INTRODUCTION

Chili pepper (Capsicum annuum L.) is considered as one of the most important commodities in Indonesia as it is widely used for household purposes and can be consumed as a fresh, dried or processed products. It is also used as main ingredients in some food industries and medicines. In 2010, chili was cultivated in 122,750 ha of Indonesian plantations with the average productivity of 6.58 t/ha which is then escalated into 8.35 t/ha in 2014 (Ministry of Agriculture, 2019). Apart from the agronomic factors, pests and diseases also contribute greatly to the low productivity of chili pepper. Some of the main diseases are bacterial leaf spot, anthracnose, Cercospora spot, Fusarium wilt, bacterial wilt and gemini virus (Melini, 2014). Bacterial leaf spot caused by Xanthomonas campestris pv. vesicatoria is one of the major pathogens that infect chili pepper plants (Potnis et al., 2015). The disease is commonly found in the cultivation of pepper plants with warm and humid environment. It infects most of the plant parts above the ground including the leaves, petioles, fruits, and stems are common symptoms of the bacterial infection (Potnis et al., 2015). Moreover, the damage and disadvantage caused by the infection are higher in the vegetative phase than in the generative phase (EFSA PLH Panel, 2014).

ARTICLE INFO

**Keywords:**
- Bacterial leaf spot
- Chili pepper
- Nano-chitosan
- Synthetic bactericide

**Article History:**
- Received: February 15, 2017
- Accepted: October 21, 2019

*) Corresponding author:
E-mail: rizkita@sith.itb.ac.id

**ABSTRACT**

Nano-chitosan is considered as a prospective replacement for synthetic bactericides. In this study, the antibacterial activity of nano-chitosan and synthetic bactericides was compared in four chili pepper cultivars (Bianca, Lado, Kiyo, and Tanamo) infected by Xanthomonas campestris. To assess the effect of nano-chitosan and synthetic bactericide on the growth of the X. campestris-infected chili pepper plants, some parameters were observed including the plant height, number of leaves and chlorophyll content. It was shown that nano-chitosan was highly effective in controlling the pathogen infection on Bianca, Lado, and Tanamo, but not significant on Kiyo. The application of synthetic bactericide, however, was effective on Bianca and Lado, but not significant on Kiyo and Tanamo. It was also shown that the application of nano-chitosan can improve the growth of the X. campestris-infected chili pepper plants based on the significant difference on the plant height, number of leaves and chlorophyll content of cultivars tested, especially in Kiyo, Lado, and Tanamo. The application of synthetic bactericide, however, did not significantly improve the growth of the X. campestris-infected chili pepper plants. Nano-chitosan was shown to be effective in reducing the infection of X. campestris and potentially be used as an alternative to synthetic bactericide.
Thus far, streptomycin and copper-based synthetic bactericides are common methods used to control the *X. campestris* infection. However, massive usage of synthetic bactericides was proven to be inefficient and potentially lead to more serious problems, such as pesticide residual accumulation, resistance of the pathogen, disease epidemic, eradication of natural enemies and environmental hazards. Moreover, the usage of synthetic pesticides can potentially increase 25% of the production cost (López-Caballero, Gómez-Guillén, Pérez-Mateos, & Montero, 2005). Therefore, it is important to find a disease control method with natural materials or biopesticides to be used as an alternative to protect plants from the *X. campestris* infection.

One of the potential biomaterials to be used as an antimicrobial is chitosan. Chitosan (poly (1,4)-2-amino-deoxy-β-D glucose) is the deacetylated product of chitin which is commonly found in crustacean shells. It is a simple linear polysaccharide that constitutes the β-1,4 linked D-glucosamine (GlcN) and N-acetyl-D-glucosamine (GlcNAc) (Katiyar, Hemantaranjan, Singh, & Bhanu, 2014). Chitosan is known to induce plant growths (Dzung, Khanh, & Dzung, 2011), contain antifungal (Atai, Atai, Amini, & Salehi, 2017; Dananjaya et al., 2017) and antibacterial properties (Cui, Bai, Rashed, & Lin, 2018; D’Almeida et al., 2017). Investigation on the role of nano-chitosan against pathogens have been reported in rice (Pham et al., 2019) and tomato (Chun & Chandrasekaran, 2019; Santiago et al., 2019).

In order to evaluate the potential of nano-chitosan as an alternative to synthetic bactericides on limiting the *X. campestris* infection to chili pepper plants, comparative study was conducted on four chili pepper varieties such as Bianca, Kiyo, Lado, and Tanamo. The research was designed using the completely randomized factorial design with five replications and four plants in each replication. Statistical analysis was performed using two way analysis of variance (ANOVA) followed by least significant difference (LSD) test. P-value ≤ 0.05 is considered as significant.

### Plant Preparation

Seeds of four chili pepper cultivars (Bianca, Lado, Kiyo, and Tanamo) were sowed in eight seedling trays with a soil mixture of top soil, manure, cocopeat, and husk (1:1:1:1). Watering was conducted 2-3 times per day, depending on the environmental factors. Growmore 32:10:10 fertilizer was applied on the first three weeks of growth with a dose of 1 g/L followed by NPK Mutiara 18:18:18 with a dose of 3.5 g/L. Insecticide was applied when needed.

### Pathogen Infection Method and Treatments Application

Nano-chitosan with a concentration of 1 mg/ml and pH 6.4 was applied on four chili pepper cultivars every 10 days using the foliar spray method started from day 22 after planting. A synthetic bactericide with streptomycin sulfate active ingredient, also with the same method, was applied to four chili pepper cultivars once a week started from day 22 after planting. One week after first application of nano-citosan and synthetic bactericide, a foliar spray method was used to inoculate 10^8 CFU/ml of *X. campestris* on plants with 4-5 leaves (± day 30 after planting) and followed by disease severity measurement.

### Disease Scoring System and Growth Parameters

Symptoms of the infection were observed for 12 days since the first day of inoculation, once in three days interval by observing symptom on the stems and leaves, and divided into 8 quadrants of infected area. Disease severity was measured using the Horsfall Barratt scoring system (Horsfall & Barratt, 1945) with modification, where 1 = not infected with disease, 2 = 1-3% infected with disease, 3 = 5-12% infected with disease, 4 = 12-
25% infected with disease, 5 = 26-50% infected with disease, and 6 = ≥ 50% infected with disease. A score of 1-2 is classified as low severity, scores 3-4 as moderate severity, and 5-6 as high severity. Growth parameters including the plant height, number of leaves, and chlorophyll content were observed every week for three weeks. Plant height was measured from the basal of the stem until an apical growing point. Leaf count was performed only for the mature ones whereas the chlorophyll content was measured using the Chlorophyll Meter SPAD-502 Plus Konica Minolta (SPAD unit) every 14 days.

RESULTS AND DISCUSSION

Effect of Nano-Chitosan and Synthetic Bactericide on the Degree of Infection of X. campestris-Infected Chili Pepper Plants

On chili pepper leaves, the infection of X. campestris can be observed by the appearance of a small brown spot which is then spreads throughout to almost all area of the leaf, turning leaf to yellow and defoliate (Fig. 1). When the four chili cultivars (Bianca, Tanamo, Kiyo, and Lado) were infected with X. campestris, Lado was shown to be the most resistance followed by Kiyo, Tanamo and Bianca (Fig. 2). Lado and Kiyo cultivars were shown to have a lower degree of X. campestris infection compared to Tanamo and Bianca. In comparison to the standard/control resistance and susceptible cultivars, Lado has high resistance to X. campestris infection whereas Kiyo, Tanamo, and Bianca have a moderate resistance level.

When the four cultivars were treated with nano-chitosan and synthetic bactericide (Fig. 3 and Fig. 4), the application of nano-chitosan was effective in reducing the degree of X. campestris infection on Bianca, Lado, and Tanamo, but not in Kiyo. The application of synthetic bactericide, however, was effective on Bianca and Lado, but not on Kiyo and Tanamo (LSD test α = 0.05, Fig. 3). Based on the ANOVA test with P-value ≤ 0.05, cultivars significantly influence the resistance of chilli pepper plants with F-value of 31.52 and P-value 0, similar with the usage of bactericidal compounds with F-value of 39.99 and P-value 0. This result suggests that there is an interaction between cultivars and the usage of bactericidal compounds (nano chitosan and synthetic bactericide) to resistance of X. campestris-infected chilli pepper plants (F-value 13.09 and P-value 0).

Fig. 1. Stages of bacterial leaf spot infection on chili pepper leaves: A) The initial infection was started by the appearance of a small brown spot on the leaf, observed 6 days post-infection; (B) Bacterial spot has spread throughout the leaf; (C) The last stage of infection, indicated by yellow and nearly defoliated leaf
Fig. 2. The degree of Infection of *X. campestris* on four chili pepper cultivars (Bianca, Kiyo, Lado, and Tanamo) compared to the standard/control resistance and susceptible cultivars. The degree of infection was calculated 12 days post inoculation. The experiment was conducted in 5 replications.

Fig. 3. The effect of nano-chitosan and a synthetic bactericide on the degree of *X. campestris* infection on four chili pepper cultivars (Bianca, Kiyo, Lado, and Tanamo). The degree of infection was calculated 12 days post inoculation using the Horsfall Barratt scoring system. The experiment was conducted on 4 cultivars with 5 replications. The data were analyzed further using two way analysis of variance (ANOVA) followed by LSD test with P-value ≤ 0.05. The untreated and pathogen only-treated plants were used as controls.
In contrast to other cultivars, Kiyo was shown not to be significantly different in all treatments (LSD test \( \alpha = 0.05 \), Fig. 3). Kiyo and Lado were shown to be more resistance than Tanamo and Bianca (Fig. 2). In Bianca, the application of nano-chitosan and synthetic bactericide was shown to be significantly effective on decreasing the infection of \( X. \) campestris (LSD test \( \alpha = 0.05 \), Fig. 3). However, the application of synthetic bactericide was shown to be more significant than nano-chitosan. In contrast, the application of nano-chitosan on Tanamo cultivar was more effective in decreasing the infection of \( X. \) campestris compared to the synthetic bactericide (LSD test \( \alpha = 0.05 \), Fig. 3). Based on the Horsfall & Barratt (1945) scoring system, Bianca has the highest degree of infection when challenged with \( X. \) campestris (1.28%, Fig. 3) which is less than 3% (index 2) suggesting that the four cultivars tested have low severity to \( X. \) campestris. Nevertheless, the application of nano-chitosan was shown to be effective in reducing the infection of \( X. \) campestris on four chili pepper cultivars and potentially be used as an alternative to synthetic bactericide.

Environmental conditions may contribute to the low degree of \( X. \) campestris infection. The temperature of 29.78°C and relative humidity of 66.75% can inhibit the growth of \( X. \) campestris because the pathogen grows optimal in warm conditions and high humidity with temperature of 25 to 30°C and 80% humidity (EFSA PLH Panel (EFSA...
Panel on Plant Health), 2014). According to EFSA PLH Panel (EFSA Panel on Plant Health) (2014), *Xanthomonas campestris* is able to penetrate the plant cell wall through natural openings such as stomata, lenticels, and hidatodes. Foliar spraying of nano-chitosan forms a thin film on the surface of the plant, thus creating a defense barrier that protects the plant from pathogen infection. It can also reduce the stomatal opening, thus diminish the chance of pathogenic penetration through a stomatal opening in some cultivars such as in Tanamo, Kiyo, and Lado (Xing et al., 2011).

Chitosan has been shown to inhibit multiple pathogens growth during *in vitro* bioassay at minimum concentration as shown in Table 1 (Rabea, Badawy, Steurbaut, & Stevens, 2009). However, the antibacterial activity can only be observed in acidic condition with a pH below 6.5 (El Hadrami, Adam, El Hadrami, & Daayf, 2010). Indirectly, to control and reduce infection, chitosan is widely used as a chelating agent that accommodate plants obtaining nutrients and minerals, thus inducing the plant immune system. It can inhibit the growth of pathogens when applied on foliar or directly to the plant growing medium. It has lower toxicity towards mammals or humans, which is an advantage over other antimicrobial substances (Wang et al., 2012).

Chitosan nanoparticle is more effective than regular size chitosan due to its smaller size and compact form. It has higher particle charges and higher affinity which enables it to bond with microbial cells and produce more effective interaction with the microbes. The water impermeable layer that formed after the application of nano-chitosan can also block the channels on cell surfaces and inhibit nutrient transport to microbes (Qi, Xu, Jiang, Hu, & Zou, 2004). Nano-chitosan is able to increase plant resistance through its ability as an elicitor by inducing defense responses in plants. The defense mechanisms are carried out by inducing morphological and physiological changes in plants. Chitosan can induce the synthesis of chitinase and glucanase enzymes that degrade pathogen cell wall and induce host plant immune system (Katiyar, Hemantaranjan, & Singh, 2015). Nano-chitosan can also induce the accumulation of H$_2$O$_2$ as a signal to the healthy part of the plant to speed up the healing process (El Hadrami, Adam, El Hadrami, & Daayf, 2010). It is able to induce the accumulation of phytoalexin as the antimicrobial response and provides further protection against other symptoms of infection (Uthairatanakij, da Silva, & Obsuwan, 2007) since nano-chitosan is able to act as PAMPs/MAMPs (Pathogen/Microbe-Associated Molecular Patterns) or common elicitors which induce non-host resistance and systemic immunity priming. Defense response may be developed by increasing the amount of H$^+$ and Ca$^{2+}$ that enter the cytosol, MAP-kinase activation, callus formation, abscisic acid, jasmonic acid (JA), phytoalexins, and pathogenesis-related protein synthesis (El Hadrami, Adam, El Hadrami, & Daayf, 2010). Calcium is one of the important signaling processes in plants because elicitor works by inducing changes in the free calcium concentration in cytosol ([Ca$^{2+}]_{cyt}$) (Katiyar, Hemantaranjan, & Singh, 2015).

**Table 1.** Minimal concentrations of chitosan to inhibit multiple microbial growths

| Microbes                  | Minimum Inhibitory Concentration (ppm) |
|---------------------------|----------------------------------------|
| **Bacterial:**            |                                        |
| *Agrobacterium tumefaciens* | 100                                    |
| *Bacillus cereus*         | 1000                                   |
| *Erwinia* sp.             | 500                                    |
| *Escherichia coli*        | 20                                     |
| *Pseudomonas fluorescens* | 500                                    |
| *Xanthomonas campestris*  | 500                                    |
| **Fungi:**                |                                        |
| *Botrytis cinerea*        | 10                                     |
| *Fusarium oxysporum*      | 100                                    |
| *Piricularia oryzae*      | 5000                                   |
| *Rhizoctonia solani*      | 1000                                   |
According to Uthairatanakij, da Silva, & Obsuwan (2007), chitosan can also induce a broad spectrum of the immune system of plants (Systemic Acquired Resistance or SAR) that made plants more resistant. SAR is developed around the infected part of the plants, so the plants become more resistant to secondary infection. Chitosan can also induce genes involved in plant defense responses such as genes that regulate PAL (Phenylalanine Ammonia-Lyase) and protease inhibitors (Katiyar, Hemantaranjan, & Singh, 2015). Furthermore, nano-chitosan can increase the activity of Tyrosine Ammonia-Lyase (TAL) on phenylpropanoid synthesis pathway and trigger the production of secondary metabolites such as lignin, flavonoid, and phytoalexin which have roles in plant defense. In susceptible plants, nano-chitosan will increase the production of polyphenol oxidase (Uthairatanakij, da Silva, & Obsuwan, 2007).

In contrast to chitosan that limits disease infection by improving plant resistance, synthetic bactericide with streptomycin sulfate as an active ingredient reduces infection by suppressing the microbial growth and inhibiting protein synthesis by binding to 16S rRNA of the 30S bacterial ribosomal subunit. It also interferes with the binding of methionyl-tRNA to the 30S subunit, causing errors in reading codons and reduce the bacterial growth (Sharma, Cukras, Rogers, Southworth, & Green, 2007).

Effect of Nano-Chitosan and Synthetic Bactericide on the Growth of the *X. campestris*-Infected Chili Pepper Plants

The plant height, number of leaves and chlorophyll content (SPAD Unit) were measured to determine whether nano-chitosan and synthetic bactericide is able to preserve the plant growth of the *X. campestris*-infected chili pepper plants. Based on the ANOVA test with P-value ≤ 0.05, the selection of chili cultivars (F-value 187.58 and P-value 0) and the usage of bactericidal compounds (F-value 18.6 and P-value 0) showed a significant effect on the plant height, suggesting a significant interaction between cultivars and bactericidal compounds used (nano-chitosan and synthetic bactericides) (F-value 2.69 and P-value 0.01).

The application of nano-chitosan had shown an increase in the plant height of Kiyo and Tanamo cultivars, but not on Bianca and Lado (LSD test α = 0.05, Fig. 5). On the contrary, the application of synthetic bactericide did not significantly improve the plant height on all cultivars tested, instead it reduced the plant height in Kiyo cultivar (LSD test α = 0.05, Fig. 5). As a control, the treatment of *X. campestris* only significantly reduced the plant height in Lado, but not in the other three cultivars (LSD test α = 0.05, Fig. 5). Overall, the application of nano-chitosan was shown to be potential on improving the growth of chili pepper, especially in Kiyo and Tanamo cultivars.

---

**Fig. 5.** The effect of nano-chitosan and synthetic bactericide on the plant height of four *X-campestris* infected chili pepper cultivars, measured 42 days after planting. The experiment was conducted on 4 cultivars with 5 replications. The data were analyzed further using two way analysis of variance (ANOVA) followed by LSD test with P-value ≤ 0.05. The untreated and pathogen only-treated plants were used as controls.
This result is supported by the Uthairatanakij, da Silva, & Obsuwan (2007) study that showed the effect of nano-chitosan in increasing plant productivity during the vegetative stage. It was shown that chitosan is able to induce plant growth by increasing the plant response to gibberellin, auxin, and cytokinin hormones. Spraying nano-chitosan on plant shoots can increase synthesis of auxin in shoot apical meristem via the tryptophan pathway. In addition, spraying nano-chitosan on young leaves can improve gibberellin hormones that speed up cell elongation for plant growth. Chitosan contains reactive N-groups and able to increase nitrogen mobility in the soil (Uthairatanakij, da Silva, & Obsuwan, 2007). Chitosan can also assist in water absorption due to its hydrophilic properties that may increase the nutrient transport (Ravi Kumar, 2000).

Based on the ANOVA test with P-value ≤ 0.05, the selection of chili cultivars (F-value 109.24 and P-value 0) and the usage of bactericidal compounds (nano-chitosan and synthetic bactericides, F-value 10.29 and P-value 0) have a significant effect on the number of leaves, suggesting a significant interaction between cultivars and bactericidal compounds used (F-value 2.51 and P-value 0.01). It was shown that the application of nano-chitosan had significantly increased the number of leaves in Lado and Tanamo cultivars, but not in Bianca and Kiyo (LSD test α = 0.05, Fig. 6). The application of synthetic bactericide, on the other hand, only shown a higher number of leaves in Lado, compared to the pathogen only-infected plants. Similar to the plant height measurement result, the treatment of X. campestris (pathogenic control) only significantly reduced the number of leaves in Lado, but not in the other three cultivars (LSD test α = 0.05, Fig. 6).

The increase number of leaves in Lado and Tanamo cultivars treated with nano-chitosan may be related to the chitosan characteristics that could increase the absorption of nutrients in the soil and improve nitrogen usage in the leaf growth (Nguyen Van, Dinh Minh, & Nguyen Anh, 2013). In addition, chitosan is a chitin-derived product that becomes a nitrogen source for plant growth. It assists in photosynthesis that aid the production of new cells, cell elongation, tissue thickening, and improvement of the vegetative growth (Uthairatanakij, da Silva, & Obsuwan, 2007). When treated with the X. campestris alone, the low number of leaves in Lado cultivar (Fig. 6) was supposedly due to the H$_2$O$_2$ accumulation and cell death of the infected leaves (Kim, Choi, & Hwang, 2010).
SPAD unit indicates the greenness of leaf level that linear to total chlorophyll and nitrogen content, as well as the photosynthesis efficiency (Percival, Keary, & Noviss, 2008). Based on the ANOVA test with P-value ≤ 0.05, the usage of bactericidal compounds (F-value 3.16 and P-value 0.03) and the selection of chili cultivars (F-value 11.41 and P-value 0) have a significant effect on the formation of chlorophyll, but there were no interaction between both (F-value 0.83 and P-value 0.59).

It was shown that there is a significant difference in the chlorophyll content of the nano-chitosan-treated cultivars compared to the other treatments (LSD test α = 0.05, Fig. 7). The increase of chlorophyll content in chili pepper plants applied with nano-chitosan is possibly due to the increasing amount of nutrition intake by the plant’s roots (Nguyen Van, Dinh Minh, & Nguyen Anh, 2013). Based on the research conducted by Dzung, Khanh, & Dzung (2011), the application of nano-chitosan improve plant nutrition intake in coffee plants by 9.49% on nitrogen intake; 11.76% on phosphorus intake; 3.77% on potassium intake, and 18.75% on calcium and magnesium intake. According to Dzung, Khanh, & Dzung (2011), besides improving the nutrition intake, the increase of chlorophyll content in plants can also caused by differential expression of chloroplast gene affected by nano-chitosan, resulting in chloroplast enlargement. In contrast, the application of synthetic bactericide on four cultivars infected by X. campestris only serves to inhibit the spread of pathogens and not to improve the plant growth (plant height, number of leaves and chlorophyll content). Streptomycin sulfate has no effect on plant growth because it works directly by inhibiting the bacterial growth. It was not absorbed by the plant cells and did not involve in plant metabolisms (Harris, 1953).

Fig. 7. The effect of nano-chitosan and synthetic bactericide on the chlorophyll content of four cultivars of chili pepper plants. The experiment was conducted on 4 cultivars with 5 replications. The chlorophyll content was measured using the Chlorophyll Meter SPAD-502 Plus Konica Minolta (SPAD unit) every 14 days. The data were analyzed further using two way analysis of variance (ANOVA) followed by LSD test with P-value ≤ 0.05. The untreated and pathogen only-treated plants were used as controls.
CONCLUSION

Nano-chitosan was highly effective in controlling the infection of bacterial spot disease (X. campestris) on Bianca, Lado, and Tanamo, but not significant on Kiyo cultivar. On the other hand, the application of synthetic bactericide was effective in controlling the X. campestris infection on Bianca and Lado, but not significant on Kiyo and Tanamo. Nano-chitosan was also shown to improve the growth of the X. campestris-infected chili pepper plants based on the significant difference on the plant height, number of leaves and chlorophyll content of cultivars tested, especially in Kiyo, Lado, and Tanamo. In contrast, the application of synthetic bactericide did not significantly improve the growth of the X. campestris-infected chili pepper plants. The application of nano-chitosan was shown to be effective in reducing the infection of X. campestris and potentially be used as an alternative to synthetic bactericide.

ACKNOWLEDGEMENT

The authors thank PT East West Seed Indonesia Cap Panah Merah for the in-kind contribution and academic material support during the experiment and to PT. Indofood and Banana group ITB for financial supports.

REFERENCES

Atai, Z., Atai, M., Amini, J., & Salehi, N. (2017). In vivo study of antifungal effects of low-molecular-weight chitosan against Candida albicans. Journal of Oral Science, 59(3), 425–430. https://doi.org/10.2334/josnusd.16-0292

Chun, S. C., & Chandrasekaran, M. (2019). Chitosan and chitosan nanoparticles induced expression of pathogenesis-related proteins genes enhances biotic stress tolerance in tomato. International Journal of Biological Macromolecules, 125, 948-954. https://doi.org/10.1016/j.ijbiomac.2018.12.167

Cui, H., Bai, M., Rashed, M. M. A., & Lin, L. (2018). The antibacterial activity of clove oil/chitosan nanoparticles embedded gelatin nanofibers against Escherichia coli O157:H7 biofilms on cucumber. International Journal of Food Microbiology, 266, 69–78. https://doi.org/10.1016/j.ijfoodmicro.2017.11.019

D’Almeida, M., Attik, N., Amalric, J., Brunon, C., Renaud, F., Abouelleil, H., ..., Grosgogeat, B. (2017). Chitosan coating as an antibacterial surface for biomedical applications. PLoS ONE, 12(12), e0189537. https://doi.org/10.1371/journal.pone.0189537

Dananjaya, S. H. S., Erandani, W. K. C. U., Kim, C. H., Nikapitiya, C., Lee, J., & De Zoysa, M. (2017). Comparative study on antifungal activities of chitosan nanoparticles and chitosan silver nano composites against Fusarium oxysporum species complex. International Journal of Biological Macromolecules, 105(Part 1), 478–488. https://doi.org/10.1016/j.ijbiomac.2017.07.056

Dzung, N. A., Khanh, V. T. P., & Dzung, T. T. (2011). Research on impact of chitosan oligomers on biophysical characteristics, growth, development and drought resistance of coffee. Carbohydrate Polymers, 84(2), 751–755. https://doi.org/10.1016/j.carbpol.2010.07.066

EFSA PLH Panel (EFSA Panel on Plant Health). (2014). Scientific opinion on the pest categorisation of Xanthomonas campestris pv. vesicatoria (Dodge) Dye. EFSA Journal, 12(6), 1–26. https://doi.org/10.2903/j.efsa.2014.3720

El Hadrami, A., Adam, L. R., El Hadrami, I., & Daayf, F. (2010). Chitosan in plant protection. Marine Drugs, 8(4), 968–987. https://doi.org/10.3390/md8040968

Harris, W. E. (1953). Effect of five antibiotics in varying concentrations on growth of young corn plants. Butler University Botanical Studies, 11(6), 71–86. Retrieved from http://digitalcommons.butler.edu/cgi/viewcontent.cgi?article=1217&context=botanical

Horsfall, J. G., & Barratt, R. W. (1945). An improved grading system for measuring plant diseases. Phytopathology, 36, 655. Retrieved from http://www.garfield.library.upenn.edu/classics1986/A1986A666500001.pdf

Katiyar, D., Hemantaranjan, A., & Singh, B. (2015). Chitosan as a promising natural compound to enhance potential physiological responses in plant: a review. Indian Journal of Plant Physiology, 20(1), 1–9. https://doi.org/10.1007/s40502-015-0139-6

Katiyar, D., Hemantaranjan, A., Singh, B., & Bhanu, A. N. (2014). A future perspective in crop protection: Chitosan and its oligosaccharides. Advances in Plants & Agriculture Research, 1(1), 23–30. https://doi.org/10.15406/apar.2014.01.00006

Kim, N. H., Choi, H. W., & Hwang, B. K. (2010). Xanthomonas campestris pv. vesicatoria
effector avrbst induces cell death in pepper, but suppresses defense responses in tomato. Molecular Plant-Microbe Interactions, 23(8), 1069–1082. https://doi.org/10.1094/PMPI-23-8-1069

López-Caballero, M. E., Gómez-Guillén, M. C., Pérez-Mateos, M., & Montero, P. (2005). A chitosan-gelatin blend as a coating for fish patties. Food Hydrocolloids, 19(2), 303–311. https://doi.org/10.1016/j.foodhyd.2004.06.006

Meilin, A. (2014). Hama dan penyakit pada tanaman cabai serta pengendaliannya. Jambi: Balai Pengkajian Teknologi Pertanian Jambi. Retrieved from http://jambi.litbang.pertanian.go.id/ind/images/PDF/14bookcabe.pdf

Ministry of Agriculture. (2019). Basis data statistik pertanian. Retrieved from http://aplikasi.pertanian.go.id/bdsp/newdata.asp

Nguyen Van, S., Dinh Minh, H., & Nguyen Anh, D. (2013). Study on chitosan nanoparticles on biophysical characteristics and growth of Robusta coffee in green house. Biocatalysis and Agricultural Biotechnology, 2(4), 289–294. https://doi.org/10.1016/j.jbcab.2013.06.001

Percival, G. C., Keary, I. P., & Noviss, K. (2008). The potential of a chlorophyll content SPAD meter to quantify nutrient stress in foliar tissue of sycamore (Acer pseudoplatanus), English oak (Quercus robur), and European beech (Fagus sylvatica). Arboriculture and Urban Forestry, 34(2), 89–100. Retrieved from https://www.semanticscholar.org/paper/THE-POTENTIAL-OF-A-CHLOROPHYLL-CONTENT-SPAD-METER-Percival-Keary/1614f77e9be3ad31c19d09a6fd1fd4c58d5d4eb27

Pham, T. T., Nguyen, T. H., Thi, T. V., Nguyen, T.-T., Le,T. D., Hoang Vo, D. M., ... Bach, L. G. (2019). Investigation of chitosan nanoparticles loaded with protocatechuic acid (PCA) for the resistance of Pyricularia oryzae fungus against rice blast. Polymers, 11(1), 177. https://doi.org/10.3390/polym11010177

Potnis, N., Timilsina, S., Strayer, A., Shantharaj, D., Barak, J. D., Paret, M. L., ... Jones, J. B. (2015). Bacterial spot of tomato and pepper: diverse Xanthomonas species with a wide variety of virulence factors posing a worldwide challenge. Molecular Plant Pathology, 16(9), 907-920. https://doi.org/10.1111/mpp.12244

Qi, L., Xu, Z., Jiang, X., Hu, C., & Zou, X. (2004). Preparation and antibacterial activity of chitosan nanoparticles. Carbohydrate Research, 339(16), 2693–2700. https://doi.org/10.1016/j.carres.2004.09.007

Rabea, E. I., Badawy, M. E. I., Steurbaut, W., & Stevens, C. V. (2009). In vitro assessment of N-(benzyl)chitosan derivatives against some plant pathogenic bacteria and fungi. European Polymer Journal, 45(1), 237–245. https://doi.org/10.1016/j.eurpolymj.2008.10.021

Ravi Kumar, M. N. V. (2000). A review of chitin and chitosan applications. Reactive and Functional Polymers, 46(1), 1–27. https://doi.org/10.1016/S1381-5148(00)00038-9

Santiago, T. R., Bonatto, C. C., Rossato, M., Lopes, C. A. P., Lopes, C. A., Mizubuti, E. S. G., & Silva, L. P. (2019). Green synthesis of silver nanoparticles using tomato leaf extract and their entrapment in chitosan nanoparticles to control bacterial wilt. Journal of the Science of Food and Agriculture, 99(9), 4248–4259. https://doi.org/10.1002/jsfa.9656

Sharma, D., Cukras, A. R., Rogers, E. J., Southworth, D. R., & Green, R. (2007). Mutational analysis of S12 protein and implications for the accuracy of decoding by the ribosome. Journal of Molecular Biology, 374(4), 1065–1076. https://doi.org/10.1016/j.jmb.2007.10.003

Uthairatanakij, A., da Silva, J. A. T., & Obsuwan, K. (2007). Chitosan for improving orchid productivity and quality. Orchid Science and Biotechnology, 1(1), 1–5. Retrieved from http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.571.4861&rep=rep1&type=pdf

Wang, Y., Li, L., Li, B., Wu, G., Tang, Q., Ibrahim, M., ... Sun, G. (2012). Action of chitosan against Xanthomonas pathogenic bacteria isolated from Erwinia carotovora. Molecules, 17, 7028–7041. https://doi.org/10.3390/molecules17067028

Xing, Y., Li, X., Xu, Q., Yun, J., Lu, Y., & Tang, Y. (2011). Effects of chitosan coating enriched with cinnamon oil on qualitative properties of sweet pepper (Capsicum annuum L.). Food Chemistry, 124(4), 1443–1450. https://doi.org/10.1016/j.foodchem.2010.07.105