*Asian Jr. of Microbiol. Biotech. Env. Sc. Vol. 25, No. (4) : 2023 : 748-755*

***ISSN-0972-3005***

**DOI No.: http://doi.org/10.53550/AJMBES.2023.v25i04.026**

# SCREENING OF MICROBIAL CONSORTIA AGAINST SORGHUM CULTIVARS

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(Received 9 July, 2023; Accepted 28 August, 2023)

***Key words****: Microbial consortia, Screening, Variety, Hybrid, Sorghum.*

**Abstract–** The study was conducted at ARS, Amaravathi, Guntur district, Andhra Pradesh, to find the efficiency of different microbial consortia by screening them against sorghum cultivars viz., variety (CSV-27) and hybrid (CSH-25). Microbial Consortium 1 (*Azotobacter*, PSB, KRB, ZnSB and PGP isolate), Microbial Consortium 2 (*Azospirillium*, PSB, KRB, ZnSB and PGP isolate) and Microbial Consortium 3 (*Azotobacter*, *Azospirillium*, PSB, KRB, ZnSB and PGP isolate) were formulated. Variety (CSV-27) and hybrid (CSH-25) of sorghum were used for screening the three types of microbial consortia. CSV-27 was more responsive to three types of microbial consortia compared to control. But for CSH-25 there was no much difference between the microbial consortia inoculated treatments and control. So CSV-27 was used for further pot and field experiments. $MC_3$ and $MC_2$ performed better than $MC_1$. Plant height, shoot dry weight, root dry weight, PGPR population of microbial consortia, available nutrient content and nutrient uptake of CSV-27 and CSH-25 were significantly highest in $T_4$ (Microbial Consortium -3) followed by $T_3$ (Microbial Consortium -2), $T_2$ (Microbial Consortium -1). So Microbial Consortium -2 and Microbial Consortium -3 were screened as comparatively better and utilized for further experiments.

## INTRODUCTION

All over India variety of crops were grown depending on the area, native soil texture and weather. Sorghum is one of the usual grown crop, it is vital life sustaining crop in many parts of the world, ranking fifth after wheat, rice, maize and barley. There is a ranking in grain producing country among them India ranks second after USA. In India it is the third important crop after rice, wheat. Sorghum is primarily used for the food in the different areas of India. Importance states producing sorghum crop are Maharashtra, Karnataka, Andhra Pradesh and Madhya Pradesh. Nutritionally sorghum is superior to all other cereals and therefore it requires to improve the crop yield (Prathibha and Siddalingeshwara, 2013).

## MATERIALS AND METHODS

Pot experiment was conducted to study the effect of developed microbial consortia against host crop under green house conditions.

### Location of the Experiment

The pot culture experiment for screening of the microbial consortia was carried out at Agricultural Research Station, Amaravathi.

### Physical and Chemical Properties of the Soil

The soil of the experimental site was black soil with good drainage and fine bed. Representative soil sample was collected from the field prior to pot filling and was analysed for the physico-chemical and biological properties by adopting standard procedures at Department of Agricultural Microbiology, APGC, Lam and Department of Soil Science, RARS, Lam, Guntur.

### Microbiological Properties of the Experimental Soil

Viable population of total soil bacteria, fungi, Actinomycetes, *Azospirillum*, *Azotobacter*, phosphate solubilizing bacteria, potassium releasing bacteria, zinc solubilising bacteria and PGPR isolates were analyzed by the standard serial dilution plate count method (Vlassak *et al*., 1992). The microbial colonies appearing after the stipulated time period of incubation were counted as Colony Forming Units (CFU) $g^{-1}$ fresh weight of the soil sample. The microbial populations were expressed as number of colony forming units per gram of soil. AM spore count was determined by wet sieving and decantation procedure as outlined by Gerdemann and Nicholson, (1963).

### Soil Preparation

Soil was sterilized at 121 $^{o}$C for 15 minutes at 15 lb pressure and about 7 kg of sterilized soil was filled into each pot. CSV-27 variety and CSH-25 hybrid of sorghum were selected and sown at the rate of 6-8 seeds per pot then thinning was done and only 2 plants per pot were maintained.

Location : ARS, Amaravathi
Season : *Kharif*
Design : CRD (pot culture)

### Treatments

Total 4 treatments were designed for both variety and hybrid with 3 replications each

- $T_1$ : Control
- $T_2$ : Microbial consortium 1
- $T_3$ : Microbial consortium 2
- $T_4$ : Microbial consortium 3

### Treatment Inoculation

Microbial consortia were prepared and added to the pots at the rate of 3 ml/ pot according to the treatments.

### Observations recorded

Plant height, shoot weight, root fresh weight, root dry weight, total dry weight, N and P nutrient uptake

The plant height was recorded at 30 days interval, it was measured from the ground level to tip of the top most leaf of the plant. Shoot weight was recorded after the harvesting. The plants were weighed and weight was expressed in gram per plant. Root fresh weight was recorded after harvesting. The roots were removed carefully from the pots and soil adhered was removed and fresh weight was expressed in gram per plant. Root dry weight of the crop was recorded (after harvest). Root samples were washed and dried in an oven at 60 $^{o}$C till constant weight was observed. The roots were weighed and dry weight was expressed in gram per plant. Shoot and root dry weight of the crop was recorded (after harvest). Plant samples were washed and dried in an oven at 60 $^{o}$C till constant weight was observed. The plants were weighed and dry weight was expressed in gram per plant.

### Plant analysis

Plant samples collected at maturity stage were processed and analyzed for N and P by adopting the standard procedures.

### Nitrogen uptake

Nitrogen content (%) in leaf was estimated by the micro kjeldhal method (Piper, 1960).

### Phosphorus uptake

The plant samples were digested with triacid mixture consisting of $HNO_3$: $H_2SO_4$: $HClO_4$ (9:4:1). The digest was made up to 100 ml. The phosphorus content in the triacid digest was determined by vanado molybdo phosphoric acid yellow color method (Piper, 1960). The intensity of yellow color was measured by using spectrophotometer at 420 nm wave length.

**Nutrient (N and P) uptake:** The nutrient uptake was calculated using the following formula and expressed in g plant$^{-1}$.

$$\text{Nutrient uptake (g plant}^{-1}) = \frac{\text{Nutrient content (\%)} \times \text{Dry matter production (g plant}^{-1})}{100}$$

## RESULTS AND DISCUSSION

Both varities (CSV-27) and hybrid (CSH-25) of sorghum were used for screening the microbial consortia. Three types of microbial consortia were developed: Microbial consortium-1 ($MC_1$) (*Azotobacter* + PSB + KRB + ZnSB + PGPR isolate), Microbial consortum-2 ($MC_2$) (*Azospirillium* + PSB + KRB + ZnSB + PGPR isolate) and Microbial consortium-3 ($MC_3$) (*Azotobacter* + *Azospirillium* + PSB + KRB + ZnSB + PGPR isolate).

At 30DAS in CSV-27 plant height was highest in $T_4$ ($MC_3$) 59.50 cm, which was significantly higher than $T_3$ ($MC_2$) 54.67 cm. At 90 DAS plant height was highest in $T_4$ ($MC_3$) 135.60 cm, which was significantly higher than $T_3$ ($MC_2$) 124.63 cm. At 120 DAS plant height was highest in $T_4$ ($MC_3$) 139.83 cm, which was significantly higher than $T_3$ ($MC_2$) 128.83 (Table 1).

Plant height (CSV-27) was found significantly highest in all the intervals of crop growth in $T_4$ ($MC_3$) where *Azotobacter*, *Azospirillum* both were used in consortia preparation, compared to the other microbial consortia applied treatments and control (Table 1). The results were similar to the experiments conducted by Burd *et al*. (2000), where he stated that plants inoculated with and *Azotobacter*, *Azospirillum* and *Pseudomonas* strains might enhance plant height and productivity by synthesizing phytohormones, increasing the local availability of nutrients, facilitating the uptake of nutrients by the plants and antagonizing plant pathogens.

Rafi *et al.* (2012) reported that inoculation of foxtail millet (cv. Chitra) with two strains of *Azospirillum* and one strain of a phosphate solubilizing bacterium individually and in combination significantly increased plant height over plants in control. *Azospirillum* and phosphate-solubilizing microorganisms increased plant height of rice significantly at flowering stage over control (Arangarasan *et al*., 1998) and in pearl millet (Guggari and Kalaghatagi, 2005). Rafi *et al*. (2012) reported that coinoculation of *Azospirillum* and PSB significantly increased the shoot height of foxtail millet over the control and the individual inoculants.

At 30DAS in CSH-25 hybrid sorghum plant height was higher in $T_3$ ($MC_2$) 45.77 cm, which was statistically on par with $T_4$ ($MC_3$) 45.43 cm. At 90 DAS plant height was higher in $T_4$ ($MC_3$) 98.23 cm, which was statistically on par with $T_3$ ($MC_2$) 98.10 cm. At 120 DAS plant height was higher in $T_3$ ($MC_2$) 98.83 cm, which was statistically on par with $T_4$ ($MC_3$) 98.57 cm (Table 1).

Plant height (CSH-25) was highest in $T_3$ ($MC_2$) at 90DAS while at 30DAS and 60 DAS plant height was higher in $T_4$ ($MC_3$). Esmailpour *et al*. (2013) stated that there was an increase in shoot length of wheat plants inoculated with beneficial microorganisms due to the increase in absorption of nutrients by plant, improvement of soil characteristics such as contents of organic materials and increase in accessible nitrogen.

Plant height showed a significant difference among the treatments in both variety and hybrid of sorghum plants. But there was comparitively more influence of microbial consortia inoculated treatments with variety, while in hybrid there was not much difference among the microbial consortia inoculated treatments and control.

### Shoot fresh weight and shoot dry weight of sorghum crop

Shoot fresh weight (CSV-27) was highest in $T_4$ ($MC_3$) 132.12 g plant$^{-1}$, which was significantly higher than $T_3$ ($MC_2$) 114.02 g plant$^{-1}$ and comparitively lowest shoot fresh weight was recorded in $T_1$ (control) 80.42 g plant$^{-1}$. Shoot fresh weight (CSH-25) was highest in $T_4$ ($MC_3$) 89.46 g plant$^{-1}$, which was significantly higher than $T_3$ ($MC_2$) 86.79 g plant$^{-1}$ and comparitively lowest shoot fresh weight was recorded in $T_1$ (control) 80.53 g plant$^{-1}$ (Table 2).

Shoot fresh weight was highest for both CSV-27 and CSH-25 in $T_4$ ($MC_3$). In CSV-27comparitively better shoot fresh weight was observed in all the three treatments inoculated with microbial consortia than the control. While for CSH-25 there was no much difference between the control and microbial consortia applied treatments (Table 2).

Shoot dry weight (CSV-27) was highest in $T_4$ ($MC_3$) 20.43 g plant$^{-1}$, which was significantly higher than $T_3$ ($MC_2$) 18.23 g plant$^{-1}$ and comparitively lower shoot dry weight was recorded in $T_1$ (control) 10.74 g plant$^{-1}$. Shoot dry weight (CSH-25) was significantly higher in $T_4$ ($MC_3$) 15.74 g plant$^{-1}$, which was significantly higher than $T_3$ ($MC_2$) 15.52 g plant$^{-1}$ and comparitively lower shoot dry weight was recorded in $T_1$ (control) 11.34 g plant$^{-1}$ (Table 2).

Shoot dry weight was higher for both CSV-27 and CSH-25 in $T_4$ ($MC_3$). In CSV-27 comparitively better shoot dry weight was observed in all the three treatments inoculated with microbial consortia than

**Table 1.** Effect of microbial consortia on sorghum plant height at different intervals of crop growth under green house conditions

| Treatments | Variety –CSV-27 (cm) | | | | Hybrid–CSH-25 (cm) | | | |
|---|---|---|---|---|---|---|---|---|
| | 30 DAS | 60 DAS | 90 DAS | 120 DAS | 30 DAS | 60 DAS | 90 DAS | 120 DAS |
| $T_1$ | 37.83 | 74.83 | 81.83 | 86.17 | 40.83 | 91.77 | 95.83 | 96.43 |
| $T_2$ | 49.33 | 100.93 | 108.77 | 112.77 | 41.90 | 93.70 | 96.13 | 96.83 |
| $T_3$ | 54.67 | 119.93 | 124.63 | 128.83 | 45.77 | 93.73 | 98.10 | 98.83 |
| $T_4$ | 59.50 | 130.73 | 135.60 | 139.83 | 45.43 | 95.07 | 98.23 | 98.57 |
| SE(m) | 0.25 | 0.12 | 0.18 | 0.16 | 0.14 | 0.21 | 0.19 | 0.21 |
| CD (P=0.05) | 0.83 | 0.37 | 0.59 | 0.54 | 0.45 | 0.69 | 0.63 | 0.70 |
| CV | 0.86 | 0.19 | 0.27 | 0.24 | 0.54 | 0.39 | 0.34 | 0.37 |

$T_1$: Control
$T_2$: Microbial Consortium 1 (*Azotobacter* + PSB + KRB + ZnSB + PGPR Isolate)
$T_3$: Microbial Consortium 2 (*Azospirillium* + PSB + KRB + ZnSB + PGPR Isolate)
$T_4$: Microbial Consortium 3 (*Azotobacter* +*Azospirillium* + PSB + KRB+ ZnSB + PGPR Isolate)

the control. While for CSH-25 there was not much difference between the control and microbial consortia applied treatments.

The results were similar to Aly *et al*. (2012) who revealed that soil inoculation by both *Azotobacter vinelandii* and *Streptomyces* sp. enhanced root depth, shoot length, dry weights of root and shoot and mineral and protein content due to nitrogen fixation, auxins production or unidentified compounds.

**Root fresh weight and root dry weight of sorghum**

Root fresh weight (CSV-27) was highest in $T_4$ ($MC_3$) 105.09 g plant$^{-1}$, which was significantly higher than$T_3$ ($MC_2$) 89.23 g plant$^{-1}$ and comparitively lowest root fresh weight was recorded in $T_1$ (control) 69.58 g plant$^{-1}$. Root fresh weight (CSH-25) was higher in $T_4$ ($MC_3$) 83.50 g plant$^{-1}$, which was statistically on par with $T_3$ ($MC_2$) 83.48 g plant$^{-1}$ and comparitively lowest root fresh weight was recorded in $T_1$ (control) 77.60 g plant$^{-1}$ (Table 2).

Root fresh weight was highest for both CSV-27 and CSH-25 in $T_4$ ($MC_3$). In CSV-27 comparitively better root fresh weight was observed in all the three treatments inoculated with microbial consortia than the control. While for CSH-25 there was no much difference between the control and microbial consortia applied treatments.

Root dry weight (CSV-27) was highest in $T_4$ ($MC_3$) 28.33 g plant$^{-1}$, which was significantly higher than $T_3$ ($MC_2$) 25.38 g plant$^{-1}$ and comparitively lowest root dry was recorded in $T_1$ (control) 13.44 g plant$^{-1}$. Root dry weight (CSH-25) was higher in $T_3$ ($MC_2$) 25.41 g plant$^{-1}$, which was significantly higher than $T_4$ ($MC_3$) 24.43 g plant$^{-1}$ and comparitively lowest root dry was recorded in $T_1$ (control) 20.43 g plant$^{-1}$ (Table 2).

The results were in line with Jagnow (1990) who reported that inoculation of wheat with *A. chroococcum* and *B. megatherium* in combination significantly increased the fresh and dry weights of wheat over control treatment.

For CSV-27 variety of sorghum root dry weight was highest in $T_4$ ($MC_3$) while for CSH-25 root dry weight was highest in $T_3$ ($MC_2$). Also in CSV-27 variety of sorghum comparitively better root dry weight was observed in all the three treatments inoculated with microbial consortia than the control. While for CSH-25 there was not much difference between the control and microbial consortia inoculated treatments.

Root weight was generally more responsive to microbial inoculation. Dual inoculation with *Azospirillum* and PSB increased the dry weight of roots in pearl millet (Mane *et al*., 2000). Production of phytohormones especially auxin (IAA) helps in root development (Takahashi, 2013) and thus helps for better establishment of plant. Production of phytohormones (IAA) by microbes and improvement in root weight by microbial inoculants was well established.

The dual inoculation of *Azospirillum* and PSB increased the dry root weight of ragi plants over other treatments (Rafi *et al*., 2012). Similar results were also reported by other workers regarding increased root dry matter production due to microbial inoculation. A significant increase in root dry weight due to inoculation with 2 strains of *Azospirillum brasilense* over control plants in *Setaria italica* (Nur *et al*., 1980 and Cohen *et al*., 1980). Similarly, increased dry weight of roots and shoots due to inoculation with PSB (*Bacillus circulans*) was reported in finger millet (Raj *et al*., 1981).

**Table 2.** Effect of microbial consortia on different growth parameters of sorghum crop under green house conditions

| Treatments | Variety –CSV-27 (g plant$^{-1}$) | | | | | Hybrid–CSH-25 (g plant$^{-1}$) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Shoot fresh weight | Shoot dry weight | Root fresh weight | Root dry weight | Total dry weight | Shoot fresh weight | Shoot dry weight | Root fresh weight | Root dry weight | Total dry weight |
| $T_1$ | 80.42 | 10.74 | 69.58 | 13.44 | 24.18 | 80.53 | 11.34 | 77.60 | 20.43 | 31.77 |
| $T_2$ | 99.23 | 16.51 | 82.32 | 20.64 | 37.16 | 84.67 | 13.60 | 79.71 | 22.40 | 35.16 |
| $T_3$ | 114.02 | 18.23 | 89.23 | 25.38 | 43.61 | 86.79 | 15.52 | 83.48 | 25.41 | 40.94 |
| $T_4$ | 132.12 | 20.43 | 105.09 | 28.33 | 48.76 | 89.46 | 15.74 | 83.50 | 24.43 | 40.17 |
| SE(m) | 0.32 | 0.10 | 0.17 | 0.22 | 0.23 | 0.19 | 0.21 | 0.21 | 0.24 | 0.41 |
| CD (P=0.05) | 1.07 | 0.34 | 0.56 | 0.74 | 0.76 | 0.64 | 0.68 | 0.70 | 0.79 | 1.36 |
| CV | 0.53 | 1.09 | 0.34 | 1.77 | 1.04 | 0.39 | 2.53 | 0.45 | 1.78 | 1.92 |

**$T_1$: Control**
$T_2$: Microbial Consortium 1 (*Azotobacter* + PSB + KRB + ZnSB + PGPR Isolate)
$T_3$: Microbial Consortium 2 (*Azospirillium* + PSB + KRB+ ZnSB + PGPR Isolate)
$T_4$: Microbial Consortium 3 (*Azotobacter* + *Azospirillium* + PSB + KRB+ ZnSB + PGPR Isolate)

## Total plant dry weight of sorghum

Total plant dry weight (CSV-27) was significantly higher in $T_4$ ($MC_3$) 48.76 g plant$^{-1}$, followed by $T_3$ ($MC_2$) 43.61 g plant$^{-1}$ and comparitively lowest was recorded in $T_1$ (control) 24.18g plant$^{-1}$ (Table 2).

The results were on par with Sharifi and Khavazi (2011) who reported the effect of PGPR on dry matter accumulation of maize hybrids in three levels control, *Azotobacter* or *Azospirillum* and *Azotobacter* + *Azospirillum*. The results showed improved grain yield, plant height and dry matter accumulation with dual inoculants application.

Total plant dry weight (CSH-25) was highest in $T_3$ ($MC_2$) 40.94 g plant$^{-1}$, which was statistically on par with $T_4$ ($MC_3$) 40.17 g plant$^{-1}$ and comparitively lowest total plant dry weight was recorded in $T_1$ (control) 31.77 g plant$^{-1}$ (Table 2).

In CSV-27 variety of sorghum comparitively better dry weight was observed in all the three treatments inoculated with microbial consortia than the control. While for CSH-25 there was no much difference in total plant dry weights of microbial consortia inoculated treatments and control. Bacteria present in the rhizosphere of young plants preferentially utilizes simple amino acids, whereas bacteria from mature plants utilizes more complex carbohydrates indicating that there is change in the quality of plant root exudates and the bacterial population exhibits ability to respond under competition (Dandurand and Knudsen, 2002).

## Available nutrients in the soil at the harvesting stage of variety and hybrid of sorghum (CSV-27 and CSH-25)

### a) Available Nitrogen in the soil

Available nitrogen content (CSV-27) was 74.19 Kg ha$^{-1}$ in the initial soil sample (Table 3). At the time of harvest available nitrogen was highest in $T_4$ ($MC_3$) 108.39 Kg ha$^{-1}$ which was significantly higher than $T_3$ ($MC_2$) 99.46 Kg ha$^{-1}$ and lowest available nitrogen was found in $T_1$ (control) 60.76 Kg ha$^{-1}$. At the time of harvest (CSH-25) available nitrogen was highest in $T_4$ ($MC_3$) 92.46 Kg ha$^{-1}$ which was significantly higher than $T_3$ ($MC_2$) 91.51 Kg ha$^{-1}$ and lowest available nitrogen was found in $T_1$ (control) 60.86 Kg ha$^{-1}$ (Table 3).

Available nitrogen content in the soil at the time of harvest was highest in $T_4$ ($MC_3$) in both CSV-27 and CSH-25. The treatment $T_4$ was with combined inoculation of *Azotobacter* and *Azospirillium*. The reason for the highest available nitrogen content in the treatment was due to the synergistic activity of both the organisms. The available nitrogen content was comparitively better in all the microbial consortia inoculated treatments of CSV-27 than the control, also $T_3$ showed greater increase in the available N content compared to the other microbial consortia inoculated treatments. While in CSH-25 there was very slight difference between the microbial consortia inoculated treatments. So there was no much variation in the effect of microbial consortia on available nitrogen of CSH-25.

The important characteristic of *Azospirillum* and *Azotobacter* was that they excrete ammonia in the rhizosphere in the presence of root exudates. The combined use of both the $N_2$ fixers in the present study resulted in a higher total N content in the soil. These similar results were found by Narula and Gupta (1986).

## Available Phosphorus in the soil

Available phosphorus content (CSV-27) was 17.60

**Table 3.** Effect of microbial consortia on available nutrients at the harvesting stage of sorghum under green house conditions

| Treatments | Variety –CSV-27 (Kg ha$^{-1}$) | | | Hybrid–CSH-25 (Kg ha$^{-1}$) | | |
|---|---|---|---|---|---|---|
| | Available N | Available P | Available K | Available N | Available P | Available K |
| $T_1$ | 60. 76 | 11.83 | 202.77 | 60.86 | 11.46 | 202.77 |
| $T_2$ | 95.54 | 25.84 | 224.12 | 90.31 | 24.44 | 225.12 |
| $T_3$ | 99.46 | 27.20 | 228.30 | 91.51 | 24.86 | 226.97 |
| $T_4$ | 108.39 | 28.94 | 231.81 | 92.46 | 25.27 | 228.14 |
| SE(m) | 0.27 | 0.32 | 0.28 | 0.26 | 0.44 | 0.31 |
| CD (P=0.05) | 0.89 | 1.05 | 0.93 | 0.87 | 1.45 | 1.03 |
| CV | 0.51 | 2.33 | 0.22 | 0.54 | 3.53 | 0.24 |

$T_1$: Control
$T_2$: Microbial Consortium 1 (*Azotobacter* + PSB + KRB + ZnSB + PGPR Isolate).
$T_3$: Microbial Consortium 2 (*Azospirillium* + PSB + KRB + ZnSB + PGPR Isolate).
$T_4$: Microbial Consortium 3 (*Azotobacter* + *Azospirillium* + PSB + KRB + ZnSB + PGPR Isolate).

Kg ha$^{-1}$ in the initial soil sample (Table 3). At the time of harvest available phosphorus was highest in $T_4$ ($MC_3$) 28.94 Kg ha$^{-1}$ which was significantly higher than $T_3$ ($MC_2$) 27.20 Kg ha$^{-1}$ and lowest available phosphorus was found in $T_1$ (control) 11.83 Kg ha$^{-1}$. At the time of harvest (CSH-25) available phosphorus was highest in $T_4$ ($MC_3$) 25.27 Kg ha$^{-1}$ which was significantly higher than $T_3$ ($MC_2$) 24.86 Kg ha$^{-1}$ and lowest available phosphorus was found in $T_1$ (control) 11.46 Kg ha$^{-1}$ (Table 3).

Available phosphorus content in the soil at the time of harvest was highest in $T_4$ ($MC_3$) in both varities and hybrid of sorghum. The treatment $T_4$ was with combined inoculation of *Azotobacter* and *Azospirillium.* This may be the reason for the highest available phosphorus content in the treatment was due to the synergistic activity of both the organisms. The available phosphorus content was comparitively better in all the microbial consortia inoculated treatments of CSV-27 than the control, also $T_3$ showed greater increase in the available P content compared to the other microbial consortia inoculated treatments. While in CSH-25 there was very slight difference between the microbial consortia inoculated treatments. So there was no much variation in the effect of microbial consortia on available phosphorus content in CSH-25.

The increase in soil phosphorus content might be due to the P-solubilizing potential of the isolates used in the microbial consortia. This may be attributed to the production of organic acids, chelating oxo-acids and solubilization of inorganic insoluble phosphates by microorganisms. Similar findings were reported earlier by Molla *et al*. (1984) and Gupta *et al*. (1994). Sundara *et al*. (2002) found that the application of PSB, *Bacillus megatherium* var. *phosphaticum*, increased the available phosphorus in soil.

### Available potassium in the soil

Available potassium content (CSV-27) was 217.64 Kg ha$^{-1}$ in the initial soil sample (Table 3). At the time of harvest available potassium was higher in $T_4$ ($MC_3$) 228.14 Kg ha$^{-1}$ which was significantly higher than $T_3$ ($MC_2$) 226.97 Kg ha$^{-1}$ and lowest available potassium was found in $T_1$ (control) 202.77 Kg ha$^{-1}$. At the time of harvest (CSH-25) available potassium was higher in $T_4$ ($MC_3$) 231.81 Kg ha$^{-1}$ which was significantly higher than $T_3$ ($MC_2$) 228.30 Kg ha$^{-1}$ and lowest available potassium was found in $T_1$ (control) 202.77 Kg ha$^{-1}$ (Table 3).

Available potassium content in the soil at the time of harvest was highest in $T_4$ ($MC_3$) in both CSV-27 and CSH-25. The treatment $T_4$ was with combined inoculation of *Azotobacter* and *Azospirillium.* This reason for the higher available potassium content in the treatment was due to the synergistic activity of both the organisms. The available potassium content was comparitively better in all the microbial consortia inoculated treatments of CSV-27 than the control, also $T_3$ showed greater increase in the available potassium content compared to the other microbial consortia inoculated treatments. While in CSH-25 there was very slight difference between the microbial consortia inoculated treatments. So there was no much variation in the effect of microbial consortia on available potassium of CSH-25.

### Effect of microbial consortia on nutrient uptake of sorghum (CSV-27 and CSH-25)

### Nitrogen uptake by sorghum

Nitrogen uptake (CSV-27) was highest in $T_4$ ($MC_3$) 24.81 g pot$^{-1}$ which was significantly higher than $T_3$ ($MC_2$) 20.75 g pot$^{-1}$ and lowest nitrogen uptake was found in $T_1$ (control) 12.69 g pot$^{-1}$. Nitrogen uptake (CSH-25) was highest in $T_3$ ($MC_2$) 20.14 g pot$^{-1}$ which

**Table 4.** Effect of microbial consortia on sorghum plant nutrient uptake under green house conditions

| Treatments | Variety –CSV-27 (g pot$^{-1}$) | | | Hybrid–CSH-25 (g pot$^{-1}$) | | |
|---|---|---|---|---|---|---|
| | N uptake | P uptake | K uptake | N uptake | P uptake | K uptake |
| $T_1$ | 12.69 | 6.52 | 14.65 | 12.59 | 6.79 | 14.65 |
| $T_2$ | 18.86 | 14.73 | 30.70 | 18.86 | 14.56 | 30.70 |
| $T_3$ | 20.75 | 17.67 | 34.64 | 19.09 | 15.67 | 31.97 |
| $T_4$ | 24.81 | 19.52 | 38.75 | 20.14 | 16.52 | 33.75 |
| SE(m) | 0.24 | 0.26 | 0.30 | 0.40 | 0.24 | 0.34 |
| CD (P=0.05) | 0.79 | 0.87 | 1.00 | 1.34 | 0.78 | 1.12 |
| CV | 2.15 | 3.13 | 1.77 | 3.95 | 3.05 | 2.11 |

$T_1$: Control
$T_2$: Microbial Consortium 1 (Azotobacter + PSB + KRB+ ZnSB + PGPR Isolate).
$T_3$: Microbial Consortium 2 (Azospirillium + PSB + KRB+ ZnSB + PGPR Isolate).
$T_4$: Microbial Consortium 3 (Azotobacter +Azospirillium + PSB + KRB+ ZnSB + PGPR Isolate).

was statistically on par with $T_4$ ($MC_3$) 19.09 g $pot^{-1}$ and lowest nitrogen uptake was found in $T_1$ (control) 12.59 g $pot^{-1}$ (Table 4).

The results were similar to Swarnalakshmi *et al*. (2013) who revealed that combined inoculation of mixtures and biofilmed bio-inoculants (*Anabaena torulosa* + *Pseudomonas striata* and/or *Anabaena torulosa* + *Azotobacter chroococcum*) were superior over single inoculation and control in terms of nutrient uptake.

Nitrogen uptake was comparitively more in all the microbial consortia inoculated treatments than the control for CSV-27. But there was no much difference in nitrogen uptake of microbial consortia inoculated treatments and control for CSH-25.

**Phosphorus uptake by sorghum**

Phosphorus uptake (CSV-27) was higher in $T_4$ ($MC_3$) 19.52 g $pot^{-1}$ which was significantly higher than $T_3$ ($MC_2$) 17.67 g $pot^{-1}$ and lowest phosphorus uptake was found in $T_1$ (control) 6.52 g $pot^{-1}$. Phosphorus uptake (CSH-25) was highest in $T_4$ ($MC_3$) 16.52 g $pot^{-1}$ which was significantly higher than $T_3$ ($MC_2$) 15.67 g $pot^{-1}$ and lowest phosphorus uptake was found in $T_1$ (control) 6.79 g $pot^{-1}$ (Table 4).

The similar results were observed by and Krishnaveni (2010) that the application of microbial inoculants increased the uptake of both macro- and micronutrients. It was observed that microbial inoculants application had enhanced the uptake of all plant nutrients especially phosphorus content in the plant tissue.

Phosphorus uptake was comparitively more in all the microbial consortia inoculated treatments than the control for CSV-27. But there was no much difference in phosphorus uptake of microbial consortia inoculated treatments and control for CSH-25.

Ramakrishnan and Bhuvaneswari (2014) found that finger millet treated with *Azospirillium* + PSB increased the plant growth and N, P and K uptake. Co-inoculation of *Bacillus polymyxa* and *Pseudomonas striata* strains showing phosphate-solubilizing ability along with a strain of *Azospirillium brasilense* resulted in significant increase in N and P uptake as compared to individual inoculations in sorghum was reported by Alagawadi and Gaur (1992).

**Potassium uptake by sorghum**

Potassium uptake (CSV-27) was highest in $T_4$ ($MC_3$) 38.75 g $pot^{-1}$ which was significantly higher than $T_3$ ($MC_2$) 34.64 g $pot^{-1}$ and lowest potassium uptake was found in $T_1$ (control) 14.65 g $pot^{-1}$. Potassium uptake (CSH-25) was highest in $T_4$ ($MC_3$) 33.75 g $pot^{-1}$ which was significantly higher than $T_3$ ($MC_2$) 31.97 g $pot^{-1}$ and lowest potassium uptake was found in $T_1$ (control) 14.65 g $pot^{-1}$ (Table 4).

Potassium uptake was comparatively more in all the microbial consortia inoculated treatments than the control for CSV-27. But there was no much difference in potassium uptake of microbial consortia inoculated treatments and control for CSH-25.

Almost all the nutrients uptakes were higher in $T_4$ ($MC_3$) followed by $T_3$ ($MC_2$) compared to $T_2$ ($M.C_1$). Microbial consortia -3 had dual effect of *Azotobacter* and *Azospirillium* which showed positive response on plant nutrient uptake compared to the other two consortia.

Increased potassium uptake might be due to the synergistic effect between phosphorus and potassium and better root growth. The increased uptake of this nutrient might have increased the potassium content in grain and straw. The inoculation with phosphate solubilizing microorganisms also significantly increased the uptake of phosphorus which may be due to enhanced availability of phosphorus. These findings are supported by Singh *et al*. (2004).

## CONCLUSION

Sorghum variety CSV-27 performed better compared to the hybrid CSH-25. CSV-27 responded differently to the three different microbial consortia while no difference observed with CSH-25 in all the three treatments. Plant height at all the intervals was recorded and CSV-27 recorded highest plant height with microbial consortia-4, while there was no notable difference among treatments of CSH-25. Similarly shoot fresh weight, root fresh weight, root dry weight, shoot dry weight and total dry weight showed remarkable difference among treatments of CSV-27 while not much difference seen with CSH-25. In the similar manner nutrients uptake and available nutrients was significantly higher with CSV-27 compared to CSH-25.

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