6.1 Introduction

The most challenging task for the agricultural fraternity of the country is to feed the shooting population of the world with the rapidly thinning available agricultural land. Further, the crop losses tote up the already appalling situation. Recently, data for total crop losses has been recorded to be equivalent to 250 billion dollars (INR 1.5 crores) (AgriNews, 2015). This loss covers the damage caused by the fungal, bacterial, viral phytopathogens along with the pests and insects to the agricultural output. In the dwelling scenario, biocontrol strategy to prevent or reduce the crop losses seems as a silver lining. The benefit of the eco-friendly and economic approach for managing the worsening situation has been well illustrated in numerous studies carried out throughout the world under green house and glasshouse conditions for different crops and the corresponding pathogens affecting their yield (Jain et al. 2013; Landa et al. 2013; Saxena et al. 2013; Singh et al. 2014b; Błaszczyk et al. 2014; Woo et al. 2014).

For promoting plant growth and crop yield mainly, two strategies are employed; amending organic or inorganic supplements in the soils (Conn and Lazarovits 2000; Berg 2009) or application of beneficial microbes (PGPB and PGPF) into soil (Compan et al. 2005; Weller et al. 2007; Berg 2009). The organic or inorganic synthetic chemicals can only provide momentary benefits to the plants health and hence needs to be applied at proper intervals repeatedly, which increase the economic costs of its use. On the other hand, the plants harbor numerous microbes in its vicinity under normal conditions especially in the rhizospheric region which dwell in harmony with each other without addition of any external supplement (Berg et al. 2005). The microbes provide dual benefits to plant health; they provide protection to them from the pathogens and also aid
them in utilizing the insoluble nutrients present in the soil (Lutenberg and Kamilova 2009).

The multifaceted role of *Trichoderma* as PGPF has been extensively elaborated in previous studies (Harman *et al.* 2012; Woo *et al.* 2014; Singh *et al.* 2014b; Saxena *et al.* 2015). The stimulation of plant growth by the genus *Trichoderma* has been attributed to its ability to produce vitamins, to mobilize insoluble forms of biogenic nutrients like phosphorous and nitrogen along with the capacity of enhancing minerals and nutrient uptake from the soil making it available to the plants (Błaszczyk *et al.* 2014). Moreover, the fungus has been found to be capable of producing growth promoting hormones i.e. zeaxanthin and gibberellins mainly involved in enhancing seed germination along with producing glucoronic, citric coumaric acids involved in solubilization of phosphorous ions and micro elements making it available to the plants (Harman *et al.* 2004). Seed treatment and soil application with *Trichoderma* has shown promising results in enhancing plant growth having positive effect on the shoot and root length of different crops and fruits along with increasing the number of leaves, which subsequently aids in enhanced photosynthetic ability of the plant thereby increasing the overall yield (Yedidia *et al.* 2001; Porras *et al.* 2007; Jain *et al.* 2012; Singh *et al.* 2013b; Woo *et al.* 2014; Saxena *et al.* 2015).

The genus not only has direct effect on plant health but has also proved efficient in modulating microbial population in the rhizospheric region thereby aiding in plant growth indirectly (Schuster and Schmoll, 2010; Jain *et al.* 2013; Singh *et al.* 2014b). Beneficial effect of *Trichoderma* has also been reported for the Arbuscular Mycorrhizal Fungus (AMF) with production of AMF specific proteins on *Trichoderma* treatment
pointing the synergistic action of the genus on AMF growth (Al-Asbahi 2012). Their results suggest that the volatile biomolecules secreted by *T. harzianum* Rifai KRL-AG2 led to increase in AMF with roots of wheat plants (cv. Avocet S) thereby resulting in significant increment in AM-plant interaction. The beneficial role of AMF in imparting growth promotion to chilli growth and yield has been recently reported (Thilagar and Bagyaraj 2015). Increased level of plant growth promoting hormones i.e. auxins and gibberellins was recorded in combined treatment of *Trichoderma* and AMF signifying the role of the genus in fortification of the plant health (Hanefat *et al.* 2012).

An effective and promising biocontrol agent should possess dual qualities of imparting protection to the plant from the invading pathogens along with the ability to augment its growth and thereby the yield. *Trichoderma* has proved its talent in both the field very effectively showing promising results and thereby establishing itself as a potent BCA (Harman *et al.* 2004; Verma *et al.* 2007; Singh *et al.* 2012; Singh *et al.* 2013b; 2014b). However, combination of one or more compatible beneficial microbes for better growth promotion as well as effective protection from pathogens has been of much attention in recent years (Jetiyanon *et al.* 2007; Jain *et al.* 2013; Singh *et al.* 2013b; Sarma *et al.* 2014; Singh *et al.* 2014b).

Though the conventional use of the genus has been restricted to seed treatment and soil treatment, numerous opportunities remain to be explored by application of *Trichoderma* on foliar surfaces. Few studies have reported effective control of foliar pathogens by *Trichoderma* species (Freeman *et al.* 2004; Perazzolli *et al.* 2011; Sawant 2014) further strengthening the hypothesis set for the study by using phyllospheric isolated *Trichoderma* strains. The effect of selected strains in enhancing the defense
network of chilli plants against \textit{C. capsici} challenged plant has been studied in the previous chapters. The effect of the strains on the growth and yield parameters of the crop under green house and glasshouse needs to be elaborated.

6.2 Materials and Methods

6.2.1 Experimental design

The pot and field trials were carried out at Department of Mycology and Plant Pathology, Institute of Agricultural Sciences, BHU, Varanasi. Following treatments were studied: \( C = \) Control, \( 1: \) Phyllospheric BCA (BHUF4) treated plants, \( 2: \) Rhizospheric BCA (T16A) treated plants and \( 3: \) BHUF4 + T16A treated plants. The experiment was setup in completely randomized manner.

6.2.2 Inoculum preparation

As detailed in Chapter 5

6.2.3 Green house experiment

Soil mixture containing sandy soil, vermicompost and farmyard manure (2 : 1 : 1) was sterilized in an autoclave at 15 lbs pressure for 30 min for three consecutive days, and 1.5 kg of the mixture was filled in each plastic pot (15X10 cm diameter). Seedling bed of chilli (Var: Surajmukhi) was prepared in green house conditions in sterile soil mixture. Twenty one days old seedlings were transplanted in plastic pots containing sterile soil mixture. The seedlings were left for one week for acclimatization before treating them with the \textit{Trichoderma} strains.
For treatment 1, seedlings were sprayed with spore suspension of *Trichoderma* BHUF4 isolate (isolated from the phyllosphere of chilli plant) till complete drenching of the plant. For treatment 2 spore suspension of *Trichoderma* T16A isolate (obtained from the rhizosphere of chilli plant) was inoculated in the pots. For the third treatment a combination of both 1\textsuperscript{st} and 2\textsuperscript{nd} treatment was performed. Untreated plants served as control (C). For each treatment, five pots were used with each pot containing three plants. The experiment was carried out under controlled conditions with completely randomized design and was carried out twice to cross confirm the results. The samples for recording the plant growth promotion were harvested after 30 days of transplanting. Five plants from each treatment were uprooted and the growth parameters viz. shoot length, root length, no. of leaves, no. of nodes, were recorded. Amount of chlorophyll was also determined by homogenizing leaf tissue in 80\% acetone followed by measuring the absorbance at 663 and 645 nm (Arnon 1949).

### 6.2.4 Field trial

The field study was carried out for two consecutive years during the experimental period from 2012-2013 (Year 1) and 2013-2014 (Year 2) (August-December) at the experimental farm of Institute of Agricultural Sciences, Banaras Hindu University, Varanasi, India. Plots of size 2X2 m\(^2\) were prepared. Three plots were prepared for each treatment. The plots were ploughed and leveled properly and the soil was mixed with the vermicompost at the rate of 10 ton ha\(^{-1}\). Twenty days old seedling of chilli plant (Var: Surajmukhi) were sown in the plots with plant to plant distance of 30 cm and line to line distance of 45 cm. Each plot was transplanted with 24 chilli plants. The BCAs were applied in a similar way as described for greenhouse experiment after every 15, 30, 45
and 60 days after transplanting (DAT) of the seedlings. Samples were harvested after 66 and 150 DAT for accessing the growth parameters. Ten plants were randomly uprooted to calculate the plant height, root length, total biomass (dry weight) with number of flowers and fruits for each treatment. The yield of fruits obtained for each treatment was also calculated after harvesting the fruits from each plot and represented in q/ha. The experimental set up was maintained in completely randomized design.

6.2.5 Statistical analysis

All the experiments were repeated twice unless otherwise stated. The values from different experiments as shown in figures are mean of five replications ± standard deviation (SD). The data was subjected to analysis of variance (ANOVA) using SPSS Ver. 16 (SPSS Inc., Chicago, IL). The treatment mean values were compared with Duncan’s multiple range tests at P≤0.05 significance level. All experiments were repeated once with similar results and the field experiments were carried out in a completely randomized block design. Yield data was pooled from all the harvests for all plots and expressed as q/ha.

6.3 Results

6.3.1 Green house experiment

Application of selected Trichoderma isolates (BHUF4 and T16A) exhibited significant results in promoting plant growth and yield. Treated plants showed enhanced growth when compared to untreated control plants. Maximum shoot length (1.4 fold increase in comparison to untreated control) was recorded in plants treated with dual consortia in which BCAs were applied by foliar spray as well as soil treatment (BHUF4+T16A).
However, the results were at par with the increment recorded in plants treated singly with the *Trichoderma* strains showing 1.32 and 1.34 fold increase obtained on treating the plants with BHUF4 (obtained from phyllosphere) and T16A (obtained from rhizosphere), respectively. Similar trend was recorded when the root length of the plants was measured with maximum increase recorded in BHUF4+T16A treated plants (1.4 fold increase) followed by comparable results exhibited by BHUF4 (1.29 fold increase) and T16A (1.29 fold increase) treated plants separately.

The cumulative effect of increase in root length and shoot length in respect of total plant height was recorded maximum for the plants treated with both the BCAs (1.25 fold increase) while similar increment was recorded for single BCA treated plants (1.22 fold increase) when compared to control plants (Figure 6.1 (A)). In accordance to the results recorded for shoot and root length and the total plant height, the trend in the increase in total biomass of the plants also exhibited similar pattern. The plants treated with both BCAs (BHUF4 +T16A) exhibited maximum root and shoot dry weight showing 1.6 fold increment when compared to control plants while the treatment with single BCA; BHUF4 and T16A, gave 1.5 and 1.4 fold increment, respectively (Figure 6.1B).

When the increase in number of nodes and number of leaves was considered, it was found that application of BHUF4 *Trichoderma* strain gave increased number of both nodes (1.3 fold increase) and leaves (1.6 fold increase) which was at par to the T16A treatment (1.3 fold increase in no. of nodes and 1.4 fold increase in no. of leaves) when compared to the untreated control plants (Figure 6.1A). However, the maximum increment in the number of leaves (1.6 fold increase) was recorded in the plants that were
treated with the combined application of BHUF4 and T16A *Trichoderma* strains as compared to control plants.

Corresponding to the increase obtained in number of leaves for the treated plants, consequent increment was recorded for total chlorophyll content of the leaves along with simultaneous increase in chlorophyll a and b content (chl a and chl b). Chlorophyll a content was found to be maximally increased in plants treated with combined application of BHUF4 and T16A isolates (1.22 fold increase) as compared to control plants. While the total chlorophyll content and chlorophyll b content was recorded to be significantly enhanced in plants treated with single BCA (1.6 and 1.3 fold increase) (Figure 6.1C). Comparable elevation in growth parameters was recorded for plants treated with both the *Trichoderma* strains irrespective of their source of isolation as well as mode of application in comparison to the untreated plants (Figure 6.2).

### 6.3.2 Field Trial

A field trial for two consecutive years was carried out to access the effect of BCAs treatment on the growth and yield parameters of chilli plant. The sampling was carried out at two different time intervals (65 DAT and 150 DAT) in both the years and the selected growth parameters along with yield in terms of total fruits harvested was recorded for all the treatments (Table 6.1 (A), 6.1 (B), 6.2 (A), 6.2 (B) and Figure 6.3).

During year 1 (2012-2013) plants that were treated with combination of the selected *Trichoderma* strains (BHUF4 and T16A) gave augmented growth parameters.
Figure 6.1 Effect of selected *Trichoderma* strains (BHUF4 and T16A) on the growth parameters of chilli plants under green house conditions at 30 DAT when applied either singly or in combination. Results are expressed as mean of five replicates and vertical bars indicate standard deviations of the means. Different letters indicate significant differences among treatment results taken at the same time interval according to Duncan’s multiple range test at $P \leq 0.05$. 

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All the parameters including plant height (1.8 fold), root length (1.4 fold), total biomass (1.8 fold) and number of flowers (1.8 fold) was recorded higher when compared to untreated control plants at 65 DAT. Similar trend was also observed when sampling was carried out at 150 DAT with elevated parameters recorded for dual consortia treated plants showing 1.4 fold increase in plant height, 1.6 fold increase in root length, 1.8 fold increase in total biomass, 1.8 and 2 fold increase in number of branches and fruits, respectively, when compared with the control plants.

**Figure 6.2** Plant growth promotion activity of selected *Trichoderma* isolates BHUF4 and T16A on chilli plants, either singly or in combination C- Control, 1- BHUF4 treated plants, 2-T16A treated plants and 3-BHUF4+T16A treated plants.

Plants treated with BHUF4 strain recorded maximum elevation in comparison to control plants for number of branches, flowers and fruits with fold increase values equivalent to 1.7, 1.8 and 1.8 fold at 65 DAT. At 150 DAT, the number of branches and fruits were recorded to have 1.6, 1.5 and 1.5 fold increase, respectively, for BHUF4
treated plants. BHUF4 treatment was also found equally effective in increasing the plant height (1.5 fold increase), root length (1.3 fold increase) along with increase in the total biomass (1.6 fold increase) in comparison to control plants. The augmentation of plant growth parameters by BHUF4 strain was at par with that obtained by the treatment of T16A strain at both the sampling duration, showing 1.7 fold increment in plant height, 1.4 fold increment in root length and 1.7 fold increment recorded in the total biomass of the treated plants at 65 DAT while 1.2, 1.6 and 1.8 fold increment in plant height, root length and total biomass, respectively, at 150 DAT. The plants showed increased number of branches (1.8 fold), flowers (1.3 fold) and fruits (1.8 fold) at 65 DAT on treatment with T16A isolate in comparison to control plants, which was at par at 150 DAT with fold increment equivalent to 1.5 and 1.2 for number of branches and fruits, respectively.

During 2nd year (2013-2014), the application of both the strains demonstrated significant increase in plant height (2.2 fold increase), root length (1.5 fold increase), total biomass (1.4 fold) along with number of branches, flowers and fruits (2.3 fold, 1.7 fold and 2.3 fold, respectively) at 65 DAT, while 2.3, 1.5, 1.8, 1.7 and 1.8 fold increase in plant height, root length, total biomass, number of branches and fruits at 150 DAT, respectively. Comparable increase of growth parameters were recorded for plants that were treated with single Trichoderma isolate at 65 and 150 DAT.

BHUF4 treatment resulted in 1.7, 1.4, 1.2, 2.25, 1.2 and 1.65 fold increment in plant height, root length, total biomass along with number of branches, flowers and fruits, respectively at 65 DAT, while 1.97, 1.5, 1.7, 1.4 and 1.4 fold increase in height, root length, biomass, number of branches and fruits at 150 DAT.
Table 6.1 Effect of selected *Trichoderma* isolates (BHUF4 and T16A) on growth parameters of chilli plant under field conditions (A) at 65 DAT (Days after transplanting) and (B) 150 DAT during the year 2012-2013

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Plant Height (cm)</th>
<th>Root length (cm)</th>
<th>Total Biomass (g)</th>
<th>No. of branches/plant</th>
<th>No. of flowers/plant</th>
<th>No. of fruits/plant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>$11\pm3.29^a$</td>
<td>$8.67\pm0.57^a$</td>
<td>$6\pm1^a$</td>
<td>$3\pm0.82^a$</td>
<td>$4.6\pm1.35^a$</td>
<td>$5.7\pm1.34^a$</td>
</tr>
<tr>
<td>BHUF4 treated</td>
<td>$16.6\pm3.13^b$</td>
<td>$11.67\pm1.52^b$</td>
<td>$9.33\pm0.58^b$</td>
<td>$5\pm1.76^b$</td>
<td>$8.2\pm3.15^{bc}$</td>
<td>$10.3\pm5.5^b$</td>
</tr>
<tr>
<td>T16A treated</td>
<td>$18.5\pm2.37^b$</td>
<td>$12^b$</td>
<td>$10\pm1^b$</td>
<td>$5.3\pm1.95^b$</td>
<td>$6\pm2.30^b$</td>
<td>$8.9\pm5.06^{ab}$</td>
</tr>
<tr>
<td>BHUF4+T16A treated</td>
<td>$20\pm2.6^b$</td>
<td>$12.33\pm1.53^b$</td>
<td>$10.67\pm0.58^b$</td>
<td>$5.1\pm1.52^b$</td>
<td>$8.5\pm2.91^c$</td>
<td>$10\pm3.68^b$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Plant Height (cm)</th>
<th>Root length (cm)</th>
<th>Total Biomass (g)</th>
<th>No. of branches/plant</th>
<th>No. of fruits/plant</th>
<th>Yield (q/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>$27.4\pm6.65^a$</td>
<td>$12^a$</td>
<td>$11.67\pm0.58^a$</td>
<td>$6.8\pm2.62^a$</td>
<td>$13.7\pm2.75^a$</td>
<td>$77\pm4.58^a$</td>
</tr>
<tr>
<td>BHUF4 treated</td>
<td>$33.75\pm5.16^{ab}$</td>
<td>$17.33\pm1.53^b$</td>
<td>$19\pm2^b$</td>
<td>$10\pm1.41^b$</td>
<td>$21\pm3.27^b$</td>
<td>$99.67\pm1.15^b$</td>
</tr>
<tr>
<td>T16A treated</td>
<td>$33.5\pm6.77^{ab}$</td>
<td>$19\pm2^b$</td>
<td>$19.33\pm1.53^b$</td>
<td>$10.6\pm2.91^b$</td>
<td>$16.9\pm4.97^{ab}$</td>
<td>$100.33\pm2.08^b$</td>
</tr>
<tr>
<td>BHUF4+T16A treated</td>
<td>$38.4\pm8.49^b$</td>
<td>$19\pm1^b$</td>
<td>$21.33\pm1.53^b$</td>
<td>$12\pm2.62^b$</td>
<td>$27.9\pm6.69^c$</td>
<td>$102.67\pm3.21^b$</td>
</tr>
</tbody>
</table>

Results are expressed as mean of five replicates ± standard deviations of the means. Different letters indicate significant differences among treatments results taken at the same time interval according to Duncan’s multiple range test at $P \leq 0.05$. 
Table 6.2 Effect of selected *Trichoderma* isolates (BHUF4 and T16A) on growth parameters of chilli plant under field conditions (A) at 65 DAT (Days after transplanting) and (B) 150 DAT during the year 2013-2014

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Plant Height (cm)</th>
<th>Root length (cm)</th>
<th>Total Biomass (g)</th>
<th>No. of branches/plant</th>
<th>No. of flowers/plant</th>
<th>No. of fruits/plant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>8.8±1.93&lt;sup&gt;a&lt;/sup&gt;</td>
<td>9.33±0.58&lt;sup&gt;a&lt;/sup&gt;</td>
<td>8.72±0.78&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2±1.05&lt;sup&gt;a&lt;/sup&gt;</td>
<td>6.2±1.55&lt;sup&gt;a&lt;/sup&gt;</td>
<td>6.4±1.35&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>BHUF4 treated</td>
<td>15±2.79&lt;sup&gt;b&lt;/sup&gt;</td>
<td>12.68±1.53&lt;sup&gt;b&lt;/sup&gt;</td>
<td>10.4±0.91&lt;sup&gt;b&lt;/sup&gt;</td>
<td>4.5±1.08&lt;sup&gt;b&lt;/sup&gt;</td>
<td>7.5±3.2&lt;sup&gt;a&lt;/sup&gt;</td>
<td>10.6±1.43&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>T16A treated</td>
<td>17.9±2.73&lt;sup&gt;c&lt;/sup&gt;</td>
<td>13.33±2.08&lt;sup&gt;b&lt;/sup&gt;</td>
<td>12.05±1.29&lt;sup&gt;b&lt;/sup&gt;</td>
<td>4.4±1.84&lt;sup&gt;b&lt;/sup&gt;</td>
<td>6.9±2.3&lt;sup&gt;a&lt;/sup&gt;</td>
<td>11.5±1.58&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>BHUF4+T16A treated</td>
<td>19.2±1.99&lt;sup&gt;c&lt;/sup&gt;</td>
<td>14±2&lt;sup&gt;b&lt;/sup&gt;</td>
<td>11.84±0.87&lt;sup&gt;b&lt;/sup&gt;</td>
<td>4.6±0.84&lt;sup&gt;b&lt;/sup&gt;</td>
<td>10.6±2.27&lt;sup&gt;b&lt;/sup&gt;</td>
<td>14.5±2.68&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Plant Height (cm)</th>
<th>Root length (cm)</th>
<th>Total Biomass (g)</th>
<th>No. of branches/plant</th>
<th>No. of fruits/plant</th>
<th>Yield (q/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>15.26±6.03&lt;sup&gt;a&lt;/sup&gt;</td>
<td>12.87±0.27&lt;sup&gt;a&lt;/sup&gt;</td>
<td>12.87±0.27&lt;sup&gt;a&lt;/sup&gt;</td>
<td>6.1±1.45&lt;sup&gt;a&lt;/sup&gt;</td>
<td>16.2±2.8&lt;sup&gt;a&lt;/sup&gt;</td>
<td>76.67±1.53&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>BHUF4 treated</td>
<td>30±6.77&lt;sup&gt;b&lt;/sup&gt;</td>
<td>21.84±1.45&lt;sup&gt;b&lt;/sup&gt;</td>
<td>21.84±1.45&lt;sup&gt;b&lt;/sup&gt;</td>
<td>8.5±2.83&lt;sup&gt;b&lt;/sup&gt;</td>
<td>23±4.7&lt;sup&gt;b&lt;/sup&gt;</td>
<td>104.33±3.51&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>T16A treated</td>
<td>30.5±6.28&lt;sup&gt;b&lt;/sup&gt;</td>
<td>22.4±0.52&lt;sup&gt;b&lt;/sup&gt;</td>
<td>22.44±0.52&lt;sup&gt;b&lt;/sup&gt;</td>
<td>8.8±1.99&lt;sup&gt;b&lt;/sup&gt;</td>
<td>25±4.76&lt;sup&gt;bc&lt;/sup&gt;</td>
<td>105±3&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>BHUF4+T16A treated</td>
<td>35.1±4.51&lt;sup&gt;b&lt;/sup&gt;</td>
<td>23.27±1.22&lt;sup&gt;b&lt;/sup&gt;</td>
<td>23.27±1.12&lt;sup&gt;b&lt;/sup&gt;</td>
<td>10.2±3.6&lt;sup&gt;b&lt;/sup&gt;</td>
<td>28.9±8.14&lt;sup&gt;c&lt;/sup&gt;</td>
<td>107±3.6&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

Results are expressed as mean of five replicates ± standard deviations of the means. Different letters indicate significant differences among treatments results taken at the same time interval according to Duncan’s multiple range test at P ≤ 0.05.
Similarly, T16A treated plants recorded 2 fold increase in plant height, 1.5 fold increase in root length, 1.4 fold increase in total biomass and 2.2, 1.1, 1.8 fold increase in number of branches, flowers and fruits at 65 DAT. At 150 DAT, T16A treated plants exhibited significant increase in plant height (2 fold), root length (1.6 fold), biomass (1.7 fold) with increased number of branches as well as fruits (1.4 fold and 1.5 fold, respectively).

Significant increase in the overall yield was recorded for the *Trichoderma* treated plants with similar increment in yield obtained in all the treatments when compared to untreated control plants during 1st season (Table 6.1 (B)) while in the second season, maximum yield was obtained in plants treated with both the *Trichoderma* isolates (1.4 fold increase) followed by the plants treated singly with T16A (1.37 fold) and BHUF4 (1.36 fold) strains signifying the synergistic action of both the strains in modulating growth parameters of the chilli plant.

![Figure 6.3](image)

*Figure 6.3* The effect of selected *Trichoderma* strains on the growth parameters of chilli plant in field conditions.

### 6.4 Discussion

Microbes live in harmony under natural conditions in the rhizospheric region of the soil. The concept of application of one or more microbes in consortia for providing better
protection along with augmenting the yield and growth has started taking gear as an effective biocontrol strategy. The exudates from the plant roots harbor the beneficial microbes by providing them shelter and nutrition, which in return aids in solubilising the unavailable form of nutrients to the plants and also help to protect them from the unwanted and harmful microbes. This symbiotic relationship of plants and microbes occur naturally and has been well described by various workers (Mariano and Kloepper 2000; Gray and Smith 2005; Figueiredo et al. 2010; Jain et al. 2012; Singh et al. 2013b; Saxena et al. 2013). The beneficial microbes may include bacteria, fungi, actinomycetes or the arbuscular mycorrhizal fungi collectively represented as plant growth promoting bacteria (PGPB), plant growth promoting fungi (PGPF) and AM fungi (Lutenberg and Kamilova 2009; Shoresh et al. 2010). These groups of beneficial microbes are known to produce phytohormones, growth regulators like IAA, gibberellins, cytokinins, auxins, ethylene, siderophores and solubilise phosphate and nitrogen making them available to the plants which aids in its growth and yield (Glick 2012). The selected Trichoderma isolates have been screened for its efficiency in the production of IAA, phosphate solubilisation along with the ability to produce siderophores as described in previous chapter. Their ability to promote plant growth and yield under field and green house conditions could thus be related to one of their indirect mechanisms of plant growth promotion i.e. to increase nutrient solubilisation and nitrogen fixation making it available to the plant (Gupta et al. 2000; Shoresh et al. 2010). The results of the study are in agreement to the findings by Harman et al. (2004) that demonstrated the growth promoting effect of Trichoderma strain T22 on maize seedlings with significant increase in root and shoot length. Also, the beneficial effect of Trichoderma in combination with
other beneficial microbes like *Psuedomonas, Bacillus* and *Rhizobium* on plant health and growth has been elucidated by Jain *et al.* (2012) and Singh *et al.* (2013b) showing noteworthy effect of the treatment on plant growth and yield in comparison to untreated control plants. Similar results were obtained by Saxena *et al.* (2015) where the effect of different species of *Trichoderma*, on growth and tolerance to biotic stress of chickpea plants was demonstrated illustrating the ability of the genus in promoting plant growth irrespective of the species utilized.

The augmented yield of the plants could be attributed to the significant increase in chlorophyll pigments in the leaves, which could be responsible for enhanced photosynthetic activity of the plants and thereby increased metabolism and food assimilation. Also, the increase in number of leaves and branches of treated plants indicate the overall increment in the photosynthetic machinery of the plant thereby enabling them with higher carbon integration. *Trichoderma* treatment has been reported to cause significant increase in chlorophyll pigments in previous studies as well (Mastouri and Harman 2010; Jain *et al.* 2013; Saxena *et al.* 2015) ascertaining the results obtained in this study.

Another mechanism involved in promoting growth in plants by the beneficial microbes is the repression of plant pathogens by production of antibiotics, siderophores or by competition for nutrients. The subsequent ability of BHUF4 and T16A to effectively induce growth parameters of chilli plants can be attributed to their subsequent ability to restrict the growth of the harmful pathogen in the vicinity of the plant, which was evident by the shunted growth in the untreated control plants. Also, the beneficial effect of the synergistic action of application of both the strains BHUF4 and T16A to the
plants could be seen in the study where maximum increase in root and shoot length along with enhanced number of branches, nodes, flowers and fruits was recorded. This result was in accordance to the strategy of utilizing more than one microbe or consortia of microbes for effective growth and plant protection of the host plant (Jetiyanon 2007; Jain et al. 2012; Singh et al. 2013b). Previous studies on chilli has advocated the use of foliar application single BCAs like yeast (Nantawanit et al. 2010), *Trichoderma* spp. (Oanh et al. 2006), *Psuedomonas* spp. (Anand et al. 2009) but fewer studies have been undertaken to study the effect of utilizing more than one BCA on the growth promotion of chilli plant.

Interestingly, plants on treatment with BHUF4 isolate enhanced the root and shoot length along with the number of leaves with a significant increase in the dry weight of the plant. This could be attributed to the well studied systemic effect of *Trichoderma* isolates capable of augmenting plant growth through enhancing nutrient uptake (Harman et al. 2004). This study supports the use of foliar sprays of *Trichoderma* isolates that are both phyllosphere and rhizosphere competent for better plant growth. Moreover, study by Bae et al. (2011) has reported interesting results regarding the efficient colonization of *Trichoderma* isolates obtained from the phyllosphere of chilli plants in the rhizospheric region of chilli plants thereby signifying the equivalent affectivity of the *Trichoderma* strains, irrespective of their source of isolation and also their mode of application. Also, Mukherjee et al. (2014) demonstrated the efficiency of *Trichoderma* isolates obtained from the sources other than the conventional rhizospheric region having substantial affect on the growth of the cotton plants along with efficient protection against the potential pathogen *Sclerotium delphini*. The results of this study highlights the significance of
Trichoderma isolates obtained from the phyllopheric region of healthy chilli leaves for their unexplored potential to promote plant growth and yield in both greenhouse and field conditions.