

BIOLOGICAL CONTROL OF POTATO BACTERIAL WILT (*RALSTONIA SOLANACEARUM*) USING SELECTED PLANT EXTRACTS

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ABSTRACT

The current study evaluated the effect of methanol and water extracts of tobacco (*Nicotiana tabacum* L.), wild marigold (*Tagetes minuta* L.), and garlic (*Allium sativum* L.) at 50 mg·mL⁻¹ applied at different frequencies (weekly, biweekly, and monthly) on the control of potato bacterial wilt under field conditions (two growing seasons in 2021). Weekly and biweekly application of methanol extracts from tobacco and wild marigold showed higher efficacy of biological control of the pathogen (58% and 57%) on aerial parts of potato plants than monthly application (48%). In potato tubers, weekly and biweekly application of methanol extracts caused higher biological control efficacy (75.92% and 67.39%) than monthly application (52.49%). Weekly and biweekly application of methanol extracts of tobacco and wild marigold also reduced postharvest infection and postharvest yield losses caused by potato bacterial wilt during the storage period, among other treatments. These experiments conclude that weekly or biweekly application of methanol extract from tobacco and wild marigold at 50 mg·mL⁻¹ is a practical approach to control potato bacterial wilt in the field and storage.

Key words: *Allium sativum*, *Nicotiana tabacum*, *Tagetes minuta*, *Ralstonia solanacearum*, control efficacy, postharvest bulb infection, postharvest bulb loss

INTRODUCTION

Bacterial diseases are among the major limiting factors in potato production worldwide. In Rwanda, bacterial wilt caused by *Ralstonia solanacearum* (Smith) is the most problematic pathogen of potatoes because there are no known effective chemicals used against it, and cultural practices fail to manage it (Uwamahoro et al. 2018). Agrochemicals such as antibiotics or copper-derived compounds have been used to control bacterial wilt, but they failed to control it effectively (Derib et al. 2013). In addition, overuse of these conventional chemicals is associated with environmental pollution and endangering the consumers' and wild animals' welfare, as well as, the development of new strains of the bacterium,

which are more resistant to the bactericides (Vu et al. 2017; Mulugeta et al. 2020).

Therefore, identifying new alternatives that can control this pathogen in sustainable agriculture for food security and safety and which is environmentally friendly can be helpful in overcoming the damage caused by this plant pathogen (Awad 2016). Plant species belonging to different families were reported to contain renewable botanicals with antimicrobial effects, which can substitute for synthetic pesticides (Li et al. 2016). Most of the studies have focused on the *in vitro* antibacterial activity of plant extracts, but the studies on these active compounds against phytopathogenic bacteria under field conditions or during a postharvest period are crucial but still limited (Vu et al. 2017; Mulugeta et al. 2020).

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Previously, an *in vitro* screening of methanol, chloroform, and water extracts of ten plant species against *R. solanacearum* was carried out in Rwanda. The screening showed that methanol and water extracts from tobacco, wild marigold, and garlic are the most promising in managing potato bacterial wilt (Mutimawurugo et al. 2020). Thus, the objective of this study was to evaluate the efficacy of methanolic and water extracts from tobacco, wild marigold, and garlic materials at 50 mg·mL⁻¹ as well as the effective application frequency of these selected plant extracts against potato bacterial wilt under field conditions and postharvest infection (PHI) and postharvest yield losses (PHL) caused by the pathogen during storage.

MATERIALS AND METHODS

Study area

Field experiments for growing seasons A (September 2020 – January 2021) and B (February–June 2021) were performed at the University of Rwanda Experimental Farm, Busogo Campus, Musanze District, Rwanda. This region is one of the main potato production areas in Rwanda (Ndungutse et al. 2019). Climatic and edaphic conditions in the study area during seasons A and B of field experiment were collected by Meteo Rwanda. Season A was a short rain (average rainfall – 708.7 mm), while season B was a long rain (average rainfall – 816 mm). In seasons A and B, the average ambient temperature ranged from 11.2 to 22.2°C, soil temperature 20.4 and 20.3°C, ambient relative humidity 75.2% and 75.5%, and soil moisture content in season A was 26.3% and 26.8% in season B.

Preparation of bacterial inoculum

Bacterial inoculum was prepared at the Plant Pathology Laboratory of the Rwanda Agriculture Board (RAB) Northern Zone, Musanze. Bacterial inoculum used in this experiment was isolated from diseased ‘Gikungu’ potatoes. ‘Gikungu’ isolate was chosen based on the virulence test carried out earlier under a greenhouse experiment (Mutimawurugo et al. 2019) as the most virulent among other inocula tested. After isolation of the bacterium, it was identified through a vascular flow technique, cultural and morphological characteristics on Kelman’s triphenyl tetrazolium chloride (TTC), and Casamino acid–peptone–glucose (CPG) culture media (Kelman 1954; Mihovilovich 2017), as well as on

biovar and gram staining. The bacterium was then purified and stored in a sterile glycerol stock at –20°C until use.

Preparation of plant extracts

For three weeks, the collected aerial parts of tobacco (‘Virginia’), wild marigold (‘Gan Eden’), and bulb garlic (African garlic) plants were dried under ambient room temperature. This process was supplemented with oven drying at 40°C for two days. Completely dried materials were ground into powdery and then soaked in water or methanol at the ratio of 1:4 and left to shake for three days on a rotary shaker (100 rpm at 27°C). It was followed by filtration of this mixture with Whatman No. 42 filter paper and solvent evaporation using rotar vapor at 40°C and 280 rpm until complete drying. Later, precipitates were diluted with 50 mg·mL⁻¹ with 1% dimethyl sulfoxide (DMSO) and stored at 4°C until use (Mwitari et al. 2013). Methanol and water extracts were chosen because they inhibited the growth of bacteria at a higher level than chloroform extracts in previous *in vitro* screening experiments (Mutimawurugo et al. 2020).

Preparation of potato tubers and planting

The biological control efficacy (BCE) of plant extracts application frequencies against potato bacterial wilt was evaluated on susceptible potato cultivar – ‘Kirundo’ under field conditions. Certified and visually healthy potato tubers were obtained from the Kinigi RAB Station. Tubers were washed in running tap water, surface sterilized by using 70% ethanol for five minutes, and after rinsing in sterile distilled water, they were left to dry for one hour under room temperature conditions. Then, the tubers were soaked overnight in methanolic or water extracts of tobacco, wild marigold, and garlic previously diluted at 50 mg·mL⁻¹ with 1% DMSO or in 1% DMSO and 2% copper oxychloride used as negative and positive controls, respectively. The following day, the tubers were left standing under shade for a day to allow the sticking of active compounds. The tubers were then inoculated by soaking them overnight in bacterial suspension at a concentration of 10⁸ CFU mL⁻¹ and incubated for 24 hours at room temperature to enhance the sticking of the bacteria prior to planting. Treated tubers were grown under field conditions for three months. Before planting, the experimental plot was double dug to a depth of 20 cm, lined with a polyethylene sheet (to reduce bacterial cells spreading

in the plot soil), and filled with the top soil mixed with NPK 17:17:17 (300 kg·ha⁻¹). The field experiments were laid out in a split-split plot design and three replications. Tobacco, wild marigold, and garlic were also revealed to be the most promising plant extracts in controlling *R. solanacearum* among ten test plant extracts in the same experiment. The concentration of 50 mg·mL⁻¹ was selected from a pilot greenhouse experiment, which was conducted to determine the effective dose of selected plant materials against potato bacterial wilt. In season A the preceding crop was beans, in season B it was maize. In both seasons, potato plants were grown at spacing of 75 cm (inter-row) and 30 cm (intra-row).

Plant extracts application

The experimental factors used in this *in vivo* test were three plant materials (tobacco, wild marigold, and garlic), two solvent (methanol and water) extracts, and three application frequencies (weekly, biweekly, and monthly). Plant extracts were applied by injecting three potato haulms per plant at the third leaf from the top with 50 µL of plant extracts at a concentration of 50 mg·mL⁻¹ every week, every two weeks, and every month, from 30 to 60 days after planting. Thus, application of extracts were made five, three, and two times. A positive control (2% copper oxychloride) was applied biweekly as recommended, whereas a negative control (1% DMSO) was applied at the same frequencies as plant extracts. This study used four main plots: three plots with plant extracts (tobacco, wild marigold, and garlic) and one plot of control (positive or negative). Each main plot with plant extracts was subdivided into two subplots (water and methanol as solvents). Each subplot in turn was split into three sub-subplots (application weekly, biweekly or monthly). Therefore, in each main plot with extracts six treatments were used (two solvent extracts × three application frequencies), which resulted in 18 treatments for three main plots of plant extracts. In each treatment, under field conditions, 48 plants (six treatments × eight plants) in total, per main plot per replication. In addition, each main plot was replicated three times in the field. In the case of controls, one plot was split into two subplots (negative and positive controls). The subplot of 1% DMSO that was used as a negative control was subdivided into three sub-subplots (weekly, biweekly,

and monthly application), while in the subplot of positive control 2% copper oxychloride was only applied biweekly. Therefore, four treatments were used in this main control plot. In each treatment, eight potato plants were also grown per replication and therefore, 32 plants in total in this main plot. Every treatment was also replicated three times in the field. Briefly, 22 treatments replicated three times were used during this field experiment.

Data collection in the field experiments

The BCE of application frequencies of plant extracts against potato bacterial wilt was evaluated from 20 to 50 days after the first plant extract injection (50–80 days after planting) with an interval of 10 days. In these field experiments (seasons A and B 2021), sampling on disease incidence (DI) was done on the four plants per each experimental treatment in each replication. The plant was considered diseased when it showed the usual symptoms of bacterial wilt.

In addition, disease incidence – DI (%) on tubers was evaluated at harvesting time by the formula of Priou et al. (2001):

$$DI = \frac{n}{N} \times 100;$$

where DI – disease incidence; n – number of infected plants; and N – total number of plants assessed.

From this experiment, biological control efficacy – BCE (%) of plant extracts against bacterial wilt was calculated according to Guo et al. (2004):

$$BCE = \frac{(DI_{control} - DI_{treatment\ group})}{DI_{control}} \times 100.$$

Data collection in postharvest experiments

In addition, the efficacy of extracts application and frequencies in managing tuber PHI and PHL caused by bacterial wilt in storage was determined. Therefore, 18 healthy harvested tubers from the field were picked from each treatment (from three replications). Prior to storage, surface-sterilized tubers were submerged in plant extracts or controls and bacterial suspension at the same pattern as in seed preparation for field experiments prior to planting. After that, tubers were stored under ambient room temperature in polythene bags for 37 days, during which the observation of tuber PHI and total PHL caused by *R. solanacearum* was evaluated. This period of 37 days of storage depended on the health of the tubers because at 37 day, most of the tubers nontreated with extracts have already rotted,

and there were no more samples to be used. Application frequencies of plant extracts were also achieved weekly, biweekly, and monthly (in the same pattern as in field experiments) by soaking healthy tubers in extracts or controls. The number of infected tubers and the total number of stored tubers were used to calculate the percentage of PHI and the percentage of total PHL, as described by Rahman et al. (2012). Each treatment was stored in three bags (considered as replications). Data collection in postharvest started from 7 to 37 days of storage with an interval of one week.

Data analysis

In the field experiments, the mean of DI of sampled plants from each treatment was calculated and used to calculate the BCE of each treatment in three replications starting from 20 to 50 days after the first injection of plant extracts. In the field experiments, a split-split plot design was considered, while the postharvest design was a factorial and completely randomized design. During postharvest, the same average was used to calculate the percentage of PHI and total PHL caused by potato bacterial wilt after 37 days of storage. The analysis of variance (ANOVA) was carried out using SAS software version 9 (TS M0) to determine the difference in BCE of methanol and water extracts from tobacco, wild marigold, and garlic species applied every week, every two weeks and every month at 50 mg·mL⁻¹ against bacterial wilt incidence in potato plants and tubers, PHI, and PHL. The treatment means were separated using Tukey's test ($p \leq 0.05$).

RESULTS

Influence of plant extracts and application frequency on aerial parts of potato plants during field culture

The BCE of methanol and water extracts from tobacco, wild marigold, and garlic, which were applied weekly, biweekly, and monthly, was determined in seasons A and B from 20 to 50 days after extract injection (DAI). During the whole observation period, there were no interactions between all these experimental factors in terms of BCE against the pathogen (Table 1). Therefore, the effect of these independent variables on DI and BCE were tested separately. Thus, the BCE of plant extracts against

bacterial wilt in potato plants was evaluated separately in seasons A and B. Along both seasons, tobacco, wild marigold, and garlic extracts significantly reduced DI, thus resulting in higher BCE as compared to copper used as positive control (Fig. 1). Tobacco extract at the end of growth reduced DI by 56.5% and 70.4%, wild marigold extract by 50.8% and 65.6%, and garlic extract by 44.8% and 56.1% in seasons A and B, respectively, compared to the positive control. BCE had the same pattern in each term. The most effective was application of tobacco extract, than marigold, garlic, and copper. No big differences in BCE were observed between tobacco and marigold extracts, but between tobacco and garlic extracts usually differences were significant. In the season A, BCE values were lower due to less infection in the field.

The BCE values presented the same patterns in both seasons regarding application frequency. Always the lowest value was obtained with copper application. The DI of potato plants in terms of application frequency was reduced at the end of storage by: 54.4% and 68.9% for weekly application, 53.6% and 64.9% for biweekly application, and 43.8% and 58.4% for monthly application, in seasons A and B, respectively, which was highly significant to the BCE value in copper. Weekly application was the most effective followed with biweekly and monthly, but no significant differences were noted between weekly and biweekly application (Fig. 2).

No significant differences in BCE were obtained between solvent extracts, except at 30 (season A) and 40 DAI (seasons B), where methanol extract expressed higher BCE than water extract (Fig. 3). At the end of the observation period, methanol and water extracts reduced DI in potato plants by 52.7% and 66.0% (season A) and by 48.6% and 62.1% in season B, compared to the copper control.

Influence of plant extracts and application frequency on tubers infection after harvesting

During the observation period, there was no interactions between all these experimental factors regarding the BCE of plant extracts against potato bacterial wilt on tubers. In both seasons, there were no significant differences between treatments regarding extracts (Fig. 4). All these extracts led to lower DI and higher BCE compared to copper. DI in potato tubers was 54.6% and 63.6% for tobacco, 57.0% and 60.1%

for wild marigold, and 41.2% and 56.7% for garlic in seasons A and B, respectively. The frequency of weekly and biweekly application resulted in reduction in DI in tubers and a higher BCE value in both seasons compared to monthly application (Fig. 5). The BCE of the monthly application of extracts was several times higher than copper BCE in both seasons. Weekly application resulted in significantly higher

DI values of potato tubers compared to copper – 59.9% and 70.8%, biweekly application – 56.9% and 62.3%, and monthly – 35.84% and 47.36% (Fig. 5). In season A, there was no significant difference in BCE between methanol and water extracts, while in season B, methanol extracts were more effective than water extracts, but both were significantly more effective than using copper (Fig. 6).

Table 1. Data of interaction between tested factors in biological control efficacy – BCE (%) in potato plants (20, 30, 40, and 50 days after extract injection) in field experiments

Days after extract injection	Source	DF	Type III SS	Mean square	F value	Pr > F
20	PE*SE	2	92.49032	46.24516	0.15	0.8626 NS
	PE*AF	4	790.37197	197.59299	0.63	0.6406 NS
	PE*SE*AF	6	676.62616	112.77103	0.36	0.9009 NS
	S*PE*SE*AF	10	1020.98406	102.09841	0.33	0.9711 NS
30	PE*SE	2	325.99244	162.99622	0.75	0.4757 NS
	PE*AF	4	443.41670	110.85417	0.51	0.7281 NS
	PE*SE*AF	6	392.06478	65.34413	0.30	0.9344 NS
	S*PE*SE*AF	10	799.36027	79.93603	0.37	0.9563 NS
40	PE*SE	2	174.563529	87.281764	0.70	0.4986 NS
	PE*AF	4	175.900395	43.975099	0.35	0.8403 NS
	PE*SE*AF	6	743.200583	45.490298	0.37	0.6946 NS
	S*PE*SE*AF	10	1303.711089	130.371109	1.05	0.4123 NS
50	PE*SE	2	193.051781	96.525890	0.60	0.5521 NS
	PE*AF	4	293.033093	73.258273	0.45	0.7686 NS
	PE*SE*AF	6	632.939955	105.489992	0.65	0.6861 NS
	S*PE*SE*AF	10	989.792491	98.979249	0.61	0.7965 NS

PE – plant extracts, SE – solvent extracts, AF – application frequency, S – season, NS – not significantly different

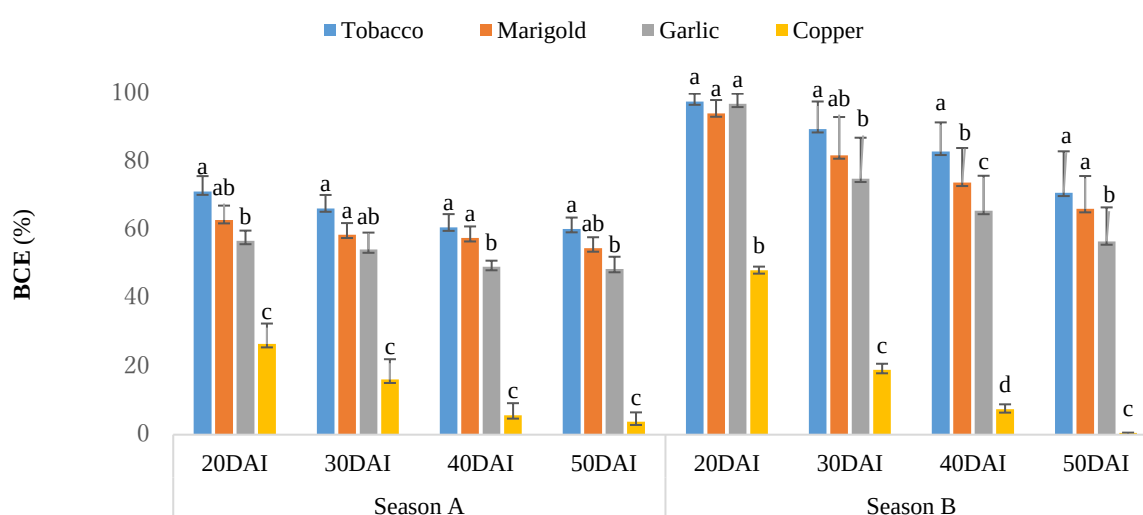


Figure 1. Biological control efficacy – BCE (%) of plant extracts against bacterial wilt in potato plants in seasons A and B 2021 on various days after extract injection – DAI

BCE = $[(DI_{\text{negative control}} - DI_{\text{treatment}}) / DI_{\text{negative control}}] \times 100$; negative control – 1% DMSO, positive control – 2% copper oxychloride; values with the same letter in the same season and measurement term are not significantly different at $p \leq 0.05$, according to Tukey's test; error bars represent the standard deviation

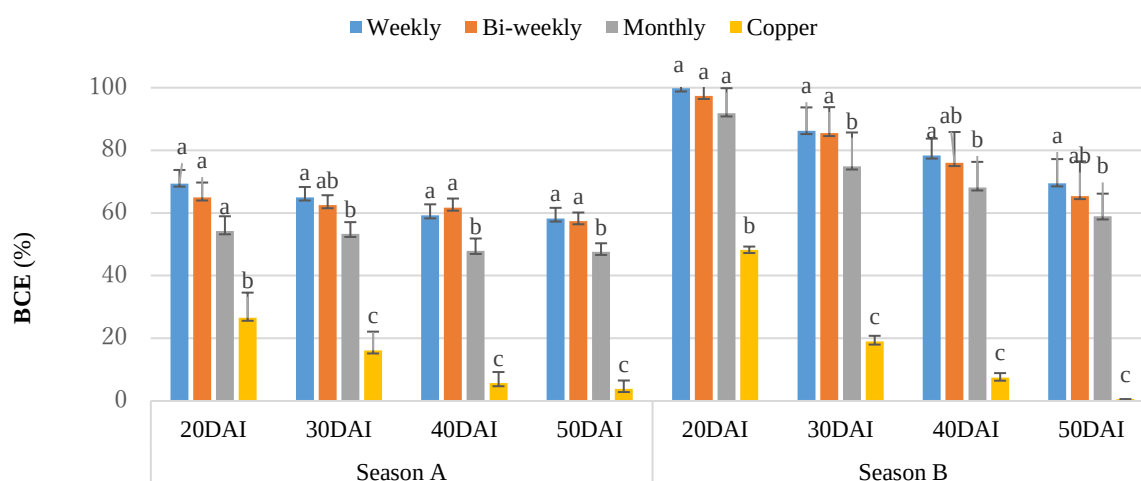


Figure 2. Biological control efficacy – BCE (%) of application frequencies against bacterial wilt in potato plants in seasons A and B 2021 on various days after extract injection – DAI

Note: see Figure 1

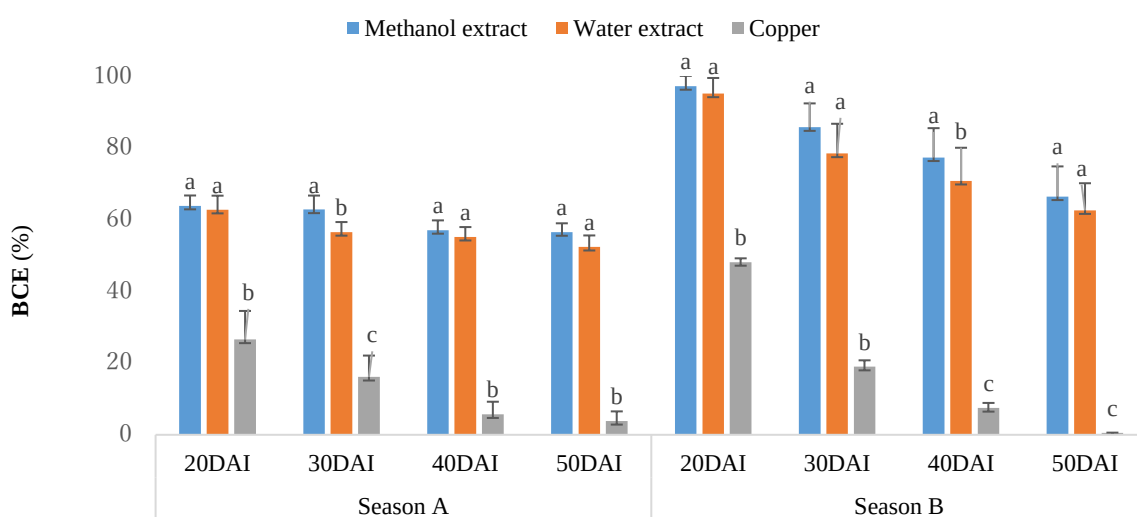


Figure 3. Biological control efficacy – BCE (%) of solvent extracts against bacterial wilt in potato plants in seasons A and B 2021 on various days after extract injection – DAI

Note: see Figure 1

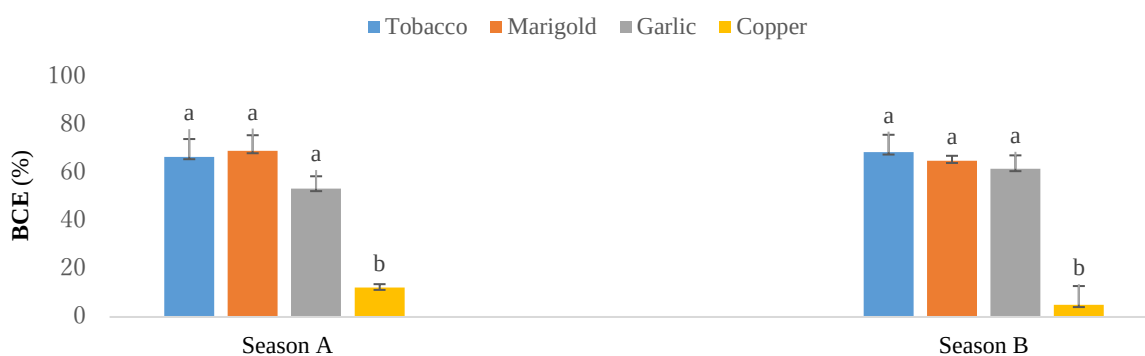


Figure 4. Biological control efficacy – BCE (%) of plant extracts against bacterial wilt in potato tubers in seasons A and B 2021

Note: see Figure 1

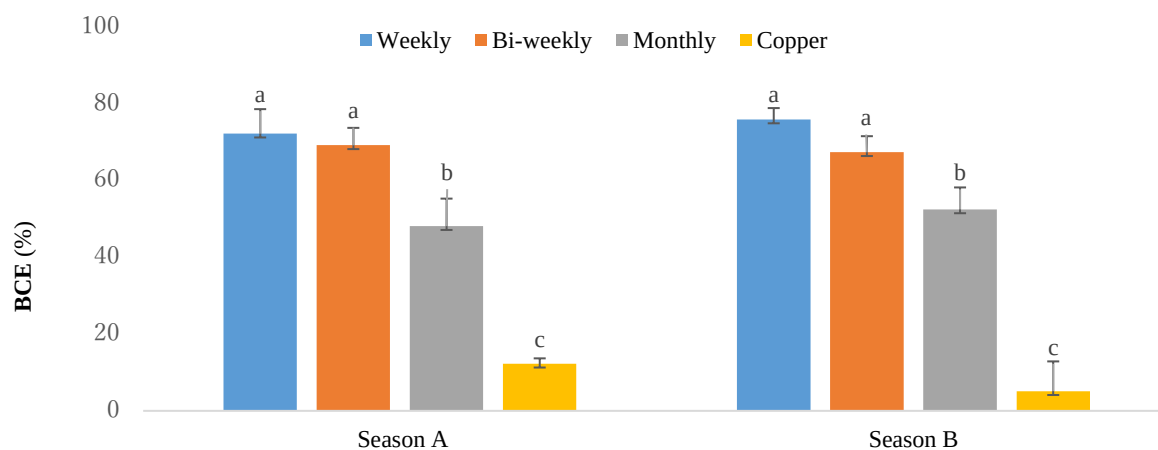


Figure 5. Biological control efficacy – BCE (%) of application frequencies against bacterial wilt in potato tubers in seasons A and B 2021

Note: see Figure 1

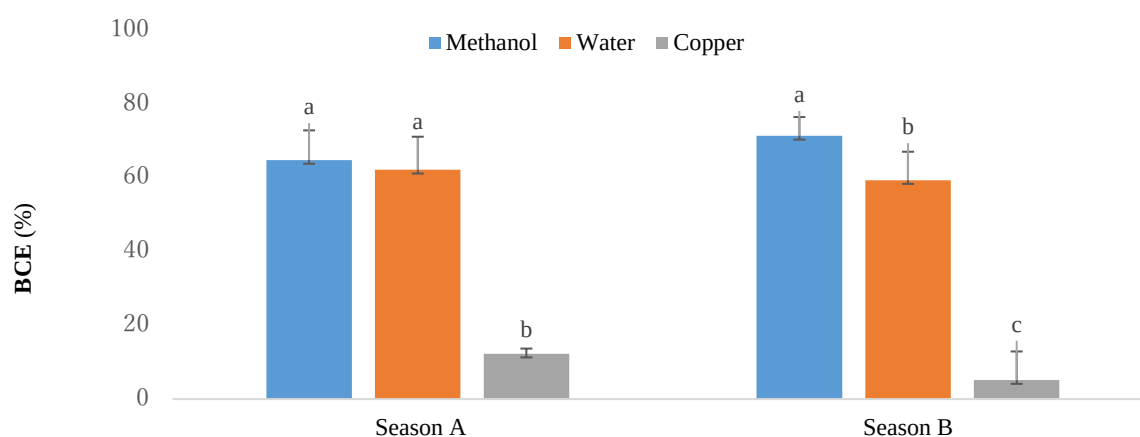


Figure 6. Biological control efficacy – BCE (%) of solvent extracts against bacterial wilt in potato tubers in seasons A and B 2021

Note: see Figure 1

Effect of plant extracts and application frequency on tubers inoculated postharvest

Weekly, biweekly, and monthly application of methanol and water extracts from tobacco, wild marigold, and garlic were tested against bacterial PHI and PHL caused by bacterial inoculation before storage. In the seasons, there were no significant differences in PHI and PHL between treatments with different plant extracts. Application of plant extracts resulted in a lower PHI and PHL rates in tubers compared with treatments with copper and DMSO (Fig. 7). Plant extracts reduced the percentage of PHI twice in both seasons compared to copper and control.

Similar proportions was obtained regarding PHL (Fig. 7).

In both seasons, application frequency of plants extracts were equally effective in reducing of PHI and PHL compared with copper and in control. The weekly and biweekly extract application was more effective than monthly application and twice as effective as copper and the control (Fig. 8).

The effect of solvent extracts on PHI and PHL showed no significant differences in both seasons, except for season B, in which the methanol extract was more effective (Fig. 9). Both, methanol and water extracts reduced PHI and PHL of tubers significantly compared with copper and DMSO.

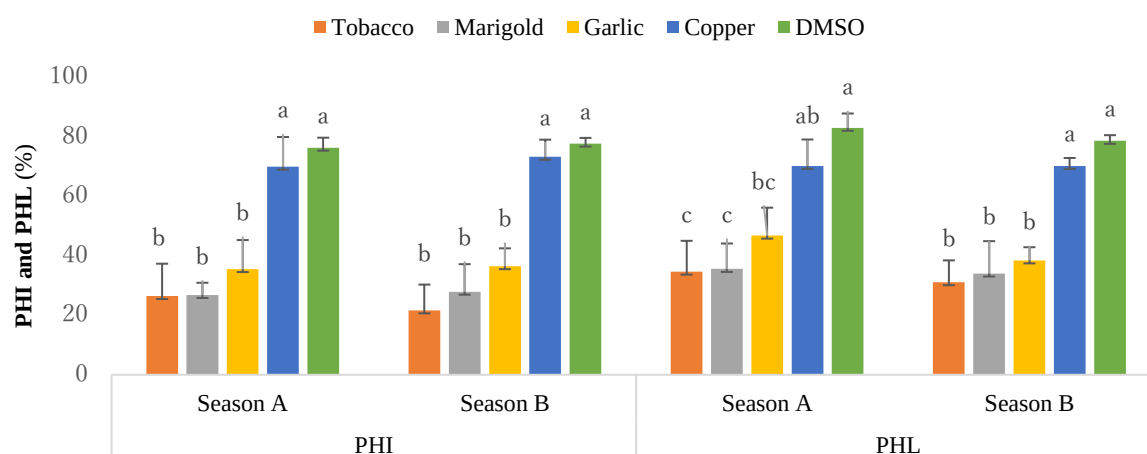


Figure 7. Effect of plant extracts on potato tuber postharvest infection – PHI and postharvest yield losses – PHL caused by *Ralstonia solanacearum* in seasons A and B 2021

Note: see Figure 1

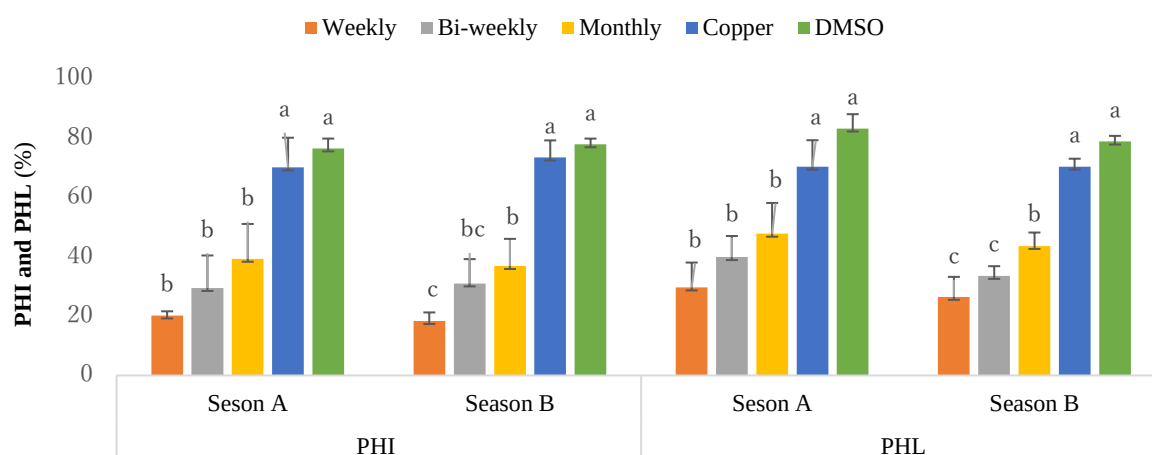


Figure 8. Effect of application frequency of plant extracts on potato tuber postharvest infection – PHI (%) and postharvest yield losses – PHL (%) caused by *Ralstonia solanacearum* in seasons A and B 2021

Note: see Figure 1

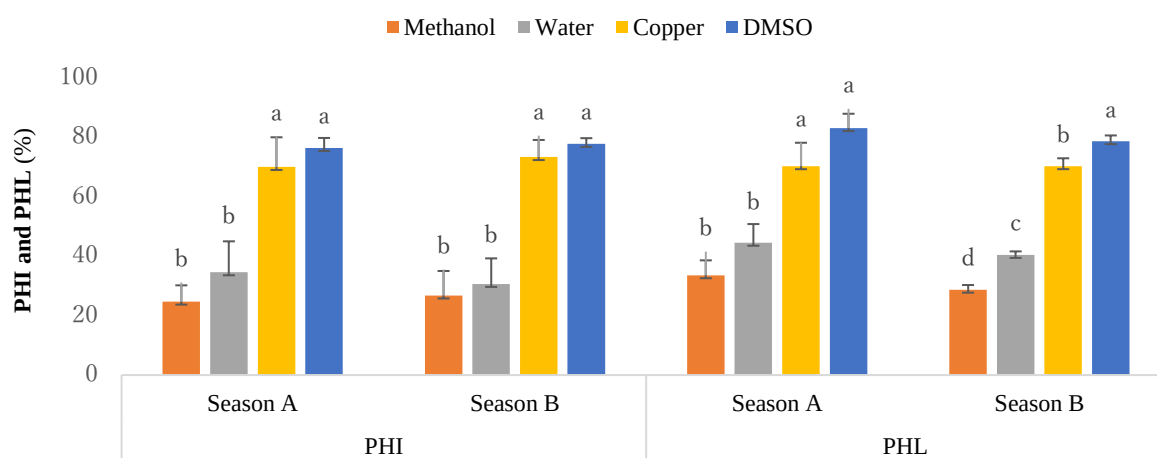


Figure 9. Effect of solvent extracts on potato tuber postharvest infection – PHI (%) and postharvest yield losses – PHL (%) caused by *Ralstonia solanacearum* in seasons A and B 2021

Note: see Figure 1

DISCUSSION

The results showed that in both seasons, methanol extract of tobacco and marigold at 50 mg·mL⁻¹, applied weekly and biweekly, reduced wilt incidences in plants and tubers more than the other treatments. The efficacy of tobacco extracts against plant pathogens was reported in earlier studies (Sharma et al. 2016). Singh et al. (2010) reported its significant activity against different strains of pathogenic bacteria, both Gram-positive and Gram-negative.

The effectiveness of wild marigold extract against pathogens was reported by Pattnaik et al. (2012) and Shahzadi and Shah (2015), and according to them, the extracts contain active compounds against different pathogens and physiological disorders. Nahak and Sahu (2017) confirmed that marigold extracts inhibited the growth of *Fusarium* wilt, canker, early blight, fruit spot, blossom end rot, and sunscald in tomatoes. Marigold extracts were found to be efficient against different bacteria like *Escherichia coli* Theodor Escherich, *B. subtilis* Ehrenberg, *Staphylococcus aureus* Rosenbach, *Pseudomonas aeruginosa* Schoter, and *Salmonella typhi* Lignieres (Senatore et al. 2004; Shahzadi & Shah 2015). Yuliar et al. (2015) reported that bacterial wilt was suppressed by plant residues from marigold plants. All these findings concur with the results from our study, where wild marigold showed antibacterial activity against *R. solanacearum* symptoms in potato aerial parts and tubers.

In the current study, garlic extract was also effective in managing bacterial wilt, although it showed slightly less efficacy than tobacco and marigold. Our experiments confirmed the results by Din et al. (2016), who found that garlic was less effective against *R. solanacearum* in tomatoes than marigold.

Our results revealed also that tobacco, wild marigold, and garlic have much higher potential against PHI and PHL caused by bacterial wilt than copper oxychloride, usually used to protect potatoes against bacterial wilt. Furthermore, all tested treatments reduced PHI and PHL in a frequency-dependent manner, i.e., dose-dependent, because all tested plant extracts reduced bacterial symptoms when applied weekly and biweekly.

It was known that the effectivity of extracts is dose-dependent due to concentration or application frequency. This study observed better protection against potato bacterial wilt when extracts were applied repeatedly every week. Singh et al. (2010) reported that tobacco extract in a higher concentration showed potential antibacterial activity against *Salmonella typhimurium*, *Bacillus cereus*, *Bacillus fusiformis*, *Staphylococcus aureus*, and *Pseudomonas aeruginosa* in human medicine. Different results proved that extracts from tobacco had antibacterial activity against test Gram-negative and Gram-positive bacteria, especially at high concentrations (Bakht et al. 2012; Ekefan et al. 2018).

Din et al. (2016), in the experiments done *in vitro* and *in vivo* on the antibacterial effect of aqueous extracts from seven species, reported the possibility of marigold in decreasing symptoms of *R. solanacearum* in tomato 60% more than streptomycin. Marigold extracts at 40 g kg⁻¹ of soil reduced disease severity by *R. solanacearum*, enhancing tomato growth and yielding more than standard antibiotics. Notably, any residues or toxic compounds from plant extracts did not pollute tomato plants and fruits.

The current study showed that methanol extracts were more effective in inhibiting bacterial wilt incidence in potato plants and tubers than water extract, which was especially obvious in season B. Sangoyomi et al. (2011) concluded that the type of solvent used for extraction of active botanicals from plant materials may be the reason for the lack of activity of some plant extracts and that other solvents than water must be used to check whether they can be effective. Also, Ncube et al. (2008) and Mwitari et al. (2013) pointed out that the type of solvent used for extraction of active botanicals from plant materials is one of the factors that affect the yield and composition of extract, which in turn influences the antimicrobial activity.

In the present study, disease incidence was lower, and the biological control efficiency was higher in potato plants and tubers in growing season B compared to season A. Different factors were studied to affect the incidence of bacterial wilt in potatoes, including temperature, moisture and rainfall, soil type, inoculum potential, and other soil biological factors, such as nematode

populations (Yuliar et al. 2015). This report agrees with the current study that DI increases with increased air temperature, especially for biovar 3, used here. For example, bacterial wilt is rarely found in regions with temperatures below 10°C (Guchi 2015). In addition, high soil moisture and periods of wet weather are associated with high disease reproduction, survival, and high incidence (Hammes 2013). However, excess rainfall and soil moisture harm the survival of the *Ralstonia* due to lack of oxygen. Also, extreme soil pH and the presence of contaminants and salts in soil decrease survival rates. Moreover, a high population of nematodes in soil also increases the development of bacterial wilt (Mansfield et al. 2012). In the present study, ambient temperature and precipitation varied in both seasons, and rainfall was much higher in season B than in season A, while the temperature conditions were opposite (Meteo data). In addition, soil type, existing inoculum, or other microorganisms in soil were not analyzed before planting, and they could have affected the incidence of the disease in the seasons. High rainfall combined with low temperature or a combination of rainfall and these other factors may have contributed to the results observed in season A.

CONCLUSIONS

This study aimed to evaluate the efficacy of methanol and water plant extracts from tobacco, marigold, and garlic used with different frequencies to protect 'Kirundo' potato plants and tubers against potato bacterial wilt caused by *R. solanacearum*. It was found that a weekly or biweekly application of the methanol extract of tobacco or wild marigold at 50 mg·mL⁻¹ is the most effective treatment recommended to protect potato plants and tubers against diseases caused by *R. solanacearum* during potato growth in the field and during storage.

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