META-ANALYSIS OF BIO-FERTILIZER POTENTIALS OF *BACILLUS* SPECIES IN ENHANCING GROWTH PARAMETERS OF TOMATO (*SOLANUM LYCOPERSICUM* L.)

OGUGUA, U. V.[1*] – OGBUEWU, I. P.[2,3] – MBAJIORGU, C. A.[2] – ADRIAANSE, P.[1]

[1]*Horticulture Center, Science Campus, University of South Africa, Florida 1710, South Africa*

[2]*Department of Agriculture and Animal Health, College of Agriculture and Environmental Sciences, University of South Africa, Florida 1710, South Africa*

[3]*Department of Animal Science and Technology, Federal University of Technology, PMB 1526, Owerri, Nigeria*

**Corresponding author*
e-mail: eoguguuv@unisa.ac.za, oguguatalks@gmail.com; phone: +27-11-670-9043

(Received 16th Nov 2023; accepted 27th Feb 2024)

Abstract. There is an increasing body of knowledge on the use of *Bacillus spp.*, a pervasive microorganism to enhance plant growth and development. However, there is scanty information on meta-analysis of bio-fertilizer potential of *Bacillus spp.* on selected growth parameters in tomato (*Solanum lycopersicum* L.). Hence, this study aimed to use a meta-analysis procedure to determine the effect of *Bacillus spp.* on the following growth parameters in tomato: plant height, shoot fresh weight and shoot dry weight, root length, root fresh weight, root dry weight, and number of leaves per plant. A systematic search conducted in AGORA, Scopus, ScienceDirect, Web of Science, Google Scholar, Pubmed, Elicit.com databases yielded 398 articles of which 51 articles were used for the meta-analysis. Random-effect model (REM) was used to generate the pooled effects estimated at a 95% confidence interval. All the analyses were performed using OpenMEE software. The results showed that *Bacillus* spp. enhanced plant height, shoot fresh weight, and shoot dry weight, root length, root fresh weight, root dry weight and number of leaves per plant. Restricted subgroup analysis showed that studied moderators (*Bacillus* strain, B-count, Dosage of bacteria, Mode of application, Days after planting (DAP), Temperature and Duration) influenced the result of the meta-analysis. There was evidence of significant heterogeneity and meta-regression analysis showed that the studied moderators explained most of the sources of heterogeneity. These results demonstrated the bio-fertilizer potential of *Bacillus* spp. in enhancing the physiological growth parameters of tomato. The present meta-analysis also sets the steps for future standardized experimental designs on the use of *Bacillus* spp. to enhance growth parameters of tomato.
Keywords: *useful microbes, crop improvement, plant growth, meta-regression, tomato*

Introduction

Tomato (*Solanum lycopersicum*) is an important *Solanaceae* crop that is grown for its fruits. Tomato is a perennial crop although it is grown as an annual crop (Shamshiri et al., 2017; Costa and Heuvelink, 2018). It is also a warm-season crop that does not tolerate frost and it grows optimally at the temperature range of 20-25°C with moderate rainfall (Shamshiri et al., 2017). It is grown either in open field or in controlled environments (greenhouse/tunnels). Tomato is the second most important vegetable after potato (Ogugua et al., 2022). The global production of tomato in 2020 was estimated at 186.8 million tons for an area of 5.3 million hectares, producing an average yield of 37 tons per hectare (Kouam et al., 2023). A recent study by Caspermeyer (2020) showed that tomato is now widely cultivated throughout the world. It is rich in minerals, carbohydrates, and vitamins (A, C, K, and B complex). Tomato accounts for

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2203_25072530

about 14% of the world's annual consumed vegetables (Kousar et al., 2020). Tomato is a major dietary source of antioxidant: carotenoids, lycopene, and flavonoids, which are known for their several beneficial health effects (Nkolisa et al., 2018). The indiscriminate use of agrochemicals has negative impact on crops and sometimes causes cancers or related illnesses (Sharma and Singhvi, 2017). Bacterial strains that have useful effects on plant growth are considered plant growth promoting bacteria (PGPB). The use of PGPB is one of the approaches currently employed for agricultural clean production (Cabra Cendales et al., 2017) to enhance crop productivity. PGPB enhances plant growth and promotes soil remediation by releasing various metabolites and hormones, through the process of nitrogen fixation, and by increasing the availability of other essential nutrients through mineral solubilization (Poria et al., 2022; Tsotetsi et al., 2022).

Bacillus spp. is one of the PGPB known to be the safest microorganisms that hold remarkable abilities for producing a vast array of beneficial substances such as, the production of Indole-3-acetic acid (IAA), 1-aminocyclopropane-1-carboxylate-deaminase (ACC-deaminase), phosphate-solubilizing enzyme (PSE), and siderophores (Oleńska et al., 2020; Tsotetsi et al., 2022). *Bacillus* and its products are considered safe for intended use in the environment (Bhattacharyya et al., 2016). *Bacillus* spp. have received much attention as bio-stimulator agents and it has been reported to stimulate plant growth (Moncada et al., 2020). *Bacillus* spp. has been found to significantly enhanced growth and development of crops other than tomato (Ogugua et al., 2018; Bavaresco et al., 2020; Zhu et al., 2021; Mengistie and Awlachew, 2022).

Nevertheless, no studies have reported on meta-analytic effects of *Bacillus* spp. amendment on the tomato (*Solanum lycopersicum* L.) growth parameters, therefore this study was initiated. In bridging the identified research gap, the authors quantitatively collated and analyzed the results of the effects of *Bacillus* spp. as a growth enhancer on tomato growth parameters from published studies. The study is aimed at availing researchers the needed information on the pooled effect of *Bacillus* as a biofertilizer on selected growth parameters in tomato and other explanatory variables reported (day after planting (DAP), *Bacillus* strain, Bacteria count and dosage of bacteria, temperature, mode of bacteria application and duration) in enhancing tomato growths. As part of this study, the needed database was generated and the resulting data was systematically analyzed.

Methods

Literature search and study selection

A systematic literature search of *Bacillus* spp. and tomato production was conducted in Agora, Web of Science, Google Scholar, Scopus, Science Direct, PubMed, Elicit.com databases to assess articles published in English. The search was done using the following search queries: closeness searching ("…" or "…"), Boolean logic (AND, OR), alternate spelling (?), wildcard ($ or *), and search words: *Bacillus* spp., *Bacillus* as growth enhancer, *Bacillus* boosting tomato growth parameters. The selection criteria for the meta-analysis were: (i) randomized and controlled studies published in peer-reviewed journals. (ii) Studies that report at least one of the growth response parameters of interest: plant height, shoot fresh weight, shoot dry weight, root length, root fresh weight, root dry weight and number of leaves per plant. (iii) Studies that reported at least one of these studied moderators: *Bacillus* strain, bacteria count and dosage, DAP,

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2203_25072530

temperature, mode of application, duration. Studies that failed to report any of the growth response parameters of interest were excluded from the meta-analysis. (iv) Studies on *Bacillus* not reported on also tomato growth response were dropped. Review papers, studies that appear in more than one database and studies not reported in English were also excluded. Three hundred and ninety-eight (398) publications were identified and 51 full-text studies selected based on the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) as displayed in *Figure 1*.

Data extraction

Data covering the surname of the first author, year of publication, study country, and moderator explanatory variables (*Bacillus* strain, bacteria count, bacteria dosages, day after planting, temperature, mode of bacteria application, and duration) were extracted from each study that met the predefined inclusion criteria (*Table A1*). Data on growth response parameters were also selected. Data presented in figures were retrieved using a Web Digitizer (https://automeris.io/WebPlotDigitizer). Standard deviation (SD) is a vital metric for meta-analysis, but in several instances, the SD of yield results was not readily available; thus, it was necessary to estimate them. Estimation of SD values is achieved through the use of an equation (SD = SE * √n), where n represents the number of replications (Ogbuewu and Mbajiorgu, 2020; Ugwu et al., 2020). Similarly, in studies where the SD nor SE values were not reported, a 10% of mean variables were assigned as the SD values (Adu et al., 2018; Ugwu et al., 2020). The influence of the estimated SD on the result was considered with sensitivity analyses (Adu et al., 2018).

Statistical analysis

In order to conduct meta-analysis, meta-regression, and predictor-treatment interaction determination, all pertinent data were saved as described above. OpenMEE meta-analysis software (Wallace et al., 2017) was then used for further analysis.

Effect size

Effect size shows the colossal difference between the variable means and treatment effects of the study interest (*Bacillus* spp. on selected tomato growth parameters) as defined in the meta-analysis. Different types of effect sizes were calculated in the study; Hedges' d and also the standard mean differences (SMD) between the treatment and control. Hedges' d was used in the study as it has been reported as the most ideal metric in meta-analysis and has more merits than the response ratio (Morales and Traveset, 2009; Adu et al., 2018) which can be used in studies that have a small sample size (Ogbuewu and Mbajiorgu, 2020; Ugwu et al., 2020). Furthermore, unequal sampling in paired groups does not influence Hedges' d (Ogbuewu and Mbajiorgu, 2020; Ugwu et al., 2020). Hedges' d was used in studies that reported mean and standard deviations (Ogbuewu and Mbajiorgu, 2020). Based on Cohen's (1988) recommendations, the difference between an effect size of < 0.2, 0.5 and > 0.8 was interpreted as small, moderate and large difference effect sizes.

According to Higgins and Thompson (2002), heterogeneity was determined using the DerSimonian and Laird test (Q-statistic) and inconsistency index (I^2 statistic). We used a random-effects model (REM) according to DerSimonian and Laird (1986) to assess the grand mean effect size of *Bacillus* spp. amendment on tomato growth parameters.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2203_25072530

The restrictive maximum likelihood (REML) method and mixed effect models were used to estimate the between-study (QB) and within-study variance. Also, treatment and covariate interaction effects were determined using standard methods (Wallace et al., 2017; Ugwu et al., 2020).

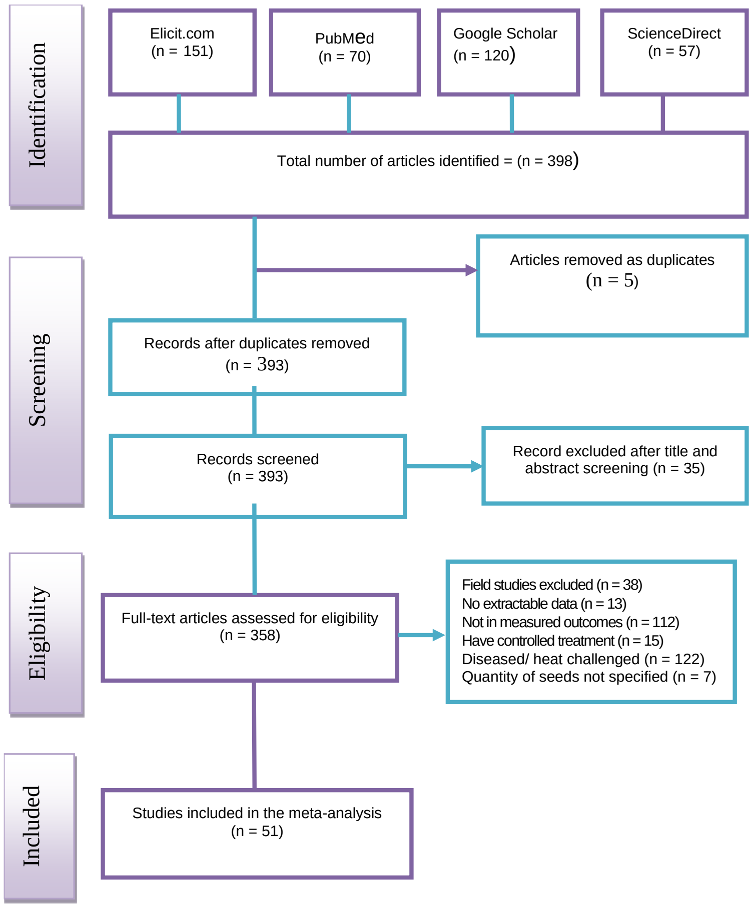

Figure 1. *Article selection flow-chart*

Sensitivity analysis and publication bias

Using sensitivity analysis, we determined whether or not the meta-analysis result was robust. It is often necessary to perform sensitivity analyses in order to determine the impact of studies that are viewed as having unjustified influence in the meta-analysis (Lean et al., 2009). Confounding factors may also be introduced when experiments are conducted in controlled environments, such as greenhouses (Sadras, 2009). When publication bias is absent, a funnel plot should resemble an inverted symmetrical funnel. If publication bias is present, for example, as a result of smaller, unpublished studies that lack statistically significant effects, the funnel plot will appear asymmetrical with a gap in the bottom corner (Higgins and Green, 2011). In order to establish publication bias, Rosenberg’s fail-safe number (Nfs) was used, which identifies the number of studies with no significant findings that would be required to negate the overall effect size. As per Borenstein et al. (2021), with a fail-safe number (Nfs) of greater than (>5*(n) + 10), where n = number of effect size, the result of a meta-analysis is regarded as robust despite the possibility of publication bias.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2203_25072530

Results

Data synopsis

A total of 51 studies out of 398 studies met the inclusion criteria and were used for analysis. Studies utilized for the meta-analysis were conducted in 21 countries that cut across 5 continents and reported on the growth parameters of tomato plants. *Table A1* provides a summary of the characteristics of 51 studies selected for the meta-analysis. As illustrated in *Figure 2,* sixteen studies identified *Bacillus* spp. as promoters of tomato growth. The most commonly used spp. were *B. subtilis*, *B. amyloliquefaciens*, *B. cereus*, *B. pumilus* and *B. megaterium*, while the least used species were *B. siamensis*, *B. aerius*, *B. pacificus*, *B. mesonae*, *B. thuringiensis*, and *B. vallismontis*.

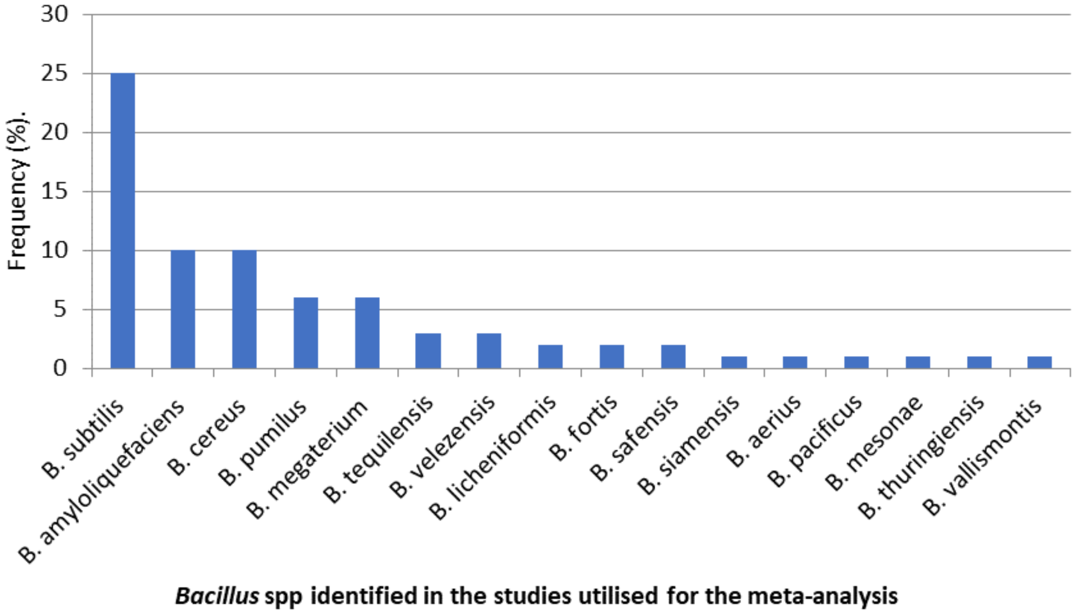

Figure 2. *Bacillus spp. used for the meta-analysis*

Data as presented in *Figure 3* show that most of the experiments were conducted in India (27%), followed by China (13%); Spain and Iran had 6% studies conducted; South Africa, Japan, Republic of Korea, Tunisia, Pakistan, Canada, Brazil and Mexico had 4% of studies each while Afghanistan, Germany, Egypt, Oman, Bangladesh, Cameroun, Malaysia, Saudi Arabia and Turkey had 2% studies conducted respectively.

Plant height

A meta-analysis of 38 articles found that *Bacillus* spp. significantly increased the height of tomato plants when compared to the control (SMD = 3.15, 95% CI: 2.80, 3.51; *Table 1*). Stratified analysis showed that *Bacillus* strain had a significant effect on tomato plant height. Similarly, dosage of *Bacillus* spp. applied to the plant, mode of application, DAP, temperature, and duration of the study had significant effects on plant height. The results of the meta-analysis showed evidence of significant heterogeneity across the 38 studies on the effect of *Bacillus* spp. on plant height (Q-statistic $p < 0.001$, $I^2 = 75\%$). However, restricted and sensitivity analysis solved the problem of significant heterogeneity in this meta-analysis (SMD = 4.35, 95% CI: 3.88, 4.81; $I^2 = 84\%$;

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2203_25072530

Table A2). Additionally, a meta-regression demonstrated significant relationship between studied moderators [*Bacillus* spp. ($Q_M = 38.6$, $p < 0.001$; $R^2 = 6\%$), bacterial count ($Q_M = 50.4$, $p < 0.001$; $R^2 = 28\%$), dosage of bacterial applied on the plant ($Q_M = 90.1$, $p < 0.001$; $R^2 = 51\%$), mode of application ($Q_M = 42.5$, $p < 0.001$; $R^2 = 29\%$), DAP ($Q_M = 47.1$, $p < 0.001$; $R^2 = 31\%$), temperature ($Q_M = 65.5$, $p < 0.001$; $R^2 = 41\%$) and duration of the study ($Q_M = 32.2$, $p < 0.001$; $R^2 = 14\%$)] and plant height (*Table 2*).

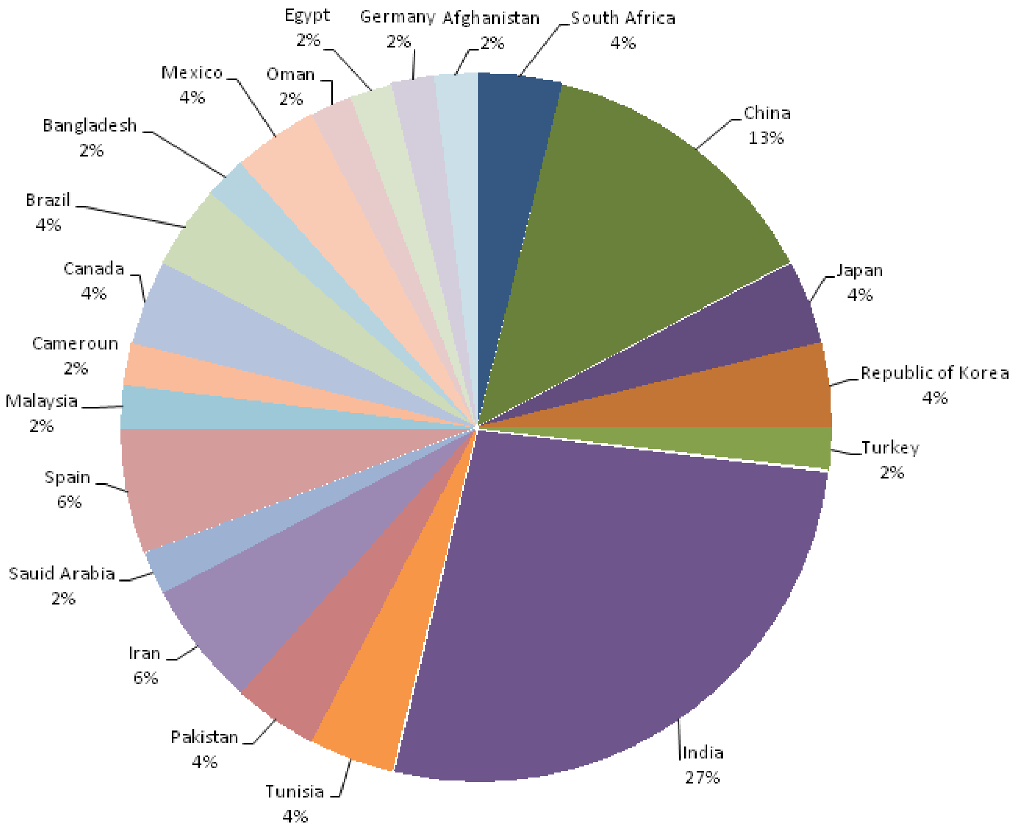

Figure 3. *Study country used for the meta-analysis*

Table 1. *Effect of Bacillus spp. as growth enhancer on tomato plant height*

Pooled/subgroup effect	NS	SMD	95% CI	I^2 (%)	Het. p-value
Overall	155	3.15	2.80, 3.51	75	< 0.001
Bacillus strain	154	3.12	2.77, 3.48	74	< 0.001
B- count	141	3.00	2.61, 3.33	73	< 0.001
Dosage of bac	124	3.27	2.86, 3.68	76	< 0.001
Mode of app	119	3.20	2.79, 3.62	74	< 0.001
DAP	131	3.17	2.79, 3.56	74	< 0.001
Temp	121	3.18	2.77, 3.60	74	< 0.001
Duration	122	3.24	2.82, 3.66	75	< 0.001

NS: number of studies included in the analysis, B-count: bacteria count, Dosage of Bac: dosage of *bacillus*, Mode of app: mode of bacteria application, DAP: days after planting, Temp: temperature of the greenhouse, Duration, duration of the study, SMD: standardized mean differences, I^2: inconsistency index, Het: heterogeneity, p: probability

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2203_25072530

Table 2. *Effect of Bacillus spp. as growth enhancer on tomato plant growth parameters*

Outcomes	Moderators	Q_M	Estimate	df	p-value	R^2 (%)
Plant height	*Bacillus* strain	38.6	4.64	15	< 0.001	6
	B- count	50.4	3.25	10	< 0.001	28
	Dosage of Bac	90.1	2.84	13	< 0.001	51
	Mode of app	42.5	4.18	8	< 0.001	29
	DAP	47.1	3.91	9	< 0.001	31
	Temp	65.5	3.29	7	< 0.001	41
	Duration	32.2	5.13	12	< 0.001	14
Shoot fresh weight	*Bacillus* strain	15.04	2.84	13	< 0.305	0
	B- count	16.05	2.58	9	< 0.066	6
	Dosage of Bac	57.80	1.06	11	< 0.01	68
	Mode of app	17.73	3.00	7	< 0.01	9
	DAP	21.30	3.16	9	0.012	17
	Temp	7.16	3.37	4	0.128	3
	Duration	47.80	1.58	8	< 0.001	40
Shoot dry weight	*Bacillus* strain	32.10	0.73	10	< 0.001	13
	B- count	85.90	0.49	10	< 0.001	42
	Dosage of Bac	86.60	0.06	10	< 0.001	90
	Mode of app	32.70	0.83	6	< 0.001	0
	DAP	58.10	0.35	11	< 0.001	61
	Temp	50.30	0.37	9	< 0.001	49
	Duration	57.60	0.48	8	< 0.001	42
Root length	*Bacillus* strain	14.9	4.46	8	0.061	10
	B- count	26.3	3.05	9	0.002	18
	Dosage of Bac	10.07	3.38	9	0.35	0
	Mode of app	4.55	4.83	5	0.473	0
	DAP	26.8	3.41	8	< 0.001	31
	Temp	1.29	3.32	3	0.73	0
	Duration	37.29	2.34	10	< 0.001	31
Root fresh weight	*Bacillus* strain	8.36	4.27	10	< 0.594	0
	B- count	23.10	1.75	4	< 0.001	50
	Dosage of Bac	35.30	1.43	6	< 0.001	67
	Mode of app	22.10	1.99	6	< 0.001	43
	DAP	32.90	2.06	8	< 0.001	47
	Temp	5.39	3.30	3	0.145	5
	Duration	19.31	2.56	5	< 0.002	34
Root dry weight	*Bacillus* strain	16.20	1.75	10	0.09	13
	B- count	69.60	0.75	10	< 0.001	64
	Dosage of Bac	15.60	1.93	7	0.03	3
	Mode of app	39.60	1.26	7	< 0.001	37
	DAP	45.80	0.80	9	< 0.001	47
	Temp	26.60	1.57	6	< 0.001	21
	Duration	15.61	1.92	7	0.03	3
Number of leaves	*Bacillus* strain	17.60	1.92	4	< 0.001	74
	B- count	14.60	2.74	7	< 0.006	63
	Dosage of Bac	6.24	5.46	3	0.10	27
	Mode of app	15.20	2.23	3	< 0.002	70
	DAP	12.63	2.47	3	< 0.006	67
	Temp	4.45	6.47	2	0.11	14
	Duration	14.60	2.74	4	< 0.006	63

NS: number of studies included in the analysis, B-count: bacteria count, Dosage of Bac: dosage of *bacillus*, Mode of app: mode of bacteria application, DAP: days after planting, Temp: temperature of the greenhouse, Duration, duration of the study, SMD: standardized mean differences, I^2: inconsistency index, Het: heterogeneity, p: probability, Q_M: coefficient of moderators, df: degree of freedom, R^2: amount of heterogeneity explained by the moderators

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2203_25072530

Shoot fresh weight

The pooled analysis of 31 trials showed that *Bacillus* spp. significantly increased the shoot fresh weight of tomato plant (SMD = 2.66, 95% CI: 2.33, 3.00; *Table 3*). Stratified analysis revealed that *Bacillus* strain acted as a moderator on the shoot fresh weight (SMD = 2.66, 95% CI: 2.32, 3.00). Furthermore, stratified analysis indicated that the bacterial count, dosage of bacterial applied on the plant, mode of application, DAP, temperature, and duration of the study had an effect on tomatoes plant height. The results of the analysis showed a significant degree of variability across the 31 studies that assessed the effect of *Bacillus* spp. on shoot fresh weight (Q-statistic $p < 0.001$, $I^2 = 70\%$). Restricted and sensitivity analysis resolved the issue of significant heterogeneity in this meta-analysis (SMD = 3.62, 95% CI: 3.16, 4.08; $I^2 = 82\%$; *Table A2*). Meta-regression found significant linear relationships between aspects of moderators (dosage of bacterial applied on the plant, mode of application, DAP, and duration of the study and shoot fresh weight (*Table 2*). However, there are no treatment effects of *Bacillus* spp., bacterial count, and temperature on the shoot fresh weight.

Table 3. *Effect of Bacillus spp. as growth enhancer on tomato shoot fresh weight*

Pooled/subgroup effect	NS	SMD	95% CI	I^2 (%)	Het. p-value
Overall	103	2.66	2.33, 3.00	71	< 0.001
Bacillus strain	102	2.66	2.33, 3.00	70	< 0.001
B- count	74	2.81	2.45, 3.17	70	< 0.001
Dosage of bac	66	2.77	2.32, 3.21	71	< 0.001
Mode of app	84	2.75	2.36, 3.14	73	< 0.001
DAP	72	2.96	2.50, 3.41	76	< 0.001
Temp	59	2.88	2.48, 3.28	70	< 0.001
Duration	103	2.66	2.33, 3.00	70	< 0.001

NS: number of studies included in the analysis, B-count: bacteria count, Dosage of Bac: dosage of *bacillus*, Mode of app: mode of bacteria application, DAP: days after planting, Temp: temperature of the greenhouse, Duration: duration of the study, SMD: standardized mean differences, I^2: inconsistency index, Het: heterogeneity, p: probability

Shoot dry weight

A total of 35 articles included in the pooled analysis revealed that *Bacillus* spp. increased tomato shoot dry weight (SMD = 1.68, 95% CI: 1.48, 1.87; *Table 4*). Results from the stratified analysis showed that *Bacillus* spp. positively influenced shoot dry weight of tomato plant. Bacterial count, dosage of bacterial applied on the plant, mode of application, DAP, temperature, and duration of the study had an impact on tomato shoot dry weight. The Q-statistic and I^2 = statistic indicated significant heterogeneity across the 35 studies on the overall effect of *Bacillus* spp. on shoot dry weight (Q-statistic $p < 0.001$, $I^2 = 60\%$). However, restricted and sensitivity analyses addressed the problem of significant heterogeneity (SMD = 1.85, 95% CI: 1.62, 2.08; $I^2 = 71\%$; *Table A2*). The meta-regression results found significant linear association between *Bacillus* spp. ($Q_M = 32.10$, $p < 0.001$; $R^2 = 13\%$), bacterial count ($Q_M = 85.90$, $p < 0.001$; $R^2 = 41\%$), dosage of bacterial applied on the plant ($Q_M = 86.60$, $p < 0.001$; $R^2 = 90\%$), mode of application ($Q_M = 32.70$, $p < 0.001$; $R^2 = 0.00$), DAP ($Q_M = 58.10$, $p < 0.001$; $R^2 = 61\%$), temperature ($Q_M = 50.30$, $p < 0.001$; $R^2 = 49\%$) and duration of the study ($Q_M = 57.60$, $p < 0.001$; $R^2 = 42\%$) and shoot dry weight (*Table 2*).

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2203_25072530

Table 4. *Effect of Bacillus spp. as growth enhancer on tomato shoot dry weight*

Pooled/subgroup effect	NS	SMD	95% CI	I^2 (%)	Het. p-value
Overall	198	1.68	1.48, 1.87	60	< 0.001
Bacillus strain	184	1.68	1.48, 1.89	60	< 0.001
B- count	184	1.68	1.48, 1.87	60	< 0.001
Dosage of bac	152	1.60	1.39, 1.80	53	< 0.001
Mode of app	161	1.56	1.35, 1.77	57	< 0.001
DAP	163	1.62	1.40, 1.83	59	< 0.001
Temp	151	1.64	1.43, 1.85	57	< 0.001
Duration	161	1.59	1.38, 1.80	58	< 0.001

NS: number of studies included in the analysis, B-count: bacteria count, Dosage of Bac: dosage of *bacillus*, Mode of app: mode of bacteria application, DAP: days after planting, Temp: temperature of the greenhouse, Duration: duration of the study, SMD: standardized mean differences, I^2: inconsistency index, Het: heterogeneity, p: probability

Root length

Restricted subgroup analysis of 23 studies demonstrated that *Bacillus* spp. enhanced the root length of tomato plant (SMD = 2.07, 95% CI: 1.67, 2.46; *Table 5*). The stratified analysis revealed that *Bacillus* strain had large effect on the root length (SMD = 2.00, 95% CI: 1.47, 2.53). Similarly bacterial count (SMD = 1.90, 95% CI: 1.48, 2.53), dosage of bacterial applied on the plant (SMD = 1.85, 95% CI: 1.38, 2.32), mode of application (SMD = 1.98, 95% CI: 1.50, 2.46), DAP (SMD = 2.00, 95% CI: 1.47, 2.53), temperature (SMD = 1.77, 95% CI: 1.32, 2.22) and duration of the study (SMD = 1.99, 95% CI: 1.60, 2.38) all had positive and large effect on root length. The results also indicated significant heterogeneity across the 23 studies for the overall effect on root length (Q-statistic $p < 0.001$, $I^2 = 76\%$ and restricted and sensitivity analysis was not able to solve this problem (SMD = 2.20, 95% CI: 1.74, 2.67; $I^2 = 82\%$; *Table A2*). Results indicated that bacterial count ($Q_M = 26.30$, $p < 0.002$; $R^2 = 18\%$), dosage of bacterial applied on the plant ($Q_M = 10.07$, $p < 0.35$; $R^2 = 0\%$), DAP ($Q_M = 26.8$, $p < 0.001$; $R^2 = 31\%$) and duration of the study ($Q_M = 37.29$, $p < 0.001$; $R^2 = 31\%$) had significant effects on the root length, while *Bacillus* strain ($Q_M = 14.9$, $p < 0.061$; $R^2 = 10\%$), mode of application ($Q_M = 4.55$, $p < 0.473$; $R^2 = 0\%$) and temperature ($Q_M = 1.29$, $p < 0.73$; $R^2 = 0\%$) had no significant effect on the root length (*Table 2*).

Table 5. *Effect of Bacillus spp. as growth enhancer on tomato root length*

Pooled/subgroup effect	NS	SMD	95% CI	I^2 (%)	Het. p-value
Overall	79	2.07	1.67, 2.46	76	< 0.001
Bacillus strain	50	2.00	1.47, 2.53	76	< 0.001
B- count	75	1.90	1.48, 2.33	77	< 0.001
Dosage of bac	51	1.85	1.38, 2.32	72	< 0.001
Mode of app	57	1.98	1.50, 2.46	75	< 0.001
DAP	50	2.00	1.47, 2.53	76	< 0.001
Temp	54	1.77	1.32, 2.22	72	< 0.001
Duration	76	1.99	1.60, 2.38	75	< 0.001

NS: number of studies included in the analysis, B-count: bacteria count, Dosage of Bac: dosage of *bacillus*, Mode of app: mode of bacteria application, DAP: days after planting, Temp: temperature of the greenhouse, Duration: duration of the study, SMD: standardized mean differences, I^2: inconsistency index, Het: heterogeneity, p: probability

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2203_25072530

Root fresh weight

The results revealed that *Bacillus* spp. enhanced root fresh weight, with a standardized mean difference (SMD = 2.72, 95% CI: 2.09, 3.36; *Table 6*). The stratified analysis revealed that *Bacillus* strain acted as a moderator on root fresh weight, with an SMD of 2.74, 95% CI: 2.09, 3.39. The stratified analysis also indicated that the bacterial count (SMD = 2.91, 95% CI: 2.25, 3.57), dosage of bacteria applied on the plant (SMD = 3.22, 95% CI: 2.42, 4.01), mode of application (SMD = 2.91, 95% CI: 2.25, 3.57), DAP (SMD = 2.95, 95% CI: 2.27, 3.62), temperature (SMD = 2.91, 95% CI: 2.25, 3.57), and study duration (SMD = 2.72, 95% CI: 2.09, 3.36) had significant effects on root fresh weight. Heterogeneity was present across the 13 studies for the overall effect on root fresh weight (Q-statistic $p < 0.001$, $I^2 = 83\%$). Significant heterogeneity was also observed on the restricted and sensitivity analysis (SMD = 4.03, 95% CI: 3.08, 4.98; $I^2 = 89\%$; *Table A2*). Meta-regression revealed that bacterial count ($Q_M = 23.10$, $p < 0.001$; $R^2 = 50\%$), dosage of bacteria applied to the plant ($Q_M = 35.30$, $p < 0.001$; $R^2 = 43\%$), mode of application ($Q_M = 22.10$, $p < 0.001$; $R^2 = 43\%$), DAP ($Q_M = 32.90$, $p < 0.001$; $R^2 = 47\%$), and study duration ($Q_M = 19.31$, $p < 0.002$; $R^2 = 34\%$) had significant effects on root fresh weight, while *Bacillus* strain ($Q_M = 8.36$, $p < 0.594$; $R^2 = 0\%$) and temperature ($Q_M = 5.39$, $p < 0.145$; $R^2 = 5\%$) showed no significant effect on root fresh weight (*Table 2*).

Table 6. *Effect of Bacillus spp. as growth enhancer on tomato root fresh weight*

Pooled/subgroup effect	NS	SMD	95% CI	I^2 (%)	Het. p-value
Overall	38	2.72	2.09, 3.36	83	< 0.001
Bacillus strain	37	2.74	2.09, 3.39	86	< 0.001
B- count	33	2.91	2.25, 3.57	77	< 0.001
Dosage of bac	28	3.22	2.42, 4.01	80	< 0.001
Mode of app	33	2.91	2.25, 3.57	77	< 0.001
DAP	32	2.95	2.27, 3.62	78	< 0.001
Temp	33	2.91	2.25, 3.57	77	< 0.001
Duration	37	2.72	2.09, 3.36	83	< 0.001

NS: number of studies included in the analysis, B-count: bacteria count, Dosage of Bac: dosage of *bacillus*, Mode of app: mode of bacteria application, DAP: days after planting, Temp: temperature of the greenhouse, Duration: duration of the study, SMD: standardized mean differences, I^2: inconsistency index, Het: heterogeneity, p: probability

Root dry weight

The results of the 19 studies selected for the meta-analysis showed that *Bacillus* spp. increased the root dry weight of tomato plants. Based on these findings, root dry weight was enhanced by *Bacillus* spp. (SMD = 1.46, 95% CI: 1.14, 1.78; *Table 7*). Stratified analysis of the results showed that *Bacillus* strain and bacterial counts moderated the root dry weight (SMD = 1.46, 95% CI: 1.14, 1.78). In addition, stratified analysis revealed that the dosage of bacteria applied to the plant (SMD = 1.31, 95% CI: 0.96, 1.67), mode of application (SMD = 1.42, 95% CI: 1.08, 1.76), DAP (SMD = 1.33, 95% CI: 1.01, 1.65), temperature (SMD = 1.37, 95% CI: 1.03, 1.72), and duration of the study (SMD = 1.46, 95% CI: 1.14, 1.78) had significant effects on root dry weight. Heterogeneity was evident across the 19 studies on the overall effect of *Bacillus* strain

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2203_25072530

and bacterial count on root dry weight (Q-statistic $p < 0.001$, I^2 = statistic = 69%). Significant heterogeneity was observed in restricted and sensitivity analyses (SMD = 1.47, 95% CI: 1.09, 1.86; I^2 = 78%; *Table A2*). Furthermore, the results of the meta-regression analysis showed that the bacterial count ($Q_M = 69.60$, $p < 0.001$; R^2 = 64%), dosage of bacteria applied to the plant ($Q_M = 15.60$, $p < 0.03$; R^2 = 3%), DAP ($Q_M = 45.80$, $p < 0.001$; R^2 = 47%), temperature ($Q_M = 26.60$, $p < 0.001$; R^2 = 21%), and duration of the study ($Q_M = 15.61$, $p < 0.001$; R^2 = 3%) had significant effects on root dry weight (*Table 2*), whereas *Bacillus* strain ($Q_M = 16.20$, $p < 0.09$; R^2 = 12%) showed a no significant effect on the root dry weight (*Table 2*).

Table 7. *Effect of Bacillus spp. as growth enhancer on tomato root dry weight*

Pooled/subgroup effect	**NS**	**SMD**	**95% CI**	**I^2 (%)**	**Het. p-value**
Overall	92	1.46	1.14, 1.78	69	< 0.001
Bacillus strain	92	1.46	1.14, 1.78	69	< 0.001
B- count	93	1.46	1.14, 1.78	69	< 0.001
Dosage of bac	75	1.31	0.96, 1.67	67	< 0.001
Mode of app	82	1.42	1.08, 1.76	68	< 0.001
DAP	85	1.33	1.01, 1.65	64	< 0.001
Temp	78	1.37	1.03, 1.72	68	< 0.001
Duration	92	1.46	1.14, 1.78	69	< 0.001

NS: number of studies included in the analysis, B-count: bacteria count, Dosage of Bac: dosage of *bacillus*, Mode of app: mode of bacteria application, DAP: days after planting, Temp: temperature of the greenhouse, Duration: duration of the study, SMD: standardized mean differences, I^2: inconsistency index, Het: heterogeneity, p: probability

Number of leaves per plant

The number of leaves per plant was enhanced by *Bacillus* spp. (SMD = 3.22, 95% CI: 1.93, 4.52; *Table 8*) with evidence of significant heterogeneity. Stratified analysis showed that *Bacillus* strain and bacterial count, dosage of bacterial applied on the plant, mode of application, DAP, temperature and duration of the study had an effect on the number of leaves per plant. Heterogeneity results followed the same trend across the five studies on the overall effect, *Bacillus* strain, bacterial count, dosage of bacteria applied to the plant, mode of application, DAP, Temperature, and duration of the study on the number of leaves per plant. Restricted and sensitivity analyses did not remove problem of significant heterogeneity (*Table A2*). Meta-regression results showed that *Bacillus* strain ($Q_M = 17.60$, $p < 0.001$; R^2 = 74%) and mode of application ($Q_M = 15.20$, $p < 0.002$; R^2 = 70%) had significant effects on the number of leaves per plant (*Table 8*), while there was no significant relationship between number of leaves per plant and moderators [bacterial count (Q_M = 14. 60, $p < 0.006$; R^2 = 63%), dosage of bacterial applied on the plant ($Q_M = 6.24$, $p < 0.10$; R^2 = 27%), DAP ($Q_M = 12.63$, $p < 0.006$; R^2 = 67%) temperature ($Q_M = 4.45$, $p < 0.10$; R^2 = 14%) and duration of the study (Q_M = 15%, $p < 0.006$; R^2 = 63%)] as presented in *Table 2*.

Analysis of publication bias

A visual analysis of the funnel plots in *Figures 4* and *5* indicates a moderate trend for studies to report greater negative effects. The asymmetrical in the funnel plots warranted further investigation; therefore, we calculated Rosenberg's fail-safe number

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2203_25072530

(Nfs) to detect evidence of publication bias. The calculated fail-safe numbers (Nfs) for the database were 39,635 (plant height), 20,161 (shoot fresh weight), 30,452 (shoot dry weight), 5, 637 (root length), 2,405 (root fresh weight), 3,980 (root dry weight), and 112 (number of leaves per plant). These values were 198, 122, 165, 45, 9, 38, and 3.2 times higher than the thresholds of 200 (5×38 + 10), 165 (5×31 + 10), 185 (5×35 + 10), 265 (5×51 + 10), 265 (5×51 + 10), 105 (5×19 + 10), 125 (5×23 + 10), and 35 (5×5 + 10), respectively, required for the mean effect size to be considered robust.

Table 8. *Effect of Bacillus spp. as growth enhancer on tomato number leaves per plant*

Pooled/subgroup effect	NS	SMD	95% CI	I^2 (%)	Het. p-value
Overall	12	3.22	1.93, 4.52	76	< 0.001
Bacillus strain	12	3.22	1.93, 4.52	76	< 0.000
B- count	12	3.22	1.93, 4.52	76	< 0.000
Dosage of bac	12	4.22	1.97, 6.48	75	< 0.003
Mode of app	12	3.22	1.93, 4.52	76	< 0.000
DAP	12	3.22	1.93, 4.52	76	< 0.000
Temp	12	3.22	1.93, 4.52	76	< 0.000
Duration	12	3.22	1.93, 4.52	76	< 0.000

NS: number of studies included in the analysis, B-count: bacteria count, Dosage of Bac: dosage of *bacillus*, Mode of app: mode of bacteria application, DAP: days after planting, Temp: temperature of the greenhouse, Duration: duration of the study, SMD: standardized mean differences, I^2: inconsistency index, Het: heterogeneity, p: probability

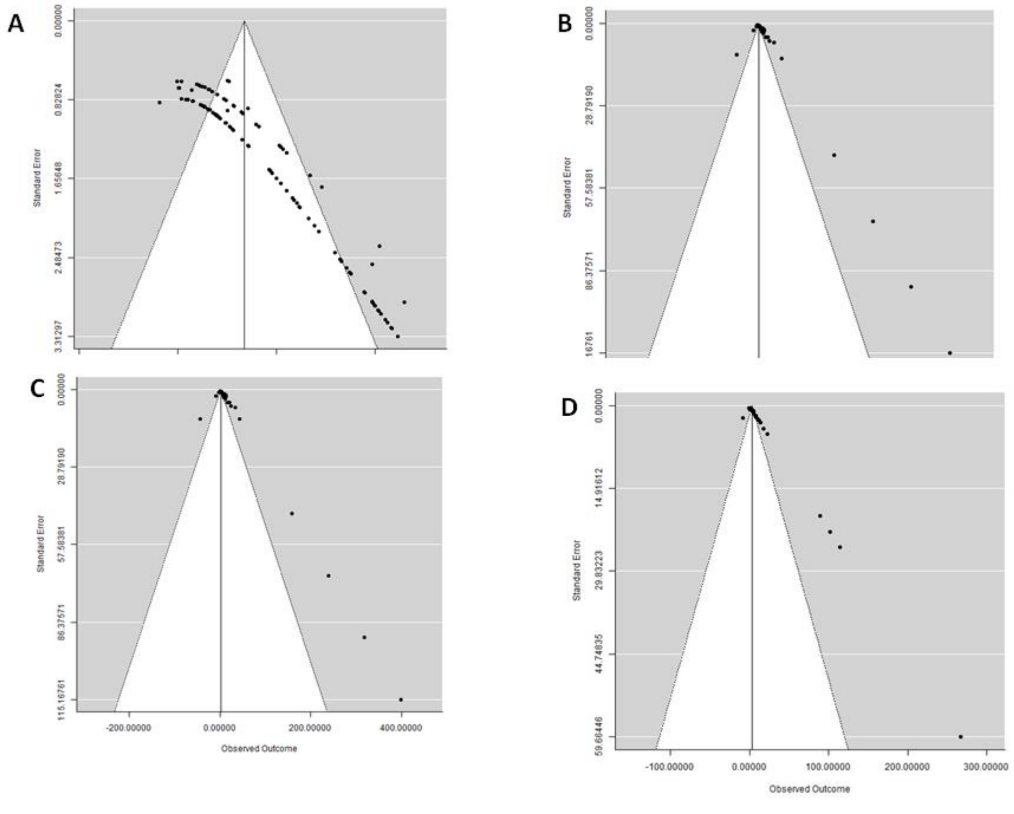

Figure 4. *Funnel graph on the effect of Bacillus spp. as a growth enhancer on (A) plant height, (B) shoot fresh weight, (C) shoot dry weight, (d) root fresh weight*

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2203_25072530

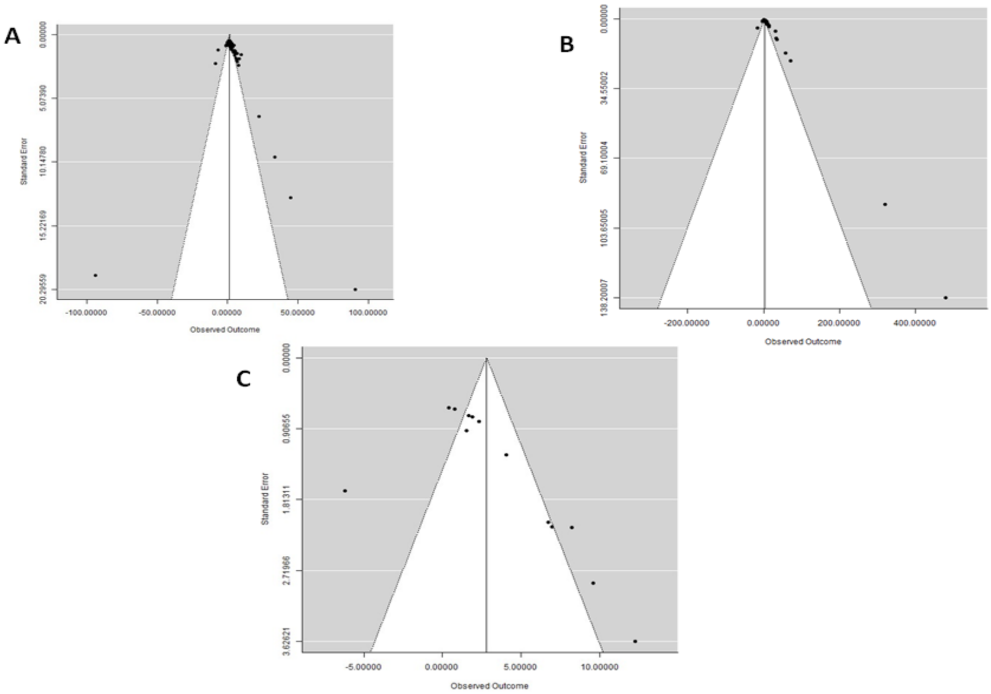

Figure 5. *Funnel graph on the effect of Bacillus spp. as a growth enhancer on (A) root dry weight, (B) root length and (C) number of leaves per plant on tomatoes*

Discussion

Overall effect of Bacillus spp. as growth enhancement on tomatoes

Plant growth is limited by nutrient shortages, and studies have shown that *Bacillus* can promote plant growth using several mechanisms including improvement in nutrient utilization (Xue et al., 2021). Also, they are known to regulate hormones such as salicylic acid (SA), jasmonic acid (JA) and abscisic acid (ABA) which aids plant growth by modulating cell division and expansion and also by reducing enzyme production (such as ACC) as suggested by Castillo et al. (2013) and Li et al. (2022). Furtherance to this, Bai et al. (2014) reported that using *Bacillus* as a biofertilizer can effectively increase plant yield and quality indicating that there is a significant potential for the *Bacillus* strains to be used as biofertilizers in agriculture, enhancing growth and production of plants from a wide range of plants (Gamez et al., 2019; Dimopoulou et al., 2021).

Overall, the findings of this study provide important insights into the relationship between the bacterial count, dosage of bacterial applied on the plant, mode of application, DAP, temperature, and duration of the study and the tomato growth parameters. These effects are discussed in the following paragraphs

Shoot biomass as enhanced by Bacillus spp.

Results obtained in the present meta-analysis confirmed that the shoot biomass which constitutes the plant height, shoot fresh weight, shoot dry weight and number of leaves were enhanced by *Bacillus* spp. Hence, indicating that *Bacillus* spp. can serve as alternative to inorganic fertilizers. In agreement with the meta-analysis study, potted tomato seedlings with cell suspensions of *Bacillus* enhanced shoot biomass, higher

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2203_25072530

levels of GA and IAA were detected in plants treated with *Bacillus* (Chowdappa et al., 2013). Additionally, the significant improvement of the shoot biomass of tomato using *Bacillus* spp. as biofertilizer has been reported by Kouam et al. (2023) on tomato varieties in Cameroun. Furthermore, Cervantes-Vázquez et al. (2021) documented similar results on tomato in Mexico. In a similar study, Akram et al. (2015) observed a significantly increase on the shoot length and total biomass of three different varieties of tomato plants, which increased tomato fruit production. Also, Almoneafy et al. (2014) reported similar result on tomato plant height, plant fresh weight and plant dry weight. Soil amendment using *Bacillus* spp. as a potential bio-fertilizer has been reported to enhance tomato shoot biomass (fresh shoot weight and plant height) when compared with untreated plants (Samaras et al., 2016). In a similar study, Li et al. (2020) used microbial inocula to increase the soil enzyme activity and available nutrients thereby improving significantly the growth of oats, alfalfa and cucumber. *Bacillus* as bio-fertilizer has also shown to significantly enhance the fresh weight of *Arabidopsis* plant (Lu et al., 2021). Again, in their studies, Hong and Lee (2014), indicated that *Bacillus* spp. boosted shoot biomass of *Peucedanum japonicum* by 62.6%. An increase in wheat biomass (total dry weight and shoot dry weight) 29.76% and 66.17% was recorded when *Bacillus* was used as bio-fertilizer (Shahid et al., 2021). In contrast, Diaz et al. (2019) reported a none significant effect of cotton plant height between the *Bacillus* treated and the untreated, similar result was reported on pepper stem diameter, plant height, and plant weight (Díaz-Pérez, 2022). Diaz et al. (2019) suggested that the none significant effect of the cotton plant height could be due to the short experimental period, hence longer study periods would be ideal to evaluate the increase in growth of plants that received the microbial inoculums. The enhancement in plant growth as elucidated by several authors has been attributed to molecules produced by the *Bacillus* spp. such as phosphate solubilization, production of hormones, and biological nitrogen fixation (Oleńska et al., 2020; Tsotetsi et al., 2022). The remarkable abilities for producing vast array of beneficial substances such as Indole-3-acetic acid (IAA), 1-aminocyclopropane-1-carboxylate-deaminase (ACC-deaminase), phosphate-solubilizing enzyme (PSE), and siderophores makes *Bacillus* the right microbe to be used in place of inorganic fertilizers. Also, auxin (IAA) as reported by Goswami et al. (2016) aids in cell elongation and division, and tissue differentiation and consequently helps in apical dominance (Goswami et al., 2016). It is possible that this could be attributed to the significant increase of the shoot biomass obtained in the present meta-analysis. Another common mechanism of plant growth promoting bacteria (PGPB) is ammonia production which is essential for nitrogen accumulation as it promotes shoot biomass that facilitates plant growth (Masclaux-Daubresse et al., 2010; Gohil et al., 2022). According to the result of this study, *Bacillus* application increased the shoot biomass of tomato plants, indicating a positive influence of *Bacillus* spp. as bio-fertilizer on the tomato shoot biomass. This highlights the bio-fertilizer potentials of *Bacillus* spp. to promote plant growth, which have a profound impact on crop productivity as indicated previously by several scholars (Janahiraman et al., 2016; Jamily et al., 2019; Masood et al., 2022; Sun et al., 2022).

Root biomass as enhanced by Bacillus spp.

Findings of the present meta-analysis indicated that the root biomass which constitutes the root length, root fresh weight and root dry weight was enhanced significantly by using *Bacillus* spp. The beneficial activities of *Bacillus* spp. to the plant provides nutrient source

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2203_25072530

that stimulate root development (Hashem et al., 2019). Also, they produce hormones and volatile organic compounds (VOCs) that regulates plant cell growth and root development through the root colonization which is the proliferation of microorganisms such as *Bacillus* spp. in, on, or around plant roots (Hossain et al., 2019).

From the result of the current meta-analysis, *Bacillus* spp. has significantly enhanced the root biomass of tomato plant. In addition, plant inoculations with *Bacillus* have been reported to significantly increased the root length, roots fresh and dry weight (Mengistie and Awlachew, 2022). In this present meta-analysis study, all the *Bacillus* spp. improved the growth parameters of tomato plants over the control (untreated). The results of this study are in agreement with the previous studies (Dilfuza, 2012; Shah et al., 2020; Salehin et al., 2021) which found positive effects of *Bacillus* spp. as a bio-fertilizer on growth parameters of tomato plants. Similarly, earlier study of Chowdappa et al. (2013) reported that inoculation of *Bacillus* spp. in potted tomato seedling enhanced the root growth. Also, Akram et al. (2015) reported that *Bacillus* spp. increased the root biomass of three different varieties (Fine Star, Río Grande, Red Power) of tomato plants. Janahiraman et al. (2016), also indicated that *Bacillus* significantly enhanced tomato root length and dry weight. Similarly, Shahid et al. (2021) using *Bacillus* as a bio-fertilizer that it increased the root length (20.91%) and root dry weight (96.63%) of wheat. The results of this meta-analysis comparably validate the earlier report of Gohil et al. (2022) which stated that IAA primarily stimulates plant growth by expanding the root system to enter into the larger volume of the soil for increased water and nutrient uptake. This deciphers the significant increase in the root biomass recorded in the study. In this regard, *Bacillus* isolates improved the plant growth by producing IAA. The production of IAA hormones is very common among the PGPB because it facilitates the root expansion and uptake of nutrients and also influences cell division and elongation (Ng et al., 2015; Gohil et al., 2022). Also, the production of hormones and the subsequent enhancement of root growth parameters are known to enhance nutrient uptake in plants (Kumar et al., 2015). The present meta-analysis showed that the mean effect sizes for the root length, root fresh and dry weight significantly improved as *Bacillus* was administered as bio-fertilizer. In agreement with the result of the current meta-analysis, Hasibuan et al. (2021), indicated that inoculating *Bacillus* as a bio-fertilizer resulted in a distinct increase in root dry weight of soybean. Furthermore, Seerat et al. (2019) recorded a significant increase in the root dry weight of paddy rice using *Bacillus* as bio-fertilizer. Ngo et al. (2019) also showed that inoculation of *Bacillus* increased root and crown root formation of rice plants. Hasibuan et al. (2021) reported in their study that *Bacillus* used as bio-fertilizer promoted the growth of soybean plants, especially in their roots, as observed in rice plants. Application of *Bacillus* as a bio-fertilizer with the ability to promote root development was reported to be beneficial in legumes, rice and other crops (Hasibuan et al., 2021). Previously, *Bacillus* has shown to have beneficial effects on rice plant, such as improving nitrogen uptake and better rooting system (Ngo et al., 2019). Contrary to this study, Gattoni et al. (2019) reported a none significant effect of cotton plant roots between the *Bacillus* treated and untreated. This could be due to the different root locations, root response to other environmental factor, including the soil type and plant species. It may possibly be assuaged as *Bacillus* releases compounds (VOC) and enzymes (ACC) for easy root colonization and support to aid water and nutrient up take (Koo et al., 2004).

Importantly, root biomass enhancement by *Bacillus* spp. involves understanding the role of *Bacillus* in promoting and increasing the biomass of tomato roots. Thus, the use of *Bacillus* spp. as a bio-fertilizer in agriculture is promising for promoting root biomass

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2203_25072530

by leveraging on the plant growth promotion (PGP) traits, induced systemic resistance (ISR) induction, biofilm formation, nutrient mobilization, and improvement of soil structure. This approach does not only contribute to increasing the plant growth and productivity but also offers sustainable and eco-friendly solutions against the use of inorganic fertilizers.

Conclusion

The current meta-analysis established the bio-fertilizer potentials of *Bacillus* spp. in enhancing the physiological growth parameters of tomato. The present meta-analysis study also sets the steps for future standardized experimental designs on the use of *Bacillus* spp. as a bio-fertilizer to enhancing growth parameters of tomato as alternative to inorganic fertilizers.

With the increasing health risks on the use of inorganic fertilizers as growth promoters in crop productivity, it is important to note that over-reliance on inorganic fertilizers can disrupt the natural balance of nutrients in the soil, leading to nutrient imbalances and reduced soil quality. This can result in the loss of soil organic matter, decreased soil fertility and increased susceptibility to erosion, *Bacillus* as bio-fertilizer have demonstrated its potential as an alternative to enhancing crop productivity. The result of the pooled estimates of the 51 primary studies indicated that *Bacillus* amendment is associated with significant improvement in plant growth and development in tomato plant.

REFERENCES

[1] Adu, M. O., Yawson, D. O., Armah, F. A., Asare, P. A., Frimpong, K. A. (2018): Meta-analysis of crop yields of full, deficit, and partial root-zone drying irrigation. – Agricultural Water Management 197: 79-90.

[2] Bai, Z. H., Zhou, C. G., Cao, J. X., Xu, S. J., Wu, S. H., Li, D. S. (2014): Effects of *Bacillus amyloliquefaciens* biofertilizer on tea yield and quality. – Agricultural Science and Technology 15(11): 1883-1887.

[3] Bavaresco, L. G., Osco, L. P., Araujo, A. S. F., Mendes, L. W., Bonifacio, A., Araujo, F. F. (2020): *Bacillus subtilis* can modulate the growth and root architecture in soybean through volatile organic compounds. – Theoretical and Experimental Plant Physiology 32(2): 99-108.

[4] Bhattacharyya, P. N., Goswami, M. P., Bhattacharyya, L. H. (2016): Perspective of beneficial microbes in agriculture under changing climatic scenario: a review. – Journal of Phytology 8: 26-41.

[5] Borenstein, M., Hedges, L. V., Higgins, J. P., Rothstein, H. R. (2021): Introduction to Meta-Analysis. – John Wiley and Sons, Hoboken, NJ.

[6] Cabra Cendales, T., Rodríguez González, C. A., Villota Cuásquer, C. P., Tapasco Alzate, O. A., Hernández Rodríguez, A. (2017): *Bacillus* effect on the germination and growth of tomato seedlings (*Solanum lycopersicum* L). – Acta Biológica Colombiana 22(1): 37-44.

[7] Caspermeyer, J. (2020): Evolution on the vine: a history of tomato domestication in Latin America. – Molecular Biology and Evolution 37(4): 1241-1242.

[8] Castillo, J. D., Lawrence, K. S., Kloepper, J. W. (2013): Biocontrol of the reniform nematode by *Bacillus firmus* GB-126 and *Paecilomyces lilacinus* 251 on cotton. – Plant Disease 97(7): 967-976.

[9] Cervantes-Vázquez, T. J. Á., Valenzuela-García, A. A., Cervantes-Vázquez, M. G., Guzmán-Silos, T. L., Fortiz, E. L., Rangel, P. P., Rueda-Puente, E. O. (2021):

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2203_25072530

Morphophysiological, enzymatic, and elemental activity in greenhouse tomato saladette seedlings from the effect of plant growth-promoting rhizobacteria. – Agronomy 11(5): 1008.

[10] Chowdappa, P., Kumar, S. M., Lakshmi, M. J., Upreti, K. K. (2013): Growth stimulation and induction of systemic resistance in tomato against early and late blight by *Bacillus* subtilis OTPB1 or *Trichoderma harzianum* OTPB3. – Biological Control 65(1): 109-117.

[11] Cohen, J. (1988): Statistical Power Analysis for the Behavioral Sciences. Second Ed. – Lawrence Earlbaum Associates, Hillsdale, NJ.

[12] Costa, J. M., Heuvelink, E. P. (2018): The Global Tomato Industry. – In: Heuvelink, E. P. (ed.) Tomatoes. CABI, Wallingford, pp. 1-26.

[13] DerSimonian, R., Laird, N. (1986): Meta-analysis in clinical trials. – Controlled Clinical Trials 7(3): 177-188.

[14] Diaz, P. A. E., Baron, N. C., Rigobelo, E. C. (2019): ‘Bacillus’ spp. as plant growth-promoting bacteria in cotton under greenhouse conditions. – Australian Journal of Crop Science 13(12): 2003-2014.

[15] Díaz-Pérez, J. C. (2022): Soil microbial inoculant has no effect on plant growth, fruit yield, fruit disorders, and soilborne diseases in bell pepper. – International Journal of Vegetable Science 28(5): 409-416.

[16] Dilfuza, E. (2012): Indole-Acetic Acid Production by Root Associated Bacteria and Its Role in Plant Growth and Development. – In: Andrew, H. K., Michelle, D. F. (ed.) Auxins: Structure, Biosynthesis and Functions. Nova Science Publishers, Hauppauge, NJ.

[17] Dimopoulou, A., Theologidis, I., Benaki, D., Koukounia, M., Zervakou, A., Tzima, A., Diallinas, G., Hatzinikolaou, D. G., Skandalis, N. (2021): Direct antibiotic activity of bacillibactin broadens the biocontrol range of Bacillus amyloliquefaciens MBI600. – Msphere 6(4): 10-1128.

[18] Gamez, R., Cardinale, M., Montes, M., Ramirez, S., Schnell, S., Rodriguez, F. (2019): Screening, plant growth promotion and root colonization pattern of two rhizobacteria (Pseudomonas fluorescens Ps006 and Bacillus amyloliquefaciens Bs006) on banana cv. Williams (Musa acuminata Colla). – Microbiological Research 220: 12-20.

[19] Gattoni, K. M., Park, S. W., Lawrence, K. S. (2023): Evaluation of the mechanism of action of Bacillus spp. to manage Meloidogyne incognita with split root assay, RT-qPCR and qPCR. – Frontiers in Plant Science 13: 1079109.

[20] Gohil, R. B., Raval, V. H., Panchal, R. R., Rajput, K. N. (2022): Plant growth-promoting activity of *Bacillus* spp. PG-8 isolated from fermented panchagavya and its effect on the growth of *Arachis hypogea*. – Frontiers in Agronomy 4: 805454.

[21] Goswami, D., Thakker, J. N., Dhandhukia, P. C. (2016): Portraying mechanics of plant growth promoting rhizobacteria (PGPR): A review. – Cogent Food and Agriculture 2(1): 1127500.

[22] Hashem, A., Tabassum, B., Abd_Allah, E. F. (2019): Bacillus subtilis: a plant-growth promoting rhizobacterium that also impacts biotic stress. – Saudi Journal of Biological Sciences 26(6): 1291-1297.

[23] Hasibuan, R. F. M., Miyatake, M., Sugiura, H., Agake, S. I., Yokoyama, T., Bellingrath-Kimura, S. D., Katsura, K., Ohkama-Ohtsu, N. (2021): Application of biofertilizer containing Bacillus pumillus TUAT1 on soybean without inhibiting infection by Bradyrhizobium diazoefficiens USDA110. – Soil Science and Plant Nutrition 67(5): 535-539.

[24] Higgins, J. P. T., Thompson, S. G. (2002): Quantifying heterogeneity in a meta-analysis. – Statistics in Medicine 21: 1539-1558.

[25] Higgins, J. P.T., Green, S. (eds.) (2011): Cochrane Handbook for Systematic Reviews of Interventions Version 5.1.0 (updated March 2011). The Cochrane Collaboration, 2011. – http://handbook.cochrane.org/ (accessed on 15th April, 2023).

[26] Hong, S. H., Lee, E. Y. (2014): Vegetation restoration and prevention of coastal sand dunes erosion using ion exchange resins and the plant growth-promoting rhizobacteria

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2203_25072530

Bacillus spp. SH1RP8 isolated from indigenous plants. – International Biodeterioration and Biodegradation 95: 262-269.

[27] Hossain, M. T., Khan, A., Harun-Or-Rashid, M., Chung, Y. R. (2019): A volatile producing endophytic *Bacillus siamensis* YC7012 promotes root development independent on auxin or ethylene/jasmonic acid pathway. – Plant and Soil 439: 309-324.

[28] Jamily, A. S., Koyama, Y., Win, T. A., Toyota, K., Chikamatsu, S., Shirai, T., Uesugi, T., Murakami, H., Ishida, T., Yasuhara, T. (2019): Effects of inoculation with a commercial microbial inoculant Bacillus subtilis C-3102 mixture on rice and barley growth and its possible mechanism in the plant growth stimulatory effect. – Journal of Plant Protection Research 59(2).

[29] Janahiraman, V., Anandham, R., Kwon, S. W., Sundaram, S., Karthik Pandi, V., Krishnamoorthy, R., Kim, K., Samaddar, S., Sa, T. (2016): Control of wilt and rot pathogens of tomato by antagonistic pink pigmented facultative methylotrophic Delftia lacustris and Bacillus spp. – Frontiers in Plant Science 7: 1626.

[30] Koo, B. J., Adriano, D. C., Bolan, N. S., Barton, C. D. (2004): Root Exudates and Microorganisms. – In: Encyclopedia of Soils in the Environment. Elsevier-Hanley and Belfus Inc, Philadelphia, PA, pp. 421-428.

[31] Kouam, I., Mabah, J., Germain Ntsoli, P., Tchamani, L., Yaouba, A., Katte, B., Bitom, D. (2023): Growth promotion potential of *Bacillus* spp. isolates on two tomato (*Solanum lycopersicum* L.) varieties in the West region of Cameroon. – Open Agriculture 8(1): 20220154.

[32] Kousar, B., Bano, A., Khan, N. (2020): PGPR modulation of secondary metabolites in tomato infested with *Spodoptera litura*. – Agronomy 10(6): 778.

[33] Kumar, A. J. A. Y., Vandana, R. S., Singh, M. O. N. I. K. A., Pandey, K. D. (2015): Plant Growth Promoting Rhizobacteria (PGPR). A Promising Approach for Disease Management. – In: Shankar, J., Singh, D. P. (eds.) Microbes and Environmental Management. Studium Press, New Delhi, pp. 195-209.

[34] Lean, I. J., Rabiee, A. R., Duffield, T. F., Dohoo, I. R. (2009): Invited review: use of meta-analysis in animal health and reproduction: methods and applications. – Journal of Dairy Science 92(8): 3545-3565.

[35] Li, A., Sun, X., Liu, L. (2022): Action of salicylic acid on plant growth. – Frontiers in Plant Science 13: 878076.

[36] Li, H., Qiu, Y., Yao, T., Ma, Y., Zhang, H., Yang, X. (2020): Effects of PGPR microbial inoculants on the growth and soil properties of *Avena sativa*, *Medicago sativa*, and *Cucumis sativus* seedlings. – Soil and Tillage Research 199: 104577.

[37] Lu, P., Jiang, K., Hao, Y. Q., Chu, W. Y., Xu, Y. D., Yang, J. Y., Chen, J. L., Zeng, G. H., Gu, Z. H., Zhao, H. X. (2021): Profiles of Bacillus spp. isolated from the rhizosphere of Suaeda glauca and their potential to promote plant growth and suppress fungal phytopathogens. – J Microbiol Biotechnol 31(9): 1231-1240.

[38] Masclaux-Daubresse, C., Daniel-Vedele, F., Dechorgnat, J., Chardon, F., Gaufichon, L., Suzuki, A. (2010): Nitrogen uptake, assimilation and remobilization in plants: challenges for sustainable and productive agriculture. – Annals of Botany 105(7): 1141-1157.

[39] Masood, F., Ahmad, S., Malik, A. (2022): Role of Rhizobacterial Bacilli in Zinc Solubilization. – In: Tabrez, S. et al. (eds.) Microbial Biofertilizers and Micronutrient Availability: The Role of Zinc in Agriculture and Human Health. Springer, Cham, pp. 361-377.

[40] Mengistie, G. Y., Awlachew, Z. T. (2022): Evaluation of the plant growth promotion effect of *Bacillus* species on different varieties of tomato (*Solanum lycopersicum* L.) seedlings. – Advances in Agriculture. DOI: 10.1155/2022/1771147.

[41] Moncada, A., Vetrano, F., Esposito, A., Miceli, A. (2020): Fertigation management and growth-promoting treatments affect tomato transplant production and plant growth after transplant. – Agronomy 10(10): 1504.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2203_25072530

[42] Morales, C. L., Traveset, A. (2009): A meta-analysis of impacts of alien vs. native plants on pollinator visitation and reproductive success of co-flowering native plants. – Ecology letters 12(7): 716-728.

[43] Ng, J. L. P., Perrine-Walker, F., Wasson, A. P., Mathesius, U. (2015): The control of auxin transport in parasitic and symbiotic root–microbe interactions. – Plants 4(3): 606-643.

[44] Ngo, N. P., Yamada, T., Higuma, S., Ueno, N., Saito, K., Kojima, K., Maeda, M., Yamaya-Ito, H., Ohkama-Ohtsu, N., Kanekatsu, M., Yokoyama, T. (2019): Spore inoculation of Bacillus pumilus TUAT1 strain, a biofertilizer microorganism, enhances seedling growth by promoting root system development in rice. – Soil Science and Plant Nutrition 65(6): 598-604.

[45] Nkolisa, N., Magwaza, L. S., Workneh, T. S., Chimphango, A. (2018): Evaluating evaporative cooling system as an energy-free and cost-effective method for postharvest storage of tomatoes (*Solanum lycopersicum* L.) for smallholder farmers. – Scientia Horticulturae 241: 131-143.

[46] Ogbuewu, I. P., Mbajiorgu, C. A. (2020): Meta-analysis of the effect of probiotic-yeast (*Saccharomyces cerevisiae*) intervention on feed intake, feed efficiency and egg-production indices in laying hens. – Animal Production Science. https://doi.org/10.1071/AN20192.

[47] Ogugua, U. V., Ntushelo, K., Makungu, M. C., Kanu, S. A. (2018): Effect of *Bacillus* subtilis BD233 on seedlings growth of sweet pepper (*Capsicum annuum*), Swiss chard (*Beta vulgaris*) and lettuce (*Lactuca sativa*). – VII International Symposium on Seed, Transplant and Stand Establishment of Horticultural Crops-SEST2016 1204: 201-210.

[48] Ogugua, U. V., Kanu, S. A., Ntushelo, K. (2022): Gibberellic acid improves growth and reduces heavy metal accumulation: a case study in tomato (*Solanum lycopersicum* L.) seedlings exposed to acid mine water. – Heliyon 8(12).

[49] Oleńska, E., Małek, W., Wójcik, M., Swiecicka, I., Thijs, S., Vangronsveld, J. (2020): Beneficial features of plant growth-promoting rhizobacteria for improving plant growth and health in challenging conditions: a methodical review. – Science of the Total Environment 743: 140682.

[50] Poria, V., Dębiec-Andrzejewska, K., Fiodor, A., Lyzohub, M., Ajijah, N., Singh, S., Pranaw, K. (2022): Plant Growth-Promoting Bacteria (PGPB) integrated phytotechnology: a sustainable approach for remediation of marginal lands. – Frontiers in Plant Science 13: 999866.

[51] Rosenberg, M. S., Rothstein, H. R., Gurevitch, J. (2013): Chaper 6: Effect Sizes: Conventional Choices and Calculations. – In: Koricheva, J., Gurevitch, J., Mengersen, K. (eds.) Handbook of Meta-analysis in Ecology and Evolution. Princeton University Press, Princeton and Oxford.

[52] Sadras, V. O. (2009): Does partial root-zone drying improve irrigation water productivity in the field? A meta-analysis. – Irrigation Science 27: 183-190.

[53] Salehin, A., Puri, R. R., Hafiz, M. H. R., Itoh, K. (2021): Effect of co-inoculation of *Bacillus* spp. strain with bacterial endophytes on plant growth and colonization in tomato plant (*Solanum lycopersicum*). – Microbiology Research 12(2): 480-490.

[54] Samaras, A., Efthimiou, K., Roumeliotis, E., Karaoglanidis, G. S. (2016): Biocontrol potential and plant-growth-promoting effects of Bacillus amyloliquefaciens MBI 600 against Fusarium oxysporum f. sp. radicis-lycopersici on tomato. – V International Symposium on Tomato Diseases: Perspectives and Future Directions in Tomato Protection 1207: 139-146.

[55] Seerat, A. Y., Ookawa, T., Kojima, K., Ohkama-Ohtsu, N., Maeda, M., Djedidi, S., Habibi, S., Sekimoto, H., Abe, A., Yokoyama, T. (2019): Evaluation of the effects of spores and their heat-treated residues from different Bacillus strains on the initial growth of rice plants. – Soil Science and Plant Nutrition 65(2): 122-136.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2203_25072530

[56] Shah, R., Amaresan, N., Patel, P., Jinal, H. N., Krishnamurthy, R. (2020): Isolation and characterization of *Bacillus* spp. endowed with multifarious plant growth-promoting traits and their potential effect on tomato (*Lycopersicon esculentum*) seedlings. – Arabian Journal for Science and Engineering 45: 4579-4587.

[57] Shamshiri, R., van Beveren, P., Che, M. H., Zakaria, A. J. (2017): Dynamic Assessment of air temperature for tomato (*Lycopersicon esculentum* Mill) cultivation in a naturally ventilated net-screen greenhouse under tropical lowlands climate. – Journal of Agricultural Science and Technology 19(1): 59-72.

[58] Sharma, N., Singhvi, R. (2017): Effects of chemical fertilizers and pesticides on human health and environment: a review. – International Journal of Agriculture, Environment and Biotechnology 10(6): 675-680.

[59] Sun, X., Xu, Z., Xie, J., Hesselberg-Thomsen, V., Tan, T., Zheng, D., Strube, M. L., Dragoš, A., Shen, Q., Zhang, R., Kovács, Á. T. (2022): Bacillus velezensis stimulates resident rhizosphere Pseudomonas stutzeri for plant health through metabolic interactions. – The ISME Journal 16(3): 774-787.

[60] Tsotetsi, T., Nephali, L., Malebe, M., Tugizimana, F. (2022): *Bacillus* for plant growth promotion and stress resilience: What have we learned? – Plants 11(19): 2482.

[61] Ugwu, S. N., Biscoff, R. K., Enweremadu, C. C. (2020): A meta-analysis of iron-based additives on enhancements of biogas yields during anaerobic digestion of organic wastes. – Journal of Cleaner Production 269: 122449.

[62] Wallace, B. C., Lajeunesse, M. J., Dietz, G., Dahabreh, I. J., Trikalinos, T. A., Schmid, C. H., Gurevitch, J. (2017): Open MEE: intuitive, open-source software for meta-analysis in ecology and evolutionary biology. – Methods in Ecology and Evolution 8(8): 941-947.

[63] Zhu, H., Zhou, H., Ren, Z., Liu, E. (2021): Control of Magnaporthe oryzae and rice growth promotion by Bacillus subtilis JN005. – Journal of Plant Growth Regulation 41: 1-9.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2203_25072530

APPENDIX

Table A1. *Master table of the primary data used in the meta-analysis*

No	Authors	Year	Country	DAP	Duration	*Bacillus* spp.	B/Count	Qtty of Bac inco (ml)	Temp	Mode of app	Growth parameters
1	Mena-Violante and Olalde-Portugal	2007	Mexico	21		*B. subtilis*	$1x10^7$	3	28	Root inoculation	P/R/L (cm), R/D/W (g), R/L (cm), R/D/W (g)
2	Ajilogba et al.	2013	South Africa	35	70	*B. amyloliquefaciens*	$5x10^7$	5	25	Root dipped	Sht/L (cm), Rt/L (cm),
3	Xu et al.	2014	China	0		*B. subtilis*	$1x10^5$	Soaked	25	Seed soaked	Sht/L, Sht/Fre weight, Sht Dry weig, Root length, Root Fresh weig, Root dry weight
4	Asaka and Shoda,	1996	Japan	0		*B. subtilis*	$7.76x10^7$	20	30	Mixed with soil	Sht/length, Sht/Dry weight
5	Xu et al.	2016	Republic of Korea	0		*B. subtilis*	$1x10^8$	20	20-30	Soil drench	Sht/L, Sht/Fresh weight, Sht/Dry weight, Rt/L, Rt/Fresh weight, Rt/Dry weight
6	Kurabachew and Wydra	2013	Germany	30		*B. cereus*	$7.8x 10^7$	20	20-30	Root Inoculation	Dry weight
7	Seleim et al.	2011	Egypt	30		*B. subtilis*	$1x10^8$	9	25-35	Root Inoculation	Fresh weight
8	Dursun et al.	2010	Turkey	30		*B. subtilis*	$1x10^8$	-	-	Sprayed on the leaves	Plt hei, Dry matter,
9	Solanki et al.	2012	India	500		*B. megaterium*	$1x10^8$	0	22-28	Dipped	Shoot length, Root length, Shoot fresh weight, Root fresh weight, shoot dry weight
10	Singh and Siddiqui	2015	India	50		*B. subtilis*	1.6×10^5, 1.3×10^5, 1.4×10^5, 1.0×10^5, 0.8×10^5, 1.2×10^5	22	20	Sprayed on the roots	Dry weight
11	Walia et al.	2012	India	0		*B. subtilis*	$1.5x10^8$	Soaked	-	Seed soak	Shoot length, Root length, shoot dry weight, Root weight
12	Abdulwareth,	2014	China	21		*B. amyloliquefaciens*	$1.0x10^7$	40	22-24	Soil drenched	Plant height, Plant fresh weight, plant dry weight
13	Jamily et al.	2018	Afghanistan	14		*B. subtilis*	$2.0x10^8$	2	28	Root Inoculation	Shoot dry weight, Root dry weight

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2203_25072530

14	Abdallah et al.	2017	Tunisia	14		*B. tequilensis*	$1.0x10^8$	25	20-30	Soil drench	Plant height, Fresh weight, Root fresh weight
15	Ramavath et al.	2019	India	0		*B. siamensis, B. velezensis, B. tequilensis, B. subtilis*	-	-	-	Soaked	Shoot length, Root length, Dry weight
16	Singh et al.	2013	India	25		*B. cereus, B. subtilis, B. licheniformis, B. amyloliquefaciens*	$2.5x10^9$	100	25-27	Mixed with soil	Shoot length, Fresh weight, Dry shoot, Root length, Fresh Root weight
17	Akram et al.	2015	Pakistan	-		*B. fortis*	$1x10^8$	100	25-27	Root Inoculation	Shoot length, Root length, Fresh weight
18	Ajilogba and Babalola	2016	South Africa	35	70	*B. amyloliquefaciens, B. cereus, B. pumilus, B. subtilis*	$5x10^7$	5	25	Root dipped	Sht/L (cm), Rt/L (cm),
19	Qiao et al.	2017	China	21	30	*B. subtilis*	$1x10^5$	20	18-30	Root Inoculation	Plant height
20	Wang et al.	2011	China	21	58	*B. subtilis, B. amyloliquefaciens*	$1x10^9$	Mixed with soil	25-27	Root Inoculation	Plant height
21	Masood et al.	2022	China	21		*B. pumilus*	$1x10^8$	1	18-24	Seed soaked	Plant height, shoot fresh weight, shoot dry weight, root fresh weight, root dry weight
22	Sun et al.	2022	China			*B. methylotrophicus*	$1x10^5$	0.25, 0.5, 0.75, 1, 1.25, 1.5	23	-	Plant height, shoot fresh weight, shoot dry weight, root length
23	He et al.	2019	China	14	63	*B. pumilus, B. amyloliquefaciens, B. mojavensis, B. putida*	$1x10^8$	1	28	-	Plant height, shoot fresh weight, shoot dry weight, root length
24	Qi et al.	2016	Japan	30		*B. thuringiensis*	$3x10^8$	3	25	Root Inoculation	Plant height, shoot fresh weight, shoot dry weight, root length
25	Janahiraman et al.	2016	Republic of Korea	21		*B. subtilis, B. cereus*	$1x10^9$	20	28	Sprayed on the leaves	Plant height, shoot fresh weight, shoot dry weight, root length
26	Yoo et al.	2019	Republic of Korea	21	21	*B. vallismortis, B. mesonae*	$1x10^{0.25}$			Root drenched	Shoot fresh weight, shoot dry weight
27	Singh et al.	2016	India	21	30	*B. amyloliquefaciens, B. subtilis, B. cereus*	$3x10^8$	50	25-30	Root inoculation	Plant height, shoot fresh weight, shoot dry weight, root length
28	Elanchezhiyan et al.	2018	India	25	50	*B. subtilis*	$1x10^{10}$		22-28	Soil drenched	Plant height, number of leaves per plant
29	Solanki et al.	2013	India	30	45	*B. subtilis, B. amyloliquefaciens*	$1X10^8$	500	28-30	Root dipped	Plant height, shoot fresh weight, shoot dry weight
30	Prabhukarthikeyan et al.	2013	India	10	60	*B. subtilis*	$3x10^8$	2	28	Soil drenched	Plant height, number of leaves per plant
31	Patani et al.	2023	India	30		*B. pumilus, B. firmus, B. licheniformis, B. cereus, B. safensis*	-	30	-	Seed soaked	Plant height, shoot fresh weight, shoot dry weight, root length
32	Shanmugam and Kanoujia	2011	India	45	90	*B. subtilis, B. atrophaeus*	$3x10^8$	50	20-30	Mixed with soil	Shoot fresh weight

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2203_25072530

33	Chowdappa et al.	2012	India	14	30	*B. subtilis*	$1x10^8$	1	25-27	Soil incorporated	Plant height, shoot fresh weight, root length
34	Mehta et al.	2014	India	50	60	*B. circulans*	$1.5x10^6$	-	-	Seed soaked	Plant height, Shoot dry weight, root length, root dry weight
35	Abdallah et al.	2016	Tunisia	7	60	*B. cereus*	$1x10^8$	25	28	Root drenched	Plant height, root fresh weight
36	Hanif et al.	2014	Pakistan			*B. megaterium, B. subtilis, B. fortis, B. theruingenesis, B. megaterium*	$1x10^8$	100	-	-	Plant height, Shoot dry weight, root length, root length
37	Kamali et al.	2018	Iran	42	45	*B. subtilis, B. velezensis,*	$1x10^8$	100	30	Root drenched	Plant height, root dry weight,
38	Ramezani Moghaddam et al.	2014	Iran	45	60	*B. pumilus*	$1x10^6$	10	25-27	Root inoculation	Plant height, root fresh weight, root dry weight
39	Almaghrabi et al.	2012	Saudi Arabia	7	-	*B. subtilis, B. amyloliquefaciens, B. cereus*	$2x10^6$	Seed soaked	20-28	Root inoculation	Plant height, shoot dry weight
40	Porcel et al.	2014	Spain	10		*B. megaterium*	$1x10^9$	0.5	18-24	Sprayed on the leaves	Plant height, shoot dry weight, root dry weight
41	Ibort et al.	2018	Spain	7	60	*Bacillus megaterium*	$1x10^7$	1	24	Sprayed on the leaves	Shoot fresh weight, root fresh weight
42	Torres et al.	2020	Spain	-	-	*B. velezensis*	$1x10^6$	5	25	Drenched	Plant height
43	Akter et al.	2023	Malaysia	14		*B. subtilis, B. tequilensis*	$1x10^8$	2	28	Dipped	Plant height, root length
44	Kouam et al.	2023	Cameroun	21	42	*B. pacificus, B. thuringiensis, B. cereus, B. aerius*	$1x10^8$	1		Stem based	Plant height, shoot fresh weight, shoot dry weight
45	Mukhtar et al.	2023	Canada	14	96	*B. safensis*	$1x10^7$	2	25	Seed soaked	Plant height, shoot fresh weight, shoot dry weight, root length
46	Mukhtar et al.	2020	Canada	14	96	*B. cereus*	$1x10^7$	20	25	Seed soaked	Plant height, shoot fresh weight, shoot dry weight, root length
47	Obrzut et al.	2021	Brazil	30		*B. subtilis*	$1.76x10^{10}$	0.05	28	Seed soaked	Plant height, shoot fresh weight, shoot dry weight
48	Nascimento et al.	2020	Brazil	35		*B. megaterium*	$5x10^1$	100	23.3		Shoot dry weight, root dry weight
49	Islam et al.	2019	Bangladesh	10	90	*B. siamensi*	$1x10^8$		25	Seed soaked	Plant height, shoot fresh weight, shoot dry weight, root fresh weight, root dry weight, root length, number of leaves per plant
50	Martínez-Cano et al.	2022	Mexico	7	35	*B. pumilus*	$1x10^9$	1	21	Sprayed on the leaves	Plant height, Number of leaves per plant
51	Khan et al.	2017	Oman	21		*B. amyloliquefaciens*	$1x10^8$	5	30		Plant height

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2203_25072530

Table A2. *Restricted and sensitivity analysis on the covariate variables*

Overall	**SMD**	**95% CI**	**I^2 (%)**	**Het. P-value**
Plant height	4.35	3.88, 4.81	84	< 0.001
Shoot fresh weight	3.62	3.16, 4.08	82	< 0.001
Shoot dry weight	1.85	1.62, 2.08	71	< 0.001
Root length	2.20	1.74, 2.67	82	< 0.001
Root fresh weight	4.03	3.08, 4.98	89	< 0.001
Root dry weight	1.47	1.09, 1.86	78	< 0.001
Number of leaves per plant	2.81	1.34, 4.27	82	< 0.001

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2203_25072530