Chapter

Pests, Diseases, Nematodes, and Weeds Management on Strawberries

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Abstract

Strawberry is an important crop for many features, including being rich in vitamins and minerals. In addition to fresh consumption, it has been appealing to a wide range of consumers in recent years. Its cultivation is in flat areas, slopes, and areas where other crops are limited. Many pests and diseases that are the main biotic stress factors cause significant crop losses in strawberry cultivation. The aim of this chapter is to reveal biotic stress factors and their management. Several plant-parasitic nematodes, fungal diseases, weeds, pests, virus diseases, and bacterial diseases are the main biotic stress factors in plant growing and fruit ripening. The preparation of this book chapter is based on previously published sources and researches and manuscripts. In this section, it is aimed to provide readers with new perspectives in terms of collecting data on nematodes, diseases, pests, weeds, and fruit ripening of strawberry plants. The effect and mechanism of those biotic stress factors on strawberry growing are discussed and revealed in this chapter.

Keywords: strawberry, biotic stress, plant-parasitic nematodes, fungal diseases, weeds, pests, virus diseases, bacterial diseases, fruit ripening

1. Introduction

Strawberry can grow in diverse ecological conditions, and it is an important crop for many countries. Many diseases and pests cause damage to not only strawberry foliar and roots but also directly to fruits. During the ripening, pests and diseases are also precisely essential. Therefore, in the beginning, it would be better to focus on the ripening process.

Fleshy fruit ripening is explained by a series of biochemical and physiological changes involving complex changes in taste, aroma, color, texture, and sugar, coordinated by plant hormones. It has a noteworthy influence on fruit quality, postharvest shelf-life, and consumer acceptance. Changes in color, taste, aroma, texture, and nutritional value during the ripening period make the fleshy fruit attractive and delicious for consumers. These changes that occur with ripening are governed by external (i.e., light, temperature, and irrigation) and internal factors (i.e., genetic regulation and hormonal control) that allow fruit characteristics to develop [1]. As it is known primarily in the model plant tomato, the climacteric fruit ripening process is coordinated by ethylene perception and signal transmission [2]. Although ethylene was not thought to have played a role in the ripening of strawberry fruit, recent studies have shown that the ripening process is much more complex in non-climacteric fruits and controlled by ethylene [3], abscisic acid [4], auxin (indole-3-acetic acid [5], gibberellic acid [6], jasmonate [7] and brassinosteroids [8].

Following the ripening, pest, disease, and weeds of strawberry plants and interaction with yield losses are given attention in this chapter.

2. Hormones involved in strawberry ripening

Ethylene controls almost all ripening processes in climacteric fruits; however, many hormones are actively involved in the ripening process of non-climacteric fruits, which makes these fruits attractive for research. In this context, strawberry (*Fragaria x ananassa*) fruit has become a model of non-climacteric fruit. A complete hormonal profile of woodland strawberry *Fragaria vesca* fruit was reported that auxin is produced mainly in achenes (seeds), whilst abscisic acid (ABA), ethylene, gibberellins, and bioactive free base cytokinins are chiefly produced in receptacles [9]. The report also indicated that ABA promotes ripening while auxin delays it. Moreover, endogenous auxin GA levels are greatly reduced in the late stages of strawberry ripening when the abscisic acid (ABA) level increases dramatically [10]. Indole-3-acetic acid (IAA) has a significant role in cell expansion, determination of fruit size, and ripening of strawberry fruits. A recent RNA-seq study describes the expression profile of auxin biosynthesis and signaling during the development and maturation of F × ananassa [11]. Based on this study, the auxin content drops by 50% in the receptacle but remains constant during ripening, supporting the idea that auxins may involve in strawberry fruit ripening in later stages.

Auxin has been shown to delay ripening by altering the expression of many genes associated with ripening [5]. Expression of FaPL and FaEGase, which are the most important enzymes responsible for softening, increased at the beginning of strawberry ripening and decreased with exogenous auxin application [12]. However, in another study, the expression of two genes encoding Xyloglucan endotransglycosylase/hydrolases (XTH), FaXTH1, and FaXTH2, significantly up-regulated by auxins treatment [13]. In the same study, gibberellins and abscisic acid up-regulated both gene expressions. Increases of FaAux/IAA1 and FaAux/IAA2 transcripts increased by the influence of naphthalene acetic acid (NAA) at the stage of large green and white fruit [14]. During strawberry fruit ripening, the ABA content increasingly grows from the green stage to the red stage (and the commencement of this rise overlaps with declines in IAA levels [15]. In other words, the ripening of strawberries is controlled by ABA in an ethylene-independent manner [16]. Exogenous application of ABA to strawberry fruits has fluctuating results during fruit ripening. IAA has been shown to play an important role in inducing cell division and expansion, which is related to the early stages of strawberry fruit development. In the later stages of ripening, ABA and sucrose are the main molecules that play a role in controlling gene expression. Expression of ABA and sucrose signaling genes and ripening-related genes such as endo-β-(1,4)-glucanases 2 (CEL2), 9-cis-epoxycarotenoid dioxygenase 2 (NCED2), MYB5, Sucrase synthase (SuSy), as endo-β-(1,4)-glucanases 1 (CEL1), Sucrose non-fermenting 1 (SNF1)—related protein kinase 2(SnRK2.2), and9-cis-epoxycarotenoid dioxygenase 1 (NCED1) were all considerably up-regulated by ABA or sucrose treatment alone, and especially with ABA + sucrose treatment [17]. However, postharvest ripening of strawberry fruits varied from the fruits attached to the plant, proposing ripening is related to the signal activated by ABA, as the application of ABA caused the modified amassing of numerous compounds including sugars, ABA, anthocyanins, and ABA-GE [18]. Treatment of ABA positively regulated the expression of FaRGL [19]. ABA is a crucial signal molecule in the advancement of strawberry ripening which was proved by the study [20]. Downregulation of FaNCED1 (9-cis-epoxycarotenoi dioxygenase, a key gene in ABA biosynthesis) inhibits ripening. A recent study showed that ABA biosynthesis is firmly connected by response and forward loops to limit ABA contents for fruit growing and to rapidly raise ABA contents for the commencement of fruit ripening [21]. To summarize the role of ABA in strawberry ripening, the expression of ABA-related genes significantly increases, and the hormone regulates many ripening-related metabolic pathways.

Gibberellic acid (GA) plays in the regulation of the growth of non-climacteric fruits, especially strawberries [6]. The expansion of receptacle cells during fruit development is coordinated by endogenous GAs. Among the bioactive GAS (GA1, GA3, and GA4), GA1 and GA4 are the most abundant in the early stages of strawberry fruit development and drop to lower levels as the fruit ripens. Exogenous treatment of GA3 retarded red color development and the loss of fruit firmness throughout the ripening period was significantly reduced in strawberry cultivars [22]. In a recent study, the application of GA3 affected the fruits quality of strawberries by changing organic acid and individual phenolic compound composition [23].

Although strawberry is known as climacteric fruit, ethylene could play a role at early stages of fruit ripening in strawberries [24]. Initially, an increase in FaPG1 gene expression was found in response to ethylene [25], and in later studies, several other genes, such as FaPG1, FaGal1, and FaGal2, were involved in cell wall modification were found to be modified by ethylene application [26]. Exogenous ethephon treatment increased the expression of biosynthesis and signaling genes, FaERF2 and FaACO1, and influenced the phytochemical profile of phenolic compounds, vitamin C contents, anthocyanins, and sugars [27]. Studies have shown that ethylene elicitors or inhibitors affect some significant feature qualities in strawberry fruits, including firmness [28]. Different hormonal treatments differentially affected hemicellulose metabolism during strawberry fruit ripening and under postharvest conditions. For example, postharvest 1-methylcyclopropene treatment up-regulated FaXynA and FaXynC expressions [29]. The physiological consequences of ethylene on strawberry fruit have been shown to depend on the developing phase of the fruit [30]. Up-regulation of ethylene-responsive transcription factor, ERF105-like gene is significantly induced under cold stress, showing that ethylene could also play an important role in abiotic stress resistance in strawberries. Although ethylene appears to be involved in a secondary role compared to abscisic acid in non-climacteric strawberry ripening, this does not disregard that ethylene may adjust some certain occurrences linked to the ripening progression.

Polyamines (PAs), ubiquitous aliphatic amines and biogenic regulators present in all living organisms, are involved in many developmental and physiological processes involving plant aging, stress, and plant growth [31]. The content of spermine (Spm) rises strongly following the commencement of fruit coloring to red, and Spm is the dominant component of the ripe strawberry fruits. The predominance of spm in ripe fruit over other PAs is due to abundant expression of the strawberry S-adenosyl-L-Met decarboxylase gene (FaSAMDC), which encodes an enzyme that produces a residue required for PA biosynthesis [32]. Polyamine oxidase 5, FaPAO5, negatively adjusts strawberry fruit ripening, as down-regulation of FaPAO5 stimulated Spd, Spm, and ABA amassing, which ultimately enhanced ripening. The opposite results were shown in FaPAO5-overexpressing in the same study [33]. The results showed that FaPAO5 plays a role in the terminal catabolism of Spd and Spm. Application of putrescine (PUS) reduced the adverse effects of osmotic stress of the nutrient solution and increased plant resistance against salt stress, showing that PAs are important regulators against abiotic stress conditions [34].

3. Plant-parasitic nematode problems on strawberry plants

Several pathogens and pests cause damage to strawberry plants. Several plant-parasitic nematodes damage strawberry plants that some feed on roots, others in foliar parts. Parasitic nematodes cause yield losses, crop size, and quality [35]. Many kinds of research have been conducted on Strawberry nematodes.

More than 4000 plant-parasitic nematodes are found on the earth [36]. In strawberry (*Fragaria x ananassa* Duch.) from soil and foliage, plant-parasitic nematodes are present in 10 genera and 15 species belonging to the order of Dorylaimida and Tylenchida [37]. *Xiphinema pachtaicum*, *Meloidogyne hapla*, *Aphelenchoides ritzemabosi*, *Criconema nutabile*, *Pratylenchus microdorus*, *Ditylenchus dipsaci*, *Longidorus caespiticola*, *Meloidogyne arenaria*, *Longidorus elongates*, *Pratylenchus penetrans*, *Helicotylenchus dihystera*, *Paratylenchus pseudoparietinus*, *Aphelenchoides besseyi*, *Tylenchorhynchus claytoni*, *Aphelenchoides fragariae*, are plant-parasitic nematodes in strawberry fields in the soil in Bulgaria [37]. *P. penetrans* is cause reddish-brown lesions on roots and increase fungus infections in the roots of strawberry [38]. *Aphelencoides fragariae*, *Aphelencoides ritzemabosi M. hapla*, *M. arenaria*, and *P. penetrans* species cause severe damage in strawberry fields and need to be controlled [37]. The virus vector nematodes: *Longidorus Criconemoides*, *Helicotylenchus Tylenchorhynchus* are frequently found in strawberry fields [37]. The root-knot nematodes, genus *Meloidogyne* Goeldi, are the most challenging in strawberry cultivation [39]. A sting nematode, *Belonolaimus longicaudatus,* is also one of the most damaging nematodes in strawberry plants [39–41]. *Aphelenchoides fragariae*, *M. hapla*, *Aphelenchoides besseyi*, *Aphelenchoides bicaudatus*, *Aphelenchoides ritzemabosi*, *Ditylenchus dipsaci*, *Longidorus elongatus*, *Meloidogyne javanica*, *Criconemella onoensis*, *Meloidogyne incognita*, *Helicotylenchus dihystera*, *Pratylenchus penetrans*, *Pratylenchus brachyurus*, *Xiphinema*, *Pratylenchus vulnus* and *Pratylenchus zeae* in Brazil [42–45].

Incidence and population density are *Aphelenchoides fragariae* (34–98), *Aphelenchoides ritzemabosi* (23–70), *Aphelenchoides besseyi* (8–11), and *Ditylenchus dipsaci* (8–16) in strawberry 15 g leaves of plant tissues [37]. Some major species of Strawberry in the USA are *M. hapla, A. besseyi, B. longicaudatus, A. fragariae,* and *P. penetrans* [39–41, 46]. Nematode existence incidence and density are vastly variable that *M. hapla* 55–125 nematodes/100 cm^3 soil) and for *M. arenaria* (14-61nematodes/100 cm^3) in Bulgaria [37].

Meloidogyne spp. is the utmost major species of plant-parasitic nematodes on strawberry plants in Egypt, and *Aphelenchoides* sp. may exceedingly decrease strawberry yields [35]. The second stage of *Meloidogyne* species is the infective stage of nematodes and J2s penetrate plant roots, modify cell development, and cause root gall formation. During the nematode infection, nematode feeds on those cells termed giant cells, and females of root-knot nematodes develop within the galls [47–49]. Root-knot nematodes cause root galls in plants [47].

Pratylenchus species also damage strawberry plants. They are migratory nematodes that cause root lesions when they enter and migrate completely throughout the roots [49]. Nematodes cause damage to reducing roots, and nematodes absorb water and nutrients [49] and therefore decrease plant growth, shorten the crop cycle, decrease production, and cause leaf drop [39]. *Pratylenchus penetrans* is also a noteworthy nematode that is related to the occurrence of a disease that causes strawberry root rot [50, 51].

Some nematodes cause damage to others in the foliar part of strawberry, and they may be found in different densities in many countries. Plant-parasitic nematodes in the soil of strawberry plant may found as: *Helicotylenchus* (421.3 nematodes/100 cm^3 of soil), *Scutellonema* (1.0 nematodes/100 cm^3 of soil), *Meloidogyne* (3.9 nematodes/100 cm3 soil), Hemicycliophora (5.3 nematodes/100 cm^3 soil), *Ditylenchus* (0.3 nematodes/100 cm^3 soil), *Pratylenchus* (1.4 nematodes/100 cm^3 soil), *Xiphinema* (0.4 nematodes/100 cm^3 soil), *Trichodorus* (0.2 nematodes/100 cm^3 soil) and *Mesocriconema* (0.2 nematodes/100 cm^3 soil) in Brazil [52]. Root-knot nematodes: *M. javanica*, *M. arenaria*, *M. incognita, M. hapla,* and other nematodes: *A. fragariae, P. penetrans, Hemicycliophora* spp. and *D. dipsaci* are found in strawberry fields in Spain [53, 54]. *A. fragariae, D. dipsaci, Criconemoides morgensis, Hirschmanniella imamure, Meloidogyne arenaria, P. penetrans, H. dihystera, Tylenchorhynchus claytoni, Psilenchus hilarulus,* and *M. incognita* are found, but the root nematodes: *M. arenaria* and *M. incognita* are utmost common species among them in strawberry fields in Korea [55]. Similarly, the species of *Pratylenchus, Xiphinema, Helicotylenchus, Rotylenchus,* and *Ditylenchus* are associated with strawberries [56].

Some strawberry cultivars can be resistant or susceptible to nematode species. The cultivars: San Andreas, Monterey, Camino Real, Oso Grande, Aromas, and Albion) are resistant to *M. incognita, M. javanica, Pratylenchus zea,* and P. *brachyurus*. However, some strawberry cultivars, such as Camarosa are susceptible to *M. hapla* and *M. arenaria* [57].

4. Fungal disease on strawberry plants

Colletotrichum acutatum and *Botrytis cinerea* are the most common pathogens in the strawberry field. Among the fungal pathogens, *B. cinerea* causes significant economic losses in the strawberry industry. In wet conditions, more than 80% of strawberry flowers and fruit can be lost if plants are not sprayed with fungicide [58, 59]. Strawberry quarantine agents include *Colletotrichum acutatum, Botrytis cinerea,* and *Phytophthora* spp. It is included in the EPPO A2 list, but as of 2015, only *Phytophthora fragariae, Verticillium dahliae, Verticillium albo-atrum,* and *Fusarium oxysporum* are included in the final A2 list [60].

Common Leaf spot (*Mycosphaerella fragariae* [Tul.] Lindau): The leaf spot pathogen, *Mycosphaerella fragariae, also* recognized as Mycosphaerella leaf spot, "rust or white spot. This disease starts on leaves as purplish spots that look like leaf scorch. Plant vigor, fruit quality, and yield are reduced by leaf spot disease [61]. Typical symptoms are on the leaves small and circular leaf spots. Leaf lesions start as small, deep purple, irregular-shaped necrotic spots on the upper leaf surface. *M. fragariae* also causes spots on fruit, petioles and cause black seeds. Plants are mostly susceptible early in the growing season. Spores of the fungus form on the spots and are spread by rain, by farm implements, or on hands when plants are wet [61, 62]. The use of resistant varieties is the utmost practical and efficient method to control leaf spot disease. Timely applications of protective fungicides and non-infected nursery plants are suggested (**Figure 1**) [63].

Antracnose (*Cercospora fragariae*): Anthracnose leaf spot disease of strawberry which caused by *Colletotrichum acutatum, C. gloeosporioides,* and *C. fragariae* species. Lesions are circular, irregular purplish/reddish, with very light-colored centers seeming merely on the upper surface and small. The spots look like usual leaf spots (caused by *M. fragariae*) but are tinier with lighter centers and further uneven shapes [64]. Lesions are dark brown, almost black, and slightly sunken on petioles and fruit. Spore production appears on the leaf, in the white centers, which develop dotted with tiny dark stroma or knots of fungal cells. Infested buds and flowers may become dry and weakened. Spread of pathogen inoculums by rain and by irrigation as well as by movement of farmer beings and animals [65]. The control of leaf spots is very difficult; fungicides may not be very effective against anthracnose of strawberries. Anthracnose can be lessened using disease-free nursery plants and elimination of infected fruit and plants from fruiting fields followed by prompt fungicide applications subsequently each rain period. In addition, resistant cultivars should be used (**Figure 2**).

Powdery Mildew (*Sphaerotheca macularis f.sp. fragariae*): Powdery mildew, caused by the fungus *Sphaerotheca macularis f.sp. fragariae* results in purplish or reddish blotches on leaves and sometimes a powdery growth. This fungus is an obligate pathogen and survives only in the living tissues of its host. This pathogen affects all aboveground parts of (leaves, flowers, etc.) the strawberry plant. In susceptible cultivars, white Powderly mycelium mass develops on the lower leaf surface. Flowers and fruit in all stages of development are susceptible to attack. Infected mature fruit remains soft and pulpy. The major effect of this pathogen is that it weakens plants and reduces yields [61, 66, 67]. The application of protective fungicides is an effective method

Figure 1.
*Symptoms of common leaf spot (*Mycosphaerella fragariae *[Tul.] Lindau) in strawberry leaves.*

Figure 2.
*Symptoms of Antracnose (*Cercospora fragariae*) in strawberry plants.*

of control. In addition to controlling powdery mildew, to use of resistant cultivars recommends. Farmers should prefer plantings with disease-free plants and mowing as suggested to remove infected plants (**Figure 3**) [68].

Gray Mold (*Botrytis cinerea*): Gray mold caused Botrytis cinerea by is a significant disease in strawberry production, which utterly affects the yield and quality of strawberries. *B. cineria* affects fruit in the field, storage, transport, and market. This pathogen is also known as 'Botrytis rot fruit' which causes huge losses in the field (more than 80% loss) during rainy and cloudy periods, just before or during harvest and storage [69]. *B. cinerea* can live in soils such as sclerotia or mycelium. Infection usually begins in fruits that come into contact with the soil. Gray mold affects flowers and green or mature fruit. Infection begins in the flower and may enter the calyx or stem, later causing fruit rot [61]. Control measures that can be taken to diminish losses due to Botrytis fruit rot contain preventing excessive vegetative growth by regulating plant density, removing diseased fruits from the field, timely fertilization, harvesting the fruit before it is fully ripe to prevent injuries, and rapid transfer of the harvested fruits to the cold storage. Protective fungicide application is recommended during the flowering period (**Figure 4**) [70].

Fungal disease also damages the roots of strawberries. *Rhizoctonia solani, Fusarium oxysporum, Pythium* sp. cause root rot disease in strawberries. In addition to the difference in the disease factor in a region, factors such as root rot formation, accumulation of soil water, oxygen deficiency in the soil, and temperature were also found to be efficient in the growth of the disease [71]. Roots die as a result of prolonged water accumulation in the soil. Instead of these roots, short thick new rootlets are formed [71]. Root rot disease agents (*Rhizoctonia solani, Fusarium oxysporum, Pythium sp*.)

Figure 3.
*Symptoms of powdery mildew (*Sphaerotheca macularis f.sp. fragariae*) in strawberry plants.*

Figure 4.
*Symptoms of Gray Mold (*Botrytis cinerea*) in strawberry fruits.*

cause stagnation in development, shrinkage of leaf surfaces, shortening of leaf stalks are in the form of drying of leaves and wilting of plants as the disease progresses. In the sub-soil part, due to the disease, the hairy roots quickly turn black and rot. Easily peeling of the bark is one of the most typical features of the disease [71]. When the roots are damaged, there is a pause in plant growth, shortening, and shrinking of the leaves. As the disease progresses, the main roots turn black and rot. With the intense death of the hairy roots, the plant loses its vitality and efficiency and dies suddenly [71]. Macrophomina crown rot (*Macrophomina phaseolina)* is also an important strawberry disease that causes plant stunting, drying of older leaves, wilting of leaves, and discoloration, which are some of the symptoms in strawberries plants [71].

Phytophthora Crown Rot of Strawberry (*Phytophthora cactorum*) causes the collapse of plants, and dark red discoloration of the crown is seen. Plants are stunted, or young leaves are wilted as initial symptoms, the disease progresses, widespread necrosis appears that is homogeneously brown in tissues [71].

5. Bacterial disease on strawberry plants

Xanthomonas fragariae and *X. arboricola* pv *fragariae* are important diseases of strawberries.

5.1 *Xanthomonas fragariae* (*Xf*) Kennedy and King, 1962, Bacterial angular leaf spot

Angular leaf spot is a potentially threatening disease of strawberry. The causative agent was identified as *Xanthomonas fragariae* and was firstly reported in the USA [72]. *Xanthomonas fragariae* is regulated as a quarantine organism in most EU countries [73]. The disease starts with small water-soaked blotches on young leaves. These symptoms form angular spots. These spots are usually bordered by small veins. Observing the lesions appear dark green under light, but using transmitted light, they become translucent. In high humidity and high-temperature conditions (over 20°C), a sticky bacterial ooze forms on the leaves. Disease lesions may coalesce as they grow and then appear as irregular stains on the upper side of the leaf. Reddish-brown lesions then become necrotic. Vascular tissue in the trunk may also be infected [74]. Bacteria cause latent infections by moving systemically via the vascular system of the plant [75]. Infected plants become less productive. The disease can result in up to 10% crop loss in strawberry yield. Plants may even die in severe infections [76]. Plants that are infected systemically produce the first infected leaves, and they served as the primary inoculum source in newly planted fields [77]. Disease symptoms may be confused with fungal diseases such as *Mycosphaerella fragariae* and a new pathovar of *X. arboricola* pv. *fragariae* [78]. *Xanthomonas fragariae* overwinter in plant debris by serving as the source of infection. The bacterium is resistant to desiccation and can easily survive on dry leaves in the soil but not independently in the soil. It creates a secondary infection in moist conditions. Infection of plants occurs both passively and actively. It is spread through rain, irrigation water. Daytime temperatures of around 20°C and cold nights, combined with high humidity or the presence of water, provide a favorable environment for infection and disease to develop [79]. Bacteria may survive for up to 2 weeks on metal and wood materials. That is why agricultural machines may carry the pathogen during an important period of time if not suitably disinfected. Machinery contamination with the bacterial ooze may cause the spread of *X. fragariae* infections [80]. *X. fragariae* is gram-negative bacterium. It is rod-shaped (0.4 × 1.3 μm size), non-spore-forming, and non-capsulated bacterium. Most cells of the bacterium are non-motile, but some of them have a single polar flagellum. Colonies are circular, entire, convex in shape, and glistening, translucent to pale-yellow on beef-extract-peptone agar [81]. Direct isolation of the bacterium on artificial nutrient media is difficult because of very slow growth. Wilbrink's medium with nitrate (Wilbrink-N) is recommended for the most suitable growth medium for isolation of the bacteria [82, 83]. Rapid screening tests based on serological (e.g., indirect immunofluorescence, (ELISA), and molecular methods are used in diagnosis. For confirmation of diagnosis, positive results in serological and molecular tests should be obtained. Several polymerase chain reaction (PCR) detection tests have been improved targeting diverse loci of the bacterial genome [84, 85]. To approve the incidence of *X. fragariae* in symptomatic plant material and latent *X. fragariae* infections and several of these tests have also been used [84–90]. Planting using certified disease-free propagation material is recommended for preventing disease occurrence [91]. Using immune strawberry cultivars such as *F. moschata* instead of susceptible ones (*Potentilla fruticose, P. Glandulosa, F. vesca,* and *F. virginiana*) is recommended [92, 93]. Eliminating infected leaves is important to reduce inoculum sources of bacteria. Copper compounds can be used for the chemical control of *X. fragariae*. Because of resistance established by the bacterium, these compounds must be applied at higher concentrations [84, 91]. Streptomycin and oxytetracycline antibiotics have shown efficacy, but these treatments are not largely registered because of high cost and resistance problems. Induction of systemic resistance using analogs of salicylic acid is also another meaning of control, but still, new developed efficient methods are needed to control angular leaf spot disease of strawberry [84, 91].

5.2 *X. arboricola pv fragariae*, Bacterial leaf blight

Bacterial leaf blight disease is caused by *X. arboricola pv fragariae* (*Xaf*). The disease was first observed on strawberry plants in northern Italy in 1993 [94]. The causative agent was reported as a new pathogen [95]. *Xaf* was determined as a quarantine organism in 2002 [96]. In 2007, it was removed quarantine list by EPPO (The European and Mediterranean Plant Protection Organization) [97]. *Xaf* reported on strawberry plants in Turkey [98]. Both *Xaf* and *X. fragariae* were reported to cause angular leaf spot or bacterial leaf blight symptoms infections on strawberry tissue [99]. Early leaf lesions of *X. arboricola* pv *fragariae* were not water-soaked on the contrary of *X. fragariae*. Disease caused dry, brown leaf spots. These lesions are large brown colored and V-shaped along the leaf margin and veins. İnfected leaves completely become wilted and turn completely yellow colored. The disease did not affect flowers, peduncles, or fruits of strawberry plants [100]. *X. arboricola* pv *fragariae* (*Xaf*) is gram-negative bacterium. The bacteria are obligate aerobes. On NA growth medium, colonies are yellow, glistening, circular, convex, 1 mm diameter. On YPGA-medium, colonies are yellow, glistening, mucoid, convex, or pulvinate, 1–3 mm diameter. Bacterial cells are 1.7–1.9 μm length, 0.5–0.65 μm width in size. Bacteria causes soft rot of potato slices. It is negative in the arginine dihydrolase test and positive in inducing HR on tobacco plant. The maximum growth temperature was determined as 39°C. Assimilation of glycerol, D-trehalose, L-glutamic acid, maltose, L-fucose, succinic acid, cellobiose, Tween-80, and D-galactose are determined as positive. *Xanthomonas arboricola* pv. *fragariae* is positive in the hydrolyzation of gelatin, esculin, and starch. Molecular (Real-time PCR assay) and Serological (indirect immunofluorescence, ELISA) tests are developed for the detection of strawberry bacterial blight pathogen (*Xaf*). PCR test (Xaf pep) was designed by replicating the pep-prolyl endopeptidase gene region (unique to Xaf) [101]. There is no effective control method of X. *arboricola* pv *fragariae* (*Xaf*). Because of the latent infections, routine testing of strawberry plant propagation material is recommended for preventing possible disease occurrence [98].

6. Pests on strawberry plants

Many pests damage strawberry plants and important pests are included in this section.

Frankliniella occidentalis Perg., *F. intonsa* Trby. (Thysanopthera: Thripidae): *Frankliniella occidentalis* and *F. intonsa* are thought as the dominant species in strawberry fields. Depending on the temperature, it can give 22 offspring per year. After the thrips spend the winter on the soil and various plants as adults, they pass to the strawberry with the formation of flower buds. In particular, flower-time populations are increasing [102]. They begin to feed with the opening of flower buds in strawberries. They damage the strawberry flower and fruit by absorbing the plant sap. As a result of suction, flower drop, low yield, small and seed fruit formation, and tanning are observed. Fruits become deformed and lose their market value [103].

On the other hand, it causes secondary damage by infecting viruses such as Thrips stylets and Tomato Spotted Wilt Virus [104]. Since it reaches a high population in a short time, there are difficulties in chemical control [103]. Weed cleaning is important in strawberry fields as a cultural precaution in the control of thrips. *Orius sp.* (Both: Anthocoridae), *Coccinella septempunctata* (Col: Coccinellidae), *Syrphus sp.* (Dip: Syrphidae), *Chrysoperla carnea* (Neur.: Chrysopidae), *Adalia bipunctata* (Col: Coccinellidae) are known. The most effective predator is *Orius sp.* has been reported. Chemical control should be done when 10 thrips/flower is determined in the flower counts in strawberry fields [102].

Tetranychus urticae and *T. cinnabarinus* are some of the most common pests on strawberries (**Figure 5**).

Common names of them are used as two-spotted spider mites or greenhouse red spider mites [105]. With the warming of the air in the spring, the spider females, which pass from the surrounding weeds to the strawberries, lay their eggs in the web they weave on the lower surface of the leaves. Therefore, the density of the networks gives information about the population. Small yellow spots and tanning are seen on the damaged leaf because of feeding by the red spider. A female can lay 100–150

Figure 5.
Adults and nymphs of Tetranychus urticae *(left) and* T. cinnabarinus *on strawberry plant and* Tetranychus urticae *adult and egg on strawberry plant (right).*

eggs in her lifetime. It completes one offspring in 10–20 days. The strawberry plant is controlled, and the damaged leaves are removed from the environment as a cultural precaution. It can be counted as controlling weeds on the edge of the garden. Biological control of *P. persimilis, Neoseiulus fallacis* (Garman) (Acari: Phytoseiidae), *Neoseiulus californicus* (McGregor), and *Galendromus occidentalis* (Nesbitt); are crucially important [106–108].

Anthonomus rubi Herbst (Coleoptera: Curculionidae): Adults of *Anthonomus rubi,* which started to appear from the flower bud period of strawberries. It especially feeds on the young leaves and flowers of strawberries. Females lay 1 egg in an unopened bud. During egg-laying, it pierces the flower stem and prevents the circulation of the sap [105]. The flower bud it lays eggs does not develop, dries up, remains on the branch, and finally falls. This form of damage is unique to *A. rubi*. The main damage is caused by females cutting the flower bud stalks while laying eggs and feeding the larvae inside the bud. The egg hatches after 5–10 days. The larval period is 14–20 days. The pupal period is about 8 days [105]. Adults emerge by piercing the flower buds at the end of June and mid-July. After feeding for a few days, it enters the summer-winter diapause; the pest gives 1 offspring per year. In high populations, bud damage can be 5–90%, and yield loss can be 60% or more. The damage rate is higher in early varieties. The main host is strawberry. Raspberry, blackberry, rose, and wild rose from the Rosaceae family are other important hosts [105].

Phytonemus pallidus (Banks): *Phytonemus pallidus* (Banks) is a pest that causes serious yield losses in strawberries [109]. It causes damage by feeding on the newly emerging young leaves, especially in the crown of the strawberry plant (**Figure 6**). Hardening, wrinkling, discoloration, and a brittle structure are observed in the sucked leaves. An increasing population is stunted and decreases both in size and number of fruits [109]. However, it can cause the death of the strawberry plant [109].

Each female individual lays approximately 90 eggs under suitable conditions and becomes an adult from an egg in 2 weeks [109]. For this reason, it can reach dense populations in a short time. As a cultural precaution in control, using healthy plant material and alternating. It is important to pay attention to the cleanliness of the garden. Strawberry plants should be examined in the spring, especially young and mature leaves. The control method should be decided according to the population situation. In its biological control, *Amblyseius cucumeris* and *A. reticulatus* Oudemans (Acarina: Phytoseiidae) species are effective in reducing the population as predators [109]. If an average of 10 individuals per leaf is detected, recommended plant protection products should be used [110].

Figure 6.
Phytonemus pallidus *(banks) on strawberry plants.*

Lygus spp. (Hem.: Lygaeidae): *Lygus elisus* (Van Duzee), *L. hesperus* (Knight), and *L. lineolaris* (Palisot de Beauvois) have been reported as species that cause extensive damage to strawberries [109]. These species are polyphagous species that damage flowers and young fruits in strawberries. Deformations and formation of seeded strawberry fruits are seen in damaged fruits. Strawberries lose their market value in dense populations and cause great economic losses. Lygus population is more concentrated in strawberry fields with weeds. The pest, which spends the winter as an adult, gives 3–4 offspring depending on the conditions during the year. It takes 30–40 days from egg to adult. In the cultural control, foreign vote control should be carried out around the strawberry production area, and plant protection products should be used, which are recommended by paying attention to the pest population in the controls made before flowering in the chemical control [110].

Spodoptera littoralis (Boisduval) (Lepidoptera: Noctuidae): It is an important polyphagous pest species commonly found in the world [111–114]. Although the main host of the pest is cotton, it can cause economically significant losses in many industrial and field crops, vegetables, and fruits [112–116]. They damage the leaves and fruits of the strawberry. Especially in the case of products such as cotton and corn around the strawberry field, it causes an increase in the pest population [115].

Chaetosiphon fragaefolli (Hom.: Aphididae): In general, adults and nymphs of Aphids live in colonies near the veins in the crown, fresh shoot, leaf, and underside of the strawberry [109]. Adults and nymphs of aphids feed by sucking plant sap on strawberry leaves [109]. As a result of feeding, damage in the form of curls, deformities, and yellow spots occurs on leaves and fresh shoots. These pests spend the winter in the egg period they lay on the branches and shoots of fruit trees.

Chaetosiphon fragaefolii spends all stages of its life on strawberries, including overwintered eggs, nymphs, wingless adults, and winged adults [105]. In addition, they cause fumagine by the development of saprophytic fungi on the sweet matter they secrete during feeding. By covering the plant surface with fumagine, the respiration of the plant is prevented. As a result of the inhibition of plant respiration, the development of the strawberry plant is weakened. As a result of adversely affecting plant development, yield and quality loss occur. For this reason, strawberry loses their market value. Cytorhabdoviruses such as strawberry aphid, Strawberry crinkle virus (CV), and Strawberry mild yellow edge virus (MYEV) cause significant damage by infecting healthy plants [117–119]. The main hosts of strawberry aphids are wild and cultivated strawberry plants (*Fragaria spp.*, *Potentilla anserina*, *F. virginianana, F. vesca*). In its control, clean seedlings should be used in the greenhouse and in the open field as cultural measures, Aphid-infested plants and weeds should be cleaned, Plant stems and weeds remaining on the ground after harvest should be destroyed. In terms of biological control, species of predators, especially Coccinellidae, Chrysopidae, and Syrphidae families, parasitoids *Aphidius spp.* are important natural enemies. Chemical control should be decided according to the population density [105].

Leafhopper (Cicadellidae): These species, which are polyphagous pests, cause damage by absorbing the plant sap from the vascular system of the plant. The toxic saliva they secrete causes injury to the plant. Short petiole and small leaf formation are seen in the damaged strawberry plant [109]. In addition, deformations in the mid-vein angle of the leaves are observed. These symptoms can be confused with Strawberry vein banding virus symptoms, but they are not the harmful Strawberry vein banding virus vector. Control: Leaf surface can be checked by visual inspection method, adults can be detected with methods such as sweep net, yellow sticky trap. In case of increased density, recommended insecticides can be used [109].

Cercopidae families of some species cause serious damage in areas with high humidity. Nymphs surround themselves with this substance by secreting a white foamy substance 1–2 cm wide. The pest that takes its name from this substance causes serious production losses [109]. If the pest is not controlled, the damage will continue until the harvest. Nymphs pierce plant roots and feed on plant sap. After feeding on the roots, it moves towards the green part of the strawberry. As a result of the feeding of nymphs, plant growth stops, small, irregularly shaped fruit formation is observed in strawberries. It causes a loss in yield. Insecticides should be used for chemical control [109].

Otiorhynchus spp., (Col.:Curculionidae): *Otiorrhynchus spp.* They lay their eggs on the soil surface, and the hatched larvae feed on strawberry roots and cause damage. *Otiorrhynchus spp*. Larval damage rate increases in sandy soils and plastic mulching. Adults also feed on strawberry leaves. Strawberry damaged because of feeding weakens, bushes, fades, and eventually, the plant dies. On the other hand, Black root rot pathogen infection can be seen in the feeding area [109]. As a cultural precaution in its control, it should avoid growing strawberries in contaminated areas. Plastic mulching should be avoided as it increases larval damage. Chemical control should be carried out in line with the recommended practices [110].

Various soil pests feed on the roots of strawberries and can cause plants to wilt and dry out. Among these pests (*Agriotes spp.), Tipula spp*. (leatherjackets), (Melolonthidae), centipedes (eg *Scutigerella spp.*), (*Agrotis spp.)* and (Noctuidae spp.). In order to decide on the control, it is necessary to have information about the populations of these pests in the soil. Strawberry plants can be recommended to be cultivated and ventilated before planting. Recommended insecticides should be used in chemical control [110].

In general, snails feed on plants at night and hide among plant wastes in the garden during the day. As a result of feeding, small and medium-sized deep holes are formed in ripe strawberry fruits. This sign of damage can be confused with other insect pests [109]. Generally, these holes are seen in silver color in snail damage. Snails generally become active depending on the soil temperature. Suitable for snail development in humid weather conditions. Elimination of favorable conditions for its survival as a cultural precaution in its control helps in the control of this pest. For example, rocks, wood, leaves, dry leaves, and excessive mulching provide shading. Fermented food traps and commercial food traps are used as biotechnical control [109].

Drosophila suzukii Matsumara 1931 (Dip: Drosophilidae): *Drosophila suzukii* is a polyphagous pest that was first identified in Japan in 1916. It damages all fruits with a soft structure, such as strawberries, during ripening and harvest [120]. Female individuals can easily lay eggs on the strawberry fruit, especially with their saw-like ovipositor (**Figure 7**). The larvae that emerge from the eggs feed on the fruit flesh of the strawberry and cause the main damage to the fruit (**Figure 7**). The larvae complete their development and become pupae on or outside the strawberry fruit. Later, adults emerge from the pupae (**Figure 7**). Damaged strawberry fruit.

softens and collapses (especially when you touch it, it feels empty) and loses its market value (**Figure 7**). The pest can multiply rapidly in a short time and reach a high population. *Drosophila suzukii* emerges from egg to adult in 8 days at 25°C. An average female lays 400–600 eggs [121]. Irrigation should be done with a drip irrigation system in gardens. Equipment that may cause the spread of the pest to other places should be kept clean [105]. Biological control: *Anthocoris nemoralis* (Hemiptera: Anthocoridae) and *Orius spp.* (Hemiptera: Anthocoridae) and as pupal parasitoids, *Pachycrepoideus vindemmiae* (Pteromalidae) and *Trichopria drosophilae* (Diapriidae) are known to be effective on *D. suzukii* population [105]. Biotechnical Control: Traps should be hung from the time of Strawberry Fruit coloration. As traps, 8–10 holes with a maximum size of 3 mm are drilled on 0.5 lt transparent plastic containers. 100–300 ml of apple cider vinegar is put into the plastic container. Strawberry is hung on its habitus with the help of support. Insecticides recommended for chemical control should be used [105].

Figure 7.
Drosophila suzukii *ovipositor structure and egg (left),* Drosophila suzukii *female and male adult individuals (middle), Drosophila suzukii damage and larvae in strawberry (right).*

7. Weeds in strawberry fields

As with other plants, strawberry like soil rich in water, air, nutrients, and organic matter. Therefore, the well-cultivated soil is an advantage for the development of weeds. Weeds are a serious problem, and weed control is one of the biggest challenges for strawberry growers. Because strawberry plants grow relatively slowly and are weak competitors, weeds can quickly invade strawberry fields [122]. Numerous annual and perennial weeds species cause damage to strawberry plants (**Tables 1** and **2**) [122].

Scientific name	Family	References
a. Annual broadleaf weeds		
Amaranthus retroflexus L.	Amaranthaceae	[122]
Amaranthus albus L.	Amaranthaceae	[122]
Anagallis arvensis L.	Primulaceae	[122]
Capsella bursa- pastries (L.)	Cruciferae	[122]
Chenopodium spp.	Chenopodiaceae	[122]
Euphorbia sp.	Euphorbiaceae	[122]
Fumaria spp.	Papaveraceae	[122]
Galium aparine L.	Rubiaceae	[122]
Geranium spp.	Geraniceae	[122]
Heliotropium spp.	Boraginaceae	[122]
Lactuca serriola L.	Composetea	[122]
Lamium amplexicaule L.	Labiatae	[122]
Malva sylvestris L.	Malveceae	[122]
Matricaria chamomillia L.	Composetea	[122]
Melilotus officinalis L. Ders.	Leguminosae	[122]
Oxalis sp.	Oxalidaceae	[122]
Polygonum aviculare L.	Polygonaceae	[122]
Polygonum persicaria L.	Polygonaceae	[122]
Portulaca oleraceae L.	Portulacaceae	[122]
Raphanus raphanistrum L.	Cruciferae	[122]
Rumex sp.	Polygonaceae	[122]
Silybum marianum (L) Gaertn	Composetea	[122]
Solanum nigrum L.	Solanaceae	[122]
Sonchus sp.	Composetea	[122]
Stellaria media (L.) Vill.	Caryophyllaceae	[122]
Tribulus terrestris L.	Zygophyllaceae	[122]
Trifolium spp.	Leguminosae	[122]
Urtica urens L.	Urticaceae	[122]
Vicia spp.	Leguminosae	[122]

Scientific name	Family	References
b. Annual narrow-leaf weeds		
Allopecurus myosuroides Huds.	Graminaceae	[122]
Echinochloa crus gali L.	Graminaceae	[122]
Echinochloa colonum L.	Graminaceae	[122]
Poa annua L.	Graminaceae	[122]
Poa trivalis L.	Graminaceae	[122]

Table 1.
Annual weeds that are problems in strawberry fields.

Scientific name name	Family	References
a. Perennial broadleaf weeds		
Convolvulus arvensis L.	Convolvulaceae	[122]
b. Perennial narrow-leaf weeds		
Cynodon dactylon L.	Graminaceae	[122]
Cyperus rotundus L.	Cyperaceae	[122]
Digitaria sanguinalis L.	Graminaceae	[122]
Sorghum halopense L.	Graminaceae	[122]

Table 2.
Perennial weeds that are a problem in strawberry fields.

Since it is a high-value product, a well-integrated control, that is, cultural, mechanical, and physical control, should be carried out together for strawberry growers for weed control [123]. Crop rotation is an important part of the weed control program in many crops. Since we use different soil treatments and different herbicides when we plant crop plants alternately, it has an important role in the control of annual and perennial weeds [124]. Before using the agricultural tools and machines we use in another area, they should be cleaned, and the transportation of weed seeds should be prevented. A carried weed seed will increase in number and spread exponentially in the following years [124]. Transportation of weed seeds with irrigation water may occur [125]. In order not to carry weed seeds on the sides of the canal to the area where we cultivate, weeds should be controlled, and their transportation should be prevented [124]. Mechanical methods of weed control include manual weeding, hoeing, tillage between rows, and mowing [124]. Black plastic mulch controls most weeds; however, black mulch usually does not warm the soil as much as clear mulch. Clear mulch provides earliness with soil warming, but clear mulch does not control weeds [126].

8. Virus diseases on strawberry plants

Over 30 viruses and virus-like diseases distressing the genus, Fragaria has been reported. Some of these viruses have different races within themselves. Strawberry varieties can cause symptoms of different severity for each race, or these disease agents can be found asymptomatically in plants. While many viruses do not show obvious symptoms in commercial strawberry cultivars, frequently observed symptoms can be observed as plant stunting, crop and yield loss, and dieback. The viruses seen in strawberries can be found in mixed infections, causing reductions in yield and fruit quality, thereby reducing the market value of the product. The most reliable method used to detect the presence of strawberry viruses is the classical molecular and biological method. It is the use of classical clone grafting, aphid transport, and PCR methods on indicator plants of *F. vesca* and *F. virginiana* clones. However, since symptom outputs take 14–21 days in this method, the use of indexing after less time-consuming and reliable methods such as Enzyme-Linked Immunosorbent Assay (ELISA) and Polymerase Chain Reaction-Polymerase Chain Reaction (PCR) helps to obtain more reliable results [127, 128]. Strawberry viruses can be transmitted by aphids, nematodes, and some other vectors, while aphids are the most important vectors. Strawberry aphids known to infect the plants by being carried by *Chaetosiphon fragaefolii* viruses are [129] *Strawberry crinkle cytorhabdovirus* (ScRV), *Strawberry mottle virus* (SMoV), *Tomato ringspot virus* (ToRSV), *Strawberry vein banding virus* (SVBV), *Strawberry pseudo mild yellow edge virus* (SPMYEV), *Raspberry ringspot virus* (RpRSV), *Arabis mosaic virus* (ArMV), *Strawberry latent ringspot virus* (SLRSV), *Strawberry latent C virus* (STLCV), *Tomato black ring virus* (TBRV), and *Strawberry mild yellow edge virus* (SMYEV), which are known to infect the plant by being transmitted by some nematode species, and whiteflies [127, 130–132]. Among the aphid-borne viruses, SCrV, SMOV, SVBV, and SMYEV are the utmost significant viral diseases observed in strawberry production areas [133–135].

Strawberry crinkle cytorhabdovirus (ScRV); The family Rhabdoviridae is included in the genus Cytorhabdovirus. They are positive-sense ssRNA viruses [136]. *Strawberry latent virus*, strains A (mild form), and B and *Strawberry vein chlorosis virus* are synonyms. It is one of the most harmful strawberry viruses worldwide. Severe strains in susceptible varieties cause leaflets to be uneven in size, distorted and wrinkled, resulting in the formation of small irregularly shaped chlorotic spots on the veins. It is on the EPPO quarantine list. The presence of the agent has been reported in Asia, Africa, America, Oceania, and many European Union member countries [132, 137].

SCrV has a limited host variety within the Fragaria species. In addition to cultivated strawberries such as *F. x ananassa*, its presence has also been determined in wild species such as *F. vesca*, *F. virginiana,* and *F. chiloensis* [138]. Nicotiana glutinosa has been reported as experimentally transduced hosts in *Physalis floridana* [139]. SCrV is locally transmitted by the strawberry aphid *Chaetosiphon fragaefolii*. It has been reported that the shoot tip meristem culture method, following the application of temperature (38°C) in obtaining SCrV-free plants, increases the percentage of success in obtaining a virus-free plant [140].

Strawberry mottle virus (SMoV), *Strawberry mottle virus* (SMoV) from the Secoviridae family, is also called *Strawberry mottle sadwavirus*. The presence of the agent has been reported in Asia, America, Oceania, and many European Union member countries. It is one of the most common viruses in many areas of strawberry cultivation in the world. There are many breeds of SMoV; weak breeds are observed as asymptomatic, while strong breeds can cause yield losses of up to 30% Strawberry aphid, *Chaetosiphon fragaefolii*, is the main vector for SMoV, while *Chaetosiphon jacobi* and *C. minor* can also transmit the virus; *C. gossypii* can also carry SMoV. The transport of SMoV occurs semi-persistently within a few minutes during the feeding period [141]. *Fragaria vesca* and *F. virginiana* clones show symptoms at different rates after inoculation with inoculation due to their sensitivity to the agent. While symptom development is observed in *F. vesca* 7–10 days after infection, this period might be lengthier in mild and moderate breeds. In indicator plants, the symptoms are barely noticeable on the leaves, or the leaves may be slightly mottled, severely stunted, and deformations leading to plant death can be observed. In the control of the agent, the use of certified virus-free plants, the fight against aphids, the isolation of infected production areas is important. Since SMoV is one of the most sensitive to temperature among strawberry viruses, it is possible to obtain virus-free plants with the combination of thermotherapy and meristem culture. It has been reported that 2–3 weeks of thermotherapy is sufficient to obtain SMoV-free plants [127].

Strawberry vein banding caulimovirus (SVBV); the virus exists merely in Fragaria spp. Its chief host *is Fragaria vesca*. It can also infect commercial strawberry cultivars, but symptoms are commonly merely seeming when strawberry exists at the same time as the latent *C 'rhabdovirus'* [137]. The agent exists in some countries in Asia, Europe, America and Oceania, and *M. persicae, Macrosiphum rosae, Amphorophora rubi*, *Chaetosiphon fragaefolii, Aulacorthum solani, C. tetrarhodum, C. thomasi, C. jacobi, A. rubifolii, M. ornatus, Aphis idaei*, *Acyrthosiphon pelargonii* have been reported to be vectors of the agent. The most effective vector of these species is *Chaetosiphon* spp. While the virus can be transmitted to indicator plants by inoculation and *Cuscuta subinclusa*, it cannot be transmitted mechanically. Depending on the indicator plant, contamination occurs within 2–5 weeks. Symptoms appear as epinastie on the midrib and petiole on the youngest leaf. Some or all the affected leaves show varying lengths of yellowish vein banding along the main vein. The second and third leaves formed after the commencement of symptoms show more severe symptoms. In the diagnosis of the agent, the UC-12 clone of *F. vesca* and the UC-12 clone of *F. virginiana* are used as the most effective indicators for detecting SVBV. In routine serological testing, the agent is diagnosed using an antiserum specific for SVBV [129].

Strawberry latent C 'rhabdovirus' (STLCV); The agent reported to be in the Rhabdoviridae family has not been defined morphologically. Its presence has been reported in America and Canada [137]. While the agent is usually asymptomatic in cultivated strawberries, in case of mixed infection with other viruses, it can cause moderate to severe leaf deformation such as excessive stunting, curling of leaves, or severe symptoms observed in other viruses with weakening of the plant. In some indicator clones of STLCV *F. vesca*, it can cause severe epinasty and shrinkage in newly formed leaves and petioles, while mild and transient symptoms are observed in other clones. Determination of the presence of the agent can be accomplished by inoculating the agent into clones of *F. vesca* or *F. virginiana* [129]. It has been reported that in the USA, no other virus component in a complex form cause severe stunting in a short time as this factor in cultured strawberries [142].

Strawberry mild yellow edge disease: It has been determined to be caused by a virus complex called *Strawberry mild yellow edge luteovirus* (race or syn; *Soybean dwarf luteovirus*) and *Strawberry mild yellow edge-associated potexvirus* [143]. By itself, it is not the principal pest for most cultivars, but solitary infection rarely occurs. The agent is only Fragaria spp. There are types. While some clones of wild species *F. chiloensis, F. vesca,* and *F. virginiana* show symptoms in nature, *F. ovalis* can carry the agent without symptoms. Many strawberry cultivars are also asymptomatic carriers of the agent. It has been reported that the so-*called Strawberry mild yellow edge-associated 'potexvirus'* virus was experimentally transferred to *Chenopodium murale* and *C. quinoa* but did not remain in the plants for a long time [144].

This disease can be seen in many countries where the strawberry plant is grown. These are Australia, Europe, Israel, Japan, South Africa, and Northwest America. There are different views on economic losses due to the existence of different strains of the virus. However, because of many studies, it has been reported that product loss is between 0 and 30%. It is asymptomatic in cultivated strawberry cultivars [145]. In natural conditions, these two viruses in strawberries have been reported to be spread by the strawberry aphid *Chaetosiphon fragaefolii*. The spread of the disease can also occur with vectors or material spread from tissue culture. There is no information about propagation by seed. It has been reported that the complex of the disease with other pathogens such as *Strawberry crinkle rhabdovirus, Strawberry veinbanding caulimovirus*, *Strawberry mottle agent* [137] can cause serious losses in plant growth, fruit quality, and yield [145]. The control of the virus can be achieved with the use of thermotherapy or meristem culture and certified virus-free production material. Control of vectors is also an important factor in the prevention of disease agents [127, 145].

Viruses Carried by Nematodes; *Arabis mosaic nepovirus* (ArMV); the agent in the Nepovirus genus of the Comoviridae family is also called *Raspberry yellow dwarf virus.* ArMV is an RNA virus with a wide host range. The presence of the agent has been reported in Asia, Africa, America, Oceania, and many European Union member countries [146, 147]. ArMV is an RNA virus with a wide host range. It was observed that 93 species from 28 different families were infected by mechanical inoculation [148]. The main hosts are strawberry, hops, raspberry (*Rubus idaeus*), *Sambucus nigra, Rheum* spp., and *Vitis* spp. The virus has also been reported in sugar beet, celery, gladiolus, horseradish, and lettuce. Several further wild and cultivated species are reported as hosts. ArMV is transmitted by seed by nematodes over short distances [149]. *Xiphinema diversicaudatum* was suspected to carry hop strains of ArMV [150].

In the diagnosis of the agent, some indicator plants are used because they produce typical symptoms. *Chenopodium quinoa* and *C. amaranticolor* produce systemic blotches that follow chlorotic local lesions [151]. *Cucumis sativus* may produce chlorotic local lesions and systemic vascular banding or yellow spots in infected cotyledons. *Phaseolus vulgaris* shows symptoms as chlorotic local lesions, systemic necrosis, and deteriorations, *Petunia hybrida* as local chlorotic lesions, tiny necrotic rings, streaks, or vascular opening. However, these symptoms are more pronounced, especially in the hops variant (ArMV-H). ArMV is mostly seen in mixed infection with *Strawberry latent ringspot nepovirus* (SLRSV), which is also a nematode-transmitted agent [137]. Diagnosis of the agent is mostly made by ELISA. The presence of ArMV in a single nematode can also be detected by electron microscopy. Another way to detect ArMV is to use cDNA clones in dot hybridization tests [152, 153]. Distribution of virus-free production material for the control of ArMV with a strict certification program. In areas with infected nematode-vector populations, fallow and/or soil fumigation for at least a year is required, as replanting virus-free material without additional precautions will be ineffective [149].

Raspberry ringspot nepovirus; *Raspberry ringspot virus* (RPRSV), which is in the genus Nepovirus of the family Secoviridae, is a single-stranded RNA virus. Asia (Kazakhstan, Uzbekistan) and Europe (France, Serbia, Romania, Germany, Norway, Bulgaria, Italy, Greece, Denmark, Hungary, Ireland, Estonia, Latvia, Czech Republic, Luxembourg, Poland, Austria, Finland, Portugal, Belgium, Russia, Spain, Albania, Switzerland, Turkey, Ukraine, England) have also been reported [147, 154]. However, the main host is *Rubus idaeus, Fragaria* spp., Fragaria x ananassa, some Rubus spp., and Prunus spp. species. *Vitis vinifera* is another important host. Experimentally, It has also been reported to be transmitted by *Chenopodium giganteum*, Cucurbita spp., Nicotiana, Petunia spp., *Solanum lycopersicum*, *Spinacia oleracea, Vigna unguiculata* species [155]. The agent can be transmitted to some herbaceous plants mechanically and by infected seeds. RpRSV can be transmitted by both species of the nematode genus Longidorus. Scottish and Dutch variants of RpRSV are most effectively transmitted by *L. elongates* [156], while the English variant is transmitted by *L. macrosoma* [157]. Other nematode species (*Xiphinema diversicaudatum* and other Longidorus species) were suspected to carry variants of RpRSV, but transmissions were not considered acceptable [158]. Although the symptoms of RpRSV in strawberries vary according to the season and the breed of the agent, it can usually result in severe stunting and death. In *Fragaria vesca,* seedlings show yellow spots in the first year of infection but no spots after that. While symptoms vary in susceptible varieties, symptoms are less common in summer at high temperatures. RpRSV causes a serious disease that reduces both growth and fruiting and even kills plants. The use of fumigants such as dazomet or dichloropropane-dichloropropene for vector nematodes in raspberry and strawberry production areas provides prevention and control of virus transmission. Rubus spp., Ribes spp., and Fragaria species, the use of healthy certified production material free from RpRSV are one of the best control methods [127, 159, 160].

Strawberry latent ringspot 'nepovirus' (SLRSV); SLRSV has a very large host range. The agent, which is mostly found latent in berry fruits such as strawberries and raspberries, can sometimes cause infections resulting in mottling and back-drying [161]. It is found naturally in many berry species as well as in cherries, grapes, plums, peaches, *Sambucus nigra*, asparagus, celery, gladiolus, daffodils, and roses, as well as in many wild species, usually asymptomatic [162]. The presence of the agent has been reported in some countries in Europe, Oceania, North America, and in Israel and Turkey from Asian countries. SLRSV can be mechanically transported to herbaceous plants. It is reported that naturally, both larvae and adults of *Xiphinema diversicaudatum* can carry SLRSV for up to 84 days and up to 70% of seed transmission in several plant species [163]. While the causative agent is usually asymptomatic, varying degrees of mottling and retrograde death can be observed in some strawberry cultivars. Reliable diagnosis is possible with SLRSV specific antisera. *Chenopodium murale*, *C. quinoa*, and *C. amaranticolor* show symptoms as systemic chlorosis, necrotic or chlorotic local lesions, and sometimes pale chlorotic mottling or necrosis. Cucumber shows local lesions in the form of systemic intervascular chlorosis or necrosis or shows no symptoms at all. During the summer, the later leaves are asymptomatic but contain the virus, while in the winter, the symptoms may persist on the newly arrived leaves. *Nicotiana rustica*, *Nicotiana tabacum*, and *Petunia hybrida* are infected without symptoms. The virus can sometimes be found in soil together with *Arabis mosaic nepovirus*, which is also carried by *X. diversicaudatum* [137].

9. Conclusion

Several diseases, nematodes, weeds, and pests cause damage to strawberry foliar, roots, and fruits, and are responsible for crop losses. Numerous plant-parasitic nematodes cause damage on strawberry plants that some feed on roots, others in foliar parts. Parasitic nematodes cause yield losses, crop size, and quality. Fungal pathogens such as *Colletotrichum acutatum* and *Botrytis cinerea* are the most common pathogens in the strawberry field and may cause damage to more than 80% of strawberry flowers and fruits. *Xanthomonas fragariae* and *X. arboricola* pv *fragariae* are important bacterial diseases of strawberries. Many pests such as *Frankliniella occidentalis* damage strawberry plants and other important pests are included in this section. Weeds are also a serious problem, and weed control is one of the biggest challenges for strawberry growers. Because strawberry plants grow relatively slowly and are weak competitors, weeds can quickly invade strawberry fields. Other important diseases are viruses and virus-like diseases that some of these viruses can cause symptoms of different severity for each race, or these disease agents can be found asymptomatically in plants. In this chapter, information about diseases, pests, weeds, and nematodes that cause yield loss in strawberry plants are brought together. Thus, it is a significant chapter for the benefit of producers, researchers, and students. It is also important to apply integrated pest management strategies to control diseases and pests in strawberry plant cultivation.

Conflict of interest

The authors declare no conflict of interest.

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