CHAPTER 1. PREVALENCE, SPECIES STRUCTURE OF CRUCIFEROUS DISEASES AND THEIR HARMFULNESS

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1.1. Importance, species structure of the main cruciferous crops and their fungal diseases

Oilseed cruciferous crops occupy more than 29.39 million hectares of agricultural land in the world with a total yield of 17 quintal/ha on average. The ability to survive and grow at low temperatures allows them to be successfully grown in cool agricultural regions, in the highlands and as a winter crop in the subtropics. Small round seeds of oilseeds contain more than 40% of oil in terms of dry matter, and after oil extraction, they are used to produce meal containing more than 40% of high-quality protein. In Western countries, the meal is used exclusively as feed for livestock and poultry, and in many countries it is used as an organic fertilizer for field crops.

The Brassicaceae family includes approximately 3.500 species in 350 different genera of many important crops that produce high-quality edible and industrial oil and vegetables. Based on the evidence that some types of vegetables were widely used in the Neolithic era [11–12], and direct references to rapeseed and mustard in ancient Indian Sanskrit writings of 2000-1500 BC [13]. Vegetable and oil cruciferous crops may have been among the first plants domesticated by humans. Greek, Roman and Chinese writings from 500-200 BC also mention these crops and their medicinal value [14]. Oilseed rape was introduced in China and Japan around the time of Christ [15] although its cultivation began in the thirteenth century in Europe, its industrial use was not widespread until its excellent qualities as a food and technical oil were recognized [16]. The use of cruciferous

crops as edible vegetable oil in Western countries is relatively recent. Unlike most other oilseeds, rapeseed comes from several species of the genus Brassica [17], including *B. napus* L., *B. rapa* L. (*B. campestris* L.) and *B. juncea* (L.) Czern. & Coss. which are known as rapeseed, rape and mustard, respectively.

Since prehistoric times, many cruciferous species have been cultivated for their edible roots, stems, leaves, buds, flowers, and seeds. Although the cultivation of this group of crops began in Europe as early as the 13th century, their industrial use did not become widespread until the 1930s when the qualities of cruciferous vegetable oils were established for lubrication and biofuel use [18]. It began to be used as edible oil even later, as the nutritional properties of previous cruciferous varieties were technologically poor, and the high content of erucic acid and glucosinolates gave the oil an unpleasant bitter taste. Varieties low in glucosinolates and erucic acid were developed through conventional breeding and were originally produced in Canada under the trade name 'Canola', defined as an oil that should contain less than two percent erucic acid and less than 30 micromoles of glucosinolates per gram of air-dried, oil-free meal. Since then, canola has become a generic term for these "double low" varieties in North America [19].

Rapeseed is mainly grown in temperate climates (Figure 1). In recent decades, rapeseed production has increased in all major growing regions: Canada, Europe, China, India and Australia [20]. *Brassica napus (winter)* and *B. rapa (spring)* are two types of rapeseed grown in different parts of the world. Globally, there is no discrimination between *B. napus* and *B. rapa* on the harvested seed market. There are varieties of both types for spring and fall sowing, which gives producers a choice of two types of crops*:* spring oilseed rape *(Brassica rapa)* and winter oilseed rape *(Brassica napus)*. In most cases*, B. napus* is more productive than *B. rapa,* but *B. rapa* matures earlier [21]. Winter rapeseed (*B. napus* var. *biennis*) is grown in regions where the crop does not die in winter, but where the regions are classified as Cfb and Dfb. In regions with harsh climatic conditions, spring rape and other types of spring cruciferous crops are grown in winter. Rapeseed is a highly profitable crop if managed properly, and the advantages of growing rape over cereals in crop rotations are widely reported [22–24].

The benefits of cruciferous crops include soil improvement, which leads to increased nutrient and water absorption. In addition, as a preceding crop, cruciferous crops suppress cereal diseases [25].

Cruciferous crops are often grown in short crop rotations: in Europe, in arable crop rotations – once every three years, and in Canada – every second year [26]. The introduction of high-yielding varieties has increased the profitability of rapeseed production, but some diseases and insect pests have a negative impact on this production. In a global study conducted in 2019 [27], The main biotic constraints have been reported to be caused by soil pathogens such as Plasmodiophora brassicae (clubroot) and Verticillium longisporum (Verticillium wilt), as well as stem pathogens such as Sclerotinia sclerotiorum (sclerotinia stem rot), Lepthospaheria maculans and L. biglobosa (blackleg or stem cancer (phomosis)), Alternaria spp. (black spot, dark spot (alternaria) of leaves and pods), Pseudocercosporellae capsellae (white leaf spot) and Pyrenopezizia brassicae (light leaf spot). Some of these diseases are recorded only in certain regions, while others, such as sclerotinia stem rot, cause significant yield reductions in all major cruciferous growing regions of the world.

The high frequency of cruciferous crops in crop rotations increases the risk of breeding and spreading soil-borne diseases by moving contaminated soil through machinery to new fields, such as tuber blight, which has become a serious constraint on vegetable cruciferous production worldwide [28]. The growing spread of clubroot as a disease in the main production regions of Canada, the UK, Germany, Poland, the Czech Republic, China and other countries is the result of the practice of narrow crop rotations due to the growing demand for rapeseed oil [29–30]. Increased production of oilseeds and cruciferous vegetables due to increased demand for products requires strategies that combine different means of control, including pathogen avoidance, pathogen exclusion, host plant protection and host plant resistance [31]. Knowledge of the epidemiology of plant diseases is important for choosing the most effective management method or combination of methods to control crop diseases.

Each pathogen has a unique, often complex life cycle, and producers must make informed decisions to avoid disease outbreaks. Crop protection management is multifaceted, and growers must consider a number of factors, such as variety selection and agronomic practices. Often, the use

of chemical pesticides is the only direct measure to limit the negative impact of plant disease during the growing season. The EU Directive on the Sustainable Use of Pesticides (2009/128/EC) encourages integrated disease management, which involves a plant protection strategy that combines preventive measures such as forecasting disease outbreaks, crop rotation where the target crop is grown at intervals of several years, and variety selection in combination with direct measures such as pesticide use.

Thus, the commonly used names are [33] for B. napus – rapeseed, canola, oilseed rape, rape, rape, rape, and Argentine rape; for *B. rapa* – spring rape, and Polish rape; and for *B. juncea* – white mustard, oriental mustard, and Indian mustard (Figure 1.1). In China, all three species are grown, but the main source of rapeseed is winter rape. In India, rapeseed and mustard can be considered rapeseed, while in North America and Europe, spring and winter rapeseed, white and black mustard, and various forms of radish are distinguished. Other oilseeds of the Brassicaceae family include *B. rapa* L. var. *toria* (rapeseed, toria), *B. rapa* L. var. *brown Sarson* (rapeseed, brown Sarson), *B. rapa* L. var. *yellow Sarson* (rapeseed, yellow Sarson), *B. nigra* (L.) Koch (black mustard), *B. hirta* Moench (*Sinapis alba* L.) (white mustard), *B. carinata*, *A. Braun* (*Abyssinian mustard, Ethiopian mustard*), *B. tournefortii* Gouan (wild turnip), *Eruca sativa* Mill. (*E. vasicaria* spp. sativa (Mill.) Thell.) (taramira), *Camelina sativa* Crantz (red flax, false flax, Dutch flax, goldenrod), *Crambe abyssinica* Hochst. ex. O.E. Schulz and *C. hispanica* L. (crambe species), *Raphanus sativum* d. var. *oleifera* Metrg. (oil radish). Traditional varieties of rapeseed grown in many countries contain 22–60% erucic acid in the oil, and the high content of glucosinolates reduces the feed value of the meal. Since the late 1970s, the Canadian varieties *B. napus* and *B. rapa* have been genetically modified to increase the content of erucic acid and glucosinolates, and in 1979 these "double low" varieties were named "canola". Thus, the previously mentioned term "canola" refers to a canola variety that contains less than 30 pmol/g of one or any combination of the four known aliphatic glucosinolates (gluconapine, progoitrin, glucobrassic-canapine and napoleiferin) in the defatted meal, and less than 2% of the fatty acyl content of the oil is erucic acid. Recently, varieties of white mustard (*B. juncea*) of the canola type have also been developed in Canada.

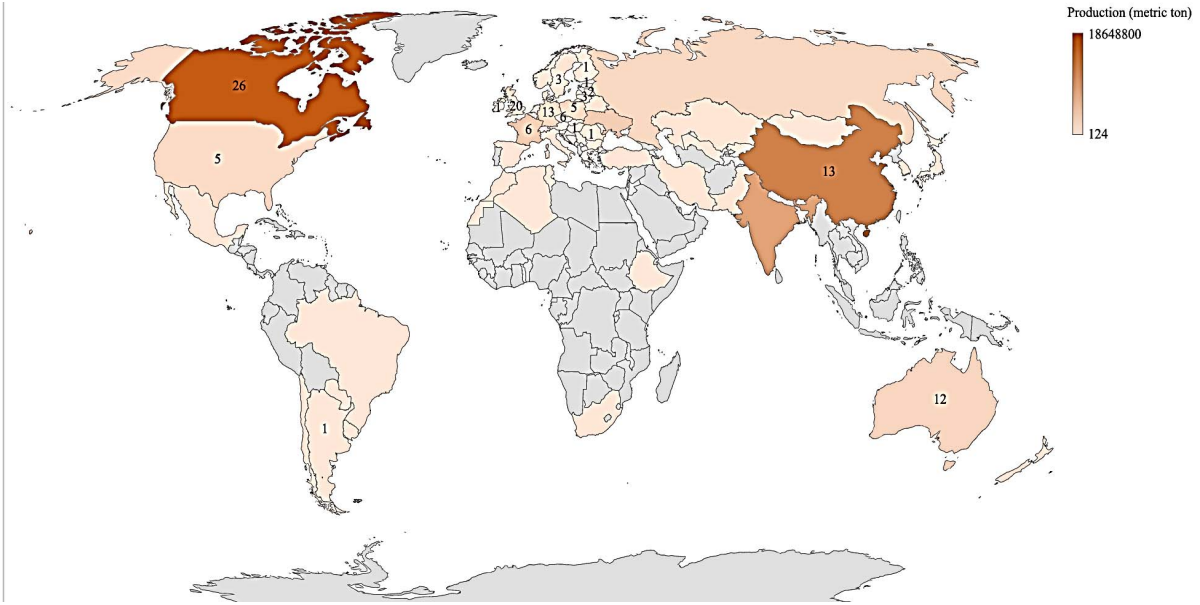

Figure 1 – Geographical location of articles on cruciferous crop diseases and global rapeseed production. Countries where research is being conducted, included in the systematic map, are marked with numbers indicating the number of studies conducted by each country. The color indicates the countries that produced rapeseed in 2022 [32]

The main groups of cultivated vegetables from the cruciferous family in the world practice of inventions are cabbage (*B. oleracea* L. var. *acephala*), including white cabbage, green cabbage, dwarf Siberian cabbage, narrow-stemmed cabbage, trochunda; cabbage (*B. oleracea* L. var. *captitata*, var. sabauda, var. bullata), including cabbage, Brussels sprouts and Savoy cabbage; kohlrabi (*B. oleracea* L. var. *gongylodes*. var. *botrytis*, var. *italica*), including cauliflower, broccoli, bush cabbage (B. oleracea L. var. fruticosa), cow cabbage, Chinese cabbage (B. alloglabra L.) and radish (*Raphanus sativus* L.) (Figs. 1.2, 1.3, 1.4).

Rapeseed oil is a relatively new oilseed crop, with commercial acreage growing in the United States, Poland, and some other countries. The oil is a potential raw material for the rubber and plastic industries.

Rapeseeds, including *B. campestris, B. juncea, B. napus*, and *B. carinata*, are an important group of oilseeds that account for almost 13.2% of the world's edible oil needs. Together, they cover about 29.39 million hectares with an annual production of 53.01 million tons worldwide. They are highly adaptable and often grown in different agro-climatic conditions around the world. Over the past two decades, the area and production of these crops have increased significantly, with total production almost tripling.

Other studies summarize that the Brassicaceae family includes 338 genera and 3709 species and contains many plants of economic importance as vegetable or perennial food crops, as well as industrial crops and animal feed crops. First, *B. napus* is one of the world's most important oilseeds. In recent years, global rapeseed production has exceeded 63.7 million tons, making it the world's second most important source of vegetable oils [36–37]. Secondly, *B. juncea* is both a condiment and an oilseed crop grown in areas with moderate to high temperatures, arid and short growing seasons, such as northern and western China, areas of northeastern Europe and arid regions of South Asia [38]. In addition, there are smaller areas of condiment and oil mustard, including mainly Indian mustard, but smaller areas of black mustard (*B. nigra*) and isolated areas of *Ethiopian mustard* (*B. carinata*) [39]. Third, until the 1950s, *B. nigra* was the dominant mustard crop. However, it was later commercially replaced by B. juncea in mustard production. In Europe and Asia, B. nigra was a rare crop in Europe and Asia, but has become more widespread in temperate areas [40]. In addition, there are several other cruciferous species that are regionally important

oilseeds, including spring rape, brown and yellow sarson, and toria (all *B. campestris*), taramira and arugula (*E. sativa* or *E. vesicaria*) [41] camelina (*Camelina sativa*).

Figure 1.1 – Cabbage family: 1 – flower; 2 – fruit; 3 – inflorescence; 4 – field cabbage; 5 – rape; 6 – field mustard; 7 – seed radish [34–35]

There are also important species of Brassicaceae that are used on a wide scale for fodder and vegetable production, including rapeseed (B. napus) [43], cabbage (*B. oleracea* var. *acephala*), radish, turnip (*B. rapa* var. *glabra*), rutabaga or swede, *Brussels sprouts* (*B. oleracea* var. *gemmifera*), cauliflower and Asian vegetables (*B. rapa* subsp., such as subsp. rapa and var. *pekinensis*) [44–45].

There is a steady upward trend in the global acreage of cruciferous crops, especially rapeseed. The upward trend of rapeseed production in the EU

countries continued in 2023 season. In particular, the harvest is expected to reach 19.6 mln tonnes compared to 19.1 mln tonnes a year earlier. The increase in the harvest of oilseeds is due to the expansion of the planted areas to the maximum level in the last 5 years – 5.94 mln ha, compared to 5.85 mln ha in 2022. Experts forecast the main increase in the area in France to 1.31 (1.23) mln ha and in Germany – to 1.15 (1.08) mln ha. Against this background, the production of the oilseed in these countries may increase to 4.55 mln tons (+1% per year) and 4.4 mln tons (+3%), respectively. In addition, analysts forecast the expansion of rapeseed acreage in Denmark and Sweden, which will also result in the increase of oilseeds harvest in this region. In turn, in the Baltic countries, rapeseed acreage will decrease by about 7%. At the same time, the production of rapeseed in this region this year may increase to 1.74 mln tonnes compared to 1.59 mln tonnes harvested in 2022. Rapeseed became widespread in Ukrainian farms after 2000, when its acreage increased more than 5 times, outpacing similar trends in sunflower. Seed production volumes have increased in recent years. This is primarily due to the growth of green energy and favorable external conditions on the global agricultural market. Another reason is the use of new, highly efficient technologies for growing the crop and high-quality seed material by producers, as well as the availability of satisfactory weather and climatic conditions for growing it in most regions of the country. There were also purely economic reasons, including high profitability of production and stable demand for rapeseed from domestic exporters and processing companies (Table 1.1).

Figure 1.2 – Types of cabbage (1 – red cabbage; 2 – white cabbage; 3 – cauliflower; 4 – kohlrabi; 5 – Peking cabbage; 6 – Brussels sprouts)

Figure 1.3 – Types of cabbage [42]

Table 1.1

Dynamics of changes in rapeseed acreage in all categories of farms in Ukraine [46]

Years	Winter and spring rape		The share of winter rapeseed, %
	(spring rape), thousand hectares	winter rape, thou hectares	
1990	89.7	84.2	93.9
2000	214.3	111.5	52.0
2010	907.4	800.5	88.2
2015	682.4	661.4	96.9
2018	1041.5	973.4	93.5
2019	1282.4	1252.5	97.7
2020	1126.6	1095.4	97.2
2021	1009.5	975.9	96.7

A significant increase in production was achieved not only due to the growth of sown areas, but also due to a significant increase in the productivity of its cultivation. In 2021, according to preliminary data,

the average yield of rapeseed reached the highest level in the history of statistical observations and amounted to 2.94 t/ha[46]

Most farms grow winter rapeseed, which has recently accounted for about 97% of all rapeseed acreage. At the same time, in 2000, the share of winter rapeseed varieties was only 52%, and in 2010 it increased to 88.2%. In 2021, this share was already almost 97%, with spring rapeseed accounting for 3% of the area.

Over the past 20 years, rapeseed production has grown at a record pace. While in 2000, about 132 thsd tonnes of rapeseed were produced, in 2021, according to preliminary data, 2557.2 thsd tonnes were already produced on the harvested area of 994.9 thsd hectares (98.5% of all sown areas) (Table 1.2).

Table 1.2

Dynamics of rapeseed production in all categories of farms in Ukraine [46]

Years	Harvested area, thousand hectares	Production volume, thousand tons	Yield, t/ha of harvested area
1990	89.6	130.2	1.45
2000	156.7	131.8	0.84
2010	862.5	1469.7	1.70
2015	671.1	1737.6	2.59
2018	1039.3	2750.6	2.65
2019	1279.2	3280.3	2.56
2020	1112.5	2557.2	2.30
2021	994.9	2924.1	2.94

In some regions, the average yield approached the record level of 3.6-3.8 t/ha. At the same time, in 13 of them, the yield level is below the average for all regions in general. In this case, agribusinesses are using a fairly effective intensification strategy to increase rapeseed production instead of expanding the acreage, as is the case with sunflower.

As you know, the key factor behind the growth of domestic rapeseed production is the increasing demand for it from the global agricultural market. Thus, according to the analysis of the latest USDA Oilseeds: World Markets and Trade for October 2021, in 2019/20 and 2020/21 marketing seasons there was an increase in the global market demand for rapeseed

and its products. This trend in the domestic market directly influenced the dynamics of the planted areas, which, due to relatively favorable weather conditions and higher average yields, led to the increase in the production and supply of rapeseed. The EU, Canada, China, and India are the major producers of rapeseed globally. According to the forecasts of USDA analysts, in 2021/2022 marketing season the total production in these countries will be about 52.6 mln tonnes or 78% of the global level. The main share of supply on the global rapeseed market is formed by the EU countries, where the forecasted production will reach almost 17.1 mln tonnes. At the same time, imports of rapeseed from China, Japan and the EU will decrease this marketing season. For domestic exporters, an important niche of the global agricultural market is not only seeds, but also their processed products, such as oil and meal. The analysis of the last two export destinations listed above indicates that the global domestic consumption of rapeseed oil and meal will remain at a fairly high level, which will lead to an increase in trade in these products in the future (Table 1.3).

The largest consumers of rapeseed are expected to be the EU (21.5 million tons), China (16.8 million), India (8.5 million) and Canada (almost 8 million tons).

Rapeseed is one of the most marginal and export-oriented crops. During the analyzed period of 2015-2021, the volume of rapeseed exports from Ukraine to the global agricultural market increased almost 8 times, and the revenue reached USD 4.2 billion. Exports of rapeseed oil have also increased in recent years (Table 1.4).

In 2021, the value of rapeseed oil exports amounted to $400.7 million, which is more than 5 times higher than in previous years. Currently, the interest of processing companies in rapeseed is growing.

Mustard production is also important for agricultural production. As noted above, several types of mustard have been introduced into the culture. Sarepta mustard (*Brassica juncea* L) originates from Southwest Asia. It is grown in India, Pakistan, Russia, Ukraine, Kyrgyzstan, and the North Caucasus. It grows as a weed in crops, along roads and near housing. Other types of mustard – white mustard (*Sinapis alba* L.), black mustard (*Brassica nigra* Koch.) are annual cultivated plants. Black mustard is cultivated in the southern part of Western Europe and West Asia, while white mustard is cultivated in Central and Northern Europe.

Table 1.3

Global balance of supply and demand in the market of rapeseed and its products (thousand tons), 2019–2021[46]

The marketing year	Rapeseed meal			Rapeseed oil			Rapeseed seeds		
	2019/20	2020/21	2021/22	2019/20	2020/21	2021/22	2019/20	2020/21	2021/22
China	9138	9442	9648	6039	6240	6377	13485	14000	14000
India	4170	4478	4657	2660	2854	2964	7400	8500	8500
Canada	5654	5936	4350	4434	4528	3350	19607	19485	13000
Japan	1280	1280	1270	1000	1000	991	4	4	4
EU	12027	12654	11913	8862	9324	8778	15241	16289	17100
Other countries of the world	7112	7272	6866	5025	5135	4849	13338	14229	14753
The world – in general	39381	41062	38704	28020	29081	27509	69075	72507	67357
Import									
China	1910	1900	1280	1940	2400	1600	2558	2800	2200
India	0	0	0	78	50	80	0	0	0
Canada	6	8	10	20	19	20	155	125	200
Japan	5	5	5	42	20	30	2242	2350	2200
EU	468	466	450	468	314	400	6211	5853	4975
Other countries of the world	5575	5839	5146	3246	3422	3276	4753	5304	4619
The world – in general	7964	8218	6891	5794	6225	5406	15919	16432	14194
Exports									
China	14	5	10	4	3	5	0	0	0
India	950	1100	1000	6	5	5	0	0	0
Canada	4904	5321	3950	3429	3439	2700	10043	10518	6300
Japan	6	0	0	2	2	2	0	0	0
EU	617	751	650	345	723	525	332	173	150
Other countries of the world	1230	1178	1329	2061	2214	2125	5530	6455	7761
The world – in general	7721	8355	6939	5845	6386	5362	15905	17146	14211
Domestic consumption									
China	11034	11337	10918	8146	8192	8200	15985	16450	16800
India	2950	3360	3600	2770	2720	2970	7600	8400	8510
Canada	710	652	436	1007	1013	985	10719	10760	7967
Japan	1288	1288	1275	1040	1035	1025	2305	2305	2285
EU	12000	12250	11950	8900	9040	8800	21700	22800	21525
Other countries of the world	11326	11799	10730	6257	6276	6083	12725	12944	12226
The world – in general	39308	40686	38909	28100	28276	28063	71034	73659	69313

Table 1.4

Exports and imports of rapeseed and rapeseed products in Ukraine [46]

Period	Product item	Export value, thousand dollars	Import value, thousand dollars	Trade balance, thousand dollars
2015	Rapeseed seeds	570107	19613	550494
	Rapeseed, mustard oils	109815	844	108971
2016	Rapeseed seeds	392474	22783	369691
	Rapeseed, mustard oils	68718	871	67847
2017	Rapeseed seeds	881549	32263	849286
	Rapeseed, mustard oils	51483	1492	49991
2018	Rapeseed seeds	49642	9656	59986
	Rapeseed, mustard oils	1386	606	780
2019	Rapeseed seeds	1247696	37605	1210631
	Rapeseed, mustard oils	118654	2246	116408
2021	Rapeseed seeds	4197365	138138	4059227
	Rapeseed, mustard oils	400723	9724	390998

It is mainly used to make Dijon mustard. Black mustard differs from Sarepta mustard by having clearer yellow corolla petals and smaller seeds. Mustard is a crop of multidirectional industrial importance due to its diverse use. The global production structure of mustard seeds is divided as follows: about 500 thousand tons are consumed for culinary purposes and about 2.7 million tons for production needs. It is grown to produce high-quality edible oil and green fodder for animals. In addition, mustard is widely known as a green manure crop because it has the unique ability to absorb hard-to-reach forms of nutrients from the soil and convert them into easily digestible forms. A by-product of fatty oil production (regardless of whether it is obtained by pressing or extraction), mustard meal, is of great interest to processors. After additional degreasing and grinding, it is converted into mustard powder, a product that is valued almost on par with oil. Mustard powder is the main ingredient in table mustard and mayonnaise, various sauces and condiments, marinades and canning mixtures. Its natural antiseptic properties due to its specific chemical composition and the presence of essential oil allow food producers to refuse to add artificial

preservatives to their recipes, which simultaneously reduces production costs and attracts consumers. The same conclusion has been reached by nutritionists from Canada, whose latest research shows that mustard seed processing waste can be used as a source of natural food preservatives. The extraction of sinapic acid from mustard seed meal can provide more choices for consumers when it comes to products containing preservatives [47].

Unfortunately, global mustard production cannot be accurately estimated. For example, India, a powerful world leader in mustard seed production, keeps statistical records under the item "Mustard + rapeseed" without separating this crop.

Ukraine has always been in the top five in terms of mustard production, but its local markets are not well integrated into the global turnover of mustard seeds and processed products, including due to differences in cultivated seed types and remoteness from the center of global production – the Asia-Pacific region [48].

Over the past ten years, global mustard acreage has fluctuated between 0.7 and 1.1 million hectares. For a long time, Canada has been the main player in the global food mustard market, accounting for up to 70% of export and import operations. The United States is also among the world's leaders in mustard production. However, statistics show that Americans do not have enough mustard of their own, so they still export it from Canada. Europe also faces a shortage of mustard. EU countries annually import up to 100 thousand tons of mustard seeds. This should be taken into account by Ukrainian farmers, especially since European purchase prices are much higher than in Ukraine.

Mustard of the highest quality that meets the developed standards is classified as food grade, and mustard that is not suitable for human consumption is classified as technical grade. Accordingly, Canada and the United States produce high-quality mustard, while the countries of the Black Sea region (Ukraine) produce ordinary food mustard. And the countries of the Indian continent (India, Nepal) grow both ordinary, food and technical mustard.

Ukraine is among the world's top ten countries in terms of mustard planted area. Ukraine's share of this seed production is 2% of global production, which is quite high and makes it one of the most important players in the global market (it is exported to 23 countries). Moreover,

the demand for Ukrainian mustard is higher due to its taste. This season, Germany and Hungary were the main importers of Ukrainian oil mustard.

The availability of markets, fertile land, moderate climate conditions, and a rich scientific base are the main advantages for growing this promising crop. Ukraine has the opportunity to successfully compete with the European market.

Thanks to increased professional capacity and favorable soil and climatic conditions, Ukraine has the potential to become a global leader in mustard production. At the same time, given the latest trends in climate change, there is a need to develop varietal mustard cultivation technologies for specific soil and climatic conditions.

Most of the mustard is grown in the southern regions of Ukraine, with about 26% of its crops, in particular, in Kherson region (15 thousand hectares). A significant part of the mustard area is also concentrated in Zaporizhzhia (8.7 thousand hectares) and Luhansk (8 thousand hectares) regions. Previously, Crimea, Luhansk and Donetsk regions were the main regions for growing mustard. Military actions have changed the trends of the Ukrainian market. However, Ukraine's weather and climate conditions allow for mustard to be grown throughout the country. The average yield of mustard is much higher compared to the rest of the world: from 1 to 1.2 t/ha of gray (Sarepta) mustard, 1.5 to 2.5 t/ha of white mustard for seeds and up to 30 t/ha of green mass.

With modern cultivation technologies, mustard can yield a harvest that is almost as good as rapeseed, and its production helps to "save farmers' nerves" in terms of the risks of unsatisfactory overwintering of rapeseed wedges in adverse weather conditions in winter. A vivid example of this is the situation that occurred in the 2011/12 season, when the degree of winter rape death reached 90–100%.

The winter mustard type has a much greater ability to maximize the use of autumn and winter moisture reserves, which is the main element of the soil water balance. Accordingly, domestic breeders have created modern varietal populations of mustard containing plants of winter, transitional, and varietal types, which, under favorable wintering conditions (relatively mild winters without sharp daily temperature changes), are able to produce high yields.

It is noted [49], that two types of mustard are most commonly used in production: gray or Sarepta mustard and white mustard, which belong to

different botanical genera. The seeds of both types are used to produce oil, mustard powder and alcohol, table mustard, etc.; the green mass is used as green manure or fodder. In recent years, due to the extremely high demand on the foreign market, black (French) mustard has also started to appear in the structure of sown areas.

The relatively greater popularity of gray mustard among other types of this crop is primarily due to its biological and ecological properties – drought resistance and the ability to form economically viable yields in areas with a high hydrothermal coefficient. Accordingly, the main areas under this type of mustard are concentrated in the Steppe and Southern Forest-Steppe. White mustard, which is more moisture-loving and cold-resistant, is grown in the northwestern regions of the country.

White mustard, compared to gray mustard, forms more leaves, accumulates biomass more intensively and in larger quantities, which is important when used for green manure. It has valuable phytomeliorative properties: its root secretions convert inaccessible, hardly soluble forms of potassium and phosphorus nutrients in the soil into available ones, and white mustard is also an excellent honey plant. The crop has a short growing season – 60–90 days before seeds are produced and 45–50 days before green mass is harvested. After 50–60 days, this crop provides a yield of 20.0–35.0 t/ha of green mass. The aboveground biomass contains 130–175 kg of nitrogen, 40–48 kg of phosphorus, and 50–187 kg of potassium. If the plants are plowed in the flowering phase, 3–5 tons of absolutely dry matter containing 120–130 kg of nitrogen, 180–190 kg of phosphorus, 130–140 kg of potassium, and 80–120 kg of calcium are introduced into the soil.

There are many advantages to using green manure crops. First of all, green fertilizers (green manure) are a source of significant soil replenishment with organic matter. The crop has a positive impact on soil structure and plays a significant phytosanitary role in reducing weeds, diseases and pests of agrocenoses. This contributes to a sharp reduction in the amount of crops treated with chemical plant protection products, which ensures the production of environmentally friendly products. Each hectare of mustard crop area leaves an average of 8.2 t/ha of plant mass after harvest, which, due to the absence of compounds in its chemical composition that inhibit bacterial decomposition, mineralizes very quickly, enriching the soil with

organic matter. Mustard can produce more than 850 kg of organic matter per hectare.

The technology of growing white mustard for green manure involves placing the crop on weed-free fields after cereals, legumes and row crops. For white mustard, it is advisable to apply mineral fertilizers at a dose of $N_{60-90}P_{45-60}K_{45-60}$. The post-harvest sowing period for mustard is the end of July in the northern regions and the first or second decade of August in the central and southern regions of Ukraine. It is sown in the early stages in the usual line method. The seeding rate is 15–20 kg/ha, and the seeding depth is 1.5–3 cm. It is sown with grain seeders.

Mustard is an excellent precursor for the vast majority of crops due to its agro-ecological properties. Due to its fast growth rate, mustard is sown even in late terms (late July – early August), after harvesting grain crops. Given these features of mustard biology, it is grown as both a main and intermediate crop. In addition, it improves the phytosanitary condition of the field. Mustard root secretions contain organic acids, which, when interacting with the soil, can convert a number of mineral nutrients into more accessible forms for the next crop and for their own needs.

The crop has a powerful phytosanitary effect – it reduces the accumulation of diseases such as cereal root rot, late blight, rhizoctonia, scab, and potato fusarium in the soil. It also radically reduces the infestation of the soil with wireworms. This is very important for monoculture grain growing.

The global market for mustard seeds is projected to be worth USD 1,084.8 million by 2032, up from USD 718.9 million in 2022, representing a USD of 4.2% [50]. During the period under review, global mustard production peaked in 2014, but declined slightly from 2015 to 2021. The countries with the highest production volumes in 2021 were Nepal, Canada and Ukraine, which together accounted for 64% of global production. From 2012 to 2021, production in Russia grew the most (average annual growth rate was +14.9%), while production in other world leaders grew at a more modest pace. In 2021, the average yield of mustard seeds in the world fell to 1.54 t/ha, which is -8.2% less than a year earlier. However, in general, the yield had a relatively even trend. The growth rate was the fastest in 2020, when the yield increased by 17%. During the study period, the average yield of mustard seeds reached a record high in 2016 – 2.3 t/ha, but from 2017 to 2021, the yield remained at a lower level.

Despite the increased use of modern agricultural techniques and methods, future yields may still be affected by unfavorable weather conditions. In 2021, the total harvested area under mustard in the world increased to 1.2 million hectares, which is 17% more than in the previous year. For the period from 2012 to 2021, the average annual growth rate of the planted area was +2.6%, but the trend shows some noticeable fluctuations that were observed throughout the analyzed period. The highest growth rates were recorded in 2018, when the area increased by 31%. The global harvested area peaked at 1.24 million hectares in 2019, but in the period from 2020 to 2021, the harvested area was slightly lower [51].

It should be noted that in 2021, Ukrainian agricultural producers supplied 35.4 thousand tons of mustard seeds to foreign markets, which is twice as much as in 2013. According to the Ukrainian Agribusiness Club, Ukraine is one of the largest exporters of mustard in the world. Canada, Germany, and India also supply large volumes of mustard seeds to foreign markets.

The main buyers of mustard are Germany, the United States, France, Nepal and Poland. Ukraine ranks fourth in terms of mustard production in the world. The largest volumes of mustard seeds are harvested annually in Canada (200 thousand tons), Nepal (150 thousand tons), Russia (90 thousand tons), Ukraine (40 thousand tons) and Myanmar (40 thousand tons). The sixth and seventh place is shared by the Czech Republic and China with an annual production of about 20 thousand tons of mustard seeds [52].

Mustard is very capricious and does not forgive mistakes. Farms that follow the technology closely get yields of up to 20–22 centner/ha. Of course, when everything coincides with the weather, and the agronomist is always on hand. Professionals understand that the optimal successful limit is a yield of 15 centner/ha. After this figure, the farm becomes a champion. If the farm has a high production culture, the grain doesn't even need a photo separator during processing, and the quality and purity immediately meet the standards. For those who do not strain themselves, invest little in cultivation and lose a lot during harvesting, the payback comes after 5–7 centner/ha. The most realistic way to achieve this is for farms that plan their crop rotation on a 5-year scale [53].

Mustard must be present in it, and it must return to the same place in at least 3 years. For example, in the Netherlands, 10% of the area must be allocated to mustard, and if everything goes well, it is used as a product,

otherwise it is used as green manure. Farms that will go through ups and downs due to weather conditions and other disasters will generally get a better financial result in such a system than those who decide to survive only on industrial crops.

Oilseed radish (*Raphanus sativum* d. var. *oleifera* Metrg.) (Figure 1.4) should be mentioned separately in terms of the prospects for the cruciferous market, which has long been considered a rare plant. However, since the mid-1970s, it has been used in spring post-mowing and post-harvest crops in the system of conveyor production of green fodder. Very quickly, this crop conquered new areas for various purposes not only in the former Soviet Union, but also in Poland, Germany, the Netherlands, and Finland. The culture was firmly established as an extremely plastic and high-yielding species, capable of growing from early spring to late autumn both in monoculture and in grass mixtures of various compositions, forming from 30 to 70 t/ha of leaf mass balanced in terms of digestible protein content in 40–50 days of vegetation.

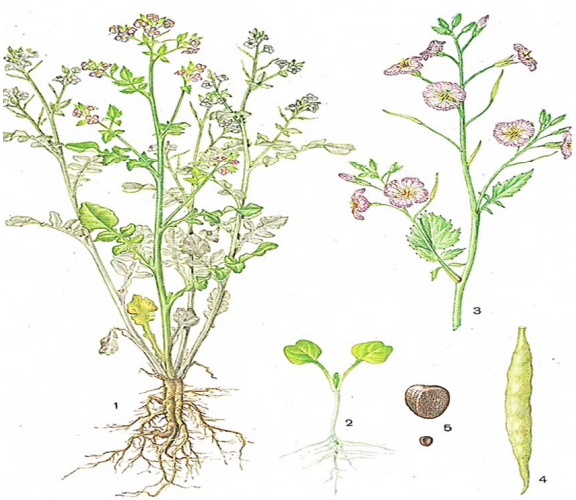

Figure 1.4 – General view of oilseed radish [54]: 1, 2 – plants in the phases of flowering – fruit formation and germination; 3 – the upper part of the stem in the flowering phase; 4 – fruit; 5 – seeds (the upper position is enlarged)

Multi-purpose study of this crop in different soil and climatic zones made it possible to formulate the main positive features that the crop potentially possesses: unpretentiousness to growing conditions and predecessor in crop rotation, high productivity and nutritional value, productive post-harvest and post-harvest use, high intensity of the root system functioning, relative tolerance to changes in sowing dates, fast growth rates, high positive reaction to mineral fertilization, high competitiveness to segetal vegetation, possible.

Unfortunately, in recent years, the area under oil radish in Ukraine has been 12–15 thousand hectares in single-species sowing and 45–50 thousand hectares in various feed mixtures. For comparison, in Russia 200–250 thousand hectares, Lithuania 100–120 thousand hectares, Poland 160 thousand hectares [55]. The reason for this, despite the multifaceted economic "portrait" of oil radish, is that the technology of its cultivation for fodder and seeds, optimized for the right-bank Forest-Steppe, is not sufficiently scientifically substantiated, given the ongoing climate change and degradation processes in the soil cover of Ukraine. As a result, when introducing new varieties of intensive oil radish into production, there is a need to establish optimal sowing dates, seeding rates and fertilization for sustainable production of fodder and seeds. In addition to rapeseed species, mustard species, radish species, and a wide range of vegetable cruciferous plants, the Brassicaceae family includes approximately 120 weed species, most of which are universal agricultural weeds such as field mustard (*Sinapis arvensis*), ragweed (*Thlaspi arvense*), while various species of *R. sativus* and wild radish (*R. raphanistrum*) form crop-weed complexes; some of these weed species have a natural ability to exchange genes and form transgenic forms with field crops [56–57].

It is reported [58], that the cabbage family (Brassicaceae) has been of interest to researchers for many decades, not only for its benefits to human health, but also in plant protection research due to the production of secondary metabolites such as glucosinolates and wax production on the leaf surface [59]. In addition, they are grown worldwide for the production of food and animal feed, edible oil, biofuels and biofumigants [60]. The family Brassicaceae includes many cultivated plants (e.g. *Brassica oleracea, B. napus, B. júncea, Armoracia rusticana* and many others), ornamental plants (e.g. Aubrieta, Iberis, Lunaria, Arabis, Draba and others)

and plants used as models in botanical sciences, such as *Arabidopsis thaliana*, *A. lyrata, A. halleri, B. napus*, *Capsella rubella, Thellungiella halophila, Arabis alpina* and others [61].

There is considerable potential to increase production and productivity of oilseeds and cruciferous vegetables through the selection of improved varieties that are resistant to biotic and abiotic stresses. Among the biotic factors that limit yields, diseases such as Alternaria, white rust, downy mildew, sclerotinia stem rot, and powdery mildew are serious.

It is noted that under the influence of the development of diseases such as downy mildew, Alternaria, Phomosis, and Cylindrosporium, the content of carotene, dry matter, fiber, and ash in the affected leaves increases, but the content of vitamin C, protein, fat, and sugar decreases significantly. The amount of amino acids in the affected rapeseed leaves, depending on the intensity of disease development, decreases by 1.4–2.7 times, in particular, essential amino acids by 1.5–2.9 times and substitutable amino acids by 0.13–2.6 times. The shortfall in seed yield from diseases, depending on the variety and technology of its cultivation, ranges from 15 to 70% or more, while its sowing and technological qualities are significantly impaired.

When rapeseed pods are damaged, the oil content in the seeds, depending on the pathogen, decreases by 1.3–3.4 times, the specific gravity of palmitic, stearic, erucic, eicosic, and linolenic acids increases significantly, while the specific gravity of oleic and linoleic acids decreases.

The most common and damaging infectious diseases of cruciferous plants in Ukraine are snow mold, black leg (rhizoctonia), downy mildew (peronosporosis), black spot (alternaria), stem cancer, or root neck necrosis (phomosis), white rot or sclerotinia (white stem disease), gray rot (botrytis), light spot (cylindrosporium), verticillium wilt (verticillium), fusarium wilt (fusarium), root bacteriosis in winter rape, mucilage bacteriosis in spring rape. Less common diseases in rapeseed are white spot (ring spot or gray stem), powdery mildew, common mosaic clubroot, wrinkle mosaic, black ring spot, turnip yellow virus, greening of flowers, etc. [62].

The diseases of cruciferous crops are ranked in the following order in terms of their harmfulness: Alternaria, Phomosis, Cylindrosporium, Root Bacteriosis, Snow Mold, Peronosporosis, Blackleg, White Rot, Gray Rot, White Spot, Fusarium Wilt, Verticillium Wilt.

The global monitoring of cruciferous diseases has identified 15 diseases that, according to scientists, pose the greatest threat to the productivity of modern varieties of cruciferous crops, primarily rapeseed [64] (Table. 1.5–1.6). Biotic stresses caused by these diseases mainly affect leaves (10 diseases) and stems (7 diseases), while only 2 diseases affect rapeseed pods and seeds.

Plasmodiophora, sclerotinia stem rot and stem cancer, phomosis, powdery mildew, peronosporosis, white rust, and Alternaria are recorded in all analyzed regions of the world.

Table 1.5

The most common diseases of cruciferous plants (global dimension) [63]

Disease	Pathogen	Root	Seedlings	Leaf	Stem	Buds/ flowers	Pods/seeds
Alternariosis	*Alternaria* spp.		x	x	x		x
Clubroot	*Plasmodiophora brassicae*	x					
Peronosporosis	*Peronospora parasitica*			x			
Fusarium wilt	*Fusarium oxysporum* f.sp. *conglutinans*				x		
Gray rot	*Botrytis cinerea*			x			
White leaf spot	*Pyrenopeziza brassicae Pseudocercosporella capsellae*			x			
Mycotic spotting	*Mycosphaerella brassicicola*			x			
Powdery mildew	*Erysiphe cruciferarum*			x	x		x
Sclerotoniosis	Sclerotinia sclerotiorum				x	x	
Complex of seedling diseases	*Rhizoctonia, Fusarium*, *Pythium* spp.	x	x				
Phomosis	*Leptosphaeria* spp.			x	x		
Sclerotonyosis	*Sclerotium rolfsii*	x	x		x		
Verticillium	*Verticillium longisporum*	x			x		
Viruses	*Turnip yellows virus Turnip mosaic virus*			x			
White rust	*Albugo candida*			x		x	

The causative agent of the disease, Sclerotinia sclerotiorum, is a devastating pathogen that can affect more than 400 plant species [64]. Its sclerotia can survive in the soil for more than 4 years (Table 1.6), which narrows the choice of crop rotation and increases the risk of sclerotia accumulation in the soil. During periods of cool and humid weather during flowering, ascospores can form and spread, usually on the lower parts of the stems under the canopy, but can also be spread by wind, insects or rain splashes to upper leaves, pods or neighboring plants [65].

Clubroot, caused by *Plasmodiophora brassicae*, has gained in importance over the past two decades as a major threat to rapeseed production worldwide. In Europe, awareness of this disease has increased only in the last 10–15 years.

Table 1.6

The top 10 most significant biotic threats in the form of cruciferous crop diseases to the cultivation of cruciferous crops in Australia, Europe, China and Canada at present [66]

Rating	Australia	Europe	China	USA Canada
1	Phomosis	Sclerotoniosis	Sclerotoniosis	Clubroot
2	Sclerotoniosis	Phomosis	Phomosis	Sclerotoniosis
3	White leaf spot	Альтернаріоз	Downy mildew	Phomosis
4	Downy mildew	Downy mildew	Powdery mildew	Downy mildew
5	White rust	Powdery mildew	Alternaria	Alternaria
6	Viruses	Verticillium	White leaf spot	Powdery mildew
7	Powdery mildew	White rust	Viruses	Viruses
8	Clubroot	Clubroot	Clubroot	Seedling disease complex
9	Alternaria	Seedling disease complex	Seedling disease complex	White leaf spot
10	Seedling disease complex *	White leaf spot	Verticillium	Verticillium

* A complex of seedling diseases consisting of Rhizoctonia, Fusarium, Pythium spp.

The average yield loss is 0.03 t/ha for every 1% increase in infection, while the potential total yield loss can reach 100%, with current field research estimates ranging from 5 to 60% [67–69]. Dormant *P. brassicae*

spores from infected root nodules remain in the soil for more than 4 years in the absence of host plants. Previous studies have shown that the half-life of dormant spores is 3.6 years [70]. In addition, a significant increase in the density of spores in the soil after modern tillage systems has been reported. Clubroota spreads mainly by moving soil containing dormant spores through agricultural machinery or through water erosion [71].

Stem blight, or blackleg, is one of the most important diseases and is associated with yield losses of 5 to 50% in Europe, Canada and Australia, where *Leptosphaeria maculans* or *Leptosphaeria biglobosa* are widespread [72–77].

L. biglobosa, which is less aggressive than *L. maculans,* is the only leptosperm species that can cause significant seed yield losses of 10 to 37% [78]. It is noted that mechanical damage and nutritional damage by cabbage root fly, cabbage stem flea and rapeseed stem weevil can significantly increase the incidence, volume of affected tissue and severity of phoma stem cancer in susceptible varieties [79–80]. While the inoculum survival time on residues in Europe is 4 years, in Western Australia, longer survival is expected – up to 4 years [81–82]. Airborne ascospores are the main source of inoculum for epidemics, and the release of ascospores is virtually unchanged in the temperature range from 5 to 20 ^{0}C, but increases significantly during precipitation [83]. The limited spreading distance, mainly within 14 cm, is estimated to be due to spraying during rain [84]. However, the spores can be carried by the wind up to 10 km away [85].

Thus, based on the global dynamics, it can be concluded that alternaria, downy mildew, white rot, phomosis, verticillium, and clubroot are the most common diseases in cruciferous crops. Less common are powdery mildew, grey rot, cylindrosporosis, white spot and others.

During the period under review, Ukraine has allocated [86]fungi from 4 classes (12 genera from spring rape plants and seeds, 11 genera from winter rape). The most numerous group was made up of fungi of the class Deuteromycetes (imperfect), which amounted to 58% on spring rape and 55% on winter rape. The smallest number of fungi of the class Zygomycetes (zygomycetes) was noted: 8% on spring rape and 9% on winter rape. The number of fungi of the classes Oomycetes and Ascomycetes was low – 17 and 18% on spring and winter rape, respectively.

It is reported [87] also that the spread and development of downy mildew and Alternaria in the forest-steppe zone of Ukraine on spring and winter rape during 1985–2005 were 58–80% and 4–25%, respectively, and phomosis – 24–50% and 3.0–14.0%. Epiphytotypes of downy mildew and Alternaria were observed in 1986, 1989, 1993, 1995, 1998, 2001; phomosis – in 1986–1989, 1993, 1995, 1998, 1999, 2000, 2001 and 2004. The prevalence of these diseases in these years was in the range of 60–100%, and the development of 15.0-35.0%. The shortfall in rapeseed yield, depending on the intensity of the development of individual diseases, ranged from 10.0 to 80.0%.

The largest number of harmful diseases of rapeseed are caused by representatives of the class Deuteromycetes. Diseases caused by fungi of the Oomycetes and Zygomycetes classes do not cause significant damage to the crop. From the class Ascomycetes, rapeseed is damaged by the fungus *Sclerotinia sclerotiorum* (Lib.) de Bary, the causative agent of white rot (Table 1.7, Figs. 1.5–1.6).

The dependence of the frequency of occurrence on the level of GTK and relative humidity in spring rape was noted in *Erysiphe communis* Grev., *Fusarium oxysporum* (Schlecht.), *Sclerotium bataticola* Taub. and fungi of the genus Alternaria.

In dry years (at low values of GTC: during the growing season – 0.29–0.52, April-May – 0.34 in combination with low relative humidity – 56–58%) it significantly decreased in the pathogens of powdery mildew, Fusarium, Alternaria and increased in the pathogen of ash rot.

Another study notes [92], that in the conditions of the phytopathological site of the Agronomic Research Station of the NUBiP of the Right-Bank Forest-Steppe Zone of Ukraine, the most harmful diseases of rapeseed are downy mildew, phomosis, alternaria, powdery mildew, root bacteriosis, etc. At a certain stage of the rapeseed plant's vegetation, diseases cause significant damage.

For example, downy mildew appears on cotyledons, young leaves, and is widespread in the budding phase. The first signs of phomosis and Alternaria were recorded on rapeseed plants when 3–5 rosette leaves were present in the autumn sowing. The massive manifestation of diseases on rapeseed was noted in the flowering phase. Powdery mildew appears in the pod setting phase on late spring rapeseed crops.

Root bacteriosis is especially dangerous in the fall and spring periods in winter rape and largely depends on the state of plant vegetation in the fall. For the first time, clubroot was also detected on rapeseed crops, which is one of the harmful diseases of cabbage crops.

Table 1.7

Classification of phytopathogenic fungi isolated from rapeseed plants and seeds [88–89]

Class, order, family	Gender	Type	Disease
Oomycetes, Peronosporales, Peronosporaceae	*Peronospora* Cda	*Peronospora brassicae* Gaeum. *f. brassicae* (Gaeum.) Dzhan	Downy mildew
Albuginaceae	*Albugo Pers.*	*Albugo candida* (Pers.) Kuntze	White rust
Zygomycetes, Mucorales, Mucoraceae	*Mucor* Mich. emend. Ehrenb.	*Mucor mucedo* Fres. *emend.* Bref	Moldy seeds
Ascomycetes, Helotiales, Sclerotiniace	*Sclerotinia* Fusc.	*Sclerotinia sclerotiorum* (Lib.) de Bary	White rot (sclerotinosis)
Erysiphales, Erysiphaceae	*Erysiphe* Link.	*Erysiphe communis* Grev. *f. brassicae* Hammar L.	Powdery mildew
Deuteromycetes, Hyphomycetales, Moniliaceae	*Aspergillus* Michtli et Fr.	*Aspergillus niger v. Tiegh*	Moldy seeds
	Penicillium Link.	*Penicillium viridicatum* Westl.	
	Botrytis Micheli	*Botrytis cinerea* Pers.	Gray rot
Dematiaceae	*Alternaria* Nees.	*Alternaria brassicae* (Berk.) Sacc.	Alternariosis
		A. brassicicola Wilts. (Schw.)	
Tuberculariaceae	*Fusarium* Link.	*Fusarium oxysporum* (Schlecht.) Snyd. et Hans	Фузаріоз
Sphaeropsidale s, Sphaeropsidaceae	*Phoma* Fr.	*Phoma lingam* (Tode) Desm.	Phomosis
Phomaceae	*Sclerotium* Taub.	*Sclerotium bataticola* Taub.	Ash rot

Studies have shown that the above diseases and their manifestation on rapeseed plants depend on the biological characteristics of pathogens, as well as on the weather conditions of the autumn and spring period. Taken together, their manifestations pose a significant threat to rapeseed plants, which is manifested in a decrease in the yield of green mass and seeds and a deterioration in the quality of oil.

In the conditions of a phytopathological station [96] also found a leafy form of phomosis in the form of elongated light gray spots covered with numerous black dots. Over time, as the leaves age, the spots darken, crack, and fall off. On winter rape, the first signs of the disease were detected 55–60 days after sowing in the phase of 4–5 rosette leaves. The first symptoms of the disease were observed on the lower leaves. The maximum development of phomosis was found 20 days after the detection of disease symptoms.

Figure 1.5 – Alternaria in spring oilseed rape (caused by Alternaria brassicae) [90]

We noted particularly severe damage when the average daily temperature decreased from 15 to 10 ^{0}C, and the air humidity increased to 85–95%. Under such conditions, there is an intensive formation of pseudothecia on the lower leaves in the form of bags with sackspores (*Leptosphaeria maculans*). At the same time, there is a tendency to increase the damage to rosette leaves by the phomosis pathogen on weakened plants due to lack of nutrients in the soil. Such plants do not survive wintering and die prematurely (Figure 1.7).

Figure 1.6 – Gray rot on winter rape pathogen: *Botrytis cinerea*) [91]

In spring rape, the first signs of the phomosis pathogen were detected on the lower leaves at the end of the budding phase. The intensity of the disease growth depended on environmental conditions and varietal characteristics of rapeseed plants. The artificially created microclimatic conditions due to the forest belt significantly enhanced the development of phomosis, and this was especially noticeable in susceptible varieties of spring rape. Later, the development of the phomosis pathogen spread to the pods in the form of gray dry spots, on which black pycnidia were formed. The seeds in the affected pods were small and much smaller than healthy ones.

The most dangerous period for pod infection is the flowering phase. When artificially infected with picnic fungus during the flowering period, the pods show massive infection with the disease. The fungus penetrates through the stigma of the pistil. The first signs of the disease appear at the ends of the lower pods, Analysis of the affected pods showed that about 84% of the seeds were brown, the rest were underdeveloped. It is known that the seed infection can remain viable for up to 4 years.

Figure 1.7 – Gray rot on white mustard caused by a pathogen: *Botrytis cinerea*) [92]

The life cycle of phomosis is also described, taking into account the hydrothermal regime of the Right-Bank Forest-Steppe zone of Ukraine. According to observations [93–94] pseudothecia develop on rapeseed plant debris in the form of a stroma of intertwined mycelial hyphae. Ascomata and antheridia are established in the stroma, and the sexual process takes place. Ascogenic hyphae with bags formed on them grow. The stroma tissue is torn, resulting in cavities. In each of them, several bags with bagospores are formed. Pseudothecia are oval in shape, 360–500 microns in diameter.

At the first stages, they are immersed in the plant's carpel, later they appear on the surface, covered with a dark-colored film. The bags are elongated, club-shaped, 90 x 10 or 138 x 16 microns in size, with pseudoparaphyses around them. Sumps are yellowish, elongated ovoid with 3–5 septa, 30–70 x 4–9 μm in size. The formed pseudothecia remain until spring. At a temperature of 4–8 ^{0}C, the ascites begin to germinate, and growth tubes are formed. Formed hyphae penetrate into the tissue through the stomata of growing leaves of winter rape. Unlike sumcospores, pycnospora germinate at a temperature of 16 ^{0}C. Hyphal infection occurs at 100% relative humidity. During the growing season of rapeseed plants, the phomosis pathogen is spread by pycnospores and sumps.

In the conditions of the phytopathological site of the Agronomic Research Station of NUBiP (Zone of the central regions of the Right-Bank Forest-Steppe of Ukraine) [97] the first symptoms of Alternaria

(*A. brassicae*) were detected on plants of winter rape (in autumn) and spring rape (in spring). The first signs were observed in the phase of 3–5 leaves in the form of dark brown, almost black individual small spots. A yellow or light green border often formed around the spots. Later, the affected tissue is covered with a black coating in the form of small-dotted sods, especially on the stems, branches, and pods. Affected pods are deformed and cracked. Seeds from the affected pods are small and underdeveloped.

In the conditions of the Right-Bank Forest-Steppe of Ukraine, the marsupial and pycnidial stages of the fungus that causes Alternaria were not found. In most cases, A. brassicae overwinters as mycelium on plant residues or wintering plants of winter rape.

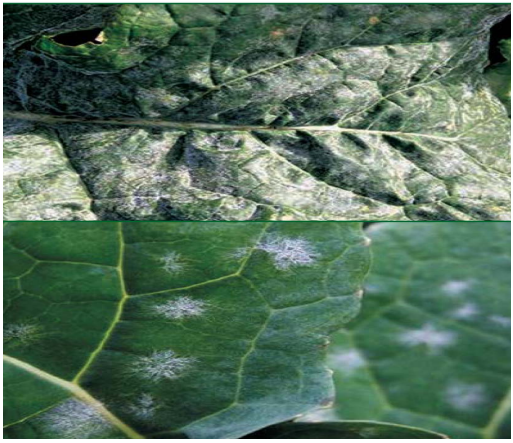

Figure 1.8 – Powdery mildew (pathogen: *Erysiphe communis* f. Brassicae, Syn. *Erysiphe cruciferarum*) [96]

In the spring, when the average daily temperature is +5 ^{0}C and the relative humidity is 90%, conidia appear, which infect young, growing leaves of winter rape and then settle on spring rape plants. The disease damage increases in the budding phase at the beginning of flowering. During flowering, the conidia penetrate the ovary, resulting in massive damage to the pods. The fungus can also be preserved by mycelium in seeds for up to 12 years [95].

The dynamics of alternaria spread and harmfulness in the conditions of the experimental field of VNAU was studied [96]. Field recordings in the conditions of the VNAU experimental field showed that Alternaria on spring rape was manifested on all parts of plants: cotyledons, leaves, stems, branches, pods. Dark brown, almost black, or light gray, rounded, zonal spots with a diameter of 1–15 mm appeared on cotyledons and leaves. A yellow or light green border was observed around the spots.

Later, the affected tissue of the spot was covered with black or gray bloom in the form of small dotted sods. On the stems, the spots were of different sizes and shapes, dark, shiny, often merged and covered a large surface of the stem or branches.

On pods, Alternaria appeared as black small shiny spots. In case of early pods damage, deep black ulcers appeared, diseased pods were usually deformed, seeds in them were small and underdeveloped. When spots or ulcers appeared on the seams of the valves, the pods cracked and the seeds spilled out, which led to significant yield losses.

The peculiarities of the dynamics of cruciferous diseases development were also studied in the experimental field of Vinnytsia National Agrarian University. Thus, the dynamics of damage to spring rape crops had its own characteristics. The year 2017 was more favorable for the development of disease signs during the rosette-flowering period, and the year 2016 was more favorable for the development of the disease on plants in the second half of the growing season during the period of fruit formation and fruit formation, which was reflected in the prevalence and development of the studied disease (Table 1.8). Thus, dry weather with low air humidity, which was observed in May-June 2016, did not contribute to the development of the disease, due to which at the end of the spring period the disease prevalence was only 2.3% with a development intensity of 0.08%, and vice versa, an increase in total moisture, especially during the period of pod and seed ripening, led to an increase in the total disease prevalence to 26–29% with a development intensity of 8.0–8.6%.

On the contrary, for the conditions of 2017, during the summer period, the prevalence of the disease increased in the third decade of May – first decade of June, where this figure was 8.6% with an intensity of its development of up to 3.7%, and during the period of ripening of fruit elements, these figures were significantly lower.

Thus, the development of Alternaria on spring rape in the conditions of the research area is facilitated by intense precipitation during June and July and high humidity under the cover of plants. According to our observations, the gradual spread of the disease during this period was facilitated by increased air humidity under the cover of plant leaves and heavy dew at night, because precipitation in June was less than normal (especially in 2017), and in July and early August, during the maturation phase of plants, their amount was even less (Table 1.8).

The same studies also found that Alternaria has a significant impact on the main structural parameters of spring rape yield.

The data in the table shows that the development of Alternaria on plants, which is estimated by points 1–3, does not significantly affect the length of the pod. It is equal to 10.7–11.3 cm in both healthy and diseased plants.

However, with the development of the disease with a score of 5, the length of the pods in diseased plants compared to healthy plants is significantly reduced and is 7.0 cm, or 3.7 cm less than in the control variant.

Table 1.8

Spread and development of Alternaria on spring rape variety Maria in the experimental field of VNAU, 2016–2017 [101]

Year	Indicators	Accounting dates, decades						
		June			July			August
		I	II	III	I	II	III	I
2016	Distribution, %	4	17	21	24	26	29	0
	Development, %	0.1	2.9	4.8	6.2	8.0	8.6	0
2017	Distribution, %	4.2	8.6	11.0	16.5	21.3	16.5	0
	Development, %	0.3	3.7	5.6	7.8	9.7	10.4	0

The slight development of Alternaria on the pods (within 1–2 points) does not significantly affect the formation of the number of seeds in the pods, which ranges from 18.3–18.6 pcs. per 1 pod. At a damage score of 5, the number of grains in a pod compared to the control (healthy pods) decreases almost twice – to 9.2 pcs.

It was noted that the development of Alternaria on the pods contributes to their premature cracking, which causes the loss of spring rape yield as a result of shedding. At the same time, slightly affected pods (score 1 and 2),

as a rule, do not open prematurely and their number in the total mass varies as in healthy plants within 3.1–5.0 pieces per 1 plant. However, with the development of the disease, which is estimated by a score of 4–5 compared to the control, it increases almost 13 times, reaching 39.5 pieces per 1 plant.

The development of Alternaria on pods most significantly affects the individual weight of seeds. With the superficial development of the disease on the pods (score 1), the weight of 1000 seeds in the affected plants does not change significantly compared to healthy plants (score 0), being in the range of 4.4–4.3 g. And with a score of 5, respectively, it decreases almost three times – 1.6 g.

Under these conditions, a natural and statistically significant decrease in the total yield of spring rape in comparison of control and plants with a damage score of 5 is observed – with a difference of 19.7 quintal/ha to the control, which actually corresponds to the natural level of spring rape yield according to the price of the point and the score of gray forest soils in the soil cover of the experimental field (Table 1.9). The regression analysis performed in the Statistica 6.0 block program allowed us to form a mathematical model of the reduction of spring rape yield (yield shortfall (Y)) in relation to a certain plant infection with Alternaria (X). This dependence is expressed by the following equation for two phases of accounting: for the flowering phase: $Y = 0.237 X + 0.208$; for the green pod phase: $Y = 0.831 X – 0.562$.

Thus, the yield loss of spring rape depends on both the weather conditions of its vegetation and the phase of intense pathogen damage. At the same time, greater yield losses should be expected when plants are damaged during the period of intensive formation of fruit elements (green and yellow-green pod phase).

Thus, the presented studies have shown that Alternaria is a rather significant factor in reducing the yield of spring rape crops. The intensity of its development depends to a large extent on the optimal ratio of high humidity at high temperatures of a moderate interval. The very harmfulness of the disease in terms of reducing the seed yield increases when the fruit elements are affected, especially during the period of already formed seeds in the pods and the beginning of their intensive ripening, which corresponds to the phase of green-yellow-green pods.

Table 1.9

Harmfulness of Alternaria depending on the intensity of damage to rapeseed plants of Maria variety in the experimental field of VNAU (average for 2016–2017) [101]

Intensity of pods damage in points	Pod length, cm	Number of seeds per pod	Number of opened pods without seeds per 1 plant, pcs.	Weight of 1000 seeds, g	Seed yield, centner/ha	Yield reduction compared to control, centner/ha
Score 0 – healthy plants	10.7	18.3	3.1	4.4	24.3	0.0
Score 1 – up to 20 surface small spots on the pod	10.5	18.6	5.0	4.3	22.8	1.5
Score 2 – more than 20 surface spots on the pod (background)	11.3	18.3	5.0	4.3	20.8	3.5
Score 3 – with 1 or 2 deep ulcers	10.1	15.8	19.9	3.3	15.3	9.0
Score 4 – with 3 or 4 deep ulcers	8.5	13.0	35.7	2.3	8.7	15.6
Score 5 – with more than 5 deep ulcers	7.0	9.2	39.5	1.6	4.6	19.7
SSD_{05}	*0.8*	*1.8*	*2.0*	*0.11*	*1.7*	–

Rapeseed powdery mildew – the causative agent is the marsupial fungus Erysiphe communis var brassicae – was found on late spring rape crops in the form of a white spider web coating on stems, leaves, and pods. Later, the leaves curl up and dry out. The pods of severely affected plants turn yellow early, their seeds are immature and small (Figure 1.13).

During the entire growing season, the powdery mildew pathogen forms conidial sporulation. It is only in the fall that dark brown spots – cleistothecia – appear on the dead stems of rape. Conidiophores on the mycelium are arranged vertically with single ellipsoidal conidia at the top. Conidia are 28–35 x 11–19 μm in size. Kleistothecia are dark brown, globose, 85–90 μm in diameter. They have branched appendages at the top. Each cleistothecium contains 4–8 pear-shaped sacs with 4–8 elliptically discolored asci measuring 19–25 x 9–14 μm. According to the results of

the research, it was found that this fungus overwinters on rapeseed residues in the vast majority of mycelium and only in some cases, depending on weather conditions, in cleistothecia. The massive manifestation of powdery mildew on spring rape plants was noted in the phase of complete pod setting.

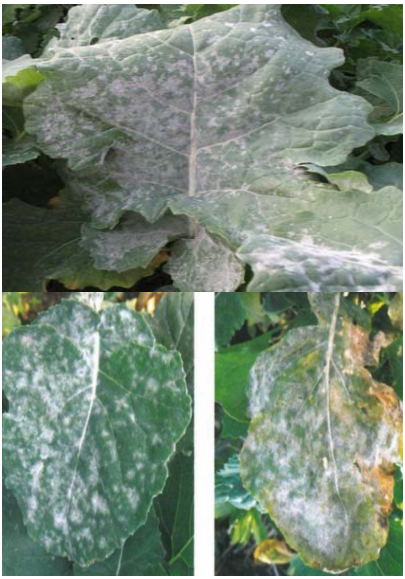

Figure 1.9 – Powdery mildew on spring rape [97]

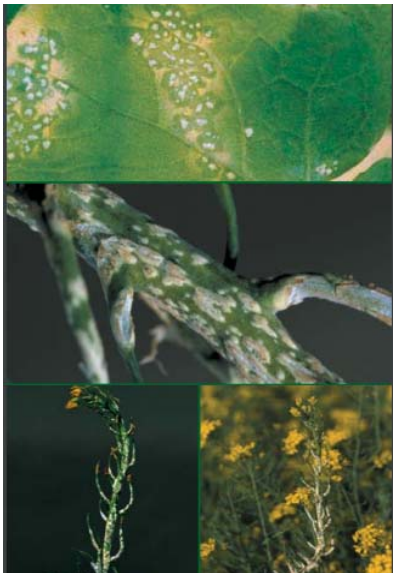

Figure 1.10 – White rust (Cause: *Albugo candida*, Syn. Cystopus candidus) [98].

The frequency of occurrence of other isolated pathogens did not depend on meteorological indicators. During 10 years of research, the frequency of downy mildew (downy mildew) in spring rape crops was high, while the frequency of white rot, phomosis and seed mold was low. The fungus Albugo candida (Pers.) Kuntze showed a periodicity of manifestation – 1 year in 3 with a low frequency of bridging (Figure 1.14).

The frequency of occurrence of Albugo candida (Pers.) Kuntze and Botrytis cinerea Pers. fungi on winter rape was found to depend on the GTC

Figure 1.11 – Rapeseed stalks affected by gray mold [99]

Figure 1.12 – Signs of verticillium wilt on the stem of spring rape [103]

and relative humidity. These pathogens were observed on winter rape crops, respectively, with a low and medium frequency of occurrence according to the GTK in April-May, exceeding 1.35, in combination with relative humidity of 62% and above. In the same years, the frequency of Phoma lingam (Tode) Desm. increased from medium to high in winter rape crops.

Regardless of weather conditions, in all years of the study, the manifestation of pathogens was noted in winter rape crops: sclerotinia (white rot) and Fusarium – with an average frequency of occurrence, downy mildew, powdery mildew and Alternaria – with medium and high frequency of occurrence (Table 1.10–1.11, Figure 1.9–1.13).

Figure 1.13 – Cylindrosporosis (White leaf spot, pathogen: *Cylindrosporium concentrium*, Syn. *Gloeosporium concentricum)* [103]

The fungi Aspergillus Michtli et Fr. emend. Ehrenb. are a constant component of rapeseed mycoflora. The frequency of their occurrence in all years of the study is low.

In another study, 22 species from four classes were identified as a result of the inventory of the species composition of spring and winter rape mycorrhizal flora: oomycetes – 1; zygomycetes – 1; ascomycetes – 2 and imperfect – 18 (Tables 1.14–1.15). In all the years of research, regardless of the prevailing weather conditions, a high frequency of occurrence was found in the pathogen of Fusarium wilt, powdery mildew, phomosis and downy mildew (Figure 1.14–1.16).

During the study of pathogen localization sites, it was found that mycoses are most often isolated from affected stems – 55.0%, root system – 44.0% and seeds – 41.0% (Table 1.15).

During pod formation, the intensity of phytopathogen infection of Athora hybrid plants increased, and symptoms of these diseases were also found on stems and pods in addition to leaves. The severely affected pods in the control variant of the experiment, where fungicides were not used, cracked. In 2020, during this period, the development of such a disease as Alternaria was the highest compared to others and amounted to 22.5%, in 2021, the highest was the development of diseases such as powdery mildew – 22.5% and Alternaria – 20.1%. In addition to Alternaria, in 2020, at the end of the growing season, the development of phomosis increased to 16.6%, downy mildew – to 18.1%, powdery mildew – 10.6% and sclerotinia – to 9.7%. In 2021, in addition to Alternaria and powdery mildew, the development of phomosis increased to 10.5%, downy mildew – to 10.1%, and sclerotinia – to 4.2%

In assessing the development of the species structure of cruciferous diseases in agricultural formations of Vinnytsia region, an example is the result of surveys of winter rape crops in one of the agricultural formations on the Athora variety. The dynamics of the development of the main phytopathogens on plants of the winter rape hybrid Athora was studied by conducting surveys of the degree of their damage four times during the growing season, namely in the phases of leaf rosette formation, stemming, early flowering and pod formation. The data of the surveys are presented in Table 1.16.

Table 1.10

Frequency of fungi occurrence on spring rape depending on the HTC and air humidity, 2013–2022 [100]

Pathogen	Frequency of occurrence									
	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
1	2	3	4	5	6	7	8	9	10	11
Peronospora brassicae Gaeum. *f. brassicae* (Gaeum.) Dzhan	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++
Albugo candida (Pers.) Kuntze	–	+	–	–	–	+	–	–	–	+
Mucor Mich. emend. Ehrenb.	+	++	+	+	+	+	+	+	+	++

(End of Table 1.10)

1	2	3	4	5	6	7	8	9	10	11
Sclerotinia sclerotiorum (Lib.) de Bary	+	++	+	+	+	+	+	+	+	+
Erysiphe communis Grev. *f. brassicae* Hammar L.	+++	+++	+++	++	+++	+++	+++	++	+++	+++
Aspergillus Michtli et Fr.	+	+	+	+	+	+	+	+	+	+
Penicillium Link	+	+	+	+	+	+	+	+	+	+
Botrytis cinerea Pers.	–	+	–	–	–	–	–	–	–	–
Alternaria brassicae (Berk.) Sacc.	+++	+++	+++	+	+++	+++	+++	+	+++	+++
A. brassicicola Wilts. (Schw.)										
Fusarium oxysporum (Schlecht.) Snyd. et Hans	+++	+++	+++	++	+++	+++	+++	+	+++	+++
Phoma lingam (Tode) Desm.	+	+	+	+	++	+	+	–	+	+
Sclerotium bataticola Taub.	–	–	–	++	–	–	–	++	–	–

Note: + – low incidence of the pathogen (up to 10% of plants are affected); ++ – medium incidence of the pathogen (up to 50% of plants are affected); +++ – high incidence of the pathogen (more than 50% of plants are affected); – no pathogen.

Table 1.11

Frequency of fungi occurrence on winter oilseed rape depending on the HTC and air humidity, 2013–2022 [101]

Pathogen	Frequency of occurrence									
	2013	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
1	2	3	4	5	6	7	8	9	10	11
Peronospora brassicae Gaeum. *f. brassicae* (Gaeum.) Dzhan	++	+++	++	+++	+++	+++	+++	+++	++	+++
Albugo candida (Pers.) Kuntze	–	+	–	–	–	+	–	–	–	+
Mucor Mich. emend. Ehrenb.	+	+	+	+	+	+	+	+	+	++

(End of Table 1.11)

1	2	3	4	5	6	7	8	9	10	11
Sclerotinia sclerotiorum (Lib.) de Bary	++	++	++	++	++	++	++	++	++	+
Erysiphe communis Grev. *f. brassicae* Hammar L.	+++	++	++	++	+++	++	+++	+++	++	+++
Aspergillus Michtli et Fr.	+	+	+	+	+	+	+	+	+	+
Penicillium Link	+	+	+	+	+	+	+	–	+	+
Botrytis Micheli	–	++	–	–	–	++	–	–	–	++
Alternaria brassicae (Berk.) Sacc.	++	+++	+++	+	++	+++	+++	++	++	+++
A. brassicicola Wilts. (Schw.)										
Fusarium oxysporum (Schlecht.) Snyd. et Hans	++	++	++	++	++	++	++	++	++	++
Phoma lingam (Tode) Desm.	++	+++	++	+	++	+++	++	++	++	+++

Note: + – low incidence of the pathogen (up to 10% of plants are affected); ++ – medium incidence of the pathogen (up to 50% of plants are affected); +++ – high incidence of the pathogen (more than 50% of plants are affected); – no pathogen.

Table 1.12

Ecological niches of spring rape pests [102]

The causative agent of the disease	Ecological niches			
	underground and root organs	leaves, stems	generative organs and seeds	leading system
Root rot	+			
Fusarium	+	(+)	(+)	(+)
Alternaria		+	+	
Peronosporosis		+	(+)	
Sclerotinia	+		(+)	
Viruses		+	+	

+ – main ecological niche, (+) – additional ecological niche.

Table 1.13

The main pathogens of white mustard seeds, 2012–2022

Species name of the pathogen	Average plant infestation, units/m²	Disease progression, %
Downy mildew *Peronospopa brassicae* Gaeum.	2.8	24.5
Powdery mildew *Erysiphe communis* Grev. f. *brassicae* Hammare L.	1.5	14.3
White rust *Cystopus candidus* Pers.	1.3	11.5
Dry rot (phomosis) *Phoma lingam* Desm.	1.0	6.5
Fusarium wilt *Fusarium oxysporum* Sch–lecht.	0.5	2.5

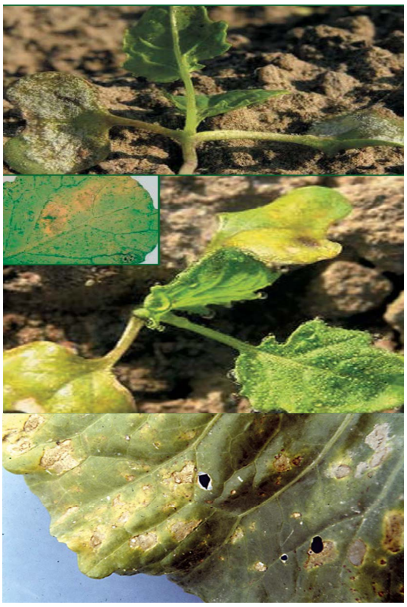

Figure 1.14 – Peronosporosis, downy mildew (caused by Peronospora parasitica) [96]

Figure 1.15 – Phomosis (pathogen: *Phoma lingam, Syn. Plenodomus lingam)* [96]

The first signs of such fungal diseases of winter rape as phomosis and downy mildew appeared on plants already in the phase of leaf rosette formation in the fall and the development of downy mildew in 2020 was already quite high – 7.3%, in 2021 it was slightly lower – 5.1%, the development of phomosis was 2.8% in 2020 The first signs of plant damage by such phytopathogens as powdery mildew, alternaria and sclerotinia pathogens were observed in the spring in the stemming phase and the development of powdery mildew during this period was the highest – 5.5 in 2020 and 10.6% in 2015, Alternaria development was 5.8% and 4.6%, respectively, and sclerotinia – 1.3 and 1.1%, respectively. During the flowering period of Athora hybrid plants in 2020, the highest development was noted for such a disease as Alternaria – 9.7%, and in 2021 for such a disease as powdery mildew – 15.1% (Table 1.16).

Figure 1.16 – Black leg (pathogen: *Olpidium brassicae, Pythium debaryanum, Rhizoctonia aderholdii)* [96]

Table 1.14

Distribution of isolated fungi by systematic groups and frequency of their occurrence on spring and winter rape, 2019–2022 [102]

Class, order,. family	Gender	Frequency of occurrence			
		2019	2020	2021	2022
Oomycetes, Peronosporales, Peronosporaceae	*Peronospora* Cda	++	+++	++	+
Zygomycetes, Mucorales, Mucoraceae	*Mucor* Mich, emend. Ehrenb.	+	+	+	+
Ascomycetes, Helotiales, Sclerotiniace	*Sclerotinia* Fuse.	–	++	+	–
Erysiphales, Erysiphaceae	*Erysiphe* Link	+++	+++	++	+
Deuteromycetes, Hyphomycetales, Moniliaceae	*Aspergillus* Michtli et Fr.	+	+	+	+
	Botrytis Micheli	–	+	–	–
	Penicillium Link	+	–	+	+
	Trichoderma Pers. et Fr.	+	+	–	–
	Verticillium Nees	+	–	–	–
Dematiaceae	*Alternaria* Nees	++	++	+	+
	Cladosporium Link	+	+	+	+
Tuberculariaceae	*Fusarium* Link	+++	++++	+++	+++
Sphaeropsidales, Sphaeropsidaceae	*Phoma* Fr.	++	+++	++	++
Myceliales, Myceliaceae	*Sclerotium Tode.*	+	++	++	+

Frequency of occurrence; + – single (up to 10% of plants are affected); ++ – medium (up to 50% of plants are affected); +++ – severe (more than 50% of plants are affected).

Table 1.15

Species composition and localization of pathogenic mycorrhizal flora of spring and winter rape, 2013–2022 [102]

Diseases	Pathogen	Location of the localization				
		root	stem	leaf	pod	seed
1	2	3	4	5	6	7
Alternariosis	*Alternaria alternata* (Fr.) Keissler; *A. brassicae* Sacc; *A. brassicicola* Wilts; *A. cheiranthi* (Fr.) Bolle; *A. consortiale* (Thiiem.) Hughes	+	+	+	+	+

(End of Table 1.15)

1	2	3	4	5	6	7
Powdery mildew	*Erysiphe communis* Grev.var *brassicae* Hammar L.	–	+	+	+	–
Peronosporosis	*Peronospora brassicae* Gaeum. *f. brassicae* (Gaeum.) Dzhan	–	–	+	–	–
Phomosis	*Phoma lingam* (Tode) Desm.	+	+	+	–	–
Tracheomycosis wilting	*Fusarium oxysporum* (Schlecht.) Snyd. et Hans	+	+	–	–	+
	Verticillium dahliae Klebahn	+		–		–
White rot	*Sclerotinia sclerotiorum* (Lib.) de Bary	+	+	–	–	–
Ash rot	*Sclerotium bataticola* Taub.	+	+	–	–	–
Gray rot	*Botrytis cinerea* Fr.		–	+	–	
Rot of seedlings Плесневение семян	*Fusarium* Link	+	+	–	–	–
	Penicillium Link	+	+	–	–	–
	Penicillium Link	–	–	–	–	+
	Aspergillus Micheli	–	–	–	–	+
	Trichoderma viridi Pers.	–	–		–	+
	Cladosporium herbarum Link	–	–	–	–	+
	Mucor Micheli emend Ehrenb.	–	–	–	–	+

Table 1.16

Dynamics of major diseases on plants of winter rape hybrid Athora (control – without fungicides)

Period of accounting	Disease development, %.									
	2020 p.					2021 p.				
	Alternariosis	Phomosis	Sclerotinosis	Perono-sporosis	powdery mildew	Alternariosis	Phomosis	Sclerotinosis	Perono-sporosis	powdery mildew
Formation rosettes leaves	–	2.8	–	7.3	–	–	2.5	–	5.2	–
Stemming	5.8	8.7	1.3	9.3	5.5	4.6	6.6	1.1	6.2	10.6
Beginning of flowering	9.7	10.3	6.9	16.2	8.3	9.9	8.7	2.3	8.3	15.1
Formation of pods	22.5	16.6	9.7	18.1	10.6	20.1	10.5	4.2	10.1	22.5

Figure 1.17 – *Verticillium wilt* (Verticillium wilt and stem rot, pathogen: *Verticillium dahliae)* [96]

Figure 1.18 – Klubroot (pathogen: *Plasmodiophora brassicae)* [96]

Thus, in 2020–2021, research on the degree of damage to winter rape plants by the main fungal phytopathogens without fungicidal protection (control) showed a high development of diseases such as Alternaria and downy mildew, an average level of diseases such as powdery mildew and phomosis, and a relatively low level of diseases such as sclerotinia, but the harmfulness of which is high even at this level of development.

The most common disease in winter and spring rape is Alternaria. The incidence of winter rapeseed in the northwestern regions ranges from 40-100%, and 35.0–81.0% in spring rapeseed; in the central and southern regions – 16–58 and 11–32%, respectively. Pods affected by Alternaria ranged from 15.0–26.0% [103].

It was found that Fusarium is also one of the most common and harmful diseases, which leads to significant plant death during the growing season [104]. In particular, her research on the Otradnensky variety found that in

Figure 1.19 – White leaf spot (causative agent: *Pseudocercosporella capsellae)* [96]

the seedling stage, losses from Fusarium can amount to 15% of the crop. The largest losses in rapeseed yield are associated with the disease at the beginning of flowering. It is noted that the disease is usually focal and spreads radially across the field during the growing season. Fusarium can also manifest itself in an acute form, causing plant death within 2–3 days [105]. The development of the disease is facilitated by hot, dry weather in the first half of the growing season [106].

The fungus causing Fusarium can grow at temperatures ranging from 10 to 35 °C. The optimum temperature for it is 18–27 °C and soil moisture content of 40–70% (of the total moisture capacity). In the field, the minimum soil temperature during the development of the disease is 16–18 °C, and the maximum is 35 °C. The development of the disease is enhanced by a lack of potassium in the soil [107].

The study on the influence of weather conditions on the infection of spring rape with Fusarium was conducted by S.I. Parshintseva (2001) [108].

According to her data, during the rosette phase of rapeseed, a 4.8°C decrease in temperature leads to a 1.0–1.6% decrease in Fusarium damage to plants. During the budding-flowering period, an increase in air temperature by 1.7°C causes an increase in the incidence of 5.5% and 26.8% in moderately susceptible and susceptible samples, respectively. During the ripening phase of rapeseed, there is also a direct dependence of damage on temperature. Thus, the author found that in all phases of rapeseed plant development, the highest temperature value corresponds to the maximum damage rate.

When comparing the damage rates and precipitation, the following was noted: the inverse relationship is observed only in cases where the amount of precipitation for the period under study differs significantly from the average summer. Sufficiently dry weather during the rosette phase did not lead to a significant increase in Fusarium damage. The greater the amount of precipitation during the budding phase, the lower the damage was and vice versa. The dependence of Fusarium damage to rapeseed plants on the amount of precipitation in the ripening phase was the same as in the rosette phase. Sources of infection are infected soil and seeds, in which the pathogen is stored mainly in the form of chlamydospores, which can remain viable in the soil for up to 11 years [109]. In the conditions of the Steppe zone, in addition to Fusarium, a great danger to rapeseed is Alternaria or black spot [110]. The main causative agent of Alternaria is the fungus Altemaria brassicae Sacc., but Altemaria brassicicola Witts. (Schw.), Altemaria alternata Keissler. are also found (Figure 1.20–1.23). However, many researchers tend to believe that Altemaria alternata Keissler is a common component of leaf surface microflora and therefore it is usually referred to as a saprophyte on rapeseed. High relative humidity (more than 95%), frequent precipitation with wind at a temperature of 22 ^{0}C during the period of filling and maturation of rapeseed contribute to the development of the disease.

Alternaria is a widespread disease in rapeseed growing areas. It manifests itself in the form of dark brown or light gray, rounded spots on stems, leaves and pods. The first signs of the disease can be found on the rosette leaves of cruciferous plant species. The causative agent of the disease is the fungus Alternaria brassicicola (Sehn), which is common and causes dark spotting. Alternaria brassicae is the causative agent of gray spot.

Figure 1.20 – Signs of damage to pods of spring and winter rape by Alternaria [101]

Figure 1.21 a – Alternaria brassicae Sacc: 1 – affected plant; 2 – affected pods, 3 – affected seeds, 4 – conidia [101]

Figure 1.21 b. – Signs of alternaria infection [96]

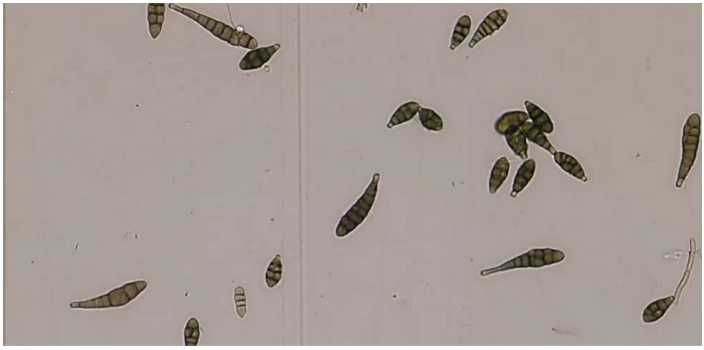

Figure 1.22 – Alternaria conidia [117]

The fungi belong to the class Deuteromycetes, order Hyphomycetales. *A. brassicicola* hyphae are 1.5–7.5 µm thick, conidiophores are olive-brown in color, solitary or in bunches of 2–12 pieces, simple, straight with a membrane. Their length is 70 and thickness is 5–8 µm. Conidia are dark

brown or olive in chains of 20 or more, sometimes they are branched, inversely club-shaped with 1–11 transverse and 6 longitudinal membranes, warty when aged, 18–130 µm long, 8–20 µm wide. *A. brassicae* has hyphae 4–8 µm thick. Conidiophores are produced in bunches of 2–10 pieces. They are simple, straight or cranked, slightly expanded at the base. They are membranous, white-gray-olive, 170 mm long and 6-11 mm thick. Conidia are solitary, sometimes in a chain of up to 4, obovate with 6–15 transverse and 1-8 longitudinal septa of gray-olive color, 75–350 x 20–30 µm in size. Conidia of *A. brassicae* germinate at 15 ^{0}C, and conidia of *A. brassicola* at 23 ^{0}C. Relative humidity is most favorable above 95%. The degree of damage to cabbage is directly related to the amount of precipitation during the flowering period. The main source of infection is the leaves of the testes with conidia, which infect it in the spring. The infection begins on the lower pods of the plant, and then gradually develops upward. Pathogen conidia spread en masse during the threshing of affected plants. They are also carried by the wind up to 2 km or more, affecting spring rape and other cabbage crops.

During periodic changes in dry and wet weather, the development of the disease can cause up to 20% or more of the yield loss. The affected pods are smaller in length, and the number of seeds per pod is correspondingly

Figure 1.23 – Signs of alternaria infection in spring rape [115]

smaller. The seeds are small, gray, and the weight of 1000 seeds is reduced by 28%. Seed germination is reduced by 27%, and seed oil content is reduced by 12%. Pathogens persist on plant debris, in seeds, and on the leaves of winter cruciferous plant species affected in the fall in the form of mycelium and conidia. Sick seeds can retain infection on the surface for up to 2 years and internal infection for up to 12 years.

Those varieties that show increased resistance to Alternaria have fewer stomata per unit area. In addition, the reduced number of conidia on the same spots in a resistant, as opposed to susceptible, variety of cruciferous plant species in a ratio of 1:3 [111].

Resistance can also be manifested by the presence of waxy coating on the leaves of cruciferous plant species.

The resistance of cruciferous plant species to Alternaria is influenced by the conditions of its cultivation, the application of high doses of phosphorus and potassium fertilizers, as well as spring foliar fertilization with nitrogen fertilizers [112].

The use of antagonist fungi in soil and hyperparasites against the pathogen has prospects for the development of biological defense [113].

Alternaria, or black spot, is caused by imperfect fungi from the genus Alternaria Nees in the class Deuteromycetes of the order Hyphomycetalesy of the family Dematiaceae.

Andersson & Olsson [114] four species of Alternaria were recorded on oilseed rape. The main species on oilseed rape in Europe is *Alternaria brassicae* Sacc, but *A. brassicicola* Witts (Schw.), *A. raphani* Groves et Skolko [115–119].

Alternaria alternata (Fr) Keissler is a common component of leaf surface microflora [120]. It is usually classified as a saprotroph on rapeseed, although some isolates can be pathogenic to the related genus *Brassica campestris* [121]. Pre-inoculation of rapeseed leaves with non-pathogenic isolates of *A. alternata* reduces *A. brassicae* infection [122–123].

Alternaria is widespread everywhere, especially in areas with sufficient moisture In the UK, it is the most economically important disease. In France, black spot significantly reduces yields once or twice every five years. Alternaria pathogens can infect plants throughout the growing season, with the greatest damage occurring when infection occurs at the end of flowering or during pod development [124].

In wet weather, the disease becomes an epiphytotic disease and can cause premature "ripening" of plants, which is manifested in pods cracking and the formation of underdeveloped seeds. The affected seeds inside the burst pods shrivel up and fall out immature in dry weather, and rot in wet weather. When the pods are damaged, the mycelium penetrates deeply into the seed embryo, as a result, they underdevelop and their germination rate decreases by 10–15% [125].

The pathogen *A. brassica* reduces the content of chlorophylls, carotenoids, total sugars and the sum of phenols, but increases the content of proteins. A significant decrease in the content of total sugar in diseased leaves is most likely due to its consumption during pathogenesis [126–127].

A number of factors contribute to the intensive growth of alternaria [128]:

– increase in the area under rapeseed and other cabbage crops, which in some areas provide a year-round cycle of susceptible host plants;

– widespread use of herbicides, which reduces wax coating on the leaves and increases susceptibility to leaf diseases;

– a tendency to early sowing in the fall.

The species composition of oilseed rape Alternaria pathogens was determined in laboratory conditions for the conditions of Ukraine. *Alternaria alternate* (Fr.) Keissler, *A. brassicae* Sacc, *A. brassicicola* Wilts, *A. cheiranthi* (Fr.) Bolle and A. consortiale (Thiiem.) Hughes were isolated from the affected leaves and pods. The most common species were *A. alternata* and *A. brassicicola*. Less frequently – A. brassicae.

Regarding *A. consortiale* (Thiiem.) Hughes, it should be noted that by the end of the spring rape vegetation, some researchers recorded surface necrosis on the stems of single plants weakened by Fusarium wilt and ash rot. The spots are initially narrow, elongated into longitudinal strips (0.2×3–5 cm) from black-olive to ash-gray, clearly defined, which subsequently increase to 3-6 cm long and 1–1.5 cm wide, acquiring an eye-shaped shape, do not merge, and are surrounded by a dark gray border. The necrotic tissue in the center of the spot lightens and turns gray, covered with very small and closely spaced black dots – microsclerotia. The fungus was isolated on CGA at a temperature of 24–25 °C. Colonies are gray in color, mycelium is septate. The conidia are acrogenic (apical), shifting sideways as the conidiogenes continue to grow. Conidia vary in shape: almost spherical, quadrangular to oblong-oblong, sometimes with short

legs. The fungus is identified as *A. consortiale* (Thiiem.) Hughes. There are also reports in the literature that fungi of the genus Alternaria can form microsclerotia and chlamydospores [129].

The annual inspection of the phytosanitary condition of spring rape, brown mustard and white mustard crops revealed the following diseases with a prevalence of more than 10.0% [130]:

– Peronosporosis, or downy mildew (the causative agent of – *Hyaloperonospora brassicae* Gäum. Göker, Voglmayr, Riethm., Weiss & Oberw).

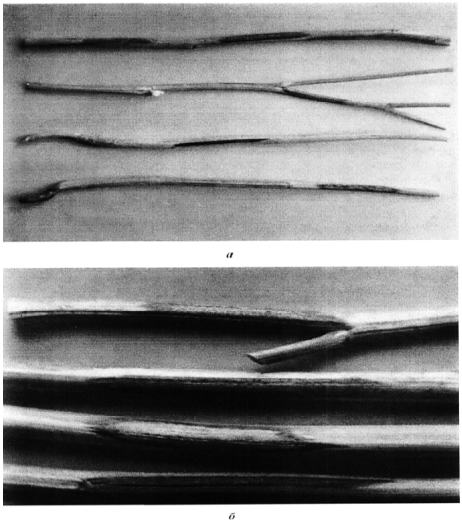

Figure 1.24 – Necrosis on spring rape stems caused by *Alternaria concortiale*: a – general view, b – enlarged spots with microsclerotia of the pathogen

Phytopathological examination of winter rape and mustard crops showed that the plants are affected by the following diseases [96]:

– Peronosporosis, or downy mildew (the causative agent is *Hyaloperonospora brassicae* Gäum. Göker, Voglmayr, Riethm., Weiss & Oberw.)

– Powdery mildew (pathogen – *Erysiphe communis* Grev. f. brassicae Hammar L.).

– Alternaria (causative agents – fungi of the genus Alternaria Nees).

– Phoma rot in the form of stem cancer (pathogen – *Leptosphaeria maculans* (Desm.) Ces. et. De Not).

– Sclerotinia, or white rot, in the stem form (causative agent – *Sclerotinia sclerotiorum* (Lib.) De Bary).

As for alternaria of cruciferous plants, the pathogen is first observed on the leaves in the form of dark brown, almost black, or light gray rounded zonal spots with a diameter of 1 to 15 mm. The color and size of the spots depends on the type of pathogen. A yellow or light green halo is observed around the spots. Later, a black or gray coating in the form of sod and small dots appears on them. This coating is a conidial sporulation of pathogens. Most often, the disease manifests itself shortly before harvesting [131].

On the stems, spots of various sizes and configurations, often elongated in the direction of the axis, dark, shiny, often merging with each other, cover a significant surface of the stem or branches. Pedicels may be affected by Alternaria. The spots on the pods are dark, small, shiny. In case of early infection, deep black depressed spots, ulcers, stretch marks form on the pods, the pods are deformed, seeds develop in them, or do not form at all. If the top of the pod is affected or the spots are located along the seam of the valves, the pods crack prematurely, which leads to seed loss. With prolonged development of the disease, when the pods or stems are covered with spots, and the pods are deformed, wrinkled and brittle, their condition is further aggravated by secondary damage by the fungus Botrytis cinerea Pers. The disease on seeds progresses in winter [132].

The disease is favored by high relative humidity (above 95%), frequent precipitation with wind, at a temperature of 22 °C during filling and ripening; seeds and thickened crops. If the temperature is below 18 °C, conidia germinate poorly. The disease is also caused by changes in wet and dry weather [133].

The conditions necessary for the development of the disease and its maximum harmfulness are warm (17–25°C), humid weather during flowering and pod filling. Infection with *A. brassicae* can occur in a relatively short period in the presence of dripping moisture. The minimum time for infection is 6 hours at 22 °C [135], according to other sources – 4 hours at 25 °C [136]. There are also sources that indicate that it takes at least 16 hours to become infected with Alternaria, and

48–72 hours for optimal infection. Infection with both species of *A. brassicae, A. brassicicola* is limited to alternating wet (above 95% relative humidity) and dry (70–80% relative humidity) periods of 16 and 8 hours, respectively. Conidia of *A. brassicicola* are abundantly formed within 20 hours at an average temperature of 13 °C and above [137].

Figure 1.25 – Signs of Alternaria on irpaccus in early spring during the process of crop vegetation recovery [134]

A. brassicae spores germinate at 0–35 °C, with an optimum of 15–20 °C, and mycelium grows at 0-30 °C, with an optimum of 20–25 °C. At 50 °C, spores and mycelium die within 10 minutes. Spores germinate at a relative humidity of > 90%, the optimum for germination and infection is 96% relative humidity. Ultraviolet light promotes sporulation in most cases [138].

The duration of the incubation period of Alternaria of rapeseed (*A. brassicae* pathogen) decreases with increasing moisture time from 6 to 24 hours and increasing temperature from 6 to 15 °C. The duration of

the incubation period also decreases with increasing leaf age. The degree of alternaria development depends on the spore concentration and leaf age [139].

Rapeseed leaves are more susceptible to Alternaria than rapeseed leaves due to the smaller thickness of the waxy coating, which prevents infection [140].

A phytotoxin specific for cabbage was isolated from A. brassicae. Sensitivity to the toxin corresponds to the sensitivity to the pathogen [141]. This toxin can be used for selection for resistance especially in tissue culture [142].

Infection of rape leaves with Alternaria species causes an increase in the content of indole and aromatic glucosinolates, it is assumed that the accumulation of glucosinolates: in the infected plant can limit the spread of the developing *A. brassicae* infection and inhibit further infection, especially in young plants.

The pathogens persist in the form of conidia and mycelium on the affected leaves of winter rape, on plant residues of cruciferous crops, cruciferous weeds, in soil, and seeds. Affected leaves are a source of inoculum for pod infection [143].

There is evidence that seed infection has little effect on seedling emergence, but there is a close relationship ($r = 0.76$) between the level of seed infection and subsequent infection of seedlings with Alternaria [144].

In case of surface denial, the seeds retain the infectious origin of the pathogens for up to two years, and in case of internal infection – up to 12 years. During the growing season of rapeseed, fungi are spread by conidia, which are transferred from plant to plant with rain drops. *A. brassicae* is a semi-saprotroph, penetrates the plant only through wounds and various insect damage [145]. Peronosporosis, or downy mildew, is no less harmful. The causative agent of the disease is the lower fungus *Peronospora brassicae* Gaeum (class Oomycetes, order Peronosporales, family Peronosporaceae), a parasite that weakens plants. Its mycelium spreads between the cells of plant tissues, but one or two conidiophores with conidia that form plaque come out through the stomata to the surface. The conidiophores are dichotomously branched, with terminal, strongly curved branches extending at an acute angle. In addition to conidial sporulation, spherical, 25–30 microns in diameter, oospores with a yellow-brown reticulate membrane are formed in the affected plant tissues [146].

Downy mildew is considered the most common disease of rapeseed and rape. The disease is common in England, Germany, China, Ukraine and Poland [147]. (Figure 1.26–1.28).

In particular, it is the most common disease in Poland. In the fall, about 30% of the leaves are affected, in the spring – 20–80% [148]. Dangerous in areas with sufficient moisture [149]. The pathogen affects almost all cruciferous plants. It is particularly severe on rape, which often spreads to rapeseed. With the intensive development of the disease, the shortage of green mass of rapeseed can be 15–25%, and seeds – 10–15% [100]. With moderate development of this disease, the yield loss of rapeseed can reach 10–20%, and in years of epiphytic development – up to 40–50%. If infection occurs in the cotyledon phase, plants may die [102].

Figure 1.26 – Tissue necrosis on rape seedlings caused by downy mildew [96]

Figure 1.27 – Signs of downy mildew [96]

Figure 1.28 – Plaque of the pathogen peronospora on rape seedlings [96]

Downy mildew is found in almost all areas of cucurbits growing in Ukraine, as well as abroad. It is a very harmful disease. The causative agent of downy mildew, *Peronospora brassicae* G., can reduce the yield of green mass and seeds of cruciferous plant species by 15–20 centner/ha or more during epiphytotic years [150]. It is known from the literature that downy mildew is very common on cruciferous plant species in England [151], Canada [152], India [153], France [154], Denmark [155], Sweden [156–157] and other countries. In Ukraine, downy mildew occurs in all areas of cruciferous plant cultivation [158–167].

Downy mildew appears on the cotyledons and leaves of cruciferous plant species in the form of brown-green and yellow spots. In the morning, in the presence of dew, or in rainy weather, a faint, delicate white coating is visible on the underside of the leaf, which later acquires a gray-purple hue. The spots often merge, forming significant lesions of the leaf blade, the leaves turn yellow and die prematurely. On the stems and pods, the spots are rounded or elongated, light brown, slightly depressed into the tissue, later covered with a light purple coating [168] (Figure 1.29).

Works by M.P. Polyakov, E.N. Vladimirskaya [169] it was noted that in the northern regions downy mildew on cabbage crops appears in the spring (April-May), then disappears and only reappears in August and September. By V.K. Kupriyanova [170] downy mildew manifests itself first on cotyledons and first leaves, with age the resistance of plants to the disease increases and only at the end of the growing season the plants are again affected by downy mildew, especially physiologically old leaves.

For the first time, a complete characterization of the signs of the disease on cabbage crops was described by S.N. Dorogin [171]. He claimed that cabbage plants are affected by downy mildew throughout the growing season. In affected plants, blurry yellowish spots appear on the cotyledons and on the first leaves. The pathogen often affects the entire leaf blade. On the underside of the leaf, a grayish-white loose coating appears in the places of spots – conidial sporulation of the fungus. Often, white rust develops on cabbage plants affected by downy mildew [172].

On young cabbage pods, downy mildew appears as grayish elongated spots, often covered with a weak scattered coating. In addition, such pods are heavily affected by Alternaria. On pods affected by downy mildew and Alternaria, the seeds are small and have low germination [173].

Downy mildew of radish caused by the oomycete Hyaloperonospora brassicae f. sp. raphani is a serious problem in the culture of radish, an edible root crop of the Brassicaceae family (Figure 1.30).

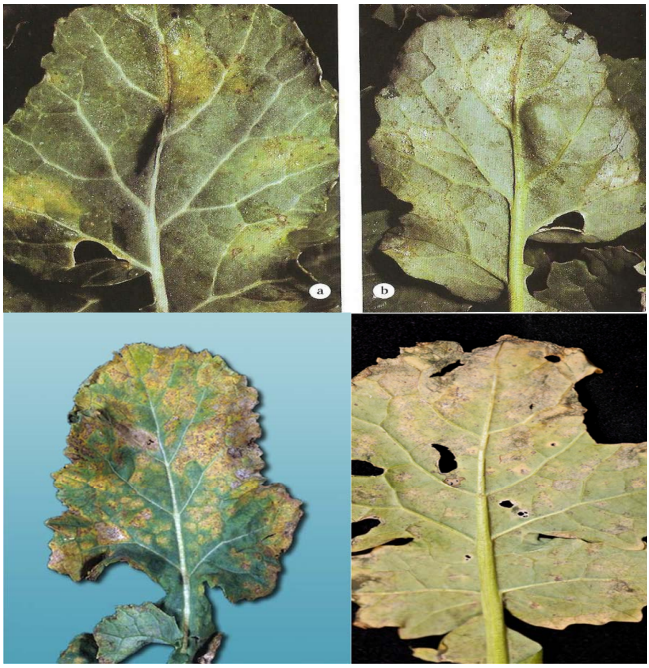

Figure 1.29 – Peronoporosis (The causative agent is a fungus *Perenospora brassicae)* [96]

The genus Hyaloperonospora (Division Oomycota; Family Peronosporaceae) is a group of biotrophic oomycetes responsible for DM disease in their respective Brassicaceae crops. Radish DM is caused by *Hyaloperonospora brassicae* f. sp. raphani, an obligate airborne pathogen that is highly dependent on air temperature and humidity. Favorable conditions for radish infection and disease spread are daytime and nighttime moderate/cool temperatures of 20 °C and 10–15 °C, respectively, associated with high humidity (RH > 80%). The first symptoms are yellow or brown spots on the upper surfaces of cotyledons and mature radish

leaves, combined with white sporulation on the corresponding abaxial epidermis. These spots eventually become necrotic and the leaf dies. VD also affects radish roots, which develop black areas with H. brassicae sporulation, scarring and cracking, making them unsuitable for sale. Foliar protection is important as the roots are infected by conidia washed from cotyledons and young leaves (Figs. 1.31–1.37).

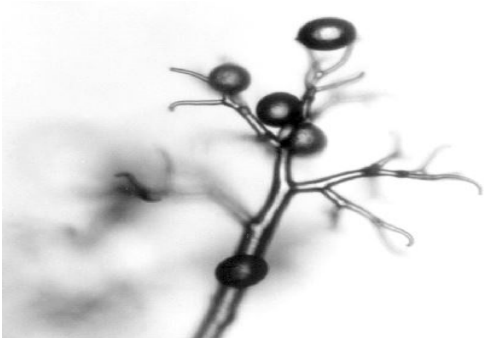

Figure 1.30 – Conidia of *Hyaloperonospora parasitica* [174]

V.P. Yagodkina [183] noted that cabbage crops are heavily affected by downy mildew. The disease causes the death of a significant part of the leaf surface of plants – the affected leaves curl and dry out. G.V. Boos and Z.V. Tymoshenko [175] note the great harmfulness of downy mildew in cabbage. By affecting blood vessels, the pathogen causes general damage to plants [176].

In the forest-steppe of Ukraine, in some years, vascular damage by the downy mildew pathogen was also observed on plants of winter cruciferous plant species. The development of the disease is facilitated by cloudy, rainy weather, when high relative humidity is created [177].

A.F. Salnikova [178] notices the rapid spread of downy mildew on cabbage in favorable conditions, which affects the entire array within a week. Spots appear on the affected plants that merge. The stems dry up and die. Leaves curl, dry out, branches break, the stomata darken and become covered with a grayish-white coating, the seeds become tiny, and their weight decreases sharply.

V.F. Peresypkin [188] indicates the lack of special research in the study of downy mildew of rapeseed.

The causative agent of downy mildew is *Peronospora brassicae* Gacéum, belongs to the class Oomycetes, order Peronosporales, family Peronosporaceae. It was isolated by E. Goiman [179] from a prefabricated form *P. pachestika.*

In the areas affected by *P. brassicae*, mycelium develops and spreads in the intercellular tissues of plants. The mycelium of *R. brassicae* is colorless, unicellular, repeatedly branched, develops intercellularly, and haustoria penetrate into the cells of the host plant, which absorbs the cell contents. At the same time, the affected cells of the host plant die along with the mycelium, but its branching is detected in neighboring parts of the plant [181].

The grayish-white coating on the affected plant tissues is conidia with conidiogenes, which come to the surface through the stomata one or two at a time from the underside of the leaf. The conidiophores are dichotomously branched and colorless. At their tops, ellipsoidal, unicellular, colorless conidia, 12–23 x 11–23 in size, are formed. Conidia size 250–450 x 6–9 μm [180].

During the growing season, the downy mildew pathogen is spread by conidia, which, after maturation, are easily separated from the conidia and transported in different directions by wind, water, insects or other means. Air movement in the summer is one of the main factors in the spread of the infection. Once in a drop of water, conidia germinate and form a hyphal process that penetrates the stomata into the plant.

Conidia formation occurs in the early morning in the presence of dew. They germinate at a temperature of 8–12 ^{0}C. The optimum temperature for the development of the disease is 10–15 ^{0}C [184–185].

In addition to conidial sporulation, rounded, 25–30 μm in diameter oospores with a yellowish mesh shell are formed in the affected plant tissues. Oospores are formed as a result of the fusion of oogonia and anisotrophs. They are covered with a double shell and lie deep in the tissues of the affected organ. The reason for the formation of oospores is unfavorable climatic conditions in the fall.

In the spring, overwintering oospores germinate into hyphal sprouts that infect young plants. Moisture is an important condition for oospore germination.

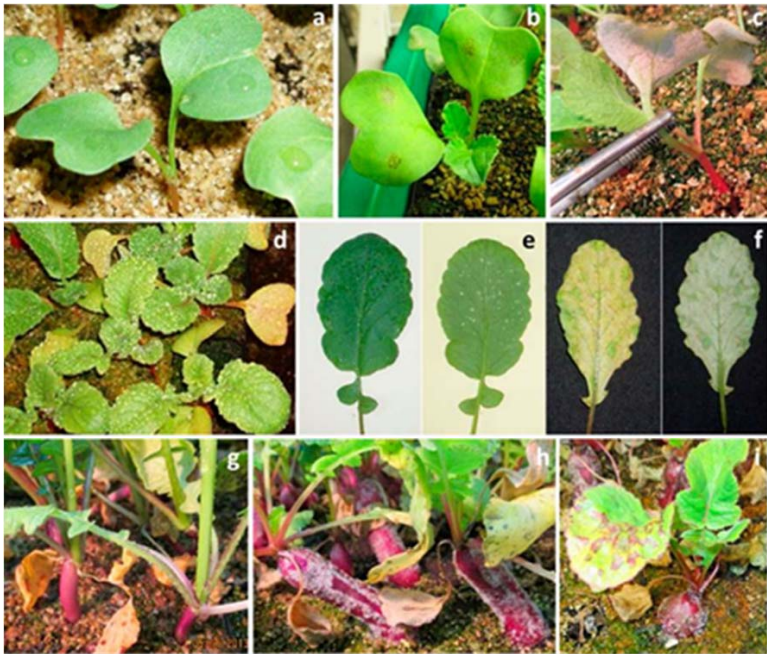

Figure 1.31 – Symptoms on plants of cruciferous species inoculated with H. brassicae at the seedling stage. Resistance: no host response and sporulation or slight necrosis on the adaxial surface of the cotyledon/leaf and root. Susceptibility: sporulation scattered over the entire abaxial surface of the cotyledon/leaf and root, or abundant and dense sporulation scattered over the entire cotyledon/leaf/root. a – Drop inoculation of cotyledons at 6-day intervals. b – Resistant cotyledons (class 1) 7 days (days after inoculation). c – Cotyledons of the pathogen sample – necrosis and lack of sporulation (class 1) 12 days. f – Adaxial and abaxial surface of a nonresistant sample with dense sporulation (class 6) 12 days. g – Daikon long red radish root of a resistant sample (class 1) 12 days. h – Long red radish root not resistant to damage (class 4) 12 days. i – Red round radish root not resistant to damage (class 4) 12 days [185]

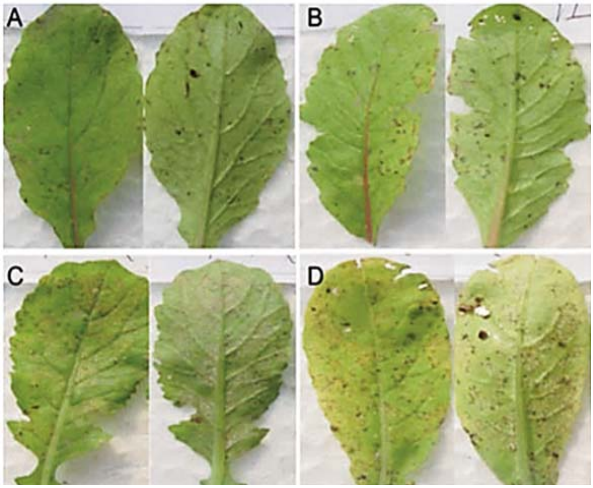

Figure 1.32 – Symptoms of a radish leaf inoculated with downy mildew spore suspension at the seedling stage. Resistance: no host response and no sporulation (A), or slight necrosis localized to the upper cotyledon/leaf surface (B). Susceptibility: sporulation is scattered over the entire lower surface of the leaf (C), or abundant and dense sporulation is scattered over the entire leaf (D) [181]

Figure 1.33 – Daikon leaf affected by downy mildew [182]

Figure 1.34 – Stem of an oil radish seed plant with dark downy mildew lesions [192]

Figure 1.35 – White sporulation inside necrotic lesions on radish seed pods [192]

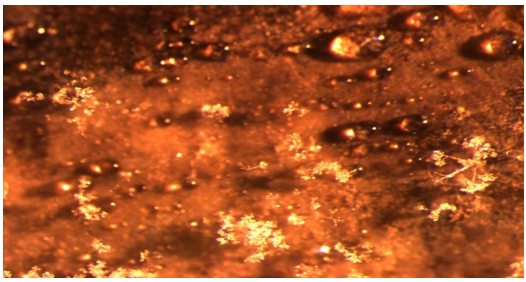

Figure 1.36 – Downy mildew spores forming on daikon stems, with magnification [192]

Figure 1.37 – *Hyaloperonospora brassicae* on wild radish; A-C: Symptoms and signs on stems and stems and inflorescences, D: Sporangia with sporangia, E-F: Sporangia. – Bars = D = 50 µm, E-F = 20 µm [183]

Oospores are preserved in plant debris. However, some authors disagree with this statement. Thus, according to V.K. Kupriyanova [186] *P. brassicae* cannot overwinter in the form of oospores on plant debris in the soil. She argues that the primary damage to plants occurs by mycelium, which is stored in the shell of the affected seeds. A number of authors confirm this opinion. They report that 10% of affected cabbage seedlings with downy mildew were obtained by sowing diseased seeds in boxes with sterile soil. But Anisimov [187] rejects the possibility of transmission of downy mildew by seeds. When the affected seeds were harvested and sown in disinfected soil, the cabbage seedlings were not affected by the disease. Research by F.W. Wang [188] was proved that *P. brassicae* is an obligate parasite, very sensitive to light, which acts on the fungus through the plant, and that high humidity is less important for the emergence of the disease compared to light.

The study of the resistance of new varieties and hybrids of cruciferous plant species to downy mildew is one of the top priorities. In his research

conducted in an artificial climate, Johnson R. [189] studied the resistance of different varieties of cruciferous plant species to downy mildew. Resistance was determined by the degree of damage to cotyledons in the germination phase, with artificial infection of plants with the pathogen downy mildew. Such winter cruciferous plant varieties as Vestal, Dippes and FON-Rehbers showed high resistance to the disease, while Metador and Margot were not resistant. In experiments conducted in 1964, 1965 and 1968, high resistance to downy mildew was found in the Report variety. Such experiments make it possible to assert that there are great opportunities for breeding work with winter rape in order to obtain varieties resistant to downy mildew.

The study of the impact of downy mildew and other major diseases on rapeseed was conducted by the National Agricultural Institute of Botany in England [190]. It has been noted that a number of cruciferous plant varieties have resistance genes against downy mildew.

In order to protect cabbage and other cabbage crops from downy mildew at different times, different authors have recommended separate measures. Dorogin S.N. suggested that the seeds of cruciferous plant species should be treated with a formalin solution (1:300) to prevent downy mildew infection, as well as to destroy plant residues and preventive spraying of plants with a 1% solution of Bordeaux liquid. A.F. Salnikova [202] given that the pathogen can overwinter in the form of oospores in the tissues of the affected organ, she recommended destroying plant residues after harvesting cruciferous plant species by plowing to full depth with a plow with a skimmer.

V.I. Timchenko [191] against seed infection recommends heat treatment of seeds in water at a temperature of 48–500 C for 20 minutes with subsequent cooling. In his opinion, it is advisable to spray vegetative cabbage plants with a 1% solution of Bordeaux liquid.

E.D. Vasylieva [192] against downy mildew of cabbage studied the effectiveness of polycarbacin and copper chloride at 0.5% concentration. In the variant where plants were treated with polycarbacin, the disease practically did not develop. The quality of the seed yield increased in the treated cabbage plants. Similar results were obtained when spraying winter cruciferous plant species with polycarbacin at 0.4% concentration [193].

A study of the effectiveness of chemicals against downy mildew on cabbage crops was conducted in the United States. Researchers studied various systemic fungicides on cabbage against downy mildew. The most effective was a systemic fungicide with the active ingredient dimethyl gylnenil and methoxy cetyl alanine methyl ester.

According to Jonson (1994) [194], on partially resistant oilseed rape material to the pathogen peronospora, necrosis was detected on the back of the leaf with minor conidia formation, and only a small number of very susceptible lines affected most of the leaves during the flowering period; this level of susceptibility reduced the yield [195].

When pods are affected by P. brassicae, the weight of 1000 seeds decreases in winter rape by 1.5 and in spring rape by 1.6 times; seed oil content – by 10.8–16.9%, respectively. The content of palmitic acid in oil from seeds of affected winter rape increases by 1.4 and spring rape – by 0.6; stearic acid – by 1.4 and 1.2; linolenic acid – by 3.5 and 1.8; erucic acid – by 2.0 and 0.4; eicosenic acid – by 1.0 and 1.4%, respectively. The content of oleic acid, respectively, decreases by 7.9 and 4.2; linoleic acid – by 1.4 and 1.2% [196].

The disease manifests itself in the spring, more often 8-10 days after germination on the cotyledons and the first leaf of spring rape. Brownish-green, yellow blurry spots appear, on the underside of which a weak scattered coating develops, at first it is white, and then acquires a gray-purple hue [197]. Individual spots have an angular irregular shape with a darker border, equally visible on both sides of the affected leaves [198]. Later it spreads to all new leaves of adult plants. According to N. Hornig (1979) [199], young leaves of rapeseed plants are affected by downy mildew only occasionally, and according to Anderson and Olsson (1961) [200]. In the later stages of rape plant growth, the impact of the pathogen conidia is limited to old leaves. As a result of the merging of spots, large areas of damage occur, the leaves turn yellow prematurely, dry up and fall off. Due to a decrease in the assimilation surface of the leaves, the plants grow more slowly and lag behind healthy ones. The disease on young plants is manifested by deformation of the leaf blade.

Spots also form on the stems and pods. They are round or elongated, light brown, slightly depressed, and in wet weather their surface is covered

with a white and later light purple coating. In case of severe damage, the pods are underdeveloped and sometimes do not form seeds.

In the spring, pathogens multiply well in the following conditions: alternating long cold, highly humid periods with warm, moist ones. In the main cultivation areas, dry weather occurs in the 2nd half of the growing season and the development of the disease stops if the cool weather persists, the mycelium moves from the leaves to the inflorescences and greatly reduces seed setting. The infection is spread by spores that are in a drop of water and enter the tissues through the closing cells of the stomata. The causative agent of this disease has races that differ in aggressiveness, but, in general, the development cycle of downy mildew is not yet well understood [201].

Optimal conditions for the development of downy mildew are 10–15 °C in rainy or very humid weather. Development slows down or stops when the weather is warmer and drier.

Optimal conditions for the spread of *P. parasitica* spores are 5–15 °C and relative humidity of 90-98%. This temperature is optimal for infection, however, infection occurs only at a relative humidity of 98% or more [209].

According to [201], conidia germinate at 8–12 °C, and plaque is best formed at 10 °C, usually at night or early in the morning when it is dewy. It is believed that the causative agent of downy mildew develops best at low temperatures of 8–16°C, in humid air and low light. According to N. Hornig [212], under optimal conditions for plant growth, it is unlikely that they will be affected. Under unfavorable growth conditions, the pathogen causes only periodic growth inhibition.

It should be noted that the same plant species are affected differently by pathogen strains collected from different ecological and geographical zones.

In winter, the infection persists in the affected plants: residues in the form of oospores, which in spring are the primary source of infection of rapeseed. It is indicated[128] the possibility of overwintering of the fungal oospores in the upper soil layer. The fungus can be located in the form of mycelium in the seed coat of rapeseed. However, more often the mycelium is preserved on wintering winter rape plants. In the spring, conidiophyte carriers with conidia are formed again on this mycelium, carried by wind and rain drops. The conidia are used to infect plants in the spring. Thus, the type of infection with this pathogen is aerogenic-droplet.

The causative agent of sclerotinosis, or white rot, is the marsupial fungus Sclerotica sclerotiorum (Lib.) de Vagu (Syn: *S. libertiana* Fuckel, *S. kaufmanuiana* Tichomirov, *S. varians* Pers., *S. ovatum* Schum., *S. brassicae* Pers., WetzeUnia sclerotiorum (d. By.) Korf et Dumont), which parasitizes more than 300 plant species belonging to 64 families of monocots and dicots in addition to rapeseed [153].

Sclerotinia sclerotiorum is a disease found everywhere. Its causative agents are pea-sized sclerotia lying in the soil at a shallow depth. They develop above-ground saucer-shaped reservoirs with spores (apothecia). Sclerotia germination and apothecia formation depend on soil temperature and moisture. From the end of April to the beginning of May, spores are released from the apothecia and carried by the wind over short distances. They are not allowed to spread to neighboring fields. The disease starts from the leaf bed (Figure 1.38–1.40).

The disease occurs on all cruciferous crops, often developing in foci. Young plants are not affected by sclerotinia. On adult plants, signs of the disease appear as watery spotting at the base of the stem, near the soil surface. The growing spotting causes semi-mildewy rot on the lower, aging leaves In wet weather, the tissues soften and rot, and then become covered with a dense, white, cotton-like coating. Large, hard, black sclerotia appear on the fungus coating, in the core of the stem. In dry conditions, the spotting on the stems is dry, light, and has a characteristic concentric structure. Plants affected by sclerotinia often break down and die. Yields from the remaining plants are very low.

Figure 1.38 – Signs of rape sclerotinia in drought conditions [96]

Figure 1.39 – Rapeseed stalks affected by sclerotinia [96]

The fungus Sclerotinia sclcrotiorum (Lin) DeBy forms black, rough, hemispherical, often glued sclerotia. Disk-shaped, light white apothecia are formed on them, containing cylindrical club-shaped asci with 8 unicellular, ovoid ascospores in each.

The pathogen persists for a long time in the form of mycelium or sclerotia in plant debris and soil, without losing its viability. Sclerotia germinate with mycelium, which infects plants. In wet weather and in the light, sclerotia form apothecia with ascospores, which, when released into the soil, give rise to mycelium, which develops saprotrophically and infects plants.

The disease is most pronounced when cruciferous species are grown monoculturally, on fertile, cold or moderately warm and moist soil. The optimum temperature required for infection is 15–23°C. Favorable conditions for the development of the disease are created in crops with a high planting density.

According to the currently existing classification, the fungus S. sclerotiorum de Vagu belongs to the higher fungi, class Ascomycetes, subclass Euascomycetidae, group of orders Discomycetes, order Helotiales of the family Sclerotiniaceae, genus Sclerotinia Fuckel. In Australia, another stem rot pathogen affecting rapeseed, *S. minor*, has been described [202].

In the UK, severe damage to winter oilseed rape by stem cancer was first observed in 1977–1978 in eastern England [203]. Crop losses reached 50% [204]. In the 80s, the disease was noted every year, but, in general,

not with a very high intensity [205–207]. Sclerotinia increased in the late 70s in Europe due to the rapid growth of rapeseed areas and shortened crop rotations [208].

The increased risk of severe white mold damage to canola in the UK is due to the growing area under the crop, the inclusion of other susceptible crops in the rotation and the growing financial pressure on farmers to plant canola more often in the same field [209]. During the survey of rape in 1986–1990 in the UK, sclerotinia was noted on less than 12% of the fields, and the disease was recorded mainly in the south-east of England [153].

The increase in sclerotinia damage in France is associated with an increase in the area under rapeseed and the inclusion of other susceptible crops, such as sunflower and legumes, in the crop rotation [210]. In northern Germany, rapeseed yield losses due to stem rot reached 50% [211].

Winter rape sclerotinia is the most frequent and damaging disease of rape in Belgium. The disease leads to uneven maturation of plants, difficulties in harvesting and sometimes a decrease in yield by more than 1 t/ha [212].

In Poland, stem cancer was first described in the late 70s [213]. The disease has spread rapidly across all regions; countries that grow rapeseed [214–216].

Commercial production of rapeseed in the southeastern United States began in 1989. The most harmful disease is the stem end rot. In the first year of canola cultivation in some areas, the incidence was 30–50%, in subsequent years it approached 100% [217].

When pods were damaged by *S. sclerotiorum*, the weight of 1000 seeds decreased in winter rape by 2.9 and in spring rape by 2.2 times, seed oil content – by 22.6-23.9%, respectively. The content of palmitic acid in the oil increased by 4.1 and 1.2; stearic acid – by 2.6 and 1.7; linolenic acid – by 4.0 and 3.6; erucic acid – by 5.0 and 5.9; eicosenic acid – by 2.6 and 4.2%, respectively. The content of oleic acid, respectively, decreases by 16.9 and 12.0; linoleic acid – by 1.4 and 4.6% [153].

White rot manifests itself on stems, leaves, flowers, pods in the form of mucous wet spots, which are later covered with a thick cotton-like white coating; in dry weather, the coating disappears, the affected tissue becomes discolored, soaked, diseased leaves die, and stems and stalks usually do not develop or are underdeveloped. All plant organs become discolored, hence the second name of the disease – white stem rape. In the affected areas,

black sclerotia are formed on the surface and inside the stem and pods, often similar in size and shape to rapeseed seeds. In case of early infection of the stems in the area of the root collar, the plants dry out [109].

The first wave of the disease is in the rosette stage, when infection occurs as a result of mycelial germination of sclerotia through contact of leaves with the soil [98].

Sclerotia of S. sclerotiorum in the soil layer (3–5 cm) germinate in April with the formation of apothecia. This occurs under moist conditions and soil temperatures of 6–10 °C; apothecia do not form in dry conditions. If a long dry period follows the formation of aphotocysts, they dehydrate, shrivel up, and produce few or no spores.

The period of existence of the aphothecia coincides with the peak of flowering. Spores are released in dry weather and light winds, cloudy and rainy weather makes it difficult for spores to escape [218].

Figure 1.40 – Sclerotinia or white rot (the causative agent is the fungus *Whetzelinia (Sclerotinia) sclerotiorum)* [96]

Ascospores germinate at 20 °C in the presence of droplet moisture and 94% relative humidity or without droplet moisture but with 100% relative humidity. at high humidity – 21 hours. Spores do not germinate at a relative humidity of 84% and below, even in the presence of dripping moisture. However, heavy rains are undesirable, as ascospores are unable to be released or washed away by the soil [81].

S. sclerotiorum infection of rapeseed stems is caused by petals that are infected first, falling on the stem or in the leaf axil and serving as a source of food for germination of ascospores. Ascospores that fall directly on the leaf surface do not develop and die. The appearance of signs of damage depends on the temperature: after 5 days at 15 °C and after 14 days at 5–8 °C [219].

During white mold infection, the pathogen produces large amounts of the necrosis-forming toxin oxalic acid [220].

Tolerance and barriers to permeability of the toxin in the organs of rapeseed plants are related to its mode of action and the structure of the host leaves [221].

In the UK, there are two main epidemiological phases of the disease, the first of which occurs in May and is associated with winter crops, the second occurs 4–6 weeks after the first and is associated with spring crops [222].

The source of infection is sclerotia of the pathogen in plant residues and seeds (as an impurity). Sclerotia can persist in soil for up to 8 years [153].

The number of sclerotia in the soil increases significantly after a severe pathogen damage to sensitive crops and decreases under conditions unfavorable for the development of the disease, and the half-life of the pathogen in these cases is approximately 2.5 years. The formation of aphoticia on winter rape is greatest when plant residues are crushed in the field in the previous season. The emergence of aphotic plants is accelerated by cultivating the crop without plowing with minimal tillage and is delayed by the spring application of a large dose of fertilizer [109].

Under conditions of high atmospheric humidity and high soil moisture, gray rot can occur on rapeseed. Damage is concentrated at the base of the stem in the form of light watery spots. Under favorable conditions, the disease can cover the entire young plant, including the top, causing it to rot. All affected plant tissues are covered with a delicate, gray, spore-forming coating of the fungus. During a drought, the disease dies down, the stems break at the site of damage, and the plant dies. Harvesting is complicated

and is accompanied by high losses. The fungus Sclerotinia fuckeliana De By has a conidial stage Bonyiis cinerea Pers. that develops bundles of large, branched sporophytes, on top of which, on swellings, ovoid, unicellular conidia are formed. Many small dark-colored sclerotia are formed on the mycelium. Apothecia with elongated mace-like asci and 8 ellipsoidal unicellular spores in each are formed on the sclerotia.

The pathogen persists in the form of mycelium and sclerotia in the affected plant residues, on which in spring a dense spore-forming coating of the fungus with conidia is formed, which carry out secondary infection during the growing season.

The causative agent of phomosis, or dry rot of cabbage, is the fungus *Leptosphaeria maculans* (Desm.) Ces. et. De Not (class Ascomycetes, subclass Loculoascomycetidae, order Pleosporales, family Leptosphaeriaceae, conidial stage Phoma lingam (Tode) Desm. – class Deuteromycetes, order Sphaeropsidales, family Sphaeropsidaceae) [223].

Phomosis is a long-known and widespread disease on cabbage crops. Phomosis was first described as a harmful disease of cabbage in 1849 in France, and was discovered in Germany as early as 1791 [224–225]. In France, during 1976–1979, widespread spread of the disease was also observed on winter cruciferous plant varieties. Depending on the weather conditions, phomosis in some years caused great damage to cabbage crops, especially in areas of high humidity and moderate temperature during the growing season [153].

In Ukraine, the massive appearance of phomosis on crops of cruciferous plant species was registered in the early 80s. The most intense damage to plants was observed in 1988, 1990, 1995, 1997, 2001, 2007, 2011, 2014 and 2019, which were very similar in terms of agroclimatic conditions and characterized by moderately warm and humid autumn, mild and short winters with significant changes in thermal conditions at the end, early spring, and significant precipitation during budding and flowering [227] (Figs. 1.41–1.42).

Phomosis on cabbage crops manifests itself from germination to pod ripening, i.e. throughout the growing season. First, discolored areas appear on the seedlings of cruciferous plant species. Then discolored small dots become visible on the plant tissue – these are pycnidia. In a day, the latter turn brown, the tissue is torn, and the spores are sprayed. The affected area of the cotyledon turns into a natural phomose burn. On diseased seedlings,

a narrow ulcer of 1-3 mm of dead epidermal cells forms along the stem. The tissue becomes discolored, colorless pycnidia are formed under the epidermis, which rapidly increase in size and darken in 1–2 days. On the 7–10th day after the disease onset, the plants lie down. On adult plants, phomosis appears as gray dry spots. Often solid areas of affected leaf tissue are formed. The spots are oval in shape with a purple border. Dark dots – pycnidia – are clearly visible against the gray background. Around the spot, the leaf tissue turns yellow. On the stems directly at the attachment points of leaf petioles, the affected tissue becomes rotten and the plant dies. Stem damage at the soil surface level is often called root cancer or root neck necrosis. Plants are stunted, acquire a chlorotic or bluish color, and often most of them wither and die [87].

The root system of adult plants is often affected in the form of dry rot. This phenomenon is especially common on cabbage. The affected root looks like a chopped off piece. Over time, the tissue becomes slimy and softens, and the vessels become woody. A plant with such a root becomes anthocyanin-colored. The lower leaves dry up, while the upper part lives on for a long time. Spots in the form of elongated brownish ulcers form along the pods. The affected pod often contains diseased seeds. It is believed that the most dangerous period for pod infection is the flowering phase. The disease develops before the pods are formed. Affected pods are underdeveloped, deformed, crack prematurely, seeds spill out [208].

Figure 1.41 – Rapeseed stalks affected by phomosis [96]

The harmfulness of the disease is manifested in the thinning of seedlings, which is caused by the death of young seedlings. Premature death of diseased leaves leads to a decrease in the assimilation surface of cruciferous plant species, resulting in a decrease in the weight of 1000 seeds, and deterioration of the fodder quality of green mass [228].

When sowing affected vegetable seeds, seedlings with signs of phomosis on the root collar or cotyledons are formed. With severe damage, the seeds do not germinate. The yield shortfall can be 50% or more [229].

By research [55] was found that the harmfulness of phomosis depends on the source of infection, its size, and environmental conditions. Seeds can be infected when threshing affected cabbage plants. Such sown seeds produce seedlings affected by phomosis by 43–82%.

The foliar form of phomosis is also dangerous. Single spots from the affected leaves are carried by the wind to healthy areas. Affected plants are stunted and many of them die. Research has shown that early and late sowing of vegetable crops is more severely affected by phomosis compared to the optimal sowing time [230].

Thickened crops of cruciferous plant species are more severely affected by phomosis than optimal ones, since the intensity of plant damage is correlated with the diameter of the stem. The thinner the stem, the more severe the phomosis [243].

In the spring, damaged plants of winter cruciferous species are much more severely affected by harrowing than without harrowing. To a certain extent, the placement of cabbage crops plays a role in reducing the damage caused by phomosis. It is advisable to place cabbage crops at a distance of 1000 meters from each other [231]. Interesting studies were conducted by researchers N.A. Naumov [174; 232], Burkhina E.K. [233] on cabbage seed crops. Severely affected cabbage seedlings planted in the ground died early. And the slightly affected ones developed poorly. Pre-sowing treatment of cabbage seeds reduced the spread of diseases, including phomosis [234].

The causative agent of phomosis has a mycelium that is articulated, whitish, sometimes dark brown, 2–8 microns thick. Due to the accumulation of nutrients, fruiting bodies – pycnidia – are formed in the places of interweaving of mycelial hyphae. The surface of the pycnidia is spherical, with a thick sclerotial membrane. Pycnidia have a convex pad at the base and a crescentic cavity at the top. They range in diameter from

45 to 390 microns in the form of dark dots on the surface of the affected organ. In the middle of them, small, 1.7–2.4 x 4.2–5.6 μm, unicellular, colorless, ovoid or elongated cylindrical pycnospora develop. When ripe, at high humidity, pycnidia secrete pinkish-purple mucus with pycnospores. The latter, once on the plant, form a seedling that penetrates the tissue and infects it. The fungus can grow at temperatures from 2 to 40 ^{0}C. Low temperatures of 2–6 ^{0}C delay development, the optimum temperature is 20–25 ^{0}C.

In addition to pycnidial sporulation, phomosis develops in the form of perithecia, in which bags with baggies of asci are formed. Perithecia are rounded, 360–500 microns in diameter. The ascospores are colorless, have 5 membranes, 4–9 x 30–70 μm in size. In the marsupial stage, the fungus is called Leptoshaeria maculans Ces. De Not. Under natural conditions, the mycelium develops between and within the cells of plant tissues. The affected plant tissue dies, and gray spots with dark dots form.

A.F. Salnikova found that when seeds and leaves of all cabbage crops are artificially infected, cabbage is most severely affected, followed by rapeseed and other crops. When seeds are artificially infected, the first sign is the formation of necrosis with pycnidia on the seedlings [59].

According to a number of researchers, the pathogen can penetrate the host plant only through damaged tissue. However, it has been established that pycnospora, once on healthy tissue, can also damage it Under optimal conditions of 21–25 ^{0}C and sufficient humidity, the incubation period is 7–8 days. Pycnidia appear only at a relative humidity of 60–90% [118].

When plants are artificially sprayed with a solution containing pycnospora during the flowering period, the pods are severely damaged. The fungus penetrates through the stigma of the pistil. The first signs are detected at the lower end of the pods and at the base of the pedicels. The analysis of the seeds obtained from the affected pods shows that about 84% of the seeds are brown, the rest are underdeveloped [153]. Diseased seeds from affected pods of cruciferous plant species are not suitable for sowing without treatment. The phomosis pathogen can persist in the soil for up to 3 years. Seeds can also be a source of infection [92].

Phomosis is spread during the growing season of rapeseed plants by wind, rain, insects, including aphids.

The disease occurs on all types of cruciferous plants. The entire aboveground mass is affected – cotyledons, leaves, stems, peduncles, seeds. On the seedlings, the disease symptoms develop in the form of a black pedicel or light brown spotting on the cotyledons, which gradually covers the plants to the top and causes their death The most characteristic signs are manifested on the root collar, which is necrotic and often cracked. On the stems of older plants, a brown, dry stripe develops from the underground part to the base of the lowest spreading leaves. Affected plants turn yellow and wilt, and their external signs are similar to those of a burn. In case of early infection, the plants die, and in case of late infection, they produce very few seeds. Sometimes large gray-brown spots 1–1.5 cm in diameter, covered with small black pycnidia, form on the leaves. Gray-brown ellipsoidal spots with a dark border appear on the testes. Affected peduncles are deformed, cracked and form small seeds covered with black dots, from which pink exudate is abundantly released in wet weather. The presence of black dots (pycnidia) on all affected parts of plants is a distinctive feature.

Pseudothecia of the fungus are black and hemispherical. Ascospores are yellow-brown, filamentous, with 5 transverse septa. Pycnidia are dark brown or black, of various sizes. Pycnospores are hyaline, unicellular.

The fungus overwinters in infected plant residues and infected seeds, where it remains viable for up to 4–7 years, depending on storage conditions. Pseudothecia with ascospores formed on overwintered plant debris carry out primary infection. The pathogen is spread by conidia through rain drops, irrigation water, wind, soil, insects or mechanical contact.

Conditions for the development of the disease. The causative agent of phomosis is a relatively weak pathogen that develops strongly in monoculture cultivation of cruciferous crops on waterlogged soils, at high air humidity (over 70–80%), temperature 21–25 ^{0}C and mechanical damage to the sprouts.

Isolates of Phoma lingam from oilseed rape can vary greatly in aggressiveness and therefore they were divided into two groups: aggressive (A) and non-aggressive (NA). On certain media, NAs have much faster mycelial growth and color liquid cultures, and in liquid culture they produce the host-specific toxin syrodesmine. Both groups also differ in the isozymes of pectinase, malate dehydrogenase, and glucose phosphate isomerase. There are differences in the morphology of their pseudothecia,

ascospores released from their pseudothecia germinate differently. These and other differences have led to the suggestion of a new species name for NA isolates, for which the designation NAV *L. biglobosun* is proposed for possible further intraspecific differentiation, and for A isolates – *L. maculans* [235].

It is assumed that syrodesmine, as a host-independent phytotoxin of *L. maculans*, can contribute to the increase in the areas of damage caused by the pathogenic fungus [236].

In studies of virulence types of *L. maculans* in rapeseed fields, a highly virulent type was found in all studied rapeseed tissues, and a weakly virulent type was present only in leaf tissues [237].

The new species of L. biglobosum differs from the aggressive dry rot pathogen *L. maculans* by the toothed disk-shaped ascocarps with enlarged apices. Ascocarps of both species were produced on canola stems when inoculated with compatible strains of Phoma anamorphs or isolates from individual ascospores at distances of 1 cm with further co-growth. Both species showed bipolar heterothallism. Of the Leptosphae species with 5-septate ascospores infecting cabbage, none fit the characteristics of L. biglobosum. The species *L. lindqnistii* on sunflower had ascospores with 1, 2, rarely 3 septa, but also had as an anamorph Phoma [238].

Aggressive and non-aggressive isolates of *Ph. lingam* behave neutrally when combined sexually [239].

Ph. lingam produces a number of secondary metabolites, including phytotoxic ones. Recently, unique isolates of the pathogen, Leyard-2 and Meifei-2, have emerged in western Canada that are neither highly nor weakly virulent. This new group of isolates is virulent to B. juncea, a species traditionally resistant to blackleg, and poses a new threat to high quality canola lines. The profile of secondary isolates was obtained. The new group requires a separate classification. Its phytotoxins and secondary metabolites and their biosynthetic pathways are being studied [240].

Ph. lingam has a very wide range of host plants from the cabbage family [241]. Field mustard is a host of highly virulent forms of stem cancer pathogens [242].

In the case of artificial infection, rapeseed was susceptible to *Ph. nigricans* isolated from a widespread weed often associated with rapeseed – field bentgrass (*Thlaspi arvense* L.), so this pathogen poses a

potential threat to rapeseed [243]. Strong phomosis damage is observed in regions with intensive rapeseed production [244].

In 1966–1967, phomosis led to large crop losses in France and became a major disease in England and the Netherlands [245]. French linear varieties Oleopus, Titus, Tonus proved to be highly susceptible to phomosis during the epiphytotic epidemic of 1966–1967 [246].

In Australia, due to the severe defeat of phomosis in the early 70s, rapeseed cultivation almost stopped [247–249]. In the areas of intensive cultivation of winter rape in northern Germany, the most harmful disease of this crop was phomosis [250].

Large yield losses of spring rapeseed due to phomosis noted in Canada [251], osses due to the shortfall in rapeseed harvest as a result of the disease annually exceed $ 30 million [252].

On a global scale, phomosis, or stem cancer, is the most harmful disease of rapeseed [253–256]. One percent of infected seeds can cause epiphytosis. There is a high degree of correlation between the number of spores and the level of damage and reduction of rapeseed yield [257].

Phomosis occurs both on seedlings and on adult rapeseed plants. On the hypocotyl of seedlings, as well as on the cotyledons, various shapes of watery spots are first found, which later dry up and become light gray or ash-colored. Scattered dark dots – pycnidia of the pathogen – can be seen in the lesions. In older plants, the lower part of the stem blackens, and phomosis at this stage initially resembles a black leg, but it does not cause continuous blackening around the stem. Over time, the bark of the stem in this area lightens and turns gray. The affected tissue is covered with dark dots – pycnidia of the pathogen.

The stems dry out, become rotten, and the plant dies. With the later development of the disease, it manifests itself on the stems, usually at the base in close proximity to the axils of the petioles of the lower leaves, in the form of ulcers. With this manifestation on the stems, the disease is called stem cancer. The ulcers are oval in shape, slightly depressed, light brown to gray in color, often surrounded by a purple border. They can slowly grow and completely cover the stem. Stem damage at the soil level (root canker and neck necrosis) often spreads to the root system, causing black sores and root dry rot. Plants are stunted, acquire a dry chlorotic or bluish color, often lie down, and most of them wither and dry out. Phomosis develops

on leaves and pods in the form of gray dry spots, on pods they are slightly depressed, often with concentric zonation. Black pycnidia are clearly visible on the surface of the spots. In addition to localized damage, there is a diffuse development of the pathogen in plant tissues, in its disease is asymptomatic. During the growing season, the pathogen is spread by pycnospora and sumkospora [88].

It is assumed that in the field, phomosis infection occurs through damage, with plant sap stimulating the development of the fungus and, accordingly, promoting infection [258].

Rapeseed phomosis increases when damaged by insects (*Psylliodes chrysocephala* and Ceutorhynchus spp.) [8]. The maximum ascospore summer of L. maculans is observed in September. This is when 60–70% of ascospores are released. The number of flying spores is regulated by precipitation and temperature. Ascospores and pycnidiospora of *L. maculans* germinating on the surface of rapeseed leaves are introduced into its tissues through stomata without the formation of apsorias – 'intercellular' hemi-biotroph [259].

Most often, *Ph. lingam* is found in rapeseed varieties containing low amounts of erucic acid. Pathogenesis is facilitated by 100% relative humidity or dripping moisture on plants. Fomites are caused by excessively early sowing of winter rape and late sowing of spring rape. The intensity of phomosis damage increases in thickened crops [101].

Figure 1.42 – Phomosis (The causative agent is the fungus *Phoma lingam*) [96].

The pathogen overwinters in the form of mycelium and pycnospores on the leaves of winter rape, in the form of pycnidia and pseudothecia on plant debris and mycelium in infected seeds [19].

It is noted that one of the most serious diseases of spring rape is *Fusarium wilt* (Figure 1.43). The disease manifests itself on rapeseed plants at all stages of crop development. Symptoms can be observed on cotyledon leaves and leaves of the lower tier, then spreading to the growth point. The disease is intense during the period of emergence of seedlings before the formation of true leaves, then it dies down and is restored again and increases during the budding, flowering and until the end of the rapeseed growing season.

Fusarium wilt (caused by *Fusarium oxysporum* f. sp. conglutinans Schlecht,: Fr.), which occurs on many species of the family Brassicacae [260]. *F. oxysporum* is characterized by the presence of specialized forms dedicated to certain host plant species and physiological races affecting individual varieties of these species [261]. Three specialized forms have been described on species of the cabbage family: *F. oxysporum*.sp. conglutinans infects cabbage (*Brassica oleracea*) and is represented by two races (Foci and Foc2); *F. oxysporum*/.sp. matthhli infects levkoy (*Matthiota incand*) and is also represented by two races (Foml and Fom^2); *F. oxysporum*, sp. Raphani 28 (For) infects radish (*Rafanus sativus*), races not described (Figs. 1.43–1.45).

The disease first appears as small yellowish spots, which then grow larger and cover the entire leaf. When the leaf is viewed in the light, a reticulation is revealed. Then the leaves lose their turgor, dry up and fall off, and young plants die. Plants that get sick in the early stages of development, with a slow course of the disease, are characterized by shortened internodes. The growing new leaves of the upper part of the stem in the chronic course of the disease have a corrugated appearance (Figure 1.45). Leaves fall off on plants that are infected during the budding phase, and buds, flowers, and stems dry out. If the plant dries up during the fruit formation phase, it dies before harvesting, and the stem of such plants has a dark color.

Lightning blight usually occurs in the middle of summer or at the end of the growing season. The leaves on such plants lose their turgor without changing color, hang down, there is no characteristic reticulation, and the plant dries quickly. A distinctive feature of the disease at all stages of rapeseed development and with different disease progression is the browning of the stem wood, which is detected during cutting.

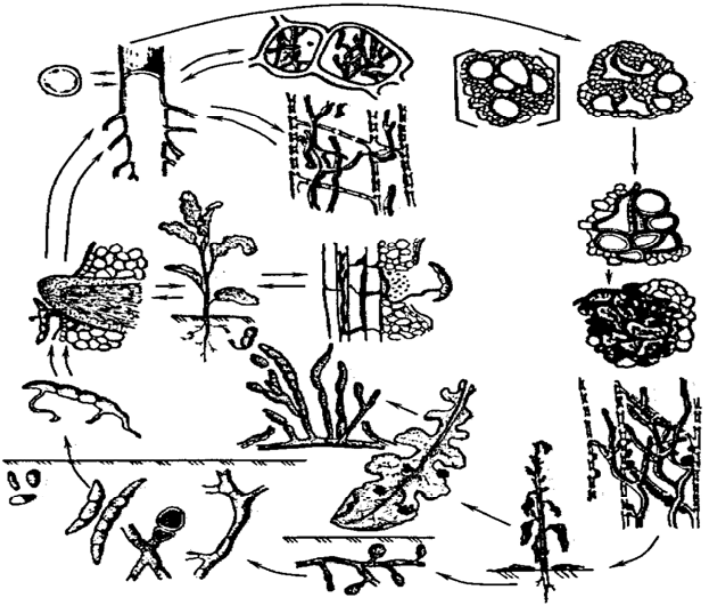

Figure 1.43 – Biological and infectious cycles of Fusarium oxysporum, which causes wilt of rapeseed [262]

Established [263], that *Fusarium oxysporum* usually overwinters as chlamydospores (thick-walled dormant spores) in the soil or on infected plant debris. Two other types of spores are also produced – macro- and microconidia. The spores germinate and penetrate the roots directly or through cracks created by new lateral roots by the expanding mycelium.

Figure 1.44 – Signs of *Fusarium wilt* in rape [264]

Figure 1.45 – Leaf chlorosis on rape leaves caused by *Fusarium wilt* [96]

Figure 1.46 – Rapeseed pods affected by *Fusarium wilt* [96]

Under conditions of moisture deficit, the symptoms will be more noticeable and easier to detect. Look out for these symptoms: yellowing, wilting, and dark brown or black discoloration of the vascular tissue, often seen on only one side of the stem or on branches, known as unilateral striation. Some plants may have orange-pink discoloration at the base

of the stem. Plants with a minor infection may also mature prematurely and be prone to shedding. There may be symptoms of plant cell or tissue death, discoloration of blood vessels, poor seed set, and premature drying. Stems and branches turn brown, but plants remain upright with intact roots. There are no visible lesions on the stems and roots. Plants are often stunted and have small pods without seeds.

The pathogen then infects the vascular tissue, which becomes discolored and clogged. The fungus produces microspores that move up the stem. The blockage of the xylem prevents water from moving up the stem, which leads to wilting of the plant. Spores also form on the above-ground parts of plants, which fall to the ground and re-infect the soil. Sometimes the seeds become infected through the vascular tissue, but usually the seeds die before this can happen. Fusarium oxysporum persists in the soil for a very long time, with spores lasting for more than 10 years. The pathogen is transported through the soil by wind, water flows, or on equipment.

Any conditions that cause stress to the plant increase the risk of infection. Fusarium wilt is influenced by environmental conditions, especially soil temperature and moisture. Warm temperatures above 16°C favor the development of the disease. Dry soils are favorable for the development of the disease. Factors that reduce root growth rate increase the plant's susceptibility to Fusarium wilt. Early planting in cool, moist soil contributes to the development of the disease.

According to the researchers, *F. oxysporum* isolates belonging to different specialized forms are genetically isolated, as each specialized form corresponds to a specific group of vegetative compatibility and a characteristic electrophoretic type of isozyme polymorphism.

The causative agent of Fusarium wilt of rapeseed, according to [8; 153], is no longer a highly specialized pathogen of *B. napus*, but is capable of infecting other members of the cabbage family. Based on the reaction of differentiator samples, it can be attributed to the cabbage-specific form, F. oxysporumf. sp. conglutinans. Genetic relatedness of isolates from different cabbage species virulent to rape is confirmed by the fact that they are vegetatively compatible. The strains tested on cabbage varieties with different resistance proved to be a race.

The damage caused by the disease depends largely on the time of its manifestation. Plants affected in the early stages of development (before

flowering) do not form a crop at all. When the disease develops in later stages, the number of pods, seeds per pod and weight of 1000 seeds decreases by 27–43, 20–35 and 28–37%, respectively. Fusarium losses due to attacks in the germination and rosette phases are partially compensated by the more powerful development of the surviving plants and an increase in their productivity. The largest yield losses are associated with rapeseed damage at the beginning of flowering. In production crops, there are usually only a few diseased plants. In the case of crop loss, there is no economic impact. However, the number of affected plants increases significantly when reseeding rapeseed [267]. The disease is found on young and adult plants. In the rosette and stemming phase, the leaves wither and the plants die. When the disease appears in later stages, in addition to symptoms on the leaves, there is damage to individual conductive bundles, which is manifested in the lightening (light green, then yellow color) of a part of the central stem, made above the damage, at the border of the bark and wood due to the penetration of the pathogen into the xylem vessels. There is no maceration of the bast, it only dries to the wood [268].

Plants that get sick during budding or flowering abruptly lose their turgor, the flower cluster droops, the stems dry out, become brittle and easily pulled out of the soil. Small underdeveloped pods may also form, and premature ripening occurs. In wet weather, a pink mycelium coating forms on the lower part of the stem of dried plants [269].

The disease is usually focal and spreads radially during the growing season. Fusarium can also manifest itself in an acute form, causing plant death within 2–3 days. Infection of plants occurs through the epidermal cells of the root sheath. The mycelium spreads through the vessels to the stem and leaves and is located along the walls of the vessel, in the intercellular spaces and sometimes enters the cell cavity. Mycelial hyphae in the vessels are thick (5–6 microns), and thin (1.5–3 microns) in the intercellular spaces and cells [270].

The fungus can grow at temperatures ranging from 10 to 35 °C. The optimum temperature for it is 18–27 °C and soil moisture content of 40–70% of the full moisture capacity. At a moisture content above 70%, development slows down and the mycelium forms a mass of chlamy dospores; at a moisture content of 40%, mycelial growth also slows down, but there is no abundant formation of chlamydospores [283].

The dynamics of the disease varies by season and depends on the temperature regime. This dependence is especially clear in the early stages of development. At low temperatures in April-May, the symptoms of the disease in most affected plants begin to appear only before flowering, and at higher temperatures, a significant proportion of plants are affected in the early stages. Varietal characteristics also have a significant impact on the dynamics of the disease. Susceptible samples vary significantly in the number of plants affected at different stages. Resistant ones get sick at later stages of development.

In some years, a significant negative correlation was noted between the percentage of Fusarium wilt damage and the content of erucic acid and glucosinolates in varieties [283].

The fungus forms one- and two-celled, colorless, rounded chlamydospores 3.5–7 μm in diameter with a thick shell, thanks to which it can easily tolerate sharp temperature fluctuations, does not die during severe freezing, and is not afraid of drying. When dry, they can withstand heat up to 8 °C. They can survive in the soil for up to 11 years. The infection enters the soil with plant residues. The main reservoir and accumulator of the infection is carrion, which explains why in crop rotations with a short rotation, the harmfulness of Fusarium can be very high, almost the same as in an infectious background The pathogen can be introduced to fields with soil clods, with irrigation water coming from infected fields [208].

There are contradictory opinions in the literature about the possibility of seed transmission of Fusarium wilt. Thus, V.F. Peresypkin [283] indicates the possibility of plant infection through seeds. However, L.G. Portenko [271] did not detect Fusarium pathogens in seeds from diseased plants, but does not deny the possibility of seed transmission due to surface contamination of seeds by small particles of affected stems. Some studies indicate the presence of the ash (charcoal) rot pathogen (*Sclerotium bataticola* Taub.) in the agrocenoses of cruciferous crops (Figure 1.47–1.49). The pathogen is a polyphage and affects more than 300 species of cultivated and wild plants. It affects sunflower in the southern regions of Ukraine, where it occurs every year, regardless of weather conditions. In years with dry and hot summers, sunflower infection can reach 90%.

The disease causes premature drying of the plants, and yields are reduced by 20–60%, which is due to a 25–35% decrease in the weight

of 1000 seeds. Oil content of seeds decreases by 2–8%, in addition, yield losses during harvesting increase due to brittleness and lodging of affected plants, and plants are more susceptible to ash rot in the budding phase. External signs of the disease appear in the second half of the sunflower growing season in the form of yellowing, drying of leaves and the formation of a brown spot in the basal part of the stem, which does not soften even in wet weather and gradually acquires a light ash color. Over time, the spot encircles the stem and spreads up the plant. Affected plants wither, dry out, the stem softens, the core dries up and it can completely crumble. The baskets and seeds are not affected and the disease is not transmitted with the seeds.

In appearance, the manifestation of charcoal rot resembles the root form of white rot, but differs from the latter by the ashy color of the affected tissues and much smaller sclerotia.

Numerous, small (50–150 microns in size) microsclerotia of the fungus are formed under the epidermis and in the stem core. In the soil in plant debris, they remain viable until the next year, and in the spring they germinate into mycelium, which penetrates directly into the seedlings and infects them.

Subsequently, during the sunflower growing season, the mycelium actively grows and spreads throughout the stem. In 10–15 days after flowering, the mycelium fills the plant's conductive system, which prevents the flow of water and nutrients.

The disease spread is facilitated by high soil temperatures (over +25...+30 °C), dry and hot weather, and the use of alfalfa as a precursor.

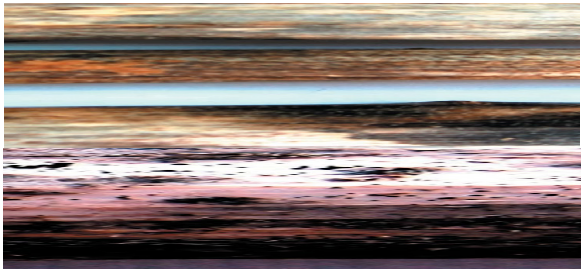

Figure 1.47 – Symptoms of ash rot on stems and roots of winter rape [96]

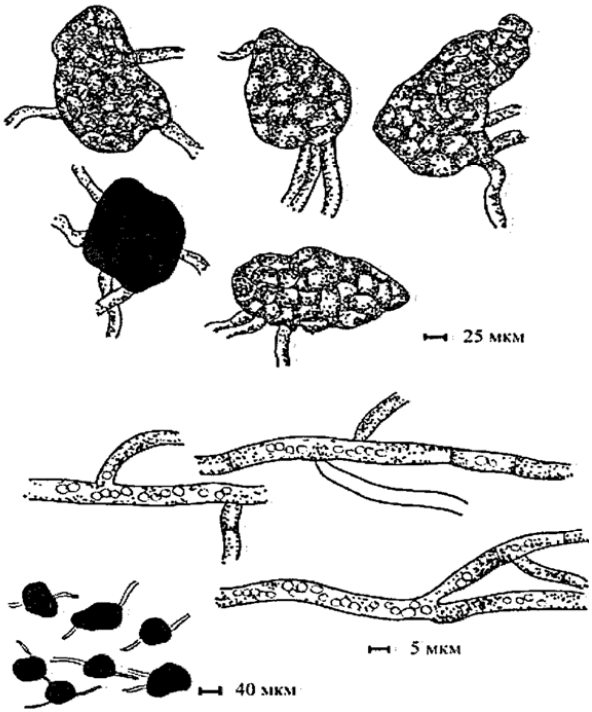

Figure 1.48 – Microstructures of Sclerotirum bataticola Taub. – the causative agent of ash rot of rape [10]

Verticillium wilt of Brassicacea species has attracted the attention of researchers relatively recently. Verticillum dahliae Klebahn (class Deuteromycetes, order Hyphomycetales, family Moniliaceae) as a pathogen of rape was first discovered in 1960 in Sweden [272]. It is now one of the most harmful diseases in this country. Its harmfulness is also high in Germany [8]. Evaluating 1992–1994 in Poland, verticillium was present in all surveyed fields [273], losses reached 30–70%. In the 80s, the disease was discovered in France [274]. Rapeseed verticillium is found in Ukraine. It causes damage in the production of cabbage family vegetables in Japan, and in recent years – in cauliflower growing areas on the California coast.

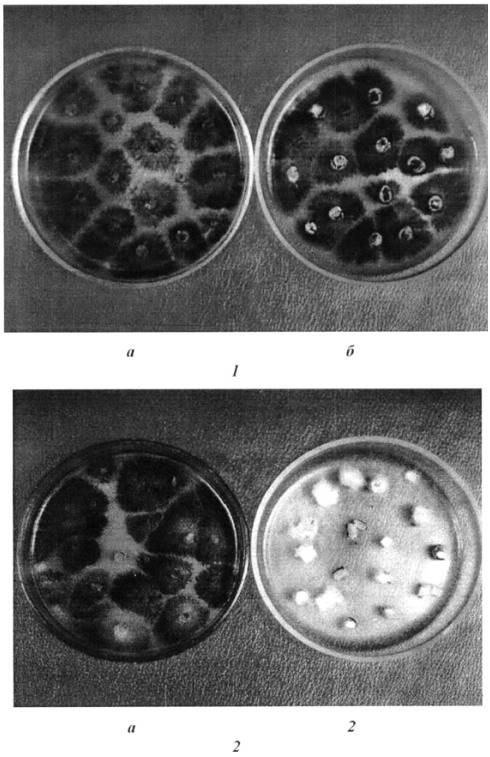

Figure 1.49 – Isolation of ash rot pathogen of rape from affected roots (a) and stems (b), where 1 – pure culture of *Sclerotium bataticola*, 2 – mixed infection with *Fusarium oxysporum* [284]

Studies of the virulence of V. dahliae of different origins for B. napus have been conducted. Isolates from rapeseed caused severe wilting of spring forms of this crop, a strong decrease in the yield of a single plant and the weight of 1000 seeds. Isolates from other host plants caused much less severe symptoms and did not affect yield. Plants infected with the potato isolate produced significantly higher yields than uninfected plants [275].

The causative agent of this disease was considered to be *V. Dahliae* [200]. However, a number of studies have shown that the conidia of pathogen isolates from affected plants of the cabbage family are almost twice as long

as those of typical *V. dahliae* isolates, so they were referred to as V. dahliae var. longisporium Stark. This species was described by Stark (1961) [289], who first isolated a long-spore isolate of the pathogen verticillosis.

A study of a large group of longisporous isolates isolated in Japan from cabbage plants showed that they differed significantly from typical V. dahliae isolates and were very similar in morphology, pathogenicity and polyphenol oxidase activity to diploid isolates (including the Stark isolate), so they were grouped into one group – "cabbage" isolates. From a comprehensive study of *V. dahliae* var. *longisporium*, *V. dahliae* and *V. alboatrum* (from alfalfa (L) and nonalfalfa (NL)), including cluster analysis of morphological, molecular and physiological characters, a significant separation of *V. dahliae* var. *longisporium* from two other species – pathogens of Verticillium wilt and it was proposed to give this species the status of an independent species – *V. longisporium* (C. Stark) Karapapa, Bainbridge & Heale [188].

Verticillium wilt is manifested at the end of the flowering phase in the form of gradual wilting or premature maturation of plants. In the lower and middle parts of the stem, as well as on the roots under the epidermis or bark, very small and closely spaced black dots can be found – microsclerotia of the pathogen. The stems and branches of diseased plants become discolored and light yellow. The leaves turn yellow, dry up and fall off. Seeds in the pods are formed in a small, poor quality, with low germination.

In the phase of pods filling and browning, healthy plants bend under the weight of the upper branches, while diseased plants are upright and stand out with their light color from the mass of healthy plants that still retain their green color. On the transverse sections of the stem or root of diseased plants, you can see the darkening of vascular bundles [187].

Infection with this disease occurs through the roots via the germinating mycelium of microsclerotia. For germination of *B. dahliae* microsclerotia, the temperature required is from 6 to 34 °C, and the optimal temperature is 15–28 °C [276].

Infestation of winter rape plants is possible as early as autumn, but on the main stem it occurs only in the spring before flowering. The first symptoms are noticeable before pod formation. It is often possible to observe plant damage simultaneously with necrosis of the root neck. The dynamics of the disease is accelerated and premature maturation of plants is observed.

The source of infection is post-harvest affected residues of rapeseed and other affected crops containing microsclerotia of the fungus.

With high atmospheric humidity and high soil moisture, gray rot may occur on rapeseed. Damage is concentrated at the base of the stem in the form of light watery spots. Under favorable conditions, the disease can cover the entire young plant, including the top, causing it to rot. All affected plant tissues are covered with a delicate, gray, spore-forming coating of the fungus. During a drought, the disease dies down, the stems break at the site of damage, and the plant dies. Harvesting is complicated and accompanied by large losses. The fungus *Sclerotinia fuckeliana* De By has a conidial stage *Bonyiis cinerea* Pers. that develops bundles of large, branched sporophytes, on top of which, on swellings, ovoid, single-celled conidia are formed. Many small dark-colored sclerotia are formed on the mycelium. Apothecia with elongated mace-like asci and 8 ellipsoidal unicellular spores in each are formed on the sclerotia. The pathogen persists in the form of mycelium and sclerotia in the affected plant residues, on which in spring a dense spore-forming coating of the fungus with conidia is formed, which carry out secondary infection during the growing season.

The causative agent of rape white spot is the fungus *Pseudocercosporella capsellae* (EU. et. er) Deigthon (class Deuteromycetes, order Hyphomycetales, family Moniliaceae). White leaf spot of rapeseed was first detected in France in 1985, and then in Canada. In Germany, the disease became widespread only in 1994. In addition to rapeseed, the pathogen can also affect ruddy (*Camelina pilosa*), and therefore it is necessary to take this disease into account when planning rapeseed cultivation in different regions of the world [277]. *P. capsellae* fungus can infect and cause disease symptoms on legumes [278].

Symptoms of the disease are noted on the leaves, but they could also appear on the stems and pods. The spots on the leaves may merge, causing a part of the leaf blades to dry out quickly [279].

The sexual stage of *P. capsellae* – *Mycosphaerella capsellae* (class Ascomycetes, subclass Loculoascomycetidae, order Dothideales, family Mycosphaerellaceae, genus Mycosphaerella) develops in the fall, and the ascospores formed during airborne transmission are the basis of primary infection. Further spread of the disease occurs with the help of conidia. Before the stem begins to stretch, 1–3 lower leaves are usually affected.

After the plants begin to grow in height, the disease spreads further, which is associated with two interdependent mechanisms: the vertical movement of conidia with rainwater to infect young upper leaves and the vertical movement of these infected young leaves due to the growth of internodes [280].

Relative humidity of no more than 80 percent or more is favorable for infection of rapeseed. The onset of infection usually coincides with the onset of precipitation. Conversely, excessively intense precipitation (40 mm in 3 hours) led to a decrease in infection, apparently due to the washing away of fungal spores. It is hypothesized that the rate of fungal spread is a linear function of temperature: incubation for 48 hours at 12 °C is equivalent to 32 hours at 18 °C. The risk period started 15–20 days after flowering and ended 2–3 weeks before harvesting [153]. The fungus *P. capsellae* is preserved on the affected plant residues in the form of thick-walled hyphae [153].

The causative agent of powdery mildew is the marsupial fungus *Ersyphe communis* Grev. f. *brassicae* Hammar L. (class Ascomycetes, order Erysiphales, family Erysiphaceae). Rapeseed powdery mildew is known in Germany, Hungary, France, England, Canada, Ukraine, Azerbaijan, Georgia and Armenia [166]. Powdery mildew is characterized by the appearance of a white, delicate, loose coating on the upper and lower sides of leaves, petioles, stems, and pods. Over time, it thickens and becomes covered with dark brown dots (cleistothecia), which gives it a dirty white or brown color. Severely affected leaves turn yellow and dry out [152].

The primary infection of plants is caused by the sowing of sowing spores released in the spring from cleistothecia that have overwintered on the affected residues. The airborne fungus infects rapeseed plants during flowering. During the growing season, the pathogen is spread by conidia [281].

Powdery mildew develops best at temperatures of 17–20 °C with periods of high humidity [8]. The pathogen persists on the remains of affected plants in the form of cleistothecia, and on overwintering plants – in the form of mycelium and fruiting bodies (Figure 1.50–1.52).

Powdery mildew appears on crops of spring cruciferous plant species, especially on late crops, in the form of a thick white coating on leaves, stems and pods. Affected leaves turn yellow and dry out. On the latter, you can find small dark dots – cleistothecia.

Figure 1.50 – Powdery mildew (the causative agent is the fungus *Erysiphe communis*) [96]

Figure 1.51 – *Powdery mildew* (beginning of winter rape plant infection) [96]

Figure 1.52 – *Powdery mildew* on the leaves of white mustard [96]

The causative agent of the disease is the marsupial fungus *Erysiphe communis* Zrev. f brassicae Hammare. It also affects cabbage, mustard and other cabbage crops. The pathogen's mycelium is multicellular and located on the surface of plant organs. It consumes nutrients with the help of haustoria, which penetrate into the cell. Initially, the fungus forms conidial sporulation, and at the end of the growing season, marsupial sporulation. Conidiophores are placed vertically on the mycelium. They contain colorless, single ellipsoidal conidia measuring 30–36 x 10–18 microns. With the help of conidia, the fungus spreads during the growing season of cruciferous plant species. Kleistothecia are dark brown, spherical, 65-180 μm, on average 90 μm in diameter, without notches when dry. They form branched appendages at the top. In the cleistothecia, 4-8 pear-shaped sacs are formed. Each of them contains 4–8 elliptical discolored asci measuring 19–25 x 9–14 microns. The fungus persists on the remains of affected plant organs of cruciferous plant species in the form of cleistothecia, from which bags with bagospores spread in spring and give rise to new plant infections [282].

The intensity of powdery mildew development on rapeseed increases with the alkaline reaction of the soil solution. This is due to the fact that at high pH in the soil, plants absorb less manganese, the content of which in the leaves is directly correlated with the intensity of powdery mildew development. There are different degrees of resistance to powdery mildew among rapeseed varieties. According to a number of researchers [283]. The most susceptible variety of cruciferous plant species to powdery mildew in Scotland was Dio. It formed an average of 42.4 conidia per 1 g of leaf tissue. High resistance to the disease was characterized by the varieties Winfred (I conidia/1g) and the sample C57E18 (1.7 conidia/1g).

In the conditions of the Agronomic Experimental Station of NUBiP, we found high resistance to powdery mildew in the varieties of spring rape Kalinovsky and Kletinny 8 [284]

The causative agent of light spot, or cylindrosporosis, is the fungus *Pyrenopeziza brassicae* (conidial stage of *Cylindrosporium concentricum* – class Deuteromycetes – order Melanconiales, family Melanconiaceae). The disease has been known since the beginning of the XIX century on cabbage, but only in the 70s of the XX century it was discovered on rapeseed. Cylindroporosis is found in all European countries [285]. Since the late 1980s, its harmfulness has been increasing in Germany [8], in the UK [286],

and causes yield losses of up to 50%. In the spring of 1983, the epiphytoty of cylinderspore on rape was noted in France [287].

With the onset of disease symptoms in November-January, the productivity of dry biomass of plants, seeds and other components of the winter rape crop significantly decreased. The manifestation of the disease in March did not have a significant impact on the evaluated parameters [288].

When pods are damaged by *C. concentricum*, the weight of 1000 seeds decreases in winter rape by 1.5 and in spring rape by 1.7 times, oil content – by 9.3–16.1%, respectively. The content of palmitic acid in the oil increases by 24–36 and 04%; stearic acid – by 2.3 and 1.0%; linolenic acid – by 2.7 and 1.4%; erucic acid – by 2.3 and 2.0%; eicosic acid – by 1.5 and 1.7%, respectively. The content of oleic acid decreases by 8.6 and 4.9; linoleic acid – by 2.6 and 1.6%, respectively [252].

Spores of the fungus, spread by the wind in the fall, cause irregularly shaped gray spots on the leaves, similar to frost damage or fertilizer burns. Gradually, shoots, buds and flowers of rapeseed plants are affected.

Infection with *C. concentricum* occurs within five days at a temperature of 5–15°C, and dripping moisture is required for the disease to develop. Under controlled conditions, necrosis developed with prolonged moistening of the leaf surface after inoculation for 16–18 hours and at a temperature of 12–18 °C. The latent period decreased from 17 to 9 hours with increasing duration of leaf surface moisture, while the number of necrosis also increased. A similar dependence was observed in the field, but the area of the affected surface was lower than that of plants in the greenhouse [289].

When rape leaves are damaged by the pathogen cylindrosporium, three aliphatic glucosinolates are induced in them in a greater proportion.

Variability in the virulence of *C. concentricum* was found in the UK [290].

The initial occurrence of the disease and the rate of its spread are higher when re-sowing rapeseed than after grain crops. Residual amounts of propyzamide, tebut and fluazifop-P-butyl herbicides increase the incidence of rape light spot [292].

Sources of infection are seeds and plant residues, on which the pathogen persists in the form of conidia, rarely marsupial sporulation (apothecia). Mycelium of the fungus can be stored in the living tissue of winter rape leaves under the cuticle [166].

The causative agent of clubroot is the fungus *Plasmodiophora brassicae* War. (class Plasmodiophoromycetes, order Plasmodiophorales, family Plasmodiophoraceae, genus Plasmodiophora). In many regions of intensive oilseed rape planting, the infected [293].

In Sweden, in the early 80s, large losses were recorded as a result of the defeat of rapeseed by this disease. In opinion [294] the main reason is a significant increase in sown areas.

Clubroot is rare in the UK, but all commercial winter oilseed rape varieties have been susceptible to the disease. The expansion of rapeseed crops to the north and west of the country, where soils are more acidic and fodder Brassicae are grown, has led to an increase in the disease88. Registered in Ukraine and Poland [2] (Figure 1.53).

Clubroot leads to a decrease in the density of productive stems, branching and the number of pods per plant [295]. Clubroot manifests itself on the roots of young seedlings and older rapeseed plants in the form of growths and swellings, which can sometimes reach significant sizes.

Figure 1.53 – Signs of clubroot on winter oilseed rape [100]

Figure 1.54 – Development of clubroot on the roots of cabbage seedlings [296]

Rapeseed is depressed, stunted; leaves turn pale green, droop in the heat, and are easily pulled out of the soil. Pods often do not form. In late autumn and especially at the beginning of the growing season in spring, plants dry out. The root system dies off, the growths rot, and most often the plants die [166]. Plants are infected by zoospores that penetrate the roots through root hairs or epidermal cells. Acidic and moist soils favor the release of zoospores.

The fungus is stored in growths in the form of dormant spores, then under the influence of soil microorganisms, the growths are destroyed and the spores enter the soil, where they can persist for up to 4–5 years [166]. According to other data, the pathogen was released from the soil 18 years after sowing a susceptible crop [297], but there is evidence that in 3–4 years the degree of infection decreases to a negligible value [298]. Diseases such as white rust – *Albugo candida* – also pose a potential danger [299–301], white leaf spot – the causative agent *Psedocercosporella capsellae* [125]; seedling diseases [302] (Figure 1.55).

Figure 1.55 – White rust on a rape leaf

Black leg. It is known in areas where cruciferous plant species are grown, mainly on heavy clayey black soils. Seedlings of cruciferous plant species are affected. Entire groups of plants lose

their turgor, turn yellow and dry out. The affected root collar becomes thin, turns dark in color, and later rots. The root system of affected plants of cruciferous plant species practically does not develop. The roots of the 2nd and 3rd orders die off. Affected plants are easily pulled out of the soil with a black leg [303]. The causative agents of this disease are semi-saprotrophic fungi from the genera Pythium Pringsh, Rhizoctonia D.C., Olpidium A. Br. These pathogens are found in the soil, multiply on various plant residues, and affect weakened seedlings of cruciferous plant species. With a strong development of the black leg, the crops of cruciferous plant species are greatly thinned out, especially in the early spring period on crops of spring cruciferous plant species [304].

White spotting. The disease is widespread on all cabbage crops, including rapeseed. It affects the leaves, rarely the stem and pods. The leaves form indeterminate grayish-white spots with a light green halo, which merge in wet weather, and the leaves curl and dry. In the affected areas, sporulation is formed in the form of small whitish pads. On the stems and pods, spots are formed in the form of elongated ulcers of grayish-white color with sparse pads. In the affected areas, the pods are bent, the seeds are small and underdeveloped. The causative agent of the disease is Cercosporella brassicae v.Hochn (Pseudocercosporella capsellae). Its mycelium is multicellular, developing in the middle of the host plant. Conidia are simple, in the form of bundles. Conidia are straight or curved, 50–130 x 4–4.5 μm in size, colorless, and have two or three septa. The fungal conidia spread mainly in wet, windy weather.

The first epiphytic development of white spot on spring rape was observed by I.L. Markov [4]. The fungus is preserved on the affected plant residues by mycelium and microsclerotia. The harmfulness of the disease is expressed by a decrease in the assimilation surface of plants, premature death of leaves, which leads to a decrease in the productivity of cruciferous plant species [305].

Root bacteriosis occurs in winter rape. Its development begins in late September or early October, with the formation of a cavity inside the root, near the root collar. As a result of the lesion, the core turns brown. According to external signs, the disease may not show signs during this period. It can only be detected by a longitudinal section of the root. In the spring, especially with sudden changes in air temperature, as well as the influence

of unfavorable wintering conditions, the affected roots of rapeseed become slimy, soften, and the rosette of leaves is easily separated from the root. Plants wither and dry up [306]. Sometimes affected plants begin to form new leaves at the expense of root nutrients, and over time they droop and die [110; 307]. Under favorable overwintering conditions, affected plants of cruciferous plant species with bacteriosis can have seeds, but with a reduced yield by 30–40% [308].

The formation of cavities in the roots occurs due to uneven water supply to the plant. The reason for this is a violation of the growth of parenchymal tissue under the influence of the pathogen. The same is observed in case of excessive nitrogen application for sowing winter cruciferous plant species [309]. The cavities contain pathogens – bacteria *Xanthomonas campestreis* (p.v. campestris) Dowson or Pseudomonas fluorescens p.v. napi Peresypkin. The source of bacteriosis infection can be affected root remains of winter cruciferous plant species and other winter cabbage crops. The carriers of the infection are pests (rapeseed borer, cabbage fly and others).

Viruses and bacteria, as well as some fungal pathogens, can be stored in root tissue. For example, bacteriosis pathogens settle in the roots of winter cruciferous plant species, in places of cavity formation [310]. Soil fungi are directly related to the root system. Some of them can transmit viral infection by mobile zoospores that parasitize the roots of cultivated and wild plants. Viral diseases include a mosaic of cruciferous plant species.

The root system of cruciferous plant species can be affected by blackleg pathogens – semi-saprophytic fungi from the genera Pythium, Pzingsh, Olpidium and others. Thus, when selecting breeding material, especially in selection for immunity, breeders and phytopathologists should pay attention to such a vegetative organ as the root [166].

White rust, white blister rust are common names for the disease caused by Albugo spp. on more than 400 plant species worldwide [311–313]. The name of the disease comes from the appearance of white pustules, resulting from the enzymatic breakdown of the epidermal cell wall, on the surface of leaves and other aerial parts of the host plant.

White pustules are a mass of dehydrated sporangiospores, which, when rehydrated in water droplets, lead to infection of stomata [315]. It is a representative of the eukaryotic oomycetes of the order Albuginales of the class oomycota, which are exclusively obligate biotrophic parasites with a

wide range of host plants [316–319]. *A. candida* exhibits obligate biotrophic feeding, completely dependent on host tissue. *A. candida* reproduces by asexual sporangia or zoospores and extremely resistant thick-walled sexual oospores. In all species of pathogens, oospores are the main source of inoculation [320]. Oospores are responsible for long-term survival in plant debris and are released when the host tissue decays [322; 336]. The presence of oospores in plant debris and perennial mycelium in the living tissue of the host (including weeds) allows the pathogen to survive between the host's growing seasons [321]. Moisture on the surface of the host plant is necessary for sporangia germination and infection by zoospores. The most likely sites of primary infection are the developing cotyledons of host plants. Albugo sp. enter through stomata, form intercellular hyphae, penetrate the plant cell wall, and invade the plant plasma membrane with the help of haustoria to take up plant nutrients and release effector proteins into host cells [322]. When the zoospores come into contact with the surface of the plant leaf, they settle in the stomata, incrustate and form a germ tube that extends into the substomatal chamber and penetrates the host cell. A primary vesicle is formed in the host cell, which ensures the further development of intercellular hyphae in a sensitive interaction [323]. When the infection matures, the zoosporangia forcefully rupture the plant's epidermis, and subsequent enzymatic digestion leads to the formation of characteristic blisters (‘white blister’). The disease is characterized by both local and systemic manifestations. Local infection is manifested in the form of white or creamy yellow pustules or "blisters" on the leaves and stems. Systemic infection leads to abnormal growth, inflorescence deformation and sterile flowers, commonly referred to as "deer head", which appears as a result of hypertrophy and hyperplasia. In addition to *A. candida*, which infects oilseeds and cruciferous plants, some other Albugo species are also known plant pathogens that cause huge yield losses in field crops, such as Albugo tragopogonis on sunflower, Albugo ipomoeaepandurate on sweet potato, and Albugo occidentalis on spinach. *A. candida* is an obligate biotrophic homothallic oomycete, the causative agent of white rust. According to molecular studies, the genus Albugo includes about 50 (usually) specialized pathogens, such as *A. laibachii* in *Arabidopsis thaliana* and *A. candida* in *B. juncea* [324–327]. The impact of the disease is very high in the Indian subcontinent, as

almost all released lines grown commercially in India are susceptible to the disease.

To date, *A. candida* forms 24 physiological races that infect more than 200 plant species in 63 genera from the families Brassicaceae, Cleomaceae and Capparaceae, each specializing in different host species, of which at least 10 specialize in different Brassicaceae species [328–339]. Among the identified races, race 2 (Ac2VRR) causes severe annual yield losses in oil mustard (*Brassica juncea* [L.] Czern. and Coss.) in Europe, India, Canada and Australia, and also infects some genotypes of other Brassica species, including oilseed rape (*Brassica rapa* L.) [340–342]. Race 1 (Ac1) affects Raphanus sativus, race 4 (Ac4) affects *Capsella bursa-pastoris*, race 5 (Ac5) affects *Sisymbrium officinale*, and race 6 (Ac6) affects *Rorippa islandica*. Race 7 (Ac7) is mainly restricted to B. rapa, but has also been reported to cause disease in some *B. napus* cultivars [343] and some genotypes of *B. juncea*. Race 9 (Ac9) infects *B. oleracea*.

In Ukraine, the main bacterial disease of cruciferous crops is root rot, which causes losses of up to 25% of the crop (in some years – up to 40-70%). Root bacteriosis is more common in winter rape. The development of the disease begins in late September or early October with the formation of rotting cavities inside the roots near the root collar and further browning of the core. In the fall, the disease hardly manifests itself externally, it can only be detected by a longitudinal section of the roots. In early spring, especially in snowless winters with sharp temperature fluctuations, most of the affected roots become slimy and soaked, which leads to plant death. The rosette of leaves is easily separated from the main root. Pathogens such as the bacteria *Xanthomonas campestris* and *Pseudomonas fluorescens* settle in the cavities. As pointed [166], in case of *X. campestris* infection, necrotic V-shaped spots surrounded by a chlorotic rim are observed on the leaf blades. The source of infection of winter rape roots with bacteriosis is plant residues, as well as cultivated and weedy cruciferous plants susceptible to this disease, especially rape.

Symptoms of bacteriosis varied in nature, but most often manifested as light brown spotting on the leaves, weak softening of the leaf petiole, ulcers on the stem, especially in the root part, and darkening of the vascular system. In the early stages of development, the affected tissue sometimes had a darker green color than the surrounding unaffected tissue. Sometimes

the spots looked as if they were soaked in water or oily, often with a light yellow halo resulting from the diffusion of bacterial toxins into the surrounding tissue. The spots that appeared on stems or leaf petioles were usually oblong in shape.

Most often, 2 types of pathogenic bacteria were isolated, one of which caused stem and vascular burns and belongs to the pathotype *Xanthomonas campestris* pv. campestris, the second one causing bacterial spotting was identified as *Pseudomonas syringae*. The pathogenicity of the above species was proven in greenhouse and chamber conditions. The bacteria caused a hypersensitivity reaction on tobacco, geranium and plenicranthus and infected rapeseed and sunflower. The yellow-pigmented isolates we isolated did not differ from the typical *X. campestris* pv. campestris strain in their phenotypic properties.

It has been established that the sources of infection of winter rape with these bacterioses are plant residues, as well as cultivated and weedy cruciferous plants, which are often affected by xanthomonads and are carriers of bacterial infection. In addition, as a carrier of vascular infection, bacteria enter the seeds, where they remain until the next year. According to some reports, different types of insects can be carriers of rapeseed bacteriosis. In this regard, the fight against bacterial diseases of rapeseed should be integrated (destruction of plant residues, weeds, seed treatment, insecticide treatment and the use of varieties that are least affected by these pathogens).

Seed mass of cruciferous plants, as a storage object, is characterized by increased activity of physiological and microbiological processes and is prone to rapid deterioration even when stored at humidity not only regulated by SSU, but also close to critical [344].

It is believed that the reduction of glucosinolates in the so-called new "00" rapeseed varieties, along with a positive impact on the quality of seed products, has negative consequences, reducing the resistance of plants and their seeds to pathogens [9].

The limits of active growth of mold fungi are the following combinations of seed moisture and temperature: 8 % and 25 °C, 10 % and 20 °C, 12 % and 39 less than 20 °C. At 14 and 16 % seed moisture, fungi multiply so that their number increases hundreds and thousands of times even at 10 °C. At low temperatures, Aspergillus spp. and Rhizobium spp. develop evenly, while

at high temperatures, the former develops more intensively. A significant increase in the content of A. flavus, which is capable of producing the most toxic metabolites, is noteworthy.

The development of mold microflora on the seeds of high-glucosinolate rape varieties is subject to the same laws. At high seed moisture, the expected increase in the number of microorganisms is not observed. Already at a moisture content of 18.6% and a temperature of 30 °C, there is almost complete inhibition of mold microflora. This is probably due to the fact that at high seed moisture content, an increase in temperature promotes the hydrolysis of glucosinolates. Under these conditions, it is possible to activate the enzyme myrosinase, which breaks down glucosinolates to form more toxic compounds.

Conflicts of microorganisms are more sensitive to the content of glucosinolates in seeds and their hydrolysis products, especially at the time of germination (in the lag phase), and less sensitive in the logarithmic phase of growth. This is confirmed by the rapid deterioration and intensive growth of microflora in seeds with low moisture content (8–13%), which is not enough for the release and hydrolysis of glucosinolates. In seeds with excess moisture, under favorable temperature conditions, glucosinolates are hydrolyzed to form toxic products that inhibit the growth of microbial spores, In seeds with a lack of moisture, microbial spores germinate without contact with glucosinolates.

The mycelium of microorganisms, possessing a powerful enzymatic system, is not inhibited even with a high content of glucosinolates. Numerous studies have established the possibility of accumulation of toxic compounds – aflatoxins produced by storage molds – in seeds, grains and their products.

High- and low-glucosinolate rapeseed seeds differ in the rate of accumulation of aflatoxins and their group composition: in high-glucosinolate rapeseed seeds, the accumulation of aflatoxins of groups B1 and G1 is more intense; in low-glucosinolate seeds, it is slower and they are represented by only one group B [345].

Localized aflatoxins are mainly in the seed coat. The seed kernel contains fewer aflatoxins, but their absolute amount is significant, so cake and meal have a high content of aflatoxins, and they are contained in rapeseed oil in the form of traces. Aflatoxins and glucosinolates (their

non-volatile components) reduce the biological value of meal proteins, which is determined by the test organism Tetrahymena pyriformis. The toxic effect of aflatoxins and glucosinolates in the meal is summed up, the minimum concentration of them that causes the death of the test organism is reduced [346].

The list of diseases of oil radish plants is similar to the cabbage group [347–353] (Figure 1.56–1.58, Table. 1.17). And according to I. Markov [4] cruciferous crops are characterized by high ecological plasticity in relation to emerging pathogens. However, the expansion of the area under oilseeds from the cabbage family and the increase in their yield in Ukraine is constrained, first of all, by the significant harmfulness of diseases inherent in oilseeds. The harmfulness of the diseases is manifested in a significant decrease in the quality of green mass, with their development reducing the content of vitamin C, protein, fat, and sugar. According to the author's research, the amount of amino acids in the affected leaves of rapeseed, rape, oil radish, depending on the intensity of the disease development, decreases by 1.4–2.7 times, the oil content in the affected seeds, depending on the pathogen, decreases by 1.3-3.4 times, the specific gravity of palmitic, stearic, erucic, eicosinic, linolenic acids increases significantly, while the specific gravity of oleic and linoleic acids in the composition of cruciferous oils decreases. The shortfall in seed yield from diseases, in particular in oil radish, depending on the variety and technology of its cultivation, ranges from 15 to 35% with a significant deterioration in its sowing qualities. According to the results of a comprehensive evaluation of the oilseed collection at NUBiP of Ukraine (Table 1.17), it was found that oil radish has the lowest resistance to Alternaria, downy mildew, gray and white rot, and phomosis. However, it is resistant to cylindrosporiosis and white rust and Fusarium wilt.

Alternaria ssp. The infection persists on the affected leaves of oil radish, plant residues of cruciferous crops and seeds. The disease begins to spread to young pods after flowering. Crops are particularly severely affected by high humidity and warm weather. It affects all organs of the rapeseed plant. During the germination period, it causes rotting of seedlings. On cotyledon leaves it appears in the form of dark brown spots that lead to decay and death of seedlings in the early stages of development. Light smoky spots with a light halo around the spot are formed on the leaves. Further, the

spots darken, acquiring a rounded shape up to 1 cm in diameter with a pronounced zonation from the center. Dark, rounded, depressed ulcers appear on the affected pods, deforming the pod. The stems are covered with oblong dark spots. The disease is most harmful during pod formation. The pods ripen prematurely and crack. In the years of epiphytic development of the disease, the length of the pod decreases by 8–26%, the number of seeds in the pod decreases by 12–59%, the weight of 1000 seeds – by 15–70%, the oil content in the seeds – by 11–27%.

Phoma lingam When infected seeds germinate, the disease manifests itself on the hypocotyl and cotyledons in the form of watery spots of various shapes, which, when dried, turn gray and pycnidia form on them. When seedlings are affected, dark spots appear in the root part of the stem and on the root. Subsequently, the affected areas dry up and brighten, which ultimately leads to the destruction of the root system and the death of the crop seedlings. During the growing season, the disease manifests itself on the stem in the root part in the form of dark ulcerative lesions that can spread to the root system, causing dry root rot. Oil radish plants with this type of lesion are stunted, have a chlorotic appearance, lie down and die. On leaves and pods, phomosis appears as gray dry spots with concentric zonation and dark pycnidia. The infection persists on plant residues and seeds. Phytopathological picture of the disease for oil radish in Ukraine: infection of seeds does not exceed 2%, damage to seedlings – 10–18%, stems – 30–46%, leaves and pods – 5.5–12.0% with the development of the disease 2–5%.

Peronospora brassicae. Causes premature death of leaves. In wet years, pods may be affected. The disease manifests itself on cotyledonous and true leaves. Yellow, blurry spots appear on the upper side of the affected leaf, and a gray-purple coating is visible on the lower side of the leaf, which is the conidial sporulation of the pathogen. Symptoms of the disease on the stems and pods are oblong gray-purple spots with sporulation of the pathogen. The pathogen infection is maintained by mycelium in the tissues of affected plants of oil radish and other cruciferous crops, as well as on plant residues. The source of infection can be infected seeds.

Gray rot (Botrytis cinerea). The source of infection is sclerotia and affected seeds. Affected stems are broken. The seeds are small with low sowing and technical qualities. Gray rot develops intensively in wet weather, affecting all plant organs.

Figure 1.56 – Rapeseed pod and stems affected by gray mold [69]

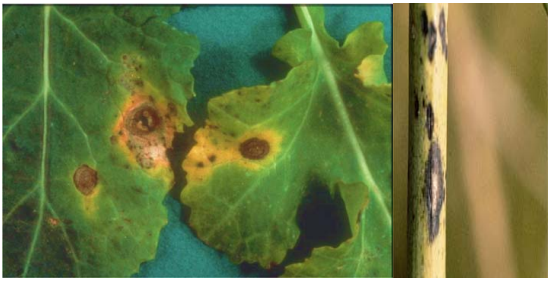

Figure 1.57 – Signs of Alternaria damage on the leaves of oilseed radish [56]

Figure 1.58 – Signs of phomosis damage to leaves and root system [56]

Figure 1.59 – Phomose dry rot of the root system of oil radish (magnification 400x) [56]

Figure 1.60 – White rot on oilseed radish pods [56]

Figure 1.61 – Leaves affected by downy mildew and signs of gray rot on oilseed radish [56]

Table 1.17

Oilseeds disease susceptibility in the conditions of the NUBiP of Ukraine, ASS [369]

Crop	Disease development, %									
	peronospo-rosis	alternaria	phomosis	cercospo-riasis	asco-chitosis	cylindrospo-rosis	white rot	gray rot	fusarium wilt	white rust
Winter rape	19.4	24.2	8.0	4.0	1.6	12.8	6.0	7.9	4.8	0.3
Spring rape	15.2	18.5	6.8	2.9	1.8	6.2	7.2	5.1	3.3	0.7
Common rape	10.3	5.5	3.5	2.2	6.5	2.7	2.2	3.2	2.0	0
White mustard	8.6	11.8	4.9	4.7	6.3	0	3.4	1.6	2.4	1.4
Gray mustard	11.4	17.2	1.4	0	6.0	0	1.0	3.1	1.8	0
Camelina	3.2	2.0	0	0	0	0	1.8	1.6	2.4	9.7
Oilseed radish	9.4	24.6	4.6	3.4	2.8	0	4.3	4.8	1.0	0
SSD_{05}	*2,4*	*2,7*	*1,3*	*1,1*	*1,1*	*1,6*	*1,1*	*1,3*	*1,0*	0,8

The affected areas look like brown, watery spots of arbitrary shape, covered with gray fluffy mycelium of the pathogen. In dry weather, the affected plant tissue dries and becomes light gray. On green pods, gray rot appears as a lightening of the pod. In wet weather, the affected pods become covered with a gray coating, and when dry, they crack. Black, small sclerotia form on the affected plant organs.

White rot (*Sclerotinia sclerotiorum*). The main source is sclerotia stored in the soil for more than 5 years. There are no resistant or slightly affected varieties. It affects stems, leaves, pods. The first signs of damage look like dark green spots with a characteristic shine, which increase very quickly in wet weather. After 3–5 days, the affected plant organs are covered with abundant, white, loose mycelium of the pathogen, from which black sclerotia of various sizes are formed. Sclerotia are formed both on the surface of the affected organs and inside the root, stem and pods. In dry weather, there is little sporulation on the surface of the affected organs, and the affected plant tissue looks discolored. Affected plants look prematurely ripe, the stems break. The disease is very harmful when the main stem is affected during the flowering period. When affected during this period, no seeds are formed. At later stages of the disease, small seeds with low sowing and technical qualities are formed: the weight of 1000 seeds is reduced by 20–60%, oil content – by more than 20%.

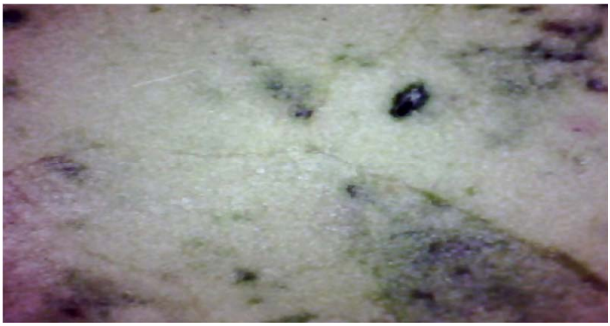

Figure 1.62 – White, felted mycelium of the white rot pathogen with the formation of black sclerotia on the surface of the oil radish leaf (magnification 200 x) [56]

Figure 1.63 – Pods of oil radish with signs of alternaria infection [56]

Cruciferous root rot has a certain pathological significance in the technology of cruciferous crops (Figure 1.64). For example, root rot of spring rape is characterized by widespread and high harmfulness in the Right-Bank Forest-Steppe of Ukraine. Under favorable conditions for pathogens, they cover up to 77% of plants, and their development reaches 64.1%. The disease is most harmful when plants are affected in the early stages of development (second pair of true leaves). The density of correlation between the decrease in seed weight per plant and the development of root rot is r = -0.63.

Investigated [354], that in the conditions of the Forest-Steppe of Ukraine in spring rape crops during the growing season, starting from the moment of seed germination, in addition to the known symptoms of the formation of bindings and drying of plants, the following signs of damage to the root system were differentiated by their nature of manifestation and development: thinning of the stem, peeling of the affected tissues, death of the main root and increased growth of lateral roots (Figure 1.64 A), formation of ulcers and their decay, ring rot (Figure 1.64 B), blackening of blood vessels (Figure 1.64 C).

Damage in the form of small ulcers with healthy edges is caused by nematodes, in particular the beet nematode (Figure 1.69 D), which later forms cysts on the root surface (Figure 1.69 E). They facilitate the penetration of fungi, resulting in very small spots in the affected areas, which later merge with each other, occupying a significant area of the root system.

A B C D E

Figure 1.64 – Diagnostic signs of damage to the root system of rapeseed: A – dying of the main root and growth of lateral roots; B – formation of cones due to the defeat of ring root rot; C – blackening of vessels with ring root rot; D – ulcers; E – cysts of beet nematode (Variety Maria, NUBiP of Ukraine "Agronomic Research Station", original) [369]

Figure 1.65 – Blackleg (pathogens – Pythium, Oomycota, Rhizoctonia, Deuteromycota, Olpidium, Chytridiomycota, etc. Occurs on mustard and rape [369]

Proved [369], that the symptoms of rapeseed root rot are not stable throughout the entire ontogeny of plants, they can change in different phases of plant vegetation. Two or more symptoms may appear on one plant and vice versa. Such a variety of symptoms may indicate the presence of a complex of root rot pathogens involved in the disease.

Root rot of spring rape has a high level of distribution and development, especially in the early stages of the crop's vegetation. Thus, in the conditions of the Agronomic Experimental Station of the Vasylkiv district of Kyiv region, during 2002–2005, the maximum prevalence of the disease reached 62.0%, the minimum – 13.8%, the maximum development – 31.0%, and the minimum – 9.4% in the varieties Kalynivskyi and Maria. A characteristic feature of rapeseed root rot is that some severely affected plants (up to the second pair of true leaves) dried up and collapsed. Therefore, they are not taken into account during subsequent surveys, resulting in an underestimation of the prevalence of root rot. A similar situation was noted in other areas of the study.

Indicators that equally reflect the harmfulness of root rot were the weight of seeds and the number of pods per plant. Thus, the decrease in these indicators due to root rot damage had an average correlation level from r = -0.56 to r = -0.63.

It is noted 370, that the mycobiota of the spring rape root system is represented by fungal species belonging to 22 genera, 3 divisions (Qomycota, Ascomycota, Vasidiomycota), two kingdoms (Chromista and Fungi). The main share of them is made up of fungi of the genus Fusarium (frequency of occurrence ranged from 56.9 to 64.2% over the years), Pythium (26.6–47.1%) and Rhizoctonia (15.4–22.9%). The greatest species diversity (19 species) was characterized by fungi of the genus Fusarium. The dominant among them were: *F. avenaceum, F. sambucinum* var. *minus, F. solani, F. oxysporum* (Table 1.18). The genus Pythium was represented by three species: *P. ultimum* var. *ultimum*, *P. hydnosporum*, and unidentified Pythium sp., and the genus Rhizoctonia was represented by R. solani and Rhizoctonia sp.

At the same time, it was determined [370], that low average daily temperature (+10 °C) and excessive precipitation per month, especially in the early stages of the crop's vegetation, contributed to an increase in the prevalence of spring rape root rot to 62% and development to 31%.

With more moderate levels of precipitation (no more than 20 mm per decade) and slightly higher average daily temperature (+18.6 °C), the prevalence of the disease during the growing season remained at the same level (33.9–39.3%). The development of certain pathogens was more dependent on temperature. Thus, in the studied years, with an increase in the average daily temperature during the growing season of spring rape, there was a tendency to a gradual decrease in the number of fungi of the genus Pythium (from 64.8 to 2.6%) and an increase in the number of representatives of the genus Rhizoctonia (from 6.9 to 20.4%).

Table 1.18

Species composition of micromycetes isolated from the affected root system of spring rape (Kalinovsky variety) [369]

Вид мікроміцетів	Frequency of occurrence, %			
	SE NUBIP of Ukraine "Agronomic Research Station"		"Velykosnitynske educational and research O.V. Muzychenko Educational and Research Farm	
	2002	2003	2007	2008
Pythium ultimum var. *ultimum*	32.2	15.6	27.4	22.4
P. hydnosporum	12.3	7.6	6.5	4.1
Pythium sp.	2.6	3.4	1.2	1.7
Fusarium avenaceum	11.9	10.1	11.9	6.4
F. oxysporum	2.3	6.8	8.4	7.1
F. sambucinum var. *minus*	9.1	12.4	10.3	6.4
F. solani	6.5	4.7	7.9	3.7
Інші види *Fusarium*	34.4	25.9	24.9	33.3
Rhizoctonia solani	12.2	16.4	20.3	14.8
Rhizoctonia sp.	3.2	6.4	2.6	4.1
Інші роди	5.9	17.8	11.0	19.6

At a uniform air temperature (+18.6 °C) in spring and summer, the frequency of isolation of fungi of the genus Pythium during the second survey corresponded to the level of the previous one (42.3–43.7%). At the same time, with an increase in the average daily temperature to +21.5 °C, intensive development of fungi of the genus Fusarium and

Rhizoctonia was observed. Meanwhile, precipitation was not a decisive factor. Thus, the root rot pathogens of rapeseed from the genus Pythium, in the initial phases of plant development, are able to develop at low temperatures and in a humid environment, while the development of Fusarium and Rhizoctonia species is more favorable with an increase in the average daily temperature.

Defined [369], that in vitro, the optimal growth and development of aerial mycelium of *P. ultimum* var. *ultimum* occurs on potato glucose and pea agar (Table 1.18).

Stable growth and development of the fungus with temperature changes was observed in starvation and corn medium. The linear growth of the fungal mycelium at a temperature of +10 °C on the vast majority of media ranged from 0.53 to 0.68 mm/h. At a temperature of +25 °C, the growth rate reached 1.03–1.11 mm/h in almost all variants. The appearance of the first oospores was noted after 48 hours, and after 120 hours their maximum number reached 255 pcs. in the field of view of the microscope (x100) on oatmeal agar. At +10 °C, no oospores were formed on potato glucose, pea agar and Chapek's medium (Table 1.19).

Table 1.19

Effect of temperature on the linear growth rate of mycelium and the size and number of oospores during the cultivation of *P. ultimum* var. ultimum on different media [369]

Growing medium	Growth rate, mm/h		Number of oospores on day 5, pcs.		Diameter of oospores, +/- µm	
	+10 °C	+25 °C	+10 °C	+25 °C	+10 °C	+25 °C
Potato glucose agar	0.68	1.1	0	140	none	23.7±0.1
Oat agar	0.53	1.03	16	255	none	21.0±0.1
Carrot agar	0.67	0.92	14	135	19.7±0.3	27.6±0.1
Corn agar	0.54	1.01	55	150	25.0±0.5	25.0±0.3
Starving agar	0.56	1.03	16	20	25.0±0.6	23.7±0.6
Pea agar	0.47	1.11	0	15	none	26.3±0.1
Rapeseed agar	0.43	0.85	1	30	21.0±0.1	27.6±0.3
Chapek's environment	0.67	1.01	0	0	none	none
SSD_{05}	0.09	0.1	9.4	47.3	–	–

Pathogenic isolates of Rhizoctonia spp. isolated from the root system of spring rape were identified as Rhizoctonia solani, which according to morphological characteristics and the nature of the anastomotic reaction was assigned to the group AG 2-1, and one unidentified species of Rhizoctonia sp. Defined [370], that the optimum temperature for the growth of R. solani (AG 2-1) is +20–25 °C, the linear growth rate was in the range of 0.92–0.95 mm/h, and intensive sclerotia formation was observed. For Rhizoctonia sp., a narrower temperature range of +25 °C is optimal; at the same time, the linear growth rate was within 0.87 mm/h, and at higher temperatures, slow mycelial growth, less bright color, and inhibition of sclerotia formation were observed.

The morphological characteristics of the identified 19 Fusarium species did not differ from those described in the literature. It is known that during the development cycle, fungi of the genus Fusarium form macro- and microconidia, forming sporodochia. The latter were observed in the pure culture of F. avenaceum, F. solani, *F. gibbosum* var. acuminatum. In addition, in the culture of F. solani, pionnots were formed on the studied parts of rapeseed plants. A rare phenomenon was recorded in the pure culture of F. oxysporum: germination of conidia into chlamydospores and formation of anastomosis between the two conidia. Defined [370] high pathogenicity of P. ultimum var. ultimum for *Brassica napus* L., which is manifested in the formation of a band on the root and root parts of the stem in 100% and the death of 95% of plants. The same symptoms were caused by soil infection with *Rhizoctonia solani* isolates (Figure 1.66).

P. ultimum var. *ultimum* and *Rhizoctonia solani* (AG 2-1) are characterized by high growth intensity. Their linear growth rate at the optimum temperature is 1.03–1.11 mm/h and 0.92–0.95 mm/h, respectively. The intensive growth of air mycelium of P. ultimum var. ultimum in vitro occurs at +25 °C on potato glucose and pea agar, and its oospores are better formed on oatmeal agar (255 units in the field of view of the microscope, x100). The first oospores appeared after 48 hours of incubation. The optimum temperature for the development of Rhizoctonia solani (AG 2-1) is +20–25 °C.

Isolates of the genus Fusarium Link were less pathogenic. Of the 52 studied strains isolated from the root system of spring rape, pathogenicity was confirmed for 13 strains of the following species: *F. avenaceum, F. avenaceum* var. *herbarum*, *F. moniliforme*, *F. moniliforme* var.

lactis, *F. oxysporum* var. *orthoceras*, *F. sambucinum* var. *trichoteciodes* (one strain each) and *F. oxysporum*, *F. sambucinum* var. *minus* (4 and 3 strains, respectively). They caused the formation of lighter and smaller bands. The plant severity ranged from 5.5–71.5%, and the disease development – from 2.8–53.6%. All studied strains (pathogenic and non-pathogenic) had a latent infection (latent phase).

Microscopic examination of the tissues of the affected root system revealed microscopic structures characteristic of individual pathogens: for P. ultimum – a significant number of oospores, for Fusarium spp. thin mycelium with chaotic branching, and for *R. solani* – wide, with direct branching (Figure 1.67).

Under the complex infection, an increase in the level of pathogenicity in the variant of P. ultimum var. ultimum and *R. solani* and a decrease in the level of pathogenicity under the condition of their interaction with F. avenaceum was noted (Table 1.20).

Figure 1.66 – Formation of lodging and desiccation of plants under the influence of *P. ultimum* var. *ultimum* (left) and *R. solani* (right, original) [369]

Figure 1.67 – Development of fungal structures in the affected tissues of spring rape root system (x200, original) [369]

Infection of soil with Rhizoctonia solani (AG 2-1) and P. ultimum var. ultimum leads to the death of 25 and 100% of plants, respectively. The fungi *F. avenaceum, F. avenaceum* var. *herbarum, F. moniliforme, F. moniliforme* var. *lactis*, *F. oxysporum* var. *orthoceras*, *F. sumbucinum* var. *trichoteciodes*, *F. oxysporum* and *F. sumbucinum* var. *minus* cause the appearance of a constriction on the root system and do not cause its drying out. In case of complex infection of plants with *P. ultimum* var. *ultimum* and *R. solani*, their pathogenicity increases.

Table 1.20

Pathogenicity of fungi against spring rape in soil co-infection in vitro [369]

Infestation of the soil with fungi	Gamination by 10 day, %.	Number of plants with signs of diseases, % on the day of accounting		
		15	20	
			of all	including deaths, %
Control – without infection	70.6	0.0	0.0	0.0
Pythium ultimum var. *ultimum*	0.0	not taken up		
Rhizoctonia solani	23.5	25.0	25.0	25.0
F. avenaceum	97.8	11.8	41.2	0.0
P. ultimum var. *ultimum* + *R. solani*	5.9	100.0	100.0	0.0
P. ultimum var. *ultimum* + *F. avenaceum*	64.7	0.0	18.2	18.2
R. solani + *F. avenaceum*	52.9	0.0	55.5	11.1
P. ultimum var. *ultimum* + *R. solani* + *F. avenaceum*	5.9	0.0	100.0	100.0

Investigated [369], that most isolates are in synergy with each other. Growth inhibition of *R. solani* and Fusarium species was detected when the colonies reached each other's boundaries, which is consistent with the manifestations of pathogenicity during artificial soil infection. However, this did not affect the formation of sporulation, and in the case of the *F. avenaceum* strain, it stimulated its growth. The obtained research results indicate the absence of a clearly expressed antagonism between the root rot pathogens of spring rape, which is the cause of the complex damage to plants of this crop by different pathogens simultaneously.

It has been established that the least development of the disease is achieved under the conditions of early sowing with a seeding depth of up to 2 cm and a seeding rate of up to 1.5 million units/ha. Sowing seeds with a row spacing of 45 cm and applying nitrogen fertilizers at a rate of 120 kg/ha (either once or separately) allows to restrain the spread and development of root rot in the initial stages of development. Later, this effect is not observed.

Many of the cruciferous vegetables we commonly consume belong to the cruciferous family, including broccoli, Brussels sprouts, cabbage, cauliflower, collard greens, kale, kohlrabi, mustard, rutabagas, turnips, and Chinese cabbage.

During the growing season, these crops are affected by many diseases that reduce yields and product quality. Among all the diseases, black rot, caused by the bacterium *Xanthomonas campestris* pv. *campestris* (Pam.) Dowson, is the most widespread and destructive disease of the cabbage family worldwide. Cruciferous cabbage is susceptible to the disease in cabbage, cauliflower, broccoli, kale, Brussels sprouts, Chinese cabbage, kohlrabi, turnips, mustard, radish, and rutabaga. It is one of the most destructive vascular diseases of cruciferous vegetables, which is found in all parts of the temperate and subtropical zones of the world, where there is heavy rain or heavy dew, and average temperatures range from 25 to 30 °C.

Pamela first reported the black rot [355] from Iowa, North America, on rutabagas. In 1898, Russell reported the disease on cabbage from Wisconsin. Since then, there has been a growing worldwide recognition of the seriousness of black rot in cruciferous crops. The disease was first reported on cauliflower in Norway [356]. It has since been reported to be widespread on cauliflower in all parts of the world [357].

The disease is very destructive and causes significant yield losses due to premature defoliation and reduced quality of cauliflower and cabbage heads and heads, respectively, during transportation, making them uncompetitive on the market. Yield losses of up to 50% of cabbage and 50 to 70% of cauliflower were recorded [133]. Significant crop losses due to the rapid spread of bacteria under favorable conditions, especially when growing seedlings, are also reported [358].

The pathogen systematically moves through the vascular bundles, turning them black, and causes the main symptoms on the leaves described

by different workers. The pathogen causes two types of symptoms. First, marginal chlorotic spots appear on the leaves, followed by darkening or blackening of the midrib and veins [359]. However, they report [360], that blackening of the veins is the first visible symptom associated with the accumulation of melanin in xylem cells. The pathogen colonizes the vascular system after entering the plant and produces a large amount of extracellular polysaccharide xanthan [361], which, together with the bacterial cells, clogs the xylem vessels, restricting water flow and leading to the characteristic V-shaped chlorotic lesions that begin at the leaf margins. As the bacterium moves through the plant, the vascular tissue darkens, leading to blackening of the veins. Systemic infection during storage often makes the product unmarketable. Infection with this pathogen can be accompanied by attacks by the soft rot bacterium Erwinia carotovora or the fungus *Sclerotinia sclerotiorum* [362].

Cruciferous black rot is caused by *X. campestirs* pv. *campestris* (Pam.) Dowson. It is a small, rod-shaped, aerobic, Gram-negative, non-spore-forming bacterium. The bacterium has a single polar flagellum, is positive for catalase, hydrogen sulfide, oxidase and does not produce nitrate and indole. On media containing glucose, it produces a yellowish extracellular polysaccharide called xanthan. *X. campestris* pv. *campestris* hydrolyzes starch, which is used to easily recognize the bacterium on Schaad's selective medium. Its growth is inhibited and retarded in the acidic pH range. The temperature range of survival is very wide (5–38 °C), with the optimum temperature being 30 oC and the lethal temperature around 50 °C. Described [363] bacterial colonies are yellow, shiny and mucoid, 1–2 mm in diameter, surrounded by a 2–4 mm wide zone of starch cycloheximide agar and nutrient starch cycloheximide agar and nutrient starch cycloheximide agar with antibiotics. It is known that there are six races of the pathogen in the world, of which races 1 and 4 predominate [364].

The bacterium infects all members of the cruciferous family, including rutabagas, cabbage, savoy cabbage, broccoli, turnips, radishes, kohlrabi, radishes, mustard species, and fodder cabbage [365].

The infection of cabbage with the black rot pathogen by hydatids was observed by previous researchers. Later, Clayton also observed the penetration of the pathogen through stomata on the lower surface of intact cauliflower and cabbage leaves. However, stomatal infections of

X. campestris pv. campestris have not been confirmed, and the bacterium usually enters through wounds or hydatids [366].

Typical V-shaped lesions developed when fully expanded and subordinate leaves of two-month-old seedlings sown in a greenhouse were inoculated by cutting them along the leaf margin with scissors or nail clippers dipped in a suspension of *X. campestris* pv. *Campestris* [367]. The bacterium caused black rot rapidly and in almost all inoculation sites when inoculated on hydatids or wounds of intact cruciferous plants [368]. Showed [369] a high correlation between juvenile inoculation, disease severity and resistance of mature plants, indicating that plants can be effectively evaluated at the juvenile stage to determine the resistance of mature plants to black mold. Different researchers have studied the development of black rot by artificially inoculating the pathogen using different methods. Bhide [370] compared the infection of 2-week-old, one-month-old and two-month-old cabbage seedlings with X. campestris pv. campestris by hydatids and stomata and found that hydatid infection was severe for plants of all ages, and lesions caused by the later methods did not increase, while lesions caused by the former covered most of the leaf surface and progressed down the petioles and stems. Initiation of disease by phytopathogenic bacteria depends on the concentration of the inoculum [371]. A minimum concentration of 106 cells/ml is required for the development of black rot symptoms [372]. They also observed slightly more infection of cabbage when the cell suspension was injected with a hypodermic syringe than when it was injected with a needle. They found [373] higher infection rates when seedlings were inoculated through damaged veins than through hydatids. Piercing the veins with a pin also caused more infection than spraying with a bacterial suspension. Cruciferous black rot occurs under warm and humid weather conditions. They found [374], that the disease occurs only under conditions of high atmospheric humidity. Large losses of cabbage and cauliflower have been reported due to severe outbreaks of black rot in conditions of heavy precipitation [375]. The disease was reported to be severe and very destructive in warm, humid weather conditions in various locations [376]. Reported [377], that warm summer weather is associated with the manifestation of black rot symptoms in cruciferous plants. The transfer of the pathogen with infected seeds of cauliflower and other cruciferous plants has been observed as a way of survival of *X. campestris* pv. *campestris* by

various researchers [378-381]. The bacterium also survived in the garden and on plants near the fields [382]. The bacterium can survive in naturally infected seeds for three years [383], in the remains of the diseased plant for at least one year [384–386], in host tissues for 615 days [387] and in cabbage stalk residues for 507 days [388]. The survival of the pathogen in naturally infected seeds for 18 and 28 months and in artificially inoculated seeds for 13 and 19 months when stored at room temperature and 10 °C, respectively, was reported. It was also found that the bacterium survives in infected stems and leaves in both dry and wet soil, but survival in wet soil was longer at later stages. It was also reported that the bacterium survives for 35 and 14 days in soils with a moisture content of 50 and 10–25%, respectively. The bacterium was isolated from seed washes and plant residues of cauliflower and cabbage, indicating that the pathogen survives in all of these sources, and suggested that survival on asymptomatic weed hosts may be problematic for understanding the epidemiology of the disease. Оцінювали [389] isolates of *X. campestris* pv. *campestris* collected in Japan from various diseased cruciferous plant species were tested for their virulence on cultivars with race-specific resistance to the pathogen. Only two races out of the 5 previously described were identified in Japan by differentiation. One hundred and sixty-four isolates of *X. campestris* pv. *campestris* and other *X. campestris* pathogens known to infect cruciferous plants (*X. campestris* pvs. *aberrans*, *raphani, armoraciae*, and *incanae*) were also evaluated by inoculation onto differential series of Brassica spp. to determine pathogenicity to cruciferous plants and race. Of these, 144 isolates were identified as *X. campestris* pv. *campestris* and grouped into six races, with races 1 (62%) and 4 (32%) predominating [166].

Developed [390] a sensitive and specific assay for detection of *X. campestris* pv. *campestris* by PCR using species-specific primers based on hrpF gene sequences. To evaluate the genetic diversity of pathogenic strains of *X. campestris* pv. *campestris*, the following were used [391] repeated DNA polymerase chain reaction (rep-PCR) using repeated extragenic palindromic, enterobacterial repeated intergenic consensus and BOX primers. З чорною гниллю хрестоцвітих можна боротися за допомогою культурних, хімічних, біологічних методів і методів стійкості хазяїна. З цією хворобою можна боротися шляхом обробки насіння гарячою водою впродовж 30 хвилин при температурі

50 °C. Однак це знижує життєздатність насіння і не знищує патоген повністю [392]. The location of the nursery should be changed frequently. To reduce the secondary spread of the pathogen, it is recommended to [393] use grass mulch, which reduces the degree of spraying of infected soil and, consequently, the secondary spread of the pathogen. Crop rotation with non-cruciferous crops should be maintained for 3–5 years. Assumed [394], that cultural practices can be conditioned to be used effectively for environmentally sound disease management in the field, either alone or as a component of integrated disease management. The strong antibacterial activity of Anacardium occidentale Linn. essential oil was reported against *X. campestris* pv. *Campestris* [395]. Some plant species have also been reported to have inhibitory activity against X. campestris pv. campestris. Reported [396], that extracts of twenty plant species exhibit antibacterial activity against *X. campestris* pv. *campestris* in the laboratory [397]. It is noted that biological control of this disease is still in its infancy. Endophytic bacterial strains isolated from cabbage leaves showed antagonistic activity both in greenhouse and field conditions [398]. The strains EN4 (*Kluyvera ascorbata*) and EN5 (*Alcabegenes piechaudii*) showed a decrease in disease incidence by 70.8% and 41.7%, respectively, while EN4 showed the greatest reduction in disease severity (77%) when the antagonist was applied 4 days before treatment and simultaneously, and antibiosis was considered as the mode of action of antagonists. The combined treatment of cauliflower seeds with SP009s (*Pseudomonas fluorescens*) at 1.5 units plus 4 times foliar spraying with SP007s (Bacillus sp.) at 0.1 units on days 14, 28, 32 and 46 after planting had the greatest potential to stimulate growth and reduce the intensity of black rot development, which led to a decrease in the incidence by 82.08% [399]. Various researchers around the world have used various fungicides and antibiotics in the form of foliar sprays to combat the disease. Recommended [400] 2–3 sprays with Cosid (0.5%), Cuprofix M (0.5%), copper oxychloride (0.5%) or dithane Cuprofix (0.5%) to control black rot of cabbage. Effective control of black rot has been reported with 3 foliar sprays of Kobox (containing 50% Cu) 4 g/l at 2-week intervals. Resistance to black rot caused by *Xanthomonas campestris* pv. *campestris* was studied on *Brassica oleracea*, *B. campestris* and *B. napus* [401] and suggested that the nonspecific stem resistance found in Chinese cabbage, broccoli, and kale may be an alternative means of

genetic protection against the pathogen. Resistance to the six known races of cruciferous black mold is absent or very rare in Brassica oleracea (genome C). However, race-specific broad-spectrum resistance (to typical strains of all six races) is often found in other Brassica genomes, including B. rapa (*Brassica campestris*) (genome A) [402]. As the pathogen is seed-borne and also survives in infected plant residues in the soil, success in disease control can only be achieved by applying an integrated approach to disease management. The use of *B. subtilis* for seed treatment, seed treatment + seedling treatment, seed treatment + seedling treatment + soil drenching, and seed treatment + soil drenching was effective in controlling *X. Campestris* [403]. Late infections can become a "wound" for the penetration of other putrefactive organisms and cause significant damage during storage. The bacterium survives in infected seeds for up to three years. Therefore, more attention should be paid to eliminating seed-borne infections. Controlling black mold begins with identifying potential sources of disease survival and using an integrated pest management strategy that includes host resistance, sowing disease-free seeds, avoiding disease spread, and proper sanitation. Sanitation is the primary method that reduces, eliminates, or removes the initial sources of disease. Common sanitation practices include crop rotation, seed disinfection, pruning of diseased plants, elimination of waste dumps, and destruction of alternative hosts. The development of crop varieties with disease resistance or tolerance to black mold is the focus of many breeding programs around the world. Today, many cruciferous crop hybrids with black mold tolerance are available for both fresh and processed commercial production.

1.2. Prevalence and damage of major diseases of cruciferous crops

Rapeseed diseases are less important than pests in terms of their economic value. Spring rapeseed suffers from the same diseases as winter rapeseed, but their spread and economic importance are usually less.

In continental regions, diseases cause less damage than in Western and Central Europe. If crop rotation rules are followed (returning rapeseed, including other cruciferous crops and beets, to the same place in three to four years), keeping the share of cruciferous crops, legumes and beets in the crop rotation no higher than 25%, and taking appropriate agronomic measures, fungicide use (which often does not pay off) is usually unnecessary.

But with the growing saturation of crop rotations with rapeseed and other host plants, typical crop rotation diseases are spreading more strongly. This is especially true for sclerotinia (*Sclerotinia sclerotiorum*), verticillium (*Verticillium longisporum*), cabbage clubroot (*Plasmodiophora brassicae*), root neck and stem necrosis (*Leptosphaeria maculans*, anamorph – *Phoma lingam*), gray spot (*Pyrenopeziza brassicae*, anamorph – *Cylindrosporium concentricum*) and white spot (*Mycosphaerella capsella*, anamorph – *Pseudocercosporella capsellae*), the causative agents of which accumulate in soils, as well as Alternaria spp.), whose pathogens live in terrestrial plant debris. While breeding for resistance to root collar necrosis, gray spot and cabbage clubroot has led to some success, control of verticillium and white rot has become a major problem in many growing regions.

Studies conducted in recent years have shown that the shortfall in the yield of spring rape seeds from diseases, depending on the variety and technology of its cultivation, ranges from 15 to 70% or more, with significant deterioration in its sowing and technological qualities [404–405]. In general, losses of field crops from pests have increased by 1.2–1.7 times compared to the losses of 1970–1980. The share of losses has changed significantly: from weeds it is 39.2%, diseases – 34.5%, pests – 26.3% [406–407].

It was found that when rapeseed pods are affected, the oil content in seeds, depending on the pathogen, decreases by 1.3–3.4 times, the specific gravity of palmitic, stearic, erucic, eicosic, linolenic acids increases significantly, while the specific gravity of oleic and linoleic acids decreases.

Crop losses in Germany as a result of severe alternaria damage can reach 50%, and even with moderate disease development, losses can reach 20% [408]. In Canada, losses reach up to 42% in some years [409].

When pods are affected by Alternaria, the photosynthetic surface of the valves and seeds decreases. This can cause premature "ripening" of plants, which is manifested in pods cracking and the formation of underdeveloped seeds. Affected seeds inside the burst pods shrivel up in dry weather and fall out unripe [410]. Sources of infection are infected seeds and post-harvest residues of plants, in which the pathogen is stored in the form of conidia and mycelium [411]. In this case, genotypes in which the accumulation of plastic substances depends more on plastids located in the seeds and pods are more affected. These are samples with a higher content of linolenic acid. It is possible that breeding for a lower content of linolenic acid leads to an increase in alternaria resistance. The opposite effect was not observed. Thus, when the surface of the pods was damaged by Alternaria with an intensity of more than 25%, the chemical composition of the seeds did not change [412–413]. At the same time, a high correlation was found between linolenic acid and the productivity of affected plants, and this relationship increases with the increase in the damage score. This is probably due to the fact that linolenic acid is involved in the photosynthesis of immature seeds and green pods [414–415].

Yield losses as a result of severe alternaria infection amounted to 50%, and with moderate disease development they reached 20%. In Canada, this figure reached 42%. In the UK, when about 10% of the surface area of the rapeseed pod was affected by the disease, the loss of seed yield was about 10%, and each additional percentage of damage led to a decrease in yield by 1% [416]. The weight of 1000 seeds depends on the degree of pods' damage by the disease. Thus, in spring rape of the Kovalevsky variety, it was 3.0 times lower when plants were affected by Alternaria, and in winter rape of the Tysmenytsia variety, it was 2.7 times lower compared to healthy plants. When rape plants are damaged by Alternaria, both seed weight and oil content are reduced. It was found that the oil content of winter and spring rape seeds affected by the black spot pathogen decreased by 23.2–27.5%, and the content of palmitic acid in rapeseed oil increased by 4.6–2.4%; stearic acid – by 3.2 and 2.3%; linoleic acid – by 9.1 and 5.1 %; erucic acid – by 3.6 and 3.9%; eicosene acid – by 3.3 and 2.8%, respectively.

The content of oleic acid, respectively, decreases by 19.2 and 10.9%; linoleic acid – by 4.6 and 5.6% [417–418].

In the UK, it has been found that when the surface of the pod is affected by more than 10% of the area, each additional percentage leads to a 1% reduction in yield. With a smaller pod area, yield losses vary. With 10% of the pod area affected, losses are approximately 10% [419]. The harmfulness of Alternaria is reduced in samples with rapid drying of pods, as this reduces the likelihood of damage.

Species of the genus Alternaria spp. in rapeseed agrocenosis do not have a narrow affiliation to certain organs and are able to affect all vegetative and generative organs of the plant, E. communis/brassicae – stems, leaves and pods. Species such as *P. brassicae* f. *brassicae* and *B. cinerea* affect only leaves. *F. oxysporum* and *V. dahliae* species, being the causative agents of tracheomycotic wilt, cause blockage or necrosis of the leading xylem vessels, which often leads to complete plant death. Root and stem rot pathogens are very harmful to rapeseed plants, caused by the fungi *S. sclerotiorum* and *S. bataticola*. The damage to such important plant organs as roots and stems leads to wilting or complete death of rapeseed. The fungus *Ph. lingam* is one of the most common and harmful species on winter rape and can also cause premature plant death.

The correlation between the severity of black spotting of pods on the main shoot and the yield was established ($r = -0.67$, $P < 0.02$) [420]. The weight of 1000 seeds under the influence of A. brassicae and A. brassicicola in spring rape of Kovalevsky variety is 3.0 times lower and in winter rape of Tysmenytsia variety 2.7 times lower compared to healthy [421] There is a discrepancy between the ranks of breeding samples in terms of damage and productivity reduction. Alternaria infection has a significant impact on laboratory germination of seeds and, especially, on germination energy, which varies from 62 to 90%.

Oil content of winter and spring rape seeds affected by Alternaria pathogens decreases by 23.2–27.5%. When winter rape seeds are affected by Alternaria pathogens, the content of palmitic acid in the oil increases by 4.6 and spring rape – by 2.4; stearic acid – by 3.2 and 2.3, respectively; linolenic acid – by 9.1 and 5.1; erucic acid – by 3.6 and 3.9; eicosene acid – by 3.3 and 2.8%. The content of oleic acid, respectively, decreases by 19.2 and 10.9; linoleic acid – by 4.6 and 5.6% [166].

It has been proven that seed yield losses due to downy mildew can be 10–30%. Under conditions favorable for the spread and development of Alternaria, seed yield losses can reach up to 30%, and in years of epiphytotic development of the disease – up to 50% or more, as in the case of phomosis. When rapeseed is affected by white mold, the yield loss is caused by the loss of young plants, premature seed maturation and pod cracking, a decrease in the weight of thousands of seeds and can reach 50%, and in years of epiphytic development of the disease – and more [422]. In view of the above, studies on the dependence of spring rape productivity on the disease complex are relevant in order to regulate the most effective control of plant damage by pathogens.

When pods are affected by *Ph. lingam* Desm, seed weight decreases in winter rape by 2.2 and in spring rape by 2.3 times, oil content – by 21.2–23.8%. The content of palmitic acid in the oil increases by 2.7 and 1.1; stearic acid – by 2.1 and 1.8; linolenic acid – by 5.2 and 3.0; erucic acid – by 3.8 and 2.6; eicosic acid – by 1.8 and 1.9%, respectively. The content of oleic acid decreases by 13.5 and 7.0; linoleic acid – by 2.1 and 3.4%, respectively [442].

In the course of the research, a close correlation was established (Table 1.21) between the severity of spring rape plants with diseases and the number of plants per square meter, as evidenced by the correlation coefficients obtained, the only exception was the damage by Alternaria, where the correlation coefficient was 0.51. In addition, a close correlation was found between the severity of spring rape crops with the studied diseases and the weight of seeds per plant and the number of seeds per pod. Regarding the number of pods per plant, the correlation is not close when spring rape is affected by phomosis, white rot, gray rot and a complex of the studied diseases (Table 1.21). In the study of the correlation between the weight of 1000 seeds and the severity of spring rape plants with diseases, it was found that the dependence is close in relation to the damage by all diseases, except for Alternaria.

The established close correlation between the elements of the yield structure and the severity of spring rape diseases is confirmed by the close correlation between the yield of spring rape and the severity of its diseases under study. Using the regression equations calculated on the basis of correlation and regression analysis between the values of disease severity (Y)

and seed yield (X) of spring rape, it is possible to quantitatively predict the change in yield using the values of disease severity of spring rape.

The linear regression equation of the form y = -6.4237x + 21.046 indicates that with a 1% increase in the incidence of Alternaria in spring rape, the yield of its seeds will decrease by 0.16 t/ha. Based on the coefficient of determination (R2 = (0.808)2 = 0.65), approximately 65% of changes in the yield of spring rape seeds are due to changes in the incidence of Alternaria, and 35% of changes are due to other factors.

The regression coefficient (b = -3.755) of the linear regression equation y = -3.755x + 11.945 indicates that with an increase in the amount of spring rape phomosis infection by 1%, the yield of its seeds will decrease by 0.27 t/ha. The coefficient of determination (R2 = (0.79)2 = 0.62) indicates that 62% of changes in the yield of spring rape seeds are due to changes in the amount of phomosis infestation, and 38% of changes are due to other factors.

Table 1.21

Correlation matrix between seed yield and disease incidence in spring rape [423]

Disease prevalence, %	Number of plants per 1 m², pcs.	Seed weight from 1 plant, g/plant	Structures per plant, pcs.	Seeds in a pod, pcs.	Weight of 1000 seeds, g	Yield, t/ha
Alternariosis	0.51	– 0.92	– 0.87	– 0.86	– 0.39	– 0.81*
Phomosis	0.75	– 0.98	– 0.69	– 0.93	– 0.71	– 0.79
White rot	0.84	– 0.94	– 0.52	– 0.92	– 0.83	– 0.78
Gray rot	0.93	– 0.70	– 0.07	– 0.75	– 0.96	– 0.72
Peronosporosis	0.70	– 0.93	– 0.96	– 0.94	– 0.88	– 0.90
The complex is above mentioned diseases	0.65	– 0.80	– 0.52	– 0.78	– 0.77	– 0.80

The regression coefficient (b = -5.4559) of the linear regression equation y = -5.4559x + 17.218 indicates that with an increase in the incidence of white rot in spring rape by 1%, the seed yield will decrease by 0.18 t/ha. The coefficient of determination (R2 = (0.784)2 = 0.61) indicates that 61% of changes in the yield of spring rape seeds are due to changes in the amount of white mold damage, and 39 % of changes are due to other factors.

The regression coefficient (b = -4.3224) of the linear regression equation of the form y = -4.3224x + 14.143 indicates that with an increase in the amount of gray mold infestation of spring rape by 1%, the yield of its seeds will decrease by 0.23 t/ha. The coefficient of determination (R2 = (0.715)2 = 0.51) indicates that 51% of changes in the yield of spring rape seeds are due to changes in the amount of gray mold damage, and 49% of changes are due to other factors that were not taken into account.

The regression coefficient (b = -6.0075) of the linear regression equation of the form y = -6.0075x + 18.477 indicates that with an increase in the amount of damage by peronospora of spring rape by 1%, the yield of its seeds decreases by an average of 0.17 t/ha within the considered row. The coefficient of determination (R2 = (0.899)2 = 0.8077) indicates that 81 % of changes in the yield of spring rape seeds are due to changes in the amount of damage by peronosporosis, and 29% of changes are due to other factors.

During the growing season, spring rape crops are affected by pathogens not only of one disease, but of the whole complex. Therefore, it was of interest to establish the relationship between its susceptibility to a complex of diseases (Alternaria, Phomosis, white rot, gray rot, peronosporosis) and seed yield. In the process of correlation analysis of the values of the above indicators, a close correlation coefficient of 0.80 was obtained (Table 1.22).

The regression coefficient (b = -5.3504) of the linear regression equation of the form y = -5.3504x + 16.832 indicates that with an increase in the severity of the spring rape disease complex by 1%, the yield of its seeds decreases by an average of 0.19 t/ha within the considered row. The coefficient of determination (R2 = 0.6424) indicates that 64 % of changes in the yield of spring rape seeds are due to changes in the severity of the disease complex, and 36 % of changes are due to other factors. The reliability of the presented equations is characterized by the following limits of experimental values: for yield – from 1.6-1.7 to 2.7-2.9 t/ha, Alternaria – from 1.9 to 11.0, Phomosis – from 0.7 to 6.1, white rot – from 0.9 to 8.0, gray rot – from 1.4 to 7.4 and downy mildew – from 2.4 to 9.1%. By studying the correlation-regression equation between the values of the disease complex (Y) and seed yield (X) of spring rape, it was found that the equation is valid within the experimental values from 1.6 to 3.0 t/ha for seed yield and from 0.9 to 8.5% for the disease complex.

The obtained data of correlation and regression dependence between the severity of spring rape by the studied diseases and seed yield made it possible to calculate the maximum permissible severity of plants by various diseases in order to obtain the theoretically possible calculated yield (Table 1.22), which is very important in regulating the degree of severity of spring rape by diseases. In the course of calculations, the need to reduce the severity of spring rape diseases with an increase in the planned seed yield was established.

It has been established that in order to obtain 1.5 t/ha of spring rape seeds, the damage by a complex of diseases should not exceed 11.04%, including Alternaria – 13.99, Phomosis – 8.03, gray rot – 12.47, white rot – 10.44 and peronosporosis – 11.11 %, and in order to to obtain a seed yield of 2.5 t/ha, the incidence of spring rape with a complex of diseases should not exceed 2.72 %, including Alternaria – 4.13, Phomosis – 1.99, white rot – 3.53, gray rot – 2.01 and downy mildew – 3.67 %.

A close correlation was found between the susceptibility of spring rape to a complex of diseases, including Alternaria, Phoma, white rot, gray rot and downy mildew, and such elements of the yield structure as the number of plants per square meter, seed weight per plant, number of pods per plant, number of seeds per pod and weight per thousand seeds. It was found that the correlation coefficient between seed yield and the susceptibility of spring rape to Alternaria was -0.81, Phomosis – -0.79, white rot – -0.78, gray rot – -0.72, peronospora – -0.90 and the above-mentioned disease complex – -0.80. In order to obtain the theoretically possible predicted yield of spring rape seeds of 2.5 t/ha, the damage to its crops by a complex of diseases should not exceed 2.72%, including Alternaria – 4.13, Phomosis – 1.99, white rot – 3.53, gray rot – 2.01 and peronospora – 3.67 % (Table 1.23).

Based on the research conducted [424] the study of the harmfulness of Fusarium depending on the time of appearance of external symptoms, data were obtained on the number of diseased branches on the plant, the number of diseased pods and the total number of pods formed on the plant. All these data formed the basis of an eleven-point scale developed by the authors to calculate the intensity of Fusarium wilt damage to rapeseed plants by the area of the affected part of the stem or individual branches of plants, similar to the scale proposed for calculating the development of white rot in rapeseed [381]. The scoring scale is as follows:

– 0 points – no damage;

– 1 point – one branch with up to 10% of pods of the total number of pods on the plant is affected;
– 2 points – one branch with up to 20% of pods formed;
– 3 points – one or two branches – up to 30%;
– 4 points – two to 40%;
– 5 points – three or four – up to 50%;
– 6 points – three to five – up to 60%;
– 7 points – four to five – up to 70%;
– 8 points – five to six – up to 80%;
– 9 points – six to seven – up to 90%;
– 10 points – all branches are affected – 100% of pods.

Table 1.22

Forecast of spring oilseed rape seed yield depending on its disease severity [443]

Theoretically possible estimated yield, t/ha	Affected, %					
	disease complex	including				
		alternariosis	phomosis	white rot	gray rot	peronosporosis
0,1	22,70	27.78	16.50	25.00	22.26	20.78
0,5	19,37	23.84	14.08	21.42	18.88	18.55
1,0	15,21	18.91	11.06	16.95	14.66	14.09
1,5	11,04	13.99	8.03	12.47	10.44	11.11
2,0	6,88	9.06	5.01	8.00	6.23	6.65
2,5	2,72	4.13	1.99	3.53	2.01	3.67

Table 1.23

Fusarium damage on spring rape and mustard, 2018–2021 [443]

Crops	Disease severity, % by lesion score				
	1 point	2 point	3 point	4 point	on average
Spring rape	12.6	43.2	60.4	71.2	46.8
Brown mustard	16.6	50.1	70.1	82.4	54.8
White mustard	22.7	44.8	64.1	87.2	54.7

It was also noted that disease damage to winter rape and winter mustard led to lower yield losses compared to spring crops. The highest yield losses were noted when symptoms of Fusarium wilt appeared in the flowering

phase – 100%. With a strong degree of damage to the seed filling phase (green pod), the yield per plant decreased by 8.5%, medium – by 7.4 and weak – by 3.8% compared to the control, i.e. yield losses amounted to 94.4%, 82.2% and 42.2%, respectively. Yield losses are expressed as a percentage per plant compared to the control (healthy plant). A similar pattern of yield decline was observed at a later stage of the disease: with a mild degree of Fusarium infection in the yellow-green pod phase, yield losses amounted to 3.3%, with an average – 31.1, and with a strong one reached 76.7%.

The weight of 1000 seeds of rapeseed plants affected by Fusarium wilt in the green and yellow-green pod phase was 1.4 and 1.6 g, respectively, and in healthy plants – 2.5 g. The study of some biochemical characteristics of rapeseed seeds from healthy and Fusarium-affected plants showed that with severe damage in the yellow-green pod phase, seed oil content decreased by 3.7%, and in the green pod phase – by 14.0% compared to the control (seeds from unaffected plants). As for the content of glucosinolates in the seeds, an inverse relationship is observed. The level of glucosinolates decreases from a mild to a severe degree of damage and from the later phase of plant death to the earlier one.

On the other hand, the defeat of winter rape and mustard plants by phomosis reduced their productivity by an average of 36.1–37.1%. The lowest harmfulness of the disease on both crops was observed at a degree of plant damage of 1 point, i.e. 13.2–14.1%. Differences were noted at 2 points of plant damage: the damage was moderately high (26.5%) on rapeseed crops and high (32.5%) on mustard. The infestation of rapeseed and mustard plants with 3–4 points of damage led to a significant decrease in yield (by 48.1–56.7% and 45.1–56.6%, respectively).

Thus, with a severe degree of damage in the yellow-green pod phase, the amount of glucosinolates was 8.5 μmol/g, and in the green pod phase – only 6.8 μmol/g.

Observations showed that necrosis of various sizes caused by *A. brassicae* was present only on the lower and middle leaves, not spreading to the stem of plants in all studied cultures. The mycelium of E. communis in the form of a white web covered all plants, but did not penetrate into organ tissues. The infectious material of fungi of the genus Alternaria nees was isolated on all studied crops only from the

shells of pods. In addition, single plants of rapeseed (spring and winter) and winter mustard affected by phytoplasma (pathogens – Aster yellows phytoplasma) were observed.

Thus, the damage to plants of these crops by downy mildew, powdery mildew, Alternaria and phytoplasma during the years of research at the experimental plots did not lead to a decrease in the quality and quantity of seed yield. Fusarium was the most harmful on spring rape, black mustard and white mustard; phomosis in the form of stem cancer and stem form of sclerotinia were the most harmful on winter rape and black and brown mustard. As a result of the research, it was found that Fusarium damage to plants caused an average significant decrease in the productivity of spring crops: spring rape – by 46.8%, white mustard and black and brown mustard – by 54.7–54.8%. Fusarium damage on rapeseed ranged from low (12.6%), when plants had 1 point of damage, to high (43–2-71.2%), when plants had 2–4 points of damage. Infestation of black mustard and white mustard plants with 1 point led to a decrease in yield by 16.6–22.7% (average degree of damage), and 2–4 points led to a significant decrease in yield: 50.1–82.4% on brown mustard and 44.8–87.2% on white mustard (Table 1.24).

Table 1.24

Harmfulness of phomose rot on winter rape and mustard, 2018–2021 [353]

Crop	Disease severity, % by lesion score				
	1 point	2 point	3 point	4 point	on average
Winter rape	13.2	26.5	48.1	56.7	36.1
Winter mustard	14.1	32.5	45.1	56.6	37.1

It has also been established [97], that phomosis causes a significant decrease in both the number of leaves per plant and its leaf surface in rapeseed. In healthy plants in the flowering phase, the number of leaves was 36 pcs. and in phomosis-infected plants – 30 pcs. The leaf surface area of the affected plants was 1.5 times less than that of healthy plants (Tables 1.25–1.26).

Table 1.25

Influence of the pathogen *Phoma lingam* D. on the physical and chemical properties of spring rape plant tissue (Kalinovsky variety)

Plant condition	Dry matter content, %	Osmotic pressure of cell sap, atm	Transpiration intensity mg, water per 1 cm^2 per hour
Healthy	15.21	17.31	77.51
Affected	18.10	23.31	21.23

Table 1.26

Effect of phomosis on photosynthesis intensity and photosynthetic potential of spring rape plants (Kalinovsky variety)

Plant condition	Photosynthesis intensity, mg/CO_2 per square meter per hour	Number of leaves per plant, pcs.	Leaf area of one plant, sq. cm
Healthy	3.51	36.0	601.4
Affected	1.27	30.0	400.3

The intensity of photosynthesis in healthy rapeseed leaves was 3.51 mg/CO_2 per square meter per hour, and in the affected ones – 1.27.

Along with the disruption of photosynthesis, the decrease in yield in plant disease is associated with increased respiration. The reason for the intensification of the process of respiration of the diseased plant is a response to physiological irritation caused by the penetration of pathogens.

The protective role of respiration is expressed in:

1) inhibition of the activity of hydrolytic enzymes of microorganisms;

2) decontamination of toxic compounds by oxidation to final physiolo-gically neutral decomposition products;

3) participation of oxidative enzymes in the synthesis of cell wall substances, which is associated with the restoration of the affected surface, as well as the formation of mechanical barriers to the penetration of infection and its further spread in the tissues of the host plant.

The increase in respiration rate in the tissues of the affected plant depends on its resistance to the disease. In susceptible varieties, the respiration process is weakened and even stops after a while. This is due to

the full utilization of the plastic substances of the affected tissue. In resistant varieties, however, the intensity of respiration in tissue damage remains elevated even after the infection is suppressed [425].

In addition, it is reported [445] about a 1.16-fold increase in peroxidase activity in leaves of the spring rape variety Kalynivskyi affected by downy mildew compared to the variety Valero. A similar increase in activity (1.17 times) was recorded in phomosis lesions. The analysis of the data in Table 1.27 confirms that the resistance of the spring rape variety Kalinovsky is manifested in the ability of affected plant cells to induce an increase in the amount of peroxidase. In addition, our studies also revealed [445] an increase in lignin biosynthesis in the affected tissues of spring rape.

The analysis of the data shows that in the leaves affected by downy mildew in the resistant variety Kalinovsky the lignin content was 1.3 times higher than in the relatively susceptible variety Valero. A similar increase was recorded in the case of phomosis. The increase in lignin content in plant tissues and its interaction with cell membrane components, in our opinion, contributes to the activation of the protective function in the resistant variety of spring rape Kalinovsky (Table 1.28).

In the process of research [445] the content of nitrogen (protein, non-protein, total) in rape varieties with different disease resistance was also determined.

Table 1.27

Peroxidase activity in varieties of spring rape with different disease resistance

Variety	Disease	Leaves	Peroxidase activity ml of 0.1 normative iodine per 1 g of crude substance
Kalinovsky	Downy mildew	Healthy	8.9
		Affected	12.6
Kalinovsky	Phomosis	Affected	13.3
Valero	Downy mildew	Healthy	8.5
		Affected	10.8
Valero	Phomosis	Affected	11.3

Table 1.28

Lignin content of spring rape varieties with different disease resistance

Variety	Disease	Leaves	Lignin content, %.
Kalinovsky	Downy mildew	Healthy	0.38
		Affected	0.65
Kalinovsky	Phomosis	Affected	0.60
Valero	Phomosis	Affected	0.51
	Phomosis	Affected	0.47

The table shows that in the affected plants of spring rape of the resistant variety Kalinovsky the content of protein nitrogen is 0.3% higher than in the susceptible variety Valero, non-protein nitrogen – by 0.1%, and total nitrogen, on the contrary, is lower by 0.17% (Table 1.29).

Table 1.29

Nitrogen content in varieties of spring rape with different disease resistance (in mg per 100 g of crude matter)

Variety	Disease	Leaves	Protein nitrogen	Non-protein nitrogen	Total nitrogen
Kalinovsky	Downy mildew	Healthy	2.41	0.58	2.88
		Affected	1.62	0.81	2.22
Kalinovsky	Phomosis	Affected	1.80	0.65	2.51
Valero	Downy mildew	Healthy	2.05	0.68	2.48
		Affected	1.31	0.70	2.39
Valero	Phomosis	Affected	1.36	0.59	2.17

Thus, the studies found that the loss of protein nitrogen in diseased plants of the resistant spring rape variety was less than in a similar disease of a relatively susceptible variety, and the loss of total nitrogen, on the contrary, was greater.

Thus, the defeat of *Phoma lingam* D. in plants of spring rape variety Kalynivsky is accompanied by a violation of metabolic processes in plant cells. Under the influence of extracellular enzymes of the pathogen in the affected tissues of rapeseed plants, the content of dry matter and osmotic pressure of cell sap increases, and the assimilation process is delayed, which leads to a violation of the water regime. The end result of the disturbed metabolic process in the cell is the rapid drying and death of leaves and even rapeseed plants.

Along with impaired photosynthesis, the intensity of respiration increases in diseased rapeseed cells, in which oxidizing enzymes such as peroxidase, catalase, polyphenol oxidase, etc. take an active part. Redox processes occurring in diseased plant cells under the influence of enzymes contribute to the biosynthesis of lignin in cell walls, the accumulation of ascorbic acid, etc.

The protective role of respiration is expressed in the inhibition of the activity of hydrolytic enzymes of the pathogen, oxidation and decontamination of its toxic compounds, as well as the formation of mechanical barriers to the penetration and spread of infection in host plant tissues, etc.

It has also been proven [445], that in the resistant variety Kalinovsky, the difference in ascorbic acid content in healthy and downy mildew-affected leaves was 2.7 mg%, and in phomosis – 3.4 mg%. At the same time, in the relatively susceptible variety Valero, the difference was 12.6 mg% in the first case and 13.9 mg% in the second (Table 1.30). In the Kalinovsky variety, the amount of ascorbic acid exceeded the Valero variety by 15.8 mg%, affected by downy mildew, and by phomosis – by 16.4 mg%.

Table 1.30

Ascorbic acid content in leaves of different resistance to diseases of spring rape varieties [445]

Variety	Disease	Leaves	Ascorbic acid content mg 100 g.s.p.
Kalinovsky	Downy mildew	Healthy	40.3
		Affected	37.6
Kalinovsky	Phomosis	Affected	36.9
Valero	Downy mildew	Healthy	34.4
		Affected	21.8
Valero	Phomosis	Affected	20.5

Similar studies have also shown the role of ascorbic acid in the identification of spring rape downy mildew. As a result of biochemical studies, it was found that on average over three years of research, the content of ascorbic acid in the affected leaves of susceptible plants of the Furrat variety decreased by 22.6 and 28.6% compared to healthy ones, while in

resistant varieties Vasylkivskyi – by 16.4 and 21.6% and Kovalevskyi – by 14.2 and 2.7%, respectively (Table 1.31).

Thus, the decrease in ascorbic acid content in the susceptible variety is more pronounced than in the resistant varieties. The rapid decrease in the content of ascorbic acid under the influence of the pathogen reduces the resistance of plants to the pathogen and contributes to the successful course of the pathological process.

Additionally, it is noted that when rapeseed plants are affected by the pathogen downy mildew, the activity of peroxidase increases in different resistance varieties of rapeseed Yarogoak, In resistant varieties Vasylkivskyi and Kovalevskyi, the activity of peroxidase in moderately affected leaves was on average 3 and 0.7 times higher than in the susceptible variety Furrat, and in heavily affected leaves the activity of peroxidase was 4.4 and 1.1 times higher, respectively. It should be noted that the difference in the content of peroxidase between diseased and healthy plants in all studied varieties was approximately the same. Thus, the peroxidase enzyme plays an important role in the plant's defense functions against the pathogen. In more resistant varieties, the activity of peroxidase increases and depends on the degree of disease development.

It is noted that the harmfulness of sclerotinia on winter rape and mustard also depended on the degree of plant damage, increasing from low at 1 point (9.7% and 14.8%, respectively) to high at 4 points (66.7% and 14.8%, respectively). damage (66.7% and 70.7%, respectively).

On average, the yield losses of rape due to the disease were lower compared to mustard – 35.3% and 43.9%, respectively (Table 1.31). The results of the same studies indicate (Table 1.32) that the content of the main ash elements in mg/kg of green mass varies in different resistance varieties of winter rape.

Thus, in the variety Tysmenytsia, which is the standard, the content of ash elements in healthy plants was significantly lower than in the affected ones, potassium was 20 mg/kg less, sodium – 0.8 mg/kg, manganese – 28.7 mg/kg, calcium – 9.7 mg/kg, copper – 0.8 mg/kg. The same pattern is observed for the Fedorivsky Improved and Xaverivsky varieties, although the difference is much smaller. As for iron, on the contrary, it accumulates much more in healthy plants by 39.0–43.0 mg/kg of green mass. Such data suggest that metabolic processes in affected plants are much slower and

the plants themselves begin to age earlier, and therefore more ash elements accumulate in affected plants (Table 1.32).

Table 1.31

Ascorbic acid content (leaves) in spring rape varieties with different resistance to downy mildew, mg% per 100 g of dry matter [426]

Variety	Plant condition	Ascorbic acid content in the budding phase			
		1981	1982	1984	Average
Furrat	Healthy	48.7	45.6	48.1	47.5
	Moderately injured	23.6	24.9	26.1	24.9
	Severely injured	16.5	20.1	20.0	24.9
	SSD_{05}	0.3	10.2	0.4	–
Vasilkovsky	Healthy	40.3	41.4	58.3	46.7
	Moderately injured	35.5	28.7	26.6	30.3
	Severely injured	26.4	25.4	23.4	25.1
	SSD_{05}	0.8	0.3	0.4	–
Kovalevsky	Healthy	46.4	47.3	57.7	50.5
	Moderately injured	36.0	38.0	34.9	36.3
	Severely injured	28.6	32.1	19.5	26.8
	SSD_{05}	0.2	2.2	1.9	–

Analysis of the quality indicators of rapeseed green mass showed that their content in affected plants was significantly lower than in healthy plants, and the ash content was 0.5–0.7% higher. In the winter rape variety Fedorivsky, the improved dry matter content was 0.2–0.9% higher, and protein, respectively, by 0.5–2.5%. All other parameters were equivalent (Tables 1.33–1.35).

Visual assessment of spring rape, black and white mustard, and winter rape and mustard crops during the years of research showed that the plants were affected by harmful diseases: Fusarium, Phomosis and Sclerotinia with varying degrees of damage, from 0 (healthy plant) to 4 (completely affected plant) points.

The greatest decrease in plant productivity among all studied crops was observed in [353] of the studied crops at a damage level of 4 points. However, the harmfulness of Fusarium on spring rape, black and brown and white mustard, sclerotinia and phomosis of winter mustard at plant severity of 2 and 3 points was also high, indicating a significant negative impact of these diseases on plant productivity of the studied crops. Damage to

winter rape and mustard resulted in a smaller decrease in plant productivity compared to spring crops. Fusarium infection significantly reduced the productivity of plants of spring rape, black and brown mustard and white mustard. The maximum damage of the disease reached 71.2, 82.4 and 87.2%, respectively, and the degree of plant damage was 4 points. The productivity of winter rape and brown mustard plants was significantly reduced by phomosis in the form of stem cancer and stem sclerotinia, reaching 56.7 and 66.7 %, respectively, in rape and 56.6 and 70.7% in mustard.

Table 1.32

Peroxidase activity (leaves) in spring rape varieties with different resistance to peronosporosis, ml of 0.1 N iodine per 1 g of crude matter [445]

Variety	Plant condition	Peroxidase activity during the budding phase			
		1981	1982	1984	Average
Furrat	Healthy	6.5	6.9	2.4	5.3
	Moderately injured	9.7	10.2	2.8	6.6
	Severely injured	12.6	13.1	3.2	9.7
	SSD_{05}	0.7	0.5	0.2	–
Vasilkovsky	Healthy	8.2	9.5	6.4	8.0
	Moderately injured	11.6	11.4	8.8	10.6
	Severely injured	14.6	16.7	11.0	14.1
	SSD_{05}	0.5	0.8	0.8	–
Kovalevsky	Healthy	7.9	8.8	1.6	6.1
	Moderately injured	10.8	12.2	2.0	8.3
	Severely injured	14.5	15.1	2.7	10.8
	SSD_{05}	1.4	0.6	0.6	–

Table 1.33

Content of main ash elements in mg/kg of green mass of winter rape varieties with different resistance [445]

Variety	Plant condition	K	Na	Mn	Ca	Mg	Cu	Fe
Tysmenytsia (standard)	Good Doer	28.1	1.2	60.0	34.5	2.7	5.5	136.1
	Affected	30.1	2.0	90.3	44.2	3.3	6.3	97.0
Fedorovsky improved	Good Doer	27.0	1.1	61.0	35.0	2.81	5.7	137.0
	Affected	27.5	1.62	81.1	40.1	3.16	6.1	94.0
Xavierivsciy	Good Doer	27.9	1.15	61.4	35.8	2.9	5.6	138.1
	Affected	27.7	1.53	77.5	42.2	3.06	6.0	98.5

Table 1.34

Chemical composition and nutritional value of green mass of winter rape varieties with different disease resistance [445]

Variety	Plant condition	Dry matter %	Content in dry matter, %				
			Protein	Fat	Fibre	NEF	Ash
Tysmenytsia (standard)	Healthy	13.1	18.5	4.9	26.6	40.7	9.3
	Diseased	14.3	16.7	3.1	22.2	40.1	9.8
Fedorovsky improved	Healthy	14.0	19.0	4.8	26.1	40.9	9.2
	Diseased	14.5	18.2	4.5	27.0	40.6	9.7
Xavierivsciy	Healthy	13.9	18.8	4.9	25.8	40.5	9.4
	Diseased	14.4	18.5	4.7	24.4	41.0	9.9

Table 1.35

Harmfulness of sclerotinia in winter rape and mustard, 2018–2021 [353]

Crop	Disease severity, % by lesion score				
	1 point	2 point	3 point	4 point	on average
Winter rape	9.7	26.5	38.3	66.7	35.3
Winter mustard	14.8	34.7	55.4	70.7	43.9

Additionally, it is noted that plant damage during the growing season by a complex of different diseases is a problem for cruciferous crops in all countries of cultivation. The species composition of pathogens and the harmfulness of diseases on rapeseed and mustard may differ depending on the agroecological zone of cultivation. However, some diseases significantly reduce the quality and quantity of the crop in all growing regions. These diseases include Fusarium in the form of tracheomycotic wilt, Phomosis in the form of stem cancer and stem sclerotinia. Fusarium pathogens penetrate through the root system into the stems, where mycelium develops and blocks the conducting vessels, which leads to premature drying of plants, sometimes without seed formation [446]. The stem cancer form of phomose rot on rapeseed and mustard plants leads to the formation of deep ulcers (necrosis) of various diameters on the stem. The stem tissue in this area, as well as above and below the necrosis, rots, the stem breaks in this place and the plant lodges. And even if seeds are formed, they will fall out of the pods or rot inside them [429–430]. When the infectious agent of sclerotinia gets on rapeseed and mustard plants, the surface of the stem is covered with ulcers, the ulcer quickly increases in depth and width, all affected tissue discolors and becomes fibrous over time, the stems break in the affected areas, and the

seeds ripen prematurely and fall out. On the surface and inside the affected discolored stem, sclerotia are formed in large quantities [431–432].

Weather conditions during the growing season of spring and winter rapeseed and mustard have a favorable effect on the development of many pathogenic fungi: the average daily air temperature from May to July exceeded the average annual temperature by 0.5–4.0 ^{0}C, the amount of precipitation during this period was 40–110 mm, the average relative humidity for the entire growing season of crops exceeded 58%.

Research conducted [353] indicate that yield reduction from Fusarium wilt in rapeseed depends on the condition of the plants, the timing of the onset of disease symptoms and the degree of damage. Strong, moderate and weak degrees of Fusarium damage were assessed by determining:

– the percentage of dried branches on the plant out of the total number (central and lateral branches of the first order) to healthy branches;

– the number of diseased pods (partially fulfilled and completely sterile) to healthy pods (fulfilled);

– weight of seeds from diseased pods to weight of seeds from healthy pods and other quantitative indicators.

The direction of use of rapeseed oil primarily depends on the composition of fatty acids in it, the ratio between saturated, simple unsaturated and polyunsaturated fatty acids.

The following qualitative characteristics are important for the use of rapeseed oil for food purposes:

– low content of saturated fatty acids, especially palmitic acid;

– adequate content of polyunsaturated acids;

– predominance of simple unsaturated fatty acids, especially oleic acid.

Especially valuable is the content of simple unsaturated oleic acid (C 18:1). It lowers blood cholesterol level, protects human vascular system from atherosclerotic changes, regulates blood pressure level, reduces the degree of hypertension and has positive effect on diabetics.

Fusarium wilt of yellow-seeded rape significantly worsens the biochemical parameters of seeds (Tables 1.36–1.37). Thus, with a strong development of the disease in the phase of yellow-green pod, the content of oleic acid decreases by 2.5%, and in the phase of green pod – by 6.8%. At the same time, the total content of saturated fatty acids – palmitic and stearic acids – increases in seeds collected from diseased plants up to

8% with a severe degree of damage in the green pod phase and up to 6.5% in the yellow-green pod phase, compared to 5.5% in seeds from healthy plants. Apparently, this is due to the phenomenon of senescence (acceleration of the aging process) under the influence of the pathogen, which increases the outflow of plastic substances from the pod and stem valves into the seeds. The increase in the content of polyunsaturated fatty acid linolenic acid against the background of a decrease in oleic acid from a mild to a severe degree of damage and from a late onset of disease symptoms to an earlier one makes the oil obtained from such seeds not meet the requirements for food quality, but is suitable for technical purposes.

Proved [448] a close dependence of the total yield per plant affected in the yellow-green pod phase by moderate and weak Fusarium on the weight of seeds from healthy pods and on the number of pods on the control plant, which is healthy, but to a lesser extent (Figure 1.73).

It can be concluded that Fusarium acts as a senescent agent that causes accelerated aging of pods that have completed production and leads to an increase in seed filling. With a severe degree of damage, the total number of pods and the number of healthy pods, height, weight of 1000 seeds and weight of seeds from healthy pods have the maximum impact.

When yellow-seeded spring rape plants were damaged to an average degree in the green pod phase, a high proportion of the impact on the yield of all these indicators was noted, except for the weight of seeds from healthy pods due to their small number. With a mild degree of damage in the same phase, their influence decreases, and the first and second places are occupied by the weight of seeds from healthy pods, as well as the total number of pods and the number of healthy pods per plant.

The greatest influence on the value of the weight of healthy pods per plant is exerted by such productive traits as the number of healthy branches and the number of healthy pods, as well as the weight of 1000 seeds in the case of Fusarium infection in the green pod phase to a lesser extent. By the stage of yellow-green pod, the average degree of damage, the share of participation of all the above traits drops sharply, and then slightly increases with a weak degree of damage. For healthy plants, the weight of seeds from healthy pods is strongly related to the number of branches. In the studies, the main influence on: seed weight: per plant Fusarium had

Table 1.36

Fusarium damage to yellow-seeded spring rape at the onset of symptoms of the disease at different stages of plant development [448]

Appearance of disease symptoms per phase	Degree of plant damage	Point defeat	The height of the plants, cm	Diseased branches on the plant, %	Number of pods per plant, %.		Weight of seeds per plant, г	Weight 1000 of seeds, г	Seed oil content, %.	Glucosinolates, µmol/g
					health	diseased plants				
Control (healthy plants)		–	137.0	0.0	100.0	0.0	9.0	2.5	48.7	11.0
Flowering	strong	10	91.0	100.0	0.0	100.0	0.0	–	–	–
Green pod	weak	6–7	126.0	56.7	18.0	82.0	5.2	1.6	42.5	7,9
	average	9	110.0	77.0	5.9	94.1	1.6	1.5	37.9	7,2
	strong	10	101.0	100.0	0.6	99.4	0.5	1.4	34.5	6,8
Yellow-green pod	weak	1–3	123.0	46.7	60.3	39.7	8.7	2.0	48.1	10,1
	average	4–5 –	122.0	49.3	51.4	48.6	6.2	1.9	47.1	9,9
	strong	8	112.0	75.4	28.7	71.3	2.1	1.6	45.0	8,5
SSD_{05}								0.1	0.8	0.8

Table 1.37

Effect of Fusarium on fatty acid composition of oil in spring rape [448]

Appearance of disease symptoms per phase	Degree of plant damage	Reduction of of oil content compared to the control, %	Fatty acid content in the oil, %					
			saturated		simple unsaturated		polyunsaturated	
			palmitic	stearic	oleic	erucic	linoleic	a-linolenic
Control (healthy plants)		48.7**	3.7	1.8	64.2	0.0	22.9	7.4
Green pod	weak	12.8	4.1*	2.2*	58.8*	0.0	26.2*	8,7*
	average	22.2	4.4*	2.7*	57.7*	0.0	26.5*	8,8*
	strong	29.1	4.4*	2.7*	57.5*	0.0	26.8*	8,9*
Yellow-green pod	weak	1.0	3.7	1.8	63.6	0.0	22.8	8,1*
	average	3.4	3.9	1.8	62.4*	0.0	23.8*	8,1*
	strong	7.6	4.1*	2.1*	61.7*	0.0	23.9*	8,5*
SSD_{05}			0.2	0.3	0.7	–	0.7	0.4

Note: * – significantly at the 0.05 level of significance; * * * – in control – oil content of absolutely dry seeds, %

by means of seed weight from diseased pods. The number of diseased branches, diseased pods and seed weight from diseased pods had the closest positive relationship with the yield per plant at strong and weak degrees of plant damage in the green pod phase, and had a slightly lesser effect at a strong degree of damage in the yellow-green pod phase.

Indicators – the number of diseased pods and the number of diseased branches per plant separately largely determine the yield: the first – with a strong degree of damage in the green pod phase, the second – with an average degree in the same phase.

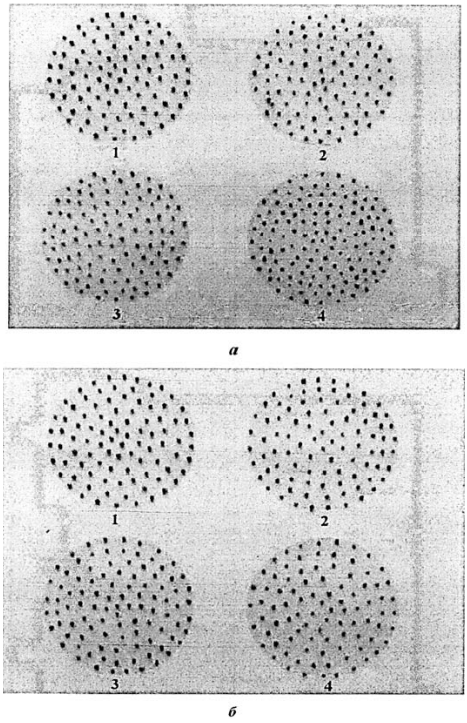

Figure 1.68 – Seeds of spring rape type "000" from plants affected by Fusarium wilt in the green pod phase (a) and in the yellow-green pod phase (b) to varying degrees: 1 – control (healthy plant), 2 – weak, 3 – medium, 4 – strong [448]

The height of diseased plants has a medium effect on the weight of seeds from diseased pods in the wilting stages of green and yellow-green pods, but these traits are not related to the severe damage of plants in the green pod stage.

Pairwise direct close relationships of seed weight from diseased pods with the number of diseased pods and the number of diseased branches with plant height were found in both phases. Moreover, with the appearance of disease symptoms on more developed rapeseed plants in the yellow-green pod phase and with a severe degree of damage, the yield from diseased pods increases in direct proportion to their number, which is the reason for the high interdependence of the traits under consideration. In turn, the number of diseased pods is determined by the number of diseased branches and height, which are private determinations of the first and second groups of traits. The determination due to their interaction, i.e., the increase in determination from the joint influence of these two groups of factors, tends to increase from a weak degree in the green pod phase to a weak degree of damage in the yellow-green pod phase.

When symptoms of Fusarium wilt appeared in the flowering phase, the combined trait of plant height and the number of diseased branches had a stronger effect on the number of formed but undeveloped fruits on the plant.

In addition to the negative impact of Fusarium on the yield structure of yellow-seeded spring rape, deterioration of seed quality was also found (Table 1.38). The germination energy of seeds obtained from affected plants in the green pod phase decreased by 15–39%, and by 6–8% in the yellow-green pod phase, and laboratory germination by 6–9 and 4–5%, respectively.

Thus, the greatest yield losses of yellow-seeded spring rape were observed when symptoms of Fusarium wilt appeared in the flowering phase – 100%. With a strong degree of damage in the green pod phase (10th damage point on an 11-point scale), yield losses amounted to 94.4, with an average (9th damage point) – 82.2 and weak (6th–7th damage points) – 42.2%. A similar pattern of yield decline was observed with later manifestation of the disease: with a weak degree of Fusarium infection in the yellow-green pod phase (1st – 3rd damage points), yield losses were 3.3%, with an average (4th-5th damage points) – 31.1, and with a strong (8th damage point) reached 76.7%. The weight of 1000 seeds of rapeseed plants affected by Fusarium wilt to a high degree in the phases of green and yellow-green pods was 1.4 and 1.6 g, respectively, which is 44.0 and 36.0% less than the weight of 1000 seeds of healthy plants.

Table 1.38

Effect of Fusarium on the sowing quality of spring rape seeds of type '000' [448]

Appearance of disease symptoms per phase	Degree of plant damage	Seed germination energy, %	Laboratory germination rate of seeds, %
Control	–	89.0	99.0
The green pod	weak	74.0*	93.0*
	average	60.0*	92.0*
	strong	50.0*	90.0*
Yellow-green pod	weak	83.0	95.0*
	average	83.0	94.0*
	strong	81.0	94.0*
SSD_{05}		9.3	3.4

Note: * – significant at the 0.05 level of significance

Under severe Fusarium wilt damage of spring rape type "000" in the yellow-green pod phase, the oil content of mature seeds decreased by 3.7%, and in the green pod phase – by 14.0% compared to seeds from healthy plants. With a severe degree of damage in the yellow-green pod phase, the amount of glucosinolates was 8.5 μmol/g, and in the green pod phase – only 6.8 μmol/g.

With a strong development of the disease in the yellow-green pod phase, the content of oleic acid in mature seeds decreases by 2.5%, and in the green pod phase – by 6.8%. The increase in the content of polyunsaturated fatty acid linolenic acid against the background of a decrease in oleic acid from a mild to a severe degree of damage and from a late onset of disease symptoms to an earlier one reduces the economically valuable characteristics of the oil and makes it suitable only for technical purposes. Fusarium infection reduces the germination energy of spring rape seeds by 15–39% when symptoms of the disease appear in the green pod phase and by 6–8% in the yellow-green pod phase, and laboratory germination of seeds by 6–9% and 4–5%, respectively.

It was noted [452], that the isolation of pathogens causing root rot of seedlings and tracheomycotic wilt of plants showed that the main cause of the disease is fungi of the genus Fusarium. The species of this genus were identified by phytopathologists. In the culture of fungi, *F. oxysporum* was found in 97.1% of cases, *F. solani* Arr. et. Wr. in 2.2%

of cases and F. buharicum (Jacz) Raillo in 0.7% of cases. The study of their morphological characteristics revealed that Fusarium oxysporum var. orthoceras prevails among them. It is characterized by filmy-webbed, felt-like or fluffy mycelium, with no color or colored in raspberry-purple tones on the Gram stain. Macroconidia are sickle-curved, often with three septa with a large number of microconidia. Several isolates isolated from rapeseed plants were represented by F. gibbosum. The main features of this species are fluffy, felt mycelium, yellowish-red in color on the Gram stain (Bondartsev scale). The macroconidia are curved, with 3–5 septa and a distinct pedicel. A large number of chlamydospores. All isolates were tested for aggressiveness before the start of the main work, which allowed us to divide them into 3 groups according to this criterion: highly aggressive, moderately aggressive and non-aggressive.

Observations [97] showed that the temperature optimum for infection of yellow-seeded spring rape with F. oxysporum is in the range of 14–16 °C, which is 6–10 °C lower than for infection of blue-seeded rape. Thus, at early terms of spring sowing of "000" type rapeseed, conditions are created that are more favorable for infection, i.e. the infectious background provides a higher susceptibility of breeding samples, and, conversely, later sowing terms are characterized by a weakened infectious background. Late sowing dates are more favorable for infection of "00" type spring rape.

The main sources of spread of rapeseed diseases are the remains of diseased plants, contaminated soil and seeds. Seed material that has not been treated is a source of diseases such as Alternaria, Fusarium, Phomosis, gray rot, downy mildew, and a number of others. Seed infection directly leads to a decrease in germination energy and a drop in germination rate. Sowing with infected seeds causes the pathogen to be transmitted to plants during the growing season, thus creating foci of infection that cause infection of the new crop. With contaminated seed, pathogens of certain diseases of spring rape can be introduced into the soil from year to year and accumulate there. The infectious germ can be located on the surface of the outer shell of healthy seeds. Such an infection does not directly affect the seed, and only during germination does it infect the seedlings. Spreading in an adult plant, it contributes to the outbreak of the disease on crops.

In addition to parasitic microorganisms, saprotrophic microorganisms, such as bacteria and fungi, grow and develop on seeds under certain

conditions. Their intensive development is accompanied by mold or rotting of seeds and leads to complete seed death if no preventive measures or measures to improve the seeds are taken in time.

Since seeds obtained from Fusarium-affected plants are characterized by low germination energy and germination rate, and the pathogen can be transmitted with seed material due to damping-off during contact with infected stems, for example, during threshing, our task was to identify the most effective fungicides to suppress the infectious origin of Fusarium on seeds and protect weakened seeds and seedlings from mold in soil conditions. For this purpose, a number of experiments were conducted in the laboratory and in the field.

The harmfulness of the above diseases of cruciferous plants is confirmed by the results of the scale assessment of the degree of plant damage in Tables 1.39–1.46. In this regard, personalized scales for some types of cruciferous crops, for example, varieties of spring and winter rape, will also be useful [97].

Table 1.39

Scale of alternariosis and sclerotiniasis lesions

Score of damage	Degree of damage	Characteristic features	Area of the affected plant surface, %
0	None	Healthy plants	0
0-1	Minor	Single spots on individual leaves	<1
1	Initial	Up to 10 spots on the plant	1–5
2	Weak	Up to 1/10 of the entire plant surface is affected	6–10
3	Average	The lesion covers 1/4 of the entire plant surface	11–25
4	Strong	The lesion covers 1/2 of the entire surface of the plant. Individual spots on the pods	26–50
5	Very strong	Most leaves have dried up, stems and pods are affected	51–75
6	Catastrophic	Most of the leaves are dead, the pods are cracking. The plants are dying	>75

Table 1.40

Scale of rapeseed damage by peronospora and phomosis

Score of damage	Degree of damage	Characteristic features	Area of the affected plant surface, %
0	None	Healthy plants	0
0-1	Minor	Single spots on individual leaves	<1
1	Weak	A lot of spots	1–10
2	Average	Affected up to U of the leaf surface, conidial sporulation of the fungus on the lower side. Individual spots on pods	11–25
3	Strong	Up to 50% of the leaf surface is affected, yellowing of the leaf blade begins, stems and pods are affected	26–50
4	Very strong	Affected leaves turn yellow and die. The pods crack	>50

Table 1.41

Rapeseed powdery mildew damage scale

Score of damage	Degree of damage	Characteristic features	Area of the affected plant surface, %
0	None	Healthy plants	0
0-1	Minor	Single pads of fungal mycelium on individual leaves	<1
1	Weak	Many pads of mushroom mycelium	1–10
2	Average	Up to 30% of the leaf surface is affected, conidial sporulation of the fungus. Individual pads of fungal mycelium on pods	11–25
3	Strong	Up to 50% of the leaf surface is affected, strong conidial sporulation of the fungus, leaf blade death begins, stems and pods are affected	26–50
4	Very strong	The affected leaves die off. The pods crack	>50

Table 1.42

Accounting for disease damage to rapeseed crops [445]

Disease	The vegetation phase	Inspected part of the plant
Blackleg, bacteriosis, fusarium	One to three true leaves	Root collar, root *
Peronospora, phomosis, fusarium, bacteriosis, snow mold. Rosette. All rosette leaves, root collar *	Rosette	All rosette leaves, root collar *
Peronosporosis, cylindrosporium, white spot, Alternaria, phomosis, white rust	Full flowering	Leaves of lower and middle tiers, stem, central and lateral cauline
Powdery mildew, fusarium, white and gray rot, Alternaria, cylindrosporium, phomosis, white rust	The green pod	Leaves of lower and middle tiers, stem, central and lateral cymes, all pods
White and gray rot, alternaria, cylindrosporium, phomosis, verticillium, fusarium	Yellow-green pod	Stem, all pods

Note: * – winter rape is inspected before the plants go into winter (in the phases of one to three true leaves and rosettes) and in spring (when the vegetation is restored).

Table 1.43

Scale for evaluation of resistance of rape varieties to downy mildew [445]

Score of damage	Characteristics of the disease manifestation	Degree of resistance
9	There are no typical signs of damage. Individual chlorotic and necrotic spots occasionally appear on the lower stem leaves	Highly resistant
7	Yellowish spots appear on the upper side of some lower leaves. 5 to 10% of such leaves are affected. The damage to the lower leaves is from 10 to 20%.	Resistant
5	There are some spots on the upper leaves.	Medium resistant
3	The damage to the upper leaves is from 5 to 20%, the lower leaves – 20–50%. Spots merge, part of the leaf dies.	Receptive
1	The whole plant is affected, the leaves gradually die off. The plant dies.	Very susceptible

Table 1.44

Scale for evaluating resistance of rapeseed varieties to phomosis [445]

Score of damage	Characteristics of the disease manifestation	Degree of resistance
9	There are no typical signs of damage. On the lower stem leaves, individual chlorotic and necrotic spots are occasionally found.	Highly resistant
7	On the lower leaves there are individual rounded spots of ash-grayish color with a brown border, yellowing of the tissue is detected around them. The damage to the lower leaves is up to 5%.	Resistant
5	On the lower leaves, grayish spots with a brown border with pycnidia in the center in the form of dots are well defined. The damage to the lower leaves is from 5 to 10%. Some spots are found on the upper leaves.	Medium resistant
3	Oval spots are well defined on the lower leaves. From 10 to 50% of the surface of the lower leaves is affected, and from 5 to 10% of the upper leaves. When such plants are ripe, the leaves are also covered with spots.	Receptive
1	On the seedlings of young plants, the stem tissue is discolored with the formation of a strip of dead tissue, the plant dies. In adult plants, the spots on the lower leaves merge, and the leaves die. The tissue of the pod valves is severely affected.	Very susceptible

Table 1.45

Scale for evaluating resistance of rape varieties to Alternaria [445]

Score of damage	Characteristics of the disease manifestation	Degree of resistance
9	There are no typical signs of damage. On some lower leaves, barely noticeable small dots are occasionally found, around which a light green color is formed.	Highly resistant
7	On some lower leaves and stem there are several dark dots around which yellowing of the tissue is observed. The damage is up to 5%.	Resistant
5	Small dots appear on the leaves and pods. Lower pods are affected up to 5%, upper pods – up to 10%.	Medium resistant
3	The lower pods are affected with deep depressed spots from 5 to 10%. The upper pods are covered with small dots from 10 to 25% of the surface and above.	Receptive
1	The lower pods curl and die. The upper ones are covered with deep depressed spots up to 5%. The pods shorten and crack. The number of seeds decreases to 20%. Seeds are small and underdeveloped.	Very susceptible

Table 1.46

Scale for evaluating the resistance of rape varieties to powdery mildew [445]

Score of damage	Characteristics of the disease manifestation	Degree of resistance
9	There are no typical signs of damage. Chlorotic and necrotic spots and a weak coating are occasionally found on individual lower leaves.	Highly resistant
7	Small pads are found on the lower leaves and stem, around which chlorotic or necrotic spots form. A white spider web coating is noticeable on the lower third of the stem and leaves. The damage is from 5 to 10%.	Resistant
5	The affected plant is up to half covered with a white spider web. The lower leaves are more severely affected with a gradual transition to moderate and weak. The damage is from 10 to 20%.	Medium resistant
3	One third of the stem and leaves are severely affected. The lower leaves curl and dry out. A white spider web coating appears on the upper leaves and stem in some places. In some places, the coating is also found on young pods. The damage is from 20 to 50%.	Receptive
1	The whole plant is affected. The leaves curl and dry out. Severely affected pods turn yellow. The seeds are small. The plant gradually dries up.	Very susceptible

Non-infectious symptoms on cruciferous crops (Figs. 1.69–1.72) caused by low temperatures, soil compaction, and lack of nutrients should not be forgotten and should be clearly separated from infectious pathogenesis.

Timely assessment of the pathogenesis of cruciferous crop agrocenoses based on typical signs of the development of such diseases is important in terms of monitoring the prevalence and harmfulness of cruciferous crops. For example, here is a typological system for evaluating rapeseed recommended by the phytosanitary services of Europe and Canada [437].

Sclerotinosis. Look for areas with dead or prematurely mature plants. Brown or discolored plants scattered throughout the green crop may indicate a low level of infection. Stem sclerotinia rot is most dangerous when stem infection occurs at an early stage, and is so severe that entire plants die before the seeds are ripe. Inspect the lower and middle sections of the stem for large discolored or yellowish-brown lesions. In some cases, even green stems can develop white fungal growths. You can find the infection very low on the stem, often where infected leaves have fallen on the stems at

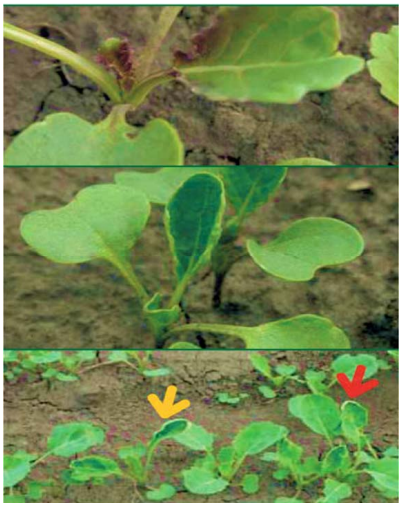

Figure 1.69 – Effect of low temperatures on rapeseed plants [433]

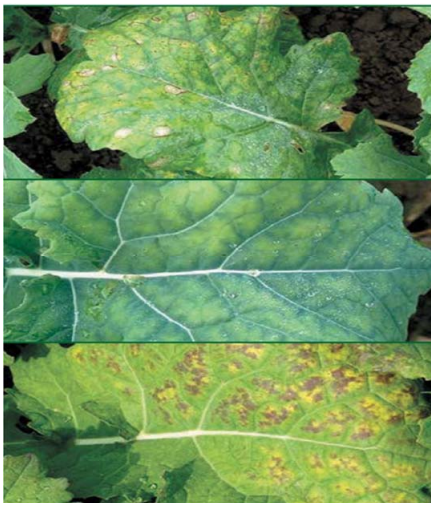

Figure 1.70 – Magnesium deficiency in cruciferous plants [434]

Figure 1.71 – Sulphur deficiency in cruciferous vegetables [435]

Figure 1.72 – Results of soil recompaction [436]

ground level. As it dries, the infected stem becomes discolored or brown like bone and may begin to crack or split. The infected stem tissue is often hollow and hard, and black sclerotia bodies that look like mouse droppings can be found inside infected stems. Sclerotinia can be found higher in the crown on lateral branches and pods, but yield losses at these infection sites are usually minimal compared to lower stem infections. Typically, yield losses due to sclerotinia stem rot account for approximately 50% of the incidence. For example, if 10% of the stems are infected, the yield loss will be approximately half of this amount, or 5%. Wet conditions right up to harvest can cause further germination of sclerotia and the appearance of

Figure 1.73 – Sclerotinia in a rapeseed field [438]

apothecia. If this late-season spore release does cause lesions on decaying leaves, these lesions form too late to cause additional yield loss, but yield loss for these infection areas is usually minimal compared to lower stem infections.

Phomosis. Look for areas with dead or prematurely mature plants. Inspect the lower and middle sections of the stem for damage. Black pepper-like dots (pycnidia) may appear in the lesions. When blackleg is severe enough to cause yield loss, the plant develops irregular, knotted, woody sores at the base of the stem. This infection will eventually grow through the stem, cutting off the flow of nutrients. If you see the plants drying up, pull them out and use garden shears to cut off the top of the root, about half an inch below the base of the stem. If more than half of the stem area is blackened, blackleg has probably reduced the yield of that plant. How to evaluate blackleg yield: If blackleg levels are higher than expected, even with a fungicide application, check the notes to see when the fungicide was applied. To be effective, the fungicide selected for blackleg control should be applied at the 2–4 leaf stage of the crop with the appropriate rate and volume of water.

A few weeks before harvesting, you may also find late-developing blackleg lesions higher up on the cruciferous stems. Look for pycnidia in the lesions on the top of the stem as a sign of blackleg. This can be caused by the less virulent blackleg pathogen L. biglobosa. Cut the stems at ground level to check for blackleg (Figures 1.74–1.75).

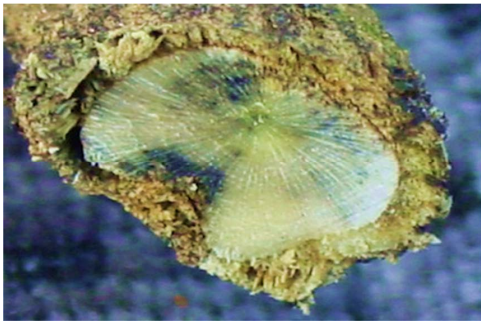

Figure 1.74 – Rapeseed stem affected by blackleg [452]

	No diseased tissue is visible on the transverse section
	Diseased tissue occupies 25% or less of the cross section
	Diseased tissue occupies 26-50% of the cross section
	Diseased tissue occupies 51-75% of the cross-section
	Diseased tissue occupies 75% or more of the cross-section
	Diseased tissue covers 100% of the cross-section, with significant narrowing of the affected tissue; tissue is dry and brittle; the plant has died

Figure 1.75 – Scale for assessing blackleg infestation in rapeseed [455]

Clubroot. Above-ground symptoms, including wilting and premature maturation, should be evident in heavily infested plants. Plants can be infected with clubroot even if no above-ground symptoms are present. It is important to pull or dig up the plants to examine the roots for clubroot. When looking for clubroot, it is important to inspect the roots of plants at

the entrance to the field, depressions, or areas with premature maturation. A mild or severe infection has almost the same risk of spreading the disease through equipment and tillage practices. If galls are present, mark the spot and pull plants around the infected plants to determine the full area of infection Keep in mind that the formation of pathogen spores on each plant is incredibly high, so you should take seriously the formation of quarantine measures to prevent the spread of the disease in this particular field as a way to slow the spread of this disease.

Alternaria. In crops, small black spots as signs of the disease gradually move up the plant, eventually reaching the pods. The maximum severity of the signs of the disease is most noticeable during the ripening phase of plants, especially after the physiological destruction of the wax coating. UV radiation, temperature fluctuations and intense precipitation destroy this wax barrier. Cool, damp weather can also exacerbate Alternaria infection, and rain splashes can spread the disease to other plants. In cases of severe Alternaria infestation, early swathing of rapeseed can have an overall economic benefit compared to later separate harvesting.

This measure prevents Alternaria from spreading to the plant pods. When infected areas account for 50% or more of the crop, early separate harvesting may be the best way to preserve the yield on these infected

Figure 1.76 – Different degrees of clubroot damage in rapeseed (this tiny clubroot gall (right position) will not affect this year's yield, but will release spores for future infestations) [456]

plants. The disease can continue to spread through the vegetative parts of the plant, and windrowing accelerates the drying of the crop.

Table 1.47

Comparison of the main diseases of rape and other cruciferous plants [455-456]

Disease	**Sclerotoniosis**	**Phomosis (pathogen *L. maculans*)**	**Phomosis (caused by *L. biglobosa*)**	**Verticillium**	**Gray stem rot**	**Fusarium wilt**
Signs on the stem	Bleached or white. The stems break easily. Dark sclerotia form inside the stems. There may be signs of white mold growth	Stem lesions with pycnidia (black spots) forming inside the lesion. The base of the stem becomes woody. Blackening is visible on the cross section	Shallow stem damage with pycnidia	Shredding of the stem tissue. Tiny black micro-sclerotia are formed under the outer peeling layer	Large stem with purple or gray specks. Pod damage is also possible	Disco-loration of the stems; yellow or reddish-brown stripes on the stems
Signs on the pod	Dried pods due to damage to the base of the inflorescence. Sometimes white mold	None	None	None	Gray spots	None
Signs at the base of the stem (on the outside)	None	Cankers	None	None	None	None
Cross section of the stem base	Clean, dry	Black areas. With severe damage, the surface is completely black	Usually the disease does not reach the base of the stem	Grayish tint along the entire section. Darkens as microsclerotia accumulate. May have an intense extension to the top of the stem	None	None

Figure 1.77 – Alternaria disease can cause pods to dry out prematurely [455]

Gray stem rot. The disease is caused by Pseudocercosporella capsellae and occurs in most rapeseed fields during the maturation of the crop, but usually develops too late in the growing season to significantly affect crop yields. Silver to purple spots appear on the stem. They can cover entire stems and continue to spread through the stubble as the plants decompose. Gray stem rot can be confused with other diseases that cause stem damage and discoloration, such as blackleg, sclerotinia stem rot, and verticillium rot. How to distinguish gray stem rot from sclerotinia (black leg): at the end of the season, cut off the top of the root at the base of the stem and look for dead blackened tissue in the bark of the stem part – this is a sign of sclerotinia (black leg) and not gray stem rot. Black spots will be visible on the black stem. With gray stem rot, the stem remains strong at the site of the lesion. Sclerotinia stem rot causes the formation of a fleshy stem, which is easily crushed after drying. Sclerotinia stem rot stems are also lighter, although it can be difficult to tell the difference if you don't have samples of both infections to compare.

Verticillium blight is a pinkish streaky and belt-like lesion with depressions and a gray discoloration at the maturity stages of rapeseed plants. The stems are crushed, revealing tiny and uniform microsclerotia under the infected layer of the stem epidermis (skin). The gray spots on the stem, if present, will be on the surface, in small numbers in a manner.

Thus, it is easier to detect verticillium directly during or after harvest. Symptoms of Verticillium are not always visible during pre-harvest diagnostics. Symptoms may only appear as a whitening of the stem on one side, which can be easily confused with sclerotinia stem rot. Transverse sections of the roots may have a grayish tint, which can be confused with black leg or gray stem rot. The best time to evaluate verticillium is after harvest, when the microsclerotia in the stem are fully developed. When the plant is fully mature, the stem peels off, revealing tiny black microsclerotia that look like ground pepper. These microsclerotia remain on the stem of the plant or fall into the soil. Although it may seem similar to the blackleg symptom, these specks are under the stem wall in verticillium and always on the surface in blackleg. The table provides more tips on how to distinguish between the main diseases of rapeseed during the period of their monitoring in the crop's agrocenoses.

Stem rot and brown girdling root rot. Rapeseed plants with brown surface symptoms at soil level are likely to be suffering from Fusarium root rot, which causes brown lesions with concentric markings. Another possibility for adult rapeseed roots is brown girdle root rot, which is a bigger problem in classic rapeseed. Symptoms of the disease are orange-brown lesions on the taproot of rapeseed, which, if severe, can encircle the root and split it off. These diseases can be much more common in short rotation rapeseed crop rotations.

Figure 1.78 – Rapeseed stem gray rot [455–456]

Figure 1.79 – Verticillium wilt in rape (peeling shows darkening / under the epidermis and outer bark of the stem) [455–456]

Figure 1.80 – Brown girdle root rot in severe damage causes complete severance of the root part from the stem (left position of the figure), which leads to lodging and death of plants [447; 484–486]

Fusarium wilt. It can lead to discoloration of the stems with a slight pinkish tint, characteristic of the fungus Fusarium. Discoloration can occur only on one side of the stem, which is a typical sign of Fusarium wilt. This disease has been virtually eliminated in modern rapeseed varieties due to genetic resistance.

Table 1.48

Comparison of the pathogenesis of blackleg, clubroot and sclerotinia in rapeseed [446–483]

Ratio indicators	Black leg	Clubroot	Sclerotoniosis
1	2	3	4
Pathogen reservoir plants	Crucifers, including some common weeds	Crucifers, including some common weeds	Broadleaf crops, including rapeseed, soybeans, sunflower, pulses
Main distinguishing features	Lesions with specks of pycnidia inside are formed on the leaves. The infection spreads to the base of the stem, where ulcers form. When you cut open stems, you will find blackened tissue inside. Moderate cases will lead to yield loss, even if the plant does not die	Galls form on the roots. In serious cases, large tuberous galls will restrict the flow of nutrients and water up and down the plant, killing the plant	Lesions form on the leaves and stems. Over time, the stems rot, then become white and brittle. Plants die prematurely, and seed set is significantly reduced. Black sclerotia form inside (and sometimes outside) the damaged stems
The stage of infection persistence	Plant residues	When each gaul collapses, it releases billions of spores into the soil	In the form of sclerotic bodies in the soil
Ways of distribution	Pseudothecia and pycnidia on infected canola residues release spores that continue the infection cycle. Pycnidiospora from pycnidia travel only a few meters. Smaller ascospores released by pseudothecia into the air can travel further	The spores move with the soil. As the soil moves, the clubroot spreads. Soil moved across fields and from field to field by machinery is the most common vector of the disease. The spores infect the roots of the host, continuing the cycle	Sclerotia form apothecia, from which spores are released. The spores can be carried by the wind for kilometers, but most of them come from fields or from fields that are connected. When release coincides with canola flowering and wet conditions, infestation can occur

(End of Table 1.48)

1	2	3	4
Crop rotation factor	2-3 year interval of cruciferous return to this field	A 2- or 3-year break between canola crops can reduce the number of viable spores by 90%, but this may still be sufficient to cause intense damage if the number of spores 1 000 000 / g of soil	The benefits of crop rotation for sclerotinia are less than for blackleg and clubroot because many crops are susceptible, sclerotia are widespread, and released spores are carried to adjacent fields. However, higher severity will be observed with shorter crop rotations
Resistant varieties	Yes	Yes	Increased resistance in selected varieties
Genetic resistance	Yes	No	No
Availability of effective fungicides	For example, in case of early damage	No	Thus, when used during the budding-flowering period

It is important to remember that monitoring and forecasting the spread and development of diseases in cruciferous crops is an integral part of integrated plant protection. Lack of forecasting makes it impossible to control and predict the phytosanitary situation of crops, timely and effective use of plant protection products. Without a forecast, epiphytoties of many dangerous diseases, significant crop losses, and cost overruns of inputs are inevitable. The forecast makes it possible to rationally organize and timely carry out preventive and eradication measures, optimize crop cultivation technologies in accordance with the actual and predicted degrees of disease development and their economic importance; plan production volumes, procurement of fungicides, improve their range, technologies and regulations for their use; inform breeding centers about the emergence of new aggressive races of pathogens in field populations.

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