AGROMIX
pISSN (Print): 2085-241X; eISSN (Online): 2599-3003
Website: https://jurnal.yudharta.ac.id/v2/index.php/agromix

Potential of *Bacillus spp*. consortium for controlling *Meloidogyne spp*. and enhancing tomato crop production

Yulmira Yanti[1*], Winarto[1], Hasmiandy Hamid[1], Pandu Chayadi Wasirin[1]
[1] Departement of Plant Protection, Agriculture Faculty, Universitas Andalas, Limau Manis, Padang, Indonesia
*Corespondence Email: yy.anthie79@gmail.com : mira23@agr.unand.ac.id

Original article

Article history
Received : October 30, 2023
Accepted : March 25, 2024
Published : March 31, 2024

Keyword
Bacillus spp.;
Consortium;
Meloidogyne spp.;
Rhizobacteria;
Tomato;

ABSTRACT

Introduction: rhizobacteria *Bacillus spp*. are microorganisms that reside in plant roots that function as biocontrol agents of plant diseases and increase plant growth and yield. Bacillus spp. consortium is a combination of several *Bacillus spp*. that synergize and do not inhibit each other. The study aimed to obtain the best *Bacillus spp*. consortium to control *Meloidogyne spp*. and increase the growth and yield of tomato plants. **Methods:** This research is experimental using a completely randomized design consisting of 2 stages, namely 1.) Compatibility test of rhizobakteria consortium *Bacillus spp*. consists of 6 treatments 4 replicates and 2.) Test consortium rhizobakteria *Bacillus spp*. selected to control *Meloidogyne spp.* and increase the yield of tomato plants. The observed variables were the development of root swelling by *Meloidogyne spp*., and the growth of seedling, vegetative, and generative phases. **Results:** The results showed that testing all isolates of rhizobacteria *Bacillus spp*. showed compatibility (compatible). *Bacillus spp.* rhizobacteria consortium can suppress the development of *Meloidogyne spp*. and showed different results compared to the control. *Bacillus spp.* rhizobacteria consortium can increase the growth of tomato seedlings and showed different results compared to the control. *Bacillus spp*. rhizobacteria consortium can increase the growth of tomato plants in the vegetative phase and showed different results compared to the control. rhizobacteria consortium *Bacillus spp*. can increase the growth of tomato plants in the vegetative phase and shows different results compared to the control. **Conclusion:** The best rhizobakteria *Bacillus spp.* consortium in suppressing the development of *Meloidogyne spp.* and increasing the growth and yield of tomato plants is *Bacillus cereus* strain RBI2AB2.2 + *Bacillus cereus* strain RBIKDA2.2.

Cite this article:
Yanti, Y., Winarto, Hamid, H., & Wasirin, P. C. (2024). Potential of *Bacillus spp*. consortium in controlling *Meloidogyne spp*. and enhancing tomato crop production. *Agromix, 15*(1), 100-108. https://doi.org/10.35891/agx.v15i1.4242

PENDAHULUAN

Tomato plants (*Lycopersicum esculentum* Miller.) are fruit-bearing plants belonging to the Solanaceae family, consisting of 220 species. Tomato fruits are rich in vitamins A, B, and C, which are beneficial for health and have high economic value (Jailani, 2022). The productivity of tomato plants in Indonesia has been increasing, with 17.31 tons/ha in 2017, 18.04 tons/ha in 2018, and 18.63 tons/ha in 2019 (Central Statistics Agency and Directorate General of Horticulture, 2021). However, the productivity of tomatoes is still very low compared to the optimal productivity potential, which can reach 50 tons/ha (Syukur *et al.*, 2015). One of the causes of low tomato plant productivity is the attack of plant disease-causing pathogens. The main diseases of tomato plants include bacterial wilt caused by *Ralstonia syzygii* subsp. Indonesians (RSI) (Yanti *et al.*, 2018), fusarium wilt caused by *Fusarium oxysporum* f.sp. lycopersici (Situmorang *et al.*, 2021), late blight caused by Phytophthora infestans (Syahputra, 2018), and root-knot disease caused by *Meloidogyne spp*. (Ramadhany *et al.*, 2021).

Meloidogyne spp. is one of the significant pathogens affecting various horticultural and food crops in Indonesia (Istiqomah & Pradana, 2015). These nematodes have a wide range of hosts and can attack more than 2000 plant species, including food crops, horticultural crops, plantation crops, and ornamental plants, with varying levels of severity (Winarto *et al.*, 2018). Attacks by *Meloidogyne spp*. reported by Raihana *et al.* (2017) caused approximately 27% damage to tomato plants.

Several control efforts against *Meloidogyne spp*. have been undertaken, such as through technical cultivation practices (Khotimah *et al.*, 2020). Research conducted by Murthi *et al.* (2015) indicated that the use of *Tagetes* spp. plants could also suppress the population density of *Meloidogyne spp*. However, currently, nematode control tends to prioritize the use of synthetic pesticides that quickly kill nematodes (Setiawati *et al.*, 2015). Continuous use of nematicides in nematode control can lead to environmental contamination (Habazar *et al.*, 2021). Therefore, it is necessary to seek alternative environmentally friendly control methods, such as biological control. One group of bacteria that has been extensively researched and developed as biological control agents is Plant Growth Promoting rhizobacteria (PGPR) (Yanti *et al.*, 2019). PGPR is a group of beneficial bacteria that are non-pathogenic to plants and can function as plant growth promoters (Sutariati & Wahab, 2012). Research by Khabbaz *et al.* (2019) stated that PGPR can stimulate plant growth through various mechanisms, including improving plant nutrition, enzyme secretion, unique phytohormone regulation, and suppression of disease-causing organisms. PGPR Bacillus subtilis and Pseudomonas fluorescens as well as the duration of seed soaking significantly affect the growth of mustard greens (Brassica juncea L.) (Noor & Melani, 2022).

The application of PGPR to achieve better results can utilize consortia compared to the use of single isolates. Bacterial consortia have several advantages such as host specificity, ability to multiply in target cells, absence of toxin production from residues, immunity to cross-protection, simple application techniques, permanent control, absence of pollution, and environmentally friendly (Sarma *et al.*, 2015). The research objective is to obtain a *Bacillus spp.* rhizobacteria consortium with the potential to control *Meloidogyne spp*. and enhance tomato crop production.

METHODS

Tools and materials

The tools that will be used are Petri dishes, binocular microscope, test tubes, forceps, spatula, measuring glass, inoculation needle, injection needle, pot-tray, laminar air flow cabinet, microwave, autoclave, vortex, boiler, stove, hand sprayer, Baermann funnel (modified), and hand tally counter.

The materials that will be used are *Bacillus spp*. bacterial isolates from Dr. Yulmira Yanti's collection, sterile coconut water, distilled water, transparent plastic, wrapping, aluminum foil, tissue, label paper, thread, raffia string, polybags sized 30 x 45 cm, tomato seeds of Warani variety, four o'clock flowers (*Mirabilis jalappa*), manure fertilizer, NPK pearl fertilizer, sterile soil, sand, *Meloidogyne spp*. eggs, Mc Farland scale 8 solution, Nutrient Both (NB) medium, Tryptic Soy Agar (TSA) medium, 1% NaOCl, alcohol, and 3G Carbofuran nematicide.

Study location

This research was conducted in the Microbiology Laboratory of the Department of Plant Pest and Disease and the Experimental Garden Technical Unit of the Faculty of Agriculture, Andalas University.

Methods employed

The research consists of 2 stages: compatibility testing of the *Bacillus spp.* rhizobacteria consortium and testing of the selected *Bacillus spp.* rhizobacteria consortium for controlling *Meloidogyne spp*. and enhancing tomato crop yields.

Compatibility test of Bacillus spp. consortium

This research is descriptive in nature and consists of 6 treatments with 4 replications each. The treatments are based on the characteristics indicated in Table 1.

Table 1. Combination of *Bacillus spp*. for compatibility test

Treatment	Combination of *Bacillus spp.* rhizobacteria for compatibility test
A	*B. thuringiensis* strainRBI2AB1.1 *B. cereus* strain RBIKDA2.2
B	*B. thuringiensis* strain RBI2AB1.1 *B. cereus* strain RBI2AB2.1
C	*B. thuringiensis* strain RBI2AB1.1 *B. subtilis* strain RBIBPL2.3
D	*B. cereus* strain RBI2AB2.2 *B. cereus* strain RBIKDA2.2
E	*B. cereus* strain RBI2AB2.2 *B. cereus* strain RBI2AB2.1
F	*B. cereus* strain RBI2AB2.2 *B. subtilis* strain RBIBPL2.3

Testing of selected Bacillus spp. rhizobacteria consortium for controlling Meloidogyne spp. and enhancing tomato crop yields

The experiment follows a Completely Randomized Design (CRD) with 9 treatments and 3 replications. The treatments consist of 6 *Bacillus spp*. consortia introduced to tomato plants and inoculated with *Meloidogyne spp*., one treatment with synthetic nematicide with active ingredient Carbofuran at 3 grams per plant and inoculated with *Meloidogyne spp*., as well as positive control treatment (without *Meloidogyne spp*. inoculation and without *Bacillus spp*. consortium), and negative control treatment (inoculated with *Meloidogyne spp*. without *Bacillus spp*. consortium).

Experiment design

Preparation of Bacillus spp. rhizobacteria

The bacterial isolates used are from the collection of Dr. Yulmira Yanti, S.Si. MP. The bacterial isolates are subcultured using the streaking method on TSA media and then incubated for 2 x 24 hours. Pure *Bacillus spp*. isolates are confirmed by Gram staining and hypersensitive reaction test.

Compatibility test of Bacillus spp. consortium

The compatibility of endophytic bacteria is tested using the cross-streak method. Two different bacterial isolates are streaked vertically and horizontally on sterilized Petri dishes containing TSA medium. The Petri dishes are then incubated for 2 x 24 hours at room temperature, and the formation of inhibition zones at the intersection of vertical and horizontal streaks is observed. The rhizobacteria consortium will be considered compatible if there are no inhibition zones between bacterial isolates (Sarkar and Chouarsia, 2017).

Multiplication of Bacillus spp. rhizobacteria *consortium*

The multiplication of *Bacillus spp.* rhizobacteria consortium consists of 2 stages: (1) Preculture, a single colony of *Bacillus spp.* rhizobacteria from pure culture are transferred into 10 ml of NB medium in a culture bottle and incubated on a rotary shaker at 150 rpm for 24 hours at room temperature. (2) Mainculture, the *Bacillus spp.* rhizobacteria consortium is prepared by combining 2 or more isolates of compatible *Bacillus spp. rhizobacteria*. 1 ml of suspension from the preculture is transferred into 23 ml (if the consortium consists of 2 isolates) of sterile coconut water in a culture bottle and incubated on a rotary shaker at 150 rpm for 2×24 hours (Yanti *et al.*, 2020). The density of the *Bacillus spp.* rhizobacteria consortium suspension is determined by comparing the suspension with a McFarland scale 8 solution (BaCl 0.8 g + $H2SO4$ 1% 9.2 g) (bacterial population density estimated at 10^8 cells/ml) (Klement *et al.*, 1990).

Preparation of growth media

The growth medium used is a mixture of sterilized soil and manure fertilizer with a composition of 2:1 (Yanti *et al.*, 2018). The soil-fertilizer mixture is sterilized in a boiler using the Tyndallization method, which involves heating at 100ºC for 1 hour. After 24 hours, the soil is sterilized again using the same method twice. After that, it is cooled for one day. Soil for seedlings is placed in pot trays at 20 g/hole, while for tomato planting, it's 10 kg/polybag.

Inoculum source and multiplication of Meloidogyne spp.

Before sampling in the field, tomato plants are prepared for the multiplication of *Meloidogyne spp*. Seeds are sown at a rate of 1 seed per polybag, with a total of 20 polybags, and the seedlings are nurtured and cared for until they are 3 weeks old after planting (WAP). The inoculum source is obtained from the roots of tomato plants showing symptoms of stunting and swelling at the root parts in Taratak Pauah, Kenagarian Sungai Nanam, Lembah Gumanti District, Solok Regency (West Sumatra). Tomato plants are selected at around 2-3 months old. Root swelling is observed by gently digging around the plant roots. Plants with symptoms of root swelling are uprooted and placed in plastic bags, then transported to the Microbiology Laboratory, Faculty of Agriculture, Andalas University for observation and collection of nematode egg masses found on the tomato plant roots. The *Meloidogyne spp*. inoculum source is inoculated with 5 egg masses per tomato plant. The propagated plants are nurtured and uprooted after 45 days after inoculation (DAI), and the roots showing symptoms of root swelling are collected. Egg masses from the propagation are collected as the inoculum source

Introduction of Bacillus spp. consortium

a. On tomato seeds

Tomato seeds are surface-sterilized in distilled water for 1 minute, then immersed in a 1% NaOCl solution for 1 minute and rinsed again with distilled water, air-dried for approximately 10 minutes. Subsequently, the seeds are soaked in the *Bacillus spp*. consortium suspension for the control group and the nematicide is soaked in sterile distilled water, each for 10 minutes. The seeds are then spread in pot trays containing the growth medium at a rate of 2 seeds per hole. Seedlings are nurtured in the nursery for 21 days. Maintenance during the nursery stage includes watering in the morning and afternoon using a hand sprayer.

b. On tomato seedlings

Tomato seedlings aged 21 days after planting (DAP) are removed from the pot trays, and then the soil adhering to the roots is washed and soaked in a *Bacillus spp*. consortium suspension with a density of 10^8 cells/ml for 15 minutes (Yanti *et al.*, 2017). For the control group and nematicide treatment, they are soaked in sterile distilled water. Then, the seedlings are transferred into polybags. The nematicide is applied during the transfer of the seedlings into polybags at a dosage of 3 gr per plant. The nematicide is applied in a circular furrow around the tomato plant roots

Inoculation of Meloidogyne spp.

a. *Meloidogyne spp*. inoculum

The inoculum consists of eggs obtained from egg masses propagated on tomato plants in a warehouse. The eggs from the egg masses are made into a suspension by collecting the *Meloidogyne spp*. egg masses that have been propagated. The egg masses are then placed in 5 ml of 0.5% NaOCl solution in a test tube and homogenized using a vortex (Harni & Samsudin, 2005). The homogenized suspension is poured into a Petri dish to count the number of eggs.

b. Inoculation of *Meloidogyne spp*. eggs into tomato plants

Meloidogyne spp. eggs are introduced into the roots of tomato plants when they are 28 days old. The soil around the roots of the tomato plant is gently opened to introduce a suspension containing approximately 1000 eggs into the soil. Subsequently, the soil is closed again.

Observations

The variables observed include the development of *Meloidogyne spp*. in the root system of tomato plants, as well as the growth of tomato plants in the seedling, vegetative, and generative phases.

Data analysis

The data will be analyzed using analysis of variance (ANOVA), and if there is a significant difference, it will be followed by a Least Significant Difference (LSD) test at a 5% significance level.

RESULTS AND DISCUSSION

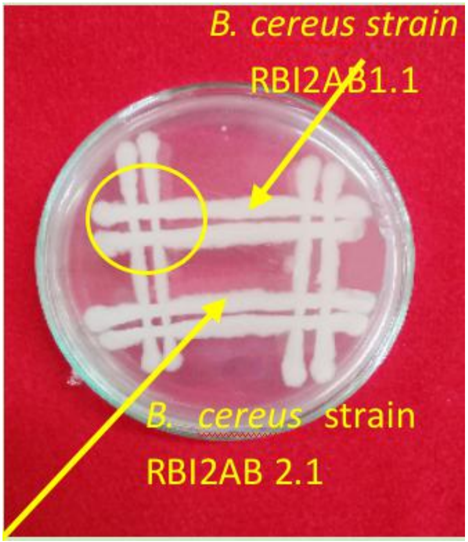
Compatibility test of *Bacillus spp. rhizobacteria*.

Testing all isolates of *Bacillus spp.* rhizobacteria showed compatibility because there was no growth inhibition (clear zone) between the meeting of the two isolates, thus they can be used as a rhizobacteria consortium. The test results are presented in Table 2 and Figure 1.

Table 2. Results of compatibility test of *Bacillus spp.* rhizobacteria consortium.

	Bacillus thuringiensis strain RBI2AB1.1	*Bacillus cereus* strain RBI2AB2.2
Bacillus cereus strain RBIKDA2.2	+	+
Bacillus cereus strain RBI2AB2.1	+	+
Bacillus subtilis strain RBIBPL2.3	+	+

Caption: + = Compatible



Picture 1. Results of *Bacillus spp.* rhizobacteria compatibility test.

The development of Root-Knot disease caused by *Meloidogyne spp*. on tomato plant roots

The consortium of *Bacillus spp.* rhizobacteria can suppress the development of *Meloidogyne spp*. and show different results compared to the control. Further test results can be seen in Table 3.

Table 3. Treatment of *Bacillus spp.* rhizobacteria consortium on the development of *Meloidogyne spp*.

Treatment	Observations			
	Number of root galls/plant	Number of egg masses/plant	Number of eggs/egg mass	Number of nematodes/300g of soil
RBI2AB1.1+ RBIKDA 2.2	22,66 ±0,063 cd	12,00±0,816 cd	264,00±6,480 c	17,33±0,730 cd
RBI2AB1.1+ RBI2AB2.1	25,00±0,707 c	11,00±0,816 cd	273,33±6,477 c	15,33±0,514 d
RBI2AB1.1+ RBIBPL2.3	18,33±0,653 d	9,33±0,327 d	227,33±0,753 d	14,33± 0,718 d
RBI2AB2.2+ RBIKDA 2.2	39,00±1,028 b	14,66±0,719 bc	308,67±0,426 b	20,33±0,541 bc
RBI2AB2.2+ RBI2AB2.1	34,33±1,830 b	17,33±0,376 b	314,33±1,525 b	23,33±0,311 b
RBI2AB2.2+ RBIBPL2.3	35,33±0,849 b	17,33±0,487 b	320,67±1,658 b	20,66±0,443 bc
Nematicide	37,66±0,395 b	17,33±0,550 b	307,00±1,224 b	20,66±0,480 bc
Control	121,67±3,880 a	32,00±1,825 a	529,33±0,615 a	39,00±0,707 a

Note: Numbers followed by the same lowercase letter in the same column are not significantly different according to LSD at the 5% level.

In Table 3, it can be observed that the consortium of *Bacillus spp*. can inhibit the number of root galls per plant, the number of egg masses per plant, the number of eggs per egg mass, and the number of nematodes per 300 grams of soil. All treatments with *Bacillus spp*. consortium shows significant differences compared to the control.

The growth of tomato seedlings

The consortium of *Bacillus spp*. demonstrates the ability to enhance the growth of tomato seedlings and shows significant results compared to the control. Further test results can be seen in Table 4.

Table 4. Consortium of *Bacillus spp*. treatment on tomato seedling growth

Treatment	Observations					
	Emergence Field Capacity of Seedlings	Seedling Height (cm)	Number of leaves (leaves)	Root length (cm)	Fresh weight (grams)	Dry weight (grams)
RBI2AB1.1+RBIKDA 2.2	28,33±0,533 b	11,03±0,904 cd	3,33±0,5726 bc	8,00±0,7071 bc	3,93±0,0254 ab	0,027±0,000 bc
RBI2AB1.1+RBI2AB2.1	27,66±0,538 b	11,30±0,603 cd	3,66±0,4697 ab	10,50±0,5717 a	3,40±0,3937 cd	0,021±0,0014 de
RBI2AB1.1+RBIBPL2.3	29,66±0,447 a	14,00±0,707 ab	4,00±0,7071 a	8,06±0,4329 c	4,30±0,1683 a	0,032±0,0014 a
RBI2AB2.2+RBIKDA 2.2	29,66±0,699 a	15,00±1,581 a	4,00±1 a	10,83±0,4344 a	4,13±0,7486 a	0,027±0,0043 bc
RBI2AB2.2+RBI2AB2.1	27,66±1,300 b	12,86±0,374 bc	3,66±0,1412 ab	9,50±1,3631 ab	3,60±0,2345 bc	0,024±0,0018 bc
RBI2AB2.2+RBIBPL2.3	26,66±0,866 c	10,63±0,677 d	4,00±1,2247 a	9,50±0,3646 ab	4,26±0,3954 a	0,028±0,0038 b
Nematicide	25,66±0,448 d	10,30±1,687 d	3,00±0,7071 c	8,33±0,7782 bc	3,26±0,4786 cd	0,017±0,0039 f
control	24,66±1,252 e	10,30±1,756 d	3,00±0,7071 c	7,5±0,6123 c	3,16±0,1920 d	0,019±0,0015 ef

Note: Numbers followed by the same lowercase letter within the same column are not significantly different according to LSD at the 5% level.

In Table 4, it can be observed that the consortium of *Bacillus spp*. can improve the emergence rate of seedlings, seedling height, number of leaves, root length, wet weight, and dry weight compared to the control. In terms of seedling emergence rate, all treatments with the *Bacillus spp*. consortium shows significant differences compared to the control. In the observation of seedling height, three types of consortium show significant differences compared to the control, namely RBI2AB2.2 + RBIAB2.1, RBI2AB1.1 + RBIBPL2.3, and RBI2AB2.2 + RBIKDA2.2, with heights ranging from 12.86 to 15.00 cm. In the observation of the number of leaves, five types of consortium show significant differences compared to the control, namely RBI2AB2.2 + RBIAB2.1, RBI2ABI.I + RBI2AB2.1, RBIAB2.2 + RBIBPL2.3, RBI2AB2.2 + RBIKDA2.2, and RBI2AB1.1 + RBIBPL2.3, with the number of leaves ranging from 3.66 to 4.00 pieces. In the observation of root length, two consortiums show significant differences compared to the control, namely RBI2ABI.I + RBI2AB2.1 and RBI2AB2.2 + RBIKDA2.2, with root lengths of 10.50 and 10.83 cm, respectively. In the observation of wet weight, four consortiums show significant differences compared to the control, namely RBI2AB1.1 + RBIKDA2.2, RBI2AB2.2 + RBIKDA2.2, RBIAB2.2 + RBIBPL2.3, and RBI2AB1.1 + RBIBPL2.3, with weights ranging from 3.93 to 4.90 grams. In the observation of dry weight, five consortiums show significant differences compared to the control, namely RBI2AB2.2 + RBIAB2.1, RBI2AB1.1 + RBIKDA2.2, RBI2AB2.2 + RBIKDA2.2, RBIAB2.2 + RBIBPL2.3, and RBI2AB1.1 + RBIBPL2.3, with weights ranging from 0.024 to 0.032 grams.

Tomato plant vegetative growth

The *Bacillus spp.* rhizobacteria consortium can enhance tomato plant growth during the vegetative phase and shows different results compared to the control. Further test results can be seen in Table 5.

Table 5. *Bacillus spp*. consortium treatment on tomato plant vegetative growth phase

Treatment	Observations	
	Plant height (cm)	The number of leaves
RBI2AB1.1+RBIKDA 2.2	121,37±0,764 c	12,66±0,381 bc
RBI2AB1.1+RBI2AB2.1	124,77±0,466 b	14,33±0,526 a
RBI2AB1.1+RBIBPL2.3	119,03±1,133 cd	13,00±0,707 abc
RBI2AB2.2+RBIKDA 2.2	129,00±0,707 a	13,33±0,546 ab
RBI2AB2.2+RBI2AB2.1	116,90±3,122 de	12,33±2,240 bc
RBI2AB2.2+RBIBPL2.3	114,37± 0,897 f	12,66±0,422 bc
Nematicide	114,37±0,671 f	11,66±0,338 c
Control	75,50± 6,773 g	11,66±0,530 c

Note: Numbers followed by the same lowercase letter within the same column are not significantly different according to LSD at the 5% level.

In Table 5, it can be observed that the *Bacillus spp*. consortium enhances plant height and leaf count compared to the control. In terms of plant height observation, all *Bacillus spp*. consortiums show significantly different results compared to the control, ranging from 114.50 to 129.00 cm. Meanwhile, in the leaf count observation, two consortiums show significantly different effects compared to the control, namely RBI2AB2.2 + RBIKDA2.2 and RBI2ABI.I + RBI2AB2, with counts of 13.33 and 14.33 leaves, respectively.

Growth of tomato plants in the generative phase

The consortium of *Bacillus spp.* rhizobacteria can enhance the growth of tomato plants in the generative phase and show different results compared to the control. Further test results can be seen in Table 6.

Table 6. Treatment of *Bacillus spp*. consortium on the generative growth of tomato plants.

Treatment	Observations		
	First flower appearance (days)	Number of fruits	Fruit weight (grams)
RBI2AB1.1+RBIKDA 2.2	34,66±0,303 c	24,00±1,224 bc	554,67±0,766 c
RBI2AB1.1+RBI2AB2.1	31,66±0,652 d	27,66±0,432 ab	607,00±2,549 b
RBI2AB1.1+RBIBPL2.3	35,33±0,567 c	22,33±1,197 cd	560,00±1,870 c
RBI2AB2.2+RBIKDA 2.2	31,33±0,748 d	31,00±0,707 a	650,67±2,802 a
RBI2AB2.2+RBI2AB2.1	37,33±0,612 b	27,66±0,583 ab	621,67±0,756 ab
RBI2AB2.2+RBIBPL2.3	36,66±0,824 b	22,00±1,581 cd	556,67±0,777 c
Nematicide	40,33±1,516 a	19,33±0,852 d	487,67±1,740 d
Control	40,66±1,650 a	18,66±0,518 d	384,00±3,162 e

Important note: Numbers followed by the same lowercase letter within the same row are not significantly different according to LSD at the 5% level.

In Table 6, it can be observed that the *Bacillus spp*. consortium enhances the appearance of the first flower, fruit count, and fruit weight compared to the control. In the observation of the appearance of the first flower, all types of consortia showed significantly different results compared to the control, ranging from 31.33 to 37.33 days. In the observation of fruit count, four consortia demonstrated significantly different results compared to the control, namely strains RBI2AB1.1 + RBIKDA2.2, RBI2AB2.2 + RBIAB2.1, RBI2ABI.I + RBI2AB2.1, and RBI2AB2.2 + RBIKDA2.2, ranging from 24.00 to 31.00 fruits. In the observation of fruit weight, all types of consortia exhibited significantly different results compared to the control, ranging from 554.67 to 650.67 grams.

The *Bacillus spp*. consortium in tomato plants can suppress the development of *Meloidogyne spp*. All types of *Bacillus spp*. consortia effectively suppress the development of *Meloidogyne spp*. compared to the control and nematicide. The *Bacillus spp*. consortium with the highest potential for suppressing the development of *Meloidogyne spp*. is B. thuringiensis strain RBI2AB1.1 + B. subtilis strain RBIBPL2.3. Isolates RBI2AB1.1 and RBIBPL2.3 can produce metabolite compounds such as siderophores, salicylic acid, and proteases (Yanti *et al.*, 2022). On the other hand, the other bacterial isolates used in the treatments are unable to produce these compounds. Siderophores produced by these isolates function to sequester iron in the plant roots, making it unavailable to pathogens. The ability of rhizobacteria to produce siderophores has a positive effect on pathogen control (Hu & Xu, 2011). Salicylic acid produced can induce plant resistance, thereby enhancing plant defense against pathogens (Fragniere *et al.*, 2011). Protease enzymes are known to affect nematode egg hatching by damaging and inhibiting the infective activity of nematodes in the second juvenile stage (Tran *et al.*, 2019). The *Bacillus spp*. consortium can provide simultaneous control mechanisms, thus effectively suppressing the development of *Meloidogyne spp*. According to Kumar and Jagadesh (2016), bacterial combinations in the form of consortia are more effective in controlling various types of plant pathogens. The *Bacillus spp*. bacterial consortium can control nematodes through antibiotic, chitinolytic, and HCN production mechanisms (Munif *et al.*, 2015). Research by Wijayanti *et al.* (2017) showed that the consortium of rhizobacteria P. fluorescens, B. subtilis, and Azotobacter sp. significantly increased total phenols and salicylic acid and affected the decrease in root rot disease severity.

Introduction of the *Bacillus spp.* rhizobacteria consortium to tomato seeds can enhance seedling growth compared to the control. The consortium RBI2AB2.2+RBIKDA2.2 is the isolate with the best potential in terms of seed emergence, seedling height, root length, and seedling vigor index. Meanwhile, in terms of leaf number, fresh weight, and dry weight observations, the consortium showing the best potential is RBIAB1.1+RBIBPL2.3. These results are likely due to the differences in the ability of each isolate to produce metabolite compounds that help stimulate tomato growth in the seedling phase. Each isolate RBI2AB2.2 and RBIKDA2.2 can produce higher levels of ammonia compared to other isolates. The ability to produce ammonia by rhizobacteria indirectly affects plant growth through biocontrol activities. Agustiyani's research (2016) also showed that the production of ammonia by rhizobacteria can enhance the germination and growth of corn seeds. Isolates RBIAB1.1 and RBIBPL2.3 are known to produce siderophores compared to other rhizobacterial isolates (Yanti *et al.*, 2022). The siderophores produced help to bind the availability of Fe, which is an essential nutrient for plants, thus enhancing plant growth (Prihatiningsih *et al.*, 2017). rhizobacteria can act as plant growth promoters by producing plant growth hormones such as IAA, nitrogen fixation, and phosphate solubilization (Guyasa *et al.*, 2018). Liu *et al.* (2022) reported that IAA and GA-producing bacteria can promote seed germination and shoot emergence.

Introduction of the *Bacillus spp.* rhizobacteria consortium can also enhance tomato plant growth during the vegetative phase. The consortium with the best potential in terms of plant height observation is RBI2AB2.2+RBIKDA2.2, while for leaf number observation, it is RBI2AB1.1+RBI2AB2.1. This is likely because both rhizobacterial consortia can produce more siderophores, ammonia, and salicylic acid compared to other rhizobacterial consortia. The production of siderophores by rhizobacteria can enhance bacterial colonization in the rhizosphere and play a crucial role in mineralizing Fe for plants (Pahari & Mishra, 2017). Fe is an essential micronutrient in chlorophyll biosynthesis and plant photosynthesis. The ability to produce siderophores also supports root elongation, which can enhance nutrient uptake and improve plant growth (Astuti *et al.*, 2021). The increase in salicylic acid due to rhizobacteria application can have positive effects on plants, including providing hormones for plants and producing antibiotics that negatively impact pathogens in the plant roots. Salicylic acid plays a crucial role in activating genes that control plant resistance to pathogen infection by inducing proteins linked to pathogenicity (Wijayanti *et al.*, 2017).

Introduction of the *Bacillus spp. rhizobacteria*l consortium in tomato plants also has better potential for tomato plant growth during the generative phase compared to the control. The consortium treatment with the best potential to enhance tomato plant growth during the generative phase is B. cereus strain RBI2AB2.2 + B. cereus strain RBIKDA2.2. This consortium type has a higher effectiveness value, presumably because it can produce secondary metabolites such as salicylic acid, protease, and ammonia at higher levels compared to other consortium types (Yanti *et al.*, 2022). The production of phytohormones by *Bacillus spp*. such as IAA, gibberellins, auxins, ethylene, cytokinins, and abscisic acid are also known to help improve plant yields (Suryaningsih, 2008).

CONCLUSION

The best *Bacillus spp. rhizobacteria*l consortium in suppressing the development of *Meloidogyne spp*. and enhancing the growth and yield of tomato plants is *Bacillus cereus* strain RBI2AB2.2 + *Bacillus cereus* strain RBIKDA2.2.

ACKNOWLEDGMENTS

The author expresses gratitude to the Direktorat Jenderal Pendidikan Tinggi by LPPM Universitas Andalas, by the Agreement on the Implementation of Excellent Applied Research Assignment Clusters for Accelerated Professorship Publication (PTU-KRP2GB-Unand) with Contract Number T/20/UN.16.17/PP Pangan-PTU-KRP2GB-Unand/2022, for funding this research.

REFERENCES

Agustiyani, D. (2016). Penapisan dan karakterisasi rhizobakteria serta uji aktivitasnya dalam mendukung perkecambahan dan pertumbuhan benih jagung (*Zea mays L.*). *Jurnal Biologi Indonesia, 12*(2), 241-248.

Astuti, L.A.D., Muslichah, D.A., Suprihadi, A., Rukmi, M.G.I., Mulyani, N., & Sutisna, E. (2021). Karakterisasi bakteri diazotrof dan pengaruhnya terhadap pertumbuhan tanaman kedelai (*Glycine max* L. Merrill). *Journal of Troical Biology, 4*(1), 40-49.

Badan Pusat Statistik dan Direktorat Jendral Hortikultura. (2021). *Data lima tahun terakhir produktivitas tanaman hortikultura*. https://www.pertanian.go.id/home/?show=page&act=view& d=61. Diakses pada tanggal 26 Juli 2021.

Fiandani, A., Swibawa, I. G., & Fitriana, Y. (2021). Pengaruh dosis bionematisida jamur *Purpureocillium lilacinum* (Syn. *Paecilomyces lilacinus*) isolat B01TG berbahan pembawa limbah pertanian terhadap keefektifanya terhadap dalam mengendalikan *Meloidogyne* spp. *Agrotek Tropika, 9(*2), 189-197.

Fragnière, C., Serrano, M., Abou-Mansour, E., Métraux, J. P., & L'Haridon, F. (2011). Salicylic acid and its location in response to biotic and abiotic stress. *FEBS letters, 585*(12), 1847-1852. https://doi.org/10.1016/j.febslet.2011.04.039

Guyasa, I. M., Sadimantara, I. G. R., Khaeruni, A. & Sutariati, G. A. K. (2018). Isolation of *Bacillus* spp. and *Pseudomonas fluorescens* from upland rice rhizosphere and its potential as Plant growth promoting rhizobacteria for local upland rice (*Oryza sativa L.*). *Bioscience Research*, *5*(4), 3231-3139.

Habazar, T., Yanti, Y., Dani, M. R., & Monica, D. (2021). Biocontrol of *Meloidogyne* sp. on tomato plants by selected *Bacillus* spp. *In IOP Conference Series: Earth and Environmental Science*, (757, (1), p. 012019). IOP Publishing.

Harni, R., & Samsudin, J. A. G. (2015). Pengaruh formula bionematisida bakteri endofit Bacillus sp. terhadap infeksi nematoda Meloidogyne sp. pada tanaman kopi. *Jurnal Tanaman Industri dan Penyegar*, *2*(3), 143-149.

Hu, Q. & Xu, J. (2011). A simple double-layered chrome azurol S agar (SD- CASA) plate assay to optimize the production of siderophores by a potential biocontrol agent *Bacillus. African Journal of Microbiology Reasearch, 5*(25), 4321-4327

Istiqomah, D. & Pradana A.P. (2015). Teknik pengendalian nematoda puru akar *(Meloidogyne* spp*.)* ramah lingkungan*. Prosiding Seminar Nasional Pencapaian Swasembada Pangan Melalui Pertanian Berkelanjutan*. Universitas Muhammadiyah Purwokerto.

Jailani. (2022). Pengaruh pemberian pupuk kompos terhadap pertumbuhan tanaman tomat (*Lycopersicum escelentum Mill.*). *Jurnal Sains dan Aplikasi*, *10*(1), 1-8.

Khabbaz, S.E., D., Ladhalakshmi, M., Babu, A. Kandan, V., Ramamoorthy., D., Saravankumar, T., Al-Mughrabi, & Kandasamy, S. (2019). Plant growth promoting bacteria (PGPB) a versatile tool for plant health management. *Can. J. Pestic. Pest Manag*, *1*(1), 1-10.

Klement, Z., Rudolph, K., & Sand, D. C. (1990). Methods in phytophatology. *Hungary:* Akademia Kiado.

Kumar, K.H., & Jagadeesh K.S. (2016). Microbia consortia mediated plant defense againt Phytophatogens and growth benefits. *South Indian Journal of Biological Sciences*, *2*(4), 395-403.

Liu, Z., Zhang, X., Li, L., Xu, N., Hu, Y., Wang, C., ... & Li, D. (2022). Isolation and characterization of three plant growth-promoting rhizobacteria for growth enhancement of rice seedling. *Journal of Plant Growth Regulation*, *41*(3), 1382-1393.

Munif, A., Halimah, D., & Giyanto. (2015). Effectiveness of endophytic bacterial consortium of coffee plant on mortality of Pratylenchus coffeae in vitro. *Pelita Perkebunan (a Coffee and Cocoa Research Journal), 31*(3), 175-185.

Murthi, R. S., Lisnawita, & Oemry, S. (2015). The potential of endophytic bacteria in enhancing the growth of tobacco plants infected with root-knot nematodes (*Meloidogyne spp*). *Jurnal Agroekoteknologi*, *4*(1), 1881-1889.

Noor, S., & Melani, D. (2022). The effect of soaking duration and application of biological agents *Bacillus subtilis* and *Pseudomonas fluorescens* on the growth of mustard green (Brassica juncea L.) seeds. *Agromix, 13*(2), 235-241. https://doi.org/10.35891/agx.v13i2.2907

Pahari, A., & Mishra, B. B. (2017). Characterization of siderophore producing rhizobacteria and its effect on growth performance of different vegetables. *Int J Curr Microbiol App Sci*, *6*(5), 1398-1405.

Prihatiningsih, N., Djatmiko, H.A., & Lestari, P. (2017). Aktivitas siderofor *Bacillus subtilis* sebagai pemacu pertumbuhan dan pengendali patogen tanaman terung. *Jurnal HPT Tropika, 17*(2), 170-178.

Raihana. (2017). Aplikasi perkembangan stadia hidup nematoda puru akar (*Meloidogyne* spp) mulai dari fase telur sampai dewasa pada pertanaman tomat (*Solanum lycopersicum* L.) di Kota Banjarbaru. *Agroekotek View*, *1*(2), 25-35.

Ramadhany, K.A., Sudana, I.M., & Singarsa, I.D.P. (2021). Tingkat perkembangan nematoda puru akar (*Meloidogyne* spp.) pada berbagai jenis tanaman tomat menggunakan pengendalian ekstrak daun kirinyuh. *Jurnal Agroekoteknologi Tropika, 10*(3), 286-293.

Sarkar, P. & Chourasia R. (2017). Bioconversion of organic solid wastes into biofortified compost using a microbial consortium*. International Journal of Recycling of Organic Waste in Agriculture*, *6*(1), 321–334.

Situmorang, D., Khalimi, K.., & Phabiola, T.A. (2021). Pengembangan formula biofungisida dan aplikasinya dalam mengendalikan penyakit layu fusarium pada tanaman tomat (*Solanum lycopersicum* L.). *Jurnal Agroekoteknologi Tropika, 10*(4), 428-438.

Suryaningsih E. (2008). *Bakteri jadi pestisida aman*. Jakarta: Trubus

Sutariati, G.A.K. & Wahab, A. (2012). Karakter fisiologis dan kemangkusan rizobakteria indigenus sulawesi tenggara sebagai pemacu pertumbuhan tanaman cabai. *Jurnal Hortikultural, 22*(1), 57-64

Syahputra, T.S., (2018). *Evaluasi efektivitas fungisida berbahan aktif mankozeb terhadap Phytophtora infestans penyebab penyakit hawar daun tomat di dataran tinggi karo*. [Tugas Akhir] Fakultas Pertanian. Universitas Sumatera Utara. 53 Halaman.

Syukur, M., Saputra, H. E., & Hermanto, R. (2015). *Bertanaman tomat di musim hujan*. Penebar Swadaya: Jakarta.

Tran, T.P.H., Wang, S.L., Nguyen, V.B., Tran, D.M., Nguyen, D.S., & Nguyen, A.D. (2019). Study of novel endophytic bacteria for biocontrol of black-pepper root-knot nematodes in the central highlands of vietnam. *Agronomy, 9*(1), 714.

Wijayanti, S.W., Rahardjo, B.T., & Himawan, T. (2017). Pengaruh rizobakter dalam meningkatkan kandungan asam salisilat dan total fenol tanaman terhadap penekanan nematoda puru akar. *Buletin Tanaman Tembakau, Serat & Minyak Industri, 9*(2), 54-63.

Winarto, Trizelia, & Liswani, Y. (2018). Aktivitas antagonistik jamur yang berasosiasi dengan nematoda bengkak akar *(Meloidogyne* spp.*)* pada rizosfer tanaman tomat. *Jurnal Proteksi Tanaman*, *2*(2), 76 – 84.

Yanti, Y., Habazar., Reflinakdon., & Nasution, C.R. (2017). Indegenous *Bacillus* spp. ability to growth promoting activities and control bacterial wilt disease (*Ralstonia solanacearum*). *Biodiversitas*, *18*(4), 1562-1567.

Yanti, Y., Hamid, H., & Syarif, Z. (2019). Screening of indigenous rhizospheric cyanobacteria as potential growth promotor and biocontrol of *Ralstonia syzygii* subsp. *indonesiensis* on chili. *International Journal of Environment, Agriculture and Biotechnology*, *4*(6), 1665-1672.

Yanti, Y., Hamid, H., Reflin, R., Yaherwandi, Y., Suhendra, D., Hariandi, D., & Suriani, N. L. (2022). Evaluation of the Effect of PGPR Strains on Tomato Growth and Suppression of Ralstonia Wilt Disease. *KnE Life Sciences*, 664-671.

Yanti, Y., Warnita, Reflin & Hasmiandy, H. (2018). Short Communication: Development of selected PGPR consortium to control *Ralstonia syzygii* subsp. indonesiensis and promote the growth of tomato. *Biodiversitas, 19*(1), 2073-2078.