are excluded; they are used in the apple industry but in much smaller quantifies than insecticides and fungicides.

2.3.2 Prioritization

The pesticides used were then prioritized based on application frequency, physical and chemical properties, toxic potential and available threshold limit values. The goal was to target particular pesticides that pose a greater health risk for applicators.

2.3.2.1 Review of toxicological, physicochemical and agronomic data

The data collected on each pesticide used includes physical and chemical properties of the active ingredients of commercial products, indicators of inherent toxicity and recommended reference or control values issued by major government agencies. Application rates of pesticides used in the apple industry were also documented. All of the data were compiled in the form of a digital file for each active ingredient.

The physical and chemical properties collected included molecular mass (M), solubility and octanol-water partition coefficient (K_{ow}). Dermal exposure was given priority as the main route of exposure (119). Skin permeation coefficient (K_p) was calculated from the revised Robinson model (120).

$$\boldsymbol{K_p} = \left(\frac{1}{10^{-1,326+0,6097\,log(K_{0w})-0,1786\sqrt{M}} + 0,0001519\Big/\sqrt{M}} + \frac{1}{2,5\Big/\sqrt{M}} \right)^{-1} \qquad \textbf{Equation 1}$$

The inherent toxicity of the active ingredients of commercial products was determined from the lethal dose (LD_{50}) or lethal concentration (LC_{50}) for the different exposure routes (oral, dermal and inhalation). The main types of exposure limit values as recommended or regulated by the major government agency for the workplace and for the general public in Canada, the United States, France and Germany were also identified (Table 13).

All of the information gathered was obtained from the major databases and documents listed in Table 14. Quantities used in apple production (kg/ha), however, were obtained for each commercial formulation from Canadian product labels, available on the PMRA website.

Table 13. Threshold limit values for pesticide active ingredients

Threshold limit value	Definition
Acceptable operator exposure level (AOEL) (mg/kg/day)	The maximum amount of active substance (absorbed) to which an operator may be exposed without any adverse health effects, according to the European Food Safety Authority (EFSA).
Acute and chronic reference dose (aRfD and cRfD) (mg/kg/day)	The maximum amount of a substance that can be ingested in a period of no more than 24 hours, on a one-time (aRfd) or lifetime (cRfD) basis, without appreciable health risk to the human consumer, according to the recommendations of the US Environmental Protection Agency (USEPA).
Acceptable daily intake (ADI_{HC}) or Tolerable daily intake (TDI_{HC}) (mg/kg/day)	The maximum amount of a substance to which an individual in the general population may be exposed daily over a lifetime without appreciable health risk, according to the recommendations of Health Canada.
Acceptable daily intake (ADI_{WHO}) or Tolerable daily intake (TDI_{WHO}) (mg/kg/day)	The maximum amount of an agent to which an individual in the general population may be exposed daily over a lifetime without appreciable health risk, according to the recommendations of the World Health Organization (OMS).
Threshold limit value - short term exposure limit (15 min) (TLV-STEL) and Threshold limit value - Time-Weighted Average (8 h) (TLV-TWA) (mg/m^3)	Airborne concentration of a chemical substance that should not be exceeded during an 8-hour workday (TLV-TWA) or for more than 15 minutes at any time during a workday (TLV-STEL), according to the recommendations of the American Conference of Governmental Industrial Hygienists (ACGIH).
Immediately dangerous to health and life (IDHL) (30 min) and Recommended exposure limit (REL) (8 h) (mg/m^3)	Average airborne concentration, based on a 30-minute exposure duration, that may not be exceeded in the workplace (IDHL), and maximum occupational exposure limit to prevent adverse health effects (8 h-workday) (REL), according to the recommendations of the US National Institute of Occupational Safety and Health (NIOSH).
Permissible exposure level (PEL) (8 h) (mg/m^3)	Average airborne concentration over 8 hours that may not be exceeded in the workplace, according to regulations of the US Occupational Safety and Health Administration (OSHA).
Valeur limite d'exposition professionnelle (VLEP) (8 h) (mg/m^3)	Average airborne concentration over 8 hours that may not be exceeded in the workplace, according to regulations of the *Agence nationale de sécurité sanitaire de l'alimentation, de l'environnement et du travail* (ANSES-France). VLEP may be mandatory or recommended.
Valeur moyenne d'exposition (VME) (8 h) (mg/m^3)	Average airborne concentration over 8 hours that may not be exceeded in the workplace, according to the recommendations of the *Institut national de recherche et de sécurité pour la prévention des accidents du travail et des maladies professionnelles* (INRS-France). This value is equivalent to the VLEP issued by ANSES (see above).
Maximale arbeitsplatz-konzentration (MAK) (8 h) (mg/m^3)	Average airborne concentration over 8 hours that may not be exceeded in the workplace, as established by the Deutsche Forschungsgemeinschaft allemand (DFG).

Table 14. Databases on physical and chemical parameters, toxicological data and threshold limit values

Database	Description
RTECS (Registry of Toxic Effects of Chemical Substances)	Toxicity data on more than 174,000 chemical substances in the Registry of Toxic Effects of Chemical Substances and the Canadian Centre for Occupational Health and Safety (CCOHS)
HSDB (Hazardous Substances Data Bank)	Database containing comprehensive peer-reviewed toxicology data for over 5,000 potentially hazardous chemicals
NIOSH Pocket Guide To Chemical Hazards	Database providing general industrial hygiene information
RED (Reregistration eligibility decision)	US EPA hazardous substance assessment documents
SAgE pesticides	An information tool on health and environmental risks and agricultural uses of pesticides in Québec
FAO/WHO	Hazardous substance evaluation documents issued by the World Health Organization (WHO) and the United Nations (UN) for the UN Food and Agriculture Organization (FAO)
PRDD (PMRA Proposed Regulatory Decision document)	Hazardous substance evaluation documents issued by Health Canada
PPDB (Pesticide Properties Database)	A comprehensive relational database of pesticide physicochemical and ecotoxicological data developed by the Agriculture and Environment Research Unit (AERU), University of Hertfordshire, for the database that originally accompanied the EMA (environmental management for agriculture) software, also developed by the AERU
INRS-VME	Document listing Institut national de recherche et de sécurité (INRS-France) VME values.
DFG-MAK	Document listing Deutsche Forschungsgemeinschaft MAK values for 2014

2.3.2.2 Risk indices

Risk indices were calculated, the guiding principle being consideration of any systemic effects of exposure, application frequency and the skin as the primary exposure route. Hence application frequency (%), skin permeability coefficient and acceptable operator exposure level (AOEL) established by the EFSA were used to determine the risk indices. In the absence of an AOEL value, the RfD established by the US EPA was used. Other parameters specific to the active ingredient, the commercial formulation and the application rate were added to come up with three risk indices:

- **Risk index for commercial formulation**

$$ri_f = \frac{f_i * K_p}{AOEL} \qquad \textbf{Equation 2}$$

where
f_i: Application frequency of a commercial formulation containing the active ingredient i (%)
K_p: Skin permeability coefficient (cm/h)
$AOEL$: Acceptable operator exposure level (mg/kg/day)

- **Risk index for active ingredient**

$$\boldsymbol{ri_i = \frac{\sum f_i * Kp}{AOEL}} \qquad \textbf{Equation 3}$$

where
$\sum f_i$: sum of the application frequencies of the commercial formulations containing the active ingredient i (%)

- **Risk index per application**

$$\boldsymbol{ri_a = ri_f * Q} \qquad \textbf{Equation 4}$$

where
Q: Weight of active ingredient *i* applied per hectare per application (kg/ha)

Lastly, the three indices were normalized as follows:

$$\boldsymbol{RI_x}\ (\%) = \frac{\boldsymbol{ri_x}}{\boldsymbol{MAX(ri_x)}} * \mathbf{100} \qquad \textbf{Equation 5}$$

where
RI_x: Normalized risk index x ($x = f, i$ or a)
ri_x: Risk index x ($x = f, i\ or\ a$)
$MAX(ri_x)$: Maximum calculated ri_x

The values used and indicated in this report are RI_f, RI_i and RI_a

3. RESULTS

3.1 PPE regulation, standardization and field efficacy

PPE is defined by the CCOHS as "equipment worn by a worker to minimize exposure to specific occupational hazards" (121). If this objective is to be achieved, the equipment must be appropriate, it must be worn and it must be effective against the risk concerned. This section looks at the existing methods employed, prescriptive as well as regulatory, to lower the risks of pesticide use with the help of PPE. The investigation of regulatory measures is based on Canadian legislation, with comparisons to US and European Union legislation. The investigation of prescriptive measures looks at the publications of recognized standards organizations, focusing in particular on skin protection, since the skin is the main route of exposure in agriculture. The profile is completed by a review of the scientific literature on the field efficacy of protective clothing.

3.1.1 PPE regulation

3.1.1.1 OHS regulations

In Canada, apple growers are subject to provincial OHS legislation in the province where they live. In Québec, this is the Act respecting occupational health and safety (122). The goal of this Act is to eliminate risk at the source and it sets forth employer and employee rights and obligations. However, it is the Regulation respecting occupational health and safety (ROHS) (125) that specifies PPE requirements as well as parameters that can require PEE use—such as air quality, noise or handling of hazardous materials. Table 15 summarizes some of these requirements effective in Québec as well as in the United States and Europe.

Table 15. PPE requirements in Québec, the United States and Europe

<table>
<tr><th></th><th>Québec</th><th>United States</th><th>Europe</th></tr>
<tr><td></td><td>ROHS (123)</td><td>29 CFR Part 1910, subpart I (124)
Occupational Safety and Health Standards (OSHS)</td><td>Directive 89/656/EEU (125)</td></tr>
<tr><td>Eye and face protectors</td><td>Compliance with CAN/CSA Z94.3-07 (126)</td><td>Compliance with ANSI Z87.1-2003 (128)</td><td rowspan="3">PPE must comply with the EU provisions of directive 89/686/EC (128)</td></tr>
<tr><td>Respiratory protective equipment (RPE)</td><td>As indicated in the Guide des appareils de protection respiratoire utilisés au Québec (129)
Selected, adjusted, used and maintained in accordance with standard CSA Z94.4-93 (130)</td><td>Approval by NIOSH, in compliance with 42 CFR part 84 (131)</td></tr>
<tr><td>Skin protection</td><td>"… wearing of protective equipment suited to the type of work performed"</td><td>Use of appropriate hand protection when hands are exposed</td></tr>
</table>

Requirements can take the form of a reference to a standard that sets and describes criteria and performance requirements; an objective to be attained (“appropriate protection”); or compliance with another statutory instrument.

The EU uses the latter approach, referral to another directive (128) that deals specifically with essential PPE design requirements. Directive 89/686/EC stipulates that an “EC-type” examination certificate is mandatory for all PPE sold on European territory, thus making characterization of minimum PPE performance a requirement.

In North America, certification of commercial PPE is not systematically required. It is mandatory only when particular certification is mentioned in a statutory instrument. For example, in Québec, RPE must be “as indicated in the *Guide des appareils de protection respiratoire utilisés au Québec,”* which means it must be approved by NIOSH. The ROHS also mentions compliance with CSA Z94.4-93 (130).

Schedule 1 of the ROHS, which stipulates permissible exposure values (PEVs) and mentions certain characteristics of regulated compounds (carcinogenic, percutaneous, sensitizer, etc.), includes few pesticides—and those that are included are mainly organophosphates, whose use has been declining for years.

In other words, Québec OHS legislation does not clearly specify how to select PPE for protection against pesticides. The lack of specific recommendations for protection of the skin, the main route of occupational exposure to pesticides, and the lack of PEVs makes it difficult to choose the right PPE for the job.

3.1.1.2 Legislation governing pesticide use

3.1.1.2.1 Overall structure

Table 16 shows the legislation applicable in Québec and its main objectives.

Table 16. Pesticide legislation

Jurisdiction	Legislation	Administrator	Objective
Canada	Pest Control Products Act (PCP and its regulations) (20)	PMRA Health Canada	Registration and labelling
Québec	Pesticides Act (21)	MDDELCC	
	Pesticides Management Code (132)		Storage, sale and use of pesticides
	Regulation respecting permits and certificates for the sale and use of pesticides (95)		Classification, permits and certificates for use and sale of pesticides
	Environment Quality Act (133)	MDDELCC	Disposal of pesticide waste

Regulation is thus shared by the federal and the provincial governments. There are also municipal bylaws that can restrict the use of pesticides, but these do not apply directly to agriculture, much less to the use of PPE.

All crop protection products imported, sold or used in Canada must be registered with the PMRA. Québec, like other provinces and territories, is responsible for regulating the sale, use, storage and disposal of pesticides. In addition, a Federal, Provincial, Territorial (FPT) Committee on Pest Management and Pesticides was established to help harmonize FPT pesticide and pest management education and control measures (134). Among other things, this committee focuses on reducing risks to protect the health of Canadians. For example, under its auspices, the Pesticide Education, Training and Certification Working Group (WGPETC) produced a number of reference works (135, 136) that specify basic knowledge for pesticide training and are used in different provinces to identify minimum basic knowledge required to obtain a certificate to use pesticides.

The review of Canadian legislation respecting pesticides did not reveal any legislation specifically addressing OHS, as is the case in the United States, with the WPS (101). However, two levels of concrete action with respect to OHS and PPE were identified: pesticide registration and the need to have a certificate to be able to apply pesticides.

3.1.1.2.2 Registration

As mentioned in Section 1.2.3.1, registration is the equivalent of marketing authorization, the guidelines for which are set forth in the Pest Control Products Act (PCP) (20) in Canada, the Federal Insecticide, Fungicide and Rodenticide Act (137) in the United States and Regulation 1107-2009 in the European Union (138). The registration applicant provides the agency responsible for registration with all information needed to authorize sale of the product. The authorization is only valid under the specified conditions (use of a pesticide on a certain type of crop, at a particular application rate, etc.). A new application for registration must thus be filed for each new pesticide or each new use of a pesticide already registered.

For the registration of a pest control product to be approved, the product must have agricultural value and the health and environmental risks must be “acceptable.” Registration is thus the result of a risk/benefit analysis performed by the competent authority—which may explain why use of a particular pesticide might be authorized in Canada but not elsewhere. As new knowledge is acquired, a commercial formulation may be withdrawn from the market or its use restricted. For example, the PMRA recently proposed a phase-out of Polyram® (metiram) use based on a new risk assessment which showed the risks for the environment, for consumers of fruits and vegetables and for workers during re-entry activities to be too high (29).

3.1.1.2.2.1 Risk assessment as the basis of PPE recommendation

The procedure used by the PMRA to assess pest control products is a fairly conventional public health risk assessment process, the framework for which is outlined in a technical paper available to the public (139). There are four steps: hazard identification; dose-response assessment; exposure assessment; and risk characterization.

- Hazard identification and dose-repose assessment

These first two steps are based on animal toxicity studies. These studies make it possible to identify toxicological properties, establish reference doses for acute and chronic effects and estimate potential cancer risks in the case of carcinogenic products. Current toxicological knowledge, however, is still too limited to estimate cumulative risk—for example from different pesticides with a common toxic mechanism.

- Exposure assessment and risk characterization

In the United States and Canada, the Pesticide Handler Exposure Database (PHED) (140) is used to estimate applicator exposure. This database consists of measured external exposure values (dermal and inhalation) obtained from studies deemed to represent as exhaustively as possible all realistic pesticide exposure scenarios. The studies were conducted independently by pesticide manufacturers, and the results were then compiled. Data quality is graded based not only on each experimental protocol (analytical parameter, study size), but also on the quantity of data available for an exposure scenario. For example, confidence in an exposure scenario is rated high if each individual exposure measurements is reliable and there are a sufficient number of measurements (15 replicates) per exposure zone for the scenario.

In a document published by Health Canada (140), 24 main exposure scenarios are mentioned covering most steps in the mixing-loading and application of pesticides and taking the following into consideration:

- Type of commercial formulation handled
- Type of application
- Use of collective protective measures
- Use of PPE

All of this information is compiled in the form of a table, as shown in Figure 3.

The first part of the table (brown border) shows dermal exposure of each body area in the selected scenario (here for mixing-loading of a liquid commercial product) depending on PPE used (lines 1 to 4). The second section (yellow border) shows inhalation exposure and the last section (green border) indicates the quality of the data. Exposure is expressed in units of weight of the active ingredient per amount of active ingredient handled (µg/kg a.i. handled).

The impact of PPE use on exposure is specified. In the case illustrated, for example, the wearing of gloves cuts hand exposure from 6,263 to 14.8 µg/kg a.i. handled, that is, a reduction of more than 99%. Whereas this protection factor was determined experimentally, standard protection factors are given for coveralls (line 3) and chemical-resistant coveralls (line 4) as there are no experimental data: 75% for coveralls (50% in the United States and 90% in California) and 90% for chemical-resistant coveralls (95% in California) (141).

Occupational exposure can be calculated by consulting these tables and compared with reference values. PPE is an option for reducing risks and keeping exposure below the reference value, with a margin of exposure (MOE) of at least 100.

Scenario 3a. ALL LIQUIDS, OPEN MIXING AND LOADING

Dermal exposure, in µg/kg ai handled

	Clothing Scenario	Head and Neck	Arm, Chest, Back, Thigh and Lower Leg	TOTAL Dermal-body Exposure	Hand	TOTAL Dermal Exposure
		A	B	A+B	C	A+B+C
1	Single Layer, No Gloves	11.83	24.50	36.33	6263.33	6299.66
2	Single Layer, Gloves	11.83	24.50	36.33	14.81	51.14
3	Coveralls over Single Layer, Gloves	11.83	6.13	17.96	14.81	32.77
4	Chem. resist coveralls	11.83	2.45	14.28	14.81	29.09

Inhalation exposure (in µg/kg ai handled)

1.60 (light), 2.5 (Moderate)

Notes:
- Original data for "Coveralls" contained only 0 - 2 replicates for body. Only head and neck contained 101- 107 replicates.
- A.M. is significantly higher then median for body exposure.
- Feet data exists but not included.

Data confidence

Clothing Scenario	Data Confidence/Items of Note
Single Layer, No Gloves	N dermal = 71 - 119, AB grade. N hands = 53 replicates, AB grade **High confidence run**
Single Layer, Gloves	N dermal = 71 - 119, AB grade. N hands = 59 replicates, AB grade. **High confidence run**
Coveralls over Single Layer, Gloves	Calculated from "Single layer, gloves" scenario using 75% P.F.
Chemical resistant coveralls	Calculated from "Single layer, gloves" scenario using 90% P.F.
Inhalation	N = 83 replicates, AB grade. **High Confidence run**

Figure 3. PHED exposure scenario (140)

3.1.1.2.2.2 PPE labels and recommendations

The need to wear PPE is determined based on assessment of exposure and consideration of certain toxicological effects or properties (skin and eye irritation LD_{50}, LC_{50}, etc.). The recommended PPE is then specified on product labels, constituting a regulatory measure. Compliance with this recommendation and with all use instructions on the label guarantees that the risk will be "acceptable." Table 17 shows PPE use options for respiratory and dermal protection (clothing and gloves) specified on labels in Canada.[20]

Table 17. Typical PPE label statements

Type of protection	Statement
Respiratory	A respirator with a NIOSH/MSHA/BHSE approved organic-vapour-removing cartridge with a prefilter approved for pesticides OR a NIOSH/MSHA/BHSE approved canister approved for pesticides.
Dermal	Chemical-resistant suit over long-sleeved shirt and long pants; chemical-resistant gloves.
	Coveralls over long-sleeved shirt and long pants; chemical-resistant gloves
	Long-sleeved shirt, long pants and chemical-resistant gloves
	Long-sleeved shirt and long pants

Note that only one type of respirator is recommended (except for fumigation), but there are four levels of dermal protection recommendations. Gloves and protective clothing do not have to be certified, but respirators do. The WPS defines "coveralls" and "chemical-resistant" (101): coveralls are a "loose-fitting one- or two-piece garment, such as a cotton or cotton and polyester coverall, that covers, at a minimum, the entire body except head, hands, and feet"; chemical-resistant means the garment is "made of material that allows no measurable movement of the pesticide being used through the material during use."

The recommendations are similar in the United States, but pesticide applicators are not required to wear chemical-resistant suits (141, 142), due to concerns about heat stress. In fact, chemical-resistant material is not as breathable as the material used for conventional coveralls. Short-sleeved shirts and short pants are sometimes recommended on labels in the United States. Glove recommendations are more specific in the United States, where labels specify that they must be made of chemical-resistant materials.

3.1.1.2.3 Pesticide applicator certification system

Under the Pesticide Act (21), anyone who uses pesticides in agriculture must be certified to do so. The Regulation respecting permits and certificates for the sale and use of pesticides (95) sets forth the conditions for application of the Pesticide Act. There are several types of certificates of qualification, depending on the type of activity and the class of pesticide concerned. Most farm operators and their employees have Class E certificates, that is, a farmer's certificate for application of pesticides. This certificate entitles the holder not only to carry out agricultural activities requiring use of pesticides but also to supervise employees carrying out such activities who may not be certificate holders.

[20] Tuduri L, Pest Management Regulatory Agency (PMRA). Personal communication. 2013.

An examination must be passed to obtain a certificate. Courses and training programs are offered covering basic knowledge about pesticides and their use that must be acquired by agricultural producers or their employees. These were developed to facilitate certification, but they are not mandatory. The Société de formation à distance des commissions scolaires du Québec (SOFAD) has also developed learning guides for agricultural producers and their employees (143, for example). SOFAD estimates that it requires 30 hours for a self-learner to cover the content of the training program "Use of Pesticides in Agriculture," including seven hours spent on occupational health and safety.

The section on PPE refers the learner to the labels of registered products to make appropriate choices, but adds the recommendations of the MDDELCC and the MSSS, summarized in Figure 4. Of note with respect to these recommendations are the following:

- The vocabulary used to describe PPE in these recommendations differs from that used on product labels.
- Chemical-resistant aprons are recommended.
- PPE recommendations depend on the stage of the work (mixing-loading or application) as well as the warning symbol on the product label.

These recommendations are also coupled with basic rules of hygiene for PPE use (wearing, washing and storing), and they include descriptions of the different types of respirators and instructions to change the cartridge in the respirator after eight hours of use.

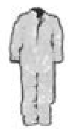
Protective clothing and equipment	During mixing-loading (concentrated pesticides)				During pesticide application		
	Precautionary symbol on labels				Type of application		
				None	Contin-uous	Aerial	Enclosed space
Chemical-resistant gloves and boots 	•	•	•	•	•	•	•
Long-sleeved shirt, long pants, coveralls 	•	•	•	•	•	•	•
Chemical-resistant apron 	•	•	•			•	
Anti-fog goggles 	•	•	Required if eye irritant			•	•
Face mask approved for pesticides 	•	•	Required in enclosed spaces		Required if  		•
Washable broad-brimmed hat (or fishing hat) 						•	•

Figure 4. MDDELCC and MSSS PPE recommendations (143)

3.1.2 PPE standardization

The review of regulations showed that dermal PPE, particularly gloves and clothing, are not systematically governed by standards in North America. However, there are in fact standards that can be used to identify and characterize dermal PPE performance and hence support and validate PPE selection. Selected results of our review are outlined below.

3.1.2.1 Chemical protective clothing

Chemical protective clothing (CPC) is one of the major families of protective clothing identified by the INRS (144). The North American standard ANSI/ISEA 103-2010 (145), the international standard ISO 16602:2007 (146) and the European standard EN 14325:2004 (147) (and related standards) all specify criteria and performance requirements for such clothing. In Canada, the CSA Group has adapted standard ISO 16602 by adding its own requirements, specifically with respect to flame resistance. As all these standards use the same principles of classification, only ISO 16602:2007 will be reviewed, for purposes of illustration.

3.1.2.1.1 Types of chemical protective clothing

Chemical protective clothing is subdivided into six types, each providing protection against a particular chemical hazard:

- Type 1: Gas-tight chemical protective suit (can be further subdivided depending on type of respirator used)
- Type 2: Non-gas-tight chemical protective suit
- Type 3: Liquid-tight CPC
- Type 4: Spray-tight CPC
- Type 5: CPC providing protection against airborne solid particles
- Type 6: CPC with limited protective performance against liquid chemicals

The level of protection decreases from Type 1 to Type 6. There are specific certification tests, performed using standardized test methods, for each type of CPC. The tests address the not only mechanical and chemical resistance of materials, seams and integrated accessories (integral visor, gloves or footwear), but also the integrity of the garment as a whole. Table 18 shows the whole garment and individual component performance tests that are performed depending on the type of garment.

Given the usual type of pesticide exposure in agriculture (splashes or liquid aerosols) Type 2, 4 or 6 CPC is suggested (148). The performance tests specific to this type of CPC are discussed later.

Table 18. ISO 16602:2007 CPC testing requirements (146)

General performance	Section	Specific performance test	Type of chemical protective clothing							
			1a	1b	1c	2	3[a]	4[a]	5	6[a]
Whole chemical protective clothing item integrity	5.4	Leak tightness	X	X	X					
	5.5	Inward leakage		X	X[b]	X				
	5.6	Liquid jet test					X			
	5.7	Liquid spray test						X		
	5.8	Particle aerosol inward leakage test							X	
	5.9	Limited liquid spray test								X
Chemical resistance of protective clothing material[c]	6.5	Permeation resistance	X	X	X	X	X	X		
	6.6	Resistance to penetration by liquid under pressure						X[d]		
	6.7	Particulate penetration resistance							[e]	
	6.8	Liquid penetration resistance								X
	6.9	Liquid repellency								X

[a] When not providing coverage of the torso, arms and legs, types 3, 4 and 5 clothing are partial body protective garments meeting only the material chemical resistance requirements for the respective type.
[b] Applicable to Type 1b chemical protective suits when the facepiece is not permanently attached to the suit.
[c] Applies to primary material used in construction of the chemical protective clothing item: may or may not be applicable to seams (see clause 7).
[d] Either permeation resistance test or test for resistance to penetration by liquid under pressure shall be applied.
[e] A test for evaluating the performance of protective clothing materials against particles is not recommended at this time.

3.1.2.1.2 Whole-CPC testing

The principle of the test method is identical for types 3, 4 and 6 CPC. It is outlined in standards ISO 17491-4:2008 (149) and ISO 17491-3:2008 (150): a subject wearing absorbent clothing underneath the CPC being tested is exposed, under controlled conditions, to a jet of liquid or a spray containing a dye. The liquid surface tension is fixed, as it affects the level of penetration through the material of the CPC (151, 152). When the test is completed, the CPC is removed, and the total area of dye staining on the absorbent garment underneath is measured. If the total stained area is less than the area of a "calibrated" stain area, then the CPC has successfully passed the test. If not, the CPC cannot be certified.

3.1.2.1.3 Testing of materials

Testing of clothing materials (including seams and other integrated parts) makes it possible to measure permeation and penetration resistance. Permeation is defined as the process by which a chemical moves through protective clothing on a molecular level (153). Penetration is the process by which a chemical moves through pores, apertures or essential openings in a material or finished item of clothing (154).

3.1.2.1.3.1 Permeation

For permeation, materials can be classified based on the time it takes for a certain quantity of a contaminant (cumulative permeation mass of 150 $\mu g/cm^2$) to move through the material, or the time it takes to attain a certain permeation rate (1 or 0.1 $\mu g/cm^2/min$ depending on the standard). Thus a material would be considered Class 1 (the least resistant) for a particular chemical if it takes 10 to 30 minutes to reach a cumulative permeation mass of 150 $\mu g/cm^2$ or Class 6 (the most resistant), if it takes more than 480 minutes to reach this mass.

Permeation tests must be performed with a number of chemicals, and requirements for classification in the least resistant class, at a minimum, must be attained. None of the standards for CPC mention testing permeation resistance to pesticide formulations.

3.1.2.1.3.2 Penetration

When one side of a porous material is exposed to a liquid chemical, the chemical may be repelled by the material, like a drop of water on the surface of a waterproof garment; it may be absorbed by the material and remain inside it; or it may pass through (penetrate) the material. The suggested test method makes it possible to determine in what proportions test products are repelled, absorbed or allowed to penetrate.

According to standard ISO 6530 (154), a material that allows less than 10% penetration is classified as Class 1 for liquid penetration resistance, whereas a material that allows less than 1% penetration is considered Class 3. Likewise, a material with a repellency index > 80% according to standard ISO 6530 (154) is classified as Class 1, and a material with a repellency index > 95% is classified as Class 3. For certification, minimum repellency and liquid penetration performance requirements must be met for a limited number of products, none of them pesticides.

3.1.2.2 Protective clothing for pesticide applicators

Standards dealing specifically with protective clothing for pesticide applicators were also identified in the literature review. The least complete of these was the German standard, DIN 32781:2010 (155). Standard ASTM F2669-12 (156) is similar to ISO 27065:2011 (157), which is the most complete standard. Standard ISO 27065:2011 will thus be used to illustrate the main defining elements of protective clothing for pesticide applicators. Table 19 summarizes test requirements for such clothing.

Table 19. Testing of protective clothing for pesticide applicators under ISO 27065:2011(157)

Requirements	Section	Performance test	Level			
			1a	1b	2	3
Material requirements	5.2.1	Liquid penetration resistance (EN 14786)	X			
	5.2.2	Liquid penetration resistance (EN 22608)		X[a]	X[a]	
	5.3	Resistance to penetration by liquid under pressure (ISO 13994 procedure E)				X
	5.4	Resistance to permeation (ISO 6529:2001 method A)				X[b]
	5.5	Tensile strength (ISO 13934-1)	X	X	X	X
	5.6	Tear resistance (ISO 9073-4)	X	X	X	X
Seam requirements	6.2.1	Seam penetration resistance (ISO 14786)	X			
	6.2.2	Seam penetration resistance (ISO 22608)		X[a]	X[a]	
	6.3	Seam resistance to penetration by liquid under pressure (ISO 13994 method E)				X
	6.4	Seam resistance to permeation (ISO 6529:2001 method A)				X[b]
	6.5	Seam tensile strength (ISO 13935-2)	X	X	X	X
Whole garment requirements	7.2	Practical performance test	X	X	X	X
	7.3.1	Low-level spray test (ISO 17491-4 method A)			X	
	7.3..	High-level spray test (ISO 17491-4 method B)				X

[a] The minimum performance requirement for Level 2 is significantly higher than that for Level lb.
[b] If, for a particular pesticide, additional testing is required to fully characterize' the material (this shall be decided on the basis of the risk assessment provided for the registration of the specific pesticide), the material shall also be tested for permeation resistance using the pesticide in question.

Unlike CPC, there is only one type of protective clothing for pesticide applicators. However, there are three levels of protection: Level 1 clothing is used when the “potential risk of contamination is relatively low,” whereas Level 3 clothing is suitable for “high exposure scenarios.” Performance requirements thus increase depending on the clothing classification level. Level 2 and Level 3 whole garments must undergo the same chemical resistance tests (same standard, same requirements) as those required for Types 4 and Type 6 CPC, respectively (see Table 18).

The clothing material requirements specify penetration resistance, but the test methods differ from those in standard ISO 16602. For example, Level 1A requires that materials be tested with the NF EN 14786 method (158,) which tests resistance to penetration by sprayed liquid chemicals: penetration must not exceed 5%. Level 1B requires that the material be tested with the ISO 22608 method (159), developed specifically for pesticide formulations: penetration must not exceed 40%. Level 2 requires that the materials be tested with the ISO 22608 test method: penetration must not exceed 5%. Level 3 clothing materials must be tested for resistance to penetration by liquid under pressure, a “worst-case” scenario.

No matter what the test method, one particular commercial formulation, Prowl 3.3 EC, must be used. The selection of this formulation as the reference test chemical is explained (160). The standard also leaves open the possibility of testing permeation of Level 3 materials by particular pesticides based on registration risk assessments.

3.1.3 Field of protective clothing

To complete the review of regulations and standards that can help in selecting appropriate PPE, a systematic literature review was performed to find out about the field efficacy of the protective clothing. Mathematical approaches used to quantify efficacy were thus documented, as were experimental methods of measuring efficacy and the types of clothing that were the subject of research.

Seventy-five articles were identified in a literature review of the years 1980-2014. Content of these articles was reviewed (reading of the abstract and of the experimental section, as needed), and 22 articles dealing specifically with the field efficacy of protective clothing were identified. The other articles evaluated comfort, air permeability, laboratory performance or skin exposure. Reports and guides by specialized agencies were also identified.

3.1.3.1 Protection factor and penetration factor

In preceding sections, the term “protection factor” is used to refer to the reduction in exposure (expressed as a %, indicating real or presumed efficacy) resulting from the wearing of PPE. The idea is to compare potential external exposure (that is, what is or would be the exposure value without PPE) to the actual exposure with PPE. However, before calculating a protection factor, a penetration factor, PF (%) must first be determined:

$$\boldsymbol{PF}\ (\%) = \frac{\boldsymbol{ADE}}{\boldsymbol{PDE}} * \mathbf{100}$$ **Equation 6 (161, 162)**

or

$$\boldsymbol{PF}\ (\%) = \frac{\boldsymbol{ADE}}{\boldsymbol{PDE+ADE}} * \mathbf{100}$$ **Equation 7 (163)**

Where:
ADE: Actual dermal exposure, that is, the amount of pesticide collected under PPE
PDE: Potential dermal exposure, that is, the amount of pesticide collected on PPE

In the studies identified, both definitions are used. Equation 6 seems better at presenting the concept of comparing exposures as described above. If we assume the protective clothing offers no protection whatsoever during application ($PF = 100\%$), then Equation 6 will give us $ADE = PDE$. Equation 7, on the other hand, gives $ADE = PDE + ADE$, or, $PDE = 0$, which makes no sense experimentally. Despite these differences in the equations, in practice there is little problem as long as $ADE \ll PDE$, which is desirable and also the reality in case of low penetration. The penetration factor *(PF)* can be used to determine the protection factor or efficacy (E), as follows:

$$\boldsymbol{E}\ (\%) = \mathbf{100} - \boldsymbol{PF} \qquad \textbf{Equation 8}$$

3.1.3.2 Experimental determination of protection factor

Equations 6 and 7 demonstrate how the protection factor can be calculated from the two variables PDE and ADE. In other words, these are the two values that must be determined experimentally. Among the methods of measuring exposure to pesticides, which Fenske et al. describe (164), two can be used to determine PDE and ADE: the patch method and the whole-body method.

3.1.3.2.1 The patch method

In the case of pesticides, this method uses 10 cm x 10 cm patches of α-cellulose which serve as passive dosimeters. The patches are placed on various areas of the body where measurement of exposure is desired. The number of patches varies, but the more there are, the more representative the measurement. The Organisation for Economic Co-Operation and Development (165) recommends eleven patches. To get a protection factor or efficacy, eleven patches are placed on the protective clothing (PDE) and eleven are placed under it (ADE). Each pair of patches in each part of the body should be at the same level, but there should be no overlap. Figure 5 shows how the patches might be placed

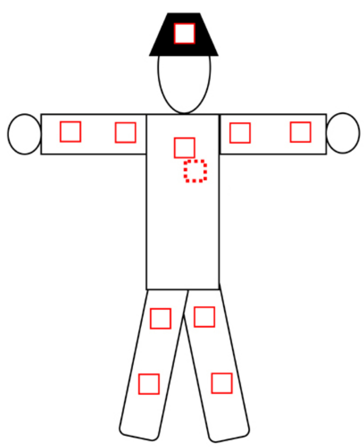


Figure 5. Layout of patches for measuring dermal exposure (40)

Measured contamination of each 100-cm^2 patch is then used to extrapolate the contamination of the part of the body concerned (over and under the protective clothing), the total contamination of the body and the protection factor. This method is easy to use, but exposure may be over- or underestimated, to the extent that pesticide deposition is not uniform on any particular body area.

3.1.3.2.2 The whole-body method

For the whole-body method, a sampling garment of cotton or a cotton/polyester blend serves as the dosimeter instead of the patches, eliminating the risk of over- or underestimation. The dosimeter is then cut into sections corresponding to different body areas and analyzed to determine the amount of pesticide deposited and estimate exposure.

Unlike with the patch method, it is not advisable to wear two dosimeters to estimate the protection factor. The outer dosimeter (on top of the protective clothing, giving the PDE) would then also serve as a protective barrier, in addition to the protective clothing, and this would affect the amounts measured on the inner dosimeter (ADE). To solve this problem, some researchers use the protective clothing as the outer dosimeter (46, 161, 162, 166). Others do two experiments, one with a dosimeter on top of the protective clothing (PDE) and the other with the dosimeter under the protective clothing (ADE) (167).

3.1.3.3 Review of scientific literature on field efficacy

Table 20 summarizes some of the characteristics of the studies of field efficacy identified in the literature. Not all give protection factors, but they can nonetheless be used to evaluate the protective effect of the clothing. For examples, Fenske (168) used the fluorescent properties of a tracer added to the spray to measure the difference in the amount of residue deposited on the skin of applicators when they wore a long-sleeved work shirt, cotton/polyester woven coveralls or nonwoven Tyvek® coveralls. The Tyvek® coveralls proved to be more effective than the woven coveralls or the work shirt. Krieger et al. (169) measured urinary metabolites of organophosphate insecticides to assess the difference in efficacy of two types of protective clothing: Kleengard XP® coveralls of nonwoven fabric and the Tyvek-Saranex (today Tychem SL®) chemical suit. The internal exposure data collected did not make it possible to determine which garment was more effective, but workers preferred the Kleengard XP coveralls because they were much better at dissipating heat and thus offered superior comfort.

As the table shows, the patch method is more commonly used (13 studies) than the whole-body method (7 studies), though the whole-body method is used in the most recent studies.

In implementing these methods, the exposure measurement can vary. For example, Vitali et al. used 10 cm x 10 cm cellulose patches placed on nine different body areas (170), whereas Norton et al. used patches of paper filter on six body areas of mannequins positioned on a tractor (171). Tsakirakis et al. (166) used cotton clothing (long-sleeved shirt and long johns) as the inner dosimeter corresponding to two body areas, whereas Espanhol-Soares et al. (172) chose a Tyvek® garment as the inner dosimeter which they cut into 16 sections (corresponding to 16 body parts).

Table 20. Studies of field efficacy of protective clothing

Reference	Exposure measurement method	Type of protective clothing (number x people)	Calculation of E?	Duration (h, min)
(40)	Patch	OWC[1] (NS[2]), protective clothing (NS)	NO	NS
(46)	Whole body	Cotton (1x5)	YES	15 min
(48)	Patch	Tyvek® (1*4), OWC (1*6)	YES	1 h 27 min - 3 h 40 min
(161)	Whole body	Cotton (1x9), cotton/polyester (1x9)	YES	1h
(162)	Whole body	Cotton/polyester (1x5), cotton (1x5)	YES	2 h
(163)	Patch	Cotton/polyester, polypropylene coverall (NS)	YES	45 min
(166)	Whole body	Cotton/polyester (1x 5), cotton (1x5)	YES	1 h 10 min - 3 h 30 min
(167)	Whole body	OWC (1x2)	YES	NS
(168)	Fluorescent tracer	Tyvek (NS), cotton/polyester (NS)	NO	50 min - 2 h
(169)	Biomonitoring	Tyvek-Saranex® (2*5), Kleenguard® (2*5)	NO	NS
(170)	Patch	Tyvek® (1*4), OWC (1*6)	YES	1 h 27 - 3 h 40 min
(171)	Patch	Goretex® (1 x1), CPC (1x 2)	NO	30 min
(172)	Whole body, tracers	Cotton, cotton/polyester (10*5)	YES	7 h
(173)	Biomonitoring, patch	OWC (NS)	YES	NS
(174)	Biomonitoring, patch	Tyvek® (1*2), cotton (1*5), waterproof garment (1*2)	NO	NS
(175)	Whole body	Cotton (NS), Tyvek® (NS), Kleenguard (NS)	YES	NS
(176)	Patch	OWC (3*4)	YES	NS
(177)	Patch	Duraguard® (NS), other materials (NS)	YES	65 min
(178)	Patch	Tyvek® (NS)	YES	NS
(179)	Patch	Tyvek® (9-12*4),	YES	NS
(180)	Patch	Goretex® (1*10)	NO	14 - 41 min
(181)	Patch, biomonitoring	Cotton (NS), OWC (NS)	YES	17 min

1: OWC: Ordinary work clothes 2: NS: Not specified or insufficient information

Test duration ranged from a few minutes to 3 hours and 40 minutes. Only one study (172) covered the equivalent of a work shift, 7 hours, but no details were given about how much time was spent mixing-loading and how much time applying the pesticide. This is important, because the longer protective clothing is worn, the greater the chance of penetration of the material (182), and hence the greater the potential for exposure. Table 21 lists the number of studies of each type of material used for protective clothing, including some subtypes. The materials most frequently evaluated were cotton, cotton/polyester and Tyvek®. Ordinary work clothes (OWC), generally a long-sleeved shirt and long pants, were also evaluated.

Table 21. Studies of specific types of protective clothing

Type of protective clothing	Subtypes	Number of studies
OWC		7
Cotton	Treated	2
	Untreated	7
Kleenguard®		2+1*
Duraguard®		1
CPC		1
Gore-Tex®		2
Tyvek®	Tyvek-Saranex®	1
	Tyvek®	7
Cotton/polyester	Treated	5
	Untreated	2

*A polypropylene garment was included as a Kleenguard®-type garment

Detailed information about the material itself is rarely provided. Sometimes the proportion of cotton to polyester in cotton/polyester blends is given. Little information is provided about the thickness of the material, a determining factor in penetration measured in the laboratory (183, 184). Cotton and cotton/polyester garments can be separated into treated and untreated garments. Treatment consists in coating the outer surface of the garment with a repellent that renders it less permeable to pesticides. The articles provide little information about the repellents used and how the coating is done. Tsakirakis et al. (162, 166), as well as Machera and Tsakirakis (161), mention the product Resist Spills®; Nigg et al. (163) mention a water repellent finish; Espanhol-Soares et al. (172) mention pretreatment with fluorocarbons; and Davies et al. (181) mention pretreatment with fluoro-aliphatic resins. The field efficacy test results for the most common materials used to make coveralls, as shown in Table 22, do not clearly indicate if repellent pretreatment adds any value, since a number of experimental parameters varied simultaneously in these studies. In the study by Davies et al. (181), in which treated and untreated versions of the same cotton coveralls were tested, the differences in protection factors were minimal. In the study by Nigg et al. (163), the protection factor ranged from 83.1% for an untreated cotton/polyester coverall to 77.9% for the same coverall treated. The promise of such pretreatments, indicated by a number of laboratory penetration tests (185, 186), thus remains to be confirmed in the scientific literature. The effect of washing (number of washings, by hand or by machine, type of detergent) on coverall efficacy also needs to be studied (172, 187, 188).

Most of the calculated protection factors, all types of garments taken together, are higher than the protection factor (75%) that the PMRA assigns to coveralls. This in itself is reassuring, but some of the values close to or below this limit raise questions about whether all are safe. In the studies by Stamper et al. (178) and Nigg et al. (163), a 75% protection factor was not achieved for ethazol, a fungicide formulated as a wettable powder under the trade name Truban®, though it was for the other products tested (chlorpyrifos as the wettable power Dursban® and fluvalinate as the emulsifiable concentrate Mavrik®). Truban is still registered in Canada, and applicators who use it must, according to the label, wear coveralls (189). This raises the question of the effect of the commercial formulation on a garment's protection factor, a question raised by a number of researchers (160, 190-192). In other words, apart from the fabric of the coveralls, it is the physical characteristics of the spray (viscosity, surface tension) rather than the chemical structure of the active ingredient that explain the extent of penetration.

Table 22. Calculated protection factors (%) for common materials

Reference	Cotton	Cotton/polyester	Tyvek®
(46)	87.3-93.6		
(48)			99.2
(161)	97.3	99.6* (GM)	
(162)	98.3 (GM[1])	98.4* (GM)	
(163)		61.7*; 77.9*; 83.1; 81.3*	
(166)	97.3; 98.8	98.9*; 99.3* (GM)	
(172)	95.8*	97.1*	
(175)	81.9; 89.6		82.7
(178)			99; 89; 66; 96
(179)			97
(181)	96; 99.3; 96.4*; 99.4*		

[1] GM: geometric mean *Treated with a repellent

3.1.4 Discussion

The review of regulations showed that PPE recommendations for agricultural producers derive from the pesticide registration process. The Act respecting occupational health and safety (AOHS) as well as the Regulation respecting occupational health and safety (ROHS) tackle the question of PPE but are not specific to pesticides. Whereas respirators must be certified, recommended gloves and protective clothing do not have to be. Since the main route of pesticide exposure is the skin, and PPE is, at the present time, the unavoidable strategy for minimizing risk in the industry, this lack of guidance, this lack of visibility of the dermal protection efficacy of PPE, seems to be a weakness in risk assessment and prevention.

Label recommendations for protective clothing range from long pants and a long-sleeved shirt to chemical-resistant coveralls, to which standard protection factors are assigned in assessing risk. It may be that the protective clothing used in the PHED studies provided valid justification for the regulatory protection factors selected. But to what extent, in the absence of clear specifications, can we be sure that the clothing selected and worn by agricultural workers is equivalent to that in the PHED studies? To what extent is the language on the labels open to interpretation? Are real protection performances variable?

These questions are particularly pertinent given that penetration, that is, the passage of pesticides (formulations) through woven garments, such as shirts and coveralls, depends, among other things, on the thickness of the fabric and the type of weave (151, 184). For our purposes, chemical resistance is determined by experimental measurement of the movement of a pesticide through material, as defined in the WPS (101). Unfortunately, such resistance data in the case of pesticides is extremely rare, raising doubts about the protection actually provided by garments used. As the recently developed Agricultural Handlers Exposure Database (AHED),[21] a more homogeneous exposure database than the PHED, gradually comes into use, better validation of standard protection factors (such as the PMRA's 75% standard protection factor for coveralls) may be possible, though it will be up to producers to interpret the recommendations on protective clothing labels.

With respect to the PMRA's recommendation of chemical-resistant gloves, the US regulations must be consulted for clarification. The US regulations incorporate the work of Schwope et al. (193). A choice of glove materials and thicknesses based on the pesticide formulation used can thus be suggested on labels. The question of using single-use gloves, which are thinner and less resistant but allow greater dexterity, for certain tasks (mixing-loading, nozzle unclogging, manual thinning, etc.) should be examined, with more in-depth assessment of the risks involved, as suggested in a study by Roff (194). In fact, cumulative use, day after day, of chemical-resistant gloves means that the applicator must follow a regimen of glove changing and hygiene procedures to prevent internal contamination of the gloves, contamination of the applicator himself/herself and contamination of the workplace.

It would seem advisable to consult standards to ensure that PPE adequately performs the tasks for which it is designed (195). The literature review on this topic showed there are tools that can help to clarify the recommendations on product labels. An unsystematic review of several pest control product labels in Europe confirmed that Type 3 and Type 4 CPC can already be recommended as PPE for pesticide applicators. It's a first step, but it's not enough. As the materials of Type 3 and Type 4 CPC have not been tested with pesticides, it is likely that some of them do not provide the expected protection. An ANSES study published in 2010 (113) looks at this. ISO 27065, which was specifically developed for applicators of liquid pesticides and reentry workers, cam partially fill this gap. This standard classifies protective clothing into three performance levels, depending on the scope of the anticipated risk, and these can then be used in conjunction with product registration risk assessments and the recommended skin protection levels on product labels to determine clothing required. Nonetheless, we must not forget that the standards we are discussing can be used to characterize and compare clothing and material performances in a laboratory setting only.

Our review of the scientific literature demonstrated the current state of knowledge of the field efficacy of protective clothing for pesticide handlers. The variability of the experimental conditions, and the lack of characterization of the materials tested, makes it hard to summarize the findings. Protection factors of garments made of the more common materials are often greater than 95%. However, lower results for specific combinations (a particular pesticide and a particular type of protective garment) raise questions about how often the standard 75% protection factor assigned to coveralls by the PMRA is actually met.

Agricultural practices, which also partly determine type of pesticide application (and type of sprayer used), are not addressed in detail in Section 3.1.3. Nonetheless, this is another factor that can affect exposure and penetration (141). The experience of the applicator, not specified in any of the articles, can also affect contamination level (196). In other words, actual compliance with

[21] http://www.exposuretf.com/Home/AHETF/AHETFDataDevelopment/AHED/tabid/99/Default.aspx

safe handling and safe procedures in real work situations (compared to situations described in the PHED database and the reviewed articles) is another possible source of bias (197).

Lastly, all of these studies focused on the inherent efficacy of the clothing, without discussing the users' physiological comfort. Nonetheless, heat experienced during the work day and consequent perspiration can negatively affect not only PPE use compliance rates but also the rate of pesticide penetration through clothing (198). In addition, skin absorption seems to increase with perspiration (199). In other words, a 75% protection factor as defined to date, does not necessarily actually mean a 75% reduction in internal pesticide intake.

3.2 Québec apple growers: a socioeconomic, organizational and personal profile

This section of the research report is based on data from three complementary sources: the questionnaire survey of Québec apple growers, the interviews of a sample of growers, and our observations of this sample.

3.2.1 Sociodemographics

The questionnaire survey revealed certain characteristics of Québec's apple producers (Table 23). Average and median age of the apple growers who participated in the survey was 53. A 2013 breakdown of the population by age confirmed this is an aging population.[22]

Just over one-third of the respondents (36%) are university graduates, while 30% have a college diploma and 34% graduated from primary school, high school or technical school. Virtually all (99%) have certificates for pesticide application. The non-mandatory training offered to help in obtaining this certificate was taken by 93% of respondents. Average and median number of years of experience using pesticides were 21 and 20 years respectively. Average and median number of years of experience as an orchard operator or owner were 19.5 and 16.5 years respectively. Many owners thus worked on apple-growing operations before becoming owners.

Just over half of the growers interviewed had taken over or bought out the family farm. Most had learned the trade by working with their parents. Others studied agriculture at school. In terms of learning the trade, those who had not grown up on a farm and had purchased an orchard found the learning curve to be "very steep." Even those with a college or university education find it is a continuous learning process, through trial and error, and state that the real learning takes place on the job, in the field. In addition to understanding basic concepts, growers must be able to adapt to changes in practices and deal with the unexpected.

Almost all of the operations fall into one of three legal categories: company or corporation (33%); partnership (35%); and small individual or family farm (sole proprietorship)—a key reality in the apple-growing industry.

[22] Original distributions for all survey questions are available on request.

Table 23. Sociodemographics of Québec apple growers

	%
Age	
34 years of age or under	7
35-54 years of age	46
Over 55 years of age	47
Highest level of education completed	
Primary school, high school or technical school	34
CEGEP (college)	30
University	36
Years of experience using pesticides	
9 years or less	27
10-19 years	20
20-29 years	21
30 years or more	32
Years of experience as an operator	
9 years or less	28
10-19 years	27
20-29 years	19
30 years or more	26
Legal status of operation	
Sole proprietorship	32
Partnership	35
Company or corporation	33

The growers very clearly expressed their passion for their work and their pride in a job well done: “I want to continue to innovate. I want to develop.” Freedom of action is highly prized : “ … to be able to say to myself, in the evening: OK, tomorrow morning, I’m going to do this … To be able to say I’m not comfortable with this, so I’m not going to do it.” Restrictions however, are growing, and freedom is decreasing: “Everyone wants to tell us how to do our job.”

The difficulties of the lifestyle were also expressed: “If I had to start over, if I were 20 again, I wouldn’t be doing this … There are difficult times … I wouldn’t do it again.” Expressed as well was the difficulty making a living in this business: “I love it, but I don’t want to starve to do what I love.”

Apple-growing is seasonal work, running from April to September, with a particularly intense period of pesticide application from late April to late June: “We spray every week during this period. It’s really tough.” Time pressure with respect to pesticide use is a significant stress for apple growers and is frequently mentioned. Work days are long: “Sometimes I work round the clock. I have no sense of time … By 10 at night, I’m tired, exhausted … but I still have to put things away or repair things that aren’t working … Sometimes at night, I feel like .. ‘the morning after a night on the town.'" Work-family balance during the intensive production period is a concern for some: "We're apple producers 24/7."

The work is also very demanding mentally. Concentration, discipline and diligence are required to succeed: "It's a question of diligence, and we must run our business properly, and know our land ... there's nothing complicated in this, but it takes concentration … self-discipline … and diligence." Since the weather is such an important factor, planning is impossible. There is always the unexpected to deal with and results are never certain: "There's no exact science … there was one year when I got it just right, really just right …."

Together, these stress factors can lead to physical and mental burnout. We heard a lot about stress related to market pressure and environmental pressure: " … the worst, what my brother and I discuss often, is the stress of the business. I feel like I am always just trying to catch up" There is also stress associated with administrative restrictions and obligations, which have increased dramatically: "Now I have to join CanadaGAP.[23] It's going to mean even more paperwork … it never ends, it just never ends, it's terrible."

3.2.2 The Québec apple industry

3.2.2.1 Economic context

Economic constraints were a recurring theme in interviews with growers. They see these constraints as constantly growing and as a major contributor to stress.

Apple orchards have an average size of 11.6 ha and the median is 7 ha. Nearly half (43%) of growers own 5 ha or less, and one orchard out of five is no larger than 2.4 ha (Table 24). This reality is illustrated by other data from the questionnaire. Nearly half (48%) operate a small orchard where they are the only person handling pesticide. The great majority of respondents (82%) said they personally participate in mixing-loading, application and cleanup.

The data also show a practice that is quite common among apple growers, namely, increasing their production and revenue by operating part of someone else's orchard. This raises the operated area to 12.5 ha on average while the median rises to 8 ha.

[23] http://www.canadagap.ca/welcome/

Table 24. Key orchard characteristics

		%
Area owned		
	5.0 ha or less	43
	5.1–10.1 ha	21
	10.2–20.2 ha	23
	20.3 ha or more	13
Total area operated		
	5.0 ha or less	40
	5.1–10.1 ha	22
	10.2–20.2 ha	22
	20.3 ha or more	16
Percent of revenue generated by apple production		
	1–50%	26
	51–75%	14
	76–99%	22
	100%	38
Principal sales strategy		
	Roadside stand and U-Pick	24
	Packer	41
	Other, combinations	35

The cost of land is foremost among growers' concerns. Unless they inherited their farm or have paid off their mortgage, the high cost of land makes it very difficult for a family to live on the revenue from a small operation. To ensure a "middle class" lifestyle, they go into debt, buy or operate other orchards and try to optimize their productivity, in particular by using pesticides. The high cost of land sometimes forces small growers to hold another job in addition to operating their orchard.

Financial insecurity also came up during the interviews. Growers have to lay out considerable funds for several months before money starts coming in from apple sales in the fall; as a result, they have to "carry expenses for at least half the year," with no guaranteed profits at the end of the season.

All growers find the cost of pesticides high. For a small operation, it is the biggest expense; for a larger operation, it is the second biggest after labour. We were told all costs are generally on the rise.

The cost of trees is another economic constraint that came up. Growers report buying dwarf or semi-dwarf trees to replace standard trees (old-variety, tall trees) that are unproductive or sick. Some growers, in the hope of improving productivity, pull up healthy dwarf trees and replace them with other varieties less vulnerable to pests. In addition to the costs of purchase, removal and replanting, replacing trees means lost production and therefore lost revenue for at least six years. When a tree is sick and has to be replaced, "that's 10 years of dead loss."

The high cost of equipment (mainly the sprayer and tractor) is documented. Growers report that for a few years, under the MAPAQ Prime-Vert program, the Québec government subsidized up to 70% of the cost of a low-drift sprayer, but this subsidy was no longer available at the time of the interviews. Most growers prefer tractors with closed cabs, for reasons of safety and comfort, but this purchase often has to be delayed because of cost. According to growers, no subsidy was offered for the purchase of a cab tractor.

Premiums for disability and critical illness insurance are very high. Our investigation shows that 35% of growers have no insurance, 41% have private insurance, 11% pay CNESST contributions and 13% have both types of coverage. The only growers who pay CNESST contributions are those who have employees and are obliged to do so. Small growers find the CNESST contributions too high for their own insurance needs.

3.2.2.2 Economic strategies

The interviews show that the economic context described above influences growers in various ways. Productivity, profitability and generating enough revenue to make a living are major concerns. Productivity is measured in tonnes/hectare, but also in quality/hectare; some varieties offer quantity, others quality. Growers seek to improve productivity in a number of ways, for example by producing different varieties, planting dwarf trees, experimenting with different tree training techniques, and using pesticides.

All growers want to get the best possible price for their produce. Selling to wholesalers or packers, who offer the highest price and access to major retail chains, is the main strategy for 41% of them (Table 24). According to our interviews, this strategy means meeting more stringent requirements, in terms of both food safety—in the form of CanadaGAP certification—and appearance. Growers pointed out that while the direct and indirect costs of CanadaGAP certification are very high, the grower does not necessarily benefit financially. Nearly one in four growers prefer to remain independent by selling the apples directly at a roadside stand or market, or through U-Pick operations. Finally, 35% of respondents adopt various strategies including the production of cider or other apple products.

Quality largely determines the type of market where the apples will be sold. Growers say there is growing pressure to use pesticide due to consumer demands in terms of size and appearance. The interviews show that growers targeting the wholesale market have an overall tendency to apply more treatments. Conversely, growers who sell through U-Pick or roadside stands, or who voluntarily turn to other products such as cider or juice, do not rely as much on pesticide: “When people pick the apples and eat them right away, there’s no danger they’ll go bad in the warehouse, so a lot of the time you don’t have to apply a fungicide.” “We don’t need our apples to be all red and shiny. Even with imperfections, the cider is still good.” Other growers, who opt for processing at the end of the season because their crop was downgraded, or who sell only some of their apples at roadside stands, do not reduce their use of pesticides.

Growers try to diversify their revenue. For nearly four in ten (38%), apple production accounts for all their revenue, while others combine it with other fruit such as pears and plums, which have similar requirements in terms of tree training and pesticide use (**Table 24**).

3.2.2.3 Environmental context

Growers see a wide range of environmental constraints, and during the interviews they described the impact on their work: “There are a lot of risks in fruit-growing: insects, fungi, frost, hail, more and more deer ...”

For some growers, climate change is an underlying factor: “We’ve never seen weather like this before.” Others note the continuous arrival of new insects: “We have insect problems we didn’t have 20 years ago. Bugs that were a minor problem have become a major problem, and vice-versa.”

Past decisions about the organization of apple production in Québec have lasting effects. The concentration and proximity of orchards in some regions are described as indirect factors in the use of pesticides: “You can’t have an orchard concentration like we have here and say OK, tomorrow morning I’m going organic. It’s impossible.” “We don’t all manage our orchards the same way. When I look at my areas that are infected, well, they’re often just along the road. On the other side … there are the neighbours.” Large-scale monoculture, practised for many years with the McIntosh apple for example, has long-term effects on pesticide use: “The McIntosh is the variety you have to treat the most for scab. It’s mind-boggling … Sometimes we have to spray 32 times in a year ... At first we didn’t have to spray as much, but then it became a monoculture. People were misinformed about certain fungicides, the fungi developed resistance, and now we’re stuck with that.” The establishment of orchards in poorly drained areas or near forests is another source of difficulties: “You get an orchard that has a history of insects and pathogens … you’ll have more insects and will probably need more spraying.” Many growers say they are looking for varieties that are less vulnerable to pests and infections so they can reduce pesticide use and hence their workload.

In some cases, growers time their spraying operations to have the least impact on birds, bees and other animal species: “I do it in the evening, when there are no bees around.” Wind is another constraint for growers trying to reconcile concern for the environment with protecting their crop. Some mentioned ways to reduce drift: “I try to spray in the evening or early in the morning, when there’s not much wind.” However, most of the interviewees reported that sometimes they absolutely have to spray, even if wind conditions mean not as much product will reach its target (cost to the grower) and some of it will drift (cost to the environment and human health for nearby residents): “It’s a big factor because when it’s windy, the product doesn’t get applied very well … Sometimes you absolutely have to spray. It’s windy but you do it anyway, because you have no choice ...”

Environmental constraints at times will dictate the choice of pesticide, especially among the different products designed to prevent an infestation or to eradicate an existing one. Under certain environmental conditions, more than one product may be suitable, while in other cases there may be only one that will be as effective as desired.

3.2.3 Production organization

3.2.3.1 Changing practices in pesticide use and IFP

Growers described how pesticides and their use have changed over the last 15 years or so.

3.2.3.1.1 Pesticides

The list of chemicals used[24] is a long one: fungicides, insecticides, miticides, fertilizers (calcium, magnesium), antibiotics, thinners, growth regulators, moss herbicides and boron. Growers spoke of major changes in pesticides: “Other products were used at first … DDT, malathion, etc. … In those days, the products were designed for just one application.” The fact that chemicals today are not as strong could nevertheless have a worrisome side effect: increased resistance. “The flip side is that we have products that are easier to resist.” However, some growers report that the concentrations have been increased for certain products: “When I started in the business, this product was approved for application at four kilos per hectare, now it’s six.”

Insecticides have seen the most significant changes, in particular with the gradual elimination of organophosphates: “We don’t have organophosphates that kill everything, any more ... We have one thing that will go after the codling moths, something else to go after the weevils, everything is targeted.” There has been less change in fungicides, which are the most widely used of all the pesticides—up to 75% of all applications, according to some growers—and are considered less toxic than insecticides. For some fungicides, like Polyram, use has nonetheless diminished significantly over the past few years: “We thought Polyram was fairly non-toxic for humans and the environment, now we realize that’s not true. I apply a lot less of it than I used to.” In addition, some new products were not properly applied at first and yielded poor results; consequently, growers continued to prefer the old products. The main change regarding fungicides seems to be the distinction between preventive and eradicating treatments.

Another change reported has to do with the use of products for new practices; for example, chemical thinners, which in many cases have replaced hand-thinning: “Before, we would spray maybe one or twice for thinning, to try and get bigger apples. Now, we have to apply thinner maybe four times.”

Growers expressed the hope that new products would be less toxic: “There are lots of things we used before but don’t any more. There are new products, and of course, every time there’s a new product, it’s supposed to be better than the old one, but often it takes a while for that to be evident. But I’m optimistic that it’ll be true, that the products will be better or more targeted … and a lot less toxic for the user and the environment.”

3.2.3.1.2 IFP

At a time of growing pressure on agricultural producers, new pesticide use practices associated with integrated fruit production (IFP) and ecological farming principles have been developed, and the growers we met with had much to say about them. The old methods, which consisted in

[24] See Section 3.3 for frequency of pesticide application.

applying treatments uniformly over the entire orchard, are being abandoned due to two imperatives: improving efficiency by developing more targeted actions based on regular monitoring, and reducing pesticide use along with its environmental impacts: “There’s been a big change from the old way, where we sprayed according to the calendar instead of what was going on in the orchard.”

By monitoring the crop to assess the severity of an infestation and predict its spread, the grower is able to better target the use of chemicals. New directives specify the best time to apply product: “I’ve seen a huge change, plus there’s the RIMpro software now … It’s revolutionized our practices.” Both fungicides and insecticides are applied to targeted areas rather than the whole orchard: “Before, when the agronomist from MAPAQ said ‘Spray!’ you would spray everything.” IFP also means not applying the same treatment to different varieties, and using specific products to target different insect species.

One indirect effect of targeted application is an increase in the number of spraying operations: “I recheck my traps the next day. Damn! They’re above the threshold, which means I have to go out again the next evening. It bugs me because I could have done the whole orchard and saved myself a lot of trouble. But my conscience would have bothered me, and so I say well that’s IFP… So I have to go out again the next night or two days later. But that’s how it works.” “It seems to me it used to be 24 spraying operations, back in the day, but now it’s more like 30-something.” Growers spoke about combining several products in one application to save time: “Spraying is a horrible job, so if we can combine products, we do it.” It is not rare to combine three different products in one operation; fertilizers, in particular, are said to be added to almost every spraying operation: “Because we have a lot to apply, each time we go out, we take the opportunity to apply fertilizer. We don’t go out just to apply fertilizer, it costs too much in labour and machinery.” Fungicides and insecticides are sometimes combined, along with growth regulators. Mixing means the grower also has to consider compatibility and mixing order. “If I’m applying several things, I put in the fertilizer first, then the insecticide, then the fungicide.” One guideline regarding product mixing is to avoid doing it in very hot weather.

Variable rate application is also discussed in IFP in connection with the recommendations on product labels, which are often stated in terms of maximum and minimum doses for a given surface. Experienced growers report doing tests and observing that they could obtain the same result by applying the minimum dose or even less, as long as it was applied at the right time: “There are a whole bunch of pesticides, like captan, you don’t apply the dose it says on the label. Polyram, I don’t apply the dose on the label, it still works, and it’s even been shown by different people.” “I still use the product and get results, and I’ve never applied the dose on the label.” “We’ve even tried half-doses of miticide … it doesn’t kill predators and it does an acceptable job.” The dose can sometimes also be reduced for an isolated orchard, when there is no danger of infestation from surrounding orchards. Other growers go even farther, saying it is better not to spray at all for certain insects: “When I don’t spray for mites, the next year the problem has disappeared. If I apply miticide, one thing’s for sure: next year, I have to spray again because I’ve killed not only the mites but their predators too.” Other growers, however, do not believe pesticide applications can be much reduced: “OK, I’m going into processing, cider, ice cider, I’m going organic. But it’s still the same problem, it doesn’t necessarily reduce the number of spraying operations.”

The use of fungicides and insecticides to prevent rather than eradicate infestations was also mentioned. The advantages of prevention through "contact" products were emphasized. In particular, since the objective is to prevent infestations, preventive treatment allows more control. Eradicative treatment, by contrast, has several disadvantages: higher cost, development of resistance, medium- and long-term negative impacts on natural predators and especially on bees.

Other IFP practices involve replacing pesticides with less environmentally toxic substances or systems. Examples include everyday products—very economical but still effective—such as vegetable oil and potassium bicarbonate ($KHCO_3$), as well as the use of pheromones to disrupt mating of fruit flies. Many growers are concerned about negative impacts on natural predators: "I think about potential effects on the user or on beneficial species. We have to be careful about that."

Product application can be made more effective through the use of trailed sprayers with low-drift nozzles and by taking into account tree size and leaf area index by using the tree row volume method to calculate the quantity and dose required according to whether the trees are standard, semi-dwarf or dwarf size. The number of nozzles used and their orientation also vary according to tree size and leaf area index.

The data from the questionnaire corroborate the interviews and confirm that IFP principles and practices are well accepted. A majority of the respondents (51%) reported applying these practices, while 30% said they apply conventional practices. A third group said they apply a combination of practices including IFP, conventional methods and organic methods (Figure 6).

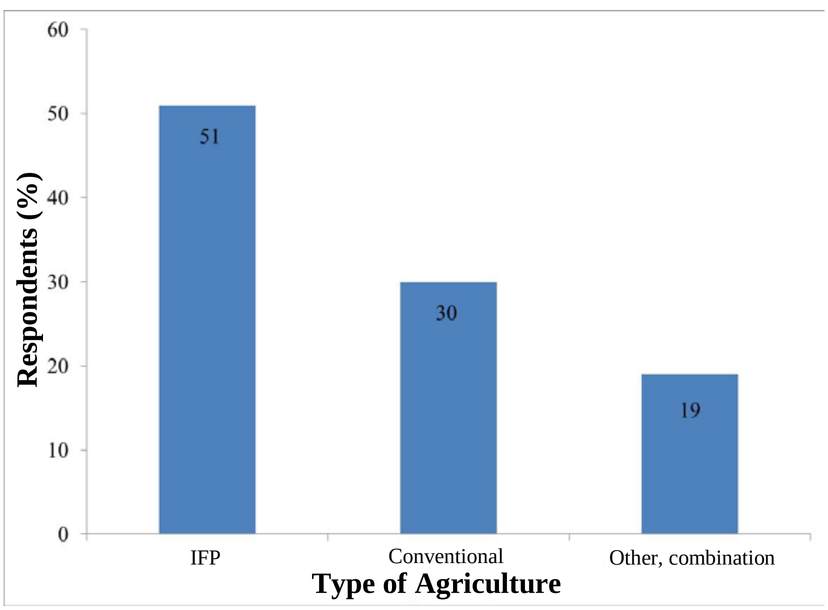


Figure 6. Distribution of growers according to the type of agriculture practised (n=164)

3.2.3.2 Information about choice and use of pesticides

As practices change under pressure from increased competition and IFP, information plays a critical role. Data from the questionnaire indicate that pesticide manufacturers and vendors are the information source most used by growers (66%), followed by *Réseau-pommier* experts (57%) and technical clubs (just over 50%). Three other sources were mentioned by a similar proportion of respondents (about 38%): product labels and datasheets, MAPAQ advisors, and workshops (Figure 7).

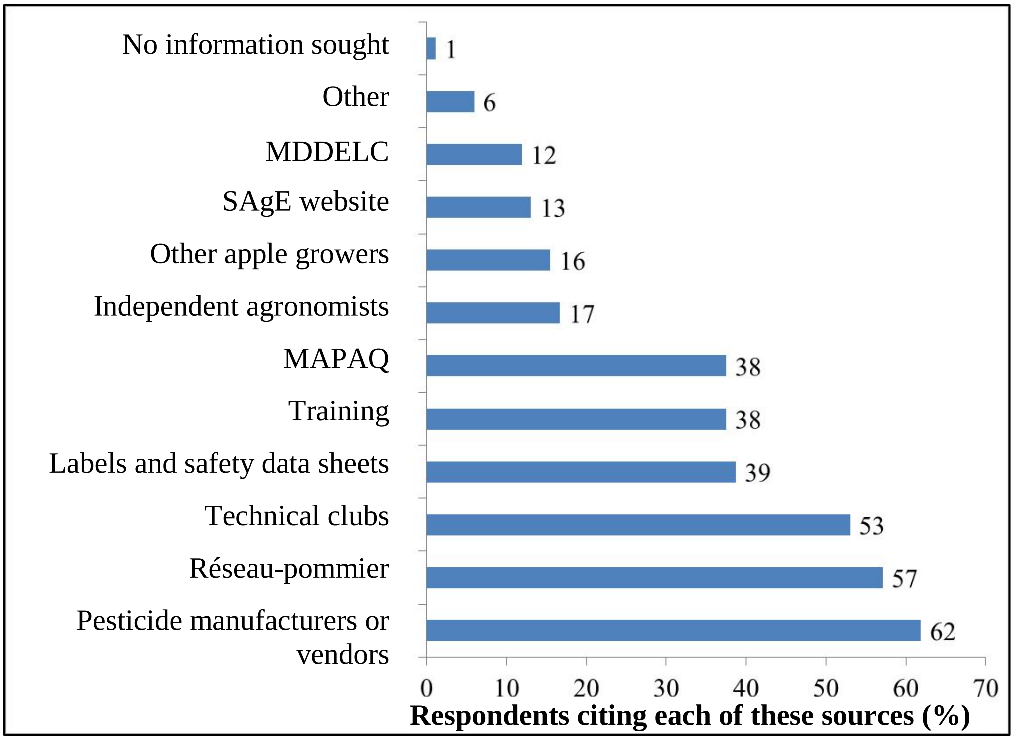


Figure 7. Growers' information sources for pesticide selection

In the interviews, we were able to find out more about where growers get their information on pesticides. Overall, they said there was not much exchange of information among themselves, but this seems to be changing, in particular with young growers. For a long time, MAPAQ and pesticide vendors were the main information sources. Since MAPAQ assigned only one agronomist to each region, services were not very accessible; then, a few years ago, it started providing information through telephone messages and their website. Today, MAPAQ agronomists still offer advisory services to growers in some regions.

The growers we interviewed appear to depend more on their technical clubs than on vendors for information about pesticides. One reason seems to be that vendors do not have the scientific knowledge that growers are more and more in need of. Another is that vendors lack credibility as advisors on which product to use and how much: "They're in a conflict of interest, that's for sure!" "I'm really uncomfortable with that …"

Technical clubs have become the preferred information source for many growers, for three main reasons: agronomic know-how, objectivity as to which products to buy and availability. The advice offered by these technical clubs seem to be sought after more for insecticides—which are complex to use—than for fungicides. Technical clubs and agronomists possess information that is both scientific and practical, and they share it with growers. This seems to have garnered results and won growers' trust: "I never use an insecticide unless they've recommended it." "He's been advising me for years, and my apples are high quality. Why go against that?"

With regard to the changes linked to IFP, the role of technical clubs and agronomists concerning products and dosages contributes to their credibility. The detailed information produced by technical clubs is all the more important because the other sources are short on answers. According to the survey data, 39% of growers refer to the product label for information. Some explained that when they acquire credible information from their technical clubs or other sources, they know what they need and are less likely to be influenced by the product vendor. Only the grower can make the final decision: "I can ask the vendor's opinion about this or that, but when I get to that point, I know what I want." Vendors who are also growers seem to have more credibility: "He's a vendor *and* a grower, and he helped me a lot last year."

Local services offered by technical clubs also provide information adapted to the specific conditions of each orchard, both for diagnostics and for treatment. Availability is an important factor: "I can call my agronomist as late as 10 in the evening and as early as 6 a.m." Although the technical clubs offer important services, they cannot meet the demand; some growers are denied membership or are unable to access all the services.

Some growers hire an independent agronomist, while others continue to use the information sources available, mainly pesticide vendors.

3.2.3.3 Effects of economic constraints on pesticide use

The survey data show that only a small minority (9%) base their choice of pesticide primarily on compatibility with IFP (Figure 8). For most growers (66%), efficacy is the most important factor, even before cost (13%) or the risk to human health or the environment (12% in each case) (Figure 8).

The interviews corroborated these findings: "Often you have two or three products for the same thing, but sometimes there's one that'll do a better job." Interviewees explained that they absolutely must obtain the best yield possible, and they make decisions that they believe will best serve this objective. Some of the practices go against IFP principles. For example, some growers reported using the product they think will be the most effective, even if it is not recommended for IFP or has a high health risk index (HRI) or environmental risk index (ERI): "I always try to maintain a balance with nature. So of course I use toxic chemicals as little as possible. If there's an alternative, I'll take it. If not, well then I have no choice, because my aim is to produce high-quality fruit. I'm not willing to sacrifice 20, 30% of the crop by refusing to use a toxic chemical."

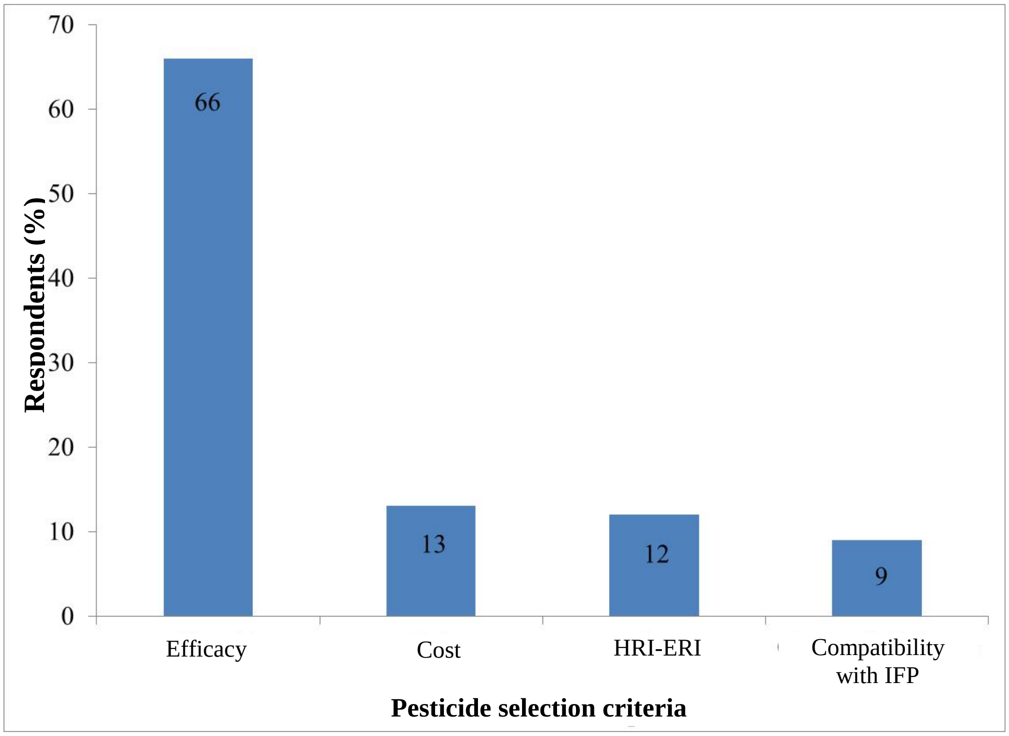


Figure 8. Distribution of growers according to criterion for pesticide selection (n=147)

When a preventive treatment has been washed away by rain, an eradicating treatment is perceived as being the most effective and therefore the surest solution, despite the known risks: "I know about the studies in Europe, how it's not good for the bees. I know all that, but then what choice do we have?" The perception of product efficacy also takes into account the possible side effects. Preventing pests from developing resistance to products is a higher priority than protecting user health or beneficial species: "To prevent resistance, I'll take Plan B. And for sure, Plan B can be more toxic for me and for beneficial species."

Similarly, the HRI and health hazard warnings are rarely the determining factor when it comes to selecting pesticides. Growers might forgo spraying to comply with the preharvest interval or because they have a U-Pick operation and do not wish to cause discomfort for customers. But they will not refrain from spraying to protect their own health: "The risk to my health isn't a deciding factor. Instead, I look at the history, cost, application costs …"

Compromises between treatment efficacy and IFP principles were also mentioned in connection with dosages. Some growers seem to prefer applying "a little less," others "a little more." Some apply less than the indicated dosage because they believe it is wasteful—or even environmentally harmful—to apply that much product, even within the proposed range. Those who would rather not take any chances apply the manufacturer's maximum recommended dosage: "I always try to apply the maximum recommended dosage, because I don't want any problems." Still others say they exceed the recommended dosage because they think it will make the treatment more effective: "We were using Dodine at nearly double the dosage. You could have scab on the leaves, but at least it wouldn't reach the apples, especially if you applied a double dose in warm weather … 85°F ... then it was very, very effective."

3.2.3.4 The pesticide trap

Because growers want to sell their apples at the best price possible, they use pesticides. A small number of respondents said they felt trapped: “We’re kind of enslaved by it all. It’s the pesticide trap.” “We’re the ones who spray too much, but there’s a good reason.”

Pressure has increased over the years, and pesticide use is not diminishing; in fact, it may even be rising. As the chemicals available become less effective in controlling pests, dosages have to be increased. Some growers wonder why this is so: “We need to ask ourselves about that, too. What caused this situation: are the chemicals creating a dependency, have the trees grown weaker? It’s debatable, but in any case I think it needs to be studied.”

3.2.4 Pesticide use and exposure

Observations were conducted in 12 participating operations with the aim of producing an initial inventory of exposure situations linked to pesticide use. By taking the data from our exploratory analysis of the observation results and combining them with the survey and interview data, we were able to produce an overview of typical exposure situations associated with technical determinants and the resulting work methods. In pesticide use, the two primary tasks—in terms of both time and direct exposure—are (1) mixing the product and loading the sprayer, and (2) applying the product. Based on our exploratory analysis of each task and the related exposure situations, we identified three types of exposure determinants: site layout, certain product characteristics, and equipment. Growers are also occasionally exposed during secondary tasks, described during the interviews but less documented in our study. These will be discussed later on.

3.2.4.1 Mixing the product and loading the sprayer

This preparatory stage is short in duration—typically around 10 minutes. Our observations showed a wide variability in terms of products, site layout and resulting work methods. First, the pesticides to be used are retrieved from the storage area and the necessary quantities are measured out. The sprayer is filled with water, then the products are added to the sprayer tank in a specific order.

A number of factors may contribute to a pesticide handler’s exposure. During this stage, the products are handled in concentrated form. There are also time constraints: timing of the product application is determined by weather conditions, and once the product is mixed, it must be applied rapidly before it loses its potency. In fact, according to the survey responses, it is during this stage that accidental contact with pesticides occurs most frequently. The mixing and loading operation is repeated several times, depending on the size of the area to be treated and the tank capacity. The risk is therefore multiplied by the number of times the operation is repeated.

3.2.4.1.1 Pesticides

3.2.4.1.1.1 Product formulation

Product formulation (powder, liquid, granules, flakes) can also have an effect on work and the resulting exposure. Our observations showed that powders can be aerosolized and form a cloud when removed from the package, during measurement or when poured into the sprayer. Powder residues were noted on equipment and tools. Keeping one's back to the wind is a protective strategy documented in the interviews and during our observations. Powders are more difficult to mix, and some growers say they have to be dissolved in a pail of water before they are poured into the sprayer; this means one more step than is required for liquids. In the sprayer, powders are often dissolved by the agitator, but we observed applicators leaning over the opening to check the process visually and sometimes to speed it up with a stick.

Most growers prefer liquids for their ease of use: they do not generate dust, and quantities are measured rather than weighed. Nevertheless, our observations revealed situations where applicators were exposed to splashing or spilling from containers. Some growers mentioned another disadvantage: "Apparently liquid products are not as good. They don't keep as long." Still, product formulation is a negligible factor in the grower's buying decisions, since there is not much choice: nearly all fungicides, for example, are in powder form.

3.2.4.1.1.2 Packaging

Pesticides are sold in a variety of packaging: drums, pails, plastic-lined paper sacks, heavy-duty plastic bags, cans, bottles, water-soluble pouches, etc. Container weight (up to 20 kilos), shape and type can make handling difficult. For example, sacks are held close to the body to facilitate carrying or handling; heavy containers are supported against a knee or hip while the contents are poured onto the scale. Some growers will plunge their arm into the bag to bring out a small quantity in a measuring container.

Methods for opening containers also vary. Sacks are opened with a knife or scissors; drums are pierced with a screwdriver to facilitate air flow. Water-soluble pouches are sometimes opened and the product poured into the tank so it will dissolve more rapidly. Liquids are sometimes sold in graduated containers, in principle obviating the need for a measuring bucket; however, the containers are opaque, which makes it difficult to read the graduations, so the extra step of transferring to a measuring container has to be done in any case.

3.2.4.1.2 Site layout

During our visits we observed that product storage facilities take various forms: a shed, part of a barn or garage, a room in a warehouse, a trailer, an old commercial refrigerator, etc. The layout in storage facilities and work areas also varies widely. But among apple-growing operations both large and small, many do not follow the environmental or health and safety recommendations regarding, for example, recovery basins, ventilation systems, separate storage of different products, first-aid kits, or access to a source of water in the warehouse. In some cases, pesticides were stored in a multipurpose area alongside farm implements, tools and PPE, and where machine maintenance or other activities were carried out. In other cases, however, the warehouse had a concrete floor and a door that locked, products were stored in an area used solely for that purpose, and a pesticides warning was posted.

Since growers use large quantities of fungicide, some buy it in advance and store it: "I know I'll go through fungicide, so I have it brought in by the pallet." Insecticides, on the other hand, seem to be bought as needed: "We use so many different products in a season depending on weather and infestations, so we order a little each week and store it here. Sometimes I have a bit left over. Last night I ordered for the coming week … But you don't want to buy too much."

Some growers weigh or measure the product in the warehouse. Others do it outside, weather permitting (rain, wind), since they have more room to work and can reduce their exposure. Some powders must be poured into a container and weighed on a scale. In some cases, the scale seemed precariously positioned, wobbly, and liable to cause spills. Graduated containers are also used, either for liquids or for habitual quantities of powders, which eliminates weighing. Sometimes products are mixed together or diluted with water, and a stick may be used for mixing. Some growers seem extremely meticulous about calculating the dosage, measuring or weighing the product very carefully. Others say they adjust the concentration a little to simplify things, so they don't have to buy more product when just a small area remains to be treated, or to avoid having quantities left over: "So I reduce the dosage just a bit, then I don't have to buy a litre and be stuck with 800 millilitres that I have no use for and that probably won't be any good next year."

Site layout also depends on the environment or terrain (sloping, near a river, etc.) and on access to water, a critical factor. In some cases, the pesticide warehouse is far from any water, which may necessitate traveling back and forth and handling the products repeatedly. Sometimes distance forces the grower to use a vehicle to haul the pesticide from the warehouse to the water source and filling station. Some growers use a pickup or trailer for this, while others simply put the product in the tractor cab.

Water may come from a system in the orchard or from a tank installed near where the sprayer is filled, or it may be pumped from a pond or lake. The sprayer is filled by means of a garden hose, or a larger hose (greater capacity), sometimes equipped with a flow regulator. Some setups have two taps: one for filling and one for rinsing hands, the sprayer or the containers.

Growers explained that because loading the sprayer can be time-consuming, water flow is very important. However, too strong a flow can cause splashing or spilling. In addition, when the sprayer is too full, it's difficult to mix the product in, and a stick or branch has to be used for mixing. Some tie a sock to the end of the high-capacity hose to filter algae, small stones etc. out of the water and to limit splashing. Generally speaking, the filling areas were not set up properly: instead of a recovery basin, the sprayer was sitting on gravel, dirt (soaked with product) or grass (burned by product).

3.2.4.2 Pesticide application

The pesticide mix is applied on the orchard by means of a tractor-pulled sprayer. Applying the content of a sprayer tank can take anywhere from half an hour to three hours, depending on tank capacity and tractor speed. The monitoring results determine whether the entire orchard must be treated, or only sections of it. The operation may be repeated several times, depending on the area to cover.

Growers explain that the wind determines where they will begin the operation and in which direction they will proceed. This is because wind causes drift and could send the spray toward the applicator: "It's about work methods. I can start over here or over there, I can start where I want. But if I see that I'm getting a face full every time I turn, I'll start at the other end." "When I'm about to take a corner and there's a strong side wind, I'll turn so I get it in the back rather than in the face."

Sometimes tree type and row width make it difficult for a cab tractor to get through. As the trees grow, the rows become narrower and the use of a cab tractor can be more difficult. Some growers prune the trees or replant them in a different configuration to be able to use their cab tractor throughout the orchard. In operations where pesticide is applied by more than one person, the task is divided according to specific characteristics of the rows and equipment. Respondents stressed the importance of having each person always spraying the same area, in order to get to know the orchard layout and avoid incidents.

3.2.4.2.1 Sprayer

The sprayer is made up of a tank, a fan and nozzles. The tank has an agitator at the bottom and a covered opening at the top for loading. The sprayer is pulled by a tractor. The sprayers seen in the orchards we observed were either conventional airblast or tower type (Figure 9).

Figure 9. Two types of sprayers observed

We observed that sprayer design can have an impact on work methods and pesticide exposure. For example, tank capacity has an effect on tank height, diameter and length, and therefore on access to the opening for filling. Depending on the model, the opening may be centred or off-centre to facilitate access, and there may be a running board but in some cases it is not aligned with the opening. If there is no running board, some stand on a crate or the sprayer wheel to get near the opening and check the tank level or see whether the product is dissolving properly. If the tank is large or the opening hard to reach, sometimes the grower has to lean against the tank completely, from legs to chest. Opening the nozzles and positioning them to reach the desired height forces growers to come into contact with pesticide-covered parts of the equipment. Some models have a small water tank for hand-washing, and some have a tank level sight gauge. Some have a siphoning system for transferring the product from container to tank, thus obviating the need for pouring, but we were told this does not work as well for liquids as it does for powders.

We observed a number of sprayer malfunctions: a leaking valve or nozzle, a cover that did not close properly, etc. We also witnessed incidents during loading, such as spillovers, water splashing out, and accidental spraying when the agitator was turned on because the nozzles were not closed all the way.

3.2.4.2.2 Tractor cab

A tractor is used to pull the sprayer through the orchard. The tractor cab is the only collective protective equipment used in apple growing. Growers were unanimous about the comfort and safety of working in a cab. Those who apply product without one confirmed that the task is extremely demanding: “The stuff gets all over you when it’s windy …” “It bugs me, it’s really uncomfortable. When it rains, you have to wear a big yellow poncho over the whole thing.” According to the survey data and our observations, one in three growers (34%) were still applying pesticide without a tractor cab in 2013.

Nevertheless, not all cabs offer the same airtightness or protection, according to our observations. The interviewees—especially those who use an open tractor—stressed the high price of the new cab tractors needed to operate in dwarf tree plantations. Some growers use old tractors retrofitted for pesticide application, with a cab that does not close properly or is not equipped with a filtering system or air-conditioning (Figure 10). Even new tractors apparently do not always come with proper filters. Some growers reported using the tractor with the included all-purpose filter, although they know this is not recommended, rather than buying other filters. Some rent tractors not equipped with carbon filters from snow removal contractors.

Figure 10. Non-airtight tractor cabs observed

Yet the air filter is a critical component of the protection offered by a cab. According to the survey data, 39% of growers with cab tractors use activated-carbon filters, while 26% use filters offering a combination of activated carbon and particle filtration. However, 18% reported using only a particle filter, and a similar proportion (17%) did not know what type of filter was in their tractor (Figure 11).

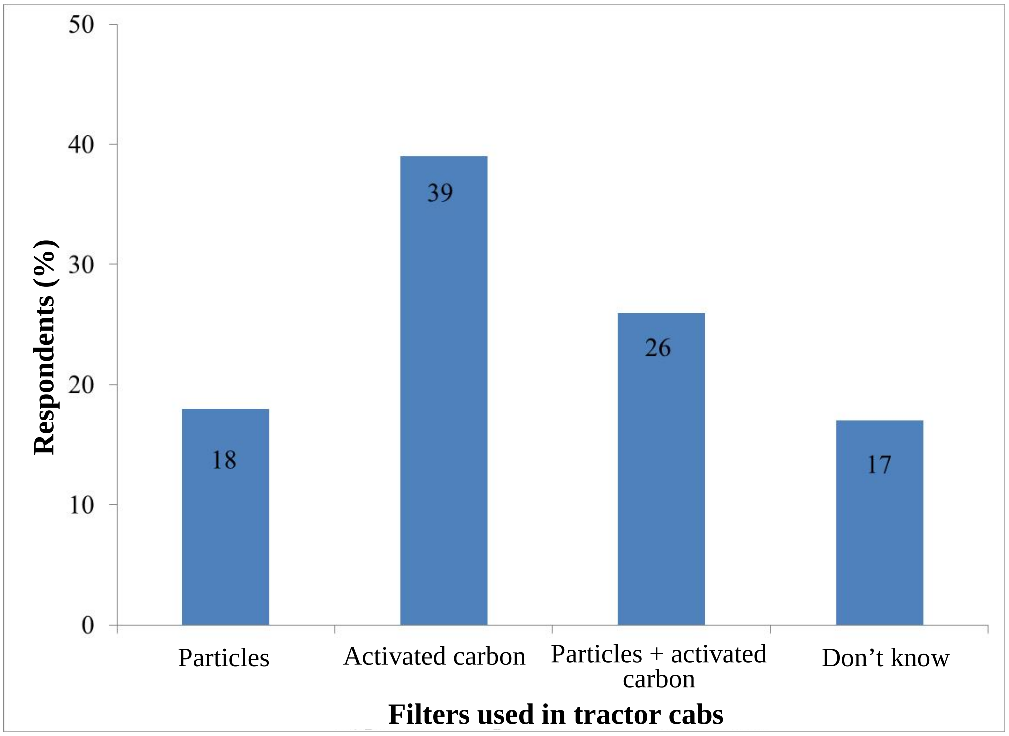


Figure 11. Distribution of growers according to filters used in tractor cabs (n=108)

The interviews revealed that growers have difficulty obtaining information about filters and how to use them, even when buying a new tractor sold specifically as a model for orchard pesticide application. The information available from manufacturers, sales representatives or user manuals is inadequate. The price of filters was also mentioned as an obstacle: depending on the model, about $550 each, and some cabs require two filters.

Filter replacement, too, poses problems. One in two growers (53%) reported replacing it at least once a year, and 20% at least once every two years. Frequency of replacement varied widely, ranging from once a year to never in the past seven years.

Aside from the filter problem, growers spoke of contamination occurring when pesticide residue is transferred from clothing, hands, gloves or boots to the cab interior. During application, potential exposure increases each time the operator gets out of the cab, usually to check or adjust the nozzles. This involves climbing down from the tractor, climbing onto the sprayer, adjusting the nozzles and getting back behind the wheel: "It's very, very hard when you're handling product … You have to load the tank so of course you're handling the product, then you get in the tractor. You spray for a while and something breaks down, a nozzle is clogged, you have to get out, go fix it, and get back in the tractor. So all that protective equipment, you can forget about it, it's all contaminated … you contaminate everything." "You touch a hand, the steering wheel, the gear shift, you scratch your ear … So, you know, it's everywhere." In the opinion of some, the cab gives a false sense of safety, and it's better to spray with no cab but with good respiratory protection: "I'm sure I'm better protected outside than inside a cab."

In addition to long hours, pesticide application is physically demanding in other ways—in particular during hot weather. Growers try to perform the operation when the temperature drops, if possible: “There are days when it’s really hot, but you have to spray. So you try to do it in the morning or evening.” “You’re working under the blazing sun at 30, 35 degrees; at those temperatures, you’d be hot even at the beach in your swimsuit.” And working inside a tractor cab is not a magic solution: “Even if you have air-conditioning, at some point you need real air.”

According to the survey data, 88% of those with a cab tractor have air-conditioning in the cab. When the cab has no AC or the system has broken down, or when the weather is extremely hot, growers admit to spraying with the windows open, otherwise the cab would be stiflingly hot. They may also keep the side windows or rear window open for better visibility, since certain products—especially fungicides—stick to the windows. “And when I say the cab is covered, I mean it’s really dripping and the guys have to come back here and hose it down because you can’t see a thing, not even with the windshield wipers …”

Moreover, product application is stressful for the body, especially in small tractors where space is limited. With or without a cab, the operator has to twist around constantly, often to the same side (the side with the controls) to see whether the jets are functioning. The operator is subjected to vibrations and shaking: “It’s built to go in among the trees, so it’s small and compact. But I’m tall. Plus, it’s pretty bone-jarring.” A cab nevertheless provides better comfort than an open tractor. It reduces exposure to dust and to noise from the sprayer fan and tractor motor. It protects the operator from cold during nighttime or springtime spraying operations, and from rain throughout the growing season.

3.2.4.3 Secondary tasks

In addition to the primary tasks of mixing-loading and applying pesticides, which involve direct exposure to the product, our interviews revealed that growers carry out many unavoidable secondary tasks on a recurring basis, and these involve indirect exposure: monitoring, pruning, mowing, and cleaning equipment and empty containers. For some of these tasks, protection takes the form of re-entry intervals and PPE.

Monitoring consists in counting specimens of targeted pests in order to decide on a treatment strategy or assess the efficacy of a spraying operation. Some growers perform this task themselves. Others benefit from a monitoring service provided by their technical club at regular intervals, but still want to perform a more rigorous—and visual—inspection of trees, leaves or traps. Monitoring is done weekly or several times a week, as a complement to directives from the technical club or the agronomist, which may be based on monitoring done far away from the grower’s operation. The aim is to ensure good surveillance and take preventive measures as rapidly as possible: “If you see insect damage in your trees and your fruit, it’s because you haven’t taken precautions, you haven’t monitored carefully enough.” Monitoring is done throughout the season, at any time, before and after application. Inspections take place rapidly: “We look at the trap, then we’re out of there.” Growers are nevertheless exposed to pesticide residue during these inspections, and our interviews revealed that they frequently fail to observe the re-entry interval and neglect to wear PPE.

Pruning is done manually by all the growers we met with. They explained that the preparatory pruning done in winter for tree training does not involve any exposure. If the pruning has not been completed by spring, it may continue into the spring after the start of pesticide application but before the appearance of foliage. Growers believe exposure is limited under those conditions. Pruning is also done for thinning in summer, when chemical thinning has not proven effective or cannot be applied. Pruning of standard trees is also done after flowering, to control growth. After an infection such as fire blight, the infected parts must be cut off. When this happens, there is greater contact with leaves and residue, and exposure is therefore greater: "In summer, the foliage is dense, so when you're pruning you get into the tree and really come into contact with it." Pruning is done with manual or air shears. The re-entry interval is rarely observed for these operations, and PPE seems to be very rarely worn.

Mowing weeds around apple trees is another secondary task that may involve indirect exposure to pesticides. The purpose of weed control is to help tree growth, make it easier to work around the trees, and prevent insects from proliferating in the weeds. It is done mechanically by means of a tractor pulling a mower of some type. Some growers say they try to observe the re-entry interval and to wait as long as possible after pesticide application before mowing: "I try to stretch it out as much as I can." PPE does not seem to be very commonly used: "Nobody I know does that."

After application, the tractor and the sprayer have to be cleaned, because many products, especially fungicides, will stick to them. Cleaning helps to maintain visibility in a tractor cab, improve comfort on an open tractor, and prevent skin exposure during contact with the equipment. Some growers reported washing their tractor and sprayer before each loading, others at the end of the day, and still others only after applying fungicides or as needed. Cleaning can be done with a watering hose or, in some cases, a pressure washer. Cleaning products, sponges and rags are sometimes used. Gloves and boots are worn at all times, while only half the growers said they wore waterproof clothing.

Hosing-out of empty containers was observed on some occasions and described during interviews. It may be done after loading the sprayer or at some other time. The plastic container is partially filled, shaken, and the contents are poured into the tank. This is done three times (the "triple-rinse rule"). Growers wear the same PPE for this operation as during equipment cleaning.

Many growers say they recycle the containers by placing them in a bag and taking them back to the pesticide supplier. Others throw them out with the household garbage. Some pile them up in a field and burn them rather than having to handle them and take them somewhere. Still others say they keep some of the containers, rinse them and use them for another purpose such as gathering fallen apples.

3.2.4.4 Re-entry interval

The re-entry interval is the minimum time after application before other activities can take place in that area, as indicated on some product labels and on the SAgE Pesticides website. The interval is generally between 12 and 48 hours but may be longer, depending on product toxicity and on the crop treated. This measure is designed to protect workers from dermal exposure, and growers seem to be very familiar with it. According to the survey data, the great majority of growers always or often observe the recommended re-entry interval, but 22% admitted that they do not (Figure 12).

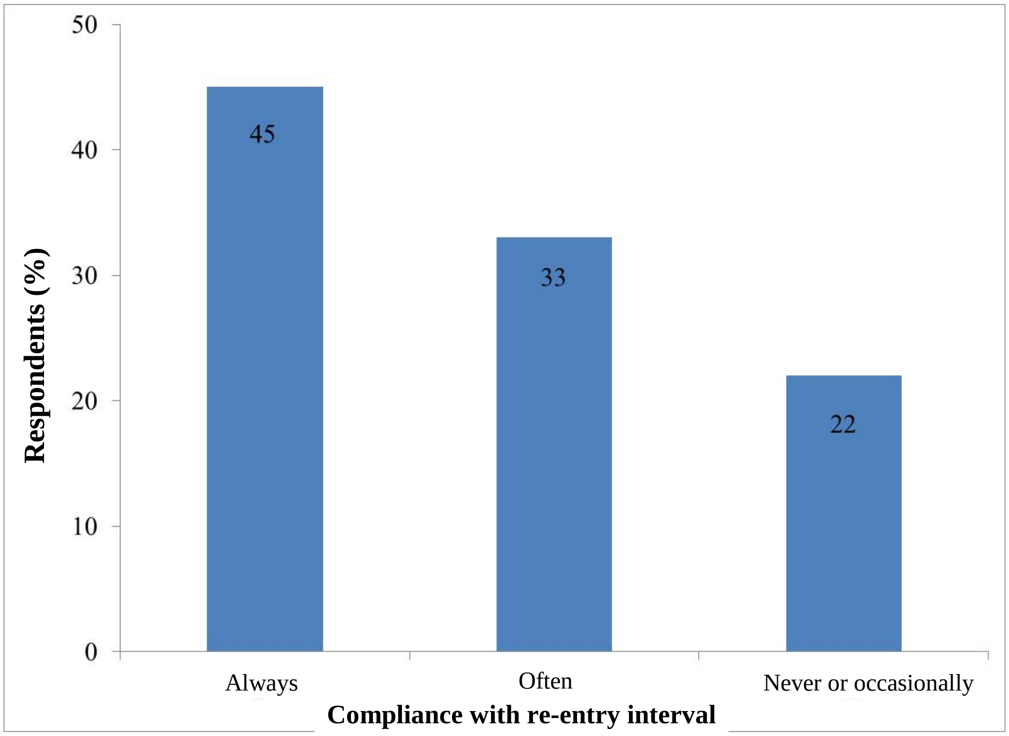


Figure 12. Distribution of growers according to compliance with re-entry interval (n=156)

The growers we interviewed were all aware of the re-entry interval: “It started gradually, yes, it’s changing now.” “So you can go back into the orchard 24 hours after spraying. Then it’s less dangerous, it’s OK to work there.” Some growers explained that they do not have the option of observing the interval, since they have customers entering the orchard to pick their own apples: “And because I offer U-Pick as well, I don’t have any choice.” Growers described different strategies for observing the re-entry interval: pesticide applications can be staggered with tasks such as mowing and pruning; product application can be scheduled around those tasks, or some of them can be done from inside the tractor cab; and new areas can be prepared between spraying operations. There is less spraying in July and August, which facilitates matters.

The interviews help in understanding why over half the growers do not always observe the re-entry interval. There are significant time constraints, especially when pesticide treatments are applied in close succession. Some re-entry intervals—seven days for Imidan, for example—are described as much too long and interfering with orchard maintenance. Recurring secondary tasks such as monitoring cannot be avoided, and growers go back into the orchard before the re-entry interval has lapsed: “I do my own monitoring … I don’t wait till after the interval.”

Growers seem relatively comfortable with this situation if it affects only themselves; they assume the possible risks: “But sometimes we go in anyway. Let’s say I spray my insecticide tonight, and I have to mow the hay tomorrow because the mower is scheduled to be there. So tomorrow I’ll go in and mow. So I’ve sprayed tonight, but tomorrow the hay is full of pesticide! And I’ll be in there, stirring it all up.”

When their employees are affected, various practices are described; some take precautions: “Where it gets complicated is with my employee, who works in the orchard. So tonight when I spray, I have to keep in mind what he'll be doing tomorrow. I spray but I give him about 24 hours. Say I spray a bit before, and I skip the places where he'll be working, and I spray a bit more after. But then sometimes it starts to rain … And then later, the part that I skipped will be hard to treat."

Others do not try to observe the re-entry interval; in their opinion, it is simply impossible: "If I observed it … early May … late June, there'd be nobody working in the orchard." "When the guy comes to spray, the employees get out of the orchard … then as soon as the sprayer has gone by, they go back in. They came to work for the day, a spraying operation was scheduled for that block, you can't send them home, what do you do with them? That job was scheduled. There might be 15 men in the orchard, that's just the way it is." "So my apple trees are full of chemicals. My employees are working in there, I see the chemicals on the trees, but what can I do?" "If I don't apply fungicide, I won't have any apples."

Some have different strategies according to whether they are applying a fungicide or an insecticide: "Let's say it's a strong insecticide … I won't have people going in two hours later. No, not the workers … No, there are limits." None of the growers we interviewed wear PPE when going into a pesticide-treated area, and they all said it was difficult to persuade the workers to do so.

3.2.5 Risk perception, PPE and health

3.2.5.1 Risk perception

3.2.5.1.1 General

The interviews revealed a changing perception of pesticide risk: "We're careful … Look, I have apple trees in my yard, and on evenings when the wind is blowing hard toward the house, I don't even spray, because I know I'll be sleeping there that night. You know, we're more reasonable these days. We never used to care, but now …"

The level of risk awareness varies, however: "You hear all kinds of stories, but you don't really pay attention until you've experienced it yourself." Some growers are confident: "It might not be as dangerous as all that. It's a reasonable assumption, because my father was never sick, and neither was Mr. _____, and everybody knew how he worked." "It's less dangerous now. The HRI—that's the health risk index—has gone down a lot. There's a lot less exposure to LD50 and lethal doses and all that." "They say the products we work with today aren't very toxic. A lot less toxic for the user and the environment. I'm optimistic that it's true."

Growers tend to downplay the risk to which they are exposed. Some argue that their exposure is short and that they are less exposed than agricultural advisors: "The people who do monitoring all day long in the apple trees … They have to go in there." Others refer to other known health hazards: "You know, it's no worse than smoking cigarettes."

Others expressed grave concerns: "Of course it's a health hazard." "I'm not stupid, you know, and I don't want anything bad to happen. And you never know, those products are toxic after all." "I don't know, they must have done tests, but … maybe they'll find out in 25 years."

Some growers said they do not have enough information about the risks they are exposed to and how to avoid them: “I know there are risks in my line of work … but I always think, what exactly is the risk? Yes, there are particles and toxic substances, but are some products more toxic than others? We’re not well informed.” Health risks and preventive measures are not usually included in the information provided by pesticide vendors or agricultural advisors. Nevertheless, the latter can have an influence on growers’ perception of risk: “If she doesn’t want to go in there, well, that makes you stop and think.”

3.2.5.1.2 Variations in risk perception

The survey data revealed that growers’ perception of pesticide risks has several facets.

First, risk perception varies according to the different stages of pesticide use. Based on the survey data, the risk to users involved in mixing-loading and applying the product is seen by the great majority of growers as high (82%) or very high (94%). By comparison, the risk involved in cleanup is seen as high or very high by only two thirds of respondents (Figure 13).

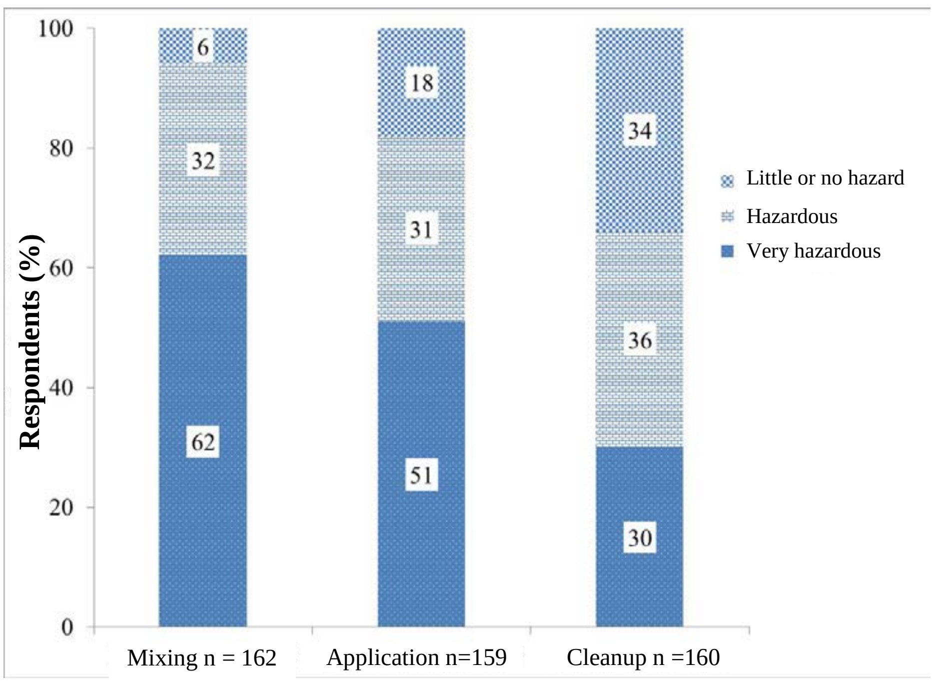


Figure 13. Distribution of growers according to perception of health risk of three stages of pesticide use

Accidental contact with pesticides seems to contribute to this perception; 55% of such incidents occur during mixing-loading, 36% during application and 9% during cleanup.

During interviews, a number of growers explained that it is the handling of concentrated products that makes mixing-loading the most hazardous stage. For other growers, however, the greatest exposure—and hence the highest risk level—occurs during application without the protection of a tractor cab. Lastly, some were of the opinion that the worst risk arises during secondary tasks such as monitoring, pruning and mowing, since these activities are done repeatedly and without protection.

On average, eight out of ten growers believe that the pesticides they use (insecticides, fungicides and herbicides) are hazardous or very hazardous. Risk perception nonetheless varies widely depending on the type of product. For example, the survey data show that insecticides and miticides are considered hazardous or very hazardous by almost all respondents (96%), followed by fungicides and bactericides (81%), and lastly herbicides (76%) (Figure 14). However, the proportion of growers who consider the product very hazardous is much greater for insecticides and miticides than for the other three types of products (fungicides, bactericides and herbicides). It should also be noted that product mixes, which are more and more popular, are seen as hazardous or very hazardous by 91% of growers. Product mixes are seen as very hazardous by more growers (53%) than fungicides and bactericides, and by almost as many as for insecticides and miticides.

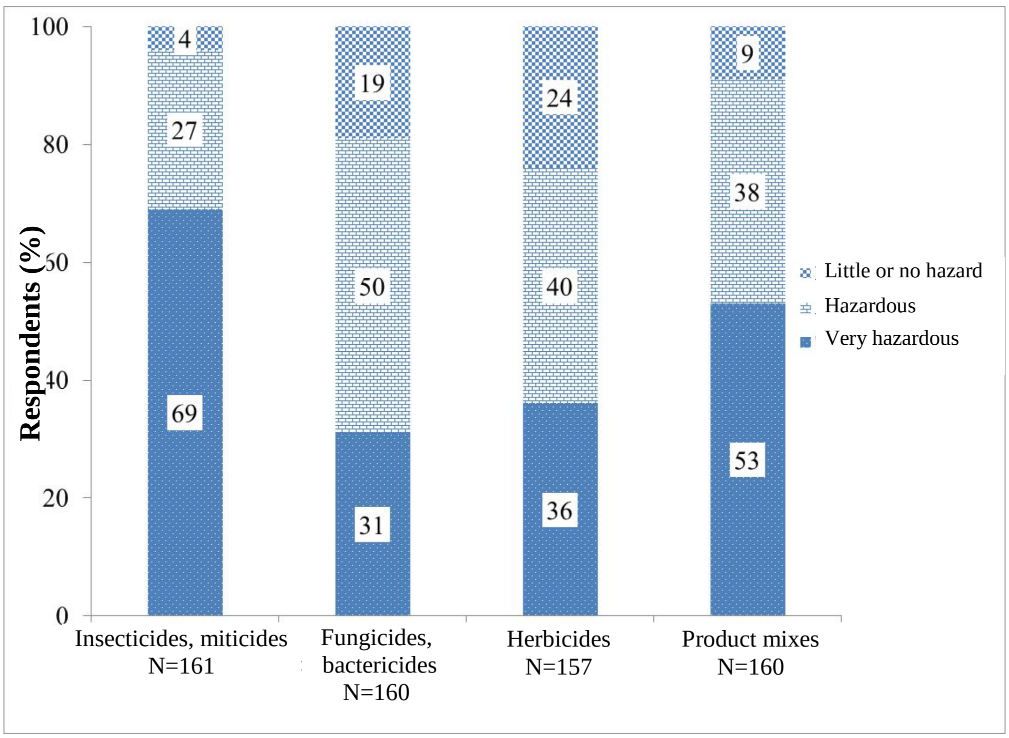


Figure 14. Distribution of growers according to perception of health risk of different product types

For most of the growers we interviewed, insecticides are the most hazardous products; some refer to them as "poisons." Certain insecticides are seen as particularly toxic: "When I spray Imidan, it stinks like hell. You have to wear a mask because it smells so bad … It's not a good thing, it's one of the last organophosphates … It's not some innocent cleaning product …" Products used as preventive treatment are seen as less hazardous than eradicating treatments, which have systemic effects.

The interviews further revealed that the information available to growers on pesticide risk, and how to avoid it, is unclear or insufficient. Some growers learned during their training on pesticide use that fungicides were as hazardous as insecticides; later, they were told that fungicides were less hazardous and that it was not necessary to take as many precautions when using them: “Everybody said ‘Yeah, but fungicides are not pesticides ...’ They said ‘No, no, fungicides don’t hurt the bees.’ So it’s like everybody thinks fungicides are less toxic than insecticides. Maybe it isn’t true, but anyway that’s what we all think.” Other growers added a cautionary note: “Fungicides are not as hazardous, but with the quantities we’re applying, at some point that’s got to be risky too.” In some cases a product has been in use for a long time, and new information changes growers’ opinion of it: “Polyram, a fungicide we thought was fairly safe for humans and the environment, now we realize it’s more serious. I’m using it a lot less now.” Regarding the risks involved in using product mixes: “Anyway, if there are any, I’m not aware of them. We don’t really know much about it. Is it more toxic? Hard to know.”

Product concentration can also be a factor in the level of risk perceived. New products are more concentrated and are seen as more hazardous: “It’s not 90% filler, it’s almost pure active ingredient.” “I think products are probably stronger and more concentrated today than they used to be.”

For some small growers who sell at roadside stands and have U-Pick operations, the fact that they only use small quantities of pesticide also has an effect on risk perception and practices: “It’s different for him. I understand that maybe he has to put on the suit and all that equipment, because he’s going to spend 12 hours spraying. But me, it only takes three hours and I’m done, whereas he has to load his sprayer several times.”

Risk perception also depends on product formulation (Figure 15). Products in powder form are clearly seen as more hazardous than liquids or granules; in fact, almost all the respondents rated powders as being hazardous or very hazardous. We noted that the largest difference between the three product formulations was the proportion of growers who saw them as very hazardous: three out of four growers viewed powders as very hazardous, compared to only 35% for liquids and 23% for granules. This was corroborated and explained in the interviews. Liquids are seen as being safer because they cannot be dispersed into the air and breathed in, as powders can, and because they are measured with a graduated container rather than a scale, which makes the operation seem safer: “We have the impression that liquid is less harmful.”

As for the risks linked to the different types of exposure, growers’ perceptions vary widely. Almost all (97%) rated inhalation exposure as hazardous or very hazardous. A slightly lower proportion—about nine out of ten—viewed ingestion and skin exposure as hazardous or very hazardous (Figure 16). However, the risk perception for skin exposure is actually much lower than for the other two types of exposure, since it is seen as very hazardous by only one in two growers and as hazardous by four in ten growers.

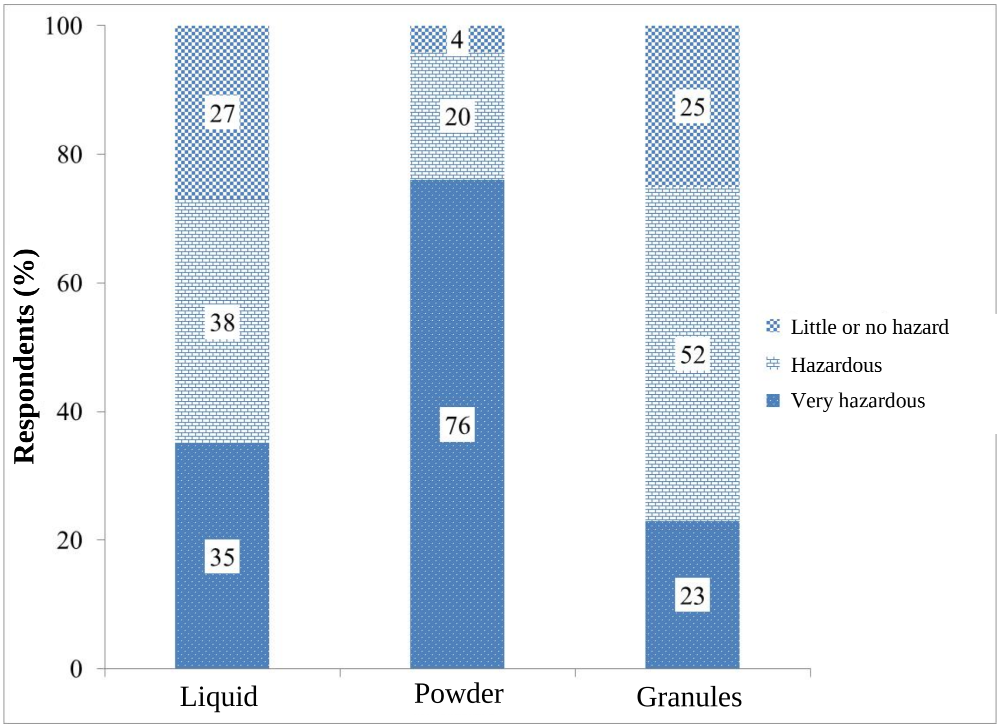


Figure 15. Distribution of growers according to perception of health risk of different commercial pesticide formulations (n=162)

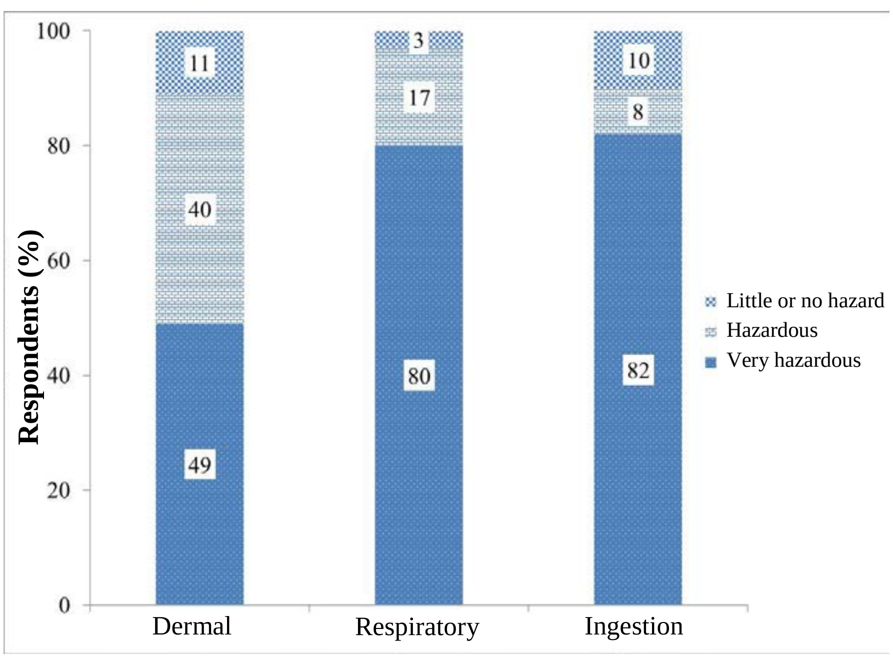


Figure 16. Distribution of growers according to perception of health risk depending on type of exposure (n=158)

Lastly, growers have divided opinions on the nature of the health risks of pesticide use. Nearly half (46%) were more concerned about long-term effects, while 41% felt that both immediate and long-term impacts must be considered. A small proportion (13%) said they were concerned only with immediate effects, or that there was no risk, or that they did not know.

Interviews confirmed that growers are aware of the possible health effects of pesticides. The short-term effects reported—such as headaches, dizziness or skin irritation that goes away right after a shower—are readily observable and seem to contribute to the perception of a low level of risk. The long-term effects are not as well-known and elicit more concern. Some growers are of the opinion that each person reacts differently to pesticides and other products (e.g., pollen).

3.2.5.2 Public perceptions

Public perceptions about the dangers of pesticide are also a concern for growers. The extensive use of pesticide in apple production is public knowledge: “We’re the ones who use the most pesticide.” Some growers acknowledge that nearby populations could be affected: “We spray when there’s no wind, but of course it has an effect on the surrounding area.” Nevertheless, some feel the public is misinformed: “Not enough communication or knowledge, so you can get the idea that growers aren’t careful.” “People know I spray for a reason. It costs money, and it’s a health hazard. The guy who sprays isn’t doing it just for fun.” Several pointed out the hypocrisy: “Everybody talks about how bad pesticides are, but nobody wants to eat an apple covered with bumps and spots.” Moreover, growers who wear protection while applying product may be contributing to public fears: “When they see me suited up like an astronaut to spray insecticide, they’re all afraid.”

Growers emphasize that they want to protect their employees, family and friends. Some warn the neighbours or wait for the children to have vacated the nearby school before beginning a pesticide application. Others say they sometimes send their family away from the orchard if there is a high wind and they absolutely need to apply pesticide: “It was blowing that way, and I had to spray, so she went to her mother’s place.”

3.2.5.3 Personal protective equipment

Some of the more experienced growers, when interviewed, recalled that when they first began using pesticides, they wore no personal protective equipment: “There was no ear protection, no glasses unless you needed them, and you just sprayed and the product would land on you.” Things have changed today, yet it seems PPE is not a topic growers discuss among themselves, and several of them deplored the lack of information.

According to the survey data, nearly six out of ten growers base their choice of PPE primarily on efficacy. Comfort and suitability for the task are the primary factors for only 22% and 10% of respondents respectively, while 10% cited cost or availability.

3.2.5.3.1 Information on PPE

During interviews, growers complained that it is difficult to know which PPE to wear when applying a given product, and to obtain information about PPE effectiveness: “We go to the trouble of wearing PPE, but how do we know what we’re doing is right? Are you supposed to protect the eyes more, or the lungs or the skin? We don’t know.” In addition, it seems that once PPE has been purchased, the decision to wear it is highly dependent on whether or not it is comfortable and well-suited to the task. From the interviews it was clear that wearing PPE—impermeable coveralls, headgear and respirators in particular—adds to thermal discomfort: "It's too hot with those boots on." "It bugs me, it's super uncomfortable." "We try to wear masks but it's not so easy in 30-degree weather." Some complained that impermeable gloves are not suitable for certain tasks, and that disposable gloves stick to the skin and are difficult to put on and remove.

The survey data show that nearly half of all growers depend on pesticide vendors for information when it comes to selecting PPE (Figure 17). Only one in four consult the product labels and datasheets, and slightly fewer than that rely on specialized PPE suppliers.

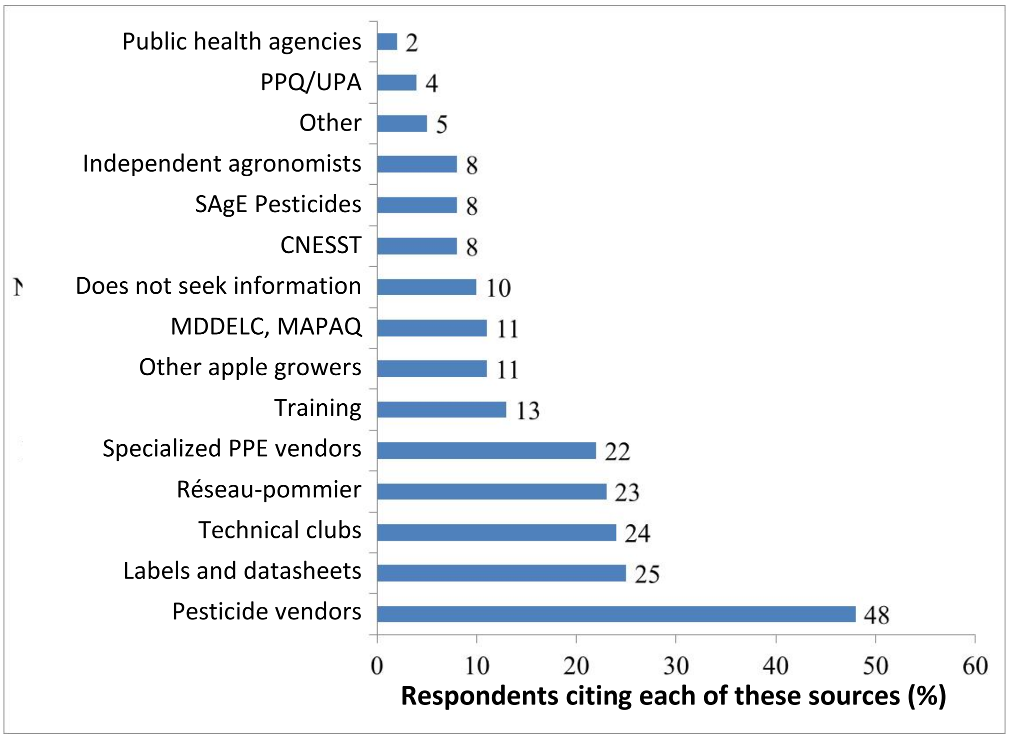


Figure 17. Growers' sources of information for PPE selection

Interviews confirmed that many pesticide vendors are also in the PPE supply business. Some of them, not all, give a little information about PPE. Product labels are also a source of information, and some growers seem satisfied with the information found there. For others, however, this information is insufficient or imprecise; for example, PPE recommendations can be very similar from one product to the next. "There isn't any real information. You can have 30 different products, you look at the labels, they all say the same thing: Wear protective equipment, but that's about it." Others said they do their own research and need no assistance.

Some growers mentioned having learned about PPE during the training required for the pesticide use permit, and said they base their selection of PPE on that. The SAgE pesticides website is another information source cited by a small number of growers. Industrial workwear and equipment stores or hardware stores may also sell PPE and their staff may in some cases provide advice.

3.2.5.3.2 PPE use

Based on the survey data, we can draw an overall picture of PPE use by apple growers and provide more specific information about related practices.

The data suggest that, generally speaking, the use of PPE (all types) is quite frequent. Between 60% and 85% of growers reported that they always or often wear PPE, depending on the type of pesticide being applied. We noted that PPE use more or less corresponds to risk perception. The proportion of growers using PPE is quite similar for product mixes, insecticides and fungicides, and in all three cases markedly higher than for herbicide application. However, frequency of PPE use varies according to product type: the number of growers who always wear PPE is highest for insecticides, slightly lower for mixes and fungicides, and significantly lower for herbicides (Figure 18).

Moreover, the results vary according to PPE item. Different items are not all used with the same frequency, and there is considerable variation depending on the product use stage.

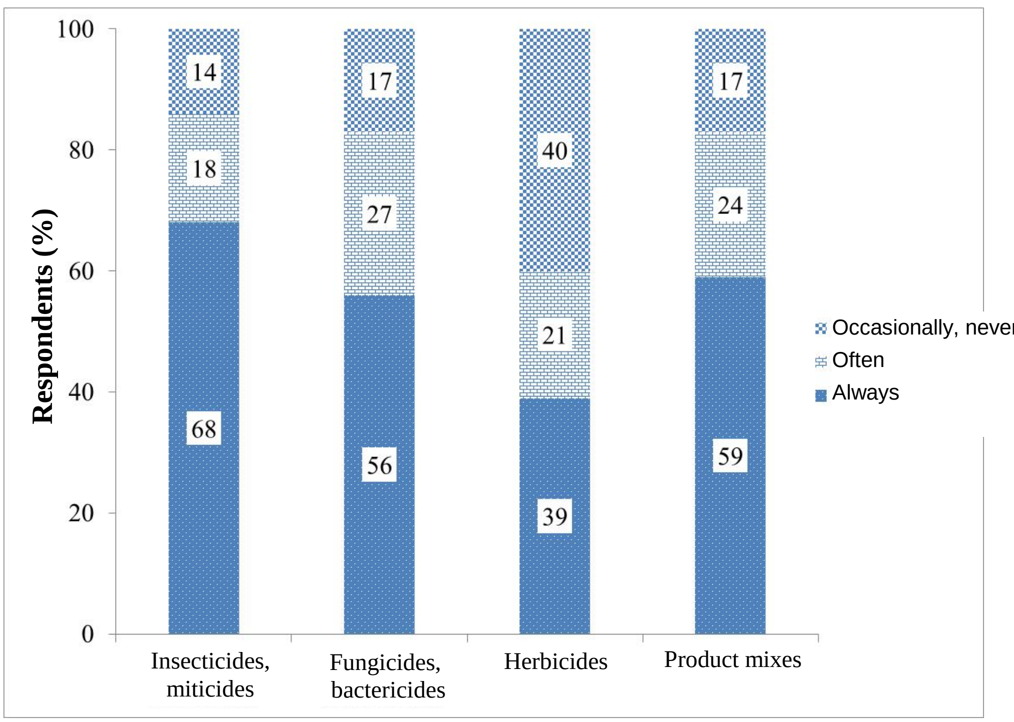


Figure 18. Distribution of growers according to PPE use for different product types (n=140)

During mixing-loading (Figure **19**), half-face and sometimes full-face masks are worn much more often than supplied-air respirators; more than half the respondents said they always or often use the former during this stage. The protective clothing worn always or often by the greatest number of growers are, in decreasing order, chemical-resistant clothing (52%), fabric work clothing or coveralls (35%), and Tyvek coveralls (29%); chemical-resistant aprons are not worn very often (16%). The use of chemical-resistant gloves is very common: 82% of growers said they often or always wear them, and those who always wear them constitute the largest group.

Only 37% said they use disposable gloves. Rubber boots are widely used as well: three out of four growers often or always wear them. As for safety glasses, they are often or always worn by nearly six out of ten growers.

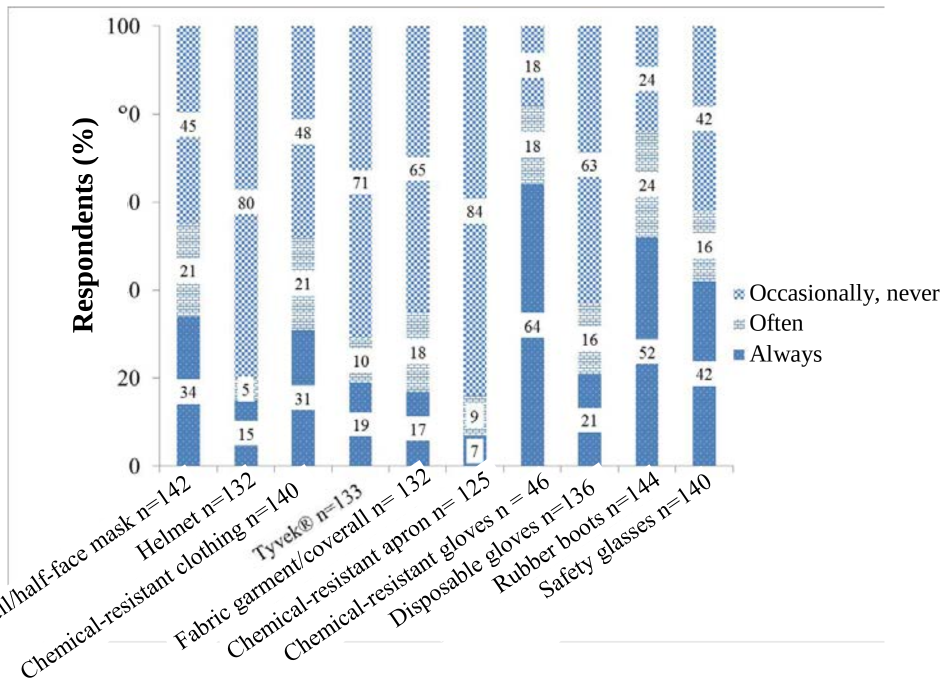


Figure 19. Distribution of growers according to PPE worn during pesticide mixing-loading

Use of all PPE items decreases for the application stage (

Figure **20**). For respiratory protection, growers seem to use either full-face or half-face masks or helmets; 37% often or always use masks, while 27% often or always use helmets. Protective clothing, too, is worn less frequently than during mixing-loading. Chemical-resistant clothing is nevertheless worn often or always by 42% of growers, while other types of clothing are worn by fewer than one in four. Based on the survey data, 66% of respondents have a cab tractor. Our observations confirmed that the availability of a cab tractor influences the use of PPE, in particular respiratory protection and chemical-resistant clothing. These are not worn so much when the applicator is working from inside a cab but are indispensable otherwise. Chemical-resistant gloves are still quite widely used during this stage: half the growers use them often or always. Disposable gloves are used by only 23% during application. The use of rubber boots remains common: 56% use them often or always, which means that some of the growers with cab tractors still wear their boots during this stage. In addition, 36% report wearing safety glasses often or always, which is almost equivalent to the proportion of growers who apply pesticide without the protection of a cab.

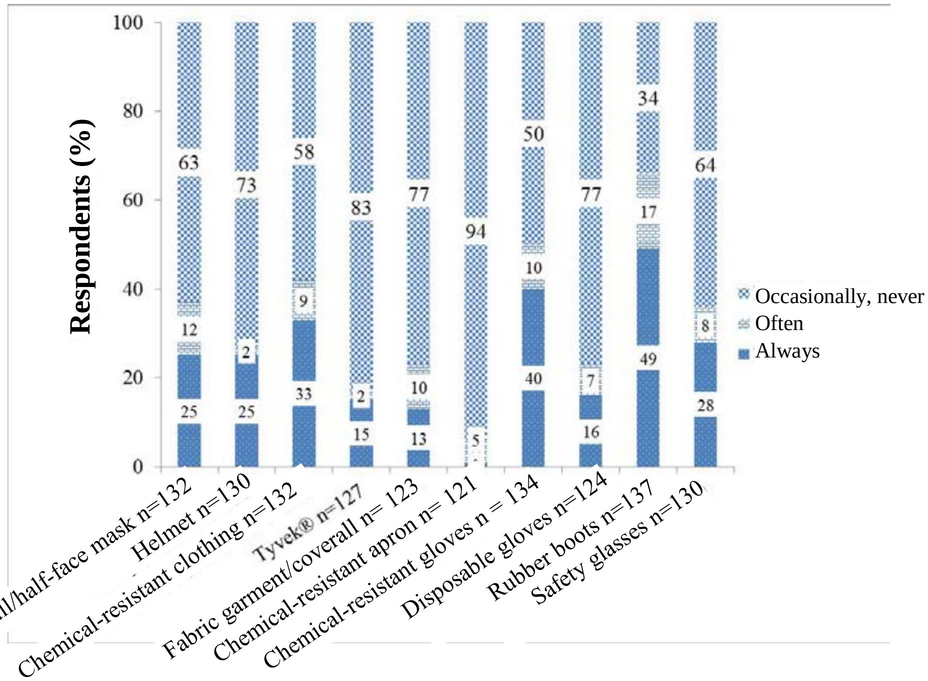


Figure 20. Distribution of growers according to PPE worn during pesticide application

Lastly, for cleanup, practices with regard to PPE differ again. The majority of growers reported that they often or always wear rubber boots (81%) and chemical-resistant gloves (73%). Chemical-resistant clothing and safety glasses are each worn often or always by 54% of growers. Other PPE, in particular respiratory protection, is used by very few (Figure 21).

PPE use, therefore, varies according to both equipment item and product use stage. Chemical-resistant gloves are the most widely worn, for all stages, followed by rubber boots. Regardless of product use stage, chemical-resistant clothing is worn by at least four out of ten growers. We observed that some growers who work from an open tractor wear the selected protective clothing during all stages of pesticide use. Respiratory protection is more commonly used during mixing-loading; for application, it is worn primarily by growers who do not have a cab tractor. Lastly, fewer than one in four growers wear respiratory protection during equipment cleanup.

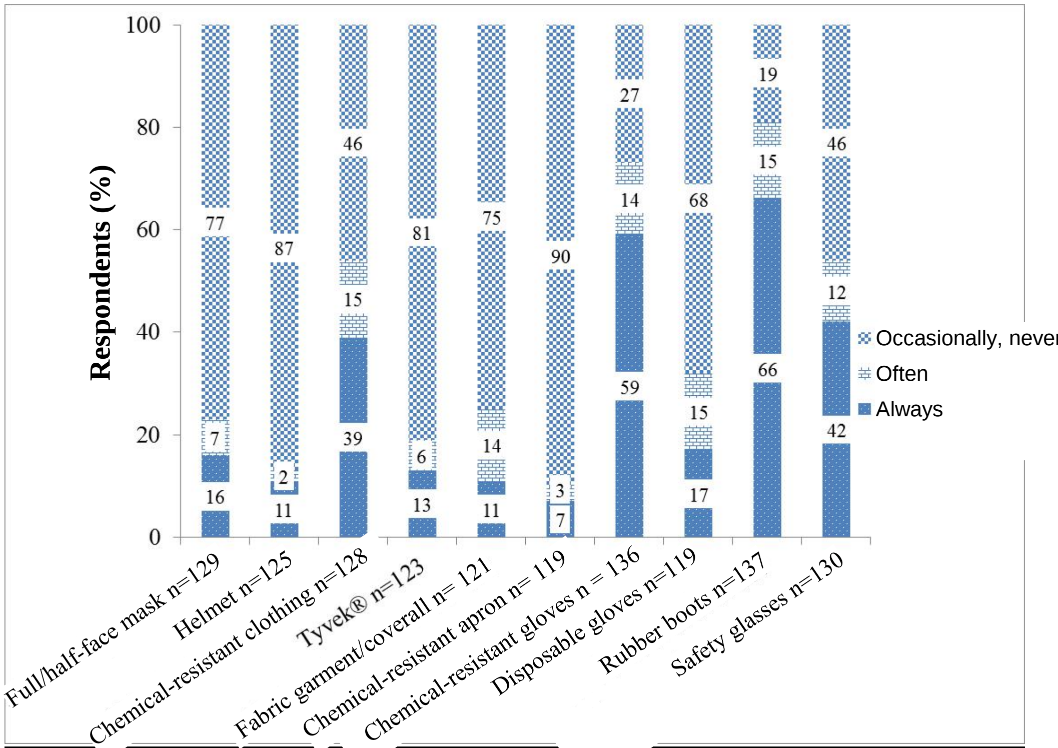


Figure 21. Distribution of growers according to PPE worn during cleanup

3.2.5.3.2.1 Respiratory protection

For all product use stages taken together, only a small proportion (15%) of growers said they do not wear respiratory protection. Of those who do wear respiratory protection, 58% said they use organic vapour cartridges. A smaller number use combined vapour/particulate cartridges or just particulate cartridges, and a very small number use multigas cartridges. Another 8% of respiratory protection users were unable to specify the type (Figure 22).

According to the survey data on cartridge replacement, a little over three growers in four (77%) replace the cartridges in their respiratory protection equipment at least once per season. The others are divided into two small groups: those who replace the cartridges at least once a month (12%), and those who wait until they perceive an odour or were unable to say how often they replace the cartridge (11%). Interviews revealed that growers do not have enough information on cartridge life. Moreover, because respirators are not used continuously and are often exposed to air during storage between uses, it is difficult to estimate their actual remaining life.

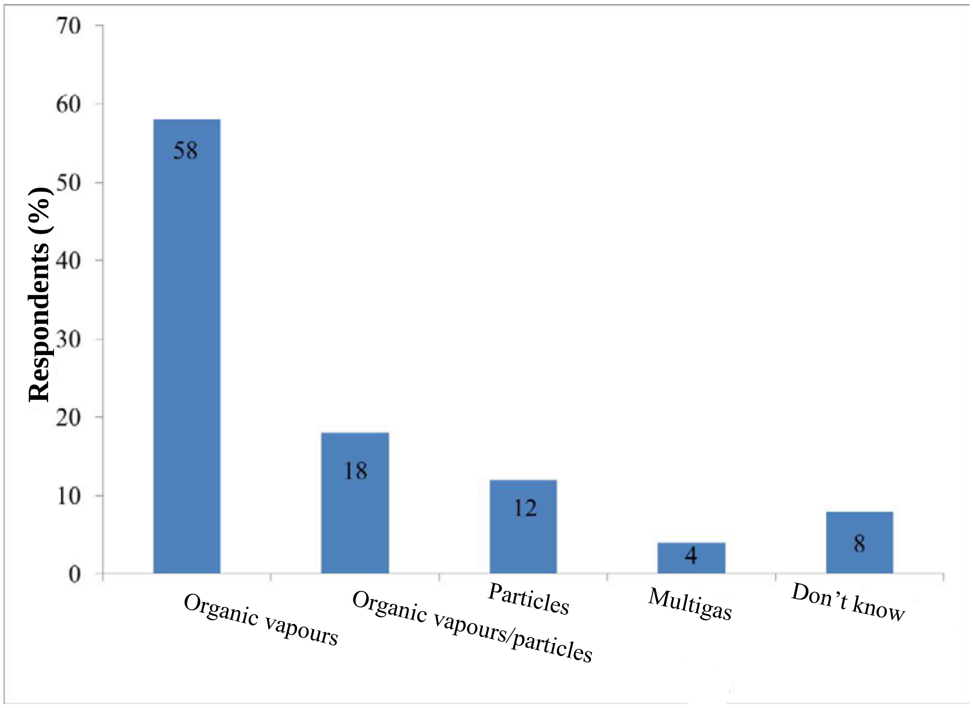


Figure 22. Distribution of growers according to type of respiratory protection most often used (n=125)

3.2.5.3.2.2 Skin protection

For all tasks and all pesticide types taken together, almost all growers (90%) use chemical-resistant gloves. About one quarter (24%) choose nitrile gloves, while the others, in smaller proportions, use commercially available gloves made of various materials. Nearly one in four growers were unable to say what type of gloves they use (Figure 23).

Replacement frequency was documented for a small number of growers (n=46), 39% of whom said they replace their gloves at least once a month, and 33% at least once a season. More than one out of four said they do not replace gloves until they are worn out.

The survey further revealed that disposable gloves are also widely used (by 81%). Use of this type of glove is quite frequent: for all tasks taken together, a little over four growers in ten said they always or often use them. In fact, their use was frequently observed in the orchards we visited. Several growers explained during interviews that disposable gloves let them perform many tasks and operations without too much discomfort, and offer greater dexterity than chemical-resistant gloves, which are usually thicker and stiffer. Some growers wear disposable gloves at all times. Some wear chemical-resistant gloves over disposable ones for certain operations, such as measuring product or driving an open tractor during application. They explained that layering ensures greater protection and removing the outer gloves when getting in the tractor cab reduces contamination inside the cab.

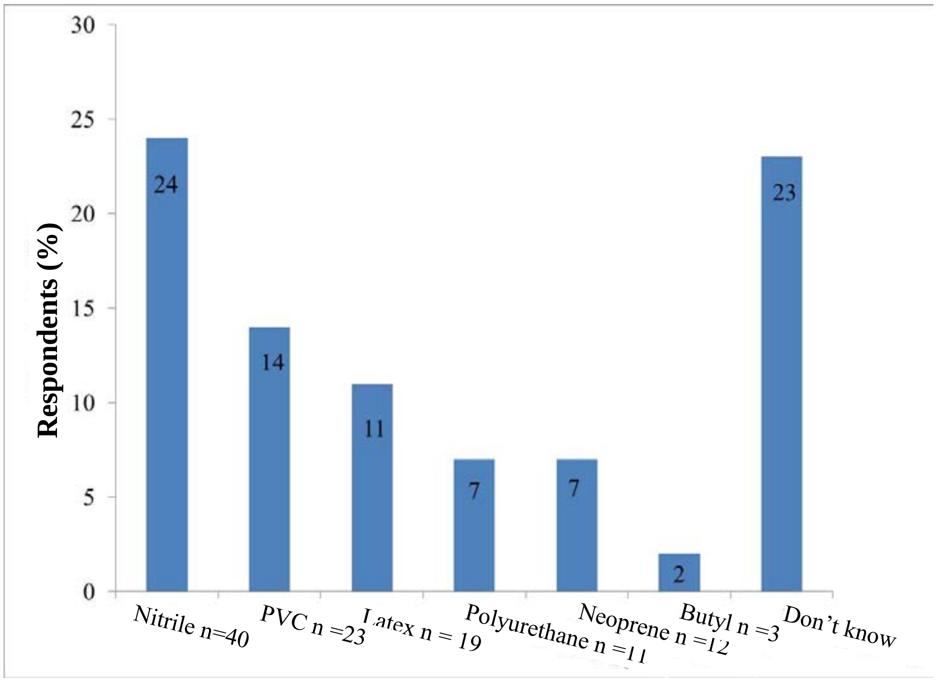


Figure 23. Proportion of growers reporting use of various types of chemical-resistant glove

As for protective clothing, the interviews revealed that, according to growers, not only Tychem® garments but also rain gear may be considered chemical-resistant.

We observed that some of the growers with open tractors wore their protective clothing for all three stages. Conversely, some of the growers using cab tractors did not wear protective clothing for any of the stages.

Lastly, the great majority (76%) said they change their clothes immediately after applying pesticide; the others change at some other time, usually at the end of the day (n=151). During interviews, several growers said they remove their work clothes rapidly and take a shower afterward. Most said they rinse their hands after handling insecticide, while some said they wash their face.

3.2.5.4 Personal health

Three out of four growers are satisfied or very satisfied with the user safety guarantee that comes with PMRA registration of pesticides. Of this number, however, only 22% ranked it as very satisfactory (Figure 24). Nearly 40% said they are concerned or very concerned about their health, due to their past or present use of pesticides. Interviews revealed that the possible effects of their work on their health are very rarely discussed with families or other growers. Even in the absence of serious effects on their health, a few admitted feeling worried: "I haven't had any symptoms, but that doesn't mean I don't think about it." "Yes, I'm worried. I'd be lying if I said I wasn't." Some growers said that as they grow older, they are more careful about their health, without being more specific. Others said it was the effects of stress on their health that had them worried, not pesticides.

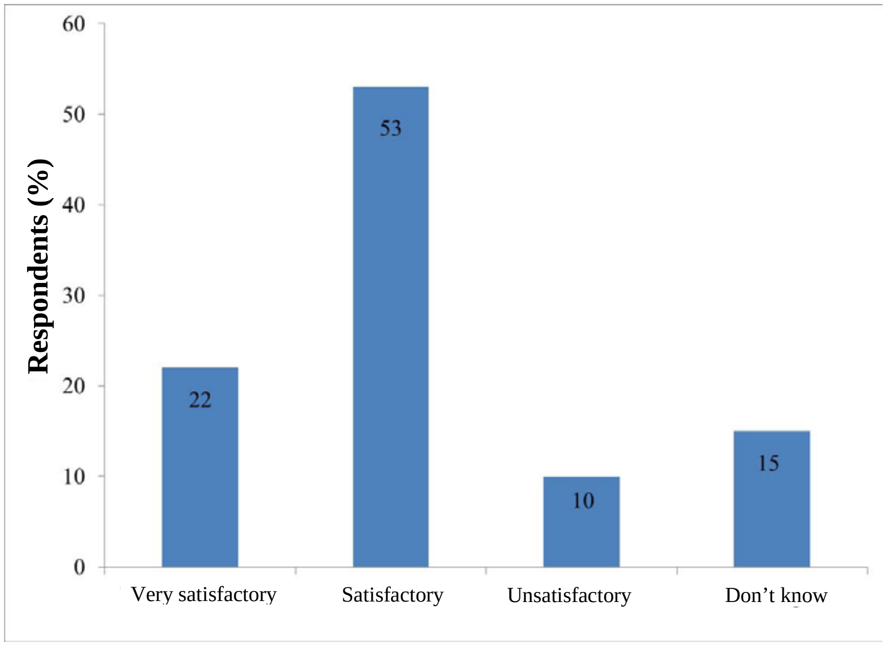


Figure 24. Distribution of growers according to opinion of PMRA registration as a safeguard of user health (n=161)

With regard to their own health, four out of ten growers (39.2%) reported feeling symptoms after pesticide exposure (n=62). Of these, the majority (82.3%, or about a third of all respondents) reported neurological symptoms, and 61.3%, or one quarter of all respondents, reported skin irritation; other symptoms were reported by smaller numbers of respondents. Only 5% had seen a doctor for health problems they believed were linked to pesticide exposure.

During interviews, growers talked a little about signs of possible effects of pesticide use on their health, or on the health of family members or other people close to them. Many spoke of minor reactions, temporary irritations they had experienced or that had been reported by people they know. This type of effect seems occasional and does not appear to be a great source of worry; for example, an insecticide that irritates the face, skin burning under the shower after handling Captan, redness of the skin during pruning, the "poison ivy" effect of a herbicide, itchiness, a pimple or red patch on the skin near the skirt of the respirator. Other effects reported by growers, such as dizziness or vomiting, seem to indicate temporary acute intoxication.

A few growers mentioned a worrisome incidence of severe chronic problems in their communities, such as cancer, Alzheimer's and multiple sclerosis, both in the general population and among people who had worked on farms. "There are cancer cases … They've discovered that mercury can be a factor. Back in the day, they used to use mercury-based pesticides … We have lots of Alzheimer's in our area." On the other hand, some spoke of people they know or former growers who lived very long and in excellent health despite years of exposure: "One of my neighbours, his father, in the days when they still used DDT, well he never wore any gloves when he mixed the product. He lived to be 90."

None of the growers reported any accident; most said they carry a cell phone while applying product, in case of an accident. Nevertheless, we observed some growers who were entirely alone during all operations in the orchard, with no possibility of notifying someone rapidly in the event of a problem.

3.2.6 Discussion

3.2.6.1 Review of objectives and methodology

Social research in OHS has shown that practices develop in particular social contexts and must be analyzed with those contexts in mind. Practices are adapted to the constraints and resources of the context in which they develop. They reflect the capabilities (resources of all kinds) and attitudes (ideas, values, beliefs) of stakeholders and reveal their comprehension and competency (200-202). This was the approach taken in developing the portrait drawn below that documents the situation of Québec apple growers.

In line with the study objectives, our data enabled us to draw a broad portrait of pesticide and PPE use in Québec, its contexts and practices. The questionnaire data, statistically analyzed, provide a wide-angle view, while growers' comments noted during interviews made it possible to validate and enrich the information on the topics addressed, and to record their views on subjects that are more difficult to document through a questionnaire. Finally, our own observations further complemented the first two types of data and enabled us to describe a few typical exposure situations.

The survey participation rate and the complementarity of the three data types, which enabled us to produce a detailed picture of the contexts and practices in question, constitute strong elements in terms of the quality of information generated. In addition, a comparison of our study results with those of similar studies further confirms the validity of our results. Nevertheless, caution should be exercised when generalizing the results, due to the impossibility of constituting a random sample for the three types of data collection.

3.2.6.2 Apple growers and their operations

The survey data confirm that the Québec apple industry is made up of small businesses and microbusinesses; this information was already available from MAPAQ and the association *Producteurs de pommes du Québec*. Although the survey slightly underestimated the smaller operations, more than 60% of growers operate areas smaller than 10 ha. As noted in other studies, work organization and safety are very particular in agriculture. Small operations have few systematic procedures, little perception of risk, and little investment in work areas or equipment. The owner is often an operator (203, 204). Most of the growers in our study do all the mixing-loading, application and cleanup themselves. Just over four in ten growers said they were the only person in their operation to hold a pesticide permit (205, 206). Interviews revealed that some growers were operating areas of up to 20 ha alone or with occasional assistance. (This observation applies to growing only; in all orchards, harvesting requires the hiring of workers.)

Apple growers are an aging population. The average age is 53, and nearly half are over 55. Average experience as a grower and as a pesticide user is significant: close to 20 years in both cases. Perceived control (207, 208) and the level of pesticide safety knowledge/training (108, 110, 209, 210) have been associated with OHS practices. With respect to attitude, the risk perception (84, 211-213) of experienced farmworkers, and their tendency to rely on entrenched trade know-how and to underestimate risk, have been documented (203).

The growers we met with expressed great pride in their work and a sense of a job well done. Several, however, spoke of the physical and mental demands of being a small grower, the unexpected events and environmental constraints, as well as the increasing complexity of apple production. Although a few believe the business can be learned in agricultural school, all are convinced of the necessity of continuing to acquire many kinds of know-how in the field (214). Almost all the growers had a pesticide permit and most of them had taken the optional preparatory training. However, they do not tend to discuss issues of production or OHS with each other. The concerns expressed by all the interviewees with regard to financial insecurity, the high cost of land and chemicals, and the need to improve productivity in the face of globalization and intense competition have been documented in other studies (203, 215).

3.2.6.3 Changes in apple growing and pesticide use

Apple growing requires the intensive use of pesticides, and the pesticides available on the market are constantly changing. Growers confirmed that integrated fruit production (IFP), a sustainable approach, has been gaining ground over the past 15 years. Abandonment of the old way, where treatments were applied uniformly over an entire orchard, arises from two main concerns: (1) to improve efficiency through better targeting of pesticide applications based on regular monitoring, and (2) to reduce the quantities of pesticides used and their environmental impact. The survey and interviews confirmed that many growers are adopting IFP and are engaged in a significant transformation of culture and practices (99, 216).

Data from the survey and interviews show that growers are situated along a continuum of voluntary practices ranging from complete adoption of IFP principles to very little adoption. Interviewees explained in very clear terms that they had to safeguard their orchard's survival by ensuring maximum output along with a level of quality that would fetch the best prices on the market. This situation—reported by a wide range of growers, regardless of orchard size—has given rise to various strategies for balancing economics with IFP principles. Some referred to pesticide use as a trap. In the face of severe environmental constraints, efficacy remains the main criterion for most growers when it comes to pesticide selection—more important than IFP compatibility or health risk index (73, 217-219). Growers trying to sell through large distribution networks tend to apply more pesticide. Conversely, growers who sell directly to consumers or who process the apples are able to reduce the dosage or number of treatments somewhat, since they are not under the same pressure with regard to the apples' appearance or shelf life. The fact that pesticide residues are frequently detected confirms that apple growers still rely heavily on these chemicals (9).

Involvement by the Québec departments of agriculture (MAPAQ) and the environment (MDDELCC), as well as the UPA, the public health branch and agricultural experts associated with *Réseau-pommier*, is facilitating the transition to IFP. Vendors are still the main source of information about selecting and using pesticides for most growers, but *Réseau-pommier* experts and technical clubs advisors are increasingly solicited for their scientific and technical knowledge; this trend has been documented by other studies as well. Growers expressed reservations about vendors' objectivity and credibility with regard to product selection and doses

(206, 220). Lastly, for growers truly interested in reducing the environmental impact of their operations as well as the amount of money they spend on pesticides, there is growing interest in the services offered by technical clubs due to the importance of monitoring and targeted treatment in IFP (205, 206). In fact, it seems these clubs are unable to keep up with the demand for their services.

3.2.6.4 OHS in apple growing

Agriculture is not considered a priority sector in the Québec regulatory framework; interventions and inspections by the CNESST (Québec's workplace safety and insurance board) are difficult to conduct and extremely rare, as noted in other studies as well (84, 205, 206). Our interviews revealed that growers are resistant to any increase in government regulation or control, and very few are registered with the CNESST.

IFP, which aims at primary prevention of occupational health and safety risks, is a topic of interest among apple growers since it promotes the elimination or reduction of pesticide use. While apple growers are concerned about the environment, the integration of OHS objectives into IFP's ecological objectives does not seem to be making much headway. Consequently, health risks for users and the public are not a major factor in pesticide selection, regardless of orchard size. Technical advisors seem to have little influence in this respect, for the time being.

Growers were unanimous about the advantages of using a cab tractor for application. Yet in 2013, one-third of them had not purchased such a tractor, mainly because of the price (102). We noted during our observations that not all cabs offered the same protection; some were in poor condition while others were not designed for pesticide application. In addition, cab airtightness and safety are highly dependent on using appropriate filters in good condition. We learned during interviews that the information made available to growers was clearly insufficient, even when they were buying a new tractor. Growers' ability to get the protection expected from cab tractors thus seems limited by purchase cost, equipment condition and lack of information.

Our on-site observations enabled us to document other exposure situations involving storage areas, product mixing and sprayer loading. In many cases, the recommendations on storage area setup, use of a catch basin or work methods were not followed. While growers demonstrated mastery of complex skills in all aspects of pesticide application and tree training, work organization at the product mixing and loading stages did not seem to receive as much attention, even though growers said they recognized that there were significant risks (206). In these situations, informal measures or practices acquired through experience are sometimes used to reduce exposure. Container shape and weight, product formulation and sprayer design have a strong influence on work method and are linked to numerous situations in which there is a high risk of dermal or inhalation exposure.

Re-entry into treated areas for secondary tasks such as monitoring, pruning or mowing is also linked to situations of repeated exposure, which so far have not been extensively studied (94, 108, 114, 221). The re-entry interval, indicated on product labels and on the SAgE website, is well known and understood; three out of four growers said they always or often observe it. Even though we did not observe the tasks associated with re-entry, they were discussed at length during interviews. In practice, growers are rarely able to comply with the re-entry interval during the period of intensive pesticide use, and none of our interviewees wore PPE during re-entry. This seems attributable to risk perception, time constraints and work habits that are hard to change.

Our quantitative and qualitative data did not enable us to document significant differences in risk perception and safety practices in relation to orchard size. Pesticide risk perception varies mainly according to stage of use and the physical form of the product. Three out of four growers said they were satisfied or very satisfied with the safety guarantee that comes with product registration by the PMRA. Nevertheless, there seems to be some cognitive dissonance (222), since four out of ten growers reported various symptoms following exposure to pesticides, and a similar proportion said they were worried about their health because of their past or present use of pesticides. It is well documented that awareness and information are critical to any risk reduction approach, yet the growers we interviewed complained of insufficient information about risks and how to eliminate or mitigate them. They wanted to know: Are fungicides as hazardous as insecticides? Do operators of small orchards have to take as many precautions as those operating large orchards? Is skin exposure as dangerous as inhalation exposure? When should the tractor filters be replaced? Information is available on product labels and data sheets, as well as on the SAgE pesticides website, but apparently these sources are rarely consulted. Moreover, it has been noted that because the impact on health takes a long time to manifest, there is a tendency to down play the effects of pesticide exposure, resulting in a reduced perception of risk in agriculture (70, 218, 223). The overall results indicate that the prevention practices of apple growers are influenced by insufficient or unclear information about pesticide risks and how to protect oneself against them (207).

Although the labels of approved products state that user safety is only guaranteed if the user follows the instructions and wears PPE, it seems this is not sufficiently clear. The survey data indicate that PPE (of all types) is worn quite frequently: 60 to 85% of growers reported that they always or often wear PPE. It is known that the wearing of PPE reflects the overall perception of risk. However, the survey and interview data show that apple growers do not make systematic or rigorous use of PPE, and this is corroborated by other studies.

The data indicate, first, that two growers in the same area will adopt different behaviours in identical exposure situations, with one choosing to wear all the recommended PPE and the other none at all. Secondly, growers who reported wearing respiratory or skin protection during mixing-loading, for example, do not necessary wear it each and every time. The deciding factors seem to be risk perception and time constraints, as well as whether or not the PPE is comfortable and suited to the task. Additional factors include the type of pesticide and the product use stage. For instance, there is a broad consensus that insecticides are more hazardous than fungicides, and that mixing-loading is a riskier activity than application.

The results for PPE use also vary when broken down according to equipment type, since not all equipment is used with the same frequency. The wearing of chemical-resistant gloves and rubber boots is widely established practice in most situations. However, despite a high level of risk perception, growers who said they always or often wear respiratory protection when mixing-loading product were in the minority (20 to 50%), as were those who reported wearing Tyvek® or chemical-resistant clothing (30 to 50%) (83).

The choice of PPE poses a further problem, especially with regard to skin protection. Pesticide sales representatives are often PPE suppliers as well. As a result, our data indicate that growers have difficulty not only in obtaining reliable, clear information as to exactly what protective equipment is needed in a given situation, but also in procuring that equipment. Information about how to use and store PPE and when to replace it is also lacking. Growers' perception of risk does indeed seem to influence the use of PPE (84, 106). However, their ability to reduce their exposure by using PPE is also quite limited by the shortage of information about what PPE is required, what is available, and whether it is suited to the task (68, 112, 204).

3.3 Priority formulations and active ingredients

In this section, we rank the fungicides and insecticides used in the apple-growing industry according to the risk they present for pesticide handlers based on the approach developed for this project and the research on pesticides used outlined in Section 2.3.

Table 25 and Table 26 present the insecticides and fungicides used in the apple-growing industry, ranked according to application frequency among the growers surveyed. They also show, for each pesticide, the risk indices and the values used to calculate them—i.e., application rate (in kg of active ingredient per hectare) and dermal permeability coefficient (K_p)—as well as the threshold limit values (TLVs) set by the European Food Safety Authority (EFSA) and the US Environmental Protection Agency (EPA).[25]

According to the survey, the most-used fungicides are Polyram (metiram), Captan, Maestro (captan), Manzate (mancozeb) and copper-based commercial formulations. The most-used insecticides are Imidan (phosmet), Sevin (carbaryl), Calypso (thiacloprid), Altacor (chlorantraniliprole) and Decis (deltamethrin).

Based on the three risk indices, the fungicides rank as follows, from most to least hazardous for handlers: Captan, Maestro (captan), Flint (trifloxystrobin), Scala (pyrimethanil), Fontelis (penthiopyrad) and Vangard (cyprodinil). Insecticides rank as follows: Imidan (phosmet), Sevin (carbaryl), Decis (deltamethrin), Envidor (spiridiclofen), Matador (λ-cyhalothrin), Diazinon and Silencer (λ-cyhalothrin).

[25] More complete tables are available on request.

Table 25. Fungicides used in apple growing – Application frequency (f_i), risk indices based on permeability coefficient (K_p) and application rate (Q), and TLVs (AOEL and cRfD)

Commercial formulation	Active ingredient	f_i (%)	Risk index			Q (kg/ha)	K_p (cm/h)	TLV	
			RI_f	RI_i	RI_a			AOEL EFSA (mg/kg/day)	cRfD EPA (mg/kg/day)
Polyram	Metiram	70	0.5	0.5	4.7	4.80	$4.7x10^{-6}$	0.016	0.0004
Captan	Captan	68	16.5	29.4	100.0	3.00	$1.0x10^{-3}$	0.1	0.13
Maestro	Captan	54	12.9	29.4	78.3	3.00	$1.0x10^{-3}$	0.1	0.13
Manzate	Mancozeb	49	0.9	2.0	8.3	4.50	$2.8x10^{-5}$	0.035	0.05
Copper	Copper*	44	0.1	0.1	0.3	1.60	$2.5x10^{-5}$	0.25	NA
Flint	Trifloxystrobin	42	100.0	100.0	21.2	0.11	$6.1x10^{-3}$	0.06	0.038
Dithane	Mancozeb	34	0.6	2.0	5.8	4.50	$2.8x10^{-5}$	0.035	0.05
Scala	Pyrimethanil	32	45.5	45.5	36.7	0.40	$7.4x10^{-3}$	0.12	0.17
Sovran	Kresoxim-methyl	27	2.6	2.6	1.0	0.18	$3.8x10^{-3}$	0.9	0.36
Streptomycin 17	Streptomycin	23	0.1	0.1	0.1	0.92	$6.9x10^{-6}$	ND	0.05
Nova	Myclobutanil	22	8.6	8.6	2.4	0.14	$2.7x10^{-3}$	0.16	0.025
Penncozeb	Mancozeb	21	0.4	2.0	3.9	4.80	$2.8x10^{-5}$	0.035	0.05
Fontelis	Penthiopyrad	17	45.5	45.5	27.6	0.30	$1.2x10^{-2}$	0.1	0.09
Inspire	Difenoconazole	7	5.4	5.4	0.8	0.07	$5.2x10^{-3}$	0.16	0.01
Equal	Dodine	4	0.5	0.5	1.5	1.46	$2.6x10^{-4}$	0.045	0.02
Kasumin	Kasugamycin	1	0.0	0.0	0	0.10	$1.5x10^{-4}$	NA	0.113
Vangard	Cyprodinil	1	21.7	21.7	12.3	0.28	$2.3x10^{-2}$	0.03	0.03

* Different commercial formulations are available but not identified here. Copper oxychloride was used for the copper data.
NA: not available

Table 26. Insecticides used in apple growing – Application frequency (f_i), risk indices based on permeability coefficient (K_p) and application rate (Q), and TLVs (AOEL and cRfD)

Commercial formulation	Active ingredient	f_i (%)	Risk index			Q (kg/ha)	K_p (cm/h)	TLV	
			RI_f	RI_i	RI_a			AOEL EFSA (mg/kg/day)	cRfD EPA (mg/kg/day)
Imidan	Phosmet	80	0.4	0.4	7.0	1.88	$1.6x10^{-3}$	0.02	0.011
Sevin	Carbaryl	53	0.4	0.4	11.2	2.91	$1.3x10^{-3}$	0.01	0.01
Calypso	Thiacloprid	52	0.1	0.1	0.1	0.21	$4.1x10^{-4}$	0.02	0.004
Altacor	Chlorantraniliprole	42	0.0	0.0	0	0.10	$2.8x10^{-4}$	0.2	1.58
Decis	Deltamethrin	39	2.8	2.7	0.3	0.01	$8.6x10^{-3}$	0.0075	0.01
Delegate	Spinetoram	34	0.1	0.1	0.1	0.11	$3.1x10^{-4}$	0.011	0.0249
Assail	Acetamiprid	23	0.0	0.0	0	0.17	$3.2x10^{-4}$	0.124	0.065
Agri-mek	Abamectin	23	0.1	0.1	0	0.01	$1.3x10^{-4}$	NA	0.0012
Ripcord	Cypermethrin	21	0.4	0.4	0.3	0.10	$1.6x10^{-2}$	0.06	0.06
Rimon	Novaluron	18	0.3	0.3	1.2	0.49	$2.1x10^{-3}$	0.009	0.011
Envidor	Spiridiclofen	18	3.8	3.6	6.1	0.18	$3.0x10^{-2}$	0.009	0.0065
Matador	λ-Cyhalothrin	15	100.0	100.0	11.2	0.01	$6.4x10^{-2}$	0.0006	0.001
Success	Spinosad	14	0.0	0.1	0	0.09	$9.7x10^{-4}$	NA	0.0249
Intrepid	Methoxyfenozide	12	0.0	0.0	0.1	0.24	$3.2x10^{-3}$	0.1	0.1
Ambush	Permethrin	11	0.1	0.2	0.2	0.20	$4.6x10^{-2}$	NA	0.25
Admire	Imidacloprid	9	0.0	0.0	0	0.09	$1.6x10^{-4}$	0.08	0.057
Pounce	Permethrin	8	0.1	0.2	0.2	0.20	$4.6x10^{-2}$	NA	0.25
Acramite	Bifenazate	7	0.6	0.6	2.4	0.43	$4.4x10^{-3}$	0.0028	0.01
GF-120	Spinosad	7	0.0	0.1	0	0.00	$9.7x10^{-4}$	NA	0.0249
Kanemite	Acequinocyl	5	1.3	1.2	3.7	0.33	$5.3x10^{-2}$	0.014	0.027
Entrust	Spinosad	4	0.0	0.1	0	0.09	$9.7x10^{-4}$	NA	0.0249
Apollo	Clofentezine	4	0.1	0.1	0.2	0.30	$2.8x10^{-3}$	0.01	0.013
Nexter	Pyridaben	3	0.0	0.0	0.1	0.45	$6.5x10^{-4}$	0.005	0.005
Up-cyde	Cypermethrin	2	0.0	0.4	0	0.10	$1.6x10^{-2}$	0.06	0.06
Movento	Spirotetramate	2	0.0	0.0	0	0.14	$3.6x10^{-4}$	0.05	0.05
Confirm	Tebufenozide	2	0.1	0.1	0.3	0.24	$7.7x10^{-3}$	0.008	0.018
Diazinon	Diazinon	2	4.0	3.9	100.0	2.75	$7.2x10^{-3}$	0.0002	0.0002
Carzol	Formetanate hydrochloride	1	0.0	0.0	0	1.84	$1.1x10^{-5}$	NA	0.00065
Clutch	Clothianidin	1	0.0	0.0	0	0.11	$2.6x10^{-4}$	0.1	0.098
Permethrin	Permethrin	1	0.1	0.2	0	0.75	$4.6x10^{-2}$	NA	0.25
Actara	Thiametoxam	1	0.0	0.0	0	0.10	$4.4x10^{-5}$	0.08	0.012
Silencer	λ-cyhalothrin	1	4.0	100.0	0.4	0.01	$6.4x10^{-2}$	0.0006	0.001

NA: not available

The normalized risk indices—calculated on the basis of application frequency (%), permeability coefficient (K_p) and the active ingredient TLV as established by the EFSA (AOEL)—provide an overview of the substances for which exposure levels should be assessed more carefully and a strategy developed for reducing risk through proper PPE. However, this approach has limitations.

First, the application frequency comes from a questionnaire filled out by 168 apple growers. It would be preferable to determine the actual quantity of chemicals purchased in Québec and used in apple orchards. The figures obtained from the survey questionnaires nevertheless indicate, in a general way, how much of each pesticide is present in that type of workplace. The use of a compound is not necessarily a precise indicator of the quantities to which workers are exposed, since the amount of active ingredient varies considerably from one product to the next, as does the number of applications per season. To weight the risk index RI_f accordingly, a per-application risk index RI_a was calculated using the mass of active ingredient applied per hectare in one application. The ranking obtained with RI_a is very similar for fungicides, where the same five active ingredients are found as in RI_f, although their order of importance changes. But the weighting has a significant impact for insecticides: only diazinon, λ-cyhalothrin and spiridiclofen are still among the five most hazardous active ingredients, the others having changed dramatically in rank.

It should be noted that this weighting does not take into account the number of applications per season; it simply indicates the general magnitude of potential risk. Some active ingredients are used in large quantities—several kilograms per hectare—while others require only a few dozen grams per hectare. These values thus indicate the toxicity of active ingredients in relation to the quantities used, although a more accurate ranking would be possible if we had actual data on pesticide use in the apple industry.

Acceptable operator exposure level (AOEL) was used in the risk calculation because it is the highest acceptable dose for people working with pesticides. It also corresponds to absorbed dose, although an absorption fraction of 1 is often assumed by default. In cases where no AOEL was available, we used the chronic reference dose (cRfD) established by the EPA, even though it is an estimate of exposure in the general population rather than workers. Both values are based on the maximum dosage administered to the most sensitive test animals—or, if data are available, to humans—without producing harmful effects (the no observed adverse effect level, or NOAEL). Uncertainty factors are applied to take into account individual variability, animal-human extrapolation and study duration (subchronic to chronic), or when the lowest observed adverse effect level (LOAEL) is retained as the reference dose.

In addition, to estimate the risk associated with dermal exposure, a dermal permeability coefficient was considered in the calculation of the risk index. This coefficient comes from a permeability model that takes into account the mass and octanol/water partition coefficient (K_{ow}) of the active molecule (120). Because pesticides are reported to enter the body primarily through the skin in farm workers, the permeability coefficient is needed to estimate systemic exposure. However, it is very possible that the theoretical permeability coefficient calculated here is not representative of actual absorption rates, since these are calculated for pure active ingredients. K_{ow} and molecular mass are not the only aspects to consider in dermal absorption of pesticides; the state of the formulation (solid or liquid) and its level of dilution have a known influence

(224). Moreover, the presence of “non-active” ingredients such as organic solvents and surfactants may increase dermal absorption (225).

In short, the risk indices proposed in this study are a first step and can serve not only to determine the pesticides for which exposure should be studied more in depth, but also to identify the ones that present a lower level of risk and to prioritize their use in the apple industry. The indices are based on a threshold absorption dose not to be exceeded to prevent health risks for these workers, combined with a dermal permeability coefficient, and taking into account application frequency and application rate. Samuel et al. (92) also proposed an approach for establishing risk indices for pesticides in Québec. The approach used in the present study yields a more precise ranking of apple industry pesticides that are potentially more hazardous and need further study, because it is based on systemic risk indices linked to mainly dermal exposure. The approach of Samuel et al. (92), on the other hand, is based on the intrinsic toxicity of the active substance (toxic potential). It uses toxicological risk indices (TRI), which are based on a bank of toxicological data developed by the toxicology centre of the Québec public health institute (INSPQ). The TRI is calculated by taking into account the total of acute risks (oral, dermal and inhalation LC_{50} and LD_{50}) added to the total of chronic risks (carcinogenicity, genotoxicity, endocrine disruption, reproductive effects and development inhibition) based on a qualitative evaluation of the various chronic effects evaluated by a score indicating the gravity of the effect. This TRI is then adjusted by a weighting factor, depending on the type of formulation, to calculate the health risk index (HRI) for an active substance in a commercial formulation. More points (2 instead of 1) are assigned to liquid or solid formulations designed to be released in gaseous form. Like the risk indices in the present study, a compensation factor is also applied to take into account not only the quantity applied but also the concentration of active substance in the commercial product. A risk index for a formulation is calculated by adding up the indices for all the active substances it contains.

4. GENERAL DISCUSSION

Pesticide use is firmly anchored in modern society and has long been associated with the development of productivist policies around the world. More recently, consumers have begun seeking more quality in their diets, which translates into greater consumption of fruits and vegetables, preferably fresh, and preferably pleasing in appearance (226).

At the same time, although certain harmful effects are acknowledged, the real impacts of occupational pesticide exposure remain partially invisible, since the associated diseases are under-reported by growers (85, 86) and under-diagnosed by physicians (88). In Québec, only 41.5% of farms (227) and less than a quarter of apple growers (our data) are registered with the CNESST (Québec's workplace safety and insurance board). Québec OHS authorities have very little involvement in agriculture, as it is not a priority sector for them. This situation seems to contribute to persistent confusion about the real level of risk in pesticide use, which may influence the practices of apple growers.

4.1 Prevention at source

All pesticides used in Canada must undergo the registration process described earlier. This is mainly to ensure that the chemicals used in agricultural production have an acceptable level of risk for the health of users, the public and the environment. Registration is a way of controlling the sale and use of pesticides at source. However, some authors have expressed reservations about its actual impacts (69, 228): they maintain that registration encourages agricultural productivism and supports pesticide companies while making pesticide-related health problems invisible, or less visible. Each time a product is submitted for registration, the regulatory agency tries to establish safe agricultural practices that would enable use of the product and bring the risk to an acceptable level. In other words, agencies try to mitigate the general risk inherent in pesticide use by focusing more on the exposure aspect than the hazard aspect.

Apart from registration, policies designed to reduce pesticide use and the associated risk have been developed. The 2011 *Stratégie phytosanitaire québécoise en agriculture* (SPQA), mentioned in Section 1.2.3.1, aims to achieve a 25% reduction in environmental and health risks by 2021, in comparison with the 2006–2008 reference period (89). The most recent report from the MDDELCC (229) seems to indicate that this target will be difficult if not impossible to achieve. In 2012, the pesticide pressure index [26] had actually risen 18% over the 2006–2008 benchmark, while the risk indices HRI and ERI remained relatively stable. A recent report by the Auditor General of Québec (219) confirmed that pesticide use continues to increase.

The SPQA relies mainly on promoting IFP to achieve its pesticide use reduction target. Apple growers are open to the idea of IFP and believe in its benefits, especially for the environment. However, our data indicate that, when the time comes to choose a pesticide, economic and environmental constraints often push growers to choose what will be most effective rather than what is in line with IFP or has the best ERI or HRI. The requirements of packers, who pay the best price, together with pressure from consumers for blemish-free fruit, seem to be pushing growers who sell through these channels to use more pesticides than those who sell directly to

[26] The pesticide pressure index is a measure of the amount of active ingredient sold per hectare under cultivation.

consumers. This puts growers in a difficult position and seems to indirectly encourage practices that do not always fit with IFP (69, 73, 218, 219, 230). Apple growing is still a largely small-scale industry. Our quantitative and qualitative data did not reveal any significant size-related differences in risk perception and documented practices.

The health component of the SPQA, which is aimed at reducing pesticide exposure among farm workers and in the general population, is not as well-known as the environmental protection objective associated with IFP. Given the environmental, economic and time constraints, growers seem less inclined to consider their present or future health in determining their IFP practices or work methods; this remains a challenge (205). *Réseau-pommier* experts and technical clubs advisors have regular exchanges with apple growers, and they have a high level of credibility. They could possibly play a greater role not only in the adoption of less pesticide-dependent practices but also in conveying the OHS message underlying IFP and the SPQA. OHS authorities often use intermediaries when dealing with small businesses (205, 206, 222, 231).

IFP is a promising avenue for achieving the SPQA's objectives, but it remains a voluntary practice in Québec. Elsewhere—in New Zealand (206), for example—IFP objectives and practices are the subject of mandatory certification that also includes criteria regarding food safety and OHS management. The Québec agricultural industry could study the pros and cons of such an approach.

Without a paradigm shift in agricultural production, the most effective avenues in terms of workplace hazard prevention—namely, eliminating, reducing or substituting risks at source—thus appear to be a challenge (219). As a result, a large part of the burden of prevention is transferred to farms, farmers and their employees.

4.2 Risk prevention through engineering and administrative controls

Administrative controls, which did not receive much attention in this study, will be discussed in this section in an extremely preliminary way. They are nevertheless important and can contribute to risk mitigation. Because of apple growers' reality, OHS measures are liable to be perceived as more constraints piling up day after day. One strategy could be to make better use of the existing regulations. For example, the requirement to obtain a permit to apply pesticide or oversee a spraying operation is a good precaution, but not all growers seem to appreciate the optional course that goes with it (232). It might be time to review its content with input from growers and other stakeholders, and to redefine the scope of each course section. In our experience, growers have various sources of information about cultivation practices, sprayer maintenance, etc., but there is very little in the way of an information network regarding OHS. The revision could therefore consist in augmenting the section on OHS in both the course and the participant's guide. A literature review showed that for many authors, enhancing knowledge through mandatory training is one possible way of improving safety performance (233).

In our study, we noted that many stakeholders and growers relied on tractor cabs to reduce exposure. Besides the high cost, cited mainly by those who do not own such equipment, our field observations, the survey results, a reading of the normative literature and certain discussions with members of standards committees indicate that tractor cabs often do not provide the anticipated protection. On many occasions we noted visible signs of non-airtightness (holes for wires to pass through, defective seals), and sometimes the operator had to open the windows while applying certain products because the windshield wipers were inadequate. In addition, because of the difficulty of finding information on cab maintenance, often the wrong filters were used or filters were not replaced frequently enough. Some growers mentioned indirect exposure through contamination of the cab interior due to repeated entering and exiting of the cab during application and the presence of residue on clothing.

From a normative viewpoint, the shortcomings of cabs are well known. The first US standards to set out the performance specifications needed to achieve the defined levels of protection—standards adopted by the CSA in Canada (234, 235)—were withdrawn, partly due to problems in the test methods used to qualify cabs. Quality problems in cab manufacturing and design also made it impossible to certify new tractors coming off the assembly line (104). For these reasons, the American Society of Agricultural and Biological Engineers (ASABE) withdrew the standards and proposed a new series, which remains incomplete so far (102, 236, 237). This new series of standards (not adopted in Canada) is, however, less ambitious: its aim is simply to guide manufacturers in the design of safer cabs. Consequently, it will be up to individual growers to define their protection needs according to their activities, by means of an "occupational health and safety management system" which they will have implemented. Our experience with apple growers leads us to believe that, for most of them, the implementation of such a system will require enormous effort, and that choosing a cab for their specific needs will therefore be extremely difficult. Meanwhile, the European Union has decided to classify cabs according to performance criteria (238). Although the first tests conducted on cabs in operation before the European standards came into force indicated that very few were in the top category, the situation should improve as the performance criteria become more widely known.

Regarding sprayers, our field observations revealed numerous design parameters that can influence exposure. For example, the tank does not always have a running board; this makes it difficult to access the opening at the top and increases the risk of skin contact with tank surfaces contaminated during spills, when pesticide is poured into the tank, or during application. It is nonetheless possible to design equipment so as to reduce exposure, as demonstrated by certain sprayer models that have a siphoning system to get the product into the tank with minimal handling.

Finally, the layout of the product storage and handling area was problematic at a large proportion of the operations we visited. The weight and shape of pesticide containers, as well as product formulation, are other determining factors in exposure situations. Mixing-loading is the phase where growers perceive the greatest number of risky situations and where accidental contact is most frequent—and with concentrated products, to make matters worse. Work organization could benefit from many improvements supported by information, training and technical expertise (204, 205). Given that a farm—especially a small farm—is often a home where the entire family lives (227), this goes beyond simple occupational health and safety concerns.

4.3 Risk prevention through personal protective equipment (PPE)

4.3.1 PPE: Clear designations, commercial availability and cost

An examination of how the Pesticide Handlers Exposure Database (PHED) is used for risk analysis during the registration process shows that PPE is the primary measure chosen for reducing exposure to levels deemed acceptable or safe. Despite our request to the PMRA, we could not find out what proportion of registered pesticides require the use of PPE to keep exposure at a safe level. A recent US study of pesticide labels (239) showed that of the 1,868 labels examined, 1,583 recommended wearing long-sleeved shirts and long pants, and 152 recommended adding coveralls. Moreover, 1,552 of those same labels recommended chemical-resistant gloves, while 140 did not mention any type of glove. Given the key role played by PPE in the legislated objective of reducing pesticide risks, a central aim of the study was to understand the possibilities for implementing such a mechanism.

Clear designation of which PPE provides dermal protection against pesticides seems to be a problem. Vague descriptions lead to differing interpretations by growers who must make choices. Moreover, risk analyses do not take into account or estimate the probable differences between PPE chosen by growers and the PPE used in the PHED studies—and the little scientific literature available on the effectiveness of protective clothing against pesticides is no help here either. Laboratory tests of clothing material penetration demonstrate differences depending on the characteristics of the material (160), but these results cannot be directly transposed to penetration under real conditions.

Standardization could solve this problem, by ensuring the protective clothing used in studies making up the PHED and designated on product labels and in guidelines is the same as the clothing actually used in the field. Standardization implies developing a particular risk analysis approach, adopting proven test methods and obtaining approval by consensus from a standards committee. This first stage has already been completed with the current version of ISO 27065 on performance requirements for protective clothing (157). A standard is not immune to error, however, and this one will have to be updated and field studies conducted to ensure the actual efficacy of clothing labelled compliant, as well as making sure such clothing meets growers' needs, particularly with regard to physical comfort. Using our risk indices (see Section 3.3), we can, on a preliminary basis, identify just a few pesticides that should have priority for such studies.

Nonetheless, the question of commercial availability would still need to be addressed. Indeed, the existence of a standard does not guarantee that certified clothing will be manufactured. To encourage mass production of such clothing, protective clothing manufacturers—both established ones and newcomers to the market niche—must see a return on their investment. We are putting forth the hypothesis that the CSA's adoption of ISO 27065, along with references to that standard on pesticide labels, should help create a market in Canada. Since Brazil seems to be more advanced than any other nation in terms of ISO 27065 application (240), an in-depth study of the Brazilian system could contribute to the process in Canada.

Québec apple growers turn first to their pesticide supplier for personal protective equipment and information. Some of the growers we interviewed expressed frustration about the difficulty of finding PPE. A quick investigation in a small number of stores confirmed that very few PPE items (respiratory protection, gloves, protective clothing) were available.

Some authors (212) maintain that the cost factor is also important in the selection and purchase of PPE. This does not seem to be the case for apple growers. Their management of PPE (frequency of filter changes, number of gloves made of different materials and frequency of glove changes, re-use of disposable clothing, etc.), as seen through the survey, our observations and the interviews, could however lead them to underestimate the actual cost of personal protection. Nevertheless, some growers claimed they were ready to pay whatever it costs for safe and effective PPE.

In summary, it seems that management of the PPE offering, from design to local distribution, deserves extensive consideration. Cooperation with the US—which dominates the world's agricultural industry and is Canada's largest natural trade partner—is all the more promising since relations have already been established between the PMRA and the EPA.

4.3.2 Compliance with PPE requirements

Even if an offering of effective, certified and easily identifiable PPE were assured, the question remains: how to convince growers to buy it and wear it? This is critical to the entire OHS system, since the safety and compliance sought by institutions cannot depend on coercion, especially in agriculture (206, 241). Surveys (57, 109) unanimously agree that PPE use is not widespread enough. In Québec, the results published by MAPAQ (99) and our own study results are along those same lines. Our survey data on PPE have only to do with mixing-loading and application; the "secondary" tasks, those involving re-entry into treated areas, were only documented during interviews. The survey responses regarding compliance with the re-entry interval were quite positive on the whole. But our interview data revealed that re-entry is an important parameter to consider, in the sense that re-entry intervals are seldom complied with and growers do not wear the recommended PPE. Moreover, significant levels of contamination were measured during these tasks in some operations (108, 221). Concerted action is needed to promote better observance of this precaution.

To improve PPE adherence rates and compliance within agricultural operations, action can be taken at several levels. Our investigation enabled us to appreciate the complexity of the situations in which growers decide whether or not to wear PPE, and we were also able to document a number of determining factors.

The ways in which risk perception and information are linked to PPE use constitute a broad field of research that exceeds the scope of this project. Nonetheless, our meetings with growers clearly showed that they lack clear information about pesticide risks and that PPE is not used in a careful or systematic way. This suggests that pesticide information and training would do well to include explanations about exposure and risk in real-life situations as well as clear recommendations that would take into account the possibilities for prevention at source as well as the growers' way of thinking and habitual work methods (108, 230, 242, 243). The OHS message could also be more present in the advice dispensed by agro-industry advocates (206, 222).

It has been demonstrated that the mere availability of PPE in an operation promotes its use (110), and that the explicit engagement of company management and OHS supervisors, along with open support for certain safety measures, encourages employees to adopt safe behaviours (84, 244). Yet our visits to orchards revealed that owner-operators themselves do not use PPE systematically and do not feel they are in a position to impose it on their employees. This has been reported time and time again in small operations (80, 81). We did not, however, study the situation of employees with regard to OHS practices in orchards.

About a third of apple growers cited comfort and suitability for the task as factors influencing their decision to wear PPE or not. PPE is often viewed as restrictive, and the literature is almost unanimous in reporting that agricultural workers find it uncomfortable (72, 106, 245, 246). It is also seen as poorly suited to agricultural tasks (106, 247). Designing equipment that takes actual working conditions and the user's work activity into account should be regarded in R&D circles as an essential condition for encouraging targeted groups to adopt and wear PPE.

In connection with respiratory protection, filter/cartridges specifically approved for use with pesticides (131) used to be commercially available. They have been replaced by OV/P100, which is the technical name for the filter/cartridge currently recommended on pesticide labels. A new approach could consist in developing a cartridge with less inhalation resistance (thus more comfortable) and a shorter service life, which would greatly simplify PPE management (no storage or re-use). The use of activated-carbon fibre (ACF) as a medium for trapping vapours and particles (248-251) seems within reach of tangible applications. Balanay et al. (251) suggest using ACF to develop efficient respirators that would provide short-term protection for first responders and emergency staff. It should be noted that the need for a specific type of respiratory protection is not unique to agriculture. [27] As for skin protection, Canadian recommendations are based on conventional garments: long pants and a long-sleeved shirt are thus considered sufficient protection in many situations. This should not cause much discomfort compared to other recommendations that require wearing a coverall or a chemical-resistant coverall over one's clothing. The layers of clothing and the air between them create resistance to the transfer of vapour and heat (253). A recent study has shown that air permeability correlates with physiological strain (254). Given that air permeability is inversely proportional to protective performance (255), the choice of dermal protection is crucial, since overprotection can be as harmful to health as underprotection. Innovations that improve performance without compromising comfort include applying a finish on the outer surface to enhance repellency, or treating textiles with starch or cellulose to enhance sorption and thus reduce skin contact (245). However, the levels of protection and comfort reported for such materials and garments are still relatively undocumented, making it difficult to predict how well they will be accepted by farm workers.

Exploring this avenue was one of the aims in creating the International Consortium for the Development and Evaluation of PPE for Pesticide Operators and Re-entry Workers. Its members include not only PPE and textile researchers and experts but also people from France's agency

[27] Aware of the impact of not wearing respirators in health care—as discovered during the SARS crisis and the, followed by H5N1 in 2005 and H1N1 in 2009—researchers proposed specifications for an alternative respirator called B95, which, compared to the conventional N95, was better adapted to the specific needs of health-care workers (252).

for food, environmental and occupational health & safety (ANSES), the EPA and other regulatory bodies, and pesticide industry representatives. The consortium first aims to work together to develop ISO 27065-compliant protective garments and test them in different agricultural settings in order to evaluate their durability and their acceptability among agricultural workers from different geographical areas. The PPE research community in Québec could solicit the collaboration of the farm industry to evaluate the efficacy and physiological comfort of such garments in the field. The risk indices developed during this initiative, based on the skin as the main doorway into the body, could then act as a compass by prioritizing the molecules and formulas to be measured.

Our multidimensional portrait of pesticide and PPE use and their contexts and practices, along with our literature review, have led us to make a few suggestions for reducing pesticide risk that could be of benefit to the entire agricultural industry or to apple growers specifically. It is up to the institutions and stakeholders involved to discuss the relevance of these suggestions, how to adapt them, and what tangible actions to implement.

5. CONCLUSION

This project has addressed the chemical risks linked to pesticide use among Québec apple growers. We adopted a multidisciplinary approach based on several types of data and complementary perspectives. This approach enabled us to make an in-depth investigation of PPE, document the context and practices related to pesticide use among Québec apple growers, and categorize the main pesticides used in apple growing according to their level of risk. To put the role of personal protection into context, possible improvement through other prevention strategies—such as elimination at source and collective protection measures—was also considered.

The reduction—or even elimination or substitution—of pesticide use is largely the domain of institutions and the society they represent. But agricultural producers are on the front line, confronted daily with contradictory objectives: reduce pesticide use, protect the environment, produce perfect apples, be competitive, keep the business running, and preserve their own physical health.

The PMRA, a Canadian federal agency, authorizes the marketing of pesticides after a registration procedure and, in a way, filters out pesticides that present an unacceptable level of risk. In Québec, the SPQA, whose monitoring and concertation committee is coordinated by MAPAQ, works to reduce the risk of pesticide use in agriculture. It promotes an integrated approach that has existed in apple growing for about 15 years under the name "integrated fruit production" (IFP). Most growers say they agree with the principles of IFP. Their ability to participate in a collective effort and effect real change in their work methods is not in doubt. In terms of pesticide practices, this translates into choosing products that are less harmful to human health and the environment and applying them to specific areas at specific times. However, given the environmental and economic pressures they face, many growers adopt pesticides or practices that are less compatible with IFP. The current message on pesticide risk to their health is not having the expected results. Concerted action, supported by the intermediaries who have the most presence and credibility among growers, is required if health protection is to be incorporated into growers' operating strategies.

Collective measures for preventing pesticide risk exist in agriculture, but extensive corrections related to design, marketing and information could make them more effective. Cab tractors, owned by two out of three growers, are appreciated, but they seem incapable of optimally meeting the objective of reducing exposure under current conditions. The study revealed problems with cab airtightness and a real lack of information about choosing and managing air filters. This is not unique to Québec; an examination of international standards and scientific literature on the topic confirms that tractor cab certification can be problematic and that performance is not always up to par. Sprayer design does not systematically take into account practical aspects such as accessing the tank opening and handling the product as little as possible during filling. In addition to equipment design, our exploratory analysis of work methods identified a number of other factors that determine exposure during mixing-loading and application: in particular, the layout of the storage and loading area, packaging format and product formulation have a strong influence on work methods and exposure situations.

Personal protection is of critical importance in agriculture. Our investigation yielded an extensive review of the agricultural pesticide protective equipment available and its use by apple growers in Québec.

The PMRA determines what PPE is needed to keep exposure of agricultural producers at an acceptable level, and the corresponding directives are printed on the pesticide label. The required respiratory protective device must be certified, whereas dermal protection is simply described in generic terms. This could result in the selection of inappropriate protective garments that do not offer the level of protection that was assumed when the risk assessment was done. Given the key role of PPE in controlling pesticide exposure, it seems important to clearly designate which garments offer the characterized performance. ISO 27065, which is specific to protective clothing worn by pesticide applicators, could be put to good use since it classifies clothing into three protection levels, enabling users to choose the appropriate level according to the anticipated risk in a work situation. To complement the standardization data, more attention should be given to characterizing the performance of protective garments under real conditions, since this would give more teeth to the recommendations. The current PPE offering has shortcomings, but improvement is possible. Standardization would have to be harmonized with regulation in a consultative effort involving pesticide manufacturers, garment manufacturers and governments, for the protective garment industry—both local and international—is still embryonic.

Besides the shortcomings in the PPE offering, PPE use by agricultural producers raises many questions. Our study of apple growers was aimed at gaining a better understanding of their reality. Québec has more than 500 farms—most of them small—that grow apples. Pesticide registration conditions and the many exposure situations make PPE use unavoidable. Yet growers say they lack clear information about pesticide risk and the best ways to manage it. Our data show that only one quarter of growers consult the product label for PPE recommendations. In addition, they do not use PPE systematically—a finding reported in many other studies of agricultural operations. One avenue to be studied is how to more fully take into account PPE comfort and suitability under real working conditions. The literature contains frequent references to the ways in which risk perception and information about risk on the one hand, and temporal and financial constraints on the other, affect safety practices. The PMRA and the provinces, acting jointly, could require mandatory recurrent training on pesticide use, thus ensuring that growers are better informed about PPE.

This study sheds some light on the implementation of the health component of the 2013 SPQA and suggests some areas for improvement. For the rest, the OHS research community wishes to keep working with all stakeholders and institutional and scientific actors concerned about the sustainable development of Québec agriculture. In this, OHS research can find its basis in the SPQA, which outlines the challenges faced by Québec agriculture today.

BIBLIOGRAPHY

1. Ministère de l'Agriculture, des Pêcheries et de l'Alimentation du Québec. *Donner le goût du Québec*: *Livre vert pour une politique bioalimentaire*. 2011.

2. Ministère de l'Agriculture, des Pêcheries et de l'Alimentation du Québec. *Plan stratégique 2011-2014.* 2012.

3. Ministère de l'Agriculture, des Pêcheries et de l'Alimentation du Québec. *Profil de la main-d'oeuvre agricole au Québec 2007.* 2009.

4. Ministère de l'Agriculture, des Pêcheries et de l'Alimentation du Québec. *Monographie de l'industrie de la pomme au Québec*. 2015.

5. Van Drooge HL, Groeneveld CN, Schipper HJ. "Data on application frequency of pesticide for risk assessment purposes." *Annals of Occupational Hygiene*. 2001;45(1001):S95-S101.

6. Sauphanor B, Simon S, Boisneau C, Capowiez Y, Rieux R, Bouvier JC, et al. "Protection phytosanitaire et biodiversité en agriculture biologique. Le cas des vergers de pommiers." *Innovations agronomiques*. 2009;4:217-228.

7. Savoie L, De Oliveira D, Roy M. *Enquête sur les pratiques phytosanitaires des pomiculteurs québécois en 1990*. 1992.

8. Canada Food Inspection Agency. *National Chemical Residue Monitoring Program, 2012-2013 Report.* 2014.

9. Ministère de l'Agriculture, des Pêcheries et de l'Alimentation du Québec. *Synthèse - Résidus de pesticides dans les fruits et légumes frais vendus au Québec, 2007-2011*. 2012.

10. Agriculture and Agri-Food Canada. *A Snapshot of the Canadian Apple Industry, 2010*. 2012.

11. Dorff, E. *The changing face of the Canadian fruit and vegetable sector: 1941 to 2011*. Statistics Canada, 2014.

12. Statistics Canada. *Fruits and Vegetables Survey*. On-line: http://www5.statcan.gc.ca/cansim/a31?id=3407&actionMode=tableDefinitions&lang=eng&retrLang=eng

13. Food and Agriculture Organization. *Compilations spéciales*. 2015. http://faostat3.fao.org/download/Q/QC/E.

14. Ministère de l'Agriculture, des Pêcheries et de l'Alimentation du Québec, Institut de la statisque du Québec. *Profil sectoriel de l'industrie horticole au Québec*. 2014.

15. Statistics Canada. *2011 Census of Agriculture – Special tabulations.*

16. Institut de la statisque du Québec. 2015. On-line. http://www.stat.gouv.qc.ca/statistiques/agriculture/pomiculture-pommes/index.html.

17. Ministère de l'Agriculture, des Pêcheries et de l'Alimentation du Québec. *Monographie de l'industrie de la pomme au Québec*. 2011.

18. Fishel FM. *Pest management and pesticides: a historical perspective*. University of Florida, IFAS Extension. 2013;Pl219:1-5.

19. Aktar MW, Sengupta D, Chowdhury A. “Impact of pesticides use in agriculture: their benefits and hazards.” *Interdisciplinary Toxicology*. 2009;2(1):1-12.

20. Canada. *Pest Control Products Act*, S.C. 2002, c. 28.

21. Québec. *Pesticides Act*, Chapter P-9.3. 1997.

22. Health Canada. *Pest Control Products Sales Report for 2011*. 2012.

23. Ministère du Développement durable, de l'Environnement et de la Lutte contre les changements climatiques. *Bilan des ventes de pesticides au Québec, année 2011*. 2014.

24. Korol M. *Fertilizer and pesticide management in Canada*. Statistics Canada, 2004.

25. Statistics Canada. *Census of Agriculture - compilations spéciales*. 2006.

26. Statistics Canada. *Census of Agriculture - compilations spéciales*. 2001.

27. Beaulieu MS, MacDonald T, Benbrook C, Mineau P. *Pesticide Use and Pest Management Practices of Canadian Apple Growers 2005*. Statistics Canada, 2005.

28. Pest Management Regulatory Agency (PMRA). *Azinphos-methyl Re-evaluation Decision Document RRD2004-05*. 2004.

29. Pest Management Regulatory Agency (PMRA) *Proposed re-evaluation decision for Metiram, PRVD2014-03*. 2014.

30. Zuskin E, Mustajbegovic J, Schachter EN, Kern J, Pavicic D. “Respiratory function in vineyard and orchard workers.” *American Journal of Industrial Medicine*. 1997;31(2):250-255.

31. Hoppin JA, Umbach DM, London SJ, Alavanja MCR, Sandler DP. “Chemical predictors of wheeze among farmer pesticide applicators in the Agricultural Health Study.” *American Journal of Respiratory and Critical Care Medicine*. 2002;165(5):683-689.

32. Hoppin JA, Umbach DM, London SJ, Henneberger PK, Kullman GJ, Coble J, et al. “Pesticide use and adult-onset asthma among male farmers in the Agricultural Health Study.” *European Respiratory Journal*. 2009;34(6):1296-1303.

33. Ndlovu V, Dalvie MA, Jeebhay MF. “Pesticides and the airways: a review of the literature.” *Current Allergy and Clinical Immunology*. 2011;24(4):212-217.

34. Mothemela M. “Pesticides and dermatoses.” *Current Allergy and Clinical Immunology*. 2010;23(1):37-39.

35. Spiewak R. “Pesticides as a cause of occupational skin diseases in farmers.” *Annals of Agricultural and Environmental Medicine*. 2001;8(1):1-5.

36. Blanc-Lapierre A, Bouvier G, Garrigou A, Canal-Raffin M, Raherison C, Brochard P, et al. “Effets chroniques des pesticides sur le système nerveux central: état des connaissances épidémiologiques.” *Revue d'épidémiologie et de santé publique*. 2012;60(5):389-400.

37. Snijder CA, te Velde E, Roeleveld N, Burdorf A. “Occupational exposure to chemical substances and time to pregnancy: a systematic review.” *Human Reproduction Update*. 2012;18(3):284-300.

38. Mackenzie RS, McManus IC, Harrison V, Mason O. “Neurobehavioral problems following low-level exposure to organophosphate pesticides: a systematic and meta-analytic review.” *Critical Reviews in Toxicology*. 2013;43(1):21-44.

39. Baldi I, Bouvier G, Cordier S, Coumoul X, Elbaz A, Gamet-Payrastre L, et al. *Pesticides: Effets sur la Santé*. Paris, France, Les éditions Inserm, 2013.

40. Baldi I, Lebailly P, Jean S, Rougetet L, Dulaurent S, Marquet P. “Pesticide contamination of workers in vineyards in France.” *Journal of Exposure Science and Environmental Epidemiology*. 2006;16(2):115-124.

41. Hines CJ, Deddens JA, Coble J, Kamel F, Alavanja CR. “Determinants of captan air and dermal exposures among orchard pesticide applicators in the Agricultural Health Study.” *Annals of Occupational Hygiene*. 2011;55(6):620-633.

42. Firth HM, Rothstein DS, Herbison GP, McBride DI. “Chemical exposure among NZ farmers.” *International Journal of Environmental Health Research*. 2007;17(1):33-43.

43. De Cock J, Heederick D, Kromhout H, Boleij JSM, Hock F, Wegh H, et al. “Determinants of exposure to captan in fruit growing.” *American Industrial Hygiene Association Journal*. 1998;59(3):166-172.

44. Alavanja MCR, Sandler DP, McDonnell CJ, Lynch CF, Pennybacker M, Zahm SH, et al. “Characteristics of pesticide use in a pesticide applicator cohort: the Agricultural Health Study.” *Environmental Research*. 1999;80(2):172-179.

45. Lebailly P, Bouchart V, Baldi I, Lecluse Y, Heutte N, Gislard A, et al. “Exposure to pesticides in open-field farming in France.” *Annals of Occupational Hygiene*. 2009;53(1):69-81.

46. Machera K, Goumenou M, Kapetanakis E, Kalamarakis A, Glass CR. “Determination of potential dermal and inhalation operator exposure to malathion in greenhouses with the whole body dosimetry method.” *Annals of Occupational Hygiene*. 2003;47(1):61-70.

47. Laughlin J. “Protective clothing for professional pesticide users.” *Proceedings of the Second International Conference on Urban Pests*. 1996: 45-56.

48. Protano C, Guidotti M, Vitali M. “Performance of different work clothing types for reducing skin exposure to pesticides during open field treatment.” *Bulletin of Environmental Contamination and Toxicology*. 2009;83(1):115-119.

49. Work Safe BC. *Standard practices for pesticide applicators*. 2010.

50. Belleville D, Boudreault D, Carrier G. *Analyse des risques à la santé associés à l'exposition aux organophosphorés utilisés dans les vergers de la Montérégie*. Régie régionale de la santé et des services sociaux Montérégie, 1997.

51. Zhao MA, Yu A, Zhu YZ, Kim JH. “Potential dermal exposure to flonicamid and risk assessment of applicators during treatment in apple orchards.” *Journal of Occupational and Environmental Hygiene*. 2015;12(8):D147-D152.

52. Moon JK, Park S, Kim E, Lee H, Kim JH. “Risk assessment of the exposure of insecticide operators to fenvalerate during treatment in apple orchards.” *Journal of Agriculture and Food Chemistry*. 2013;61(2):307-311.

53. Choi H, Moon JK, Kim JH. “Assessment of the exposure of workers to the insecticide imidacloprid during application on various field crops by a hand-held power sprayer.” *Journal of Agriculture and Food Chemistry*. 2013;61(45):10642-10648.

54. Kim E, Moon J-K, Lee H, Kim S, Hwang Y-J, Kim B-J, et al. “Exposure and risk assessment of operators to insecticide acetamiprid during treatment on apple orchard.” *Korean Journal of Horticultural Science and Technology*. 2013;31(2):239-245.

55. Kim E, Moon J-K, Choi H, Hong S-M, Lee D-H, Lee H, et al. “Exposure and risk assessment of insecticide methomyl for applicator during treatment on apple orchard.” *Journal of the Korean Society for Applied Biological Chemistry*. 2012;55(1):95-100.

56. Berthet A, Heredia-Ortiz R, Vernez D, Danuser B, Bouchard M. “A detailed urinary excretion time course study of captan and folpet biomarkers in workers for the estimation of dose, main route-of-entry and most appropriate sampling and analysis strategies.” *Annals of Occupational Hygiene*. 2012;56(7):815-828.

57. Hines CJ, Deddens JA, Coble J, Alavanja MCR. “Fungicide application practices and personal protective equipment use among orchard farmers in the Agricultural Health Study.” *Journal of Agricultural Safety and Health*. 2007;13(2):205-223.

58. Fenske RA, Curl CL, Kissel JC. “The effect of the 14-day agricultural restricted entry interval on azinphosmethyl exposures in a group of apple thinners in Washington state.” *Regulatory Toxicology and Pharmacology*. 2003;38(1):91-97.

59. Fenske RA, Simcox NJ, Camp JE, Hines CJ. “Comparison of three methods for assessment of hand exposure to azinphos-methyl (Guthion) during apple thinning.” *Applied Occupational and Environmental Hygiene*. 1999;14(9):618-623.

60. Simcox NJ, Camp J, Kalman D, Stebbins A, Bellamy G, Lee IC, et al. “Farmworker exposure to organophosphorus pesticide residues during apple thinning in central Washington State.” *American Industrial Hygiene Association Journal*. 1999;60(6):752-761.

61. De Cock J, Heederik D, Kromhout H, Boleij JS, Hoek F, Wegh H, et al. “Exposure to captan in fruit growing.” *American Industrial Hygiene Association Journal*. 1998;59(3):158-165.

62. Karr C, Demers P, Costa L, G., Daniell WE, Barnhart S, Miller M, et al. “Organophosphate pesticide exposure in a group of Washington State orchard applicators.” *Environmental Research*. 1992;59(1):229-237.

63. McJilton CE, Berckman GE, Deer HM. “Captan exposure in apple orchards.” *American Industrial Hygiene Association Journal*. 1983;44(3):209-210.

64. Hansen JD, Schneider BA, Olive BM, Bates JJ. “Personnel safety and foliage residue in an orchard spray program using azinphosmethyl and captan.” *Archives of Environmental Contamination and Toxicology*. 1978;7(1):63-71.

65. Wolfe HR, Armstrong JF, Staiff DC, Comer SW, Durham WF. “Exposure of apple thinners to parathion residues.” *Archives of Environmental Contamination and Toxicology*. 1975;3(3):257-267.

66. Garrigou A, Baldi I, Dubuc P. “Apports de l'ergotoxicologie à l'évaluation de l'efficacité réelle des ÉPI devant protéger du risque phytosanitaire: de l'analyse de la contamination au processus collectif d'alerte.” *Pistes*. 2008;10(1):17.

67. Garrigou A, Mohammed-Brahim B, Carballeda G, Pasquereau P, Thibault J-F, Teiger C. “L'usage des différentes formes de mesures en ergonomie et en ergotoxicologie: mesurer pour connaître ou mesurer pour transformer?” 48e Congrès de la Société d'ergonomie de langue française (SELF). Paris, 2013:1-9.

68. Garrigou A. *Le développement de l'ergotoxicologie: une contribution de l'ergonomie à la santé au travail* [qualification to supervise research]. Université de Bordeaux 2. 2010.

69. Jouzel J-N, Dedieu F. “Rendre visible et laisser dans l'ombre.” *Revue française de science politique*. 2013;63(1):29-49.

70. Palis F, Flor RJ, Warburton H, Hossain M. “Our farmers at risk: behaviour and belief system in pesticide safety.” *Journal of Public Health*. 2006;28(1):43-48.

71. Union régionale des caisses d'assurance maladie de Bretagne (URCAM), Direction régionale des affaires sanitaires et sociales de Bretagne (DRASS). *Perceptions des risques sanitaires encourus par les utilisateurs de pesticides*. 2003.

72. Nicol AM, Kennedy SM. “Assessment of pesticide exposure control practices among men and women on fruit-growing farms in British Columbia.” *Journal of Occupational and Environmental Hygiene.* 2008;5(4):217-226.

73. Hubbell BJ, Carlson GA. “Effects of insecticide attributes on within-season insecticide product and rate choices: the case of U.S. apple growers.” *American Journal of Agricultural Economics.* 1998;80(2):382-396.

74. Alavanja MCR, Sandler DP, McMaster SB, Zahm SH, McDonnell CJ, Lynch CF, et al. “The Agricultural Health Study.” *Environmental Health Perspectives*. 1996;104(4):362-369.

75. Baldi I, Lebailly P, Rondeau V, Bouchart V, Blanc-Lapierre A, Bouvier G, et al. “Levels and determinants of pesticide exposure in operators involved in treatment of vineyards: results of the PESTEXPO study.” *Journal of Exposure Science and Environmental Epidemiology*. 2012;22(6):593-600.

76. Baker BA, Alexander BH, Mandel JS, Acquavella JF, Honeycutt R, Chapman P. “Farm family exposure study: methods and recruitment practices for a biomonitoring study of pesticide exposure.” *Journal of Exposure Analysis and Environmental Epidemiology*. 2005;15(6):491-499.

77. Ministère de l'Agriculture, des Pêcheries et de l'Alimentation du Québec. *Fiche d'enregistrement des producteurs - compilations spéciales*. 2010.

78. Champoux D, Brun J-P. “Dispositions, capacités et pratiques de SST dans les petites entreprises: opinions de patrons, d'employés et d'intervenants en SST au Québec.” *Pistes*. 2010;12(2):18.

79. MacEachen E, Kosny A, Scott-Dixon K, Facey M, Breslin FC, Kyle N. “Workplace health understandings and processes in small businesses: a systematic review of the qualitative literature.” *Journal of Occupational Rehabilitation* 2010;20(2):180-198.

80. MacEachen E, Breslin C, Kyle N, Irvin E, Kosny A, Bigelow P. *Effectiveness and implementation of health and safety programs in small enterprises: a systematic review of quantitative and qualitative literature*. Institute for Work and Health, 2008.

81. Walters D. *Health and safety in small enterprises. European strategies for managing improvement*. Peter Lang International Academic Publishers, Brussels, 2001.

82. Curwin B, Sanderson W, Reynolds S, Hein M, Alavanja M. “Pesticide use and practices in an Iowa farm. Family pesticide exposure study.” *Journal of Agricultural Safety and Health*. 2002;8(4):423-433.

83. Kearney GD, Xu X, Balanay JA, Allen DL, Rafferty AP. “Assessment of personal protective equipment use among farmers in eastern North Carolina: a cross-sectional study.” *Journal of Agromedicine*. 2015;20(1):43-54.

84. Perry MJ, Marbella A, Layde PM. “Association of pesticide safety beliefs and intentions with behaviors among farm pesticide applicators.” *American Journal of Health Promotion.* 1999;14(1):18-21.

85. Stocks SJ, Turner S, Carder M, Hussey L, McNamee R, Agius RM. “Medically reported work-related ill-health in the UK agricultural sector.” *Occupational Medicine*. 2010;60(5):340-347.

86. Bekal S, Burigusa G, Dion R, Gervais C, Richardson M, Samuel O. *Une politique bioalimentaire pour un Québec en santé.* Brief submitted for general consultations on the *Livre vert pour une politique bioalimentaire*. INSPQ. 2011.

87. Commission de la santé et de la sécurité du travail (CSST). *Saviez-vous que... Travaillez sur une ferme c'est dangereux ?* 2011.

88. Reigart JR, Roberts JR. *Recognition and Management of Pesticide Poisonings*. Washington, D.C., U.S. Environmental Protection Agency. 1999.

89. Ministère de l'Agriculture, des Pêcheries et de l'Alimentation du Québec. *Stratégie phytosanitaire québécoise en agriculture 2011-2021*. 2011.

90. Kovach J, Petzoldt C, Degni J, Tette J. “A method to measure the environmental impact of pesticides.” *New York's Food and Life Sciences Bulletin*. 1992;139:2-8.

91. Chouinard G, Dieni A. *Production fruitière intégrée 2015*. 2015. https://www.agrireseau.net/documents/Document_89426.pdf.

92. Samuel O, Dion S, St-Laurent L, April M-H. *Indicateur de risque des pesticides du Québec - IRPeQ - Santé et environnement*, Ministère de l'Agriculture, des Pêcheries et de l’Alimentation du Québec, Ministère du Développement durable, de l'Environnement et de la Lutte contre les changements climatiques, Institut national de santé publique du Québec. 2007.

93. Chouinard G, Kovach J, Bellerose S, Cormier D, Pelletier F. “Pesticide risk indicators and apple production systems in northeastern North America: a case study” *Proceedings of the 50th Annual Conference of IFTA*. Tasmania, Australia. 2007:15-19.

94. Samuel O, St-Laurent L, Dumas P, Langlois E, Gingras G. *Pesticides en milieu serricole: caractérisation de l'exposition des travailleurs et évaluation des délais de réentrée.* Research report R-315, IRSST, 2002. http://www.irsst.qc.ca/media/documents/pubirsst/r-315.pdf.

95. Government of Québec. Regulation respecting permits and certificates for the sale and use of pesticides, chapter P-9.3 r-2. 1997.

96. Vanoosthuyse F, Philion V, Chouinard G, Cormier D, Tardif J. *Entrepôt à pesticides au verger de l'IRDA*. 2011.

97. Mulqueen P. "Recent advances in agrochemical formulation." *Advances in Colloid and Interface Science*. 2003;106(1-3):83-107.

98. Landers A, Helms M. "Solutions for safer spraying: reducing risk of pesticide exposure through use of engineering controls." *Lake Plains Vegetable News*, February, Letter 2, Vol. XIII, Albion NY, Cornell Cooperative Extension. 2004:16-18.

99. Ministère de l'Agriculture, des Pêcheries et de l'Alimentation du Québec. *Indicateur de la gestion intégrée des ennemis des cultures-résultats 2012*. 2014.

100. Coffman CW, Stone JF, Slocum AC, Landers AJ, Schwab CV, Olsen LG, et al. "Use of engineering controls and personal protective equipment by certified pesticide applicators." *Journal of Agricultural Safety and Health*. 2009;15(4):311-326.

101. US Environmental Protection Agency (EPA). *Part 170—Worker Protection Standard*. 2007.

102. American National Standards Institute (ANSI), American Society of Agricultural and Biological Engineers (ASABE). ANSI/ASABE S613-2.1 - *Tractors and self-propelled machinery for agriculture - Air quality systems for cabs - Part2: Cab & HVAC design*. 2013.

103. European Committee for Standardization (CEN). EN 15695 1- *Agricultural tractors and self-propelled sprayers - Protection of the operator (driver) against hazardous substances- Part 1: Cab classification, requirement and test procedures*. 2009.

104. Job RW. ASABE AETC PM23/2/1 *Environmental cabs*. ASABE 2013.

105. Andrews MC. *Advisory on maintenance of enclosed cabs*. Sacramento, California, Department of Pesticide Regulation, California Environmental Protection Agency, 2002.

106. Carpenter WS, Lee BC, Gunderson PD, Stueland DT. "Assessment of personal protective equipment use among Midwestern farmers." *American Journal of Industrial Medicine*. 2002;42(3):236-247.

107. Perry MJ, Marbella A. "Compliance with required pesticide-specific protective equipment use." *American Journal of Industrial Medicine*. 2002;41(1):70-73.

108. MacFarlane E, Chapman A, Benke G, Meaklim J, Sim M, McNeil J. "Training and other predictors of personal protective equipment use in Australian grain farmers using pesticides." *Occupational and Environmental Medicine*. 2008;65(2):141-146.

109. Isin S, Yildirim I. "Fruit-growers' perceptions on the harmful effects of pesticides and their reflection on practices: the case of Kemalpasa, Turkey." *Crop Protection*. 2007;26(7):917-922.

110. Strong LL, Thompson B, Koepsell TD, Meischke H. “Factors associated with pesticide safety practices in farmworkers.” *American Journal of Industrial Medicine*. 2008;51(1):69-81.

111. Arbuckle TE, Cole DC, Ritter L, Ripley BD. “Biomonitoring of herbicides in Ontario farm applicators.” *Scandinavian Journal of Work Environment and Health*. 2005;31(SUPPL. 1):90-97.

112. Garrigou A, Baldi I, Le Frious P, Anselm R, Vallier M. “Ergonomics contribution to chemical risks prevention: an ergotoxicological investigation of the effectiveness of coverall against plant pest risk in viticulture.” *Applied Ergonomics*. 2011;42(2):321-330.

113. Agence française de sécurité sanitaire de l'environnement et du travail (AFSSET). *Efficacité de protection chimique des combinaisons de protection chimique - Constat de l'efficacité de protection chimique des combinaisons de type 3 et 4 au regard de la perméation*. 2010.

114. Desrosiers R, Bourque J-F, Brochu Y, Duchesne R-M, Gingras B, Laurin Y, Letendre M. *Pesticides et agriculture : bons sens, bonnes pratiques*. 2nd edition, Les Publications du Québec, Sainte-Foy, Québec. 2003.

115. Labrecque S. *Pesticides en agriculture*. CSST, UPA, Ministère de la Santé et des Services Sociaux, 2002.

116. Agriculture and Agri-Food Canada. *Profil de la culture de la pomme au Canada*, 2009.

117. Cole ST. “Comparing mail and web-based survey distribution methods: results of surveys to leisure travel retailers.” *Journal of Travel Research*. 2005;43:422-430.

118. Ekman A, Dickman PW, Klint A, Weiderpass E, Litton JE. “Feasibility of using web-based questionnaires in large population-based epidemiological studies.” *European Journal of Epidemiology*. 2006;21(2):103-111.

119. Vermeulen R, Stewart P, Kromhout H. “Dermal exposure assessment in occupational epidemiologic research.” *Scandinavian Journal of Work Environment and Health*. 2002;28(6):371-385.

120. Wilschut A, Ten Berge WF, Robinson PJ, McKone TE. “Estimating skin permeation: the validation of five mathematical skin permeation models.” *Chemosphere*. 1995;30(7):1275-1296.

121. Canadian Centre for Occupational Health and Safety. 2011. http://www.ccohs.ca/oshanswers/prevention/ppe/designin.html.

122. Québec. *Act respecting occupational health and safety*, ch S-2.1. 1979.

123. Québec. *Regulation respecting occupational health and safety*, ch S-2.1 r-13. 2015.

124. United States. *Occupational Safety and Health Standards*, Part 1910. 2007.

125. European Union. Council Directive (89/656/EEC) of 30 November 1989 on the minimum health and safety requirements for the use by workers of personal protective equipment at the workplace. 1989.

126. Canadian Standards Association (CSA). *CAN/CSA Z94.3-07 - Eye and Face Protectors.* 2007.

127. American National Standards Institute (ANSI). *ANSI Z87.1-2003 - Practice for occupational and educational eye and face protection*. 2009.

128. European Union. Council Directive (89/686/EEC) of 21 December 1989 on the approximation of the laws of the Member States relating to personal protective equipment 1989.

129. Lara J, Vennes M. *Guide des appareils de protection respiratoire utilisés au Québec*. 2002.

130. Canadian Standards Association (CSA). *CSA Z94.4-93 - Selection, Use, and Care of Respirators.* Occupational Health and Safety Division. 1993.

131. United States. *Approval of Respiratory Protective Devices*, CFR 42-Part 84. 1995.

132. Québec. *Pesticides Management Code* , ch P-9.3 r-1. 2014.

133. Québec. *Environment Quality Act*, ch Q-2. 2011.

134. Health Canada. *Evaluation of the Pesticide Program 2010-2011 to 2013-2014*. 2015. http://www.hc-sc.gc.ca/ahc-asc/alt_formats/pdf/performance/eval/pesticide-pesticides-2010-2014-eng.pdf

135. National Task Force on Pesticide Education, Training and Certification. *Basic Knowledge Requirements for Pesticide Education in Canada: Applicator Core and Aerial Module*. 2003.

136. Pesticide Education, Training and Certification Working Group (WGPETC). *Standard for Pesticide Education, Training and Certification in Canada*. 2005.

137. United States. *Federal Insecticide, Fungicide and Rodenticide Act*. 2012.

138. European Union. Regulation (Ec) No 1107/2009 of the European Parliament and of the Council of 21 October 2009 concerning the placing of plant protection products on the market and repealing Council Directives 79/117/EEC and 91/414/EEC. 2009.

139. Pest Management Regulatory Agency (PMRA). *A Decision Framework for Risk Assessment and Risk Management in the Pest Management Regulatory Agency*. 2000.

140. Pest Management Regulatory Agency (PMRA). *Canadian PHED Tables, Final Version*. 2002.

141. Gerritsen-Ebben RMG, Brouwer DH, Van Hemmen JJ. *Effective Personal Protective Equipment - Default setting of PPE for registration purposes of agrochemical and biocidal pesticides.* Report TNO V7333, 2007.

142. Black C, Shaw A, Harned C. *A dialog: PPE for dermal protection. The pesticide stewardship alliance.* Savannah, GA.2015.

143. Dethier L, Durand N, Ferland C. *Use of Pesticides in Agriculture*. SOFAD, 2012.

144. Mayer A, Garbowsky C. *Les vêtements de protection : Choix et utilisation*. INRS report ED 995, 2007.

145. American National Standards Institute (ANSI), International safety equipment association (ISEA). *ANSI/ISEA 103-American National Standard for Classification and Performance Requirements for Chemical Protective Clothing*. 2010.

146. International Organization for Standardization (ISO). *ISO 16602 Protective clothing for protection against chemicals – Classification, labelling and performance requirements*. 2007.

147. Association française de normalisation (AFNOR). *NF EN 14325 - Protective clothing against chemicals - Test methods and performance classification of chemical protective clothing materials, seams, joins and assemblages*. 2004.

148. Association française de normalisation (AFNOR). *FD S 74-600 - Personal protective equipment - Plant health treatments - Recommendations for the choice, use, maintenance, storage and elimination of skin protection equipment*. 2006.

149. International Organization for Standardization (ISO). *ISO 17491-4 - Protective clothing — Test methods for clothing providing protection against chemicals. Part 4: Determination of resistance to penetration by a spray of liquid (spray test)*. 2008.

150. International Organization for Standardization (ISO). *ISO 17491-3 - Protective clothing — Test methods for clothing providing protection against chemicals. Part 3: Determination of resistance to penetration by a jet of liquid (jet test).* 2008.

151. Lee S, Obendorf SK. "A statistical model to predict pesticide penetration through nonwoven chemical protective fabrics." *Textile Research Journal*. 2001;71(11):1000-1009.

152. Jain R, Raheel M. "Barrier efficacy of woven and nonwoven fabrics used for protective clothing: predictive models." *Bulletin of Environmental Contamination and Toxicology*. 2003;71(3):437-446.

153. International Organization for Standardization (ISO). ISO 6529 - *Protective clothing — Protection against chemicals — Determination of resistance of protective clothing materials to permeation by liquids and gases*. 2001.

154. International Organization for Standardization (ISO). ISO 6530 - *Protective clothing — Protection against liquid chemicals — Test method for resistance of materials to penetration by liquids*. 2005.

155. German Institute for Standardization (DIN). DIN32781- *Protective clothing - Protective suits against pesticides*. 2010.

156. American Society for Testing and Materials (ASTM international). ASTM F2669-12 - *Standard performance specification for protective clothing worn by operators applying pesticides*. 2012.

157. International Organization for Standardization (ISO). ISO 27065:2011 - *Protective clothing -- Performance requirements for protective clothing worn by operators applying liquid pesticides.* 2011.

158. Association française de normalisation (AFNOR). *NF EN 14786 - Protective clothing - Determination of resistance to penetration by sprayed liquid chemicals, emulsions and dispersions - Atomizer test*. 2006.

159. International Organisation for Standardization (ISO). *ISO 22608:2004 – Protective clothing – Protection against liquid chemicals – Measurement of repellency, retention, and penetration of liquid pesticide formulations through protective clothing materials.* 2004.

160. Shaw A, Schiffelbein P. “Protective clothing for pesticide operators: Part 1 - selection of a reference test chemical for penetration testing.” *International Journal of Occupational Safety and Ergonomics*. 2015:1-13.

161. Machera K, Tsakirakis A. “Dermal exposure of pesticide applicators as a measure of coverall performance under field conditions.” *Annals of Occupational Hygiene*. 2009;53(6):573-584.

162. Tsakirakis AN, Kasiotis KM, Charistou AN, Arapaki N, Tsatsakis A, Tsakalof A, et al. “Dermal and inhalation exposure of operators during fungicide application in vineyards. Evaluation of coverall performance.” *Science of the Total Environment.* 2014;470-471:282-289.

163. Nigg HN, Stamper JH, Easter E, DeJonge JO. “Protection afforded greenhouse pesticide applicators by coveralls: a field test.” *Archives of Environmental Contamination and Toxicology*. 1993;25(4):529-533.

164. Fenske RA. “State-of-the-art measurement of agricultural pesticide exposures.” *Scandinavian Journal of Work Environment and Health*. 2005;31(1):67-73.

165. Organisation for Economic Co-operation and Development (OCDE). *Guidance document for the conduct of studies of occupational exposure to pesticides during agricultural application.* 1997.

166. Tsakirakis AN, Kasiotis KM, Arapaki N, Charistou A, Tsatsakis A, Glass CR, et al. “Determination of operator exposure levels to insecticide during bait applications in olive trees: study of coverall performance and duration of application.” *International Journal of Hygiene and Environmental Health*. 2011;214(1):71-78.

167. Lesmes-Fabian C, Garcia-Santos G, Leuenberger F, Nuyttens D, Binder CR. “Dermal exposure assessment of pesticide use: the case of sprayers in potato farms in the Colombian highlands.” *Science of the Total Environment*. 2012;430:202-208.

168. Fenske RA. “Comparative assessment of protective clothing performance by measurement of dermal exposure during pesticide applications.” *Applied Industrial Hygiene*. 1988;3(7):207-213.

169. Krieger RI, Dinoff TM, Korpalski S, Peterson J. “Protectiveness of Kleengard LP and Tyvek-Saranex 23-P during mixing/loading and airblast application in treefruits.” *Bulletin of Environmental Contamination and Toxicology*. 1998;61(4):455-461.

170. Vitali M, Protano C, Del Monte A, Ensabella F, Guidotti M. “Operative modalities and exposure to pesticides during open field treatments among a group of agricultural subcontractors.” *Archives of Environmental Contamination and Toxicology*. 2009;57(1):193-202.

171. Norton MJT, Drake CR, Young RW. “Protectiveness of Gore-Tex and PVC spray suits in orchard pesticide spraying.” *Journal of Environmental Science and Health*. 1988;B23(6):623-641.

172. Espanhol-Soares M, Nociti LAS, Goncalves Machado-Neto J. “Procedures to evaluate the efficiency of protective clothing worn by operators applying pesticide.” *Annals of Occupational Hygiene*. 2013;57(8):1041-1053.

173. Rubino FM, Mandic-Rajcevic S, Ariano E, Alegakis A, Bogni M, Brambilla G, et al. “Farmers' exposure to herbicides in North Italy: assessment under real-life conditions in small-size rice and corn farms.” *Toxicology Letters*. 2012;210(2):189-197.

174. Aprea C, Terenzoni B, De Angelis V, Sciarra G, Lunghini L, Borzacchi G, et al. “Evaluation of skin and respiratory doses and urinary excretion of alkylphosphates in workers exposed to dimethoate during treatment of olive trees.” *Archives of Environmental Contamination and Toxicology*. 2004;48(1):127-134.

175. Chester G, Adam AV, Inkmann Koch A, Litchfield MH, Tiunman CP. “Field evaluation of protective equipment for pesticide operators in a tropical climate.” *Medicina del lavoro*. 1990;81(6):480-488.

176. Fenske RA, Blacker AM, Hamburger SJ, Simon GS. “Worker exposure and protective clothing performance during manual seed treatment with Lindane.” *Archives of Environmental Contamination and Toxicology*. 1990;19(2):190-196.

177. Nigg HN, Stamper JH, Easter EP, Mahon WD, DeJonge JO. “Protection afforded citrus pesticide applicators by coveralls.” *Archives of Environmental Contamination and Toxicology*. 1990;19(5):635-639.

178. Stamper JH, Nigg HN, Mahon WD, Nielsen AP, Royer MD. “Pesticide exposure to greenhouse handgunners.” *Archives of Environmental Contamination and Toxicology*. 1989;18(4):515-529.

179. Nigg HN, Stamper JH, Queen RM. “Dicofol exposure to Florida citrus applicators: effects of protective clothing.” *Archives of Environmental Contamination and Toxicology*. 1986;15(1):121-134.

180. Putnam AR, Willis M, D., Binning LK, Boldt PF. “Exposure of pesticide applicators to nitrofen: influence of formulation, handling systems, and protective garments.” *Journal of Agriculture and Food Chemistry*. 1983;31(3):654-660.

181. Davies JE, Freed VH, Enos HF, Duncan RC, Barquet A, Morgade C, et al. “Reduction of pesticide exposure with protective clothing for applicators and mixers.” *Journal of Occupational Medicine*. 1982;24(6):464-468.

182. Obendorf SK, Csiszár E, Maneefuangfoo D, Borsa J. “Kinetic transport of pesticide from contaminated fabric through a model skin.” *Archives of Environmental Contamination and Toxicology*. 2003;45(2):283-288.

183. Zhang X, Raheel M. “Statistical model for predicting pesticide penetration in woven fabrics used for chemical protective clothing.” *Bulletin of Environmental Contamination and Toxicology*. 2003;70(4):652-659.

184. Lee S, Obendorf SK. “Statistical model of pesticide penetration through woven work clothing fabrics.” *Archives of Environmental Contamination and Toxicology*. 2004;46(1):1-9.

185. Hobbs NE, Oakland BG, Hurwitz MD. *Effects of barrier finishes on aerosol spray penetration and comfort of woven and disposable nonwoven fabrics for protective clothing. Performance of protective clothing.* 1986;ASTM STP 900:151-161.

186. Leonas KK, DeJonge JO. *Effect of functional finish barriers on pesticide penetration. Performance of protective clothing*. 1986;ASTM STP 900:177-186.

187. Shaw A, Lin Y. “Effects of laundering upon the removal of atrazine and metolachlor from cotton, cotton/polyester, and polyester fabrics treated with fluorochemical finishes.” *Bulletin of Environmental Contamination and Toxicology*. 2001;66(3):319-325.

188. Oliveira ML, Machado-Neto JG. “Permeability of two types of cotton fabric used in personal protective clothing to the insecticide methamidophos.” *Bulletin of Environmental Contamination and Toxicology.* 2005;75(6):1156-1162.

189. Everris NA Inc. Truban® Fungicide 2012.

http://www.plantproducts.com/ca/images/Truban_30WP_label_2013-05-13.pdf

190. Staiff DC, Davis JE, Stevens ER. “Evaluation of various clothing materials for protection and worker acceptability during application of pesticides.” *Archives of Environmental Contamination and Toxicology*. 1982;11(4):391-398.

191. Leonas KK. “Effect of pesticide formulation on transmission: a comparison of three formulations.” *Bulletin of Environmental Contamination and Toxicology*. 1991;46(5):697-704.

192. Laughlin JM, Easley CB, Gold RE, Hill RM. “Fabric parameters and pesticide characteristics that impact on dermal exposure of applicators.” *Performance of Protective Clothing*. 1986;ASTM STP 900:136-150.

193. Schwope AD, Goydan R, Ehntholt D, Frank U, Nielsen A. “Permeation resistance of glove materials to agricultural pesticides.” *American Industrial Hygiene Association Journal*. 1992;53(6):352-361.

194. Roff M. “The short-term protective effects of 'non-PPE' gloves used by greenhouse workers.” *Annals of Occupational Hygiene*. 2015;59(8):1044-1057.

195. Cohen HJ, Liverman CT. *Certifying Personal Protective Technologies: Improving Worker Safety*.” Washington, D.C., The National Academies Press, 2011.

196. Gao B, Tao C, Ye J, Ning J, Mei X, Jiang Z, et al. “Measurement of operator exposure to chlorpyrifos.” *Pest Management Science*. 2013;70(4):636-641.

197. Miguelino ES. “A meta-analytic review of the effectiveness of single-layer clothing in preventing exposure from pesticide handling.” *Journal of Agromedicine*. 2014;19(4):373-383.

198. Raheel M. “Pesticide transmission in fabrics: effect of perspiration.” *Bulletin of Environmental Contamination and Toxicology*. 1991;46(6):837-844.

199. Brouwer DH, Marquart H, Van Hemmen JJ. “Proposal for an approach with default values for the protection offered by PPE, under European new or existing substance regulations.” *Annals of Occupational Hygiene*. 2001;45(7):543-553.

200. Bourdieu P. *Raisons pratiques. Sur la théorie de l'action*. Édition du Seuil, Paris, 1994.

201. Crozier M, Friedberg E. *L'acteur et le système*. Édition du Seuil, Paris, 1977.

202. Giddens A. *The Constitution of Society. Outline of the theory of structuration*. University of California Press, Berkeley and Los Angeles, 1984.

203. Lambert M, Grimbuhler S. *Rôle de la perception de la sécurité dans la performance sécuritaire: étude de cas des viticulteurs de la région Bordelaise*. Société d'ergonomie de langue française (SELF); 2015; Paris.

204. Davillerd C. *Prévention et port des équipements de protection individuelle. 4. L'utilisation de produits phytosanitaires*. Rapport INRS NS 213, 2001.

205. Fiske T, Earle-Richardson E. “Farm safety research to practice: the long road from the laboratory to the farm.” *Journal of Agromedicine*. 2013;18(1):11-17.

206. Olsen K, Harris L-A, Laird I, Legg S, Perry M, Hasle P. “Differential intervention strategies to improve the management of hazardous chemicals in small enterprises.” *Policy and Practice in Health and Safety*. 2010;8(2):57-76.

207. Vaughan E. “Chronic exposure to an environmental hazard: risk perceptions and self-protective behavior.” *Health Psychology*. 1993;12(1):74-85.

208. Arcury TA, Quandt SA, Russell GB. “Pesticide safety among farmworkers: perceived risk and perceived control as factors reflecting environmental justice.” *Environmental Health Perspectives*. 2002;110(2):233-240.

209. Perry MJ, Marbella AMS, Layde PM. “Association of pesticide safety knowledge with beliefs and intentions among farm pesticide applicators.” *Journal of Occupational and Environmental Hygiene*. 2000;42(2):187-193.

210. Avory G, Coggon D. “Determinants of safe behaviour in farmers when working with pesticides.” *Occupational Medicine*. 1994;44(5):236-238.

211. Dellavalle CT, Hoppin JA, Hines CJ, Andreotti G, Alavanja MC. “Risk-accepting personality and personal protective equipment use within the Agricultural Health Study.” *Journal of Agromedicine*. 2012;17(3):264-276.

212. Matthews GA. “Attitudes and behaviours regarding use of crop protection products—a survey of more than 8500 smallholders in 26 countries.” *Crop Protection*. 2008;27(3-5):834-846.

213. Schenker MB, Orenstein MR, Samuels SJ. “Use of protective equipment among California farmers.” *American Journal of Industrial Medicine*. 2002;42(5):455-464.

214. Spoljar P. “Modernisation de l'agriculture et santé mentale: les contradictions au travail.” *Pistes*. 2015;17(1):26.

215. Salaris C. “Agriculteurs victimes des pesticides: une nouvelle mobilisation collective en santé au travail.” *La nouvelle revue du travail.* 2014;4.

216. Chouinard G, Zoghlami S, Pelletier F. *Enquête sur l'adoption des pratiques de production fruitière intégrée (PFI) dans les différentes régions pomicoles du Québec et recommandations pour son implantation*. IRDA, 2008.

217. Butault J, Dedryver CA, Gary C, Guichard L, Jacquet F, Meynard JM, et al. *Quelles voies pour réduire l'usage des pesticides?* 2010.

218. VanTassell LW, Ferrell MA, Yang B, Legg DE, Lloyd, JE. “Pesticide practices and perceptions of Wyoming farmers and ranchers.” *Journal of Soil and Water Conservation.* 1999;54(1):410-414..

219. Cinq-Mars J. Rapport du Vérificateur général du Québec à l’Assemblée nationale pour l’année 2016-2017, Rapport du commissaire au développement durable. (2016)

220. Brunier S. “Le travail des conseillers agricoles entre prescription technique et mobilisation politique”(1950-1990). *Sociologie du travail*. 2015;57(1):104-125.

221. Baldi I, Lebailly P, Bouvier G, Rondeau V, Kientz-Bouchart V, Canal-Raffin M, Garrigou A. “Levels and determinants of pesticide exposure in re-entry workers in vineyards: results of the PESTEXPO study.” *Environmental Research.* 2014;132:360-369.

222. Schenk L, Wester BA. “Covert chemicals, tangible trust: risk management of chemicals in the workplace.” *Policy and Practice in Health and Safety.* 2014:12(1):91-106

223. Tucker M, Napier TL. “Perceptions of risk associated with use of farm chemicals: implications for conservation initiatives.” *Environmental Management*. 1998;22(4):575-587.

224. Aggarwal M, Battalora M, Fisher P, Huser A, Parr-Dobrzanski R, Soufi M, et al. “Assessment of in vitro human dermal absorption studies on pesticides to determine default values, opportunities for read-across and influence of dilution on absorption.” *Regulatory Toxicology Pharmacology*. 2014;68(3):412-423.

225. Brand RM, Mueller C. “Transdermal penetration of atrazine, alachlor and trifluralin: effect of formulation.” *Toxicological Sciences*. 2002;68(1):18-23.

226. Lopez Camelo AF. *Manual for the Preparation and Sale of Fruits and Vegetables.* Food and Agriculture Organization of the United Nations. 2007.

227. Burigusa G, Girard S-A, Gagné M, Maurice P. *Avis de santé publique sur la prévention des traumatismes à la ferme au Québec.* Institut national de santé public du Québec. 2011.

228. Jas N. “Public health and pesticide regulation in France before and after Silent Spring.” *History and Technology: An International Journal*. 2007;23(4):369-388.

229. Ministère du Développement durable, de l'Environnement et de la Lutte contre les changements climatiques. *Bilan des ventes de pesticides au Québec 2012*. 2015.

230. Galt RE. “From homo economicus to complex subjectivities: reconceptualizing farmers as pesticide users.” *Antipode.* 2013;45(2):336-356.

231. Eakin JM, Lamm F, Limborg HJ. “International perspective on the promotion of health and safety in small workplaces.” In: *Systematic Occupational Health and Safety Management: Perspectives on an International Development*. Amsterdam, Edition Pergamon. 2000: 227-48.

232. Dumas-Quesnel M, Formation en SST. *Animation scientifique - Utilisation des pesticides dans l'agriculture*. 2014; IRSST.

233. Ali W, Clayden C, Weir R. “Attitudes and behaviours towards pesticide risk reduction.” *New Zealand Health Technology Assessment*. 2006.

234. Canadian Standards Association (CSA). *M676-06 (ANSI/ASABE S525-1.2 JAN03)-Agricultural cabs - Engineering control of environmental air quality. Part 1: Definitions, test methods, and safety practices*. 2006.

235. Canadian Standards Association (CSA). *CSA M677-99-Agricultural cabs - Environmental air quality. Part 2: Pesticide vapor filters - Test procedure and performance criteria.*1999.

236. American National Standards Institute (ANSI), American Society of Agricultural and Biological Engineers (ASABE). *ANSI/ASABE S613-3-Tractors and self-propelled machinery for agriculture - Air quality systems for cabs - Part3: Filters for environmental cab HVAC systems*. 2013.

237. American National Standards Institute (ANSI), American Society of Agricultural and Biological Engineers (ASABE). *ANSI/ASABE S613-1-(R2013)-Tractors and self-propelled machinery for agriculture - Air quality systems for cabs - terminology and overview*. 2014.

238. European Committee for Standardization (CEN). *EN 15695-2-Agricultural tractors and self-propelled sprayers - Protection of the operator (driver) against hazardous substances - Part 2: Filters, requirements and test procedures*. 2009.

239. Shaw A., Harned C. “Analysis of personal protective equipment requirements on labels of pesticides for agricultural use.” *Journal of Pesticide Safety Education.* 2013;15:17-29

240. National Association of State Departments of Agriculture Research Foundation (NASDA). *Personal protective equipment for agricultural pesticide operators: policies, process, and standards/certifications required in the United States, European Union, and Brazil.* 2013.

241. Chaumény C. “La nouvelle approche en prévention-inspection: convaincre, soutenir, contraindre.” *Prévention au travail.* 1996;9(3):7-14.

242. Garrigou A, Baldi I, Jackson M. “The use of pesticides in French viticulture: a badly controlled technology transfer!” *Work.* 2012;41(Supplement 1):19-25.

243. Feola G., Binder C. “Why don’t pesticide applicators protect themselves? exploring the use of personal protective equipment among Colombian smallholders.” *International Journal of Occupational and Environmental Health.* 2010;16(1):11-23.

244. Mayer B, Flocks J, Monaghan P. “The role of employers and supervisors in promoting pesticide safety behavior among Florida farmworkers.” *American Journal of Industrial Medicine*. 2010;53(8):814-824.

245. Obendorf SK. *Improving the functionality of clothing through novel pesticide protection. In: Functional Textiles for Improved Performance, Protection and Health*. Cambridge, Woodhead Publishing Limited. 2011:433-60.

246. Elmore RC, Arcury TA. “Pesticide exposure beliefs among Latino farmworkers in North Carolina's Christmas tree industry.” *American Journal of Industrial Medicine*. 2001;40(2):153-160.

247. Wadud SE, Kreuter MW, Clarkson S. “Risk perception, beliefs about prevention and preventive behaviors of farmers.” *Journal of Agricultural Safety and Health*. 1998;4(1):15-24.

248. Balanay JA, Crawford SA, Lungu CT. “Comparison of toluene adsorption among granular activated carbon and different types of activated carbon fibers (ACFs).” *Journal of Occupational and Environmental Hygiene*. 2011;8(10):573-579.

249. Hayashi T, Lee TG, Hazelwood M, Hedrick E, Biswas P. “Characterization of activated carbon fiber filters for pressure drop, submicrometer particulate collection and mercury capture.” *Journal of the Air and Waste Management Association*. 2000;50(6):922-929.

250. Lorimier C, Le Coq L, Subrenat A, Le Cloirec P. “Indoor air particulate filtration onto activated carbon fiber media.” *Journal of Environmental Engineering*. 2008;134(2):126-137.

251. Balanay JA, Bartolucci AA, Lungu CT. “Adsorption characteristics of activated carbon fibers (ACFs) for toluene: application in respiratory protection.” *Journal of Occupational and Environmental Hygiene*. 2015;11(3):133-143.

252. Gosch ME, Shaffer RE, Eagan AE, Roberge RJ, Davey VJ, Radonovich LJ. B95: “A new respirator for health care personnel.” *American Journal of Infection Control*. 2013;41(12):1224-1230.

253. Havenith G, den Hartog E, Martini S. “Heat stress in chemical protective clothing: porosity and vapour resistance.” *Ergonomics*. 2011;54(5):497-507.

254. Epstein Y, Heled Y, Ketko I, Muginshtein J, Yanovich R, Druyan A, et al. “The effect of air permeability characteristics of protective garments on the induced physiological strain under exercise-heat stress.” *Annals of Occupational Hygiene*. 2013;57(7):866-874.

255. Lee S, Obendorf SK. “Use of electrospun nanofiber web for protective textile materials as barriers to liquid penetration.” *Textile Research Journal*. 2007;77(9):696-702.