The Effect of Plant Growth Promoting Rhizobacteria (PGPR) on Germination and Seedling Growth of *Sorghum bicolor* L. Moench

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**Abstract.** Germination is the first important step of the plant growth in the land. The germination and growth of sorghum in marginal land can be optimized by inoculating with PGPR (inoculants), hydrogel and CMC (carriers). The aim of the research was to evaluate the response of germination and seedling growth of sorghum using PGPR inoculation with hydrogel and CMC as carriers (*in vitro*) and pots containing sterile sand (*in vivo*). The experiment used PGPR (*Azospirillum lipoferum* 1103D, *Azotobacter chroococcum* 4103D, and *Bacillus* sp. 3D), and hydrogels as the reserve water, as well as carboxymethyl cellulose (CMC) as the adhesive media. The results showed that the combination of PGPR-mix (*Azospirillum, Azotobacter, Bacillus*) with hydrogels as bio-organic fertilizer and CMC as carriers has promoted the growth of the roots, shoots and vigour index of *in vitro* sorghum germination, as well as increased the root length, shoot length and total dry weight of sorghum seedlings in pots containing sterile sand. The best result of *in vitro* experiment (root length = 8.67 cm; shoot length = 12.6 cm; and vigor index = 2127.00) was obtained by sorghum seed inoculated with single PGPR inoculant (*A. lipoferum*) with carrier of CMC. The root length, shoot length and total dry weight of the highest sorghum seedlings were obtained by PGPR-mix inoculants without carriers (46.5 cm, 12 cm, and 0.477 g), PGPR-mix with carrier of CMC (48.67 cm, 15.67 cm, and 0.431 g), and PGPR-mix with carrier of hydrogel (48.67 cm, 15 cm, and 0.430 g).

1. Introduction

The soil plays an extremely important role to plant life. Soil is a culture medium to a plant which provides 3 nutrients (C, O, and H) from atmosphere and 13 nutrients (N, P, K, Ca, Mg, S, Cl, Fe, Mn, Cu, Zn, B, and Mo) from soil [1]. Soil is a habitat to functional microorganisms’ life that directly and indirectly provides nutrition to a plant. The fertility and health of soil physically, chemically, and biologically depend on an organic content of soil. If an organic content of soil is lower than 1%, then the soil falls in a category of infertile soil.
The fertility of soil is determined by several components including soil structure, type of soils, microbe communities, type of microbes, and type of plants. If one of the components is damaged due to the continuous use of chemical fertilizer, the environment of soil will become infertile (marginal). This condition disturbs a germination process of seed in soil. The germination process started from imbibitions and terminated on the process of elongated radicle [2]. Velocity and diversity of radicle growth on germination are early indications of seed quality and crop production for optimization [3]. Germination process from dormant seed to radicle release until growth phase of seed depends on seed viability, suitability of environment condition, and breaking effort of seed dormant [4]. Optimization of germination on soil with poor nutrient and microorganisms (marginal) can be promoted with a functional bacteria or plant growth promoting rhizobacteria (PGPR) as a stimulant, CMC (carboxymethyl cellulose) as an absorbent agent of water and an adhesive, and hydrogel as a material of water reserves and plant nutrition. The three materials are safe for soil and environment because they do not leave residues on crop products, environment, and human health [5]. PGPR, hydrogel and CMC are raw materials for bio-organic fertilizers. Wu, Cao, Li, Cheung, and Wong (2005) reported that organic biofertilizers have competence in increasing the soil health, promoting plant growth, and increasing crop production [6].

PGPR are a group of functional bacteria that have the ability as a growth promoter (biostimulant). The process occurs by synthesising and regulating the concentrations of various Growth Regulator (GR) or Plant Growth Regulator (PGR) such as Indole acetic acid or IAA [7]. The functional bacteria (PGPR) produce IAA hormone and Acc-deaminase, and can provide nutrient on soil by fixing N2 from atmosphere with symbiosis and asymbiosis. They are equally able to dissolve P nutrient bound with Al, Fe, and Ca on soil by synthesising PMEase enzyme (Phosphomonoesterase). PGPR can control the activity of pathogens of plant-disturber organisms (biocontrol) and decomposers of agrochemical compounds [8], and may control pathogens derived from soil (bioprotectant) by multiple compounds or anti-pathogenic metabolites such as siderophore, chitinase, antibiotics, and cyanide [9]. The group of PGPR will instantly occupy and colonize the plant roots (rhizosphere) aggressively and fast after inoculation in seeds, germs, and soil. This PGPR will immediately provide nutritional inputs needed for plant growth [10]. Some of the bacteria belonging to PGPR are Flavobacterium, Herbaspirillum, Acetobacter, Acinetobacter, Alcaligenes, Arthrobacter, Bacillus, Beijerinckia, Burkholderia, Serratia, Enterobacter, Erwinia, Pseudomonas, Azospirillum, Azotobacter, and Rhizobium [11]. Bacteria groups may associate with plants with carrier materials in the form of liquid, hydrogel, and CMC media.

Hydrogels are the product of a collection of polymeric materials (macromolecular gel) that have a three-dimensional hydrophilic structure [12], while hydrogel is superabsorbent which is also used as a water absorbing agent [13]. Hydrogels are often used in agricultural environments, especially in dry areas to support water requirements during germination [14]. Wang and Gregg [15] have used hydrogels to support water availability in horticulture. Carboxymethyl cellulose (CMC) is a water absorbent agent and an adhesive that can bind water so that water molecules are trapped on gel structure previously formed by CMC [16]. This material is highly soluble in hot and cold water [17] so that inoculated seeds and germs will be attached and inoculated directly to plant roots.

Sorghum (Sorghum bicolor L.) is used as a test plant on the effect of organic biofertilizer based on PGPR, CMC, and hydrogel. Sorghum originates from semi-arid tropical regions and is usually sensitive to low temperatures and is mostly grown in tropical and subtropical regions with an average temperature of over 18°C [18]. Some uses of sorghum are as a source of feed, animal feed and industrial raw materials. Sorghum can grow on marginal land; even the growth of the root does not show symptoms of poisoning in the former mining ground [19].

The objectives of this study were to (1) evaluate the germination response and growth of sorghum seeds to inoculation of PGPR with hydrogel and CMC as the carriers in vitro and pots containing sterile sand (in vivo), and (2) to determine the effect of inoculant PGPR with hydrogel and CMC as a carrier on
the development of population of PGPR in sterile sand. The results of this study are expected to increase germination, improve soil health, promote plant growth, and increase crop production on marginal soils continuously in the future.

2. Materials and Methods
2.1. Inoculant of PGPR
PGPR inoculants used in the germination of sorghum seeds in vitro are functional bacteria inoculum (phosphate solubilising bacteria and non-symbiotic nitrogen-fixing bacteria). The bacteria have been analysed for their ability to produce IAA, nitrogenase, PMEase, and available P. All the bacteria used in this study were isolated from tin mining land on Bangka Island which has been analyzed for its effectiveness and identified as *Azotobacter chroococcum*, *Azospirillum lipoferum* (1103D isolate), and *Bacillus* sp. (3D isolates), (4103D isolate) based on the Bergey Systemic Bacteriology method [20-22]. Furthermore, the stored bacteria were cultivated again in Pikovskaya, Mannitol Ashby [24], and Caceres media [25]. After 3 days incubation, all bacteria were cultured in Erlenmeyer flask that contained liquid Pikovkaya (+ Ca₃(PO₄)₂ as a source of P), Caseres, and Ashby Mannitol media as the carriers. The bacteria were then shaked in room temperature for 24 hours until bacterial population reaches 10¹⁰ cfu/mL (± 3 days). The ratio of liquid inoculant combinations of 3 Rhizobacteria is 1:1:1. The ratio of hydrogel and CMC (carriers) combination with each single bacterium inoculum and mixture is 1:1.

2.2. Germination (in vitro)
Super-2 variety sorghum seeds were taken from Sorghum Research Central in Maros, South Sulawesi. The water-absorbent agent and adhesive materials used carboxymethyl cellulose (CMC) and hydrogel for water reserves and carriers. Sorghum seeds were sterilized using sodium hypochlorite 0.02% for 2 minutes, then washed with sterile aquades for 3 times. Clean seeds were immersed in Erlenmeyer flask, each containing 25 mL of liquid inoculant of *Bacillus* sp.3D, *A. lipoferum* 1103D, and *A. chroococcum* 4103D (single and mixed) combined with hydrogel and CMC as the carriers. Seeds soaked with 25 mL of sterile aquadest, 100 mg of CMC in 25 mL of aquadest, and 100 mg of hydrogel in 25 mL of aquadest were used as treatment controls. All treatments were incubated on rotary shaker for 12 hours with medium velocity (60 rpm) at room temperature. The next step, 100 sorghum seeds were inoculated with *Rhizobacteria*, hydrogel and CMC then were arranged on filter paper in sterile Petri dish (15 cm diameter) moistened with 10 mL of sterile aquadest. A volume of 5 mL of extract of each treatment from seed immersion in Erlenmeyer flask was added. All set of treatments, including control were arranged in 4 replications. All works were carried out in a sterile laminar air flow. Petri dishes were taped and incubated at 27 °C for 7 days in the incubator in a dark room. The moisture of the media during the germination process was maintained by providing a sterile aquadest. Seeds are considered to germinate at the time of the appearance of radicals [26]. Percentages and strength indexes were calculated after 7 days. The Vigour Index was calculated by the method of Abdul and Anderson [27] with the formula: VI = (average root length + average shoot length) (% germination). All data were analysed with analyses of variance (ANOVA) using SPSS software version 12.0. Mean ratio of data were obtained after performing Duncan test (P <0.05).

2.3. Green house experiment (in vivo)
The experiments on the effects of PGPR with hydrogel and CMC as the water-absorbent agent and the adhesive materials on the growth of sorghum seedlings were done in the greenhouses (in vivo) in the Microbiology Division, Research Center for Biology, Indonesian Institute of Sciences (LIPI). In this experiment we used pots containing 300 grams of sterile sand as the planting medium, super sorghum type 2 seeds as the experimental objects, *Bacillus* sp. 3D, *A. lipoferum* 1103D, *A. chroococcum* 4103D as the
bacteria which will be tested for its effectiveness in an in vivo experiment, CMC and Hydrogel as the adhesive and absorbent water or carriers. The sorghum seed was washed and inoculated by soaking the seeds in a glass backer containing the extracts from Bacillus sp. 3D, A. lipoferum 1103D, A. chroococcum 4103D (PGPR). The culture of three bacteria were then mixed for 30 minutes. Other treatments were hydrogel and CMC applied to the planting hole before the sorghum seeds were planted. A total of 5 seeds of sorghum that have been inoculated were planted in the pot. After germination and sprouting, 2 plants were removed but 3 plants were kept in the pot. This was done in all pot experiments. The moisture of the planting media was maintained by watering it daily with Mülller solution. The dose of the solution was in accordance with the dose of field capacity for sand [28].

This experiment has 15 combinations of treatments and 1 control, each treatment was repeated 3 times. The combination of the treatments in this experiment was arranged as follows: 1). K (Controls): The sorghum seeds and planting medium were without bacteria inoculation and without carriers (hydrogels and CMC); 2). A: The sorghum seeds and planting medium were inoculated with Bacillus sp. 3D; 3). B: The sorghum seeds and planting medium were inoculated with A. chroococcum 4103D; 4). C: The sorghum seeds and planting medium were inoculated with A. lipoferum 1103D; 5). D: The sorghum seeds and planting medium were inoculated with Bacillus sp. 3D; A. chroococcum 4103D; A. lipoferum 1103D (Mix); 6). E: The sorghum seeds and planting medium were given a CMC; 7). F: The sorghum seeds and planting medium were inoculated with Bacillus sp. 3D plus CMC; 8). G: The sorghum seeds and planting medium were inoculated with A. chroococcum 4103D plus CMC; 9). H: The sorghum seeds and planting medium were inoculated with A. lipoferum 1103D plus CMC; 10). I: The sorghum seeds and planting medium were inoculated with Mix PGPR plus CMC; 11). J: The sorghum seeds and planting medium were given a hydrogel; 12). K: The sorghum seed and planting medium were inoculated with Bacillus sp. 3D plus hydrogel; 13). L: The sorghum seeds and planting medium were inoculated with A. chroococcum 4103D plus hydrogel; 14). M: The sorghum seeds and planting medium were inoculated with A. lipoferum 1103D plus hydrogel; 15). N: The sorghum seeds and planting medium were inoculated with mixed PGPR plus Hydrogel; 16). O: The sorghum seeds and planting medium were inoculated with mixed PGPR plus Hydrogel and CMC. Sorghum seedling was harvested after 30 days of the planting and their parameters were measured, namely: The shoot length (Cm), the root length (Cm), and the total dry weight (gram) of the seedling. Population of the bacteria in the rhizosphere of the pot plant was calculated after harvesting by plate count method. The data obtained were analyzed statistically using SPSS software version 12.0. The average data comparison was performed by Duncan P test <0.05.

3. Results and Discussion
The results of PGPR (Bacillus sp. 3D, A. chroococcum 4103D, A. lipoferum 1103D), hydrogel and CMC showed that there were significant different effect (P<0.05) on germination (in vitro) and seedling growth of sorghum (in vivo) (Table 1, Table 2, Figure 1, and Figure 2).

3.1. Germination (in vitro)
Treatment of inoculation of PGPR bacteria and carriers (hydrogel and CMC) had different effects on germination of sorghum seed (Table 1 and Figure 2).

| No. | Treatment | Shoot Length (cm) | Root Length (cm) | Vigor Index |
|-----|-----------|------------------|-----------------|-------------|
| 1   | K         | 3.7±0.17          | 2.84±0.41       | 683.00±13.61 |
| 2   | A         | 3.60±0.15         | 0.84±0.05       | 444.00±19.29 |
| 3   | B         | 3.59±0.04         | 1.31±0.16       | 490.00±14.44 |
| 4   | C         | 5.54±0.16         | 2.76±0.17       | 916.00±46.60 |
| 5   | D         | 6.40±0.42         | 6.00±0.60       | 1154.00±74.85 |
6  E  1.83± 0.05\textsuperscript{a}  1.21±0.07\textsuperscript{ab}  304.00±4.37\textsuperscript{a}
7  F  3.13±0.11\textsuperscript{bc}  1.60±0.13\textsuperscript{b}  473.00±17.68\textsuperscript{c}
8  G  4.52±0.08\textsuperscript{c}  2.25±0.09\textsuperscript{c}  677.00±1.76\textsuperscript{d}
9  H  8.67±0.26\textsuperscript{h}  12.60±0.68\textsuperscript{i}  2127.00±80.03\textsuperscript{j}
10  I  6.13±0.27\textsuperscript{f}  4.69±0.45\textsuperscript{g}  1082.00±59.80\textsuperscript{h}
11  J  2.25±0.05\textsuperscript{b}  1.26±0.13\textsuperscript{b}  351.00±7.69\textsuperscript{ab}
12  K  3.05±0.25\textsuperscript{b}  0.93±0.02\textsuperscript{b}  398.00±26.24\textsuperscript{bc}
13  L  3.45±0.40\textsuperscript{b}  2.59±0.05\textsuperscript{c}  604.00±40.41\textsuperscript{c}
14  M  4.55±0.19\textsuperscript{e}  2.27±0.09\textsuperscript{d}  682.00±25.01\textsuperscript{c}
15  N  5.45±0.38\textsuperscript{f}  3.13±0.08\textsuperscript{f}  829.00±78.79\textsuperscript{g}
16  O  5.56±0.44\textsuperscript{f}  4.63±0.02\textsuperscript{f}  910.00±36.10\textsuperscript{h}

Notes: ± SD is value from 3 replications. The number followed by the same letter are not significantly different at (p<0.05) level of Duncan’s test.

Figure 1. The effect of PGPR with hydrogel and CMC on germination of sorghum seed (in vitro)

The average value of the shoot length, root length, and vigor index on seeds treated with \textit{A. lipoferum} plus CMC (H: 8.67 cm; 12.60 cm; 2127.00), \textit{Bacillus} sp. + \textit{A. lipoferum} + \textit{A. chroococcum} (D: 6.40 cm; 6.00 cm; 1154.00), and mix PGPR plus CMC (I: 6.13 cm; 4.69 cm; 1082.00) was the highest yield and the lowest yield was in the CMC (1.83 cm; 1.21 cm; 304.00) and hydrogel (2.25 cm; 1.26 cm; 351.00). This is reasonable that giving inoculants that contain mixed PGPR will have a positive effect on germination compared to single bacteria-containing inoculants. The influence of the inoculant with single bacteria on germination, the result (shoot length, root length, and vigor index) was lower than control, except in germination which was inoculated with bacteria \textit{A. lipoferum} 1103D. The results of this study support the results of research from Mathivanan et al. [30], Hameeda et al. [31] in \textit{Pennisetum glaucum} L, and Sengupta et al. [32] in corn seeds. The results of this research were supported by the reports of Lenin and Jayanthi [33], that the bacteria \textit{A. lipoferum}, \textit{A. chroococcum}, and \textit{Bacillus megaterium} as PGPR have the effect in increasing seed germination and vigor index better than control treatment, even showing significant differences.
3.2. Green house experiment (in vivo)

The success in the germination of *Sorghum bicolor* as indicated by the high value of Vigor Index is triggered by the involvement of PGPR that is able to infect seedlings with IAA, one of the Auxin plant growth hormones groups [34]. IAA is produced by the bacteria from the PGPR group. The effect of PGPR inoculation supported by hydrogel and CMC in the growth of *Sorghum bicolor* seedlings and the population of bacteria in a pot of sterilized sand can be seen in Figure 2 and Table 2.

![Figure 2](image_url)

**Figure 2.** The effect of PGPR with hydrogel and CMC on seedling of sorghum (in vivo)

**Table 2.** The effect of PGPR on seedling growth of sorghum seed (in vivo)

| No. | Treatment | Shoot Length (cm) | Root Length (cm) | Total Dry Weight (g) | Bacteria Population (cfu/g of sand/pot) |
|-----|-----------|-------------------|------------------|----------------------|-----------------------------------------|
| 1   | K         | 26.66±1.45a       | 4.667±0.88a      | 0.083±0.01a          | 0                                      |
| 2   | A         | 41.00±3.12b       | 6.83±0.93b       | 0.150±0.01bc         | 1.75 x 10^7                            |
| 3   | B         | 40.67±3.48cd      | 6.83±0.60b       | 0.220±0.01d          | 1.50 x 10^7                            |
| 4   | C         | 44.33±0.88cdefg   | 10.66±0.33f      | 0.337±0.03f          | 3.25 x 10^7                            |
| 5   | D         | 46.50±0.87g       | 12.00±2.08g      | 0.477±0.01g          | 5.25 x 10^8                            |
| 6   | E         | 31.67±1.67b       | 4.83±0.17b       | 0.223±0.01d          | 0                                      |
| 7   | F         | 46.33±2.73fg      | 8.33±2.03c       | 0.270±0.02e          | 3.75 x 10^8                            |
| 8   | G         | 41.40±2.96def     | 8.166±0.44de     | 0.197±0.01cd         | 2.25 x 10^8                            |
| 9   | H         | 45.83±1.92dfg     | 12.00±1.53g      | 0.337±0.03f          | 6.25 x 10^8                            |
| 10  | I         | 48.67±1.86g       | 15.67±4.81f      | 0.431±0.02f          | 2.75 x 10^9                            |
| 11  | J         | 45.67±2.33defg    | 7.16±0.93bc      | 0.237±0.01de         | 0                                      |
| 12  | K         | 31.00±2.08ab      | 8.00±1.53bc      | 0.130±0.02ab         | 1.03 x 10^8                            |
| 13  | L         | 39.33±7.88c       | 7.66±1.76cd      | 0.127±0.02ab         | 3.75 x 10^8                            |
| 14  | M         | 43.83±7.10defg    | 7.16±0.73c       | 0.227±0.01d          | 5.00 x 10^8                            |
| 15  | N         | 48.67±3.34g       | 15.00±0.58h      | 0.430±0.01g          | 7.00 x 10^9                            |
| 16  | O         | 47.55±0.86g       | 14.89±1.30b      | 0.473±0.02f          | 2.75 x 10^9                            |

Notes: ± SD is value from 3 replications. The number followed by the same letter are not significantly different at (p<0.05) level of Duncan’s test.

The results in the Table and Figures above show that the values of the root length, shoot length, and total dry weight of sorghum seeds are statistically significant. The values of the measurements of the parameters with moderate to highest effect on the treated seeds are shown consecutively: Mix PGPR (D: shoot length = 46.50 cm; root length = 12.00 cm; total dry weight = 0.477 g; bacterial population = 5.25 x 10^8 cfu / g sand / pot), *A. lipoferum* plus CMC (H: shoot length = 45.83 cm; root length = 12.00 cm; total dry weight = 0.337 g; bacterial population = 6.25 x 10^8 cfu / g sand / pot), mix PGPR plus hydrogel and CMC (O: 47.55 cm; 14.89 cm; 0.473 g; 2.75 x 10^9 cfu / g sand / pot), mix PGPR plus hydrogel (N: shoot length = 48.67 cm; root length = 15.00 cm; total dry weight = 0.430 g; bacterial population = 7.00 x 10^9 cfu / g sand / pot), and mix PGPR plus CMC (I: shoot length = 48.67 cm; root length = 15.67 cm; total dry
weight = 0.431 g; bacterial population = 2.75 \times 10^9 \text{ cfu / g sand / pot}). While the lowest measuring values were obtained on seeds which were not inoculated, i.e. in pots with control treatment (shoot length = 26.66 cm, root length = 4.667 cm; total dry weight = 0.083 g; bacterial population = 0 \text{ cfu / g sand / pot}), hydrogel (shoot length = 45.67 cm; root length = 7.16 cm; total dry weight = 0.237 g; bacterial population = 0 \text{ cfu / g sand / pot}); and CMC (shoot length = 31.67 cm; root length = 4.83 cm; total dry weight = 0.223 g; bacterial population = 0 \text{ cfu / g sand / pot}). Thus the group of PGPR bacteria (Bacillus sp. 3D + A. chroococcum 4103D + A. lipoferum 1103D) which were single bacterium, mixed bacteria, and mixed with hydrogel and CMC as carriers inoculated on seeds of sorghum (in vivo) are proven to bring positive impact to the germination of the seeds. The results indicate that bacteria supported by hydrogel and CMC as carriers are effectively infected the sorghum seeds, thus the imbibitions process, the development of radicle, and development of roots and seedlings can normally develop to eventually produce healthy sorghum seedlings. This is in supporting the previous studies by Harris [35] that the contribution of hydrogel was increased the growth of sorghum under semiarid condition.

The success of PGPR bacteria in supporting the healthy growth and development of sorghum is also supported by the volume of bacteria population that is inoculated into growth media and seeds. Soil and seeds are inoculated with bacteria extract with population of $10^{10}$ cfu/mL. After inoculation usually the number of bacteria population will decrease. Nevertheless, the population will continue to grow and colonize the root zone. This is proven by the measurement of population in sorghum’s root areas. The result of average measurement is $10^7$ cfu / mL to $10^9$ cfu / mL. The amounts are higher from the minimum level of the number of bacteria in fertile soil. According to Obaton [36] the fertile soil at least has to have microbial population of $\geq 10^7$ cfu per soil gram. A similar results was reported by Suman et al. [37] that the bacteria (A. chroococcum, Pseudomonas fluorescence, and Trichoderma viride) based bio-inoculant hydrogel can produce maximum population of $99.6 \times 10^8, 3.9 \times 10^7,$ and $2.9 \times 10^7$ cfu per mL which are highly potential in increasing of shoots and roots growth of wheat crops. In other word, the number of bacteria population $10^7$ cfu per ml to $10^9$ cfu per ml will be able to support the developments of shoot and root length. The success is also supported by hydrogel which involves in the increase of seed and plant developments, also the number of bacteria populations in media of sands. This is in supporting the previous studies by Seshadri et al. [38] and Akhtar et al. [39]. The sand media itself has large porous, thus need the involvement of hydrogel in aeration improvement, water and nutrition supplies.

Thus the results of all studies on in vitro and in vivo germination were due to bacteria consortia (PGPR) with hydrogel and CMC as carriers. Tiwari et al. [40] reported that the plants showed the increase of biomass, the increase of shoot length and the growth of root length after inoculation with PGPR bacteria that induced IAA hormone production directly [41]. In particular, the PGPR group of the genus Bacillus, Azospirillum, and Azotobacter which has been considered as an important component of biofertilizer [42], because after inoculated on the plant, it immediately spreads and dominates the rhizospheres and colonizes the root surface area [43], particularly on some of the roots of tropical grass plants [44]; they may also occur in the roots of the sorghum plant. This phenomenon indicates that the participation of PGPR with hydrogel and CMC as the absorbent and the adhesive were very important and the possibility of such combinations is a novelty that is easy to do with relatively low cost to help eco-friendly agriculture in the future.

4. Conclusion

The PGPR treatment combined with CMC (adhesive) in sorghum seeds can improve germination index and increase growth of root and shoots in in vitro. Mixed-PGPR (Bacillus sp. 3D + A. chroococcum 4103D + A. lipoferum 1103D), mixed-PGPR with CMC, and A. lipoferum with CMC are the best combinations to increase the germination of sorghum seeds in vitro.
Single and mix-PGPR (Bacillus sp. 3D, A. chroococcum 4103D, A. lipoferum 1103D) with hydrogel and CMC (carrier) on sorghum seeds can increase the roots length, shoots length, and total dry weight of sorghum seeds in pots containing sterile sand (in vivo). Bacillus sp. plus CMC, A. lipoferum plus CMC, mixed PGPR plus hydrogel, mixed PGPR plus hydrogel and CMC were the best combination for sorghum seedling growth and bacteria population (107 cfu / mL to 109 cfu / mL). The combination is an easy thing to do with a relatively low cost to help eco-friendly farming in the future.

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