ISSN: 2278-5213

RESEARCH ARTICLE

Effect of *Kappaphycus alvarezii* SLF treatment on Seed germination, Growth and Development of seedling in some Crop plants

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Abstract

Effect of the Seaweed Liquid Fertilizer (SLF) of *Kappaphycus alvarezii* on the efficacy of germination, growth potential, biochemical changes during seedling growth and yield response in Paddy (*Orysa sativa* L.), *Arachis hypogea* L. (Groundnut) and *Capsicum annum* L. (Chilli) was investigated at different concentrations viz., 1%, 2%, 5% and 10%. The treatment increased plumule and radicle growth markedly in addition to their fresh weight in the seedlings of the plants. Growth of plumule, radicle and fresh weight of the seedlings of Paddy, and Chilli registered a significant increase to an extent of 44%, 63% and 75% and 43.2%, 95% and 64% respectively, in response to 2% *K. alvarezii* SLF treatment. Groundnut recorded an increase of 44.4%, 43.6% and 65% against 1% SLF treatment for the same parameters of growth. The yield of paddy and chilli were significantly increased up to 27% and 23% under glass house condition by 2% SLF supplemented with 100% recommended rate of chemical while groundnut recorded 30.6% increase in yield with 1% SLF supplemented with 100% recommended rate of chemical fertilizer. Biochemical constitutions such as Chlorophyll a and b, protein, carbohydrate and lipid also increased significantly in response to 2% and 1% SLF under glass house condition. The study revealed that the SLF of *K. alvarezii* can be effectively used at low concentrations to promote germination, growth and yield in crop plants.

Keywords: Seaweed liquid fertilizer, germination, growth potential, biochemical changes, paddy, chilli.

Introduction

Agricultural enhancers are defined as biological or non-biological agents which reduce the time of growth and increase the production and/or quality of the agricultural products as well as the time of the flowering and fruition, the fruit size, etc. (Crouch and Van Staden, 1993). Seaweed liquid fertilizer has been shown in the recent past to possess great potential as an organic biostimulant and this potential still remains to be exploited in Indian agriculture. Crop plants are known to respond positively with enhanced growth and yield in response to the application of seaweed extracts as foliar spray, seed treatment with the extract and soil treatment as manure (Aitken and Sen, 1965; Tay *et al.,* 1985, 1987; Jeannin *et al.,* 1991). Seaweed liquid fertilizers are enhancing the growth and yield of certain commercial crops (Sridhar and Rengasamy, 2010; Sangeetha and Thevanathan, 2010). The potential of seaweed liquid fertilizers are reported to be due to nitrogen, phosphorus, potash contents and the presence of trace elements and metabolites, and plant growth regulators (Booth, 1969; Mooney and Van Staden, 1986). Treatment with SLF of many marine algae were found to develop tolerance to environment stress (Zhang *et al.,* 2003) and increase nutrient uptake from soil in crop plants (Verkleij, 1992; Turan and Kose, 2004). The current global scenario firmly emphasizes the need to adopt eco-friendly agricultural practices for sustainable agriculture.

Chemical agriculture has made an adverse impact on the healthcare of not only soil but also the beneficial soil microbial communities and the plants cultivated in these soils. To meet the increasing demand of organic fertilizer many viable options have to be explored (Chhaya, 1997) and one such option is the use of seaweed extracts as fertilizer (Zodape, 2001). Many algal extracts have been tried in the past to find out an effective SLF for use in agriculture. However, the alga *Kappaphycus alvarezii*, which is widely cultivated for its carageenan content has not been tried for this purpose and the present study attempt to evaluate the fertilizer potential of this algal SLF in promoting linear growth and yield of some crop plants, namely the paddy, groundnut and chilli.

Materials and methods

Preparation of different concentrations of SLF: Freshly collected *Kappaphycus alvarezii* thalli were crushed in a French press and the extract obtained was used as 100% SLF. Different concentrations of SLF viz., 1%, 2%, 5% and 10% (V/V) were prepared from the above stock using distilled water and the diluted preparations were used for different experiments.

Experimental plants: Three different agricultural crops namely *Oryza sativa* L. (Paddy), *Arachis hypogea* L. (Groundnut) and *Capsicum annum* L. (Chilli) were used as test plants for the present study.

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Table 1. Application of different concentrations of SLF and chemical fertilizers on test plants.

Treatments	Chemical fertilizer	Farm yard manure (FYM)	Seaweed liquid fertilizer (SLF)
T 1	At normal level	At normal level	1%
T 2	At normal level	At normal level	2%
T 3	At normal level	At normal level	5%
T 4	At normal level	At normal level	10%
T 5	No chemical fertilizer	At normal level	1%
T 6	No chemical fertilizer	At normal level	2%
T 7	No chemical fertilizer	At normal level	5%
T 8	No chemical fertilizer	At normal level	10%
T 9	No chemical fertilizer	At normal level	No SLF
T 10	At normal level	No FYM	No SLF
T 11	At 50 % normal level	At normal level	5%
T 12 (Agricultural control)	At normal level	At normal level	No SLF
T 13	No chemical fertilizer	No FYM	No SLF

*Normal level of farmyard manure is 500 g/pot.

The effect of different concentrations of *K. alvarazii* SLF on the plants was studied with reference to their growth, biochemical characteristics and yield. Certified seeds of the experimental plants were obtained from Tamil Nadu Agro Service Centre, Chengalpattu, Tamil Nadu.

Laboratory studies: Twenty seeds of each plant were surface sterilized with 0.1% mercuric chloride for 1 min and washed thoroughly in sterilized distilled water. They were then soaked in different concentrations of SLF viz., 1%, 2%, 5% and 10% for 6 h, 12 h and 24 h durations separately. The treated seeds of paddy and chilli were placed on sterilized moist handmade filter paper in petriplates and allowed to germinate in the laboratory under 30 µE $m^{-2}s^{-1}$ light intensity, 12 h/12 h light/dark cycle and 24 ± 1°C. Every day, 2 mL of distilled water was added on the filter paper to compensate the loss of water through evaporation. The length of radicle and plumule and fresh weight of germinated paddy seedlings were recorded on 5^{th} d while that of chilli seedlings on 10^{th} d since they showed delayed germination and growth. Surface sterilized groundnut seeds were planted in acid washed, coarse river sand in paper cups (7.5 cm diameter and 9.5 cm height). Each cup contained 300 g of acid washed sand and 5 treated seeds planted 2.0 cm below the surface. The cups were moistened with distilled water and kept under laboratory conditions of light and temperature describe above. Linear growth measurements of the germinated seedlings and their fresh weight were recorded at the end of 7^{th} d.

Glasshouse studies: Experiments similar to that described for laboratory studies were conducted in a glass house under normal light intensity at room temperature (30ºC). However, the seedlings were raised in earthen pots (12' x 12') containing a mixture of river sand, red soil and garden soil at a ratio of 1:1:1, instead of paper cups. Thirteen different treatment schedules were followed for all three test plants (Table 1).

Paddy: Seedlings of rice cv. ADT43 were raised separately in pots containing 6 kg garden soil, 500 g FYM and 3.5 g DAP as base fertilizer. Thirty days old seedlings were then planted in experimental pots. Each experimental pot received 8 seedlings at equal interval and the study period extended up to 120 d. During the experimental period, the developing seedlings received chemical fertilizers as per the normal agricultural practice in the region (Agricultural crops, 2005-2006) (Table 2). Along with fertilizer application, the seedlings received SLF treatments as per the schedule outlined in Table 1. Different concentrations (100 mL) of SLF such as 1%, 2%, 5% and 10% were applied to the respective experimental pots in soil drench and spray treatments. On the day of transplantation, the SLF was applied as soil drench, whereas the SLF was applied as foliar spray on 30^{th}, 50^{th} and 70^{th} d. Thirty days old experimental plants were carefully removed from the pots and the following parameters of growth were recorded viz., height, fresh weight and dry weight of shoot, root and total plant; number of tillers of third young leaf. The third young leaf was analyzed for different biochemical parameters viz., chlorophyll a, chlorophyll b, total chlorophyll, total protein, carbohydrate and lipid content.

Yield: On 90^{th} d after transplantation, the paddy plants were harvested and different biometric parameters such as number of tillers, number of panicles, number of spikelets, grains, filled and unfilled grains, total weight of filled and unfilled grains, total yield and straw weight were determined.

Groundnut: The study was conducted for a period of 105 d. The seeds of groundnut cv. VRI1 were soaked in tap water for 24 h and two seeds were sown just 2 cm below the surface at equal interval in each earthen pots and irrigated daily. Thirteen different treatments were followed as listed in Table 1. Application of chemical fertilizers was made as per the agriculture practice (Table 3).

Table 2. Schedule of chemical fertilizer application on *Oryza sativa.*

Days (After transplantation)	Normal level of chemical fertilizer/pot	Normal level of chemical fertilizer/ha. (recommended by Agricultural Department)
0 d	Urea - 0.25 g Super phosphate - 0.28 g Potash - 0.07 g	Urea - 36 Kg Super phosphate - 40 Kg Potash - 10 Kg
30th d	Urea - 0.25 g Potash - 0.07 g	Urea - 36 Kg Potash - 10 Kg
50th d	Urea - 0.25 g Potash - 0.07 g	Urea - 36 Kg Potash - 10 Kg
70th d	Urea - 0.25 g Potash - 0.07 g	Urea - 36 Kg Potash - 10 Kg

Table 3. Schedule of chemical fertilizer application on *Arachis hypogea.*

Days (After transplantation)	Normal level of chemical fertilizer/pot	Normal level of chemical fertilizer/ha. (recommended by Agricultural Department)
0 d	Urea - 0.12 g Super phosphate - 0.24 g Potash - 0.38 g	Urea – 17 Kg Super phosphate - 34 Kg Potash - 54 Kg
45th d	Calcium phosphate - 1.414 g	Calcium phosphate - 200 kg

Table 4. Schedule of chemical fertilizer application on *Capsicum annum.*

Days (After transplantation)	Normal level of chemical fertilizer/pot	Normal level of chemical fertilizer/ha. (recommended by Agricultural Department)
0 d	Urea - 0.25 g Super phosphate - 0.25 g	Urea - 35 Kg Super phosphate - 35 Kg
30th d	Urea - 0.53 g	Urea - 75 Kg
60th d	Urea - 0.25 g	Urea - 36 Kg
90th d	Urea - 0.25 g	Urea - 36 Kg

Experimental conditions are same as described for paddy except that the foliar application of SLF was done on 30th, 45th and 60th d. Thirty days and 60 d old plants of groundnut were carefully removed from the pots and their height, fresh weight and dry weight of shoot, root and total plant; number of branches and area of third young leaf were recorded. The biochemical parameters of the third young leaf namely, chlorophyll a, chlorophyll b, total chlorophyll, total protein, carbohydrate and lipid content were also determined.

Yield: Pods from 105 d old plants were collected and their fresh weights were recorded as yield.

Chilli: This study was conducted for a period of 120 d. The seeds of chilli (*C. annum*) cv. VRI1 were soaked in tap water for 24 h and sown in earthen pots containing 6 kg garden soil and 500 g FYM and 3.5 g DAP as basal fertilizer. Thirty days old seedlings were uprooted and transplanted into the thirteen different experimental pots (Table 1). Four seedlings were transplanted in each experimental pot and application of chemical fertilizers was made as per the agriculture practice (Table 4). Experimental conditions are same as described for paddy and groundnut except that the foliar application of SLF was made on 30th, 60th and 90th d after transplantation.

Thirty days and 60 d old plants were uprooted and recorded for different parameters of growth namely, height, fresh weight and dry weight of shoot, root and total plant; number of branches and third young leaf area. The biochemical parameters of the third young leaf such as chlorophyll a, chlorophyll b, total chlorophyll, total protein, carbohydrate and lipid content were also recorded.

Yield: Three pickings of ripe fruits were made on 60, 75 and 90 d and their fresh weight was recorded as yield. Five replicates were maintained for all the experiments detailed above. Chlorophyll in the samples was estimated following the procedures of Mackinney (1941). The samples were extracted with known quantities of 80% acetone and the absorbance recorded at 645 and 663 nm in a DU 40 Beckman spectrophotometer. The amounts of chlorophyll a, chlorophyll b and total chlorophyll were calculated using the following formula:

$$\text{Total chlorophyll (mg/g)} = \frac{20.2 \times A645 + 8.02 \times A663}{1000 \times \text{weight of the sample}} \times \text{Volume of extract}$$

$$\text{Chlorophyll a (mg/g)} = \frac{12.7 \times A663 - 2.69 \times A645}{1000 \times \text{weight of the sample}} \times \text{Volume of extract}$$

$$\text{Chlorophyll a (mg/g)} = \frac{12.7 \times A663 - 2.69 \times A645}{1000 \times \text{weight of the sample}} \times \text{Volume of extract}$$

$$\text{Chlorophyll b (mg/g)} = \frac{22.9 \times A645 - 4.68 \times A663}{1000 \times \text{weight of the sample}} \times \text{Volume of extract}$$

Phenol-sulphuric acid method (Dubois *et al.,* 1956) was employed to estimate total carbohydrate levels in the samples. ANALAR grade glucose was used as the standard. Protein was estimated by the method of Bradford (1976) using BSA as the standard. Lipid in the samples were extracted in chloroform: methanol (2:1 v/v) and estimated following the procedures of Folch *et al*. (1956). Cholesterol (SIGMA) was used as the standard.

Results

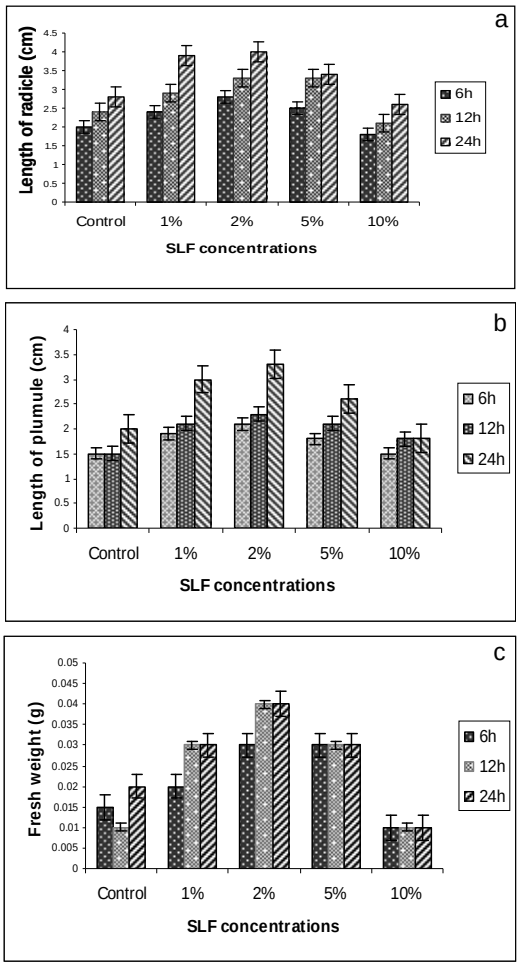
Effect of K. alvarezii SLF on germination and seedling growth-Oryza sativa (Paddy): Treatment with the SLF of *K. alvarezii* improved the efficacy of germination by 20% as compared to the control seeds i.e. water treated and recorded 100% efficacy. The seeds treated with SLF of *K. alvarezii* exhibited enhanced seedling growth which was both dose (1%, 2%, 5% and 10% of SLF) and duration of treatment dependent (6 h, 12 h and 24 h) (Fig. 1a, b and c). Maximum levels of linear growth of both plumule and radicle were noticed in seedlings treated with 2% SLF for 24 h (Fig. 1). The increment in linear growth of plumule and radical was more than 44% and 63%, respectively, when compared to control. Similar treatment with the SLF increased the fresh weight of the seedlings also by 75% (Fig. 1c).

Arachis hypogea (Groundnut): Germination efficacy was 100% in treated seeds. Arachis hypogeal seedlings too exhibited enhanced seedling growth plumule length and radicle length in response to *K. alvarezii* SLF treatment. The response was directly proportional to the dose and duration of treatment viz., 6 h, 12 h and 24 h (Fig. 2a, b and c). The seedlings treated with 1% SLF at 6 h duration exhibited maximum growth where the length of the radicle and plumule recorded an increase of nearly 43.6% and 44.4%, respectively, over control. Similarly, the fresh weight of seedling was 1.3 g as against only 0.79 g in control for this treatment.

Capsicum annum (Chilli): Capsicum annum also recorded similar responses to the treatment of *K. alvarezii* SLF (Fig. 3a, b and c). Germination efficacy of the seeds irrespective of the dose and duration of treatment was 100% as compared to 87% of the untreated seeds. Among the different treatments, seedlings grown at 2% SLF for 6 h duration showed maximum growth (Fig. 3a and b). The length of radicle and plumule increased by 95% and 43.2%, respectively when compared to control. The fresh weight of these seedlings was 0.052 g as against 0.031g in control i.e. which is 67% more than that of the control.

Effect of SLF treatments on the growth of paddy harvested 30 d after transplantation: Paddy treated with 100% recommended dose of chemical fertilizers (CF) and FYM at normal level (T2) and 2% SLF showed maximum plant height of 50.4 cm followed by T1 seedlings (1% SLF+CF+FYM) with 47.5 cm (Table 5).

Fig. 1. Effect of *K. alvarezii* SLF on the seedling growth of *O. sativa.*



The T12 (agricultural control) seedling exhibited 42 cm of linear growth whereas the water control seedlings (T13) were only 23 cm tall i.e. nearly 50% shorter than the T2 and T1 seedlings. Shoot length recorded a maximum of 37.8 cm in T2 plants followed by T1 plants (35 cm). The length of fibrous roots of T2 and T1 plants showed also showed similar responses with values that were 40% more than that of control (T12). The total fresh weight was also maximum in T2 plants (5.8 g/plant) and this was followed by the plants of T1 (5.2 g) and T3 (4.2 g). The T1 and T2 plants showed a maximum of 9 tillers per plant while the control plants (T12) had only 6 tillers. Changes in the levels of total protein, carbohydrates and lipid contents of the paddy plants harvested 30 d after transplantation is shown in Fig. 4, 5 and 6. Effect of the SLF treatment on some of the biochemical parameters of developing paddy plants i.e. 30 d after transplantation is given in Fig. 4. The third young leaves were used in these studies. The treated plants always contained higher levels of total protein, carbohydrate and lipid in these leaves when compared with those of the controls (T12 and T13).

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Fig. 2. Effect of *K. alvarezii* SLF on the seedling growth of *A. hypogea.*

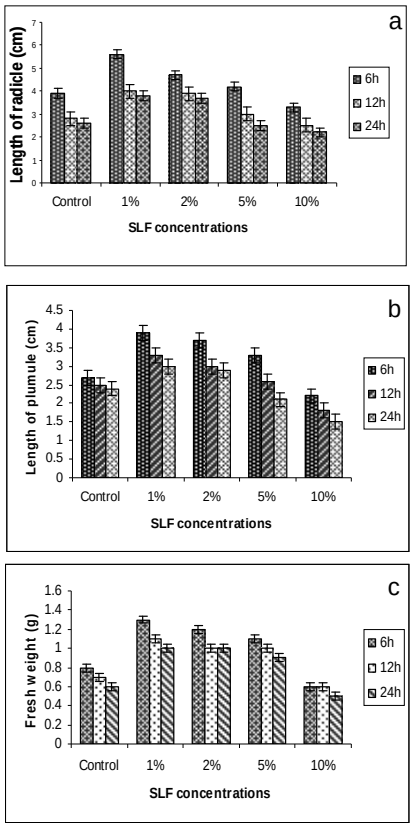


Fig. 3. Effect of *K. alvarezii* SLF on the seedling growth of *C. annum.*

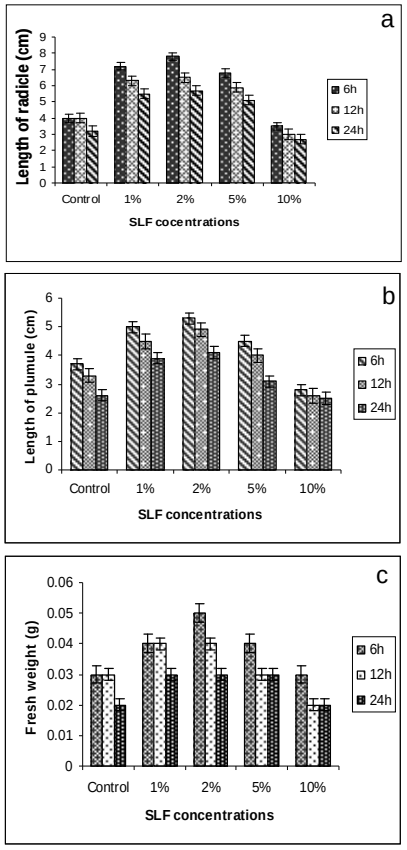


Fig. 4. Effect of *K. alvarezii* SLF on total protein, total carbohydrate and total lipid content of *O. sativa* on 30th d under glass house conditions.

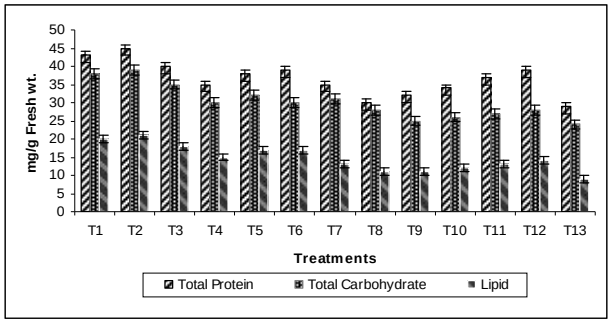


Fig. 5. Effect of *K. alvarezii* SLF on pigments of *O. sativa* on 30th d under glasshouse conditions.

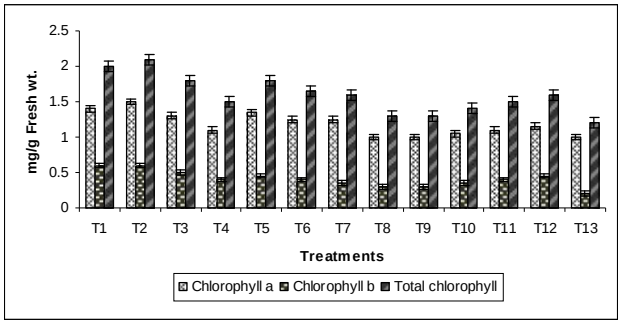
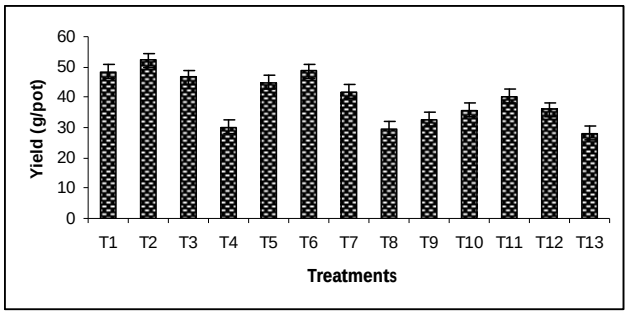


Fig. 6. Effect of *K. alvarezii* SLF on the yield potential of *O. sativa* under glass house conditions on 90th d after transplantation.



Though the treatments with SLF to the plants growing in soil supplemented with FYM (T5, T6, T7 and T8) was able to increase the levels of protein, carbohydrate and lipids in the leaves, treatments with SLF in addition to CF and FYM (T1, T2, T3 and T4) proved to be highly effective and a significant increase could be recorded in the levels of these biochemical parameters. This is accompanied by higher levels of chlorophylls in these plants (Fig. 5). The levels of chlorophyll a, b and total chlorophyll were maximum in T2 plants and their values were 1.5, 0.6 and 2.1 mg/g, respectively. At this age, the leaves of agricultural control (T12) had only1.15, 0.45 and 1.6 mg/g of chlorophyll a, b and total chlorophyll respectively. Different parameters such as number of panicle, number of spikelets, total number of grains, total number of filled and unfilled grains, grain weight and yield were recorded in the paddy plants at 90th d after transplantation (Table 6).

Table 5. Effect of *K. alvarezii* SLF on the growth of *Oryza sativa* under glass house conditions on 30th d after transplantation.

Treatment	Total plant height (cm)	Shoot height (cm)	Root height (cm)	Total fresh weight (g)	Shoot fresh weight (g)	Root fresh weight (g)	Total dry weight (g)	Shoot dry weight (g)	Root dry weight (g)	Number of tillers
T1	47.5±2.04^{ab}	35.0±3.58^{a}	12.5±0.86^{a}	5.2±1.40^{ab}	3.8±0.40^{a}	1.4±0.26^{ab}	0.9±0.42^{abc}	0.7±0.10^{ab}	0.2±0.05^{acdef}	9.0±1.00^{a}
T2	50.4±0.45^{a}	37.8±1.83^{b}	12.6±2.53^{a}	5.8±0.95^{a}	4.0±1.50^{a}	1.8±0.30^{a}	1.2±0.58^{a}	0.8±0.10^{a}	0.4±0.24^{a}	9.0±1.00^{a}
T3	43.0±7.54^{bc}	34.0±2.00^{bc}	9.0±3.60^{bcd}	4.2±0.87^{abc}	2.5±1.15^{b}	1.7±0.61^{a}	0.9±0.41^{ab}	0.6±0.13^{abc}	0.3±0.08^{abc}	7.0±1.00^{b}
T4	26.5±4.37^{fg}	20.0±3.04^{hij}	6.5±0.86^{de}	2.5±1.44^{cde}	1.6±0.36^{bcd}	0.9±0.10^{bcd}	0.7±0.46^{bcd}	0.4±0.10^{de}	0.3±0.10^{bcd}	4.0±1.00^{d}
T5	39.7±5.22^{cd}	29.0±2.17^{de}	10.7±1.54^{abc}	3.5±1.80^{bcd}	2.2±1.71^{bcd}	1.3±0.20^{ab}	0.8±0.05^{abc}	0.4±0.13^{cde}	0.4±0.10^{ab}	5.0±1.00^{cd}
T6	37.0±2.64^{cd}	25.5±2.38^{efg}	11.5±2.72^{ab}	3.5±2.33^{bcd}	2.5±1.92^{b}	1.0±0.44^{bc}	0.8±0.16^{abcd}	0.5±0.13^{bcd}	0.2±0.02^{bcde}	6.0±1.00^{bc}
T7	30.0±4.58^{ef}	22.0±4.58^{ghi}	8.0±0.50^{cd}	3.2±0.82^{cde}	2.3±0.53^{bc}	0.9±0.51^{bcd}	0.6±0.46^{bcd}	0.3±0.10^{efg}	0.3±0.10^{bcd}	5.0±1.00^{cd}
T8	20.5±1.27^{g}	16.5±2.42^{j}	4.0±2.49^{e}	1.5±1.48^{e}	1.2±0.61^{cd}	0.3±0.10^{e}	0.4±0.20^{cd}	0.2±0.10^{fg}	0.2±0.10^{def}	4.0±1.00^{d}
T9	25.3±2.90^{fg}	21.1±1.03^{ghi}	4.2±0.87^{e}	1.8±1.82^{de}	1.4±0.72^{bcd}	0.4±0.20^{de}	0.3±0.17^{d}	0.2±0.10^{fg}	0.1±0.03^{fg}	4.0±1.00^{d}
T10	30.3±3.65^{ef}	23.9±1.21^{fgh}	6.4±2.26^{de}	2.0±0.70^{de}	1.5±1.26^{d}	0.5±0.26^{cde}	0.4±0.17^{cd}	0.3±0.19^{ef}	0.05±0.01^{g}	4.0±1.00^{d}
T11	35.6±2.66^{de}	26.6±2.19^{ef}	9.0±3.22^{bcd}	2.2±0.20^{de}	1.6±1.06^{bcd}	0.6±0.46^{cde}	0.5±0.17^{bcd}	0.4±0.10^{de}	0.1±0.05^{fg}	5.0±1.00^{cd}
T12 (c)	42.0±3.00^{bc}	33.0±3.00^{dc}	9.0±2.98^{bcd}	3.0±0.50^{cde}	2.0±0.24^{bcd}	1.0±0.10^{bc}	0.7±0.40^{bcd}	0.4±0.08^{cd}e	0.2±0.10^{cde}	6.0±1.00^{bc}
T13	23.0±4.52^{g}	18.5±2.88^{ij}	4.5±1.00^{e}	1.6±1.05^{de}	1.2±0.62^{cd}	0.4±0.10^{de}	0.3±0.10^{d}	0.1±0.05^{g}	0.1±0.05^{efg}	4.0±1.00^{d}
CD (0.05)	6.2622	4.5482	3.1848	1.9143	1.1019	0.5444	0.5432	0.1987	0.1429	1.7331

Values are means of triplicates with ± SD. Values in the column with same alphabets are not significantly different as analyzed by ANOVA (5% level; LSD).

Table 6. Effect of *K. alvarezii* SLF on the growth of *Oryza sativa* under glass house conditions on 90th d after transplantation.

Treatment	Number of panicles / tiller	Number of spikelets /tiller	Total number of grains/hill	Number of filled grains/hill	Number of unfilled grains/hill	Filled grains weight (g)/hill	Unfilled grains weight (g)/hill	Total grains weight (g)/hill
T1	13.0±1.00^{a}	83.0±7.21^{b}	1194.0±50.47^{a}	1140.0±102.01^{b}	58.0±6.08^{f}	12.2±0.50^{a}	1.0±0.20^{gh}	13.2±0.34^{a}
T2	14.0±1.00^{a}	96.0±8.00^{a}	1258.0±47.03^{a}	1212.0±48.86^{a}	45.0±5.56^{f}	13.0±1.00^{a}	0.8±0.05^{h}	13.8±0.65^{a}
T3	10.0±1.00^{b}	77.0±12.52^{b}	1054.0±56.00^{b}	974.0±56.66^{c}	68.0±6.08^{f}	8.2±0.75^{c}	1.4±0.20^{fg}	9.6±0.65^{c}
T4	6.0±1.00^{de}	54.0±7.93^{d}	651.0±60.55^{e}	508.0±26.22^{f}	156.0±11.53^{bc}	5.4±0.60^{fg}	2.5±0.50^{ab}	7.9±0.36^{e}
T5	9.0±1.00^{b}	72.6±6.80^{bc}	955.0±57.10^{c}	839.0±15.87^{d}	115.0±18.68^{de}	8.4±0.36^{c}	1.0±0.10^{gh}	9.4±0.20^{cd}
T6	8.6±0.57^{bc}	83.6±3.21^{b}	1028.0±64.21b^{c}	912.0±23.57^{c}	102.0±10.44^{e}	9.3±0.26^{b}	0.9±0.20^{h}	10.2±0.26^{bc}
T7	6.0±1.00^{de}	64.0±3.60^{cd}	754.0±62.26^{d}	626.0±32.51^{e}	128.0±16.09^{d}	6.7±0.43^{e}	1.5±0.10^{ef}	8.0±1.00^{e}
T8	4.6±0.57^{ef}	37.3±6.43^{e}	524.0±26.00^{f}	349.0±30.00^{hi}	175.0±13.22^{b}	4.5±0.50^{g}	2.0±0.20^{cd}	6.5±0.60^{f}
T9	4.3±0.57^{f}	54.3±3.51^{d}	554.0±38.93^{f}	403.0±21.93^{gh}	178.0±23.51^{b}	6.0±0.46^{ef}	2.4±0.40^{abc}	8.4±010de
T10	5.3±0.57^{ef}	59.0±6.56^{d}	667.0±7.93^{e}	460.0±27.22^{fg}	164.0±12.49^{b}	6.2±0.53^{ef}	2.0±0.20^{cd}	8.2±0.55^{e}
T11	7.3±0.57^{cd}	61.6±3.51^{cd}	787.0±50.86^{d}	623.0±25.53^{e}	175.0±9.53^{b}	7.8±0.40^{c}	1.9±0.20^{de}	9.7±1.13^{c}
T12 (c)	8.6±0.57^{bc}	63.3±7.23^{cd}	811.0±19.15^{d}	667.0±31.51^{e}	135.0±10.00^{cd}	8.8±0.44^{bc}	2.1±0.40^{bcd}	10.9±0.87^{b}
T13	5.3±0.57^{ef}	34.0±2.64^{e}	527.0±17.34^{f}	296.0±24.33^{i}	217.0±28.61^{a}	4.6±0.36^{g}	2.8±0.43^{a}	7.4±0.40^{ef}
CD (0.05)	1.3425	11.6260	80.1399	65.6927	25.3599	0.8761	0.4653	1.0562

The T2 paddy plants produced maximum panicles of 14/tiller and T1 had 13/tiller. Similarly, the T2 plants contained maximum number of spikelets per tiller (96/tiller) followed by T1, T3 and T6 plants. Agricultural control (T12) plants had only 63.3 spikelets/tiller and in universal control, it was 34/tiller. Higher number of panicles and spikelets per tiller in T2 and T1 plants resulted in correspondingly high number of filled grains too. The total number of filled grains in T2 plants was 1212 with a total grain weight of 13.8 g/hill and the number of unfilled grains was also very low in these plants (45 unfilled grains/hill). Grain yield in T1 plants was next only to T2 plants and their grain yield was 13.2 g/hill which 26.6% and 21.1% greater than that of T12 control plants (Table 6). Among the experimental paddy plants, the T2 plants recorded maximum yield of 52.3 g/pot followed by 48.4 g/pot in T1 plants compared to T12 control (36.0 g/pot). The increments of the yield recorded at T2 and T1 were 45.3% and 34%, more than the control plants respectively. All the yield related parameters are statistically significant.

Effect of SLF treatments on the growth of groundnut harvested 30 d after transplantation: Thirty days after transplantation, the groundnut plants were analyzed for linear growth and the third young leaves of these plants for their biochemical properties.

The treated plants always exhibited higher growth rate than the agricultural and universal control plants. Maximum plant height of 31.0 cm was recorded in T1 plants followed by T2 (30.5 cm) and the shoot length in these plants were 22 cm and 21.5 cm, respectively (Table 7). The root length also was high in T1 and T2 plants (each 9 cm). The T1 plants registered maximum total fresh weight (12.0 g) and dry weight (2.85 g). High rate of linear growth was accompanied by a corresponding increase in the total number of leaves in T1 (68/plant) and T2 plants (65), which were more than 41.6% and 35.4% to that of agricultural control (T12).

Data presented in Fig. 7 shows the changes in the levels of protein, carbohydrate and lipid content of the third young leaves of groundnut plants in response to SLF treatment. Protein and carbohydrate levels in the leaves showed a positive response to the treatment as compared to control plants while a marginal increase alone could be observed for their lipid content. T1 and T6 plants had maximum level of total protein (36 mg/g). Treatment with 10% SLF of *K. alvarezii* slightly decreased the positive effect of SLF on these biochemical parameters irrespective of the presence of CF and FYM. However, the decrease in the positive effect did not lower the levels of these components below that of the control plants (Fig. 6).

Table 7. Effect of *K. alvarezii* SLF on the growth of *Arachis hypogea* under glass house conditions on 30th d after transplantation.

Treatment	Total plant height (cm)	Shoot Height (cm)	Root height (cm)	Total fresh weight (g)	Shoot fresh weight (g)	Root fresh weight (g)	Total dry weight (g)	Shoot dry weight (g)	Root dry weight (g)	Number of branches	Leaf area (cm^2)	Total number of leaves
T1	31.0±3.46^{a}	22.0±3.60^{a}	9.0±0.50^{a}	12.0±1.73^{a}	11.3±2.13^{a}	0.75±0.10^{a}	2.85±0.42^{a}	2.45±0.20^{a}	0.4±0.10^{a}	17.0±2.64^{a}	10.5±1.32^{a}	68±4.58^{a}
T2	30.5±2.17^{a}	21.5±3.00^{a}	9.0±1.50^{a}	11.5±1.80^{ab}	10.8±1.58^{ab}	0.70±0.10^{ab}	2.8±0.40^{a}	2.4±0.17^{a}	0.4±0.10^{a}	16.0±1.00^{a}	10.4±1.92a	65±6.55a
T3	26.0±2.00^{b}	19.5±1.80^{ab}	6.5±0.62^{b}	10.0±1.83^{b}	9.5±1.32^{b}	0.50±0.18^{cdef}	2.4±0.26^{b}	2.05±0.20^{b}	0.35±0.05^{ab}	11.0±2.00^{b}	7.6±0.72^{b}	55±3.00^{b}
T4	18.5±2.29^{def}	13.5±2.00^{d}	5.0±1.32^{cde}	4.2±1.12^{ef}	3.8±0.96^{ef}	0.40±0.15^{def}	1.2±0.20^{de}	1.02±0.12^{ef}	0.18±0.03^{f}	6.0±1.00^{de}	3.9±0.79^{def}	40±4.00^{ef}
T5	22.0±2.64^{bd}	17.8±2.36^{bc}	4.2±0.52^{defg}	7.0±1.00^{cd}	6.45±0.80^{cd}	0.55±0.15^{bcd}	1.7±0.20^{c}	1.45±0.20^{cd}	0.25±0.05^{cdf}	11.0±1.72^{b}	5.1±1.05^{cd}	49±6.08^{bcd}
T6	23.0±2.64^{b}	18.4±2.94^{ab}	4.6±0.72^{def}	6.9±1.50^{cd}	6.32±1.01^{cd}	0.58±0.04^{abc}	1.8±0.40^{c}	1.56±0.20^{c}	0.24±0.02^{cdf}	11.0±1.00^{b}	4.6±0.75^{cde}	52±4.00^{bc}
T7	20.5±1.32^{de}	16.5±3.04^{bcd}	4.0±0.30^{defg}	5.1±1.65^{de}	4.73±0.63^{de}	0.37±0.02^{efg}	1.5±0.30^{cd}	1.27±0.06^{d}	0.23±0.06^{cdf}	9.0±1.00^{bc}	4.2±0.43^{def}	43±4.35^{de}
T8	16.5±1.32^{ef}	13.7±1.80^{d}	2.8±0.52^{g}	3.2±0.52^{ef}	2.98±0.27^{f}	0.22±0.02^{g}	0.7±0.20^{f}	0.48±0.13^{g}	0.22±0.04^{cdf}	8.0±1.00^{cd}	3.0±0.50^{def}	32±2.00^{gh}
T9	17.0±2.64^{ef}	13.8±1.73^{d}	3.2±0.91^{fg}	3.7±0.26^{ef}	3.35±1.03^{ef}	0.35±0.15^{fg}	1.1±0.20^{e}	0.9±0.05^{f}	0.2±0.02^{df}	7.0±1.00^{cd}	3.9±0.36^{def}	35±3.00^{fg}
T10	18.0±3.00^{def}	14.2±1.70^{cd}	3.8±0.75^{efg}	4.0±1.00^{ef}	3.58±0.80^{ef}	0.42±0.11^{cdef}	1.2±0.30^{de}	0.94±0.12^{f}	0.26±0.04^{cdf}	6.0±1.00^{de}	4.2±1.05^{def}	40±5.00^{ef}
T11	20.0±4.00^{def}	14.6±1.92^{cd}	5.4±0.79^{bcd}	4.5±1.00^{ef}	4.03±0.95^{ef}	0.47±0.08^{cdef}	1.5±0.17^{cd}	1.22±0.12^{de}	0.28±0.04^{bc}	9.0±2.00^{bc}	5.0±1.00^{c}	47±3.00^{bcde}
T12 (c)	24.0±1.00^{b}	17.8±2.36^{bc}	6.2±1.11^{bc}	7.5±0.86^{c}	6.97±1.10^{c}	0.53±0.03^{bcde}	1.7±0.26^{c}	1.41±0.21^{cd}	0.29±0.04^{bcd}	11.0±1.00^{b}	5.9±0.79^{c}	48±3.00^{bcd}
T13	16.0±3.00^{f}	13.1±1.73^{d}	2.9±0.65^{g}	3.0±0.50^{f}	2.79±0.29^{f}	0.21±0.03^{g}	0.6±0.20^{f}	0.42±0.07^{g}	0.18±0.03^{f}	4.0±1.00^{e}	2.7±0.43^{f}	25±2.64^{h}
CD (0.05)	4.2895	3.6653	1.4808	1.9780	1.7319	1.7319	0.3574	0.2493	0.0880	2.4585	1.6668	7.1585

Fig. 7. Effect of *K. alvarezii* SLF on total protein, total carbohydrate and total lipid contents of *A. hypogea* on 30th d under glass house conditions.

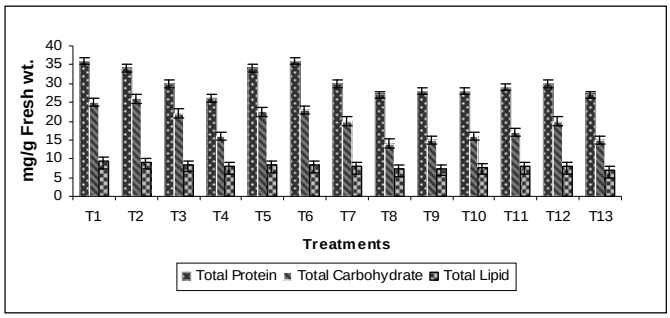


Fig. 8. Effect of *K. alvarezii* SLF on pigments of *A. hypogea* on 30th d under glass house conditions.

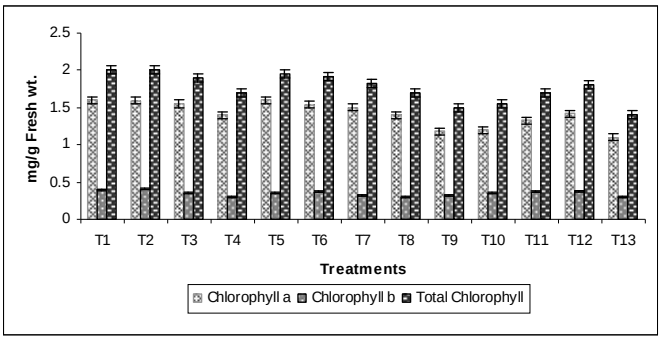
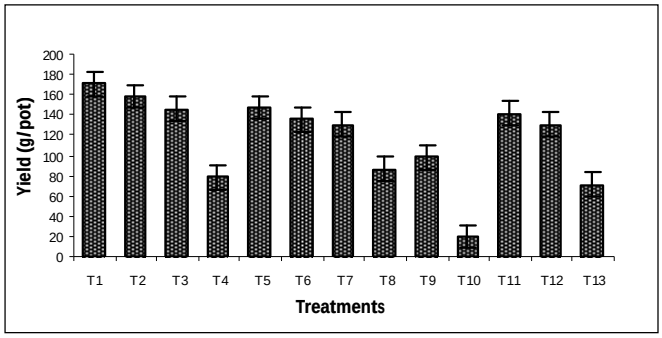


Fig. 9. Effect of *K. alvarezii* SLF on the yield of *A. hypogea* under glass house conditions on 105th d.



The photosynthetic pigments were always high in the SLF treated plants (Fig. 8). Maximum levels of chlorophyll a, b and total chlorophyll were recorded in the leaves of T1 plants with the values of 1.6, 0.4 and 2 mg/g, respectively. A marked increase could be observed in the levels of total chlorophyll and chlorophyll a in the leaves of these plants.

Effect of SLF treatments on the yield of groundnut on 105th d: Among the experimental plants, the T1 plants recorded maximum yield of groundnut of 170.6 g/pot followed by 158.3 g/pot in T2 plants which were more than 30.6% and 21.2% respectively when compared to agricultural control (130.6 g/pot). All the yield related parameters were significantly (one way ANOVA; P=5%) higher in the 1% SLF treated groundnut plants under glass house condition (Fig. 9).

Effect of SLF treatments on the growth of chilli at 30 d after transplantation: Experimental conditions are the same as described for paddy and groundnut. As observed for paddy, the T2 and T1 plants of chilli registered maximum total plant height of 41.8 cm and 42.8 cm, respectively under glass house conditions followed by T3 plants which received 5% SLF treatment along with recommended CF and FYM dosage (37.5 cm). The dry weights of shoot and roots were maximum in T2 and plants (2.6 g and 0.6 g) followed by T1 plants (2.5 g and 0.4 g). The number of branches in T2 (14/plant) and T1plants (13/plant) were 55.5% and 44.4% more than that recorded in agricultural control plants (T12), respectively. The leaf area of T2 plants also was larger than the other experimental plants and control. The leaves of T2 plants had and laminar area of 8.1 cm^2 whereas in agricultural control it was only 6.2 cm^2. The one way ANOVA (P=5%; LSD) revealed that all the growth parameters were significantly higher in the 2% SLF treated chilli plants under glass house condition (Table 8).

Table 8. Effect of *K. alvarezii* SLF on the growth of *Capsicum annum* under glass house conditions on 30th d after transplantation.

Treatment	Total plant height (cm)	Shoot height (cm)	Root height (cm)	Total fresh weight (g)	Shoot fresh weight (g)	Root fresh weight (g)	Total dry weight (g)	Shoot dry weight (g)	Root dry weight (g)	Number of branches	Leaf area (cm^2)	Total number of leaves
T1	41.8±1.40^{a}	32.5±1.56^{ab}	9.3±1.80^{a}	17.0±1.00^{ab}	14.8±0.80^{a}	2.2±0.26^{ab}	2.9±0.26^{ab}	2.5±0.10^{a}	0.4±0.08^{b}	13.0±2.00^{ab}	7.2±0.40^{b}	45.0±4.35^{ab}
T2	42.8±3.46^{a}	35.0±2.00^{a}	7.8±1.47^{ab}	18.5±1.00^{a}	15.9±0.78^{a}	2.6±0.52^{a}	3.2±0.26^{a}	2.6±0.43^{a}	0.6±0.10^{a}	14.0±2.00^{a}	8.1±0.70^{a}	46.0±4.00^{a}
T3	37.5±1.00^{b}	30.5±1.80^{bc}	7.0±1.50^{bc}	15.0±1.00^{bc}	13.0±0.50^{b}	2.0±0.20^{bc}	2.5±0.45^{bc}	2.2±0.20^{ab}	0.3±0.04^{c}	12.0±2.64^{abc}	7.2±0.36^{b}	41.0±5.00^{abc}
T4	26.5±4.58^{ef}	24.0±3.00^{e}	2.5±0.50^{g}	9.0±1.32^{e}	8.0±0.50^{d}	1.0±0.30^{de}	1.8±0.10^{e}	1.6±0.17^{c}	0.2±0.02^{d}	7.0±1.73^{defg}	4.1±0.45^{f}	30.0±5.56^{efg}
T5	32.0±2.00^{cd}	25.0±2.00^{e}	7.0±1.00^{bc}	12.0±1.80^{d}	10.7±0.40^{c}	1.3±0.30^{de}	2.1±0.17^{cde}	1.8±0.10^{bc}	0.3±0.05^{c}	9.0±2.00^{cde}	5.2±0.36^{e}	32.0±5.29^{ef}
T6	33.5±3.00^{c}	27.0±2.00^{de}	6.5±1.00^{bcd}	13.0±1.73^{cd}	11.6±0.60^{c}	1.4±0.50^{d}	2.3±0.36^{cd}	2.0±0.36^{bc}	0.3±0.05^{c}	10.0±1.73^{bcd}	5.3±0.45^{e}	38.0±6.24^{bc}
T7	28.6±4.00^{de}	24.0±2.00^{e}	4.6±0.40^{ef}	11.5±1.00^{d}	10.3±1.17^{c}	1.2±0.26^{de}	2.0±0.17^{de}	1.8±0.26^{c}	0.3±0.02^{cd}	8.0±1.73^{def}	4.5±0.34^{f}	30.0±4.35^{efg}
T8	21.0±1.73^{gh}	18.0±1.73^{g}	3.0±0.50^{fg}	7.0±0.50^{ef}	6.2±0.40^{e}	0.8±0.20^{e}	0.8±0.20^{f}	0.7±0.10^{d}	0.1±0.02^{e}	6.0±2.00^{efg}	3.2±0.20^{g}	24.0±3.46^{g}
T9	23.1±2.50^{fg}	19.0±2.00^{f}	4.1±0.60^{efg}	7.5±1.00^{ef}	6.5±0.50^{e}	1.0±0.30^{de}	1.2±0.17^{f}	1.1±0.20^{d}	0.1±0.02^{e}	5.0±1.73^{fg}	4.0±0.34^{df}	29.0±2.64^{efg}
T10	33.5±3.00^{c}	28.5±2.29^{cd}	5.0±1.32^{de}	11.5±1.00^{d}	10.3±0.30^{c}	1.2±0.20^{de}	2.0±0.43^{de}	1.8±0.30^{c}	0.3±0.05^{cd}	5.0±1.73^{fg}	5.5±0.34^{de}	30.0±2.64^{efg}
T11	34.5±2.00^{bc}	29.0±2.29^{cd}	5.5±1.00^{cde}	12.5±1.00^{d}	11.0±1.73^{c}	1.5±0.20^{cd}	2.0±0.30^{de}	1.7±0.34^{c}	0.3±0.05^{c}	7.0±1.00^{defg}	6.0±0.10^{c}	35.0±4.35^{ce}
T12 (c)	33.5±1.73^{c}	27.0±2.00^{de}	6.5±1.00^{bcd}	12.0±1.00^{d}	10.6±1.00^{c}	1.4±0.36^{d}	2.2±0.10^{cde}	1.9±0.26^{bc}	0.3±0.04^{c}	9.0±2.00^{cde}	6.2±0.34^{c}	36.0±3.46^{ce}
T13	19.0±1.00^{h}	15.0±1.80^{g}	4.0±1.00^{efg}	6.5±1.00^{f}	5.7±0.60^{e}	0.8±0.20^{e}	1.2±0.26^{f}	1.1±0.17^{d}	0.1±0.02^{e}	4.0±1.00^{g}	3.0±0.17^{g}	25.0±3.60^{fg}
CD (0.05)	3.5921	3.3509	1.7743	2.0058	1.3984	0.5272	0.4757	0.4309	0.0791	3.2240	0.5803	7.6204

Fig. 10. Effect of *K. alvarezii* SLF on total protein, total carbohydrate and total lipid contents of *C. annum* on 30th d under glass house conditions.

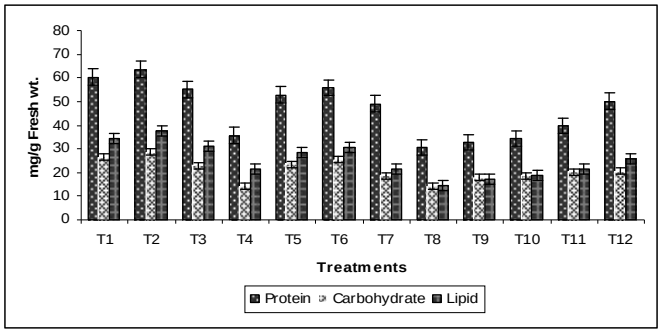


Fig. 11. Effect of *K. alvarezii* SLF on pigments of *C. annum* on 30th d under glass house conditions.

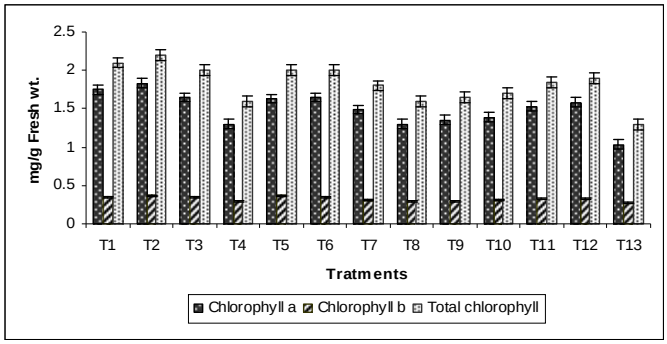
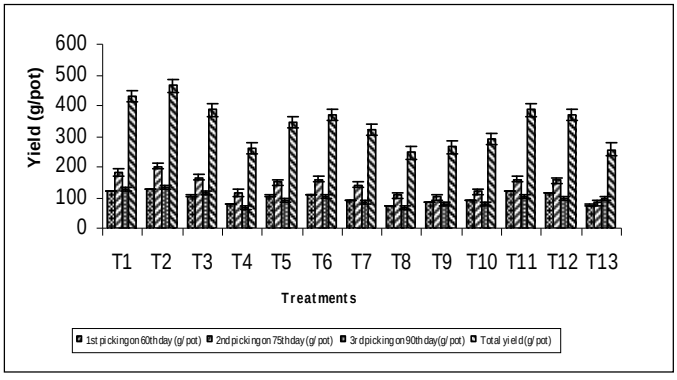


Fig. 12. Effect of *K. alvarezii* SLF on the yield of *C. annum* under glass house conditions at different periods.



Effect of SLF treatments on the biochemical parameters of chilli: The T2 experimental plants has maximum protein content (70.3 mg/g), followed by T1 plants (65.7 mg/g). The values in these two experimental sets were 15.24% and 7.7% more than that of control plants respectively (T12) (Fig. 10). In T13 plants (universal control), the protein content was only 32.6 mg/g. Total carbohydrate levels also showed a similar trend with a total carbohydrate of 30.7 mg/g in T2 plants followed by T1 plants (28.5 mg/g) when compared to 23.7 mg/g in agricultural control (T12). Similarly, the levels of chlorophyll a, b and total chlorophyll were at their maximum in T2 plants with 1.83, 0.37 and 2.2 mg/g respectively while the agricultural control plants (T12) had 1.68, 0.32 and 1.9 mg/g of chlorophyll a, b and total chlorophyll (Fig. 11).

Effect of SLF treatments on the yield of chilli at different periods (60, 75 and 90 d after transplantation): Chillies are normally harvested 3 times and hence, the experimental set up in our studies also was designed for three harvests on 60th, 75th and 90th d after transplantation to determine the yield. As observed for linear growth, it was the T2 plants that recorded maximum total yield (sum of the yield in 1st, 2nd and 3rd picking) of 464.9 g/pot followed by T1 plants of 429.4 g/pot (Fig. 12). The yield in agricultural control (T12) was only 368.2 g/pot which are nearly 23% and 15% less than the T2 and T1 plants. All the yield related parameters are statistically significant.

Discussion

The results presented in this study clearly shows the efficacy of the SLF preparation from *Kappaphycus alvarezii* in promoting seed germination, linear growth, biochemical components, pigment composition and yield in the commercial crops namely, paddy, groundnut and chilli.

Linear growth of seedlings, increased leaf area accompanied by enhanced quantities of pigments and protein content could be normally expected to increase the yield potential of a crop. Our studies also recorded higher yield in the experimental crop plants, especially when treated with low concentrations of the SLF of *K. alvarezii*. Seaweed extracts have always been shown to promote germination efficacy and linear growth in many earlier studies (Booth, 1965, 1969; Blunden and Woods, 1969; Bhosle *et al.,* 1975; Bukhari and Untawale, 1978; Dhargalkar and Untawale, 1980; Sridhar and Rengasamy, 2002). Booth (1965, 1969) reported the seaweed products to enhance the germination rate of seeds, increase the uptake of plant nutrients, impart a high degree of frost resistance and confer resistance against pathological fungi and insect pests. Extracts obtained from *Spatoglossum asperum, Ulva lactuca* and *Enteromorpha intestinalis* has been shown to enhance efficacy of seed germination and growth of the seedlings of black gram, groundnut and maize (Bukhari and Untawale, 1978). Dilute seaweed extracts were more effective in these experiments than the concentrated extracts (Bukhari and Untawale, 1978). Bhosle *et al.* (1975) studied the effect of low concentration of the extracts of *Padina tetrastromatica* and *Sargassum tenerrimum* on the growth of *Phaseouls vulgaris* under laboratory conditions and observed that at 10% concentration, the extracts promoted growth. Further, the extract of *P. tetrastromatica* was found to induce good response over that of *S. tenerrimum*. The effects of SLFs of *Hypnea musciformis*, *Spatoglossum asperum, Stoechospermum marginatum* and *Sargassum* sp. were studied on different crops like green chillies, turnips and pineapple (Dhargalkar and Untawale, 1980). They concluded that the substances present in the SLFs promoted the growth of crops and the yield of fruits.

Commercial seaweed extracts such as Kelpak and ashed Kelpak are known to significantly increase the root mass and leaf surface area of the wheat seedlings irrespective of K supply. However, the Kelpak treatment did not show any effect on the roots of plants receiving an adequate K supply (Beckett and Van Staden, 1989). Certain sugars present in the seaweed extract have been suggested to provide additional energy source for increased plant growth (Blunden and Woods, 1969). Increased seedling growth has also been related to the presence of Phenyl Acetic Acid (PAA) and other closely related compounds (P_CH_PAA) in the SLF (Taylor and Wilkinson, 1997). Seaweeds are known to contain appreciable quantities of plant growth regulators (Mooney and Van Staden, 1985), Cytokinin (Smith and Vanstaden, 1984), IAA (Abe, *et al.,* 1972), gibberllins and gibberllin like substance (Radley, 1961; Sekar *et al.,* 1995). Sridhar and Rengasamy (2002) have suggested that the growth promoting activity of seaweed extracts was due to the presence of macro and micro-elements as well as plant growth promoters (PGRs) like cytokinin (Sridhar and Rengasamy, 2002).

Conclusion

The promotion of germination, linear growth and yield by the SLF of *K. alvarezii* in the experimental plants as observed in our studies can also be attributed to the possible presence of PGRs and essential minerals in the SLF.

Acknowledgements

We submit our gratitude to M/s Pepsico India Holdings Ltd. and Abiram Seth of Aquagri Pvt. Ltd. for providing project and financial support. We are also grateful to Prof. R. Thevanathan, Presidency College, Chennai for his encouragement and moral support.

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