Jurnal Perlindungan Tanaman Indonesia, Vol. 26, No. 2, 2022: 175–183
DOI: 10.22146/jpti.75321
Available online at http://jurnal.ugm.ac.id/jpti
ISSN 1410-1637 (print), ISSN 2548-4788 (online)

Research Article

Effect of Brassicaceae Waste Application on Soil Nematode Community

Ahmad Yusuf Ibrahim[1)], Supramana[1)]*, & Giyanto[1)]

[1)]*Department of Plant Protection, Faculty of Agriculture, IPB University*
Jln. Kamper, IPB Dramaga Campus, Bogor, West Java 16680 Indonesia

**Corresponding author. E-mail: supramana@apps.ipb.ac.id*

Received June 10, 2022; revised July 1, 2022; accepted December 30, 2022

ABSTRACT

Brassicaceae are known to contain compounds with biofumigant properties. This study aimed to determine the effect of Brassicaceae waste on soil nematode community. Broccoli leaves and stems (*Brassica oleracea* var. *italica*), cabbage leaves and stems (*B. oleracea* var. *capitata*), kailan stems (*B. oleracea* var. *alboglabra*), radish leaves (*Raphanus sativus*), and leaves of kamanilan weed (*Rorippa indica*) were tested in this study. The total glucosinolate content of Brassicaceae waste was estimated using the palladium method with a modified spectrophotometer. The experiment was carried out in polybags containing 500 g of soil-infested nematodes. Brassicaceae waste (15 g/polybag) was chopped and mixed into the soil, watered, and polybags were tightly closed for 14 days. The experiment was arranged in a completely randomized design with nine treatments and five replications. The results of the total glucosinolate analysis showed that broccoli, radish, and kamanilan leaves fall into the high category (144.7–185.2 µmol/g); cabbage leaves, cabbage stems, and kailan stems fall into the medium category (52.0–56.0 µmol/g); and broccoli stems were in the low category (35.4 µmol/g). There was no correlation between total glucosinolate contents and their effect on suppressing soil nematode communities at the applied effluent dose. The population of bacterivorous nematodes increased in each waste treatment, especially in kamanilan leaf treatment (*R. indica*) which reached 13,008 individuals. These results indicated that kamanilan weed has good potential to improve soil health. The treatment of Brassicaceae waste against soil nematode communities showed a low diversity index, an uneven evenness index, and a high dominance index.

Keywords: bacterivorous nematodes; biofumigants; glucosinolates; *Rorippa indica*

INTRODUCTION

Plants from the Brassicaceae family have been widely cultivated in Indonesia. According to *Badan Pusat Statistik* [BPS] (2021), several types of Brassicaceae including cabbage, mustard greens, cauliflower, and radishes were ranked third, seventh, 18th, and 23rd as the most produced horticultural crops in Indonesia during 2020. Total production each four type of Brassicaceae were 1,406,985 tons, 667,473 tons, 204,238 tons, and 24,902 tons. The number of cultivated Brassicaceae plants will certainly positively correlate with the amount of plant waste produced. Several studies have shown that Brassicaceae plant waste effectively controlled phyto-nematodes, especially the root-knot nematode (RKN), *Meloidogyne* spp. (Daulay, 2013; Rosya, 2015; Nur *et al.*, 2016; Prihatin, 2019).

According to Kirkegaard (2004), the ability of Brassicaceae plant waste to control phytopathogens is thought to be due to the presence of biofumigant compounds contained in it. Biofumigants are volatile toxic compounds produced by plants and are toxic against pests and plant pathogens. Biofumigant compounds from Brassicaceae plant waste are produced from the hydrolysis of glucosinolate compounds (GSL) into isothiocyanate compounds (ITS) with the help of water and the enzyme myrosinase (Yulianti, 2009). Glucosinolate compounds are not toxic to microorganisms, but play an important role in forming ITS compounds. These ITS compounds are volatile and toxic to plant pathogens (Bones & Rossiter, 1996; Fahey *et al.*, 2001).

Several studies on the contents of glucosinolate compounds in Brassicaceae plant waste have been

carried out using high-performance liquid chromatography (HPLC). However, in Indonesia, examining the levels of glucosinolate compounds using the HPLC method is still rarely carried out due to the unavailability of standard comparison compounds and other factors. An alternative to HPLC method is palladium method using modified spectrophotometry based on Mawlong *et al.* (2017) that can be used to estimate the total glucosinolate content.

Research on the effectiveness of Brassicaceae plant waste as a biofumigant has been widely studied in Indonesia to control *Meloidogyne* spp. on a laboratory, greenhouse, micro plot, and field-scale (Daulay, 2013; Rosya, 2015; Nur *et al.*, 2016; Prihatin, 2019). However, research on the effect of Brassicaceae plant waste on other soil nematode communities has not been carried out. Therefore, this study aimed to determine the effect of the application of Brassicaceae plant waste on the soil nematode community.

MATERIALS AND METHODS

Research Time and Place

The research was conducted at the Plant Nematology Laboratory, Faculty of Agriculture IPB University and the Pasir Sarongge Experimental Garden in Cianjur Regency. The research was conducted from January 2022 to March 2022.

Measurement of Glucosinolate Contents in Brassicaceae Plant Waste

There are five types of Brassicaceae plant waste with a total of seven treatments tested in this study, namely broccoli leaves and stems (*Brassica oleracea* var. *italica*), cabbage leaves and stems (*B. oleracea* var. *capitata*), kailan stems (*B. oleracea* var. *alboglabra*), horseradish leaves (*Raphanus sativus*), and kamanilan weed leaves (*Rorippa indica*). Waste was obtained in fresh condition from around the Pasir Sarongge plantation in Cianjur Regency, West Java. Estimating total glucosinolate levels was carried out using a spectrophotometer with a modified method by Mawlong *et al.* (2017). A portion of plant waste was saved for GSL measurement and the remaining was used in pot experiment described in the following section. The portion of the Brassicaceae plant waste was prepared by grinding it with liquid nitrogen to result in flour-like end product. Each Brassicaceae waste flour was then defatted using a Soxhlet apparatus with n-hexane solvent and was dried. The dried Brassicaceae waste flour was then taken as much as 0.1 g and then homogenized with 80% methanol in a 2 mL vial tube and incubated overnight at room temperature. After incubation, the mixture was centrifuged at 3000 rpm (revolutions per minute) for four minutes. The supernatant (liquid above the precipitate) formed was transferred to a new 2 mL vial tube and 80% methanol was added until the volume reached 2 mL.

The extract contained in the supernatant mixture was then taken as much as 100 µL, added with 0.3 mL ddH_2O and 3 mL 2 mM sodium tetrachloropaladate (58.8 mg sodium tetrachloropaladate + 170 µL concentrated HCl + 100 mL ddH_2O). The mixture was then incubated for one hour at room temperature. Blank samples were prepared using the same method without additional extract (replaced with 100 µL ddH_2O). After the incubation process, the absorbance value of the mixture was measured at a wavelength of 425 nm (A_{425}) using a spectrophotometer. Determination of the estimated total glucosinolate content is done by entering the optical density value of the sample, whose absorbance value is measured into the equation $Y = 1.40 + 118.86 \times A_{425}$. Each sample was measured three times the absorbance value and the average value was entered into the equation.

Application of Brassicaceae Plant Waste

Each type of Brassicaceae plant waste tested was chopped to about 1 cm. Furthermore, each chopped Brassicaceae plant waste was then placed into a polybag containing 500 g of soil and watered for the incubation process for two weeks. The soil used in this study was taken from areas around Pasir Sarongge (Cianjur Regency, West Java) which had experienced intensive input for horticultural cultivation. The dose for each Brassicaceae waste treatment was 15 g for each polybag. As a positive control, the nematicide Furadan 3G (active ingredient carbofuran) was applied at the recommended dose (1 g/polybag). The negative control did not receive any treatments. All polybags were tightly tied like other treatments.

Soil Nematode Analysis. This method referred to European and Mediterranean Plant Protection Organization [EPPO] (2013). The initial nematode population before treatment and after treatments were counted in this study. The entire soil inside the polybags were removed and levelled on the sack. The sample soil was composited using sacks whose sides that were alternately lifted. This process was repeated three times. From a total 500 g of soil, already homogeneous soil was taken by half (250 g) to the laboratory for extraction process of soil nematodes. Soil samples that had been composited were taken as much as 100 g, put into a container containing 800 mL of clean water, and then stirred and left for 20 seconds. The mixture was then filtered in several stages using 20-mesh, 50-mesh, and 100-mesh sieves, with a 20-mesh sieve at the top and a 100-mesh sieve at the bottom. The mixture that passes through a multilevel sieve was accommodated in a new container and filtered using a 500-mesh sieve. The mixture retained on a 500-mesh sieve was then put into a centrifugation tube and then centrifuged for five minutes at 1700 rpm. The suspension formed in the tube was discarded and the precipitate at the bottom of the tube was added with 40% sugar solution, homogenized, and centrifuged again for one minute at 1700 rpm. The suspension formed was then filtered again using a 500-mesh filter, rinsed with clean water, and put into a collection bottle. The suspension in the collection bottle was made up to 40 mL. The soil nematodes' abundance was calculated using a sampling method using a stereo microscope. For each extraction replication, the population was counted three times. The formula for calculating the nematode population is as follows (Ibrahim & Kurniawati, 2020):

$$N_i = \sum_{i=1}^{n} \frac{V}{v} \times n_i$$

N_i = the total population of nematode community *i*, n_i = population of nematode community *i* observed on the counting dish; V = volume of extracted nematode suspension (mL); v = volume of nematode suspension in counting dish (mL).

The soil nematode communities observed were phytonematodes (plant-parasitic nematodes), bacterivorous nematodes, and fungivorous nematodes. Nematode observations were carried out directly on fresh samples. The determination of nematode group was determined based on the shape of the feeding apparatus. Bacterivorous nematodes have a feeding apparatus shape like a hollow funnel, phytonematodes have a needle-like stylet on feeding apparatus area, and fungivorous nematodes have a stylet without basal knob at the base of the stylet (Mulyadi, 2009; Li *et al.*, 2017).

The study was conducted using a completely randomized design (CRD) consisting of nine treatments: broccoli stems and leaves, cabbage stems and leaves, radish leaves, kailan stems, kamanilan weed leaves, positive control, and negative control. Each treatment consisted of five polybags as replication. The nematode population density data obtained were tabulated using Microsoft Excel 2013 and then analyzed for variance (ANOVA) using IBM SPSS version 22 and continued with the Tukey test at a 5% significance level.

Analysis of Soil Nematode Community Index

Diversity Index. Analysis of the diversity of soil nematode communities in each treatment was determined using the Shannon-Wiener index based on the following formula Shannon & Weaver (1949):

$$H' = -\sum_{i=1}^{n} \left[\frac{n_i}{N} \times \ln\left(\frac{n_i}{N}\right) \right]$$

H' = Shannon-Wiener diversity index; n_i = the number of individuals of nematode-i community; N = total number of individuals of all types of nematodes.

The range of values from the calculation of the Shannon-Wiener index can be interpreted as follows: $H' > 3$ = high diversity; $1 < H' < 3$ = moderate diversity; $H' < 1$ = low diversity.

Evenness Index. The evenness of the soil nematode community was analyzed using the Pielou evenness index with the following formula Pielou (1977):

$$E = \frac{H'}{H\,max} = \frac{H'}{\ln(S)}$$

E = Pielou evenness index; H' = diversity index; S = number of soil nematode community. The criteria of Pielou's evenness index can be interpreted as follows: 0.00 – 0.25 = uneven; 0.26 – 0.50 = less evenly; 0.51 – 0.75 = fairly even; 0.76 – 0.95 = almost evenly; 0.96 – 1.00 = evenly.

Dominance Index. The dominance of a nematode community in each treatment was analyzed using the Simpson dominance index with the following formula Simpson (1949):

$$C = \sum_{i=1}^{n} \left(\frac{n_i}{N}\right)^2$$

C = Simpson dominance index; ni = the number of individuals of nematode species i; N = the total number of individuals in the applied treatment. The criteria for the Simpson dominance index (C) are as follows: $0 < C < 0.5$ = low dominance; $0.5 < C < 0.75$ = moderate dominance; $0.75 < C < 1$ = high dominance.

RESULTS AND DISCUSSION

Total Glucosinolate Content of Brassicaceae Plant Waste

Determination of the criteria for the total glucosinolate content of Brassicaceae plant waste referred to Ishida *et al.* (2012) by dividing the total glucosinolate content into three categories. The low category has an estimated glucosinolate content of 30–40 µmol/g, the medium is 50–70 µmol/g, and the high is 90–100 µmol/g. Based on the results in Table 1, the Brassicaceae plant wastes that fall into high glucosinolate content were broccoli leaves, kamanilan leaves (weeds), and horseradish leaves with each glucosinolate content of 185.2 µmol/g, 147.9 µmol/g, and 144.7 µmol/g.

Brassicaceae waste categorized as medium glucosinolate content were cabbage stems, cabbage leaves, and kailan stems with 56.0 µmol/g, 55.6 µmol/g, and 52.0 µmol/g, respectively. Meanwhile, Brassicaceae waste categorized as low in glucosinolate content were broccoli stem with a glucosinolate content of 35.4 µmol/g. The stem part of the Brassicaceae plant waste has never been tested to control phytonematodes, so a separate test was carried out between the leaves and stems to determine whether the total glucosinolate content have major roles as a biofumigant or not.

According to Kirkegaard *et al.* (2001), several factors can affect the hydrolysis process of glucosinolate into ITS compounds, including the availability of water, the speed at which plant tissue are damaged, and dose of waste applied (GSL hydrolyzed into ITS correspond to the amount of waste). In addition, ITS compounds formed tend to be more stable if there is water on the soil surface. It is possible that one or more of these factors have not been met, causing the hydrolysis of glucosinolate compounds to become ITS compounds did not occurred optimally in this study. This implies that the high content of glucosinolate compounds was not necessarily directly proportional to the ITS compounds produced (Tsao *et al.*, 2000).

Table 1. Estimation of glucosinolate (GSL) levels of seven types of Brassicaceae plant waste

No.	Sample	Total of GSL (µmol/g)	Category
1	Broccoli leaves	185.2	high
2	Broccoli stem	35.4	low
3	Cabbage leaves	55.6	medium
4	Cabbage stem	56.0	medium
5	Radish leaves	144.7	high
6	Kamanilan leaves	147.9	high
7	Kailan stem	52.0	medium

It should be noted that glucosinolate levels in this study were only estimates used as a substitute for the unavailability high-performance liquid chromatography (HPLC) method (Mawlong *et al.*, 2017). Glucosinolate compounds consist of several groups, such as aromatic, indolyl, and aliphatic groups (Kirkegaard *et al.*, 2001). Likewise, the ITS compounds produced also consist of several groups. It is possible that there are types or groups of glucosinolates that are more efficiently hydrolyze into ITS, and it is also possible that there are types of ITS compounds that are more toxic than other. One of the types and groups of these two compounds can be detected using the HPLC method.

Effect of Brassicaceae Plant Waste on Nematode Community

Soil nematodes are easily distinguished based on their feeding apparatus that makes it possible to infer their food type and roles in soil as communities. Information about nematode communities in the soil can provide information on nematode diversity and be used as a parameter of soil health conditions (Stirling, 2014). Bacterivorous nematodes are a group of nematodes that live freely in the soil and consume bacteria as food. Bacterivorous nematodes have a

Figure 1. The dominant nematode communities found in soil samples with 1000× magnification: (A) bacterivorous nematodes with mouth shape like a hollow funnel; (B) phytonematodes with stylet; (C) fungivorous nematodes without basal knob at the base of the stylet

mouth shaped like a hollow funnel (Figure 1A), allowing this group of nematodes to suck and digest the bacteria around them as a food source (McSorley, 2009).

Phytonematodes were characterized by the presence of a needle-like stylet on the anterior end of their body (Figure 1B). In summary, this stylet punctures and sucks contents of plant cells as a food source. Like phytonematodes, fungivorous nematodes also have a stylet on the anterior end of their body (Figure 1C). This stylet is used pierce and suck fungal hyphae. Most of the fungivorous nematodes belong to the order Aphelenchida. Fungivorous nematodes have a metacorpus, but no basal knob at the base of the stylet. In addition, fungivorous nematodes are more mobile than phytonematodes.

Results indicate there is no significant difference in the phytonematode population between the initial population and the final population after the treatment of Brassicaceae plant waste (Table 2). The types of Brassicaceae plant waste that were applied represented three categories of glucosinolate levels (low, medium, and high levels). Besides glucosinolate levels in Brassicaceae plant waste, there may be other factors that affect the abundance of the phytonematode population in each applied treatment. This result was different from Rosya's research (2015) which stated that incubation of Brassicaceae waste for two weeks can reduce the phytonematode population of *Meloidogyne* spp. It is possible that each phytonematode species has different response to Brassicaceae waste as a biofumigant. In addition, other factors such as the amount of waste and the soil conditions used may have caused differences.

Population of bacterivorous nematodes significantly increased after treatments of all types of Brassicaceae plant waste (Table 2). It indicates that the total glucosinolate content of the Brassicaceae plant waste may not the main factor influencing the abundance of bacterivorous nematodes in the soil. Increase of bacterivorous nematode population can be correlated with the high population of bacteria due to the application of organic matter (including plant waste) to the soil (Bittman *et al.*, 2005).

Bacterivorous nematodes are useful in the soil because they act as intermediaries in the rapid decomposition of organic matter by bacteria. The presence of bacterivorous nematodes can control bacterial population to remain in the logarithmic phase. In addition, this nematode also acts as a transfer of bacteria so that the decomposition process can occur more evenly (Ferris *et al.*, 2004; Mulyadi, 2009; Subowo, 2010).

Data on bacterivorous nematodes obtained in this study provide information that nematodes can be used as biological indicators of soil health (Khanum *et al.*, 2022). This is in line with Mulyadi's (2009) statement that nematodes could function as a biological measurement (bioassessment) using certain species or nematode communities as indicators. The soil used in this study came from upland land where synthetic chemical pesticides were intensively applied. The synthetic chemical pesticides that were often applied included herbicides, fungicides, bactericides, and nematicides. This caused the population of each nematode community in soil samples before treatment to be relatively low (Table 2).

Table 2. Population abundance of several types of nematodes in each treatment of Brassicaceae plant waste

Treatment	Nematodes Population[2]			
	Phytonematodes	Bacterivorous	Fungivorous	Unknown
Initial population[3]	256.00 b	8.00 a	5.33 a	0.00 a
Control (-)	104.00 a	34.67 a	8.00 a	0.00 a
Control (+)	146.67 ab	13.33 a	5.33 a	0.00 a
Broccoli leaves	138.67 ab	4536.00 b	325.33 b	26.67 abc
Broccoli stem	205.33 ab	7896.00 b	200.00 b	50.67 bc
Cabbage leaves	277.33 b	2250.67 b	0.00 a	69.33 c
Cabbage stem	192.00 ab	4685.33 b	149.33 b	0.00 a
Radish leaves	242.67 b	4880.00 b	0.00 a	40.00 abc
Kamanilan leaves	210.67 b	13008.00 b	565.33 b	8.00 ab
Kailan stem	200.00 b	5173.33 b	240.00 b	34.67 abc

[1]Data has been transformed using a logarithmic transformation.
[2]Numbers in the same column followed by the same letter show no significant difference based on Tukey's follow-up test at the level of =5%.
[3]Initial population of nematodes before 2 weeks incubation treatment.

The consideration of using bacterivorous nematodes as an indicator of soil health is that their life cycles are relatively short causing them to quickly respond to environmental changes. In addition, bacterivorous nematodes can also represent biological condition of the soil because the population development is in line with the abundance of bacteria in the soil. The abundance of bacterivorous nematodes in the soil will positively correlate with soil fertility because these nematode groups can accelerate the availability of nutrients needed by plants (Mulyadi, 2009).

In addition, there was also a significant increase in the population of fungivorous nematodes in soil treated with waste from broccoli leaves, broccoli stems, cabbage stems, kamanilan weed leaves, and kailan stems. Fungivorous nematodes is included in the group of nitrogen releasing nematodes (NRN) just like bacterivorous nematodes. Bacterivorous nematodes contribute more to N mineralization process than fungivorous nematodes (Ferris & Matute, 2003). However, radish leaf waste (high glucosinolate content) and cabbage leaf waste (medium glucosinolate content) had different effects than other types of Brassicaceae plant waste. The two types of waste suppressed the existence of fungivorous nematodes until their population was zero, even though the two types of waste had different categories of glucosinolate levels. This shows that the total glucosinolate content of Brassicaceae plant waste is also not the only determining factor that can suppress the population of fungivorous nematodes in the soil.

The ratio of bacterivorous nematodes was higher than that of fungivorous nematodes, indicating that the nutrient cycle process through the decomposition process occurred rapidly. The increase in the two nematode communities can benefit by accelerating the availability of N elements from organic matter that can be utilized by plants after the decomposition process. The level of abundance of bacterivorous and fungivorous nematodes was influenced by the C:N ratio of the organic matter applied (Stirling, 2014; Yadav *et al.*, 2018). The rapidly increasing population of bacterivorous nematodes in the soil samples can also indicate that the application of Brassicaceae plant waste could improve the health and fertility of polluted soil, even though the application has only been done once. The continuous use of Brassicaceae plant waste as green manure and biofumigant will improve soil health in the long term.

In addition to the types of nematodes whose roles are known, there are also types of nematodes which roles in soil remain to be determined. This type of nematode has an unclear feeding apparatus and is different from other nematodes observed in this study. These nematodes were found in the treatments of broccoli leaves, broccoli stems, cabbage leaves, radish leaves, kamanilan leaves, and kailan stems. The number of nematodes with unknown roles were most commonly found in the treatment of cabbage leaf waste.

Table 3. Diversity index (H'), evenness index (E), and dominance index (C) of soil nematodes for each type of Brassicaceae plant waste treatment

Treatment	Diversity Index	Evenness Index	Dominance Index
Initial population	0.23	0.21	0.90
Control (-)	0.74	0.68	0.56
Control (+)	0.42	0.38	0.79
Broccoli leaves	0.40	0.29	0.82
Broccoli stem	0.26	0.19	0.90
Cabbage leaves	0.46	0.42	0.76
Cabbage stem	0.29	0.27	0.87
Radish leaves	0.23	0.21	0.90
Kamanilan leaves	0.25	0.18	0.89
Kailan stem	0.36	0.26	0.84

Interestingly, kamanilan weed leaf was able to increase the population of bacterivorous nematodes and fungivorous nematodes. In fact, the population of bacterivorous nematodes in the kamanilan weed leaf treatment was higher than other treatments. Kamanilan is ubiquitous weed in agricultural land. The use of kamanilan as biofumigant producer is more efficient than cultivated Brassicaceae because it is a cosmopolitan and grows fast.

In addition, kamanilan weeds have also been studied by Asmoro *et al.* (2021) as a refugia plant for the parasitoid *Diadegma semiclausum* in the cabbage agroecosystem for *Plutella xylostella* pest control. This study indicated that the kamanilan weed could increase the longevity of *D. semiclausum* up to 16.90 ± 1.37 days and increase its parasitization level to *P. xylostella* up to 46.94 ± 2.24%. Thus, it can be said that this kamanilan weed has the potential to be used as a refugia plant to control plant pests as well as a biofumigant to control plant pathogens.

Index Analysis of Soil Nematodes Community

Results showed that all types of treatments applied had a low diversity index (H' < 1)(Table 3). This showed that the types of nematodes that exist in each treatment were not diverse and there are types of nematodes that are superior to other types of nematodes.

The results of the evenness index showed that the initial population of nematodes, treatment of broccoli stems, radish leaves, and kamanilan leaves showed an unevenness of nematode species in the soil applied by these materials. The treatments with less evenly distributed nematode types were control (+), broccoli leaves, cabbage leaves, cabbage stems, and kailan stems. In contrast, the control treatment (-) had a fairly even index.

Based on the diversity index and evenness index results, it is suspected that there are types of nematodes that dominate after the application of treatment and the incubation process. Therefore, an examination of the dominance index was carried out with the results showing that all treatments applied other than the control (-) treatment had a high dominance index. These results indicate that there are types of nematodes dominate in terms of population. It can be seen that the most dominating after treatment of Brassicaceae plant waste was the bacterivorous nematode group (Table 2).

When the Brassicaceae plant waste is applied as a biofumigant, the entire soil nematode community is most likely affected and the population declines. Nematode groups that have a short life cycle will recover faster causing population of bacterivorous nematodes increased rapidly compared to the population of other nematode groups. Bacterivorous nematodes are included in the colonizer nematode group because they have a short life cycle, fast reproduction, high colonization ability, tolerance to disturbances, relatively high population fluctuations, and have an r-strategy (Bongers, 1990).

Furthermore, Ferris *et al.* (2001) developed the cp (colonizer-persisters) scale to classify the developmental duration of each type of nematode based on several types of criteria. The scale has a value from 1 to 5 (cp-1 to cp-5). The majority of bacterivorous nematodes belong to the cp-1 scale, fungivorous nematodes and phytonematodes fall into the cp-2

scale, and Mononchida and Dorylaimida belong to the cp-4 scale (Mulyadi, 2009).

CONCLUSION

All Brassicaceae waste tested represented the categories of high (broccoli, turnips, and kamanilan leaves), medium (cabbage leaves, cabbage stems, and kailan stems), and low (broccoli stems) total glucosinolate content. At a dose of 15 g in 500 g soil, the total glucosinolate content of Brassicaceae waste did not have direct effects on suppressing the population of soil nematode communities. The application of Brassicaceae may be selective in suppressing certain types of phytonematodes. However, on the other hand, it can rapidly increase the abundance of bacterivorous nematodes which is an indicator of soil health, especially in the treatment of kamanilan weed leaves (*R. indica*). The treatment of Brassicaceae waste against soil nematode communities showed a low diversity index, uneven evenness index, and high dominance index.

ACKNOWLEDGEMENT

Authors would like to thank the *Lembaga Pengelola Dana Pendidikan* (LPDP) that funded this research and also to Laboratory of Plant Nematology, Department of Plant Protection, IPB University that has facilitated this research.

LITERATURE CITED

Asmoro, P.P., Dadang, Pudjianto, & Winasa, I.W. (2021). Screening Insectary Refugia Plants that Increase the Performance of *Diadegma semiclausum* Hellen (Hymenoptera: Ichneumonidae) against Diamondback Moth Larvae. *Biodiversitas*, *22*(10), 4254–4260. https://doi.org/10.13057/biodiv/d221016

Badan Pusat Statistik. (2021). *Produksi Tanaman Sayuran 2020*. Retrieved from www.bps.go.id/indicator/55/61/1/produksi-tanaman-sayuran.html

Bittman, S., Forge, T.A., & Kowalenko, C.G. (2005). Responses of the Bacterial and Fungal Biomass in a Grassland Soil to Multi-Year Applications of Dairy Manure Slurry and Fertilizer. *Soil Biology and Biochemistry*, *37*(4), 613–623. https://doi.org/10.1016/j.soilbio.2004.07.038

Bones, A.M., & Rossiter, J.T. (1996). The Myrosinase-glucosinolate System, its Organization and Biochemistry. *Physiologia Plantarum*, *97*(1), 194–208. https://doi.org/10.1111/j.1399-3054.1996.tb00497.x

Bongers, T. (1990). The Maturity Index: An Ecological Measure of Environmental Disturbance Based on Nematode Species Composition. *Ecologia*, *83*, 14–19. https://doi.org/10.1007/BF00324627

Daulay, N.S. (2013). *Sisa Tanaman Cruciferae sebagai Biofumigan untuk Mengendalikan Nematoda Puru Akar (Meloidogyne spp.)* [Bachelor thesis]. Bogor, Indonesia: Institut Pertanian Bogor.

European and Mediterranean Plant Protection Organization. (2013). PM 7/119 (1) Nematode Extraction. *EPPO Bulletin*, *43*(3), 471–495.

Fahey, J.W., Zalcmann, A.T., & Talalay, P. (2001). The Chemical Diversity and Distribution of Glucosinolates and Isothiocyanates among Plants. *Phytochemistry*, *56*(1), 5–51. https://doi.org/10.1016/S0031-9422(00)00316-2

Ferris, H., Bongers, T., & de Goede, R.G.M. (2001). A Framework for Soil Food Web Diagnostics: Extension of the Nematode Faunal Analysis Concept. *Applied Soil Ecology*, *18*(1), 13–29. https://doi.org/10.1016/S0929-1393 (01)00152-4

Ferris, H., & Matute, M.M. (2003). Structural and Functional Succession in the Nematode Fauna of the Soil Food Web. *Applied Soil Ecology*, *23*(2), 92–110. https://doi.org/10.1016/S0929-1393(03)00044-1

Ferris, H., Venette, R.C., & Scow, K.M. (2004). Soil Management to Enhance Bacteriovore and Fungivore Nematode Populations and Their Nitrogen Mineralization Function. *Applied Soil Ecology*, *25*, 19–35. https://doi.org/10.1016/j.apsoil.2003.07.001

Ibrahim, A.Y., & Kurniawati, F. (2020). The Efficacy of Chitosan to Control Nematode *Aphelenchoides besseyi* Christie through Seed Treatment. *IOP Conference Series: Earth and Environmental Science*, *468*, 1–6. https://doi.org/10.1088/1755-1315/468/1/012025

Ishida, M., Nagata, M., Ohara, T., Kakizaki, T., Hatakeyama, K., & Nishio, T. (2012). Small Variation of Glucosinolate Composition in Japanese Cultivars of Radish (*Raphanus sativus* L.) Requires Simple Quantitative Analysis for Breeding of Glucosinolate Component. *Breeding Science*, 62, 63–70. https://doi.org/10.1270/jsbbs.62.63

Khanum, T.A., Mehmood, N., & Khatoon, N. (2022). Nematodes as Biological Indicators of Soil Quality in the Agroecosystems. In C. Belle & T.E. Kaspary (Eds.), *Nematodes – Recent Advances, Management and New Perspectives* (pp. 1–12). London, England: IntechOpen Limited. https://doi.org/10.5772/intechopen.94719

Kirkegaard, J.A. (2004). Biofumigant Potential of Brassicas I Variation in Glucosinolate Profiles of Diverse Field-grown Brassicas. *Plant Soil*, *201*(1), 71–89.

Li, Q., Liang, W., Zhang, X., & Mahmood, M. (2017). *Soil Nematodes of Grassland in Northern China*. London, England: Elsevier Inc. http://doi.org/10.1016/B978-0-12-813274-6.00001-6

Mawlong, I., Kumar, M.S.S., Gurung, B., Singh, K.H., & Singh, D. (2017). A Simple Spectrophotometric Method for Estimating Total Glucosinolates in Mustard De-oiled Cake. *International Journal Food Properties*, *20*(12), 3274–3281. https://doi.org/10.1080/10942912.2017.1286353

McSorley, R. (2009). *Soil-inhabiting Nematodes*. Retrieved from https://entnemdept.ufl.edu/creatures/nematode/soil_nematode.htm

Mulyadi. (2009). *Nematologi Pertanian*. Yogyakarta, Indonesia: UGM Press.

Nur, M.J., Supramana, & Munif, A. (2016). Keefektifan Limbah Tanaman Brassicaceae untuk Pengendalian Nematoda Puru Akar (*Meloidogyne* spp.) pada Mikroplot di Lapangan [Effectivenes of Brassicaceae Plant Wastes to Control the Root Knot Nematodes (*Meloidogyne* spp.) at a Field Microplot Scale]. *Jurnal Hama Penyakit Tumbuhan Tropika*, *16*(2), 99–106. https://doi.org/10.23960/j.hptt.21699-106

Pielou, M. (1977). *Mathematical Ecology*. Toronto, USA: John Wiley and Sons.

Prihatin. (2019). *Keefektifan Biofumigasi Limbah Tanaman Brassicaceae untuk Pengendalian Nematoda Puru Akar (Meloidogyne spp.) pada Tanaman Mentimun* [Master thesis]. Bogor, Indonesia: Institut Pertanian Bogor.

Rosya, A. (2015). *Keefektifan Limbah Brassica sebagai Biofumigan dalam Pengendalian Nematoda Puru Akar (Meloidogyne spp.) pada Tanaman Tomat* [Master thesis]. Bogor, Indonesia: Institut Pertanian Bogor.

Shannon, C.E., & Weaver, W. (1949). *The Mathematical Theory of Communication*. Illinois, United States: University of Illinois Press.

Simpson, E.H. (1949). Measurement of Diversity. *Nature*, *163*, 688. https://doi.org/10.1038/163688a0

Stirling, G.R. (2014). *Biological Control of Plant-Parasitic Nematodes*. Australia: CABI.

Subowo, G. (2010). Strategi Efisiensi Penggunaan Bahan Organik untuk Kesuburan dan Produktivitas Tanah melalui Pemberdayaan Sumberdaya Hayati Tanah. *Jurnal Sumberdaya Lahan*, *4*(1), 13–25.

Tsao, R., Yu, Q., Friesen, I., Potter, J., & Chiba, M. (2000). Factors Affecting the Dissolution and Degradation of Oriental Mustard-Derived Sinigrin and Allyl Isothiocyanate in Aqueous Media. *Journal Agricultural Food Chemistry*, *48*, 1898–1902. https://doi.org/10.1021/jf9906578

Yadav, S., Patil, J., & Kanwar, R.S. (2018). The Role of Free Living Nematode Population in the Organic Matter Recycling. *International Journal of Current Microbiology and Applied Sciences*, *7*(6), 1–9. https://doi.org/10.20546/ijcmas.2018.706.xx

Yulianti, T. (2009). Biofumigan untuk Pengendalian Patogen Tular Tanah Penyebab Penyakit Tanaman yang Ramah Lingkungan. *Jurnal Balai Penelitian Tanaman Tembakau dan Serat*, *3*(2), 154–170.