Full Length Article

Effects of *Bacillus salmalaya* Strain 139SI Inoculation on Yield and Nutrients Uptake of Oil Palm

Md Hoirul Azri[1,2], Salmah Ismail[1*] and Rosazlin Abdullah[1]

[1]*Institute of Biological Sciences, Faculty of Science, University of Malaya, 50603 Kuala Lumpur, Malaysia*
[2]*Department of Plant Science, Kulliyyah of Science, International Islamic University of Malaysia, 25200 Kuantan, Pahang, Malaysia*
*For correspondence: salmah_r@um.edu.my

Abstract

Integrating the application of inorganic fertilizer with bacterial inoculants could enhance plant nutrient uptake and increase crop yield. However, their effects on oil palm plantation industry are still less studied. Thus, this study was designed to evaluate the potential of *Bacillus salmalaya* strain 139SI inoculant on the enhancement of soil fertility, nutrient uptake, yield and eventually, the quality of oil produced. The results demonstrate that inoculation of *B. salmalaya* strain 139SI produced higher palm fresh fruit bunch (FFB) yield over the untreated. Integrating the 139SI inoculant with inorganic fertilizer resulted in more substantial FFB yield than palm received recommended inorganic fertilizer rate. Enhancement of N level in soil and nutrient uptake was also recorded in strain 139SI inoculated palm. While the number of bunches produced by palm, the oil extraction rate and fatty acid profile shows comparable reading among all treatments. Thus, the results suggest that the application of *B. salmalaya* strain 139SI inoculant and inorganic fertilizer is effective for improving soil fertility, nutrient uptake and yield of oil palm. © 2018 Friends Science Publishers

Keywords: Plant growth promoting rhizobacteria; Soil fertility; Crop yield; Fatty acid analysis

Introduction

Palm oil, the oil derived from the mesocarp of a tropical crop of *Elaeis guineensis* Jacq, is of one the most consumed vegetable oil in the world. Oil palm was introduced in Malaysia in early 1870's as an ornamental plant, since then, it has undergone expansion and modernization to become the most important commodity crop in Malaysia with total area cultivated with oil palm in 2016 reached 5.74 million hectares (MPOB, 2017). Many factors involved in spurring the oil palm industry, of which, agronomic practice plays one of the most important roles. This is because oil palm growth and yield are recognized for highly responsive to fertilizer input. A high demand for nutrients, especially from fertilizer input is not surprising, in view of its high dry matter production (Wahid *et al*., 2005).

Based on previous studies, a hectare of oil palm plantation is estimated to require approximately between 100 to 200 kg/year of nitrogen (N), 50 to 100 kg/year of phosphate (P), and 200 to 300 kg/year of potassium (K) for optimum yield production (Wahid *et al*., 2005; Bakar *et al*., 2011; Lee *et al*., 2014). As a comparison, a hectare of wheat required nutrient inputs of N, P, and K at 100 to 120, 60 to 75 and 50 to 60 kg/year, respectively (Khalid *et al*., 2004; Rana *et al*., 2012). While rice needed 100 to 180 kg/year of N, 50 to 100 kg/year of P and 60 to 120 kg/year of K for

every hectare (Sagarika *et al*., 2015; Xu *et al*., 2015; Hoseinzade *et al*., 2016). These huge amounts of fertilizer are needed by oil palm to replace the nutrients that are removed continuously through the harvested fresh fruit bunch (FFB). However, nutrient leaching, precipitation, erosion, volatilization and denitrification could cause low fertilizer use efficiency since the major portion of the applied inorganic fertilizers is not available to the plants (Powell *et al*., 2010). Furthermore, over-fertilization may result in undesired economic and environmental problems, including underground water contamination due to nitrate leaching into waterways, increased gaseous emissions of ammonia and nitrous oxide to the atmosphere and soil degradation that could cause a decline in crop yields (Diacono and Montemurro, 2010; Zaman *et al*., 2015).

As attempts to address this problem, the best agronomic practices that are efficient, sustainable and less harmful to the environment have to be developed. One of the best options is integrating the application of inorganic fertilizer with microbial inoculant such as plant growth-promoting rhizobacteria to optimize the use of fertilizer and minimize nutrient losses. As reported by previous research, integrated nutrient management with inorganic fertilizers and microbial inoculant can improve crop productivity as well as soil fertility (Tiyagi *et al.*, 2015; Hoseinzade *et al.*, 2016; Thilagar *et al*., 2016). The beneficial effects of these

bacteria have been attributed to their ability in assisting resource acquisition through enhancement of nutrient availability in soils and production of numerous plant growth regulators that promote root development resulting in more efficient uptake of nutrients and water (Ahemad and Kibret, 2014).

Surprisingly, there is no report related to the effects of bacterial inoculant on oil palm yield and subsequently, the quality of oil produced. Hence, this one-year field study was initiated to discover the potential of integrating the bacterial inoculant with inorganic fertilizer in the oil palm plantation industry.

Materials and Methods

Bacterial Strain

B. salmalaya strain 139SI was provided by Molecular and Bacteriology Laboratory, University of Malaya. The strain 139SI originally isolated from rhizosphere soil obtained from the agricultural farm. The species classification of this strain was based on phenotypic characteristics, phylogenetic analysis and 16S rRNA G+C characterization (Gen Bank accession No: JF825470.1; ATCC BAA-2268) (Ismail and Dadrasnia, 2015). The strain 139SI was maintained in BBL^{TM} Brain Heart Infusion (BHI) slants at 4°C until required. The strain was also tested for plant growth-promoting features and was found able to produce indole acetic acid (IAA) (18.5 ± 0.4 μg/mL), based on the method described by Gordon and Weber (1951), positive for N_2-fixing activity using the method of Baldani *et al.* (2014). Phosphate solubilization was evaluated with the National Botanical Research Institute's Phosphate (NBRIP) plate culture (Nautiyal, 1999) and siderophore production based on the chrome azurol S approach (Schwyn and Neilands, 1987). For inoculums preparation, bacterial cells from 2 day-old cultures on BHI plate were scraped from the plate and suspended in PBS buffer (10 mM NaH_2PO_4 containing 0.8% NaC1, pH 6.5). The strain 139SI suspension was then diluted with PBS to a final concentration approximately 1 x 10^9 CFU/mL, based on the optical density at 600 nm, and was confirmed by plate counting.

Trial Site and Experimental Design

The field trial was conducted in Batu Pahat, Johor (2°21' N, 102°40'E) from June 2015 until May 2016. [Mean temperature: 30/23°C (day/night), relative humidity: 60 – 75%,]. Average rainfall 220 mm. Soil chemical properties of the 0–30 cm layer: N = 0.11%, P = 0.05%, K = 0.08%, Ca = 0.15%, Mg = 0.1%. The study was conducted on 10-year-old of *Dura* x *Pisifera* oil palm progeny, planted in a triangular system with a distance of 9 m x 9 m x 9 m at a density of 148 palms per hectare.The treatment involved were: (T1) Untreated palm, (T2) palm received inorganic fertilizer, (T3) palm inoculated with *B. salmalaya* strain 139SI and (T4) palm given a combination of inorganic

fertilizer and inoculated with strain 139SI. Each treatment plot had 36 palms, with 4 replications, in a randomized complete block design. The oil palm in T1 and T2 were served as control. The oil palm in T3 and T4 received *B. salmalaya* 139SI inoculation at the rate of 1 L palm^{-1} month^{-1}. An inorganic fertilizer regime comprising ammonium sulfate as the N source (110 kg N ha^{-1}), di-ammonium phosphate as the P source (60 kg P ha^{-1}), and muriate of potashas the source of K (180 kg K ha^{-1}), was applied to the palm in T2 and T4. The fertilizer regime was applied thrice a year.

Analysis of Nutrient Contents in Soil and Plant Samples

Palm nutrient status was determined according to the method described by Lee *et al.* (2014). Frond from the treatment palm was sampled at approximately 20 cm long and was cut into small pieces to facilitate the drying process. Soil samples were collected around 0.5 m from the base of the palm tree with an auger at depths of 0 – 40 cm. Rachis and soil samples were collected from each individual palm to make sure the data precisely represent the nutrient status of the palm and soil. All the rachis and soil samples from one treatment plot were bulked into one bag respectively. The samples were then dried at 80°C for 3 days before finely ground to pass through a 1 mm sieve. The pH of the dried soil was measured using a pH meter (soil to water ratio of 1:4). The total nitrogen content of the palm and soil samples was estimated by micro-Kjeldahl method (Bremner and Mulvaney, 1982). While the analysis of Phosphorus (P), Potassium (K), Magnesium (Mg), Calcium (Ca) and Sulfur (S) was determined by Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES) (model PerkinElmer Optima 2100 DV).

Fresh Fruit Bunch (FFB) Yield

The oil palm FFB of each treatment was harvested at regular intervals of 14 days or two rounds per month. Data on FFB number and bunch weight produced from each treatment plot were recordedduring the harvesting rounds and present in monthly basis. The data recordings were taken for one year period. The yield of FFB numbers and weights per hectare were calculated based on the following formula:

$$\text{FFB number or weight hectare}^{-1} = \frac{\text{Average FFB number or weight}}{36 \text{ palm}} \times 148 \text{ palm hectare}^{-1}$$

Crude Palm Oil (CPO) Content

Approximately 1 kg of oil palm fruitlets from FFB of each treatment plot were randomly sampled and bulked into one bag during harvesting rounds. Then, the CPO extraction procedure was done according to the method described by Junaidah *et al.* (2015). The oil palm fruitlets samples were placed in a laboratory-scale autoclave and subjected to sterilization process at temperature 110°C for 20 min to deactivate the biological factors that can deteriorate the

quality of oil produced. For CPO extraction, 100 g of oil palm fruitlets mesocarp of each treatment plot was peeled off from the nut before submerged into boiling water for 10 min. The soften mesocarp was meshed by using a commercial blender and then was pressed through a 30-mesh screen to facilitate oil extraction. Subsequently, the mixture was subjected to centrifugation at 10000 rpm and 45ºC for 10 min. The upper layers consist of oil, was carefully transferred into a beaker and subjected to vacuum drying process using vacuum oven (15 inHg max; 80ºC) for 150 min.

Fatty Acid Analysis of Palm Oil

The fatty acids were converted to fatty acid methyl esters (FAME) according to the method as described in AOCS Official Method Ce 2-66 and Ce 1-62 (AOCS, 1994). Fatty acids were detected using gas chromatograph (GC) (Agilent Technologies, Wilmington, DE) equipped with a flame ionization detector (FID). One microliter of the FAMEs in *n*-hexane was loaded into automatic liquid injector. Separation of fatty acids was carried out on a BPX-70 a capillary column (30 m length, 0.32 mm i.d. 0.25 μm film thickness). Helium was used as the carrier gas at a flow rate of 1.2 mL/min. The oven temperature was held initially at 140ºC for 5 min and then increased to 240ºC for 5 min with a gradient of 4ºC/min. The temperature of injection port and the detector was set at 260ºC. Identification of FAME was achieved by comparing the retention times of the peaks with those authentic standard mixtures. The results were expressed as relative percentages of total fatty acids.

Statistical Analysis

All parameters were analyzed by one-way analysis of variance (ANOVA) performed by using SPSS software version 22. Significant differences between means were compared using a Tuckey's range test at $P \leq 0.05$.

Results

Analysis of Nutrient Contents in Soil Samples

The physicochemical characteristics of soil samples from each treatment have been presented in the Table 1. Application of inorganic fertilizer significantly increased the acidity of the soil in palm received inorganic fertilizer (T2) and inorganic fertilizer + strain 139SI (T4) compared to untreated (T1) and 139SI inoculated group (T3). The pH values of soil samples from (T2) were significantly lower than T1 by 8.9% and lower than T3 by 9.8%, respectively. Meanwhile, the pH values of soil samples in T4 were found 10.5 and 11.32% lower than those in T1 and T3, respectively.

Of all treatment, application of inorganic fertilizer was resulting in higher of total N, P and K. The percentage of total N, P and K in soil samples of T2 and T4 were

significantly higher than T1 and T3. The percentage of total N in T4 was the highest, about 112.12 and 75% higher over the unfertilized T1 and T3. The percentage of P in soil samples of T4 had also significantly higher by almost one fold compared to T1 and T3. There was also an obvious positive effect of inorganic fertilizer application on the level of K in the soil. The level of K was found significantly higher in T2 and T4 compared to T1 and T3.

In contrast, application of inorganic fertilizer and 139SI inoculation did not affect the level of Ca, Mg and S in the soil as the difference in mean values of the elements in each treatment was insignificant. The level of Ca in soil was ranged between 0.22 and 0.20% in T3 and T1 respectively. The highest level of Mg was recorded in T4 and the lowest was in T1. Meanwhile, the highest level of S was in T4, followed by T2, T1 and T3.

Analysis of Nutrient Contents in Plant Samples

Palm nutrient status from different treatment is presented in Table 2. Substantial elevated of nutrient uptake by palm was observed in inorganic fertilizer + strain 139SI (T4) treatment. The level of palm nutrient status was always found highest in T4 compared to untreated (T1), inorganic fertilizer (T2) and 139SI inoculated (T3) treatment. The level of N in T4 was increased significantly by 100, 48.28 and 28.64% than those in T1, T3 and T2 respectively. Likewise, the level of P in T4 was about 111.11, 52 and 11.76% higher than in T1, T3 and T2. The positive effect of strain 139SI inoculation on fertilized palm can also be observed in the level of K. When compared with untreated control T1 and 139SI inoculated palm T3, the level of K was significantly increased by 68.97 and 53.13%, respectively. On the other hand, the difference in an increment of K was only marginal compared to T2.

Palm inoculated with 139SI and at the same time received inorganic fertilizer also recorded a higher level of Mg, Ca and S compared to other treatment. The significantly higher level of Mg was recorded in T4, followed by T3, T2 and T1. Palm in T4 also exhibits higher level of Ca and S compared to other treatment, although the increment was not statistically significant.

Fresh Fruit Bunch (FFB) Yield

Performance of FFB yields from different treatment is described in Fig. 1. It was noted that FFB yield was varying every month. From the result obtained, the yield was peak in September with palm from inorganic fertilizer (T2) treatment recorded the highest FFB yield at 3.81 t ha^{-1} and palm from untreated (T1) recorded the lowest yield at 3.64 t ha^{-1}. In contrast, the FFB yield in February was the lowest during the trial period with the yield ranged from 2.12 t ha^{-1} in inorganic fertilizer + strain 139SI (T4) to 1.37 t ha^{-1} in untreated (T1).

Table 1: Analysis of nutrient contents in soil samples from different treatment

Group	pH	Nitrogen (%)	Phosphorus (%)	Potassium (%)	Calcium (%)	Magnesium (%)	Sulfur (%)
Untreated (T1)	7.16 ± 0.01 b	0.33 ± 0.03 b	0.16 ± 0.03 b	0.50 ± 0.05 b	0.20 ± 0.01 a	0.19 ± 0.01 a	0.09 ± 0.01 a
Inorganic fertilizer (T2)	6.07 ± 0.03 a	0.64 ± 0.05 a	0.28 ± 0.02 a	0.68 ± 0.04 a	0.20 ± 0.06 a	0.20 ± 0.03 a	0.10 ± 0.02 a
Strain 139SI (T3)	6.21 ± 0.03 b	0.48 ± 0.02 b	0.15 ± 0.03 b	0.49 ± 0.04 b	0.22 ± 0.02 a	0.20 ± 0.01 a	0.08 ± 0.01 a
Strain 139SI + inorganic fertilizer (T4)	6.12± 0.04 a	0.70 ± 0.01 a	0.29 ± 0.02 a	0.68 ± 0.11 a	0.21 ± 0.01 a	0.23 ± 0.04 a	0.11 ± 0.02 a

The individual values are depicted as mean ± standard deviation. Different letters indicate significant differences between treatments according to Tuckey's test (p<0.05)

Table 2: Analysis of nutrient content of oil palm frond samples from different treatments

Group	Nitrogen (%)	Phosphorus (%)	Potassium (%)	Calcium (%)	Magnesium (%)	Sulfur (%)
Untreated (T1)	0.43 ± 0.04 d	0.18 ± 0.02 c	0.58 ± 0.04 b	0.20 ± 0.01 a	0.43 ± 0.01 b	0.21 ± 0.02 a
Inorganic fertilizer (T2)	0.69 ± 0.04 b	0.34 ± 0.05a	0.91 ± 0.04 a	0.23 ± 0.01 a	0.49 ± 0.01 b	0.27 ± 0.02 a
Strain 139SI (T3)	0.58 ± 0.02 c	0.25 ± 0.03 b	0.64 ± 0.04 b	0.23 ± 0.02 a	0.48 ± 0.01 b	0.26 ± 0.01 a
Strain 139SI + Inorganic fertilizer (T4)	0.86 ± 0.01 a	0.38 ± 0.02 a	0.98 ± 0.11 a	0.28 ± 0.01 a	0.67 ± 0.03 a	0.31 ± 0.02 a

The individual values are depicted as mean ± standard deviation. Different letters indicate significant differences between treatments according to Tuckey's test (p<0.05)

At the beginning of the study, the FFB yield from each treatment was ranged from 2.97 to 2.69 t ha^{-1}, and the difference in mean FFB yield among the treatment was insignificant. Application of inorganic fertilizer and inoculation of 139SI to the palm has caused the difference in mean FFB yield among the treatment group became wider. The ranking order for mean FFB yield based on weight is T4> T2 > T3 and T1. Inoculation 139SI increases the FFB yield to 11.43% higher than the untreated palm of T1. However, this increment is still lower when compared to the palm received inorganic fertilizer. The effect of 139SI inoculation was more profound on palm received inorganic fertilizer at the same time. At the end of the study, palm in T4 produced a higher FFB yield by 54.29, 16.13 and 38.46% compared to T1, T2 and T3, respectively. The increment of FFB yield from palm in T4 over T1 and T3 is statistically significant.

Number of Fresh Fruit Bunches

In general, the number of bunches produced from different treatment is varying each month during the study period (Fig. 2). Based on bunches analyses carried out from June 2015 to May 2016, the mean values for number of bunches produced was reaching the highest number in Jul – Aug 2015. Then, the number of bunches produced gradually decreases and reached the lowest in Jan – Feb 2016. Analyses of variance on the data also found that the mean values of number of bunches produced among the treatment are statistically insignificant.

Yield Performance of Oil Palm

The results for annual yield performances of palm received different treatment are given in Table 3. The total number of bunches produced from each treatment throughout the study period were ranged from 1527.00 to 1547.00 of bunches ha^{-1} yr^{-1} without much significant difference. On the contrary, results obtained show that the bunch weight much affected by the inoculation of 139SI and application of inorganic fertilizer.
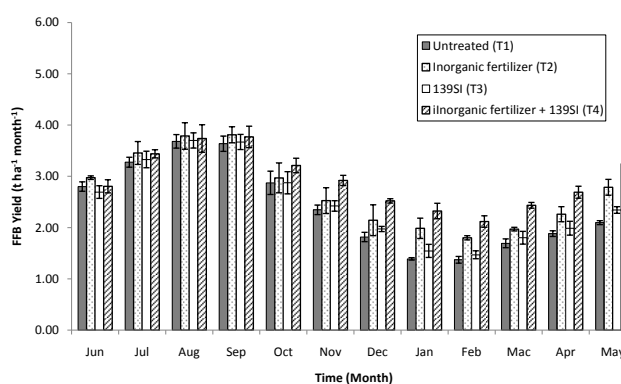
Fig. 1: FFB yield of oil palm received four different treatments from June 2015 to May 2016
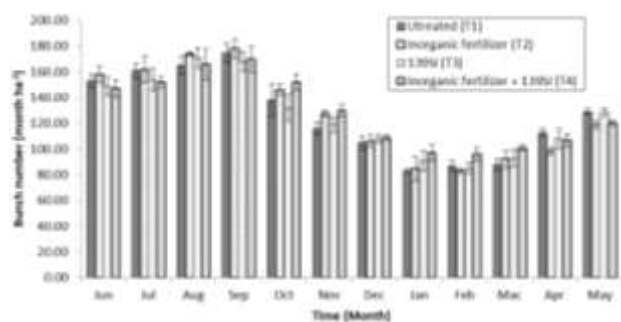
Fig. 2: Number of bunches produced from oil palm received different treatments

Of all treatment, 139SI inoculated and fertilized palm (T4) produced heaviest bunch at average 22.24 kg, 25.80, 6.87 and 20.09% heavier than bunches from untreated (T1), inorganic fertilizer (T2) and 139SI inoculated (T3) treatment respectively. The palm from T4 and T2 produced significantly heavier bunches compared to T1 and T3. Inoculation of 139SI increases the bunch weight when compared to T1. However, the increment is minimal and statistically insignificant.

Table 3: Yield performance of oil palm from different treatments

Treatment	Number of bunches (ha^{-1} yr^{-1})	Average bunch weight (kg)	FFB yield (t ha^{-1} yr^{-1})
Untreated (T1)	1533.00 ± 31.03 a	17.68 ± 1.17 b	27.54 ± 1.18 c
Inorganic fertilizer (T2)	1538.00 ± 35.12 a	20.81 ± 1.20 a	32.46 ± 3.32 a,b
139SI (T3)	1527.00 ± 29.90 a	18.52 ± 1.10 b	29.80 ± 1.37 b,c
Inorganic fertilizer + 139SI (T4)	1547.00 ± 27.47 a	22.24 ± 1.98 a	35.20 ± 1.68 a

The individual values are depicted as mean ± standard deviation. Different letters indicate significant differences between treatments according to Tuckey's test ($p<0.05$)

The average bunch weight produced by palm from each treatment directly influenced the FFB yield. The results obtained show that giving 139SI inoculant to the palm can improve the FFB yield. Although statistically insignificant, the increment of FFB yield from palm in T3 over T1 is more than 2 t ha^{-1} yr^{-1}. However, this increment is still lower compared to the FFB yield from fertilized palm. As expected, supplying fertilizer to the palm increases the FFB yield. Interestingly, Addition 139SI inoculant to the fertilized palm enhances the effectiveness of the fertilizer as the results show that palm from T4 was the most productive, produced approximately 7.66, 5.40, and 2.74 tonnes more FFB yield than those untreated (T1), 139SI inoculated (T3) and received inorganic fertilizer only (T2).
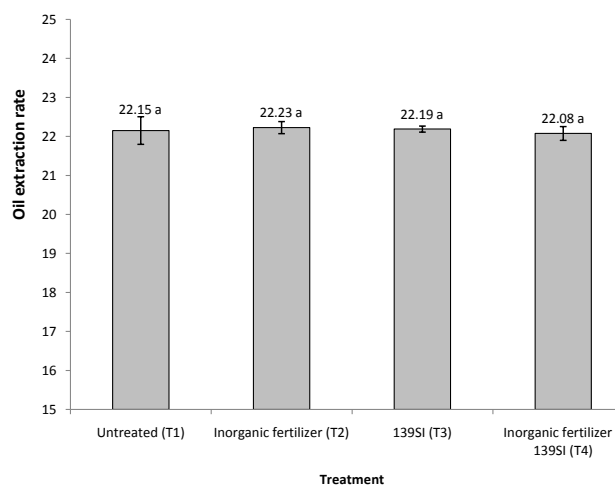
Rate of Oil Extraction from FFB

As shown in Fig. 3, Inoculation of strain 139SI and application of synthetic fertilizer had no effect on the percentage of oil extraction as all groups of treatment recorded oil extraction rate around 22%. No significant differences were found when comparing the percentage of oil extraction between treatment groups and control groups.

Fatty Acid Profile Analysis from Crude Palm Oil

The effect of 139SI inoculation and inorganic fertilizer application on main fatty acid contentin the palm oil was evaluated and the results are shown in Table 4. Fatty acids from palm oil wereclassified as saturated fatty acids (SFA), monounsaturated fatty acids (MUFA), and polyunsaturated fatty acids (PUFA). The classification is based on the number of double bonds present in the structure. The SFA consist of lauric (12-0), myristic (14-0), palmitic (16-0), margaric (17-0), stearic 18-0) and arachidic (20-0). Fatty acids that have one double bond in the fatty acid chain or MUFA included palmitoleic (16-1), oleic (18-1) and gadoleic (20-1). While linoleic (18-2) and linolenic (18-3) are categories as PUFA.

The fatty acid profile in oil derived from untreated (T1), inorganic fertilized (T2), 139SI inoculated (T3) and 139SI inoculated and fertilized palm (T4) treatment palm mesocarp display the same characteristic. The SFA is the major fatty acid found in all treatment, represented more than 50% of total fatty acid content, followed by MUFA and PUFA in which represent approximately 40 and 10% of total fatty acid content respectively. Palmitic acidis the main fatty acid found and represented about 45.13, 45.18 and

Fig. 3: Percentage of oil extraction rate from FFB for different treatment. The individual values are depicted as mean ± standard error. Different letters indicate significant differences between treatments according to Tuckey's test ($p<0.05$)

44.93% of the total fatty acidin T1, T2, T3 and T4, respectively. Oleic and linoleic also represent among major fatty acid found in all treatment in which oleic acid contribution of total fatty acid in T1, T2, T3 and T4 ranged from 38.72 to 38.47%. Meanwhile, linoleic account for 10.37, 10.44 and 10.55% of total fatty acid in T1, T2, T3 and T4 respectively. Generally, nearly equal proportion of SFA, MUFA and PUFA were observed in all treatment. The mean differences of all fatty acid percentage among treatment also small thus make the difference statistically insignificant.

Discussion

The results obtained from this study had provided sufficient evidence for the first time the positive effect of PGPR inoculation on oil palm FFB yield, especially when integrating with inorganic fertilizer, which was manifested by palm in the T4 treatment. The increasing of FFB yield clearly could be attributed by the enhancement of soil fertility and eventually improving the nutrient uptake of the palm. It is apparent from the analysis of nutrient content insoil, the N level was higher in 139SI inoculated T3 and T4 treatment. This data were consistent with our previous findings indicating the ability of strain 139SI to fix N$_2$.

Table 4: Analysis of percentage of fatty acid of crude palm oil from different treatments

Fatty acid	Treatments			
	Untreated (T1)	Inorganic fertilizer (T2)	139SI (T3)	Inorganic fertilizer + 139SI (T4)
Saturated fatty acid				
Lauric acidc12-0	0.02 ± 0.00 a	0.02 ± 0.00 a	0.02 ± 0.00 a	0.03 ± 0.01 a
Myristic acid c14-0	0.68 ± 0.04 a	0.67 ± 0.07 a	0.69 ± 0.05 a	0.69 ± 0.05 a
Palmitic acid c16-0	45.04 ± 0.15 a	45.13 ± 0.18 a	45.18 ± 0.38 a	44.93 ± 0.36 a
Margaric acid c17-0	0.09 ± 0.00 a	0.09 ± 0.00 a	0.09 ± 0.00 a	0.09 ± 0.00 a
Stearic acid c18-0	4.03 ± 0.18 a	3.95 ± 0.27 a	4.09 ± 0.25 a	4.17 ± 0.25 a
Arachidic acid c20-0	0.38 ± 0.02 a	0.38 ± 0.01 a	0.35 ± 0.03 a	0.39 ± 0.01 a
Monounsaturated fatty acids (MUFA),				
Palmitoleic acid c16-1	0.20 ± 0.00 a	0.21 ± 0.00 a	0.20 ± 0.00 a	0.20 ± 0.00 a
Oleic acid c18-1	38.47 ± 0.36 a	38.72 ± 0.53 a	38.47 ± 0.52 a	38.50 ± 0.15 a
Gadoleic acid c20-1	0.12 ± 0.00 a	0.12 ± 0.01 a	0.12 ± 0.01 a	0.12 ± 0.01 a
Polyunsaturated fatty acids				
Linoleic acid c18-2	10.42 ± 0.13 a	10.37 ± 0.28 a	10.44 ± 0.14 a	10.55 ± 0.30 a
Linolenic acid c18-3	0.30 ± 0.00 a	0.30 ± 0.01 a	0.29 ± 0.00 a	0.30 ± 0.01 a

The individual values are depicted as mean ± standard error. Different letters indicate significant differences between treatments according to Tuckey's test ($p<0.05$)

The researchers reported that PGPR enhanced plant growth and yield, as well as enriching nutrients in plants via increased mineral uptake and assimilation (Adesemoye *et al.*, 2009; Souza *et al.*, 2015; Berger *et al.*, 2017).

Apart from enhancing N in soil, 139SI also play an important role in enhancing nutrient availability to plants by solubilizing P from soil. Most of large reserves of P in soils is not soluble, which cannot be absorbed by plants and consequently limiting the plant growthand yield (Pérez-Montaño *et al.*, 2014). Furthermore, only a small percentage of P from fertilizer application is available for the use of plant because the remaining part would undergo processes such as desolubilization and precipitation (Zabihi *et al.*, 2011). Thus, increasing the population of phosphate solubilizing bacteria through inoculation is a great advantage in order to turn insoluble P to plant usable form. The effectiveness of using 139SI to enhance P availability in this study was proven with the increasing of P uptake by palm. In a similar way, PGPR such as *Azospirillum, Bacillus, Burkholderia, Pseudomonas,* and *Rhizobium* are reported able to enhance P uptake bymeans of solubilizing P through acidification, enzymatically or chelation (Sudhakar *et al.*, 2000; Mehnaz and Lazarovits, 2006; Hameeda *et al.*, 2008; Richardson *et al.*, 2009; Pereira and Castro, 2014).

In addition, previous research also found that inoculation of PGPR can enhance plant uptake of several other nutrients such as K, Mg, Ca, S, Cu, Mn and Zn (Karlidag *et al.*, 2007; Meyer *et al.*, 2007; Rana *et al.*, 2012; Goteti *et al.*, 2013). Usually, slightly decrease in soil pH improves solubilization of these nutrients. This uptake usually occurs during acidification of the soil rhizosphere via organic acid production by PGPR or via stimulation of proton pump ATPase (Mantelin and Touraine, 2004; Miransari and Smith, 2007; Pérez-Montaño *et al.*, 2014). Enhancement in macronutrient uptakes are also known to trigger changes in the mineral uptake rate (Gastal and Saugier, 1989; Touraine *et al.*, 1994). Besides that, the direct effect of IAA produced by PGPR on root development also contributes in macro and micronutrient

uptake enhancement. This would explain the slightly fall in soil pH and the enhancement of micronutrient uptake observed in T3 and T4 treatment.

It is also noted that 139SI inoculation and fertilizer application effect mainly on FFB weight rather on the numberof bunches produced from palm. This is based on the results of the present study that shows the higher FFB yieldin T2, T3 and T4 over the T1 was greatly influenced by the higher average of bunch weight. The fluctuation in FFB yield every month is due to variation in number of bunches produced. According to Chow (1988), the seasonal variation in number of bunches produced is largely influenced by climate, especially rainfall. This would explain the insignificant effect of 139SI inoculation and fertilizer application on numbers of bunches produced by palm. The pattern of FFB yield from this study is parallel with the average of FFB yield ha^{-1} reported by Malaysia Oil Palm Board (MPOB, 2015; MPOB, 2016a). Based on 2015 and 2016 report, the FFB yield was highest in August – September 2015 and lowest in January – February 2016. The same insignificant effect of 139SI inoculation and fertilizer application was also observed in the oil extraction rate. However, the performance of the oil extraction rate of palm from this study is slightly higher to the average of oil extraction rate performance data record by MPOB which was 20.23% (MPOB, 2016b). The difference of the oil extraction rate obtained from this study with the recorded by MPOB is due different technique employed to extract the palm oil.

Analysis of fatty acid composition is important because it could be used to evaluate the nutritional quality of palm oil. However, to date, there is no information regarding the effect of palm nutrient uptake on the nutritional quality of palm oil. Previous research reported that the fatty acid content in palm oil changes over the ripening period and at optimal harvesting stage or 22 weeks after anthesis, SFA recorded the highest composition of fatty acid followed by MUFA and PUFA (Prada *et al.*, 2011). Generally, the data obtained from the present

research were consistent with previous reports for crude palm oil fatty acid composition. In their research, Bafor and Osagie (1986); Sambanthamurthi *et al.* (2000); Edem (2002) and Prada *et al.* (2011) reported that SFA represented the biggest proportion of fatty acid in palm oil, i.e., around 40 – 50% of total fatty acid, whereas MUFA and PUFA represented 35 – 40% and 10 – 15% of total fatty acid, respectively.

Conclusion

Overall, the present study revealed the potential of integrating the usage of inorganic fertilizer with strain 139SI to optimize nutrient uptake by palm. This is evidenced by the results of the study has shown the beneficial effects of 139SI inoculation on the improvement of palm nutrient uptake and eventually leads to an enhancement of oil palm FFB yield. Field experiment also revealed that combination of 139SI inoculation and inorganic fertilizer produced the best FFB yield performance.

Acknowledgements

References

Adesemoye, A.O., H.A. Torbert and J.W. Kloepper, 2009. Plant growth-promoting rhizobacteria allow reduced application rates of chemical fertilizers. *Microbiol. Ecol.*, 58: 921–929

Ahemad, M. and M. Kibret, 2014. Mechanisms and applications of plant growth promoting rhizobacteria: Current perspective. *J. King Saud. Uni. Sci.*, 26: 1–20

Bafor, M.E. and A.U. Osagie, 1986. Changes in lipid class and fatty acid composition during maturation of mesocarp of oil palm (*Elaeis guineensis*) variety dura. *J. Sci. Food Agric.*, 37: 825–832

Bakar, R.A., S.Z. Darus, S. Kulaseharan and N. Jamaluddin, 2011. Effects of ten year application of empty fruit bunches in an oil palm plantation on soil chemical properties. *Nutr. Cycl. Agroecosys.*, 89: 341–349

Baldani, J.I., V.M. Reis, S.S. Videira, L.H. Boddey and V.L.D. Baldani, 2014. The art of isolating nitrogen-fixing bacteria from non-leguminous plants using N-free semi-solid media: a practical guide for microbiologists. *Plant Soil*, 384: 413–431

Berger, B., S. Baldermann and S. Ruppel, 2017. The plant growth-promoting bacterium *Kosakonia radicincitans* improves fruit yield and quality of *Solanum lycopersicum. J. Sci. Food Agric.*, 97: 4865–4871

Bremner, J.M. and C.S. Mulvaney, 1982. Nitrogen-total. *In*: *Methods of Soil Analysis, Part 2: Chemical and Microbiological Properties*, 2nd edition, pp: 595-622. Page, A.L., R.H. Miller and D.R. Keeney (eds.). Americ. Soc. Agron., Inc, Madison, Wisconsin, USA

Chow, C.S., 1988. The seasonal and rainfall effects on palm oil production in Peninsular Malaysia. *Proceedings of the 1987 International Oil Palm/Palm Oil Conferences*, pp: 46–52. Conference I: Agriculture, PORIM, Bangi, Malaysia

Diacono, M. and F. Montemurro, 2010. Long-term effects of organic amendments on soil fertility. A Review. *Agron. Sustain. Dev.*, 30: 401–422

Edem, D.O., 2002. Palm oil: Biochemical, physiological, nutritional, hematological, and toxicological aspects: a review. *Plant Foods Hum. Nutr.*, 57: 319–341

Gastal, F. and B. Saugier, 1989. Relationships between N uptake and C assimilation in whole plants of tall fescue. *Plant Cell Environ.*, 12: 407–418

Gordon, S.A. and R.P. Weber, 1951. Colorimetric estimation of indoleacetic acid. *Plant Physiol.*, 26: 192–195

Goteti, P.K., L.D.A. Emmanuel, S. Desai and M.H.A. Shaik, 2013. Prospective zinc solubilising bacteria for enhanced nutrient uptake and growth promotion in maize (*Zea mays* L.). *Int. J. Microbiol.*, 2013: 1–7

Hameeda, B., G. Harini, O.P. Rupela, S.P. Wani and G. Reddy, 2008. Growth promotion of maize by phosphate solubilizing bacteria isolated from compost and microfauna. *Microbiol. Res.*, 163: 234–242

Hoseinzade, H., M.R. Ardakani, A. Shahdi, H.A. Rahmani, G. Noormohammadi and M. Miransari, 2016. Rice (*Oryza sativa* L.) nutrient management using mycorrhizal fungi and endophytic *Herbaspirillum seropedicae*. *J. Integr. Agric.*, 15: 1385–1394

Ismail, S. and A. Dadrasnia, 2015. Biotechnological potential of *Bacillus salmalaya* 139SI: A novel strain for remediating water polluted with crude oil waste. *PLoS ONE*, 10: 1–13

Junaidah, M.J., A.R. Norizzah, O. Zaliha and S. Mohamad, 2015. Optimisation of sterilisation process for oil palm fresh fruit bunch at different ripeness. *Int. Food Res. J.*, 22: 275–282

Karlidag, H., A. Esitken, M. Turan and F. Sahin, 2007. Effects of root inoculation of plant growth promoting rhizobacteria (PGPR) on yield, growth and nutrient element contents of leaves of apple. *Sci. Hortic.*, 114: 16–20

Khalid, A., M. Arshad and Z.A. Zahir, 2004. Screening plant growth-promoting rhizobacteria for improving growth and yield of wheat. *J. Appl. Microbiol.*, 96: 473–480

Lee, C.T., Z.A. Rahman, M.M. Hanafi, C.F. Ishak, M.S. Norizan, C.C. Tan and M.S.M. Yusof, 2014. Rachis nutrient concentrations of different oil palm genotypes as affected by irrigation and terrain. *J. Oil Palm Res.*, 26: 146–153

Malaysian Palm Oil Board (MPOB), 2017. *Overview of the Malaysian Oil Palm Industry 2016*. Available at:http://bepi.mpob.gov.my/images/overview/Overview_of_Industry _2016.pdf (Accessed: 11th September 2017)

Malaysian Palm Oil Board (MPOB), 2016a. *Monthly Production of Oil Palm Products.* http://bepi.mpob.gov.my/index.php/en/statistics/production/168-production-2016/747-production-of-oil-palm-products-2016.html. (Accessed: 11th September 2017)

Malaysian Palm Oil Board (MPOB), 2016b. *OER Performance by Malaysian Palm Oil Mills.* http://bepi.mpob.gov.my/images/oer/oer-2016/6.OER%20Performance%20Jun%202016.pdf. (Accessed: 11th September 2017)

Malaysian Palm Oil Board (MPOB), 2015. *Monthly Production of Oil Palm Products.* http://bepi.mpob.gov.my/index.php/en/statistics/production/159-production-2015/685-production-of-oil-palm-products-2015.html. (Accessed: 11th September 2017)

Mantelin, S. and B. Touraine, 2004. Plant growth-promoting bacteria and nitrate availability: impacts on root development and nitrate uptake. *J. Exp. Bot.*, 55: 27–34

Mehnaz, S. and G. Lazarovits, 2006. Inoculation effects of *Pseudomonas putida*, *Gluconacetobacter azotocaptans*, and *Azospirillum lipoferum* on corn plant growth under greenhouse conditions. *Microbiol. Ecol.*, 51: 326–335

Meyer, B., J. Imhoff and J. Kuever, 2007. Molecular analysis of the distribution and phylogeny of the soxB gene among sulfur-oxidizing bacteria-evolution of the Sox sulfur oxidation enzyme system. *Environ. Microbiol.*, 9: 2957–2977

Miransari, M. and D. Smith, 2007. Overcoming the stressful effects of salinity and acidity on soybean nodulation and yields using signal molecule genistein under field conditions. *J. Plant Nutr.*, 30: 1967–1992

Nautiyal, V., 1999. An efficient microbiological growth medium for screening phosphate solubilizing microorganisms. *Microbiol. Lett.*, 170: 265–270

Official and Recommended Methods of the American Oil Chemists' Society, 1994. *American Oil Chemists' Society.* Champaign, IL

Pereira, S.I.A. and P.M.L. Castro, 2014. Phosphate-solubilizing rhizobacteria enhance *Zea mays* growth in agricultural P-deficient soils. *Ecol. Eng.*,73: 526–535

Pérez-Montaño, F., C. Alías-Villegas, R.A. Bellogín, P. del Cerro, M.R. Espuny, I. Jiménez-Guerrero, F.J. López-Baena, F.J. Ollero and T. Cubo, 2014. Plant growth promotion in cereal and leguminous agricultural important plants: from microorganism capacities to crop production. *Microbiol. Res.*, 169: 325–336

Powell, J.M., C.J.P. Gourley, C.A. Rotz and D.M. Weaver, 2010. Nitrogen use efficiency: A potential performance indicator and policy tool for dairy farms. *Environ. Sci. Policy*, 13: 217–228

Prada, F., I.M. Ayala-diaz, W. Delgado, R. Ruiz-Romero and H.M. Romero, 2011. Effect of fruit ripening on content and chemical composition of oil from three oil palm cultivars (*Elaeis guineensis* Jacq.) grown in Colombia. *J. Agric. Food Chem.*, 59: 10136–10142

Rana, A., B. Saharan, L. Nain, R. Prasanna and Y.S. Shivay, 2012. Enhancing micronutrient uptake and yield of wheat through bacterial PGPR consortia. *Soil Sci. Plant Nutr.*, 58: 573–582

Richardson, A.E., J.M. Barea, A.M. McNeill and C. Prigent-Combaret, 2009. Acquisition of phosphorus and nitrogen in the rhizosphere and plant growth promotion by microorganisms. *Plant Soil*, 321: 305–339

Sagarika, S., D. Kumar and S. Pasupalak, 2015. Effect of elevated [CO^2] and nutrient management on wet and dry season rice production in subtropical India. *Crop J.*, 3: 468–480

Sambanthamurthi, R., K. Sundram and Y.A. Tan, 2000. Chemistry and biochemistry of palm oil. *Prog. Lipid Res.*, 39: 507–558

Schwyn, R. and J.B. Neilands, 1987. Universal chemical assay for detection and determination of siderophores. *Anal. Biochem.*, 160: 47–56

Souza, E.M.D., V.L. Bassani, R.A. Sperotto and C.E. Granada, 2015. Inoculation of new rhizobial isolates improve nutrient uptake and growth of bean (*Phaseolus vulgaris*) and arugula (*Eruca sativa*). *J. Sci. Food Agric.*, 96: 3446–3453

Sudhakar, P., G.N. Chattopadhyay, S.K. Gangwar and J.K. Ghosh, 2000. Effect of foliar application of *Azotobacter, Azospirillum* and *Beijerinckia* on leaf yield and quality of mulberry (*Morus alba*). *J. Agric. Sci.*, 134: 227–234

Thilagar, G., D.J. Bagyaraj and M.S. Rao, 2016. Selected microbial consortia developed for chilly reduces application of chemical fertilizers by 50% under field conditions. *Sci. Hortic.*, 198: 27–35

Tiyagi, S.A., R. Rizvi, I. Mahmood and Z. Khan, 2015. Evaluation of organic matter, bio-inoculants and inorganic fertilizers on growth and yield attributes of tomato with respect to the management of plant-parasitic nematodes, Emirates. *J. Food Agric.*, 27: 602–609

Touraine, B., D.T. Clarkson and B. Muller, 1994. Regulation of nitrate uptake at the whole plant level. *In*: *A Whole Plant Perspective on Carbon–Nitrogen Interactions*, pp: 11–30. Roy, J. and E. Garnier (eds). The Hague: SPB Academic Publishing

Wahid, M.B., S. Nor, A. Abdullah and I.E. Henson, 2005. Oil Palm – Achievements and Potential. *Plant Prod. Sci.*, 8: 1–13

Xu, X., J. Xie, Y. Hou, P. He, M.F. Pampolino, S. Zhao, S. Qiu, A.M. Johnston and W. Zhou, 2015. Estimating nutrient uptake requirements for rice in China. *Field Crops Res.*, 180: 37–45

Zabihi, H.R., G.R. Savaghebi, K. Khavazi, A. Ganjali and M. Miransari, 2011. *Pseudomonas* bacteria and phosphorous fertilization, affecting wheat (*Triticum aestivum* L.) yield and P uptake under greenhouse and field conditions. *Acta Physiol. Plant*, 33: 145–152

Zaman, M., L.V. Kurepin, W. Catto and R.P. Pharis, 2015. Evaluating the use of plant hormones and biostimulators in forage pastures to enhance shoot dry biomass production by perennial ryegrass (*Lolium perenne* L.). *J. Sci. Food Agric.*, 96: 715–726