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Situation of chemical control in crop protection in Guelma region (North-East of Algeria) during 2019-2024

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To myself.

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*To my father "**D. Mehdi"**, who taught me to never give up. Your words, your will and your example have formed my vision. Your believe in me has given me the power to overcome everything.*

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D.S.A : Directorate of Agricultural Service (Direction des Services Agricoles)

CCLS : Cereals and Dried Vegetables Cooperative (Coopératives des Céréales et des Légumes Secs)

CASAP : Agricultural Supply Service Cooperative (Coopérative Agricole de Service des Approvisionnements)

TAA: Total Agricultural Area

UAA: Usable Agricultural Area

ha: Hectare

General introduction

General introduction

Agriculture and food production are the concepts, which are regarded to be of utmost significance in leading to progression and well-being of the individuals, curbing the problem of malnutrition and leading to developments of the communities and nation (**Kapur, 2020).**

Increase in food production is the prime-most objective of all countries, as world population is expected to grow to nearly 10 billion by 2050. Based on evidence, world population is increasing by an estimated 97 million per year. The Food and Agricultural Organization (FAO) has in-fact issued a sobering forecast that world food production needs to increase by 70%, in order to keep pace with the demand of growing population**.** However, increase in food production is faced with the ever-growing challenges especially the new area that can be increased for cultivation purposes is very limited **(Kaur and Garg, 2014).**

In Algeria, food security has been a priority for the authorities since independence of the country. Only a mere 17.4% of Algeria's total amount of land is viable for agricultural farming, according to a 2016 study by the World Bank. Algeria has a growing number of mouths to feed, with the population that was estimated to be close to 44 million in 2020 and that is increasing by an estimated 1 million a year. The government of Algeria is pursuing agriculture development and modernization as a means of diversifying the economy and attracting foreign and domestic investment outside the energy sector **(Hoogerwerf and Amrouni, 2023).**

A challenge to achieving global food safety and sustainable development is posed by pathogens, weeds and insects since they significantly reduce agricultural yields globally **(Angon et *al*., 2023).** Pests and diseases are a major cause of agricultural losses. They reduce plant density, stunted plant growth which eventually depletes food production **(Priya et *al*., 2023).** The potential losses as a result of pest infestations may vary, depending on crop and pest, from less than 50 % to more than 80 % (**Hashemi et *al*., 2021). Agrios (2005)** asserts that pests and diseases contribute to an estimated 31% to 42% of yearly global crop losses, with diseases alone accounting for 14.1% of this total. According to **Angon et *al*. (2023), y**ield losses caused by pests may be equivalent to the amount of food needed to feed nearly 1 billion individuals when considered in terms of food security.

In order to avoid and reduce crop losses caused by weeds, insects, and diseases, many types of crop protection measures have been developed. Every day, farmers all around the world make different decisions about how to protect their crops through the use of diverse techniques **(Agarwal and Verma., 2020).**

Chemical control is often the most used method to control pests. It has a long history, dating back to 2500 BC, but it only became widespread in the last 50 years. Early pesticides were often inorganic or plant-derived **(Saravi and Shokrzadeh, 2011).** Pesticide is any substance or mixture of substances used to prevent, destroy, or control pests, unwanted species who cause harm during production and storage of crops. Pesticides act through several mechanisms. Some are termed growth regulators as they either stimulate or retard the growth of pest, while repellents are known to repel pests, and attractants attract pests or chemosterilants, which sterilize pests. Pesticides with a wide range of activities and used to control more than one class of pests **(Abubakar et *al.*, 2020).**

Pesticides formulations contain both "active" and "inert" ingredients. Active ingredients are what kill the pest, and inert ingredients help the active ingredients to work more effectively **[1].** Each one of the pesticides formulations components, has a specific role to enhance the overall effectiveness and functionality of the product **[2]:**

- **One or more active ingredients,** which confers on the product the desired poisonous effect and which is responsible in whole or in part for the toxic effect.

- **Diluent,** which is a solid or liquid (solvent) incorporated into a preparation to reduce the concentration of the active ingredient. These are usually vegetable oils in the case of liquids, clay or talc in the case of solids.

- **Adjuvants or additives,** substances that have no biological action but can modify the qualities of the pesticide and make it easier to use.

The pesticides available on the market are characterized by such a variety of chemical structures, functional groups and activities that their classification is complex. In general, they can be classified according to the nature of the species to be controlled, but also according to the chemical nature of the main active ingredient. The types and quantities used vary from one country to another. Nevertheless, the classification systems are universal **(Mehri, 2008).** They can also be classified by modes of action, and toxicity **(Tudi et *al.*, 2021).**

Based on different targets of pests, pesticides are classified into many families, including the big 3 ones, who are fungicides (Chemicals which are used to prevent, cure eradicate the fungi), insecticides (Pesticide that is used to kill insects or to disrupt their growth or development), herbicides (Substances that are used to kill weeds, or to inhibit their growth or development). To these can be added various products such as acaricides (to fight mites), Molluscicides (to fight slugs and snails), Nematicides (against nematodes), Rodenticides (against rats), Avicides (used to kill birds), Larvicides (Inhibit the growth of larvae) and finally repellents (**Akashe et *al.*, 2018).**

Based on the chemical nature of the main active substance in plant protection products, they are classified into organic and inorganic ingredients. Inorganic pesticides include copper sulfate, ferrous sulfate, copper, lime, and sulfur. Organic pesticides can be classified according to their chemical structure, such as chlorohydrocarbon insecticides, organophosphorus insecticides, carbamate insecticides, synthetic pyrethroid insecticides, metabolite and hormone analog herbicides, synthetic urea herbicides, triazine herbicides, benzimidazole nematicides, metaldehyde molluscicides, metal phosphide rodenticides, and D group vitamin-based rodenticides (**Tudi et *al.*, 2021).**

Herbicides, insecticides, fungicides, nematicides, fertilizers and soil amendments are now being used in higher quantities than in the past **(Kaur and Garg, 2014).** Plant pathogens, insects, and weed pests devastate over 40% of all possible sustenance creation every year. This loss happens despite utilizing approximately 3 million tons of pesticide per year, in addition of other methods, such as biological control, microbial pesticides, insect behavior, genetic engineering, and plant immunization of pest population **(Agarwal and Verma, 2020)**.

Tostado et *al*. (2022), reports that, the global consumption of pesticides is increasing. Global pesticide use has continued to grow steadily for decades: Between 1990 and 2017 by about 80 percent. Today, pesticide consumption worldwide stands at 4 million tons globally. Half of the substances applied are herbicides, about 30 percent are insecticides and about 17 percent are fungicides against fungal infestation. The global pesticides market size reached a value of nearly 84.5 billion US dollars in 2019, with an annual growth rate of more than 4 percent since 2015. In the next few years, the rate of growth could increase further. By 2023, the total value of all pesticides used is expected to grow at a rate of 11.5 percent to nearly 130.7 billion US dollars. Many factors, like soil degradation and biodiversity loss, have contributed to the increase. The climate crisis can be another driver for pesticide use**.**

In Algeria, with the expansion of cultivated land, pesticides are being used more and more frequently for agricultural purposes. In fact, almost 400 active pesticide substances, including around 7,000 specialties, are marketed every year **(Zamoum et *al*., 2023).**

However, despite their advantages, pesticides are still destructive to the environment and people. Numerous compounds are poisonous, bio-accumulative, and ecologically stable. Some pesticides can linger in the environment for years because they are long-lasting **(Kaur et *al*., 2024).**

Risks associated with pesticide use have surpassed their beneficial effects. Pesticides have drastic effects on non-target species and affect animal and plant biodiversity, aquatic as well as terrestrial food webs and ecosystems, about 80–90 % of the applied pesticides can volatilize within a few days of application. The volatilized pesticides evaporate into the air and subsequently may cause harm to non-target organism. Uncontrolled use of pesticides has resulted in reduction of several terrestrial and aquatic animal and plant species. Additionally, air, water and soil bodies have also been contaminated with these chemicals to toxic levels (**Mahmood et *al*., 2015).**

Roger (2024), reveals that **e**very year, 385 million people (that's 44% of the world's farming population) are poisoned in the course of their work, with an estimated 11,000 people sadly losing their lives. Even more significantly, more than 100,000 people die yearly from intentional (self-harm) poisoning with pesticides. Pesticide poisoning is one of the most common methods of suicide worldwide, responsible for at least 14 million deaths since the 1960s.

Also, the excessive application of pesticides/weedicides have posed a major challenge to the targeted pests causing them to either disperse to new environment and/or adapt to the novel conditions. The adaptation of the pest to the new environment could be attributed to the several mechanisms such as gene mutation, change in population growth rates, and increase in number of generations etc. This has ultimately resulted in increased incidence of pest resurgence and appearance of pest species that are resistant to pesticides **(Harsimran and Harsh, 2014; Sharma et *al*., 2019).**

A lot of reports of pest resistance to synthetic pesticides are surfacing globally. Currently, no class of synthetic pesticides, including organophosphates, organochlorines, pyrethroids, or even fumigants, is completely immune to this phenomenon. This widespread resistance poses a significant challenge to pest management strategies **(Guèye et *al*., 2011).**

Resistance is a major pesticide-use problem. When a pesticide is used on a population of insects, plants, or other pests, one or more individuals may have a genetic mutation permitting them to tolerate the pesticide. When these resistant individuals reproduce, they pass resistance genes to their offspring. Over time, the resistant population increases until most individuals are resistant to the pesticide. Often, when resistance is observed, the response is to apply larger quantities of pesticide. This allows the pest to express resistance to the higher doses too. Or, if the applicator switches to a different pesticide, resistance develops to it as well. Because some pest species reproduce very quickly and in huge numbers, resistance sometimes develops rapidly. Hundreds of insects, mites, weeds, and plant diseases have become resistant to one or more pesticides **(Hill, 2010).**

The most common pesticide resistances in agricultural fields refer to the resistance of fungi to fungicides, the resistance of insects to insecticides, and the resistance of weeds to herbicides; in spite of the resistance of other pests that can occur, as nematodes, bacteria, mites, and so on). The resistance of fungi, insects, and weeds have been exponentially increasing in the past years around the world. The prevention of the pesticide resistance is currently an obligation for food production worldwide **(Carvalho, 2015).**

The objective of this study is to conduct a comprehensive survey of the most frequently used phytosanitary products by agricultural practitioners in Guelma (North-East of Algeria), over the past five years. This research seeks to identify the pesticides used in managing pests affecting various crops, including cereals, fruit trees, vegetable crops, and industrial tomatoes, which are prevalent in the agricultural lands of this region. This research aims to assess the potential risks of developing resistance to these products due to their repeated use.

This document includes a general introduction, a first chapter presenting the materials and methodology adopted for this study, and a second chapter presents the results obtained, accompanied by a discussion. Finally, a conclusion and a summary are inserts.

Chapter 01 : Material and methods

Chapter 01: Material and methods

1.1. Presentation of the the study area (Guelma region)

1.1.1. Geographic location

Guelma is the capital of Guelma province, it is located in northeastern Algeria (**Fig. 01**), about 65 kilometers from the Mediterranean coast. Geographically, Guelma serves as a convergence point between the industrial centers of the North, such as Annaba and Skikda, and the commercial centers to the South, including Oum El Bouaghi and Tebessa. Additionally, its proximity to the Tunisian border in the East enhances its significance as a strategic junction.

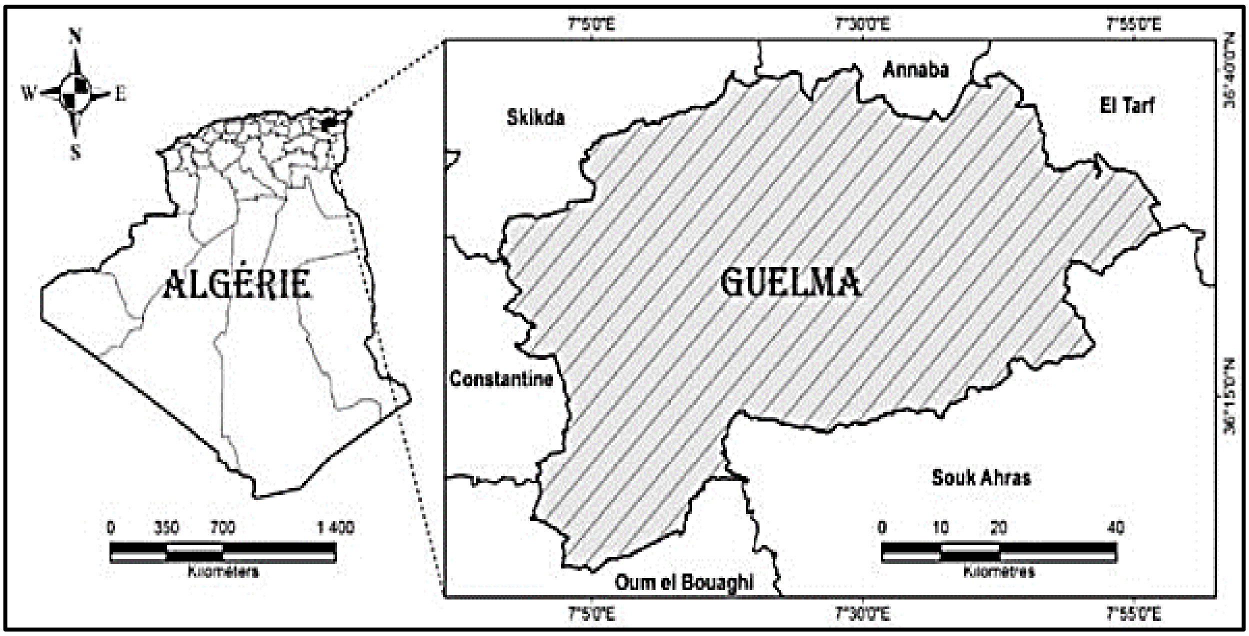

Figure 01: Geographic location of the wilaya of Guelma

(Soltani et *al.*, 2019)

With an estimated population of 556,673 in 2019 and an average population density of 151 people per km², the area covers 3,686.84 km². The longitude ranges from 6.940277996° to 7.959965001°, while the latitude ranges from 36.02512400° to 36.67331300° **(Arour, 2014).** It shares borders with:

- The wilaya of Annaba to the North,
- The wilaya of Skikda to the Northwest,
- The wilaya of Constantine to the West,
- The wilaya of Oum El-Bouaghi to the South,

- The wilaya of Souk Ahras to the East,
- The wilaya of El Tarf to the Northeast.

The wilaya of Guelma (**Fig. 02**), comprises 10 Daïra, which encompass 34 municipalities.

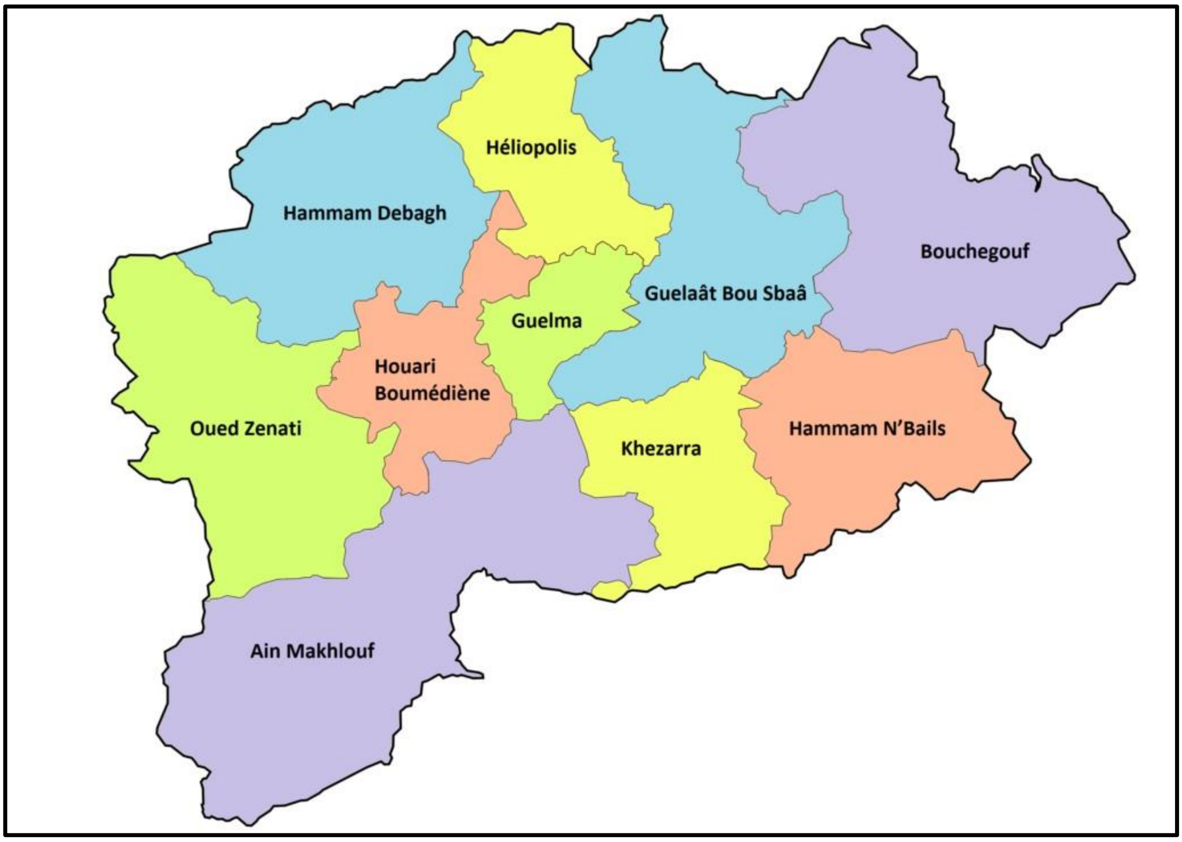

Figure 02: Daïra of the wilaya of Guelma [3]

1.1.2. Climate

The territory of the Wilaya is characterized by a sub-humid climate in the central and northern regions and semi-arid towards the South. This climate is mild and rainy in winter and hot in summer. The temperature ranges from 4°C in winter to over 35°C in summer, averaging 17.3°C. Rainfall varies from 400 to 500 mm/year in the South to nearly 1000 mm/year in the North. Nearly 57% of this rainfall is recorded during the wet season (October-May). Rainfall plays a significant role in seasonal water flow. The wet season typically extends from September to May (**Tab. 01**) **[4].**

Table 01: Monthly averages of precipitation **[5]**

Months	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
Precipitation (mm)	65,1	76,2	77,9	54,9	35,7	15,0	4,0	10,9	44,0	47,9	67,3	75,2

The temperature also plays a critical role in agriculture, influencing various aspects. T**able 02**, shows the average annual temperature of the wilaya of Guelma **[5].**

Table 02: The average annual temperature of the wilaya of Guelma

Months	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Average Temperature (°C)	10,6	10,2	13,0	16,3	19,3	23,9	27,5	27,7	24,3	21,2	15,6	11,6
Average High (Max.) Temperature (°C)	16,5	16,4	19,5	23,3	27,5	32,9	36,7	36,2	31,5	28,4	21,5	17,1
Average Low (Min.) Temperature (°C)	4,6	4,4	6,2	8,7	11,2	15,3	18,4	19,1	17,1	13,7	9,4	6,2

1.1.3. Soil types

The wilaya of Guelma has several types of soils, categorized into three zones (**Tab. 03**).

1.2. Work methodology

1.2.1. Objectives of the study

In this study, a phytosanitary survey was conducted in Guelma region, and it was carried out among administrations/institutions, pesticide product distributors, farmers, and pilot farms. In order to identify the most commonly used pesticide products in Guelma, and the plant protection strategy adopted. Therefore, this review will provide the scientific information necessary for pesticide application and management in the future.

Table 03: Soil types of Guelma region **(D.S.A, 2024)**

Zone	Soil type
Northern Zone: Extending from north to north-south	**Clayey-loamy soil**: This type of soil is characterized by the presence of clay and loam, two fine particles resulting from rock erosion. Clayey-loamy soils are often fertile as they retain water and nutrients well while allowing adequate drainage. However, they can be susceptible to erosion due to their fine texture.
Central Zone (Oued Seybouse basin): Extending from the valley formation to the Bouchegouf region.	**Clayey-sandy soil:** This soil has a unique composition, combining clay and sand particles in varying proportions. Clayey-sandy soils exhibit intermediate properties between clayey (impermeable) and sandy soils (permeable). They provide good aeration and drainage while retaining enough moisture to support plant growth.
Southern Region: Predominantly in the vast plains of Tamlouka.	**Silt-sandy soil:** This soil type exhibits characteristics intermediate between sandy soil, which drains water well, and silty soil, which retains more moisture. Such soils can be favorable for certain agricultural crops and possess good structural stability.

1.2.2. Organizations and individuals involved in this survey

The study was conducted in 2024 throughout the wilaya of Guelma and its municipalities. The organizations and individuals involved in the survey (**Tab. 04**) are selected as follows:

- **Pesticide Product Distributors:** Key entities such as CCSL, CASAP, and pesticides sellers, which plays an important role in the distribution of pesticide products.
- **Pilot Farms:** These farms are among the largest and most significant users of phytosanitary products, providing essential data on application practices and usage volumes.
- **Farmers:** As the primary applicators of these products, farmers offer invaluable insights into practical usage, effectiveness, and potential areas for improvement.
- **Pesticide Controllers:** Regulatory authorities who are responsible for overseeing the safe and legal use of pesticides, ensuring compliance with regulations and environmental standards.

This comprehensive approach ensures that the study captures a comprehensive vision of pesticide use in the region, and gathers valuable information.

Table 04: Organizations and individuals involved in the survey

Organizations and individuals	Pesticide product distributors		Pilot Farms	Farmers	Pesticide Controllers
	Organizations (CCLS, CASAP)	**Distributors of Phytosanitary products**			
Number	2	3	4	3	1

1.2.3. Data collection methodology

Our study is conducted in the field with vendors and applicators of phytosanitary products in the region of Guelma and its municipalities (Belkheir, Bouamahra Ahmed, Medjez Amar, Hadjar Mengoub, and Djebala Khemissi) over a period of three months (March, April, May). The survey is conducted through face-to-face interviews, which allowed us to establish a database on pesticides and determine the most commonly used ones in the study area.

1.2.4. Database used

The 2017 Index of Agricultural Pesticides: Published by the Algerian Ministry of Agriculture and Rural Development, has been used as an essential reference; it provides comprehensive details (including commercial names, active ingredients, concentrations, formulations, target pests, recommended crops, application dosages, pre-harvest intervals, precautions, registration numbers, …) on a wide range of pesticides available in the Algerian market. This resource serves as a reliable guide and tool for local farmers in the studied region, offering invaluable information for the selection and use of pesticides.

The 2008 Index of Acta, is also used; it is an European guide for selecting and correctly using phytopharmaceutical products (including biocontrol products and those suitable for organic agriculture) and agricultural biocides. For over 50 years, the Acta Phytosanitary Index has provided the latest knowledge in plant health and the keys to understanding plant protection through an initial section offering:

- Definitions, concepts, decision support tools, and an overview of regulations.
- A directory of products and active substances is updated annually.

1.2.5. Data analysis

The collected data was entered into an Excel spreadsheet and processed based on the variables observed in the field. Statistical parameters, such as averages and percentages, were calculated to construct distribution histograms for each application practice and analysis, by EXCEL 2019.

Chapter 02 : Results and discussion

Chapter 02: Results and discussion

2.1. Agriculture in the wilaya of Guelma

2.1.1. Spatial distribution of agricultural land in the wilaya of Guelma

The Guelma region has a total agricultural area (TAA) of 264,618 hectares, which is more than two-thirds (67.67%) of the province's total area. Among these lands, a significant portion, approximately 187,338 hectares (70.79% of the TAA), is considered suitable for agricultural activities, constituting the usable agricultural area (UAA). The area dedicated to irrigated crops has seen a steady growth, reaching 17,343 hectares in 2024 **(D.S.A, 2024).**

2.1.2. Distribution of the UAA by type of holding

Table 05 presents the different types of farms in the wilaya of Guelma.

Table 05: Distribution of the UAA by type of holding

(D.S.A, 2024).

Farms	Number	Global area (ha)	Cultivated area (ha)
Collective Farm	540	45.066,65	22,393.22
Individual Farm	2793	16.616,68	9,925
Family Farm	-	192,022.22	150,522.42
Pilot Farms	07	4.845,81	4.410,66

2.1.3. Cultivated areas of some crops in the wilaya of Guelma

Table 06 presents the distribution of agricultural activities in Guelma region for the last five agricultural seasons (2019-2024). These activities are focused on grass crops (cereals), industrial tomatoes, vegetables (vegetable crops other than industrial tomatoes), and fruit trees (arboriculture).

Table 06: Areas (ha) of some crops in the wilaya of Guelma
(D.S.A, 2024).

Years / Crops	2019/2020	2020/2021	2021/2022	2022/2023	2023/2024	Total
Cereals	91000	90888	89398	90580	94700	456566
Industrial tomatoes	4068	4667	3478	1665	2804	16682
Vegetable crops	10500	10000	9300	6500	8000	44300
Fruit trees	2100	2220	2300	2350	2600	11570
Total	107668	107775	104476	101095	108104	529118

2.2. Treated Areas and Quantities of Pesticides Used

2.2.1. Treated Areas

Table 07 presents the treated areas of various crops in the Wilaya of Guelma over the last five agricultural campaigns.

Table 07: Treated Area of Some Crops in Guelma During 2019-2024 **(D.S.A, 2024)**

Crops	Cultivated aerea (ha)	Treated aerea (ha)	Treated aerea (%)	Global treated aerea (ha)
Cereals	456566	346000	76 %	418552
Industrial tomatoes	16682	16682	100 %	
Vegetable crops	44300	44300	100 %	
Fruit trees	11570	11570	100 %	

The analysis of the results displayed in **Table 07** reveals that all crops were treated, and 94% of the cultivated areas received at least one type of pesticide treatment (herbicide, fungicide, insecticide, acaricide). The total area affected by pesticide treatments over the last five agricultural campaigns amounts to approximately 418552 hectares. However, this area varies from one agricultural campaign to another, depending on the cultivated areas and treatment practices. The 2019-2020, 2020-2021, and 2021-2022 campaigns, characterized by the COVID-19 pandemic, and the 2022-2023 campaign, characterized by pronounced drought, shows reduced activities, particularly for industrial tomatoes and vegetable crops, for which the cultivated areas significantly decreased from one year to the next. In 2023-2024, a slight increase in cultivated areas is noted for all crops compared to 2022-2023 **(Table 06).**

2.2.2. Total quantities of pesticides used in the wilaya of Guelma

The data collected from the organizations of the Directorate of Agricultural Services (D.S.A) regarding the total quantity of pesticides used for crop treatment, covered in this study **(Fig. 03)**, reveal that the amounts of phytosanitary products applied each year is considerable, ranging from 293,42 to 384,33 tons.

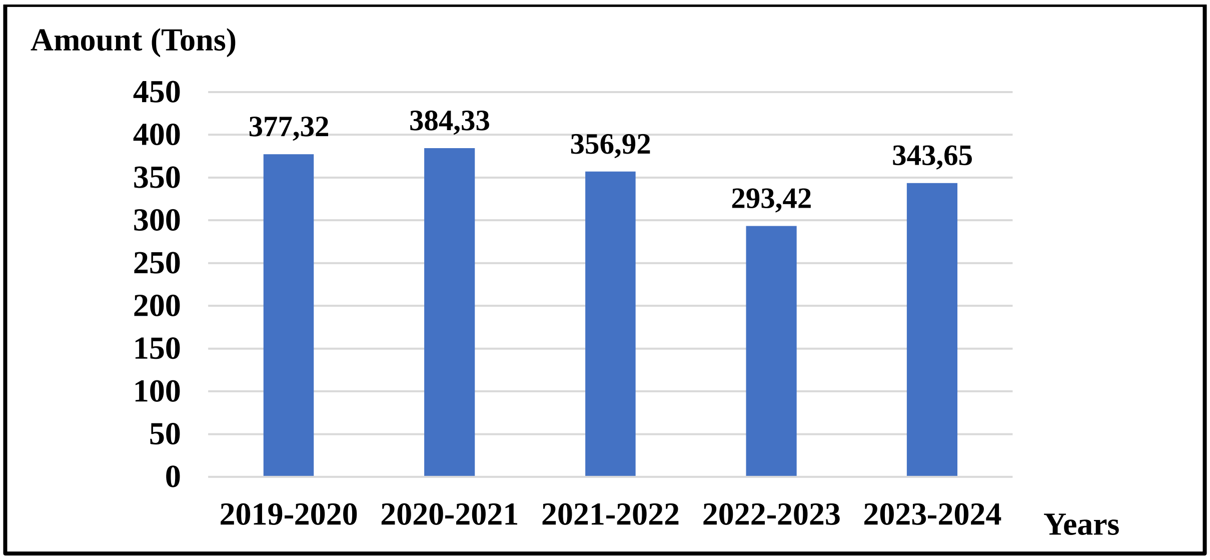

Figure 03: Quantities of pesticides used over the past five years in the wilaya of Guelma for the studied crops

Over the past five years, we note that between 2019-2020 and 2020-2021, the quantity of pesticides increased by 7 tons, from 377,320 tons to 384,33 tons, an increase of 1,86%, this can be attributed to the increase in the area cultivated in industrial tomato that consumes a lot of pesticides. However, from 2020-2021 to 2021-2022, a decrease of 27.41 tons is observed, reducing the quantity to 356,92 tons, with a decrease of 7.13%. The significant decline continues in 2022-2023 with a reduction of 63,5 tons to 293,42 tons, with a significant decrease of 17.79%.

In 2023-2024, there was an increase of 50,23 tons, (343,65 tons), with an increase of 17,12%, compared to 2022-2023. These variations can be attributed to fluctuations in crop areas and climatic conditions in the 2022-2023 season, characterized by a remarkable drought, and the destruction of crops, in particular cereals, which constitute an important part of the area cultivated in Guelma. Many farmers have abandoned their plots and stopped their activities because of drought.

The 2023-2024 campaign saw an increase in the amounts of pesticides used, reaching a value, nearly similar to the amount used in 2021-2022 (**Fig. 03).**

2.2.3. Quantities of pesticides used for different crops studied

Figure 04 shows the amounts of pesticides used to treat different crops over the last five years.

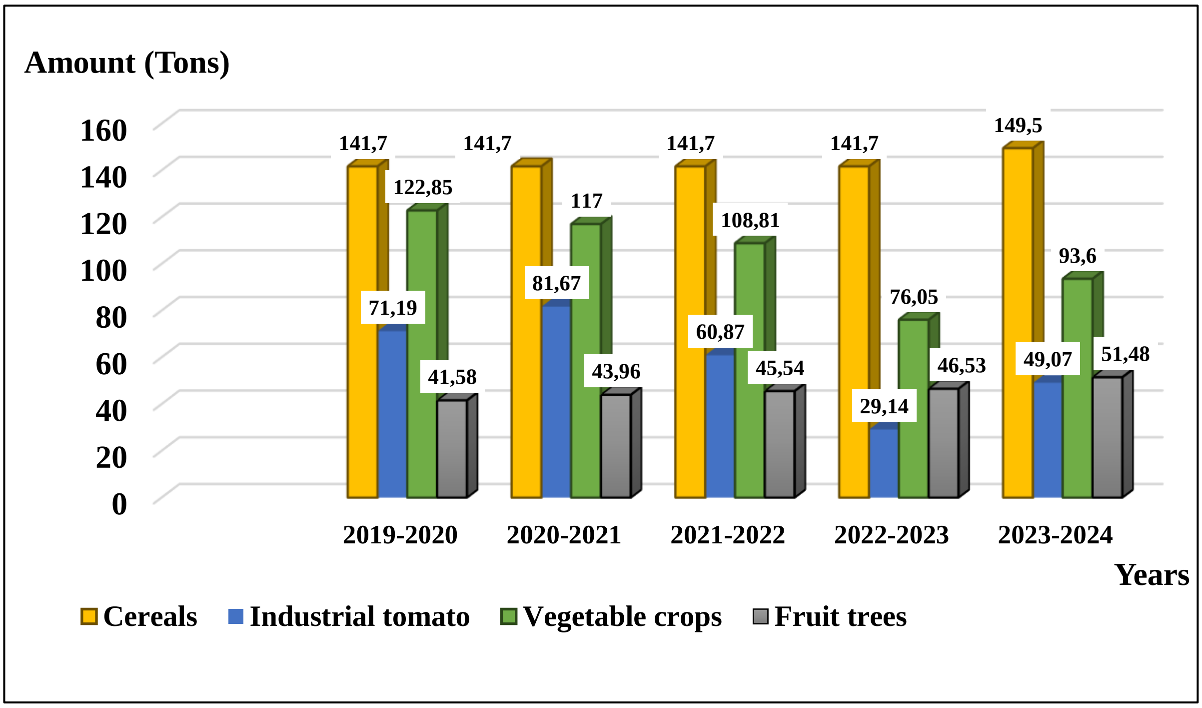

Figure 04: Amounts of pesticides used in the last five years for treatment of the studied crops

2.2.3.1. Cereal cultivation

Cereal cultivation predominates in Guelma region. The data on total amounts of pesticides used for the treatment of cereal crops over the last five years (**Fig. 04),** show a massive use of plant protection products for these crops in comparison with other crops, for all the years. This quantity is stable from 2019 to 2023 (141,7 tons). However, an increase of 5,5% (7, 800 tons) was noted for the 2023-2024 campaign compared to previous campaigns.

2.2.3.2. Industrial tomato

The exploration of **Figure 04** shows the variations in the amounts of pesticides used for industrial tomato. There was an increase of 10.482 tons in 2020-2021 compared to the previous season 2019-2020, followed by a remarkable decrease in the amounts of pesticides used (81, 672 tons in 2020-2021 and 60, 865 tons in 2021-2022). In 2022-2023, a significant decrease is observed, bringing the quantity to 29,140 tons, then an increase to 49,07 tons in 2023-2024.

2.2.3.3. Vegetable Crops (Other than Industrial Tomato)

The results of the survey show that vegetable crops consume large quantities of plant protection products. However, this quantity has declined significantly in the last three campaigns of this study, compared to the first two ones (**Fig. 04).** In 2019-2020 the quantity was 122, 850 tons, it decreased to 117, 000 tons in 2020-2021 and reached 108, 810 tons in 2021-2022. In 2022-2023 the quantity continues to decrease, reaching 76,050 tons, then a slight increase to 93,600 tons in 2023-2024. We estimated a 23,7% decrease between the first and last campaign of this study.

2.2.3.4. Fruit trees

Figure 04, also shows the amounts of pesticides used for fruit trees, for which there has been an increase in the amounts used over the past five years. In 2019-2020, the amounts of pesticides used was 41, 580 tons. This value increased slightly the following year, reaching 43,956 tons in 2020-2021. The upward trend continued over the following years, with 45, 540 tons noted in 2021-2022, 46, 530 tons in 2022-2023, and 51, 480 tons in 2023-2024. Compared to 2019-2020, the latter value represents an increase of 9,900 tons (relative increase of 23,8%).

2.3. Types of pesticides used

According to data collected through surveys of farmers and sellers of plant protection products, different types of pesticides have been identified (**Fig. 05),** insecticides, fungicides, herbicides and acaricides are most commonly used.

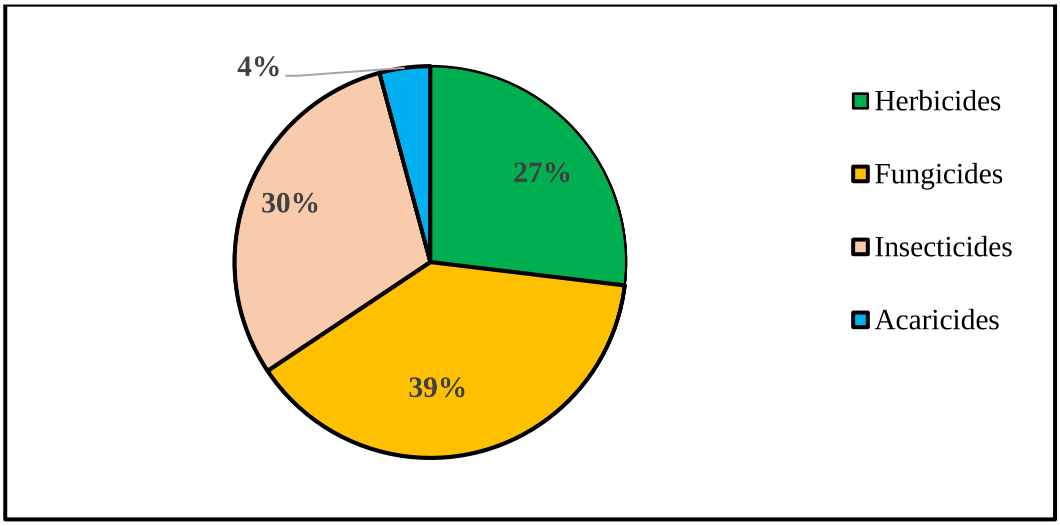

Figure 05: Types of pesticides used in Guelma region during the last five years, on studied crops.

The results repored in **Figure 05** show a predominant use of fungicides (39%). Their widespread application across various cultures explains this prevalence. Insecticides occupy the second place with a use of 30%, mainly in response to the appearance of insect pests to crops. Herbicides have a lower rate of use than fungicides and insecticides (27%), but considered important (exceeds 1/4 of the total amount of pesticides used), because of the proliferation of weeds. In contrast, acaricides have a lower percentage of use (4%), due to the acaricidal properties inherent in many insecticides.

The use of various types of pesticides and their quantities varies considerably from one crop to another. By analyzing these data, we identified the crops that consume the highest amounts and the types of pesticides most used for each type of crop.

2.3.1. Types and quantities of pesticides used in cereal crops

Figure 06, shows the most used types of pesticides and their quantities in Guelma region for the cultivation of cereals, which is the most dominant crop in the region.

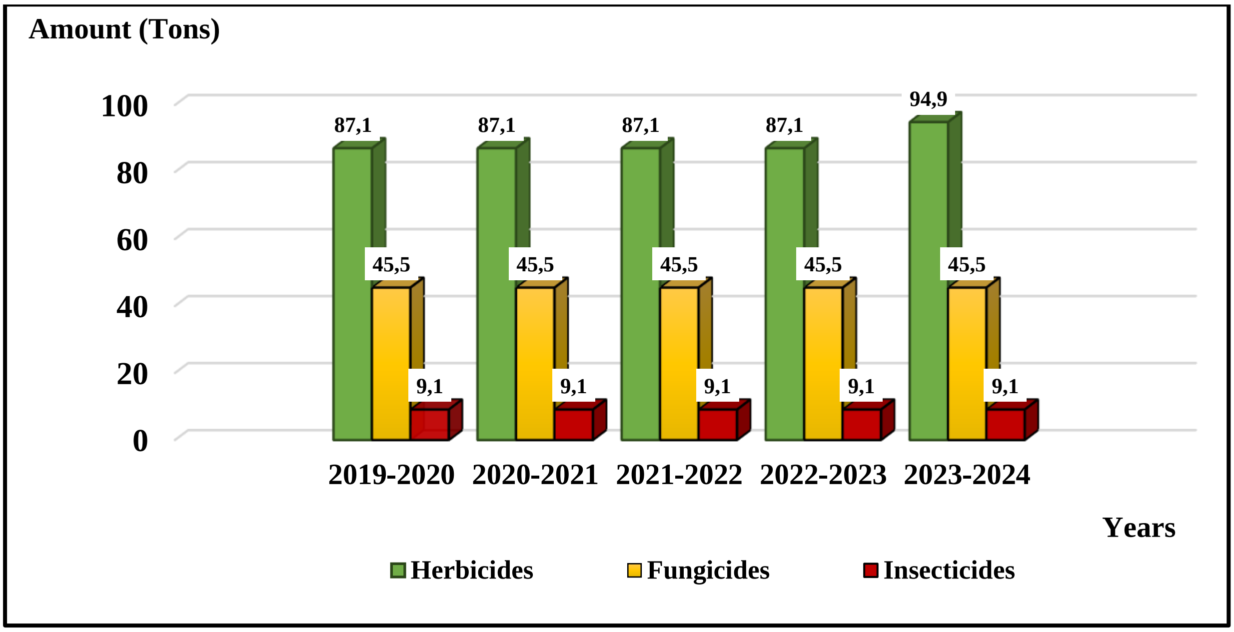

Figure 06: Distribution of the quantity of pesticides used for cereal treatment

The results obtained show that herbicides are the most widely used, with quantities of 87.100 tons from 2019-2020 to 2022-2023, before rising to 7,800 tons in 2023-2024, an increase estimated at 8,96% compared with previous years. For fungicides and insecticides, we note that the quantities used are stable, with values of 45,500 tons for fungicides and 9,100 tons for insecticides for all the crop campaigns of the study.

The quantities used are directly related to climatic conditions, which require a treatment protocol to be followed, and which have a major influence on the number of treatments, particularly for herbicides. This protocol generally involves:

- One herbicide application per cycle, carried out at the three-leaf stage of weed development, with 700g/L.
- One application of fungicides per cycle, with 1L/ha
- One application of insecticides per cycle, with 1L/ha

The treatment periods are as follows:

- Herbicides are applied from January to March.
- Fungicides are applied from February to the end of April.

- Insecticides are applied from March to May.

The excessive use of herbicides is due to the wide spread of weeds in cereal fields in Guelma region, particularly in wet years, which sometimes requires additional applications of herbicides during the growing season.

2.3.2. Types and quantities of pesticides used in Industrial tomatoes

The **figure 07** shows that the quantity of pesticide products used in industrial tomato cultivation over the last five years in the wilaya of Guelma has fluctuated from year to year.

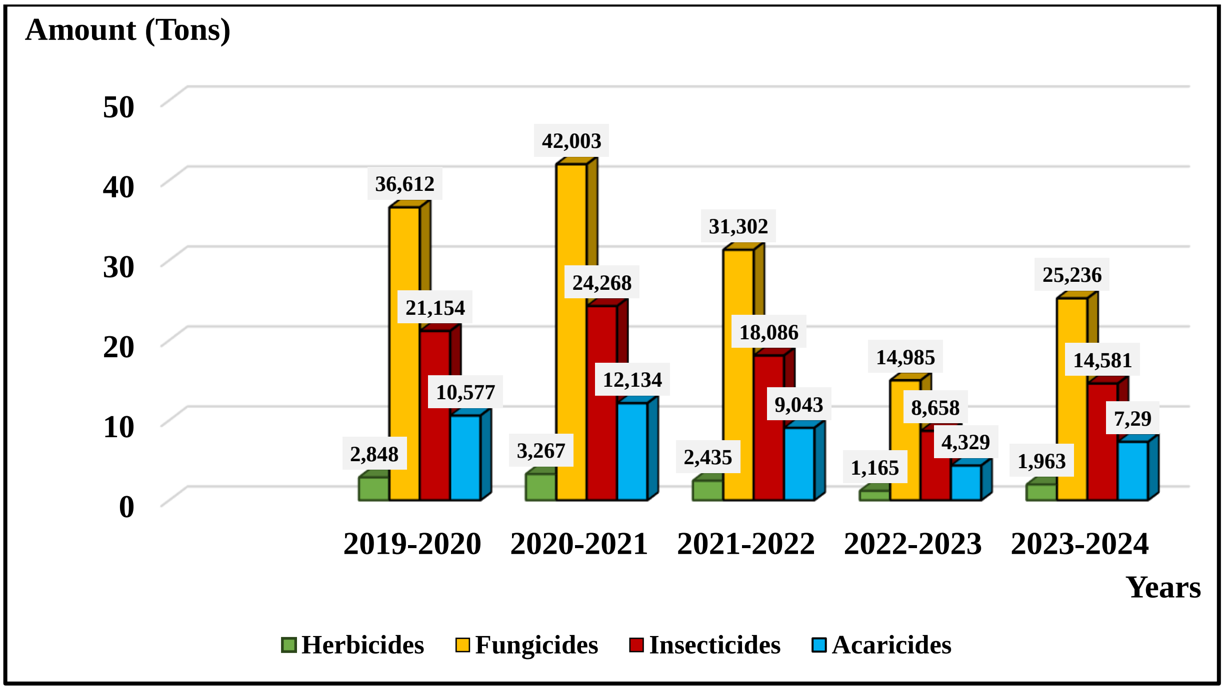

Figure 07: Distribution of the quantity of pesticides used on industrial tomatoes.

In 2019-2020, the quantity of herbicides used for industrial tomatoes is 2,848 tons. It increased by 0,419 tons in 2020-2021 to 3,267 tons. In 2021-2022, the quantity decreased by 0,832 tons compared to the previous season, reaching 2,435 tons. In 2022-2023, the quantity decreased by 1,270 tons to 1,165 tons, and in 2023-2024, it increased by 0.798 tons to 1.963 tons (**Fig. 07**).

Tomato cultivation consumes a considerable quantity of fungicides, compared with other pesticides (**Fig. 07**). In 2019-2020, the quantity used was 36.612 tons. It increased by 5.391 tons in 2020-2021 to reach 42,003 tons in 2020-2021. In 2021-2022, it decreased by 10.701 tons to 31.302 tons. In 2022-2023, it decreased by 16,317 tons to 14,985 tons compared to 2021-2022, and in 2023-2024, it increased by 10,251 tons to 25,236 tons compared to the previous year (**Fig. 07**).

The quantity of insecticides used in 2019-2020 was 21,154 tons. It increased by 3,114 tons in 2020-2021 to 24.268 tons. The following campaign, 2021-2022, the quantity decreased by 6,182 tons to 18,086 tons. In 2022-2023, there was a decrease of 9,428 tons compared to the previous campaign (8,658 tons). For 2023-2024, however, there was an increase of 5,923 tons (**Fig. 07**).

Acaricides have shown considerable variation over the years. In 2020-2021, their use increased by 1,557 tons to 12,134 tons. However, in 2021-2022, a decrease of 3,091 tons was observed, followed by a more marked decrease of 4,714 tons in 2022-2023. In 2023-2024, there was an increase of 2,961 tons (**Fig. 07**).

The results show significant variations in the use of plant protection products between 2019-2020 and 2023-2024 for all types of products (herbicides, fungicides, insecticides and acaricides). In 2020-2021, an increase of 14,72% to 14,73% was observed for each product. In 2021-2022, there was a decrease of 25.48% followed by a more marked decrease from 52,11% to 52,13% in 2022-2023. In 2023-2024, a significant increase from 68,40% to 68,42% was noted for all plant protection products. This variability can be attributed to variations in the areas cultivated and the treatment protocol, which is as follows:

- Herbicides, applied once per crop cycle.
- Fungicides, with, 5 to 8 applications per crop cycle.
- Insecticides, applied 4 times per crop cycle.
- Acaricides, with a frequency of 2 treatments per crop cycle.

These treatments are generally carried out between 15 March and 15 June (15 days before the harvest) at a dose of 1 liter per hectare.

2.3.3. Types and quantities of pesticides used in Vegetable crops (other than industrial tomatoes)

Figure 08 shows the quantity of pesticides applied to vegetable crops over the past five years. Herbicides and acaricides were not applied to any vegetable crops other than industrial tomatoes.

In 2019-2020 and 2020-2021, the quantities of fungicides fell from 54,6 tons to 52 tons, a reduction of 2,6 tons. From 2020-2021 to 2021-2022, this downward trend continued, with a reduction of 3,64 tons to 48,36 tons. The most marked decrease occurred between 2021-2022 and 2022-2023, when fungicide quantities fell from 48,36 tons to 33,8 tons, a reduction of 14.56 tons. However, in 2023-2024, there was a marked increase of 7,8 tons to 41,6 tons **(Fig. 08).**

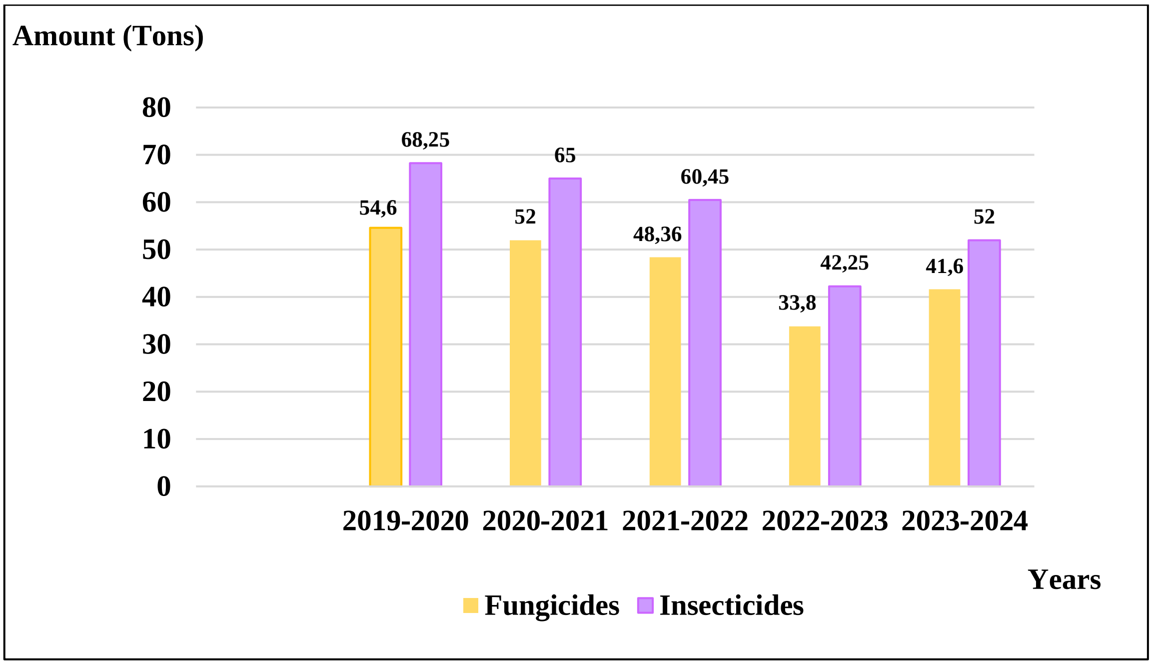

Figure 08: Distribution of the quantity of pesticides used on vegetable crops (other than industrial tomatoes)

Similarly, for insecticides, quantities fell from 68,25 tons in 2019-2020 to 65 tons in 2020-2021, a reduction of 3,25 tons. Between 2020-2021 and 2021-2022, there was a reduction of 4,55 tons, with quantities reaching 60.45 tons. The decline continued between 2021-2022 and 2022-2023, with a reduction of 18.2 tons, to reach 42.25 tons. Finally, in 2023-2024, there was a slight increase of 9,95 tons, to reach 52 tons **(Fig. 08).**

The two types of pesticide products used on this type of crop showed very similar trends in terms of percentage change each year. Fungicides and insecticides both decreased by 4,76% from 2019-2020 to 2020-2021, then by 7,00% from 2020-2021 to 2021-2022. The largest decrease for both products occurred from 2021-2022 to 2022-2023, with decreases of 30,08% and 30,09% respectively. Finally, from 2022-2023 to 2023-2024, both products saw an equal increase of 23,08%. These almost identical variations indicate a synchronised management of fungicides and insecticides over the studied period.

These products are applied at a rate of four treatments per cycle for fungicides and five treatments per cycle for insecticides at a dose of 1L/ha. Treatments are carried out between 15 March and 15 June (15 days before harvest).

2.3.4. Types and quantities of pesticides used in Fruit trees

The **figure 09** shows the quantity of plant protection products used on fruit trees during the period 2019-2024, treatment practices are similar to those used on other crops.

According to the results shown in **figure 09**, the quantities of herbicides used have increased relatively over the years. In 2019-2020, 3,15 tons of herbicides were used. In 2020-2021, this quantity increased by 0,18 tons to 3,33 tons. The following year, 2021-2022, an increase of 0,12 tons brought the quantity to 3,45 tons. In 2022-2023, the quantity increased by 0,08 tons to reach 3,53 tons. Finally, in 2023-2024, an increase of 0,37 tons was observed, bringing the total quantity to 3,9 tons. So, although the annual increases have varied, the general trend for herbicides, is a continuous increase over the whole studied period.

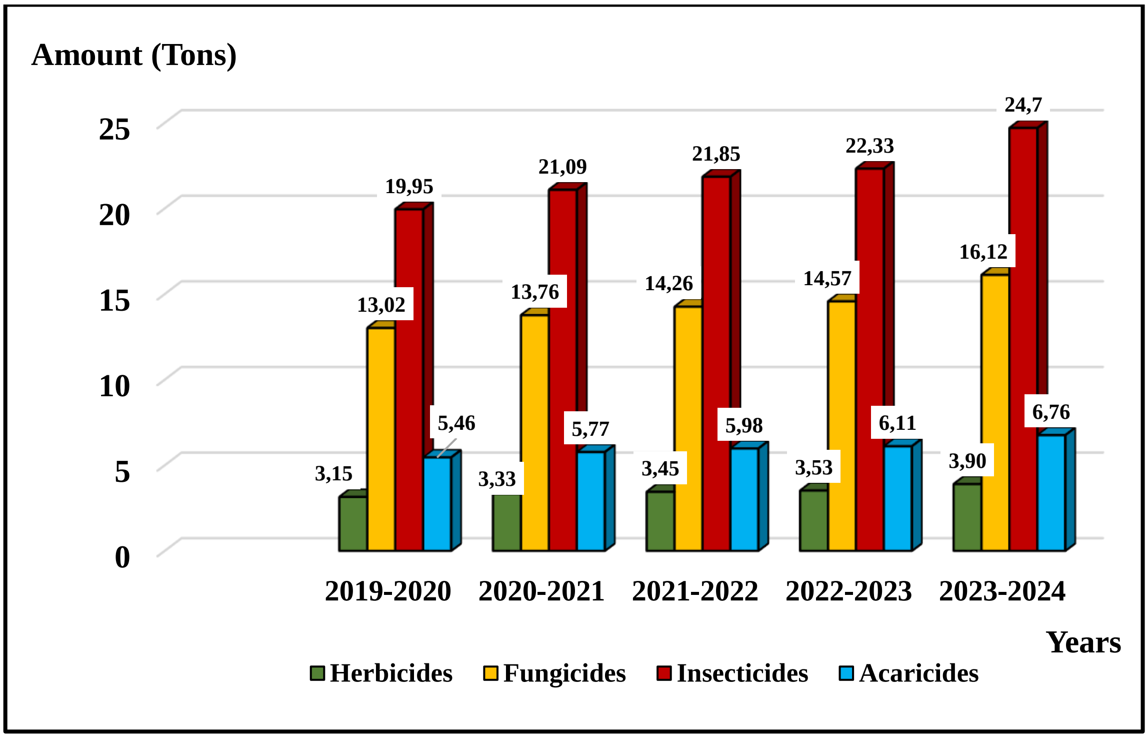

Figure 09: Distribution of the quantity of pesticides used in fruit trees.

In 2019-2020, 13.02 tons of fungicides were used. In 2020-2021, this quantity increased by 0,74 tons to 13,76 tons. In 2021-2022, a further increase of 0,5 tons took the quantity to 14,26 tons. In 2022-2023, use increased by a further 0,31 tons to 14,57 tons. Finally, in 2023-2024, a significant increase of 1,55 tons was observed, bringing the total quantity to 16,12 tons. The general trend for fungicides is also a continuous increase over the entire studied period **(Fig. 09).**

In 2019-2020, 19,95 tons of insecticides were used. In 2020-2021, this quantity increased by 1,14 tons to 21,09 tons. In 2021-2022, a further increase of 0,76 tons brought the quantity to 21,85 tons. In 2022-2023, use increased slightly by a further 0,48 tons to 22,33 tons. Finally, in 2023-2024, a significant increase of 2,37 tons was observed, bringing the total quantity to 24,7 tons. The general trend for insecticides shows continuous growth over the entire period **(Fig. 09).**

For acaricides in 2019-2020, 5.46 tons of acaricides were used. In 2020-2021, this quantity increased by 0,31 tons to 5,77 tons. In 2021-2022, a further increase of 0,21 tons brought the quantity to 5,98 tons. In 2022-2023, use increased slightly by a further 0,13 tons to reach 6,11 tons. Finally, in 2023-2024, a significant increase of 0,65 tons was observed, bringing the total quantity to 6,76 tons. Acaricides also shows continuous increase over the entire studied period (**Fig. 09**).

The percentages of total increase for each product over the period 2019 to 2024 are remarkably similar (around 23,8% for each year). This similar increase suggests a general and consistent trend of increasing use of these products in agricultural practices. Although absolute quantities vary, proportionally this indicates a systematic increase in reliance on these products for crop management over time.

Fruit trees have a treatment protocol which is:

- Three herbicide applications per crop cycle.
- Four fungicide applications per crop cycle.
- Five insecticide applications per crop cycle.
- Two miticide applications per crop cycle.
- Winter treatment one application consisting of: an insecticide application at a dose of 3 kg/ha and a fungicide application at 1 kg/ha.

The number of treatments can affect the quantity of products used. These treatments are generally carried out between 15 March and 15 June, around 15 days before the harvest period.

2.4. Active ingredients commonly used

2.4.1. For cereals treatment

2.4.1.1. Herbicides

Results obtained after interviews of the agricultural practitioners (**Tab. 08**) reveals that various commercial phytosanitary products are used for cereals treatment. In herbicides, 20 distinct active ingredients, belonging to 15 chemical families are recorded.

Based on data of **Table 08**, during the last five years we notice that, Clodinafop-Propargyl and Florasulam are the most used active ingredients in cereals treatment, followed by, Iodosulfuron-Methyl Sodium, 2,4-D, Pinoxaden and Dicamba. Acetolactate synthase inhibitors (ALS inhibitors) and Acetyl CoA carboxylase inhibitors (ACCase inhibitors) are the most one used. Others modes of action, who are less dominant have also noticed, with various mechanisms targeting different biological process such as cell division and growth inhibitors, photosynthesis inhibitors, Protoporphyrinogen oxidase (PPO) inhibitor and chlorophyll synthesis inhibitors.

Application of herbicides active substances, belonging at the same family, or with a same mode of action, for years, can reduce effectiveness of the product, and lead to the emergence of resistant species (to ALS and ACCases inhibitors in case of Guelma region). **Khammassi et *al.* (2020)** has tested 177 populations of rigid ryegrass (*Lolium rigidum*) of Tunisia, and has found resistance to Clodinafop-propargyl, Iodosulphuron + Mesosulphuron and Pinoxaden. **Scarabel et *al.* (2020)** have detected a Resistance to ALS Inhibitors in European *Cyperus esculentus L.*

2.4.1.2. Fungicides

Analysis of data obtained in this study **(Tab. 09),** reveals that, 15 active ingredients, belonging at different chemical families, especially, triazole (Cyproconazole, Epoxyconazole, Propiconazole and Tebuconazole), and Strobilurins (Azoxystrobine and Picoxystrobin) families, are used in cereals for controlling diseases.

Two major targets are distinguished: Membrane synthesis, and respiration of the fungi:

- For the first group (Azoles): the target is the biosynthesis of the membrane sterols. Eight of the fifteen active ingredients used are sterol or ergosterol inhibitors.
- For the second group (Strobilurins): the target is the fungal respiratory process. Five of the fifteen active ingredients used are respiratory inhibitors.

Other modes of action, such as Protein Kinase Inhibitors and Spore Germination Inhibitors, are noticed, but they are less prevalent and are not used as frequently, targeting various biological processes.

Table 08: Herbicides active ingredients commonly used in cereals treatment

N°	Active ingredient	Number of usage / 13 interviews	Chemical Family/Group	Mode of Action/Target
1	Clodinafop-Propargyl	4	Aryloxyphenoxy propionate (Fop)	ACCase Inhibitors (acetyl CoA carboxylase)
2	Florasulam	4	Triazolpyrimidines	ALS Inhibitors (acetolactate synthase)
3	Iodosulfuron-Methyl Sodium	3	Sulfonylureas	ALS Inhibitors (acetolactate synthase)
4	2,4-D	3	Phenoxy-carboxylic acids	Similar action to indole acetic acid
5	Pinoxaden	3	Phenylpyrazolines 'Den'	ACCase Inhibitors (acetyl CoA carboxylase)
6	Dicamba	3	Benzoic acids	Synthetic auxin
7	Mesosulfuron	2	Sulfonylureas	ALS Inhibitors (acetolactate synthase)
8	Tribenuron-Methyl	2	Sulfonylureas	ALS Inhibitors (acetolactate synthase)
9	Bentazone	2	Benzothiadiazones	Photosynthesis inhibitors/Photosystem II inhibitors
10	Fenoxaprop	2	Aryloxyphenoxy propionate 'Fop'	ACCase Inhibitors (acetyl CoA carboxylase)
11	Pyroxsulam	2	Triazolopyrimidines	ALS Inhibitors (acetolactate synthase)
12	Triasulfuron	1	Sulfonylureas	ALS Inhibitors (acetolactate synthase)
13	Propoxycarbazone-Sodium	1	Sulfonylaminocarbonyl-triazolinones	ALS Inhibitors (acetolactate synthase)
14	Amidosulfuron	1	Sulfonylureas	ALS Inhibitors (acetolactate synthase)
15	Sulfosulfuron	1	Sulfonylureas	ALS Inhibitors (acetolactate synthase)
16	Aminopyralid Acid	1	Pyridine-carboxylates	Cell division and growth inhibitor
17	Oxyfluorfen	1	Diphenyl ethers	Protoporphyrinogen oxidase (PPO) inhibitor
18	Metazachlor	1	Chloroacetamides	Cell division inhibitor
19	Imazamox	1	Imidazolinones	ALS Inhibitors (acetolactate synthase)
20	Aclonifen	1	Diphenyl ethers	Chlorophyll and carotenoid synthesis inhibitors

Table 09: Fungicides active ingredients commonly used in cereals treatment

N°	Active ingredient	Number of usage / 13 interviews	Chemical Family/Group	Mode of Action/Target
1	Cyproconazole	7	Triazole	Ergosterol biosynthesis inhibitors
2	Epoxyconazole	5	Triazole	Ergosterol biosynthesis inhibitors
3	Propiconazole	5	Triazole	Ergosterol biosynthesis inhibitors
4	Azoxystrobin	4	Strobilurins	Respiratory inhibitors
5	Picoxystrobin	3	Strobilurins	Respiratory inhibitors
6	Tebuconazole	3	Triazole	Ergosterol biosynthesis inhibitors
7	Prothioconazole	3	Triazolinthions	Sterol biosynthesis inhibitors (SBI
8	Pyraclostrobin	2	Phénylpyrazole	Respiratory inhibitors
9	Trifloxystrobin	2	Strobilurins	Respiratory inhibitors
10	Difenoconazole	2	Triazole	Ergosterol biosynthesis inhibitors
11	Spiroxamine	2	Amines, amides (spirocetalamines)	Sterol biosynthesis inhibitors (SBI)
12	Fluxapyroxad	1	Pyrazole-carboxamides	Respiratory chain blockers, inhibit amino acid, lipid, and fatty acid production
13	Fludioxonil	1	Phenylpyrrole	Protein kinase inhibitors, fungal cells burst, inhibits spore germination and mycelial growth
14	Copper sulfate	1	Inorganic substance	Spore germination inhibitors
15	Mefentrifluconazole	1	Triazole	Ergosterol biosynthesis inhibitors

An increased risk of reduced effectiveness, and development of resistant strains of fungi can occurs, against the active ingredients used. Many studies have confirmed the implantation of the resistance of many fungi against triazoles and strobilurins in many countries:

- **Bowyer and Denning, (2014)**, have reported resistance in *Aspergillus fumigatus* to various triazoles, including Difenoconazole, Propiconazole, Epoxiconazole, and Tebuconazole.

- **Jørgensen's (2008)** study confirms that the causal agent of tan spot (*Pyrenophora tritici repentis*), has developed resistance to strobilurins through mutations like F129L and G143A.

- **Allioui et *al.* (2016)**, have tested the sensitivity of 120 strains of *Zymoseptoria tritici,* the causal agent of Septoria Tritici Bloch (STB) of wheat, and they have found 3/120 resistant strains of the pathogen against Asoxystrobin, a strobilurin active ingredient. The study was conducted on samples collected in 2012 from 5 provinces of Algeria, and the resistance was detected in 2 strains from Guelma and 01 strain from Annaba province, showing a G143A mutation.

These results, confirms that the strobilurins active ingredients were used in controlling cereal's fungal pathogens, since over a decade, and resistance of fungi's populations, at strobilurins (QoIs), have riches high levels, notably in Guelma region, and especially for the Tan spot and STB agents' populations, considered among the major diseases of cereals in Algeria, notably in Guelma.

2.4.1.3. Insecticides

The **Table 10**, shows that over the past five years, Pyrethroids are the most used active ingredients, and neurotoxicity via Sodium Channel Modulators, is the most prevalent mode of action. Acetylcholine Receptor Modulators and Cholinesterase Inhibitors, are also used for controlling cereal's insects.

According to **Dong (2007)**, voltage-gated sodium channels are integral transmembrane proteins responsible for the rapidly rising phase of action potentials, and they are critical for electrical signaling in most excitable cells. Many pest populations have developed resistance to Sodium Channel Modulators, primarily through a mechanism known as knockdown resistance (kdr). Insects exhibiting kdr have reduced sensitivity of the target site (sodium channel) to pyrethroids and DDT, resulting from one or more-point mutations in the insect sodium channel protein.

Table 10: Insecticides active ingredients commonly used in cereals treatment

N°	Active ingredient	Number of usage / 13 interviews	Chemical Family/Group	Mode of Action/Target
1	Lambda-Cyhalothrine	2	Pyrethroids	Sodium channel modulators, activates nervous system causing paralysis
2	Deltamethrine	1	Pyrethroids	Sodium channel modulators, affects nervous system
3	Pyrimicarb	1	Carbamates	Cholinesterase inhibitors
4	Alpha-Cypermethrine	1	Pyrethroids	Sodium channel modulators, affects nervous system
5	Acetamipride	1	Neonicotinoids	Competitor modulators of nicotinic acetylcholine receptors (nAChR), affects nervous system

Lu et *al.* (2022), tested the effects of 10 Nicotinic Acetylcholine Receptors (nAChR) mutants, including some heterozygous mutants, against 11 insecticides. The tested mutants demonstrated moderate levels of resistance to imidacloprid, thiacloprid, acetamiprid, and triflumezopyrim.

Acetylcholinesterase resistance was confirmed by **Menozzi et *al.* (2004)**, due to the presence of several alleles in the natural population that confer varying degrees of resistance to carbamate and organophosphate compounds.

2.4.2. For vegetable crops and industrial tomatoes treatment

2.4.2.1. Herbicides

In vegetables crops and industrial tomatoes, various of phytosanitary products has been used. Analysis revealed the presence of 7 distinct active ingredients, categorized within 5 principal chemical families with different modes of actions **(Tab. 11).** Three primary modes of actions are identified: Photosynthesis Inhibitors, ACCase Inhibitors and the PPO Inhibitors.

Table 11: Herbicides active ingredients commonly used in vegetable crops and industrial tomatoes treatment

N°	Active ingredients	Number of usage / 13 interviews	Chemical family/ Chemical group	Mode of Action/Target
1	Metribuzin	4	Triazinone	Block photosynthesis at the level of photosystem II
2	Haloxyfop-R Methyl Ester	2	Organophosphorus	Inhibits the enzyme acetyl-CoA carboxylase ACCase (disrupts the growth and development of weeds cells)
3	Fluazifop-P-Butyl	1	Aryloxyphénoxy-propionates	Acetyl-CoA carboxylase inhibitors (growth arrest)
4	Cycloxydim	1	Cyclohexane-diones	Acetyl-CoA carboxylase inhibitors (growth arrest)
5	Quizalofop-P-Ethyle	1	Aryloxyphénoxy-propionates (AOPP)	Acetyl-CoA carboxylase inhibitors (growth arrest)
6	Aclonifene	1	Diphenyl ethers	Inhibition of Protoporphyrinogen Oxidase PPO (causing necrosis and death of affected tissues)
7	Terbuthylazine	1	Triazines	Inhibiting photosynthesis at the level of photosystem II (blocks electron transport between plastoquinone and cytochrome b6f complex)

Based on **table 11**, during the last five years the Photosynthesis Inhibitors and ACCase Inhibitors are the most dominant actions compared to the PPO Inhibitors.

The high frequence of using ACCases inhibitor in many types of crops leads to the increase of resistant species. **Kukorelli (2013)** noticed that the resistance to ACCase inhibitor herbicides is a widespread global phenomenon, now recognized in 42 weed species, it has become the third-most frequent form of weed resistance.

According to **Gronwald (1997)**, Photosynthesis Inhibitors resistance is related to a mutation of the chloroplast psbA gene, the substitution is Glycine for Serine at residue 264 (G264S).

PPO inhibitors were not among the most frequently mentioned, but they are known for common weed resistance, as confirmed by **Rangani (2023)**. Who identified 81 weed populations that were genotyped for all known mutations conferring resistance (target-site mutations).

2.4.2.2. Fungicides

Fungicides are the predominant treatment method employed in vegetable crops and industrial tomatoes. Analysis of data reported in **Table 12**, shows that 23 active ingredients, classified into 16 main chemical families are identified, with various modes of action.

According to **Table 12**, over the past five years, Mitochondrial Respiration Inhibitors, specifically strobilurins, have been the most prevalent mode of action, with the highest frequency of active substance usage, following this, Cellulose Synthesis Inhibitors. Other modes of action, such as RNA Synthesis Inhibitors, Protein Biosynthesis Inhibitors and the Enzyme Inhibitors has the same frequence of repetation while the Ergosterol Biosynthesis Inhibitors, Succinate Dehydrogenase Inhibitors, Cell Membrane Biosynthesis Inhibitors, Spore Germination Inhibitors has the same frequence.

Due to the high frequency use of the QoIs and the cellulose synthesis inhibitors comparing to other modes of action, the probability of resistance is high too, **Hawkins et *al.* (2019**) confirmed the existence of the QoIs resistance commonly conferred by the G143A substitution in mitochondrially encoded target site cytochrome *b*. while **Acebes et *al.* (2010)** has found resistance on cellulose synthesis inhibitors at *Arabidopsis* but not on fungi.

Yin et *al.* (2023) reported that:

- Sterol demethylation inhibitors (DMIs) resistance mechanisms have been well reviewed for several important phytopathogenic fungi including *Fusarium graminearum*, *Venturia effusa*, *Fusarium. fujikuroi*, and *Penicillium digitatum.*

- Succinic dehydrogenase inhibitors (SDHIs) resistance mechanisms have been intensively studied. Single point mutations have been noticed in *Botrytis cinerea* and *Fusarium graminearum.*

- Oxysterol-binding protein inhibitor (OSBPI) resistance has been detected in *Plasmopara viticola*, *Pseudoperonospora cubensis*, and *Phytophthora infestans* isolates**.** Resistance of plant pathogenic oomycetes to OSBPI fungicide is mainly caused by point mutations of the target, OSBP-related protein 1.

Table 12: Fungicides active ingredients commonly used in vegetable crops and industrial tomatoes treatment

N°	Active ingredients	Number of usage / 13 interviews	Chemical family/ Chemical group	Mode of Action/Target
1	Metalaxyl-M	6	Phenylamides	Inhibition of RNA Synthesis
2	Pyraclostrobine	5	Strobilurins	Inhibition of mitochondrial respiration
3	Chlorothalonil	4	chloronitriles	Inhibition of protein biosynthesis
4	Cymoxanil	4	Acetamids	Inhibition of cellulose synthesis
5	Difenoconazole	4	Triazoles	Inhibition of ergosterol biosynthesis (IBS)
6	Dimethomorphe	4	Morpholines	Inhibition of cellulose synthesis
7	Fosetyl-Aluminium	4	Phosphonates	Inhibition of pathogen growth (inhibit mycelium development)
8	Fenamidolone	4	Imidazolinones	Inhibits the respiratory chain
9	Thiophanate Methyl	4	Benzimidazoles	Inhibition of fungal DNA synthesis Inhibitor of cell division
10	Boscalid	3	Carboxamides	Succinate dehydrogenase (SDH) inhibition (SDH is essential for the cellular respiration process)
11	Azoxystrobine	3	Strobilurins	Inhibition of mitochondrial respiration
12	Propamocarb	3	Carbamates	Inhibition of cell membrane biosynthesis
13	Propinebe	3	Carbamates (dithiocarbamates)	It interferes with cellular respiration
14	Cuprocalcium Sulphur	3	Mineral products	Sulfur works by inhibiting the growth and development of pathogenic fungal spores.
15	Sulphur	3	Mineral products	
16	Ametoctradin	2	Pyrimidylamines	Inhibition of QoSI mitochondrial respiration (blocks ATP production)
17	Mancozebe	2	Carbamates (dithiocarbamates)	It inhibits the activity of enzymes involved in cellular respiration and in the biosynthesis of mushroom proteins. Mancozeb prevents the growth and reproduction of fungi
18	Copper Oxychloride	2	Mineral products	Interfering with the cell membranes of pathogenic fungi. Disrupts the metabolism of fungal cells by inhibiting various vital enzyme processes.
19	Iprovalicarbe	1	Carbamate	Acts on the development of fungi
20	Mandipropamid	1	Amides of Mandelic Acid	Inhibitor of cellulose synthase, an enzyme involved in the biosynthesis of cellulose
21	Trifloxystrobine	1	Strobilurins	Acts mainly on the germination of spores by inhibiting cellular respiration
22	Fluopicolide	1	Benzamides	Disruption of cytoskeletal proteins. Delocalization of spectrin-like proteins.
23	Benalaxyl	1	phenylamides	Prevents spore germination, destroys the formation of germ tubes and mycelia already present in tissues, and prevents sporulation.

2.4.2.3. Insecticides

Analysis of obtained data for insecticides use, revealed the presence of 19 distinct active ingredients, belonging at 9 principal chemical families **(Tab. 13**).

The study of **Zhang et *al.* (2016)** shows that intensive use of pyrethroids over the last decades has led to selection of numerous mutations in sodium channels (SCBIs) in various arthropod populations, which confer resistance to pyrethroids. Resistance to SCBIs recently emerged in populations of various agricultural pests. Two mutations, F1845Y and V1848I, in the sodium channel of the diamondback moth, *Plutella xylostella.*

Crossthwaite et *al.* (2017) has found that *Myzus persicae* has high level resistance to all commercialized neonicotinoids. Resistance was also detected in *Nilaparvarta lugens* and *Drosophila melanogaster* (Fruit fly) at high level.

2.4.2.4. Acaricides

Provided data for acaricides utilization reveals that various commercial phytosanitary products are used to control vegetables. **Table 14** indicate the presence of 9 different active ingredients, belonging at 8 principal chemical families. Growth and lipid synthesis inhibitors and allosteric modulators of glutamate-gated chloride channels (GluCl) are the most dominant mode of actions.

Two main mechanisms contribute to resistance against acaricides in (*Tetranychus urticae*). **Marcic (2012)** reported increased detoxification enzyme activity as a factor in resistance to Chlorfenapyr and Clofentezine. Additionally, **Zhang et *al.* (2022)** identified insensitivity of the target site, the glutamate-gated chloride channel (GluCl), as a mechanism for resistance to abamectin, which acts through allosteric modulation of GluCl.

Table 13: Insecticides active ingredients commonly used in vegetable crops and industrial tomatoes treatment

N°	Active ingredients	Number of usage / 13 interviews	Chemical family/ Chemical group	Mode of Action/Target
1	Lambda-Cyhalothrine	**4**	Pyrethroids	Sodium channel modulators Nervous system
2	Chlorantraniliprole	**4**	Diamines	Ryanodine receptor modulators Nervous system and uncontrolled muscle contraction, paralysis and then death
3	Deltamethrine	**3**	Pyrethroids,	Sodium channel modulators Nervous system
5	Acetamipride	**3**	Neonicotinoids	Binding to the nicotinic acetylcholine receptor, with interruption of nerve impulse transmission
6	Abamectin	**3**	Avermectins	Allosteric modulators of glutamate-gated (GluCl) chlorine channels Nervous System and Muscle
7	Cypermethrine	**3**	Pyrethroids,	Sodium channel modulators Nervous system
8	Thiamethoxam	**2**	Neonicotinoids	Modulators of nicotinic acetylcholine receptor (nAChR) competitors Nervous system
9	Alpha-Cypermethrine	**2**	Pyrethroids,	Sodium channel modulators Nervous system
11	Cartap Hydrochloride	**1**	Nereistoxin analogues	Nicotinic Acetylcholine Channel Receptor Blockers Nervous system
12	Chlorpyriphos	**1**	Organophosphorus	Inhibitor of the enzyme acetylcholinesterase, with interruption of nerve impulse transmission.
13	Spiromesifen	**1**	Derivatives of tetronic and tetramic acids	Inhibiteurs de l'acéty CoA carboxylase Regulation of growth and lipid synthesis
14	Tefluthrine	**1**	Pyrethroids,	Sodium channel modulators Nervous system
15	Diflubenzuron	**1**	Benzoylureas	Chitin biosynthesis inhibitors, type 0 Growth regulation
16	Lufenuron	**1**	Benzoylureas	Chitin biosynthesis inhibitors, type 0 Growth regulation
17	Methiocarb	**1**	Carbamates	Acetylcholinesterase (AChE) inhibitors Nervous system
18	Emamectin Benzoate	**1**	Avermectins	Allosteric modulators of glutamate-gated (GluCl) chlorine channels Nervous System and Muscle
19	Imidacclopride	**1**	Neonicotinoids	Nicotinic acetylcholine receptor antagonist

Table 14: Acaricides active ingredients commonly used in vegetable crops and industrial tomatoes treatment

N°	Active ingredients	Number of usage / 13 interviews	Chemical family/ Chemical group	Mode of Action/Target
1	Abamectin	**4**	Avermectins	Allosteric modulators of glutamate-gated (GluCl) chlorine channels Nervous System and Muscle
2	Spiromesifen	**4**	Derivatives of tetronic and tetramic acids	Inhibiteurs de l'acéty CoA carboxylase Regulation of growth and lipid synthesis
3	Tebufenpyrad	**2**	Pyrazol-carboxamides	Mitochondrial Complex I Electron Transporter Inhibitors Breathing
5	Acetamipride	**1**	Neonicotinoids	Binding to the nicotinic acetylcholine receptor, with interruption of nerve impulse transmission
6	Paraffinic Mineral Oil	**1**	Hydrocarbons	Acts on the nervous system and respiratory system, as well as suffocation by spiracle or tracheal blockage.
7	Lambda-Cyhalothrine	**1**	Pyrethroids	Sodium channel modulators Nervous system
8	Chlorantraniliprole	**1**	Diamines	Ryanodine receptor modulators Nervous System and Muscle
9	Clofentezine	**1**	Clofentezine	Mite growth inhibitors Growth regulation

2.4.3. For fruit trees

2.4.3.1. Herbicides

In fruit trees, herbicides have the lowest frequency of use among all crops. We distinguished eight active ingredients belonging to seven chemical families with diverse modes of action **(Tab. 15).**

Table 15: Herbicides active ingredients commonly used in treatment of fruit trees

N°	Active ingredients	Number of usage / 13 interviews	Chemical family/ Chemical group	Mode of Action/Target
1	Glyphosate	1	Organophosphorus	Inhibitor of aromatic amino acid synthesis
2	Oxyfluorfene	1	Diphenyl ethers	Protoporphyrinogen oxidase (PPO) inhibitor (inhibition of chloroplast synthesis)
3	Quizalofop-P-Ethyl	1	Aryloxyphenoxy-propionates (FOPs)	Acetyl-CoA carboxylase inhibitors (disrupts the biosynthesis of branched-chain amino acids (valine, leucine and isoleucine)),
4	Pendimethaline	1	Dinitroaniline	Microtubule assembly inhibitor. Inhibitor of cell division
5	Sulfosulfuron	1	Sulfonylureas	Inhibition de l'ALS (Acétolactate Synthase)
6	Fluazifop-P-Butyl	1	Aryloxyphenoxy-propionates (FOPs)	Inhibiteur de l'acétyl-CoA carboxylase
7	Metribuzine	1	Triazinones	Inhibition of photosynthesis at the level of photosystem II
8	2,4 -D-Ester	1	Phenoxyacetates	Mimicking the action of auxin (disrupting the regulation of plant cell growth)

Dependence on a single herbicide or herbicides with the same mode of action lead to the evolution of resistance**, Makhan Singh et *al*. (2017)** reported that:

- Acetolactate synthase (ALS) and acetyl coenzyme A carboxylase (ACCase) inhibitors are highly vulnerable to the evolution of herbicide resistance in weeds.
- Molecular studies have confirmed that herbicide resistant biotypes that have mutation at sites Ile1781Leu, Asp2078Gly, Cys2088Arg, can exhibit cross resistance to three sub-groups – aryloxyphenoxypropionate.

Chen et *al.* (2021), have shown that the use of pre-emergence herbicides such as dinitroanilines has increased, in part because of the relatively slow evolution of resistance to these herbicides in weeds. Target-site resistance (TSR) to dinitroaniline herbicides caused by point mutations in α-tubulin genes has been confirmed in a few weed species (e.g. *Eleusine indica*, *Setaria viridis* and, more recently, *Lolium rigidum*). Of particular interest is the resistance mutation Arg-243-Met identified in dinitroaniline-resistant *L. rigidum*, which causes helical growth when plants are homozygous for the mutation.

Baek et *al.* (2021), research noted a distribution of 38 glyphosate-resistant species, such as *Amaranthus palmeri* and *Amaranthus tuberculatus*, which were the first weeds to develop resistance at such active ingredient. **Schulz and Segobye (2017)** have studied the nature of resistance to 2,4-D in previously described resistant biotypes of wild radish (*Raphanus raphanistrum*).

2.4.3.2. Fungicides

In contrast to other pesticides, fungicides are the most frequently used for fruit trees (**Tab. 16**). Our data analysis has identified 14 distinct active ingredients belonging to 11 chemical families, all with varying modes of action to control fungal diseases.

Hahn (2014) reveals that:

- The *Botrytis cinerea* resistance development occurred very quickly due to frequent benzimidazole applications,
- The strobilurins (quinone outside inhibitors or *QoIs*) are respiration inhibitors that interact with the Qo site of the mitochondrial cytochrome bc1 complex. They are highly active against a variety of fungi and oomycetes but considered to be less effective against *B. cinerea* which contains an alternative terminal oxidase that can bypass the inhibition of the respiratory chain.
- The Mutations conferring Boscalid resistance (Carboxamides used in Guelma) have appeared in *B. cinerea* populations few years after its introduction.

Table 16: Fungicides active ingredients commonly used in treatment of fruit trees

N°	Active ingredients	Number of usage / 13 interviews	Chemical family/ Chemical group	Mode of Action/Target
1	Sulfate tetra cuivrique tricalcium	**1**	Substance inorganique	Prevents spore germination
2	Sulphur	**1**	Mineral products	Growth and development inhibitor
3	Thiophanate-Methyl	**1**	Benzimidazoles	Inhibition of fungal DNA synthesis Inhibitor of cell division
4	Boscalid	**1**	Carboxamides	Succinate dehydrogenase (SDH)
5	Pyraclostrobine	**1**	Strobilurins	Inhibition of mitochondrial respiration
6	Copper Oxychloride	**1**	Substance inorganique	Disruption of the respiratory, enzymatic and membrane activities of the fungus
7	Dodine	**1**	Guanidines	Disruptor of cell membrane integrity
8	Copper Hydroxide	**1**	Inorganique substance	Disruption of the respiratory, enzymatic and membrane activities of the fungus
9	Capture	**1**	Phthalimides	Blocks the breathing mechanism
10	Proquisitivity	**1**	Quinazolinone	Acts on spore germination by blocking the development of appresorium (germination tube)
11	Metalalxyl	**1**	Phenylamides	RNA polymerase inhibitor
12	Mancozebe	**1**	Carbamates (dithiocarbamate)	It inhibits the activity of enzymes involved in cellular respiration and in the biosynthesis of proteins. Prevents the growth and reproduction of fungi.
13	Difenoconazole	**1**	Triazoles	Inhibition of ergosterol biosynthesis (IBS)

Brent and Hollomon (2007), studies of resistance to SBIs (sterol biosynthesis inhibitors) such as triazoles demonstrate that they have a site-specific mode of action, and resistant mutants have been obtained in the laboratory by mutagenic treatment. During the 1980s, active resistance evolves in several pathogens (e.g. powdery mildew, *Venturia inaequalis*, *Mycosphaerella fijiensis var difformis*). **Deising, et *al*. (2008)** reported occurrence of resistance to Phenylamides, the *Phytophthora infestans* and *Plasmopara viticola* resistance was first reported in 1980.

Beckerman (2018), reported that, if a single fungicide continues to be used, the fungicide sensitive portion of the population is suppressed over time, and only the fungicide-resistant portion of the population remains, which goes on to reproduce and make up the majority of the population. Eventually, the fungicide is ineffective because this majority of the fungal population is no longer susceptible to it. To minimize the possibility of fungicide resistance from occurring, implement a comprehensive management strategy before resistance develops must be used and it include many practices:

1. Follow good plant health practices: Proper planting, pruning, fertilization, and sanitation can reduce reliance on fungicides, which in turn can lower the risk of their over-use and resistance.

2. Use the recommended doses as stated on fungicide labels.

3. Minimize the number of fungicide treatments per season, and apply only when necessary.

4. Do not rely solely on one fungicide with a site-specific mode of action. Use a diversity of fungicides with different modes of action that provide broad-spectrum disease control.

According to the same author, *Tank-mixing* and *Rotating*, are two tactics that can reduce the risk of fungicide resistant disease populations: tank-mixing consists of mixing a fungicide with a high resistance risk with another fungicide with a low or negligible resistance risk. Rotating fungicides involves alternating products that have different modes of action. Tank-mixing and rotating are important for two reasons. First, both practices limit the amount of time fungi are exposed to any one product. Second, other fungicides could potentially suppress any resistant populations before they have a chance to reproduce.

2.4.3.3. Insecticides

Insecticides are the second most frequently used pesticide category in fruit production (**Tab. 17**). Our study identified 11 distinct active ingredients from 8 chemical families, each with unique mode of action to target various insect pests.

Table 17: Insecticides active ingredients commonly used in treatment fruit trees

N°	Active ingredients	Number of usage / 13 interviews	Chemical family/ Chemical group	Mode of Action/Target
1	Lambda- Cyhalothrine	2	Pyrethroids,	Sodium channel modulators Nervous system
2	Abamectin	2	Avermectins	Allosteric modulators of glutamate-gated (GluCl) chlorine channels Nervous System and Muscle
3	Cypermethrine	2	Pyrethroids,	Sodium channel modulators Nervous system
4	Lufenuron	2	Benzoylureas	Chitin biosynthesis inhibitors, type 0 Growth regulation
5	Paraffinic Mineral Oil	2	Hydrocarbures	Acts on the nervous system and respiratory system, as well as suffocation by spiracle or tracheal blockage.
6	Deltamethrine	1	Pyrethroids	Sodium channel modulators Nervous system
7	Acetamipride	1	Neonicotinoids	Binding to the nicotinic acetylcholine receptor, with interruption of nerve impulse transmission
8	Pyrimicarbe	1	Carbamates	Inhibits colinesterase
9	Diflubenzuron	1	Benzoylureas	Chitin biosynthesis inhibitors, type 0 Growth regulation
10	Cyantraniliprole	1	Diamines	Ryanodine receptor modulators Nervous system and muscle
11	Chlorpyriphos- Ethyl	1	Organophosphorus	Inhibitor of the enzyme acetylcholinesterase, with interruption of nerve impulse transmission.

A study by **Lv et *al.* (2022)** found that the diamondback moth (*Plutella xylostella*) has developed resistance against the insecticide lufenuron. Lufenuron belongs to the class of insecticides known as chitin biosynthesis inhibitors.

2.4.3.4. Acaricides

Our investigation identified 4 distinct active ingredients belonging to 3 chemical families. These acaricides possess diverse modes of action to combat various mite infestations (**Tab. 18)**.

Table 18: Acaricides active ingredients commonly used in treatment fruit trees

N°	Active ingredients	Number of usage / 13 interviews	Chemical family/ Chemical group	Mode of Action/Target
1	Abamectin	1	Avermectins	Allosteric modulators of glutamate-gated (GluCl) chlorine channels Nervous System and Muscle
2	Deltamethrine	1	Pyrethroids	Sodium channel modulators Nervous system
3	Lambda-Cyhalothrine	1	Pyrethroids	Sodium channel modulators Nervous system
4	Tebufenpyrad	1	Pyrazol-carboxamides	Mitochondrial Complex I Electron Transporter Inhibitors Breathing

Vandenhole (2023), reveals that a mutation in the Glutamate-gated chloride channel (GluCl) gene of the spider mite *Tetranychus urticae* has been identified. This mutation (G314D or G326E) is known to confer resistance against the acaricide abamectin, even though abamectin does not target the GluCl channel. Also, **Herron and Rophail (2001)** have confirmed that, tebufenpyrad control failures to the development of resistance in *Tetranychus urticae*, specifically resistance to Mitochondrial Complex I Electron Transporter Inhibitors (METIs).

Conclusion

Conclusion

The agricultural sector in Algeria is one of the most important sectors, it has several characteristics, including the high use of pesticides. A survey of chemical pest control practices in crop production in Guelma region, conducted between 2019 and 2024, focused on four major crop types in the region, cereal, vegetable (excluding tomatoes), industrial tomato and fruit trees. This study highlights the following points :

- On cultivated area of 529,118 hectares, 96% of it received pesticides treatment.
- The quantities applied during the five years are 1755,631 Tons. The total amount of pesticides used varies by year, crop type, treatment type, number of treatments, treatment period and climatic conditions. This substantial amount is considered important.
- The different studied crops do not receive the same quantities and types of treatment.
- In cereal cultivation, herbicides are the most frequently applied pesticides, followed by fungicides, while insecticides have less use on cereals.
- In industrial tomatoes, fungicides consistently show the highest usage, Insecticides are also used extensively followed by acaricides who maintain a moderate level of application while the herbicides are the least used among the four types of pesticides.
- In vegetable crops, only two types of pesticides are applied. Insecticides usage remains higher than fungicides usage.
- In fruit trees, insecticides exhibit high usage, fungicides taking the second place on the frequency of use, acaricides and herbicides are used in smaller quantities.

Using pesticides with the same active ingredient or using different active ingredients with the same mode of action can lead to the development of resistance in pests. To reduce the development of resistance in pests, it is essential to apply some principal recommendations such as:

- Diversifying crop rotation to limit the development of diseases: alternating winter, spring, and summer crops, choosing different varieties, adjusting sowing density, etc.
- Combining control methods (chemical, biological, and physical).
- Alternating and/or combining active substances with different modes of action.
- Following pesticide usage recommendations to ensure maximum effectiveness (respecting appropriate doses and treatment stages).
- Optimizing treatment timing using decision support tools.

- Complying with pest threshold levels for insecticides.
- Optimizing the application of treatments (adjusting nozzles).

These results are useful for managing the intensive use of pesticides in agriculture and encouraging the use of other treatment methods like the biological control based on natural substances (biopesticides), with a view to limiting the use of chemical products to avoid the emergence of resistance, which is a major problem to manage, and also minimising their unintended effects on farmers, consumers and the environment.

In perspective of this study, it would be beneficial to compile a comprehensive list of active ingredients and their recommended dosages for combating the major pests and diseases prevalent in the region.

Abstracts

Abstract

In order to understand the situation of chemical control in crop protection in Guelma region, a survey was conducted over the last five years, between 2019 and 2024. It involved various interveners in the agricultural sector of the wilaya, including distributors of phytosanitary products, the Cereals and Dried Vegetables Cooperative (CCLS), and the Agricultural Supply Service Cooperative (CASAP), as well as users of these products, such as pilot farms and farmers. The survey focused on four major types of crops: cereals, vegetable crops (excluding tomatoes), industrial tomatoes, and fruit trees. The collected data revealed that different types of active substances, belonging to different chemical groups and modes of action, are used for the treatment of various crops. However, considerable amounts of pesticides are used each year in the wilaya, and the same active substances have been employed every year since 2019, which may promote the development of resistance to these products among pests and parasites.

Key words: chemical control, crop protection, pesticides, active ingredient, resistance.

Résumé

Dans le but de connaître la situation de la lutte chimique dans la protection des cultures dans la région de Guelma, une enquête a été menée sur les cinq dernières années, entre 2019 et 2024. Elle a concerné différents intervenants du secteur agricole de la wilaya, notamment les distributeurs de produits phytosanitaires, la Coopérative des Céréales et des Légumes Secs (CCLS) et la Coopérative Agricole de Service des Approvisionnements (CASAP), ainsi que les utilisateurs de ces produits, tels que les fermes pilotes et les agriculteurs. L'enquête a porté sur quatre types principaux de cultures : la céréaliculture, les cultures maraîchères (autres que la tomate), la tomate industrielle et les arbres fruitiers. Les données collectées ont révélé que différents types de matières actives, appartenant à différents groupes chimiques et à différents modes d'action, sont utilisés pour le traitement des différentes cultures. Cependant, des quantités considérables de pesticides sont utilisées chaque année dans la wilaya, et les mêmes matières actives sont employées chaque année depuis 2019, ce qui peut favoriser l'apparition de résistances à ces produits chez les parasites et les ravageurs.

Mot clés : lutte chimique, protection des cultures, pesticides, matières actives, résistance.

ملخص

بهدف معرفة وضع المكافحة الكيميائية في مجال حماية المحاصيل الزراعية في ولاية قالمة، تم إجراء دراسة استطلاعية على مدى السنوات الخمس الماضية، بين عامي 2019 و2024. وشملت مختلف الأطراف الفاعلة في القطاع الزراعي في الولاية، بما في ذلك موزعي منتجات الصيدلة النباتية مثل بائعي المبيدات وتعاونية الحبوب والبقول الجافة (CCLS) وكذا تعاونية خدمات الإمدادات الزراعية (CASAP) بالإضافة الى مستخدمي هذه المنتجات مثل المزارع النموذجية والمزارعين. تم التركيز في هذا الاستطلاع على أربعة أنواع رئيسية من المحاصيل: الحبوب، ومحاصيل الخضروات (باستثناء الطماطم)، والطماطم الصناعية، وأشجار الفاكهة. وكشفت البيانات التي تم جمعها، ان أنواعاً مختلفة من المواد الفعالة التي تنتمي إلى مجموعات كيميائية مختلفة ذات مواقع تأثير مختلفة، تستخدم في معالجة مختلف المحاصيل الا أنه، يتم استخدام كميات كبيرة من المبيدات كل عام في الولاية، ويتم استخدام نفس المواد الفعالة كل عام منذ عام 2019، مما قد يعزز ظهور مقاومة ضد هذه المنتجات بين الآفات والطفيليات.

الكلمات مفتاحية: المكافحة الكيميائية، حماية المحاصيل، المبيدات، المواد الفعالة، المقاومة

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