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A comprehensive review on using nanoparticles to control bacterial soft rot disease of *Solanum tuberosum* caused by *Pectobacterium carotovorum*

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***ABSTRACT* : Bacterial soft rot disease is one of the most destructive diseases of vegetables worldwide causing huge economic losses in the field, in transit and in storage or during marketing. Potato (*Solanum tuberosum*) is one of the most globally important crops its yield is badly affected by soft rot disease. It is primarily caused by *Pectobacteriaceae* family and *Pectobacterium carotovorum* is one of the most devastating plant pathogens that causes soft rot disease. Soft rot disease has a wide range of hosts of vegetable crops and ornamental plant. The effected tissue of the host becomes soft and slimy without much discoloration and bad smell. Several strategies have been developed to control potato soft rot. The use of natural plant products such as plant extracts and green synthesized silver nanoparticles has emerged as being promising alternative and safe way than the synthetic chemicals to control soft rot disease. This review discusses potato soft rot disease and the controlling measures through presenting an overview of the results of studies done on this disease.**

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I. INTRODUCTION

Soft rot is one of the devastating diseases that affects vegetables including potato. Anywhere that ornamentals and vegetables with fleshy storage tissues may be found, it can be found there as well. The disease can affect crops in the field, when they are being transported, stored, or even during marketing. Bacterial soft rot disease causes severe economic losses worldwide every year; hence, it has been regarded as a challenge for agricultural and food authorities (Gillis et al., 2014 ; Rutolo et al., 2018). It causes severe economic losses of produce than any other bacterial disease (Bhat et al., 2010).

Potato (Solanum tuberosum L.) is an attractive crop in the agricultural sector due to its great nutritional value as an excellent source of vitamins, proteins, energy, minerals, and carbohydrates (Jayanty et al., 2019). Potato is one of the most widely consumed foods all over the world, ranking fourth after corn, rice and wheat (Sáenz-Baños et al., 2022). With almost 5000 variants known, potatoes are considered the most genetically diverse crop among farmed species (Petropoulos et al., 2019). Aside from being one of the most commonly consumed vegetables, the potato crop is also related with one of the world's major food processing sectors (Farvin et al., 2012).

The potato crop is severely affected by a variety of pathogenic diseases, resulting in low yield. The most prevalent diseases that might impair potato quantity and quality are bacterial diseases caused by the pathogenic strain Pectobacterium carotovorum, such as blackleg and soft rot (Raoul des Essarts et al., 2016). Soft rot disease continues to be a problem for the potato production industry in many growing places throughout the world (Czajkowski et al., 2015; Pritchard et al., 2016).

Several methods, including physical methods, have been used to control the soft rot of potatoes, but these methods are costly, time-consuming, and have not been able to eliminate the pathogen's passage (Hajhamed et al., 2007;Czajkowski et al., 2011). Chemical methods using synthetic bactericides have also been used to suppress bacterial pathogens, but are not more useful due to their harmful effects on humans and the environment and probable resistance incidence in bacteria (Gracia-Garza et al., 2002; Jess et al., 2014). Consequently, environmentally friendly, effective, and safe biological control techniques have been recommended to reduce the soft rot of potatoes (Salem and Abd El-Shafea, 2018).

Natural compounds extracted from medicinal plants, such as, phenolic compounds, saponins, flavonoid compounds, steroids, alkaloids, and others have a long history for their bioactivity against pathogenic microbes

(El-Hefny et al., 2017 ; Gutiérrez-Morales et al., 2017). Antimicrobial compounds from medicinal plants may limit the development of bacteria, fungus, viruses, and protozoa through different processes than those of currently employed antimicrobials. They may also have significant clinical benefit in the treatment of microbial strains that are resistant to current antimicrobials (Shankar et al., 2010).

Also, Nanobiotechnology has broad applications in the agricultural sector, e.g., to combat diseases and enhance crop productivity (He et al., 2019). Recently, the use of nanobiotechnology in the management of plant diseases has gained substantial attention (Elmer and White, 2018) due to the important role of nanomaterials in the control of plant pathogenic microorganisms and, thus, an improvement in crop productivity (Worrall et al., 2018; Ali et al., 2022). Silver is a fascinating material and has been utilized for various applications since ancient time. Ag NPs have been extensively studied due to their superior physicochemical, biological and antimicrobial properties (Das et al., 2020). SNPs display multiple mode of action against plant pathogens, therefore they can be used for controlling various plant diseases in relatively safe way than the synthetic chemicals (Mendes et al., 2014). Generally, metal nanoparticles can be prepared and stabilized by chemical, physical and biological methods; the chemical approach, such as sol–gel method, chemical reduction, electrochemical techniques, photochemical reduction and pyrolysis. Physical methods apply mechanical pressure, high energy radiations, thermal energy or electrical energy to cause material abrasion, melting, evaporation or condensation to generate NPs (Sharma et al., 2009; Dhand et al., 2015). Compared with other methods, biological methods using microorganisms (Sadowski et al., 2008 ; Tsibakhashvil et al., 2010), and plants or plant extracts, are environmentally friendly and alternatives to chemical and physical methods for the synthesis of SNPs (Heydari and Rashidipour, 2015). The objective of the present review is to highlight the soft rot disease of potato and affords new alternatives for controlling.

2. Soft rot causal agents

Bacterial species belonging to Pectobacteriaceae family, generally known as soft rot Pectobacteriaceae (SRP), are one of the world's most economically important plant-specifc pathogens (Charkowski et al., 2012). Pectobacterium species are Gram-negative plant pathogenic bacteria belonging to the family Pectobacteriaceae and P. carotovorum is considered to be one of the most devastating plant pathogens that causes soft rot disease globally and possesses the widest host range of all of the soft rot bacteria (Davidsson et al., 2013; Agyemang et al., 2020). Bacterial soft rot caused by P. carotovorum has become a major global issue in a variety of vegetable crops and ornamental plant species. The disease can happen anytime during processing, storage and transportation resulted in huge economic losses in many countries (Opara and Asuquo, 2016;Fan et al., 2020).

3. Host range

Bacterial soft rot disease caused by P. carotovorum has a wide range of hosts of vegetable crops and ornamental plant among which, carrot (Agyemang et al., 2020; Siddiqui et al., 2020 and Soltani Nejad et al., 2023) reported that Carrots (Daucus carota L.) are very susceptible to soft rot bacterial infection. The bacterium, Pectobacterium carotovorum subsp. carotovorum, causes soft rot and the symptoms of a major spread appear as a soft rot and the watery, slimy decay of the taproot.

Pao et al. (2007) and Ahmed et al. (2017) stated that Tomatoes are an important economic crop worldwide and soft rot disease caused by Pectobacterium carotovorum leads to significant post-harvest losses. Potato is the fourth-most significant food crop in the world, which is essential to the food supply (Fiers et al., 2012). Cultivated potato is often prone to microbial infections. One of the most common diseases in potatoes is bacterial soft rot, caused by the pathogenic strain P. carotovorum which disseminated into the plant and tubers through the vascular vessels (Raoul des Essarts et al., 2016). P. carotovorum, can macerate parenchymatous plant tissues by producing a mass of plant cell-wall-degrading enzymes, including pectinases, proteases, cellulases, and hemicellulose then, it can cause soft rot pre- or post- harvest (Haque et al., 2017).

Maung et al. (2022) reported that, Cucumber (Cucumis sativus L.) is a widely cultivated vegetable crop around the world and cucumber fruits are consumed as fresh or pickles due to its nutritional contents such as various vitamins and minerals. Cucumber plants are susceptible to various fungal and bacterial diseases including bacterial soft rot caused by P. carotovorum which highly affects its production resulting in significant yield losses.

Pepper is an important crop and the pepper production is seriously limited by Pectobacterium carotovorum, even the plants were not affected before harvest the pathogen still can cause damage after harvesting (Ayisigi et al., 2020).

4. Symptoms

P. carotovorum is problematic not only during the pre-harvest period, but also during the post-harvest period, causing serious losses. This pathogen can release a massive array of exoenzymes including pectate lyases, polygalacturonases, proteases, and cellulases as their powerful weapons to break down pectic components of plant cell walls and membranes, thereby rotting plant tissues and subsequently leading to plant death (Agyemang et al., 2020). Wound site or natural opening is the entrance for this pathogen from soil or plant surface where they survive. Thereafter, the infection initiates inside the intercellular space or vascular tissue through the secretion of enzyme complex to promote their virulence under favorable environmental conditions (Toth et al., 2003). Then the symptoms begin as small water-soaked lesion, which enlarged rapidly. The effected tissue becomes soft and slimy without much discoloration and bad smell. The affected area becomes soft and mushy while its surface becomes discolored (Bhat et al., 2010).

5. Controlling measures

5.1. Botanicals to control bacterial soft rot of potato

Plant pathogenic bacteria are a major cause of plant diseases leading to crop loss (Kotan et al., 2014). Preventing or diminishing crop wasting due to the plant diseases is a chief concern. Many types of chemicals, pesticides and antibiotics are habitually used to restrain plant diseases; nevertheless, their use has confined success and many problems as pollution of the environment, threatening of human health (Al-Waili et al., 2012), emerging resistance by microorganisms and the high price to profit ratio (Kotan et al., 2014). Therefore, there is a great need for alternate, effective and safe antimicrobial agents.

Medicinal plants are considered as the most modern resources for

providing agents with fewer side effects that could candidate as alternatives to chemical drugs (Zangeneh et al., 2018;Goorani et al., 2019). Medicinal plants, have withdrawn attention in the scope of plant disease control. The beneficial therapeutic benefits of plant products are typically caused by the combination of secondary metabolites found in plants. The therapeutic qualities of medicinal plants are related to the presence of active compounds such as alkaloids, flavonoids, glycosides, vitamins, tannins, and coumarins (Lewis and Ausubel, 2006 ; El-Hefny et al., 2017).

Viswanath et al. (2018) reported that, the aqueous plant extracts of Datura stramonium (leaves), Ficus carica (leaves) having high efficacy in inhibiting the growth of Pectobacterium carotovorum in-vitro. Also, the effect of aqueous plant extracts on incidence and severity of soft rot disease caused by Pectobacterium carotovorum on stored potato tubers was effective in decreasing the incidence and severity of post-harvest soft rot up to one week of storage.

Aqueous plant extracts of three Egyptian plant species [lantana flowers and leaves (Lantana camara L.), lemongrass leaves (Cymbopogon citrates L), and olive cake (Olea europaea L.)], can be used as a pre-sowing method as soil treatment or foliar spray to prevent the spread of bacterial soft rot disease caused by Pectobacterium carotovorum subsp. carotovorum, in potato field. These treatments also improved the growth and yield parameters of potato plants. The treatments could protect the stored potato tubers against soften development and enhancement of the quality of potato tubers (Abdel-Gaied et al., 2020).

Shaheen and Issa (2020), with their study found that total alkaloid extract of Peganum harmala L. seeds (TAE) exhibited enhanced antibacterial activity against Pectobacterium carotovorum subsp. carotovorum, the causal agents of potato soft rot, which would be used as a new antibacterial agent. This may be important in preventing the emergence of numerous drug-resistant species. Moreover, the use of plant extracts against phytopathogens could be advantageous to limit plant diseases.

5.2. Green synthesized silver nanoparticles to control bacterial soft rot of potato

Silver is a fascinating material that has been used for various applications since ancient time. Ag NPs have been widely researched due to their superior physicochemical, biological and antimicrobial properties (Das et al., 2020). Ag NPs properties primarily depend on their size, shape, distribution, and surface characteristics which can be tuned during green synthesis by varying the concentrations of reducing agents, stabilizers, metal precursors, and reaction conditions (Pryshchepa et al., 2020).

Green synthesis refers to the biological synthesis of nanoparticles from various biomaterials such as algae, fungi, yeast, bacteria, or plant extracts (Vijayaraghavan and Ashokkumar, 2017; Zikalala et al., 2018). Green synthesis of Ag NPs is in high demand, particularly in food, biomedical, and medicinal applications, because it avoids the use of toxic and hazardous synthetic chemicals (Kumar et al., 2018; Pryshchepa et al., 2020). Plant-mediated synthesis of Ag NPs is convenient, cost-effective, and one-step technique that uses plant extracts as natural resources (Duan et al., 2015). Plant extracts are rich in polysaccharides, polyphenols, alkaloids, aldehydes, proteins, and amino acids, which can act as reducing and stabilizing agents (Rajeshkumar and Bharath, 2017). A variety of plants and their various parts, including leaf, latex, seed, flower, fruit, peel, bark, root, gum, and so on, have been employed in the synthesis of Ag NPs (Rajeshkumar and Bharath, 2017;Das et al., 2020).

Soltani Nejad et al. (2023) stated that, biosynthesized silver nanoparticles from Oak fruit exudates have antibacterial activity against Pectobacterium carotovorum subsp. Carotovorum with inhibition zones 8 ± 0.55 mm in diameter surrounding the discs treated with SNPs, compared to 14 ± 0.85 mm for the discs treated with streptomycin in in vitro conditions. And the in vivo test was used to assess the SNPs' curative effects at minimum inhibitory concentration levels to control soft rot disease in vivo. Results show that the soft rot disease was dramatically reduced by 74.3 percent for potato tubers when the SNPs were used before pathogen inoculation.

Dilbar et al. (2023) evaluated the antibacterial activity of Silver/silver chloride nanoparticles (se-Ag/AgClNPs) synthesized from the leaf extract of Stachys emodi and in combination with leaf extract (se-Ag/AgClNPs + LE) and leaf extract (LE) against Pectobacterium carotovorum, the causal agent of blackleg and soft rot of potato in vitro. The antibacterial activity showed the maximum inhibition by centrifuged silver nanoparticles alone (se-Ag/AgClNPs) and in combination with leaf extract (se-Ag/AgClNPs + LE) and leaf extract (LE) of 98%, 93%, and 62% respectively. These findings suggested that biosynthesized Ag/AgClNPs have the potential to control the growth of Pectobacterium carotovorum through in vitro activities.

CONCLUSION

Bacterial soft rot is a severe disease that affects plants in nearly every plant family causing significant crop loss worldwide. The disease is caused by several bacteria, most commonly Pectobacterium carotovorum. The symptoms of soft rot include soft, slimy without much discoloration and bad smell of the effected tissue. There are several measures that can be taken to control the disease. Plant extracts have the potential to control bacterial soft rot in potatoes. However, more research is needed to determine the effectiveness of different plant extracts and their application methods. Silver nanoparticles can be a promising approach for controlling soft rot disease in potatoes. However, more research is needed to determine the effectiveness of silver nanoparticles in field conditions and their potential impact on the environment. It is important to note that there is no completely effective soft rot treatment, but these measures can help minimize the damage.

References

Abdel-Gaied, T.G., Mikhail, M.S., Abdel-Alim, A.I., Seif El-Nasr, H.I., El-Khair, H.A. (2020). Field application of bio-control agents and aqueous plant extracts for controlling bacterial soft rot and enhancement yield quality of Solanum tuberosum L. cv. Diamond. Bulletin of the National Research Centre 44, 1-11.

Agyemang, P.A., Kabir, M.N., Kersey, C.M., Dumenyo, C.K. (2020). The bacterial soft rot pathogens, Pectobacterium carotovorum and P. atrosepticum, respond to different classes of virulence-inducing host chemical signals. Horticulturae 6, 13.

Ahmed, F.A., Arif, M., Alvarez, A.M. (2017). Antibacterial Effect of Potassium Tetraborate Tetrahydrate against Soft Rot Disease Agent Pectobacterium carotovorum in Tomato. Frontiers in Microbiology 8,1728.

Al-Waili, N., Salom, K., Al-Ghamdi, A., Ansari, M.J. (2012). Antibiotic, pesticide, and microbial contaminants of honey: human health hazards. The scientific world Journal 2012, 930849.

Ali, I., Khan, A., Ali, A., Ullah, Z., Dai, D.-Q., Khan, N., Khan, A., Al-Tawaha, A.R., Sher, H. (2022). Iron and zinc micronutrients and soil inoculation of Trichoderma harzianum enhance wheat grain quality and yield. Frontiers in Plant Science 13, 960948.

Ayisigi, M., Cokislerel, A., Kucukcobanoglu, Y., Yalcin, T., Aktas, L.Y. (2020). Green synthesized silver nanoparticles for an effective control on soft rot disease pathogen Pectobacterium carotovorum and growth stimulation in pepper. Bulgarian Journal of Agricultural Science 26, 574–584.

Bhat, K., Masood, S., Bhat, N., Bhat, M.A., Razvi, S., Mir, M., Sabina, A., Wani, N., Habib, M. (2010). Current status of post harvest soft rot in vegetables: a review. Asian Journal of Plant Sciences 9, 200-208.

Charkowski, A., Blanco, C., Condemine, G., Expert, D., Franza, T., Hayes, C., Hugouvieux-Cotte-Pattat, N., Solanilla, E.L., Low, D., Moleleki, L. (2012). The role of secretion systems and small molecules in soft-rot Enterobacteriaceae pathogenicity. Annual review of phytopathology 50, 425-449.

Czajkowski, R., Pérombelon, M., Jafra, S., Lojkowska, E., Potrykus, M., Van Der Wolf, J., Sledz, W. (2015). Detection, identification and differentiation of Pectobacterium and Dickeya species causing potato blackleg and tuber soft rot: a review. Annals of Applied Biology 166, 18-38.

Czajkowski, R., Pérombelon, M.C.M., van Veen, J.A., van der Wolf, J.M. (2011). Control of blackleg and tuber soft rot of potato caused by Pectobacterium and Dickeya species: a review. Plant Pathology 60, 999-1013.

Das, C.A., Kumar, V.G., Dhas, T.S., Karthick, V., Govindaraju, K., Joselin, J.M., Baalamurugan, J. (2020). Antibacterial activity of silver nanoparticles (biosynthesis): A short review on recent advances. Biocatalysis and Agricultural Biotechnology 27, 101593.

Davidsson, P.R., Kariola, T., Niemi, O., Palva, E.T. (2013). Pathogenicity of and plant immunity to soft rot pectobacteria. Frontiers in plant science 4, 191.

Dhand, C., Dwivedi, N., Loh, X.J., Ying, A.N.J., Verma, N.K., Beuerman, R.W., Lakshminarayanan, R., Ramakrishna, S. (2015). Methods and strategies for the synthesis of diverse nanoparticles and their applications: a comprehensive overview. Rsc Advances 5, 105003-105037.

Dilbar, S., Sher, H., Binjawhar, D.N., Ali, A., Ali, I. (2023). A novel based synthesis of silver/silver chloride nanoparticles from stachys emodi efficiently controls erwinia carotovora, the causal agent of blackleg and soft rot of potato. Molecules 28, 2500.

Duan, H., Wang, D., Li, Y. (2015). Green chemistry for nanoparticle synthesis. Chemical Society Reviews 44, 5778-5792.

El-Hefny, M., Ashmawy, N.A., Salem, M.Z.M., Salem, A.Z.M. (2017). Antibacterial activities of the phytochemicals-characterized extracts of Callistemon viminalis, Eucalyptus camaldulensis and Conyza dioscoridis against the growth of some phytopathogenic bacteria. Microbial pathogenesis 113, 348-356.

Elmer, W., White, J.C., 2018. The future of nanotechnology in plant pathology. Annual review of phytopathology 56, 111-133.

Fan, J., Ma, L., Zhao, C., Yan, J., Che, S., Zhou, Z., Wang, H., Yang, L., Hu, B. (2020). Transcriptome of Pectobacterium carotovorum subsp. carotovorum PccS1 infected in calla plants in vivo highlights a spatiotemporal expression pattern of genes related to virulence, adaptation, and host response. Molecular plant pathology 21, 871-891.

Farvin, K.S., Grejsen, H.D., Jacobsen, C. (2012). Potato peel extract as a natural antioxidant in chilled storage of minced horse mackerel (Trachurus trachurus): Effect on lipid and protein oxidation. Food Chemistry 131, 843-851.

Fiers, M., Edel-Hermann, V., Chatot, C., Le Hingrat, Y., Alabouvette, C., Steinberg, C. (2012). Potato soil-borne diseases. A review. Agronomy for Sustainable Development 32, 93-132.

Gillis, A., Rodríguez, M., Santana, M.A. (2014). Serratia marcescens associated with bell pepper (Capsicum annuum L.) soft-rot disease under greenhouse conditions. European Journal of Plant Pathology 138, 1-8.

Goorani, S., Shariatifar, N., Seydi, N., Zangeneh, A., Moradi, R., Tari, B., Nazari, F., Zangeneh, M.M. (2019). The aqueous extract of Allium saralicum RM Fritsch effectively treat induced anemia: experimental study on Wistar rats. Oriental Pharmacy and Experimental Medicine 19, 403-413.

Gracia-Garza, J.A., Allen, W., Blom, T.J., Brown, W. (2002). Pre- and post-plant applications of copper-based compounds to control Erwinia soft rot of calla lilies. Canadian Journal of Plant Pathology 24, 274-280.

Gutiérrez-Morales, A., Velázquez-Ordoñez, V., Khusro, A., Salem, A.Z.M., Estrada-Zúñiga, M.E., Salem, M.Z.M., Valladares-Carranza, B., Burrola-Aguilar, C. (2017). Anti-staphylococcal properties of Eichhornia crassipes, Pistacia vera, and Ziziphus amole leaf extracts: Isolates from cattle and rabbits. Microbial pathogenesis 113, 181-189.

Hajhamed, A., Sayed, W., Yazied, A., Ghaffar, N. (2007). Suppression of bacterial soft rot disease of potato. Egypt Journal Phytopathology 35, 69-80.

Haque, M., Oliver, M., Nahar, K., Alam, M.Z., Hirata, H., Tsuyumu, S. (2017). CytR homolog of Pectobacterium carotovorum subsp. carotovorum controls air-liquid biofilm formation by regulating multiple genes involved in cellulose production, c-di-GMP signaling, motility, and type III secretion system in response to nutritional and environmental signals. Frontiers in Microbiology 8, 972.

He, X., Deng, H., Hwang, H.-m. (2019). The current application of nanotechnology in food and agriculture. Journal of food and drug analysis 27, 1-21.

Heydari, R., Rashidipour, M. (2015). Green Synthesis of Silver Nanoparticles Using Extract of Oak Fruit Hull (Jaft): Synthesis and In Vitro Cytotoxic Effect on MCF-7 Cells. International journal of breast cancer 2015, 846743.

Jayanty, S.S., Diganta, K., Raven, B. (2019). Effects of cooking methods on nutritional content in potato tubers. American Journal of Potato Research 96, 183-194.

Jess, S., Kildea, S., Moody, A., Rennick, G., Murchie, A.K., Cooke, L.R. (2014). European Union policy on pesticides: implications for agriculture in Ireland. Pest Management Science 70, 1646-1654.

Kotan, R., Cakir, A., Ozer, H., Kordali, S., Cakmakci, R., Dadasoglu, F., Dikbas, N., Aydin, T., Kazaz, C. (2014). Antibacterial effects of Origanum onites against phytopathogenic bacteria: Possible use of the extracts from protection of disease caused by some phytopathogenic bacteria. Scientia Horticulturae 172, 210-220.

Kumar, S.S.D., Rajendran, N.K., Houreld, N.N., Abrahamse, H. (2018). Recent advances on silver nanoparticle and biopolymer-based biomaterials for wound healing applications. International journal of biological macromolecules 115, 165-175.

Lewis, K., Ausubel, F.M., 2006. Prospects for plant-derived antibacterials. Nature biotechnology 24, 1504-1507.

Maung, C.E.H., Choub, V., Cho, J.-Y., Kim, K.Y. (2022). Control of the bacterial soft rot pathogen, Pectobacterium carotovorum by Bacillus velezensis CE 100 in cucumber. Microbial pathogenesis 173, 105807.

Mendes, J., Abrunhosa, L., Teixeira, J., Camargo, E., Souza, C., Pessoa, J. (2014). Antifungal activity of silver colloidal nanoparticles against phytopathogenic fungus (Phomopsis sp.) in soybean seeds. International Journal of Biological, Veterinary, Agricultural and Food Engineering 8, 928-933.

Opara, E., Asuquo, A. (2016). An overview of characterization and identification of soft rot bacterium Erwinia in some vegetable crops. Greener J. Biol. Sci 6, 46-55.

Pao, S., Kelsey, D., Khalid, M., Ettinger, M. (2007). Using aqueous chlorine dioxide to prevent contamination of tomatoes with Salmonella enterica and Erwinia carotovora during fruit washing. Journal of food protection 70, 629-634.

Petropoulos, S.A., Sampaio, S.L., Di Gioia, F., Tzortzakis, N., Rouphael, Y., Kyriacou, M.C., Ferreira, I. (2019). Grown to be blue—Antioxidant properties and health effects of colored vegetables. Part I: Root vegetables. Antioxidants 8, 617.

Pritchard, L., Glover, R.H., Humphris, S., Elphinstone, J.G., Toth, I.K. (2016). Genomics and taxonomy in diagnostics for food security: soft-rotting enterobacterial plant pathogens. Analytical Methods 8, 12-24.

Pryshchepa, O., Pomastowski, P., Buszewski, B. (2020). Silver nanoparticles: Synthesis, investigation techniques, and properties. Advances in Colloid and Interface Science 284, 102246.

Rajeshkumar, S., Bharath, L. (2017). Mechanism of plant-mediated synthesis of silver nanoparticles–a review on biomolecules involved, characterisation and antibacterial activity. Chemico-biological interactions 273, 219-227.

Raoul des Essarts, Y., Cigna, J., Quêtu-Laurent, A., Caron, A., Munier, E., Beury-Cirou, A., Hélias, V., Faure, D. (2016). Biocontrol of the potato blackleg and soft rot diseases caused by Dickeya dianthicola. Applied and environmental microbiology 82, 268-278.

Rutolo, M.F., Clarkson, J.P., Covington, J.A. (2018). The use of an electronic nose to detect early signs of soft-rot infection in potatoes. Biosystems engineering 167, 137-143.

Sadowski, Z., Maliszewska, I., Grochowalska, B., Polowczyk, I., Kozlecki, T. (2008). Synthesis of silver nanoparticles using microorganisms. Materials Science-Poland 26, 419-424.

Sáenz-Baños, M., Latorre-Biel, J.I., Martínez-Cámara, E., Jiménez-Macías, E., Longo, F., Blanco-Fernández, J. (2022). Methodology for energy demand reduction of potato cold storage process. Journal of Food Process Engineering 45, e14127.

Salem, E.A., Abd El-Shafea, Y.M. (2018). Biological control of potato soft rot caused by Erwinia carotovora subsp. carotovora. Egyptian Journal of Biological Pest Control 28, 94.

Shaheen, H.A., Issa, M.Y. (2020). In vitro and in vivo activity of Peganum harmala L. alkaloids against phytopathogenic bacteria. Scientia Horticulturae 264, 108940.

Shankar, S.R., Rangarajan, R., Sarada, D., Kumar, C.S. (2010). Evaluation of antibacterial activity and phytochemical screening of Wrightia tinctoria L. Pharmacognosy Journal 2, 19-22.

Sharma, V.K., Yngard, R.A., Lin, Y. (2009). Silver nanoparticles: green synthesis and their antimicrobial activities. Advances in colloid and interface science 145, 83-96.

Siddiqui, Z.A., Hashmi, A., Khan, M.R., Parveen, A. (2020). Management of bacteria Pectobacterium carotovorum, Xanthomonas campestris pv. carotae, and fungi Rhizoctonia solani, Fusarium solani and Alternaria dauci with silicon dioxide nanoparticles on carrot. International Journal of Vegetable Science 26, 547-557.

Soltani Nejad, M., Samandari Najafabadi, N., Aghighi, S., Zargar, M., Stybayev, G., Baitelenova, A., Kipshakbayeva, G. (2023). Application of Biosynthesized Silver Nanoparticles from Oak Fruit Exudates against Pectobacterium carotovorum subsp. carotovorum Causing Postharvest Soft Rot Disease in Vegetables. Agronomy 13, 1624.

Toth, I.K., Bell, K.S., Holeva, M.C., Birch, P.R. (2003). Soft rot erwiniae: from genes to genomes. Molecular plant pathology 4, 17-30.

Tsibakhashvil, N., Kalabegishvili, T., Gabunia, V., Gintury, E., Kuchava, N., Bagdavadze, N., Pataraya, D., Gurielidzse, M., Gvarjaladze, D., Lomidze, L. (2010). Synthesis of silver nanoparticles using bacteria. Nano Studies 2, 179-182.

Vijayaraghavan, K., Ashokkumar, T. (2017). Plant-mediated biosynthesis of metallic nanoparticles: A review of literature, factors affecting synthesis, characterization techniques and applications. Journal of Environmental Chemical Engineering 5, 4866-4883.

Viswanath, H., Bhat, K., Bhat, N., Wani, T., Mughal, M.N. (2018). Antibacterial efficacy of aqueous plant extracts against storage soft rot of potato caused by Erwinia carotovora. Int. J. Curr. Microbiol. Appl. Sci 7, 2630-2639.

Worrall, E.A., Hamid, A., Mody, K.T., Mitter, N., Pappu, H.R. (2018). Nanotechnology for plant disease management. Agronomy 8, 285.

Zangeneh, M.M., Zangeneh, A., Tahvilian, R., Moradi, R. (2018). Antidiabetic, hematoprotective and nephroprotective effects of the aqueous extract of Falcaria vulgaris in diabetic male mice. Archives of Biological Sciences 70, 655-664.

Zikalala, N., Matshetshe, K., Parani, S., Oluwafemi, O.S. (2018). Biosynthesis protocols for colloidal metal oxide nanoparticles. Nano-Structures & Nano-Objects 16, 288-299.