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Review Paper

Grey Mold and *Alternaria* Fruit Rot: Postharvest Diseases of Pepper and Tomato

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ABSTRACT

Pepper and tomato are two of the most important vegetable crops in Serbia. Postharvest diseases affecting these crops can cause substantial losses, especially in Mediterranean and dry temperate regions. With the progression of climate change, the impact of these diseases is expected to increase under local agroecological conditions. This paper is a review of the two most prominent fungal species responsible for postharvest diseases in pepper and tomato: Botrytis cinerea and Alternaria alternata.

Key words:
fruit rot, Botrytis cinera, Alternaria alternata, storage mold

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INTRODUCTION

Pepper (*Capsicum annuum* L.) and tomato (*Solanum lycopersicum* L.) belong to the nightshade family (Solanaceae), with pepper classified within the genus *Capsicum* and tomato within the genus *Lycopersicum*. Although both species originated in the Americas, they are now cultivated globally. Each genus includes numerous cultivars of significant economic value, exhibiting a wide range of shapes, sizes, colors, and flavors. In addition to their culinary versatility, pepper and tomato cultivars are also notable for their high nutritional value and abundance of bioactive compounds with antioxidant properties (Bursać Kovačević et al., 2020). Tomato is particularly rich in carotenoids, especially lycopene, ascorbic acid and phenolic compounds (Pinela et al., 2012; Marti et al., 2018). Pepper is a valuable source of minerals, vitamins, carotenoids, capsaicinoids, and phenolic compounds (Hamed et al., 2019), all of which contribute to beneficial health effects (Borguini and Torres, 2009; Blanco-Ríos et al., 2013).
According to Food and Agriculture Organization (FAO) statistics (FAO, 2024), in 2022, tomato and pepper in the Republic of Serbia were cultivated on 7,863 ha and 10,182 ha, respectively. One of the major challenges in vegetable production is ensuring high-quality yields for both fresh consumption and industrial processing. Fruit deterioration remains a significant concern, often leading to economic losses due to decreased marketability. The postharvest process includes operations aimed at preserving the organoleptic properties and nutritional value of the produce. In vegetables, quality is largely determined by visible traits, including shape, color, and surface appearance. Postharvest practices are therefore essential for maintaining fruit quality and extending shelf life throughout the supply chain (Cristina et al., 2018).
Worldwide, postharvest losses of fresh vegetables are estimated to range between 20% and 40%, constituting a substantial economic burden on agriculture (Henz, 2017). Losses occurring during postharvest handling (estimated between 20% and 25%) are largely due to infections caused by rot-inducing pathogens (Oliveira Filho et al., 2021; Balamurugan and Kumar, 2023).
Postharvest diseases can be broadly classified according to the timing of infection. Latent infections originate prior to harvest but remain dormant until favorable conditions arise, whereas postharvest infections are predominantly

established during or after harvest, with pathogens entering through lesions induced by mechanical damage or insect activity.

In pepper and tomato, common fungal postharvest diseases include grey mold, *Fusarium* rot, *Alternaria* rot, *Cladosporium* rot, *Rhizopus* rot, watery soft rot, and *Sclerotium* rot (Frans et al., 2017). Among these, grey mold caused by *Botrytis cinerea* and *Alternaria* rot caused by *Alternaria alternata* are considered the most significant postharvest diseases affecting these Solanaceous fruits, particularly in Mediterranean and dry temperate climates (Ventura-Aguilar et al., 2021; Shen et al., 2022). In the light of climate change and its potential to increase disease prevalence, the relevance of these pathogens under Serbian agroecological conditions is expected to rise. Therefore, the following sections of this paper focus on these two major postharvest fungal diseases.

Grey mold caused by *Botrytis cinerea* Pers. Fr. [teleomorph *Botryotinia fuckeliana* (de Barry) Whetzel]

Botrytis cinerea Pers. Fr. (teleomorph *Botryotinia fuckeliana* (de Bary) Whetzel) is a necrotrophic pathogen with an exceptionally broad host range, affecting more than 1,400 plant species worldwide (Roca-Couso et al., 2021), and it is a causal agent of grey mold in numerous horticultural crops. This pathogen can infect plants at various developmental stages, including flowering, early fruit development, and maturity, often gaining entry through wounds. Wildly distributed in pepper and tomato in the Balkans, especially in greenhouse production (Figure 1), grey mold can cause significant losses during the vegetation period (Kuzmanovska et al., 2012; Rodeva et al., 2012) as well as during postharvest period (Tzortzakis et al., 2019; Brito et al., 2021; Wang et al., 2022). Tomato fruit rot is a significant disease in semi-arid climate zones during storage and transport (Elad et al., 1995). Moreover, grey mold disease caused by *B. cinerea* is considered as one of the most destructive infections of pepper (Polat et al., 2018), which can cause severe losses (Wang et al., 2022). Yield losses caused by grey mold may exceed 70% in tomato (Kuzmanovska et al., 2012), while in pepper they are estimated at approximately 25% (Naz et al., 2018).

Botrytis can infect all aboveground plant parts. Fruits damaged by growth cracking or other injuries at the calyx end are susceptible to *Botrytis* fruit rot. The diseases may develop either during the vegetation period or after harvest. Initial symptoms on fruits appear as small spots on the fruit shoulder, which subsequently enlarge into circular, water-soaked lesions. Under humid conditions, these lesions are covered with fuzzy, grey sporulation – conidia and conidiophores of the fungus (Figure 2). *B. cinerea* also can appear as a secondary decay on tissues damaged by other diseases. According to Ahmed et al. (2017), *B. cinerea* isolates were the most virulent among the isolated fungi from tomato fruits.

The primary sources of inoculum are infected plants and infected decaying plant debris. The fungus spores vitality depends on environmental conditions, while spores can remain viable for days or weeks. Low temperatures and dark conditions provide the best longevity of the spores. In greenhouse environments, spores may survive for several days, while the fungus may survive between seasons in plant material. *B. cinerea* is primarily dispersed via spores spread by water drops. Physiological changes during fruit ripening after harvest increase host susceptibility, creating favorable conditions for fungal pathogen infection. In unripe fruit, pathogens may stay dormant until ripening, when they become active and rapidly induce decay. Grey mold development is affected by the stage of fruit ripening (Figure 1). In tomato, the fungus *B. cinerea* can actively induce ripening processes to facilitate infection and disease progression (Silva et al., 2023). However, Le et al. (2013) reported that inoculum concentration had a greater impact on the severity of grey mold in pepper than the developmental stage of the fruit. In tomatoes, soft rot typically affects mature fruits after harvest, while the occurrence of 'ghost spot' in unripe fruits indicates a successful defensive host response, although it still reduces their commercial value (Williamson et al., 2007). Additionally, Brito et al. (2021) reported that *B. cinerea* isolates can completely infect tomato wounds 3 days after inoculation. As a necrotrophic fungus, it can produce toxins and reactive oxygen species (ROS) to kill the host cells (Choquer et al., 2007). Accordingly, all these characteristics highlight the complexity of managing this pathogen in order to prevent and minimize disease development.

***Alternaria* fruit rot caused by *Alternaria alternata* (Fr.) Keissl.**

Alternaria fruit rot, also known as black mold, is a disease caused by species of *Alternaria* genus, including, *A. alternata* (Fr.) Keissl. and *Alternaria tenuissima,* which was reported to cause leaf spot and fruit rot in pepper (Li et al., 2011). Among molds involved in tomato fruit rots, *A. alternata* is considered as a major biotic factor contributing to storage decay (Rizwana et al., 2021; Ventura-Aguilar et al., 2021).

The fungus *A. alternata* can infect tomato and pepper fruits on the plant, entering through the stigma. In this case, the symptoms of the infection in pepper fruits are not visible, as they are limited to the seeds and placenta (Pernezny et al., 2003). In tomato, the disease appears on the shoulders adjacent to the stem scar (Jones et al., 2006).

Furthermore, during prolonged storage, *A. alternata* becomes aggressive in injured or debilitated fruits. Environmental factors play a key role in the spread of fungal pathogens in fruits (Safari et al., 2021). Surface rot is caused by the penetration of *A. alternata* through previously damaged tissues, including injuries caused by insects, sunburn, growth cracks, low temperatures, calcium deficiency, or mechanical damage (Wall and Biles, 1993; Eshel et al., 2002). Chilli pepper fruits inoculated without injury did not develop any symptoms of *Alternaria* rot, while injured fruits exhibited symptoms of rot regardless the ripening stage and the ripe fruits were highly susceptible (Wall and Billes, 1993). However, Bulajić et al. (2005) reported that all tested *A. alternata* isolates showed a certain degree of pathogenicity on intact sweet pepper fruits. A pathogenicity test conducted by Balamurugan and Kumar (2023) indicated that only physiologically mature pepper fruits could be infected, and that the severity of fruit rot was more intensive in tomato and eggplant. Tomatoes with cracked cuticles or pericarps are especially vulnerable. As the fruits ripen, they become more sensitive. Tomato fruit rot caused by *Alternaria* spp. develops as dark brown to black, smooth, slightly sunken lesions, several centimeters in diameter (Yang et al., 2020). Symptoms of *Alternaria* rot on pepper fruits are dark, depressed lesions covered by white to grey-green mycelium. Moreover, *A. alternata* produces mycotoxins and has multiple adverse impacts on human and animal health (Escrivá et al., 2017), causing both acute and chronic health problems. The most prevalent *Alternaria* toxins are alternariol (AOH) and alternariol monomethyl ether (AME) (Bacha et al., 2023). These toxins were detected in tomatoes and their products (Xu et al., 2024), and have been considered as causal agents of esophageal cancer (De Berardis et al., 2018).
As *Alternaria* rot can occur on the fruit both in the field and during storage, careful handling of fruits during harvesting, transport, and storage is a necessary preventive measure against this pathogen.

Figure 1. Pepper fruit in greenhouse infected by *Botrytis cinerea*

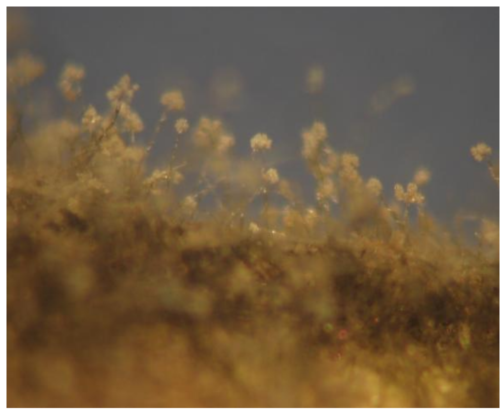

Figure 2. Conidiophores and conidia of the *Botrytis cinerea* isolate

Comparative analysis of Botrytis and Alternaria

Overall, the reviewed literature confirms the importance of *B. cinerea* and *A. alternata* in tomato and pepper production, while emphasizing distinct differences in their infection biology and disease epidemiology. *B. cinerea* is a highly aggressive necrotrophic pathogen that primarily causes grey mold, characterized by soft, water-soaked lesions covered with abundant grey sporulation. Infection frequently occurs through mechanical injuries, wounds, or natural openings, and disease development is favored by high relative humidity and moderate temperatures, particularly during storage (Droby and Wisniewski, 2018; Petrasch et al., 2019). Therefore, postharvest handling represents a key factor in disease development. In contrast, *A. alternata* typically causes black rot of fruits, frequently associated with latent infections initiated during the growing season, with symptoms appearing during fruit ripening or postharvest storage, especially under stress conditions (Thomma, 2003, Logrieco et al., 2009). The pathogen-specific differences highlight the importance of both postharvest practices and preharvest disease management strategies to successfully reduce losses in tomato and pepper production systems.

Control of tomato and pepper postharvest rot

Harvested crops, vegetables, and fruits are highly vulnerable to postharvest diseases, particularly during transport, handling, and storage (Sivakumar et al., 2016).
In assessing postharvest disease losses, it is essential to account for both the decrease in fruit yield and the deterioration of fruit quality. Postharvest disease losses are influenced by a great number of factors, including plant species, genotype susceptibility to postharvest disease, the environmental conditions within storage (temperature,

relative humidity, atmosphere composition, etc.), produce maturity and ripeness stage, treatments used for disease control, produce handling methods, and postharvest hygiene. Despite numerous studies focusing on natural methods for controlling postharvest *B. cinerea*, research addressing grey mold in peppers remains limited (Krasnow and Ziv, 2022).

Preventive measures

Control of postharvest fruit rot is carried out by avoiding conditions that can lead to infection. Leaves should provide shade for the fruits and protect them from direct sun exposure to avoid sunscald. Providing adequate fertilization with calcium prevents blossom-end rot and further colonization of saprophytic *Alternaria* species (Kumari et al., 2022).

Harvesting should not take place during very hot or very cold weather or under water stress conditions. Careful handling of fruits during harvesting and storage helps in preventing mechanical injuries. Packaging conditions need to be optimized, especially in relation to disease control (Lownds et al., 1994). The fruits should be cleaned, packed, and then immediately placed at a temperature of 8-10 °C. However, the ability of *Alternaria* to maintain good growth in cold storage conditions at low temperatures (0-10 °C) makes it one of the main causes of rot (Troncoso-Rojas and Tiznado-Hernandez, 2014). Thus, Meir et al. (1995) state that bell peppers kept at temperatures below 7 °C are highly prone to *Alternaria* rot.

The optimal temperature for *Botrytis* spp. growth ranges from 18 to 23 °C, while some growth occurs at 0-5 °C, which facilitates disease development in postharvest storage at low temperatures (Tzortzakis, 2019). Furthermore, prolonged periods of low temperatures enhance grey mold postharvest development (Krasnow and Ziv, 2022).

Host resistance

Genetically based host resistance is an important element of integrated disease management. Due to the aggressive nature of *B. cinerea*, breeding for resistance is challenging, although there are examples of successful outcomes in some horticultural crops (Tian et al., 2019). Regarding vegetable species, research has been performed mainly on tomatoes (Williamson et al., 2007) to introduce qualitative resistance (Finkers et al., 2007). Partial stem and leaf resistance were identified in wild tomato *Solanum* species*:* *S. habrochaites*, *S. chilense* and *S. neorickii* (ten Have et al., 2007). Additionally, testing of pathogenicity demonstrated a distinct differentiation between high-pigment tomato cultivars and the control, while the yellow genotypes exhibited greater disease intensity (Pane et al., 2011). Although resistant cultivars do not exist yet, present cultivars show high variability in susceptibility to the disease (Dik and Wubben, 2007).

Wild host sources of resistance to *B. cinerea* are difficult to find (Wurms et al., 1999). Recent research on pepper fruit resistance found that one local Egyptian pepper cultivar exhibited lower susceptibility to grey mold after artificial inoculation (Kamara et al., 2016). Additionally, Le et al. (2013) reported that pepper cultivar 'Aries' had significantly larger lesions and was more susceptible to *B. cinerea* than cv. 'Papri Queen', irrespective of inoculation status: preharvest or postharvest. The mechanisms of the reduced susceptibility are not known.

As a control measure, it is certainly necessary to examine the susceptibility of the most commonly grown pepper genotypes in Serbia to fruit rot caused by the fungus *A. alternata* (Peić Tukuljac et al., 2023). These authors reported that the pepper cultivar 'Amfora' had the highest tolerance to *Alternaria* infection (Figure 3).

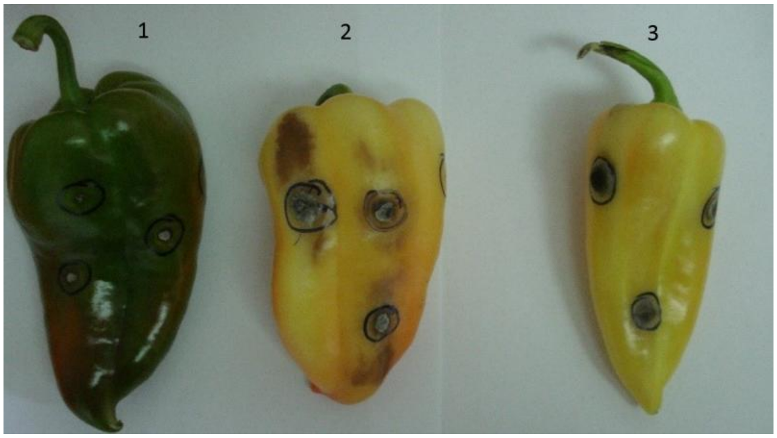

Figure 3. Tolerant cv. Amfora (1) and susceptible pepper genotypes (2, 3) to *Alternaria alternata* after artificial inoculation

Non chemical control

Non-chemical approaches to managing postharvest diseases in pepper and tomato rely on environmentally friendly strategies such as physical treatments, improved handling practices, induced resistance, and biological control, all aimed at reducing decay without the use of synthetic fungicides. To meet market demands and address concerns about chemical residues, research on biological compounds with fungicidal activity has intensified significantly (Fravel, 2005). Consequently, various natural and generally recognized as safe (GRAS) approaches, including hot water treatment, inorganic salts, plant extracts, essential oils, biocontrol agents, defense activators, and modified storage conditions, have been extensively evaluated for their effectiveness in limiting disease development. Many authors attempted to minimize losses caused by grey mold and *Alternaria* rot on pepper and tomato fruits by the above-mentioned compounds and techniques (Fallik et al., 2001; Begum et al., 2010; Luo et al., 2019; Brito et al., 2021; Rizwana et al., 2021; Dragić et al., 2022).

Postharvest decay was significantly reduced in fruits treated with hot water. Fallik et al. (1999) reported that immersing red sweet pepper in water at a temperature of 50 °C for three minutes significantly reduced decay caused by *B. cinerea* and *A. alternata*.

The severity of grey mold caused by *B. cinerea* can be reduced by maintaining high calcium content in plant tissue (Elad and Shtienberg, 1995). Dipping pepper fruits in calcium during postharvest handling and packaging may also be beneficial.

Over 300 essential oils were tested against *B. cinerea* isolates, of which 13 showed high antifungal activities (Wilson et al., 1997). Diseases caused by *B. cinerea* in numerous crops can be controlled using chitin and chitosan, natural polymers safe for consumers. Chitosan was shown to inhibit *in vitro* germination of *A. alternata* conidia (Sharma et al., 2006). In addition, when combined with edible films, chitosan decreases disease severity in bell pepper and improves storage quality (Poverenov et al., 2014).

Salicylic acid (SA) is an established activator of systemic-induced resistance in plants, which proved to be effective against bacterial and fungal plant pathogens (Mandal et al., 2009). SA, abscisic acid, and methyl jasmonate act as resistance inducers in peppers and reduce grey mold intensity in peppers harvested from plants treated with systemic acquired resistance compounds (Kamara et al., 2016). Reduction of *B. cinerea* growth in bell peppers can be achieved by spraying with harpin protein, a prominent resistance activator (Akbudak et al., 2006).

CA (cinnamaldehyde) is an environmentally friendly compound, and the study by Yang et al. (2023) provides significant data on its activity in the biocontrol of postharvest grey mold in peppers. Sodium dehydroacetate (SD) and the natural plant compound trans-2-hexenal (TH) have shown potential antifungal activity against *B. cinerea* and may be applied as alternatives for managing grey mold in postharvest green peppers (Wang et al., 2022). Application of 2% carbonate or bicarbonate salts to pepper fruits improves their resistance to grey mold, decreases fruit weight loss, and prolongs shelf life (Shaban, 2014).

Postharvest disease control by microorganisms is an eco-friendly and environmentally sustainable strategy (Fenta et al., 2023). Due to controlled conditions, storage is the most favorable environment for the use of bioagents (Wisniewski and Wilson, 1992). Control of tomato fruit rot can be achieved by *Bacillus subtilis*, *Rhodosporidium paludigenum*, *Pichia guilliermondii, Saccharomyces cerevisiae,* and *Candida tanuis* (Kilani-Feki et al., 2016; Wang et al., 2010; Zhao et al., 2008; Abd-Allah et al., 2009). Even entomopathogenic fungi have potential as tomato biocontrol agents against grey mold in greenhouse and postharvest conditions (Sarven et al., 2020).

Pseudomonas protegens plays a crucial role as a biocontrol agent against postharvest tomato decay caused by *B. cinerea*. *P. protegens* acts through multiple mechanisms such as the secretion of antifungal substances, the induction of tomato defense responses, and inhibition of mycelial growth (Ajijah et al., 2023).

Bacillus subtilis–based antagonists have demonstrated inhibitory activity against major pathogens of pepper and tomato, both during the vegetative stage and postharvest (*Botrytis cinerea, Alternaria* spp.), significantly reducing disease incidence and severity during storage (Chen et al., 2022; Karačić et al., 2024). Biofungicides based on *Bacillus subtilis* that are currently registered in Serbia for application during the vegetation period are summarized in Table 1.

Biological control is an area of plant protection which requires further research to optimize formulations and application timing to improve disease control in postharvest conditions (Krasnow and Ziv, 2022).

Table 1. Biological control agents registered in Serbia for the control of *Botrytis cinerea*, *A. solani* and *Alternaria* sp. in tomato and pepper (Aleksić et al., 2024)

Microorganism Active ingredient	**Trade name**	**Active ingredient content/strain**	**Time of application**	**Rate of application (%, kg, l/ha)**	**Pre-harvest interval (days) MNT***
Bacillus subtilis/ amyloliquefaciens	Ekstrasol[1]	Č13 $1x10^8$ CFU/cm^3	3-5 days before the first symptoms	2 l/ha	1 4
	Serenade aso[2]	Q713	13-49 BBCH	8 l/ha	1 6
	Serifel[3,4]	MBI 600	51-89 BBCH	0.5 kg/ha 0.25 kg/ha	- 6
	Taegro[5]	FYB $1x10^{10}$ CFU/g	10-89 BBCH	185-370 g/ha	1 12 OF; 10PA

Legend: Pesticides registered for control: [1] *A. solani* tomato; [2] *B. cinerea* pepper and tomato open field and protected area; [3] *A. solani* and *B. cinerea* pepper and tomato open field; [4] *B. cinerea* pepper and tomato protected area; [5] *A. solani* pepper and tomato open field and protected area; *MNT maximal number of treatment

Chemical control

In pepper and tomato, postharvest control of grey mold caused by *Botrytis cinerea* and fruit rot caused by *Alternaria* spp. is strongly constrained by regulatory limits on fungicide residues and stringent consumer safety requirements. Consequently, most synthetic fungicides effective against these pathogens are applied during the growing season, whereas their use after harvest is very limited or entirely prohibited.

Although *Botrytis cinerea* has long been recognized as an economically important pathogen of tomato, the recent registration of fungicides specifically targeting *Alternaria alternata* reflects the increasing significance of this fungus and underscores the necessity for its effective management during the growing season. The fungicides listed in Table 2 are registered for application during the vegetation period in open-field production, with some also approved for use in greenhouses or other protected cultivation systems. In the European Union, the same active substances as those registered in Serbia are approved for the control of *Botrytis cinerea* and *Alternaria alternata* on pepper and tomato crops during the growing season, reflecting a high level of regulatory harmonization between Serbia and the EU in the field of plant protection products (Regulation (EC) No 1107/2009, EU Pesticides Database). However, the specific conditions of use, including crop specificity, target pest organisms, application rates, maximum number of treatments, and pre-harvest intervals, are defined at the national level and regulated through the official plant protection product registers of individual EU Member States, in accordance with Regulation (EC) No 1107/2009.

Fungicides are applied throughout almost the entire vegetation period, from the first true leaf stage (following the cotyledonary leaves) until physiological maturity and the development of the characteristic fruit color. Applications at or near physiological maturity require strict consideration of the preharvest interval to ensure compliance with residue regulations.

Currently, there are no fungicides registered in Serbia for postharvest application on tomato or pepper. Postharvest disease management in pepper and tomato therefore relies primarily on the residual effects of preharvest treatments, combined with non-chemical approaches such as low-temperature storage, sanitation, modified atmosphere, packaging, biological control agents, and the use of generally recognized as safe (GRAS) compounds (Janisiewicz & Korsten, 2002; Palou et al., 2016; European Commission, Regulation (EC) No 396/2005). Within the European Union, the use of chemical fungicides close to harvest and during postharvest storage is strictly limited and generally regarded as a special or exceptional case (Regulation (EC) No 1107/2009).

The active ingredient in chemical control of grey and black mold has evolved considerably over the past decades. The very first fungicides applied against these diseases were inorganic copper fungicides. In the 1980s, triazole fungicides such as tebuconazole and difenoconazole were among the first active ingredients used against these diseases. During the 1990s, fungicides with different modes of action, including cyprodinil and fludioxonil, were introduced. The early 2000s saw the adoption of strobilurin and related compounds, such as trifloxystrobin, pyraclostrobin, cyflufenamid, and pyrimethanil. More recently, since 2010, a new generation of fungicides, including the succinate dehydrogenase inhibitors (SDHIs) penthiopyrad, fluxapyroxad, and fluopyram, has been developed and widely implemented. All of these compounds represent active ingredients that are still in use today in Serbia, although their application is subject to regulatory restrictions and resistance management strategies.

Table 2. Pesticides registered in Serbia for the control of *Botrytis cinerea*, *A. solani* and *Alternaria* sp. in tomato and pepper (Aleksić et al., 2024)

Active ingredient	Trade name	Active ingredient content	Time of application	Rate of application (%, kg, l/ha)	Pre-harvest interval (days) MNT*
copper hydroxide[1]	Blauvit ultra SC Everest	240 l/ha 368.5 g/l	19-79 BBCH	0.3-0.4 %	7 4
copper hydroxide+ metalaxyl[1]	Armetil OH	185 g/l + 35 g/l	14-87 BBCH	3.2 ha	21 2
copper-oxide[7]	Nordox 75 WG	750 g/kg	19-79 BBCH	0.14-0.20 %	14 tomato 7 pepper
copper- oxychloride	Cuprablau Z 35 WP[1]	350 g/kg	during vegetation	3 kg/ha	10 processing tomatoes 3 fresh market tomato 3
	Curenox 50WP[4]	500 g/kg	15-89 BBCH	1.5-2 kg/ha	10 OF 3 PA tomato 14 pepper 3-6 PA
	Oxitec 25 % hi bio[4]	250 g/ha	15-89 BBCH	3 kg/ha	3 fresh market tomato&pepper 10 OF processing tomato&pepper 5
copper- oxychloride + benalaxyl M[1]	Ridomil gold R	141.9 g/kg+ 19.4 g/kg	11-89 BBCH	5 kg/ha	3 1-2
tribasic copper sulfate[1]	Cuproxat	190 g/l	preventively	0.2 %	7 4 kg/ha
azoxystrobin[1]	Promesa Quadris Teatar Županstrobin	250 g/l	preventively	0.75 l/ha	3 2
azoxystrobin+ difenoconazole	Ortiva top[6] Quadris top[1] Teatar plus[1]	200 g/l+ 125 g/l	40-89 BBCH 16-87 BBCH 40-87 BBCH	1 l/ha 0.75-1 l/ha 1 l/ha	3 PA 7 OF 2
difenoconazole	Sekvenca[9]	250 g/kg	20-87 BBCH	0.5 l/ha	7 3
	Skoremore[1]	250 g/l	10-89 BBCH	0.3 l/ha	7 2
difenoconazole + cyflufenamid	Cidely top [9*]	125 g/l + 15 g/l	10-89 BBCH	100 ml/1000m^2	3 tomato 1 OF 2 PA
fluxapyroxad + difenoconazole	Secardis plus [10, 11]	75 g/l + 50 g/l	14-89 BBCH	1 l/ha	3 2
tebuconazole[1]	Akord	250 g/l	preventively	0.75-1 l/ha	21 3
	Akord WG	250 g/kg	19-71 BBCH	0.75 kg/ha	
	Lira	250 g/l	19-71 BBCH	0.75 l/ha	21 2

pyraclostrobin	Image/Adinik[6]	250 g/l	40-87 BBCH	0.64-0.8 l/ha	7 2
boscalid + pyraclostrobin[1,8]	Luminis Signum	267 g/kg+ 67 g/kg	the first treatment at the onset of infection; the second and third 7–10 days later	0.4 kg/ha tomato 1 kg/ha pepper	14 3
cyprodinil+ fludioxonil[12]	Atlas	375 g/kg+ 250 g/kg	65-87 BBCH	1 kg/ha	3
	Morezmo	375 g/kg+ 250 g/kg	51-89 BBCH	0.6-0.8 kg/ha	
	Switch 62.5 WG	375 g/kg+ 250 g/kg	flowering, post-flowering, and fruit formation	0.6-0.8 kg/ha	3 Switch max. 1kg/ha pepper
cyprodinil + tebuconazole[12]	Linus	187.5 g/l+ 125 g/l	flowering, post-flowering, and fruit formation	1.6-2 l/ha	7 2
fluopyram+ trifloxystrobin[12*]	Luna sensation	250 g/l + 250g/l	51-89 BBCH	0.6 l/ha	3 2
Penthiopyrad[4, 13]	Fontelis	200 g/l	51-89 BBCH	2 l/ha[4*] 2.4 l/ha [12]	3 1OF; 2PA
Pyrimethanil[2]	Pehar	400 g/l	21/23-81 BBCH	1.5-2 lha	14 3

Legend: Pesticides registered for control: [1]*A. solani* tomato; [2]*B. cinerea* pepper and tomato open field and protected area; [4]*B. cinerea* pepper and tomato protected area [6]*Alternaria* sp. tomato; [7] *A. solani* pepper; [8] *B. cinerea* pepper; [9] *A. solani* tomato (OF and PA), pepper (PA); [10]*A. solani* pepper (PA); [11] *A. solani* tomato (OF and PA); [12]*B. cinerea* tomato; [12*] *B. cinerea* tomato (PA); [13] *B. cinerea* tomato (OF); *MNT maximal number of treatment; OF open field; PA protected area

However, the use of these chemicals is associated with the health, environmental, and emerging issues related to resistant strains (Avenot et al., 2018). Nevertheless, the use of fungicides must be aligned with regulatory standards concerning maximum residue limits (MRLs) and preharvest intervals. Moreover, excessive or repeated use of single-site fungicides can contribute to the emergence of resistant pathogen strains, particularly in *B. cinerea*, which has high genetic variability and adaptability (Leroux et al., 2002). Resistance mechanisms to benzimidazole and dicarboximide fungicides in *B. cinerea* have been reported (Yarden and Katan, 1993; Stehmann and De Waard, 1996).

Novel technologies

Innovative technologies like nanotechnology offer significant potential for disease management and enhancement of plant development. As an emerging field, nanotechnology presents promising applications in agriculture, including the use of nano-fertilizers, more effective pesticides, soil quality improvement, wastewater treatment, and early detection of plant pathogens. Additionally, the use of nanoparticles can contribute to reducing postharvest losses by prolonging the storage life of agricultural products (Neme et al., 2021) through designing functional packaging materials with a reduced effect on sensory properties of vegetables and fruits (Flores-Lopez et al., 2016). Nano-coatings provide a barrier to gas and moisture exchange and help preserve flavors, colors, enzymes, antioxidants, and reduce browning, which may enhance the shelf life of foods (Zambrano-Zaragoza et al., 2018). The application of edible coatings and thin films is ubiquitous for horticultural goods.

For example, salicylic acid nanoparticles (SANPs) induce some sweet pepper resistant genes and significantly inhibit the growth of *A. alternata* (Abdel-Rahman et al., 2021). Furthermore, chitosan nanoparticles have been shown to inhibit the development of *A. alternata* during the cold storage period of pepper and to preserve fruit quality (Hernández-López et al., 2020). Nanotechnology based on nanoparticles can reduce postharvest losses by enhancing the product shelf life. On the other hand, nanoparticles could also generate health risks, as a result of easy penetration through the cell and adverse reactions within various human and animal organs as well as plant tissues. Such risks due to nanoparticles require future investigation, including the use of greener technologies and the development of easy and cheaper protocols for eradication of nanomaterials from the sites of application (Shamloo et al., 2024).

Nowadays, in postharvest storage and crop management, artificial intelligence can have a significant impact, but it is still at the research stage (Tiamiyu et al., 2023).

CONCLUSION

B. cinerea and *A. alternata* are important postharvest pathogens of tomato and pepper, causing substantial quality deterioration and consequent yield losses. This review synthesizes current knowledge on the epidemiology of these pathogens and critically evaluates available chemical, biological, and alternative control strategies applied during both vegetation period and postharvest stages. The reviewed evidence indicates a clear shift toward integrated and sustainable disease management approaches, driven by increasing regulatory restrictions on synthetic fungicides and growing consumer demand for residue-free produce.

Future research should prioritize the development of biological control agents that are reliable and effective under diverse postharvest conditions. Particular attention should be paid to pathogen performances under agroecological conditions of Serbia, including climate (first of all extremely hot and dry summers), production systems, and storage practices. A deeper understanding of the mechanisms of action of biological control agents is essential for optimizing their application strategies and improving consistency of their efficacy. Importantly, these agents should be combined with host resistance, improved postharvest handling practices, and emerging non-chemical technologies rather than relying on a single solution. Furthermore, harmonization of regulatory frameworks and integration of experimental findings into commercial applications adapted to local production systems will be crucial. All these advances will support the development of effective, environmentally sound, and economically viable strategies for managing postharvest diseases caused by *B. cinerea* and *A. alternata* in tomato and pepper production.

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