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Effect of weed management strategies on weed dynamics and yield of kharif brinjal (*Solanum melongena* L.)

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Abstract

Weed infestation is a major constraint in brinjal production, competing with crop plants for essential resources such as nutrients, moisture, light and space. In brinjal cultivation, a critical crop-weed competition period can cause substantial yield reduction of up to 49–90 %. The diverse weed flora, comprising grasses, sedges and broad-leaved weeds, makes control difficult. A field experiment was conducted at Post Graduate Research Farm, M. S. Swaminathan School of Agriculture (MSSSoA), Centurion University of Technology and Management (CUTM), Paralakhemundi, Odisha during kharif season of 2025 to assess the effectiveness of different weed management strategies including cultural, mechanical and chemical methods on weed dynamics, crop growth and yield performance in brinjal. The study was laid out in a randomised block design (RBD) with recommended agronomic practices. Observations were recorded on crop growth parameters and yield attributes along with weed density, weed dry weight, weed index (WI) and weed control efficiency. The results indicated that the weed-free plot along with all soil solarisation-treated plots performed better in crop growth and gave a good yield as well as significantly controlled the weeds. The highest yield was recorded in the weed-free plot i.e., 24.7 tonne (t) ha^{-1}, followed by the [soil solarisation + 1 hand weeding at 30 days after transplanting (DAT)] plot (22.4 t ha^{-1}) and the lowest yield was recorded in the weedy check plot i.e., 2.4 t ha^{-1}, where weed infestation was more at 30 and 60 DAT. Principal component analysis (PCA) revealed that the first principal component accounted for 92.08 % of the total variance (eigenvalue >1), justifying trait selection across two distinct clusters. Combined correlation demonstrated a significant impact of weed density of grasses and sedges on vegetative and yield-associated traits 60 DAT, highlighting the critical weed competition period. Economic study revealed that soil solarisation followed by one hand weeding at 30 DAT resulted in lower weed density and biomass and was found to be effective for weed control in brinjal, resulting in a higher fruit yield and the maximum benefit-cost ratio (2.4 : 1).

Keywords: benefit cost ratio; brinjal; correlation; kharif season; soil solarisation; weed density; weed control

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1. Introduction

Brinjal (*Solanum melongena* L.), belonging to the family Solanaceae, is an important commercial vegetable widely cultivated in India, including Odisha. It is a good source of folic acid, vitamin A, C and B-complex and also rich in minerals like phosphorus (P), sulphur (S), calcium (Ca), magnesium (Mg), potassium (K) and iron (Fe) (1). Globally, brinjal production is estimated at about 60–61 million tons and India is the second largest producer of brinjal after China, contributing 21 % of global production. The area under brinjal cultivation in India is 683.1 thousand hectares with a production of 12.9 million tonnes (t) and productivity of 19 million t ha^{-1}. In Odisha, brinjal is cultivated over 130.58 thousand ha with production and productivity of 2.2 million t and 16.83 million t ha^{-1} respectively (2). The low productivity in Odisha is mainly attributed to poor varietal selection, low soil fertility, climatic stress, improper nutrient and weed management and severe pest and disease infestations-among which weeds pose a critical challenge. Due to the wider spacing of the crop, frequent irrigation and extensive use of farmyard manure and fertilisers, weeds proliferate rapidly and compete for nutrition, moisture and light with crops and also act as an alternate host for

various insect pests and disease organisms, causing yield reductions of up to 49–90 % (3), which is higher than losses caused by insect pests (30 %) and diseases (20 %) (4). It is difficult to control the weeds manually, especially in the peak season due to labour shortage and high weed infestation in kharif season. There is limited scientific information on the effectiveness of integrated weed management in kharif brinjal. Hand weeding followed by chemical control will be more efficient to achieve season-long weed control and to attain maximum productivity (3). Mulching facilitates effective weed control (5) and promotes crop growth by conserving moisture, providing nutrients to plants and reducing soil erosion (6). Soil solarisation with transparent polyethylene film also suppresses early-stage weed growth by allowing light penetration. There are several methods to control weeds; however, none is completely effective in achieving full suppression of weeds in kharif brinjal. In brinjal cultivation, different weed control measures vary in their input costs and labour requirements, which directly influence the net return and benefit-cost ratio. In this context, net return and benefit-cost ratio play a crucial role in determining the feasibility and adoption of different weed management strategies. Weed causes substantial yield losses in brinjal in kharif season as the crop faces higher crop-weed competition during the entire crop cycle. Scanty information is available to tackle the weed menace in kharif season in brinjal. Keeping these factors in view, the present study was undertaken to identify the most effective weed control strategy for kharif brinjal in the southern Odisha region, providing actionable insights for local farmers.

2. Materials and Methods

The field experiment was conducted at Post Graduate Research Farm, M S Swaminathan School of Agriculture (MSSSoA), Centurion University of Technology and Management (CUTM), Paralakhemundi during kharif, 2025. This location is situated at 18.80° N latitude, 84.20° E longitude and at an altitude of 145 m above mean sea level under the sub-humid and sub-tropical climatic conditions of the North-Eastern Ghats of Odisha state, India. It receives an average annual rainfall of 1423.5 mm. The agro-meteorological data including average maximum and minimum temperatures, relative humidity, rainfall, evapotranspiration, sunshine hours and wind speed measured during the course of the experimental period at the PG Research Farm are presented in Fig. 1. The texture of the soil is sandy loam with slightly acidic pH. The experiment was laid out in a randomised block design (RBD) with 3 replications and 16 treatments. The treatments included in the experiment were T_1 [soil solarisation], T_2 [soil solarisation + rice straw mulch at 5t ha^{-1}], T_3 [soil solarisation + 1 hand weeding at 30 days after transplanting (DAT)], T_4 [soil solarisation + metribuzin at 0.525 kg ha^{-1} post-emergence (PoE) at 30 DAT], T_5 [rice straw mulch at 5t ha^{-1}], T_6 [rice straw mulch at 5t ha^{-1} + 1 hand weeding at 30 DAT], T_7 [rice straw mulch at 5 t ha^{-1} + metribuzin at 0.525 kg ha^{-1} PoE], T_8 [oxyfluorfen at 0.15 kg ha^{-1} pre-emergence (PE)], T_9 [oxyfluorfen at 0.15 kg ha^{-1} PE + 1 hand weeding at 30 DAT], T_{10} [oxyfluorfen at 0.15 kg ha^{-1} PE + metribuzin at 0.525 kg ha^{-1} PoE at 30 DAT], T_{11} [metribuzin at 0.525 kg ha^{-1} PoE at 30 DAT], T_{12} [brinjal + cowpea], T_{13} [brinjal + cowpea + rice straw mulch at 5 t ha^{-1}], T_{14} [hand weeding at 30 and 60 DAT (farmer's practice)], T_{15} [weed-free], T_{16} [weedy]. Soil solarisation was given with transparent polythene (150 gauge) 45 days before transplanting. Thirty-day-old healthy seedlings were transplanted with a spacing of 75 (row to row) × 60 cm (plant to plant) in a plot size of 17.64 m^2 (4.9 × 3.6 m). The brinjal variety 'VNR-212' is a high-yielding variety used in the experiment. Fertilisers were applied at the recommended dose (100 : 60 : 50 kg nitrogen, phosphorus and potassium (NPK) ha^{-1}) in the form of urea, single super phosphate (SSP) and muriate of potash (MOP). Observations on crop growth and yield parameters such as plant height, number of branches per plant, plant fresh weight, plant dry weight, number of fruits per plant, fruit weight, fruit yield per plant, total yield, economic yield, biological yield and harvest index were recorded. Weed parameters including weed density, weed dry weight and weed control efficiency were also recorded at different stages of crop growth. The recorded data were statistically analysed using analysis of variance (ANOVA) in R-based Agricultural Information System for Indian Agriculture (RAISIN) software appropriate for a RBD (7). Multivariate analysis and combined correlation were performed using online software such as KAU General R Analysis Platform for Educational Services (KAUGRAPES) (8) and RStudio version 4.5.1 respectively. The data on weed density and biomass were subjected to square root transformation (image before analysis).

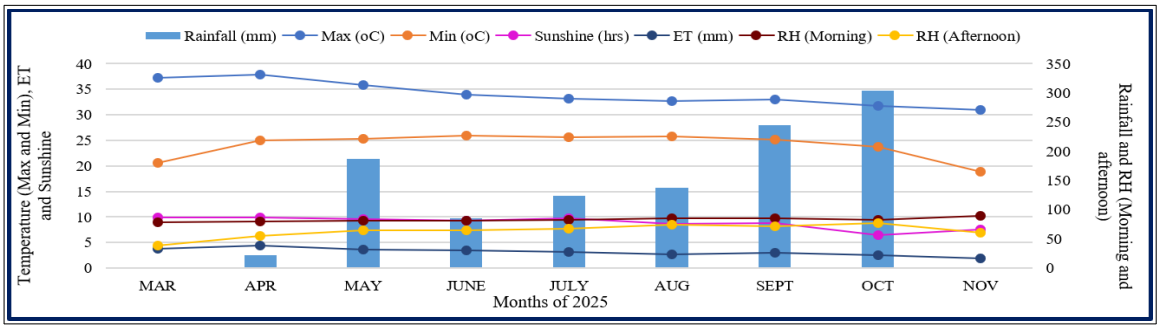


Fig. 1. Monthly average meteorological data recorded during cropping period (March to November 2025).

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Weed flora

The experimental field was infested with two species of grassy and sedge weeds and 10 species of broadleaved weeds. Grassy weeds are *Dactyloctenium aegyptium* (L.) Willd*, Echinochloa colona* (L.) Link and sedge weeds are *Cyperus rotundus* L., *Cyperus iria* L. and broad-leaved weeds were *Oldenlandia corymbose* L., *Ludwigia decurrens* Walter and *Digera muricata* (L) Mart., which are the major ones. Other broadleaved weeds were *Phyllanthus urinaria* L.*, Atriplex patula L.*, *Euphorbia hirta* L.*, Solanum nigrum L.*, *Cleome viscosa* L. and *Corchorus aestuans L.*. also found the weed species *Cynodon dactylon* (L.) Pers., *Elusine indica* (L.) Gaertn., *C. rotundus*, *Phyllanthus niruri* L., *Trianthema portulacatum* L., *Parthenium hysterophorus* L., *E. hirta*, *Amaranthus virid* L. and *Convolvulus arvensis* L. (Fig. 2) (9).

3. Results and Discussion

Effect on crop

In brinjal, parameters like plant height, total number of branches per plant, fruit length, fruit diameter, number of fruits per plant and yield were significantly influenced by different weed management treatments.

Plant height (cm)

Plant height is an important parameter in plant growth. Plant height is recorded at the final harvesting stage. The maximum plant height (107.4 cm) was recorded in T_3 [soil solarisation + 1 hand weeding at 30 DAT], which was on par with T_{15} [weed-free] i.e., 105.0 cm (Table 1). This can be attributed to less crop-weed competition, increased soil temperature (in the solarisation plot) and weed-free condition. The weedy plot (T_{16}) recorded the lowest plant height of 50.7 cm due to more weed infestation and was statistically on par with T_5, T_8, T_{10}, T_{11}, T_{12} and T_{13} (Table 2). These findings are corroborated by previous reserachers, who reported maximum plant height in a soil solarisation-treated plot (10).

Number of branches

The data for the number of branches per plant were also recorded at the harvesting stage and found to be significantly impacted by different weed management practices. The maximum number of branches per plant (12.8) was recorded in T_{15} [weed-free] and the lowest (4.3) in the T_{16} [weedy] plot (Table 2). T_{15} is significantly different from other treatments and on par with T_1, T_2, T_3, T_4, T_6 and T_{14}. The increase in the number of branches in the weed-free plot is attributed to a decrease in weed population, who reported the highest number of branches in a black-mulch-treated plot followed by a weed-free plot (11). According to the authors, it was most probably due to less crop-weed competition, which encouraged plant growth in terms of height and number of branches.

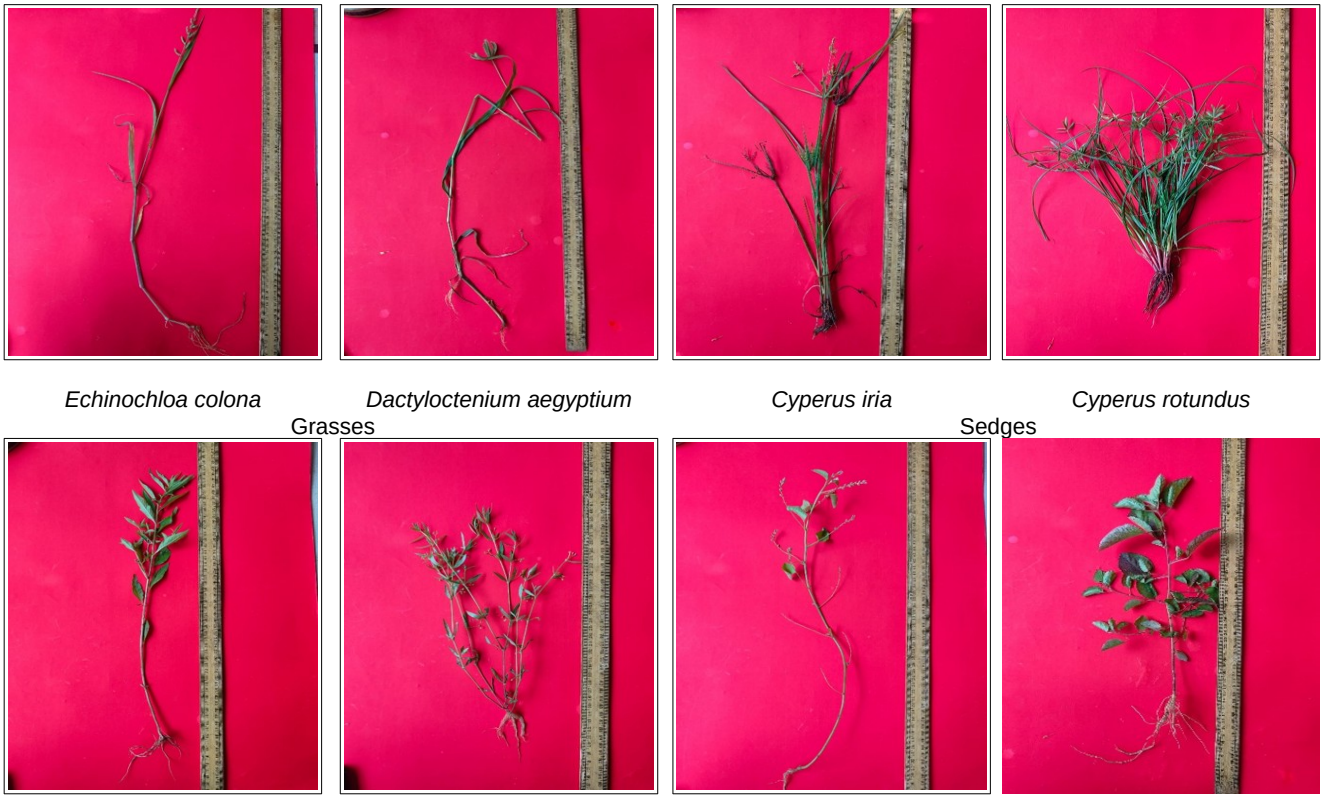


Fig. 2. Major weed flora.

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Table 1. ANOVA with treatment and error mean square

SoV	DF	PH120	NOB120	TPFW120	TPDW120	FL	FD	NFP	FYP	TY	EY	BY	HI
Treatment	15	1174.26**	18.19**	449.33*	26.67**	4.91**	0.94**	23.65**	0.42**	180.57**	2176.79**	2660.63**	588.62**
Block	2	10.63^{NS}	0.22^{NS}	125.42^{NS}	8.25^{NS}	0.08^{NS}	0.63^{NS}	0.14^{NS}	0.01^{NS}	2.13^{NS}	2.7^{NS}	0.21^{NS}	1.96^{NS}
Error	30	46.37	0.41	222.53	6.66	1.15	0.24	0.55	0.00	1.90	4.22	7.73	2.68
SoV	**DF**	**G30**	**G60**	**GDW30**	**GDW60**	**S30**	**S60**	**SDW30**	**SDW60**	**BL30**	**BL60**	**BLDW30**	**BLDW60**
Treatment	15	12.08**	11.3**	5.3**	5.64**	0.65**	1.45**	0.38**	1.11**	1.1**	3.12**	0.71**	1.43**
Block	2	0.19^{NS}	0.33^{NS}	0.07^{NS}	0.11^{NS}	0.07^{NS}	0.09^{NS}	0.02^{NS}	0.01^{NS}	0.03^{NS}	0.09^{NS}	0.07^{NS}	0.05^{NS}
Error	30	0.17	0.19	0.08	0.08	0.04	0.06	0.01	0.03	0.06	0.05	0.03	0.03

SoV: source of variation; DF: degree of freedom; Mean squares are provided for each character; *: significance at 5% level; **: significance at 1 % level; PH120: plant height at 120 days after transplanting; NOB120: number of branches at 120 days after transplanting; TPFW120: total plant fresh weight at 120 days after transplanting; TPDW120: total plant dry weight at 120 days after transplanting; FL: fruit length; FD: fruit diameter; NFP: number of fruits per plant; FYP: fruit yield per plant; TY: total yield; EY: economic yield; BY: biological yield; HI: harvest index; G30: grass at 30 days after transplanting; G60: grass at 60 days after transplanting; GDW30: grass dry weight at 30 days after transplanting; GDW60: grass dry weight at 60 days after transplanting; S30: sedges at 30 days after transplanting; S60: sedges at 60 days after transplanting; SDW30: sedges dry weight at 30 days after transplanting; SDW60: sedges dry weight at 60 days after transplanting; BL30: broadleaved weed at 30 days after transplanting; BL60: broadleaved weed at 60 days after transplanting; BLDW30: broadleaved weed dry weight at 30 days after transplanting; BLDW60: broadleaved weed dry weight at 60 days after transplanting.

Table 2. Effect of different weed management practices on crop growth, yield and yield attributing traits in brinjal (at harvest)

Treatment	PH120	NOB120	TPFW120	TPDW120	FL	FD	NFP	FYP	TY	EY	BY	HI
T_1	90.56± 10.05^{cde}	9.49± 1.21^{cd}	243.30± 22.07^{abcd}	27.60± 3.46^{abcde}	15.29± 0.97^{abcde}	6.04± 0.80^{abc}	11.37± 0.52^{bc}	0.87± 0.10^{c}	19.72± 2.94^{c}	62.65± 1.37^{cd}	90.25± 2.33^{cd}	69.43± 0.54^{b}
T_2	95.24± 5.16^{bc}	10.25± 0.30^{c}	245.05± 16.42^{abc}	28.88± 1.79^{abc}	16.06± 0.92^{abc}	6.24± 0.35^{ab}	11.92± 0.83^{bc}	0.91± 0.07^{c}	20.16± 0.92^{bc}	65.56± 2.89^{c}	94.44± 1.11^{c}	69.40± 2.25^{b}
T_3	107.45± 2.34^{a}	11.38± 0.88^{b}	247.75± 17.14^{ab}	29.27± 1.80^{ab}	16.29± 1.22^{ab}	6.71± 0.55^{a}	12.43± 0.92^{ab}	1.10± 0.10^{b}	22.44± 1.25^{ab}	79.29± 1.07^{b}	108.56± 2.52^{b}	73.06± 1.08^{a}
T_4	93.51± 6.06^{bcd}	9.91± 0.57^{c}	244.50± 17.28^{abcd}	28.28± 2.01^{abcd}	15.55± 0.75^{abcd}	6.18± 0.38^{ab}	11.77± 0.46^{bc}	0.88± 0.05^{c}	19.93± 1.72^{c}	63.77± 2.21^{cd}	92.05± 3.28^{cd}	69.29± 1.57^{b}
T_5	58.21± 4.28^{gh}	6.25±0.17^{gh}	226.30±15.35^{abcde}	23.31±2.53 defgh	13.73±0.47^{defg}	5.31±0.72^{bcd}	8.02±0.47^{gh}	0.22±0.03^{fg}	5.31±0.50^{f}	15.59±0.68^{h}	38.90±1.37^{h}	40.09± 1.39^{f}
T_6	82.45± 5.77^{de}	8.72± 0.14^{d}	238.57± 11.40^{abcde}	25.83± 3.17^{abcdefg}	14.95± 0.65^{abcdef}	5.79± 0.66^{abcd}	9.92± 1.13^{de}	0.41± 0.11^{d}	8.13± 0.99^{e}	29.86± 0.93^{e}	55.69± 3.75^{e}	53.72± 2.67^{c}
T_7	78.83± 8.21^{ef}	8.39± 0.34^{de}	235.80± 12.59^{abcde}	25.22± 1.28^{bcdefgh}	14.39± 1.33^{bcdefg}	5.52± 0.38^{bcd}	9.50± 0.71^{ef}	0.36± 0.06^{de}	6.94± 1.39^{ef}	25.90± 0.49^{f}	51.12± 1.60^{ef}	50.68± 1.12^{d}
T_8	61.04± 4.88^{gh}	6.41± 0.31^{gh}	228.67± 9.39^{abcde}	23.83± 1.33^{defgh}	13.89± 0.91^{defg}	5.34± 0.35^{bcd}	8.42± 0.63^{fgh}	0.28± 0.04^{efg}	6.08± 0.45^{ef}	20.41± 0.63^{g}	44.24± 0.88^{g}	46.15± 2.06^{e}
T_9	67.81± 8.23^{fg}	7.54± 0.17^{ef}	233.52± 16.45^{abcde}	24.99± 2.57^{bcdefgh}	14.10± 0.65^{cdefg}	5.46± 0.51^{bcd}	9.08± 0.52^{efg}	0.31± 0.09^{def}	6.76± 0.37^{ef}	22.69± 0.48^{fg}	47.69± 1.18^{fg}	47.62± 2.09^{e}
T_{10}	62.00± 9.80^{gh}	6.97± 0.19^{fg}	231.37± 10.01^{abcde}	24.17± 1.92^{cdefgh}	14.05± 1.63^{cdefg}	5.42± 0.41^{bcd}	8.87± 0.87^{efgh}	0.29± 0.03^{defg}	6.23± 1.00^{ef}	21.31± 1.35^{g}	45.48± 3.25^{g}	46.87± 0.64^{e}
T_{11}	55.19± 5.21^{h}	5.68± 1.53^{hi}	220.84± 14.46^{bcde}	22.80± 1.18^{efgh}	13.27± 1.10^{efg}	5.12± 0.34^{cd}	7.53± 0.61^{h}	0.21± 0.03^{fg}	5.14± 0.66^{f}	15.36± 0.36^{h}	38.16± 1.52^{h}	40.26± 0.75^{f}
T_{12}	52.21± 6.00^{h}	4.90± 0.21^{ij}	215.56± 13.74^{de}	21.28± 1.77^{gh}	12.81± 1.70^{g}	5.02± 0.19^{d}	5.89± 0.48^{i}	0.20± 0.01^{fg}	4.51± 0.53^{fg}	14.29± 0.51^{h}	35.57± 2.17^{h}	40.23± 1.50^{f}
T_{13}	53.28± 7.80^{h}	5.31± 0.30^{hij}	217.65± 14.96^{cde}	22.13± 1.66^{fgh}	13.15± 1.10^{fg}	5.06± 0.63^{d}	6.03± 0.95^{i}	0.19± 0.03^{fg}	4.77± 0.43^{fg}	13.81± 0.95^{h}	35.95± 2.44^{h}	38.44± 1.26^{f}
T_{14}	88.42± 5.92^{cde}	9.22± 0.20^{cd}	242.99± 11.09^{abcd}	27.11± 2.26^{abcdef}	15.17± 0.68^{abcdef}	5.93± 0.51^{abcd}	10.81± 0.66^{cd}	0.83± 0.12^{c}	16.85± 2.16^{d}	60.24± 5.88^{d}	87.35± 5.34^{d}	68.86± 2.52^{b}
T_{15}	105.06± 7.24^{ab}	12.83± 0.91^{a}	250.60± 16.99^{a}	30.47± 5.97^{a}	16.85± 0.75^{a}	6.58± 0.51^{a}	13.51± 0.94^{a}	1.26± 0.10^{a}	24.73± 2.51^{a}	91.26± 2.96^{a}	121.73± 2.31^{a}	74.96± 1.11^{a}

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T_{16}	50.71± 4.25^{h}	4.26± 0.30^{j}	211.90± 9.91^{e}	20.77± 2.74^{h}	12.64± 0.92^{g}	4.98± 0.58^{d}	2.76± 0.47^{j}	0.18± 0.02^{g}	2.43± 0.45^{g}	13.06± 1.05^{h}	33.83± 3.78^{h}	38.71± 1.38^{f}
F stat	25.33**	43.99**	2.02*	4.01**	4.26**	3.88**	42.76**	93.25**	95.15**	516.11**	344.32**	219.33**
SE(m)	3.93	0.37	8.61	1.49	0.62	0.28	0.43	0.04	0.80	1.19	1.60	0.95
CV(%)	9.06	8.07	6.39	10.17	7.40	8.66	8.05	12.57	12.24	5.34	4.36	3.02
Cohen's F	3.56	4.69	1.00	1.42	1.46	1.39	4.62	6.83	6.90	16.06	13.12	10.47

*: significance at 5% level; **: significance at 1% level; treatments with the same letter are not significantly different (p = 0.05); PH120: plant height (cm) at 120 days after transplanting; NOB120: number of branches at 120 days after transplanting; TPFW120: total plant fresh weight (g) at 120 days after transplanting; TPDW120: total plant dry weight (g) at 120 days after transplanting; FL: fruit length (cm); FD: fruit diameter (cm); NFP: number of fruits per plant; FYP: fruit yield per plant (kg); TY: total yield (t ha^{-1}); EY: economic yield (g plant^{-1}); BY: biological yield (g plant^{-1}); HI: harvest index (%).

Plant fresh weight (g)

Plant fresh weight was significantly influenced by different weed management practices. The fresh weight of the plant gradually increases from the early growth stage to the harvest stage due to continuous cell division, cell elongation and enhanced vegetative growth of plants. The fresh weight of the plant was recorded as high as 250.6 g in the weed-free plot followed by T_3 and T_2 due to enhanced growth of the plant (Table 2). T_{16} recorded the lowest fresh weight of 211.9 g (Table 2).

Plant dry weight (g)

Plant dry weight is positively correlated with fresh weight. Therefore, the highest (30.4 g) and lowest (20.7 g) dry weight of the plant were recorded in T_{15} and T_{16} respectively (Table 2). The results are in contrast with early findings, in which the highest dry weight was recorded in the hand-weeding-thrice treatment and the lowest dry weight was recorded in a herbicide-treated plot (12). This might be due to the difference in treatment combination.

Fruit yield per plant (kg)

Fruit yield per plant varies significantly among different treatments. The higher fruit yield per plant might be attributed to improved vegetative growth, enhanced fruit set and increased fruit development. The higher fruit yield per plant was recorded as 1.26 kg in T_{15} followed by T_3 and the lowest fruit yield per plant was recorded as 0.18 kg in the controlled plot (T_{16}) (Table 2). T_{16} is on par with T_5, T_8, T_{10}, T_{11}, T_{12} and T_{13}. The result obtained by previous results showed that the highest fruit yield was recorded in the plot treated with hand weeding thrice (12, 13).

Fruit yield (t ha^{-1})

A perusal of the data given in Table 2 reveals that different weed management practices exerted a significant impact on fruit yield. Significantly maximum fruit yield (24.7 t ha^{-1}) was recorded in T_{15} [weed-free] followed by T_3 [soil solarisation + 1 hand weeding at 30 DAT] and T_2 [soil solarisation + rice straw mulch at 5 t ha^{-1}]. The lowest yield was recorded in the controlled plot (T_{16}) (Table 2). T_{16} is on par with T_{12} and T_{13}. Similar results of maximum fruit yield in the weed-free plot were also reported by (14–17). The higher yield may be attributed to lower dry matter accumulation by weeds and a decrease in their population that helped in increasing the yield attributes, which ultimately led to higher yield (18). Low yield in the weedy check plot may be attributed to reduced plant growth because of competition of weeds with the crop for nutrient, moisture and light. Other yield attributes viz., number of fruits per plant, follow the similar trend as that of fruit yield.

Number of fruits per plant

Number of fruits per plant is positively correlated to fruit yield. The maximum number of fruits per plant was recorded in T_{15} [weed-free] followed by T_3 [soil solarisation + 1 hand weeding at 30 DAT] and T_2 [soil solarisation + rice straw mulch at 5 t ha^{-1}] (Table 2). T15 is on par with T_3 and significantly different from other treatments. Contrary findings are reported by previous reports, where the highest number of fruits per plant was recorded when treated with black plastic mulch followed by the weed-free treatment, which may be attributed to the difference in treatment combination (9, 19).

Fruit length (cm)

Fruit length is a yield-contributing trait recorded by taking the average length of ten fruits at harvesting. Fruit length is significantly higher in the treated plot than in the weedy plot. The weed-free plot recorded the highest fruit length of 16.85 cm followed by T_3 [soil solarisation + 1 hand weeding at 30 DAT] and T_2 [soil solarisation + rice straw mulch at 5 t ha^{-1}], with the weedy plot recording a significantly lower value (Table 2). The increase in fruit length may be attributed to greater efficacy in weed management, which reduces crop-weed competition and enables the crop to utilise more nutrition in chilli (20). Similar findings of fruit length of 16.4 cm in the weed-free plot were also reported, but the highest fruit length was recorded in the black plastic mulch treatment (19). Maximum fruit length of 10.2 cm in the weed-free plot and minimum (7.68 cm) in the weedy plot were also reported (21).

Fruit diameter (cm)

Fruit diameter was also significantly influenced by different treatments and all the treatments recorded values that were on par except the weedy plot. The highest fruit diameter was recorded in T_3 [soil solarisation + 1 hand weeding at 30 DAT] followed by the weed-free plot (Table 2). These results are in line with previous reports, reported the highest fruit length and fruit diameter in the solarisation-treated plot in both the years (10).

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Economic yield (g) and biological yield (g)

Economic yield is correlated with fruit yield produced by the plant as it is obtained by drying the fruits harvested from the plants. Therefore, it is recorded as the highest in T_{15} followed by T_3. T_1, T_2 and T_4 were on par (Table 2). Similarly, T_{16} recorded the lowest economic yield and was on par with T_5, T_8, T_{10}, T_{11}, T_{12} and T_{13} (Table 2). Biological yield is positively correlated with dry weight of plants and economic yield of plants as it is obtained by the addition of dry weight and economic yield. The highest and lowest biological yield were recorded in T_{15} and T_{16} respectively (Table 2). Higher biological yield in T_{15} is attributed to better crop growth and biomass accumulation.

Harvest index (%)

Harvest index represents the efficiency of the crop in converting total biological yield into economic yield. The highest harvest index was recorded in the weed-free plot at 74.9 % followed by T_3 (73 %) (Table 2). The higher harvest index indicates enhanced crop growth and biomass accumulation. The lowest harvest index was recorded in T_{13} and T_{16}, i.e., 38.4 % and 38.7 % respectively (Table 2). Lower harvest index may be due to lesser allocation of assimilates towards economic produce. However, a different result was obtained in previous study, reported that the highest harvest index was recorded in the herbicide-treated plot (22). This result might be due to the difference in treatment combination.

Effect of treatments on weed density

The data given in Table 3a show the weed density at 30 and 60 DAT. All the treatments significantly reduced the weed population except the weedy check. These results also matched previous findings (11, 15, 23, 24). Maintaining a weed-free condition completely checked the number of grasses, sedges and broad-leaved (BLW) weeds at 30 and 60 DAT. This result is corroborated with early results (9). The soil solarisation-treated plot registered a very low value for weed density and all the four plots were statistically on par. At 30 DAT, T_3 [soil solarisation + 1 hand weeding at 30 DAT] recorded the significantly least weed density of grasses (1.56) (2) followed by T_2 [soil solarisation + rice straw mulch at 5t ha^{-1}], T_4 and T_5.

Significantly lower population of sedges (0.88) and BLW (0.1.46) were also recorded in T_3 [soil solarisation + 1 hand weeding at 30 DAT] followed by T_2, T_4 and T_1 (Table 3a).

At 60 DAT, T_3 resulted in the minimum number of grass weeds (2.02) followed by T_2, T_4 and T_1. Likewise, at 60 DAT T_3 recorded the minimum number of sedges (1.46) followed by T_2 and T_1 (Table 3a). BLWs also were observed to be less in T_3 [soil solarisation + 1 hand weeding at 30 DAT] (0.88). T_2 and T_4 showed values that were at par (Table 3a).

Table 3a. Effect of different weed management practices on weed density of grasses, sedges and broad-leaved weeds in brinjal at 30 and 60 days after transplanting (DAT)

Treatments	G30	G60	S30	S60	BLW30	BLW60
T_1	2.08±0.49^{g}	2.93±0.60^{g}	1.46±0.21^{fgh}	1.94±0.31^{ef}	1.93±0.39^{de}	2.11±0.24^{ef}
T_2	1.74±0.46^{g}	2.46±0.82^{gh}	1.22±0.00^{hi}	1.68±0.17^{fg}	1.64±0.45^{ef}	1.77±0.17^{f}
T_3	1.56±0.32^{g}	2.02±0.39^{h}	0.88±0.30^{ij}	1.46±0.21^{g}	1.46±0.21^{f}	0.88±0.30^{g}
T_4	1.93±0.39^{g}	2.70±0.56^{gh}	1.34±0.21^{gh}	1.95±0.14^{ef}	1.77±0.17^{ef}	1.77±0.17^{f}
T_5	5.76±0.70^{abcd}	6.06±0.45^{bc}	1.95±0.14^{abcd}	2.72±0.37^{bc}	2.54±0.20^{bc}	3.08±0.16^{cd}
T_6	4.58±0.50^{f}	4.94±0.41^{ef}	1.56±0.32^{efgh}	2.20±0.13^{de}	2.47±0.32^{bc}	2.79±0.27^{d}
T_7	4.84±0.41^{ef}	5.23±0.43^{de}	1.66±0.37^{defg}	2.47±0.32^{cd}	2.47±0.32^{bc}	2.85±0.27^{d}
T_8	5.38±0.56^{bcde}	5.81±0.39^{bcd}	1.87±0.00^{bcde}	2.67±0.21^{bc}	2.41±0.12^{bc}	2.96±0.38^{cd}
T_9	5.04±0.40^{def}	5.45±0.37^{cde}	1.77±0.17^{cdef}	2.54±0.33^{bcd}	2.34±0.21^{cd}	2.86±0.10^{d}
T_{10}	5.27±0.29^{cdef}	5.75±0.44^{bcd}	1.87±0.00^{bcde}	2.67±0.29^{bc}	2.41±0.12^{bc}	2.97±0.10^{cd}
T_{11}	5.87±0.23^{abc}	6.20±0.40^{bc}	2.04±0.14^{abcd}	2.79±0.27^{bc}	2.54±0.20^{bc}	3.08±0.16^{cd}
T_{12}	6.27±0.47^{a}	6.49±0.19^{b}	2.11±0.24^{abc}	2.97±0.10^{b}	2.85±0.27^{ab}	3.49±0.16^{b}
T_{13}	6.20±0.24^{a}	6.28±0.21^{b}	2.04±0.14^{abcd}	2.90±0.31^{bc}	2.61±0.11^{bc}	3.29±0.23^{bc}
T_{14}	6.04±0.25^{ab}	4.43±0.51^{f}	2.18±0.34^{ab}	2.11±0.24^{de}	2.54±0.20^{bc}	2.24±0.45^{e}
T_{15}	0.71±0.00^{h}	0.71±0.00^{i}	0.71±0.00^{j}	0.71±0.00^{h}	0.71±0.00^{g}	0.71±0.00^{g}
T_{16}	6.49±0.35^{a}	7.55±0.43^{a}	2.34±0.21^{a}	3.63±0.08^{a}	3.19±0.18^{a}	4.88±0.16^{a}
F stat	72.85**	58.88**	14.92**	26.30**	18.18**	60.14**
SE(m)	0.24	0.25	0.12	0.14	0.14	0.13
CV(%)	9.34	9.35	12.37	10.04	10.94	8.74
Cohen's F	6.04	5.43	2.73	3.63	3.02	5.48

*: significance at 5% level; **: significance at 1% level; treatments with the same letter are not significantly different (p = 0.05); G30: grasses at 30 days after transplanting; G60: grasses at 60 days after transplanting; S30: sedges at 30 days after transplanting; S60: sedges at 60 days after transplanting; BLW30: broadleaved weeds at 30 days after transplanting; BLW60: broadleaved weeds at 60 days after transplanting.

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Effect of treatments on weed dry weight

As weed density was completely eliminated in the weed-free plot, no dry matter accumulation by weeds was observed. Data given in Table 3b depict that at 30 DAT, T_2 [soil solarisation + rice straw mulch at 5t ha^{-1}] resulted in the minimum dry weight of grasses (1.26 g) followed by T_4 [soil solarisation + Metribuzin at 0.525 kg ha^{-1} PoE at 30 DAT] (1.44 g). T_3 and T_1 resulted in values that were at par. The dry weight of sedges was lowest (0.74 g) in T_3 [soil solarisation + 1 hand weeding at 30 DAT] followed by T_2, T_1 and T_4. The BLW dry weight was minimum (1.45 g) in T3 followed by T_2. T_4 and T_1 were at par. At 60 DAT, the minimum dry grass weight was recorded (1.49 g) in T_3 followed by T_2. T_1 and T_4 were at par. Similar to 30 DAT, at 60 DAT, T_3 resulted in the minimum dry weight in sedges (1.31 g) as well as BLWs (1.04 g) followed by T_2. In BLWs T_2 and T_4 resulted in values that were at par (Table 3b).

After the weed-free condition, soil solarisation was considered the best treatment and this finding was similar to the previous report (10). The lower dry weight under the treatment may be attributed to the lower number of weeds.

Weed control efficiency and weed index

Fig. 3 illustrated the weed control efficiency at 30 and 60 DAT and weed index (WI). This figure illustrated that T_{15} exhibited the highest weed control efficiency (100 %) at both 30 and 60 DAT along with negligible WI, reflecting complete suppression of weeds and minimum yield reduction. T_{16} recorded the lowest weed control efficiency and high WI, which indicates severe weed infestation and maximum yield loss (Fig. 3). These findings are in accordance with early results (9, 19). Apart from the weed-free treatment, all the soil solarisation plots recorded a consistently high weed control efficiency, i.e., more than 80 %, with lower WI, revealing effective weed control and better crop performance (Fig. 3). Similar results were previously reported (25). Treatments such as T_6 and T_{14} performed better, but WI was higher, indicating that weed suppression was not sufficient to prevent yield loss. It clearly shows an inverse relationship between weed control efficiency and WI.

Table 3b. Effect of different weed management practices on weed biomass in brinjal at 30 and 60 days after transplanting (DAT)

Treatments	GDW30	GDW60	SDW30	SDW60	BLDW30	BLDW60
T_1	1.53±0.41^{g}	2.12±0.57^{f}	1.02±0.07^{f}	1.59±0.32^{ghi}	1.84±0.27^{de}	1.92±0.16^{fg}
T_2	1.26±0.20^{g}	1.84±0.34^{fg}	0.93±0.05^{fg}	1.44±0.09^{hi}	1.55±0.11^{fg}	1.67±0.05^{g}
T_3	1.52±0.23^{g}	1.49±0.32^{g}	0.74±0.06^{gh}	1.31±0.09^{i}	1.45±0.13^{g}	1.04±0.57^{h}
T_4	1.44±0.25^{g}	2.14±0.33^{f}	1.06±0.07^{f}	1.72±0.20^{gh}	1.77±0.21^{ef}	1.66±0.08^{g}
T_5	4.25±0.38^{ab}	4.76±0.20^{b}	1.50±0.04^{bcde}	2.33±0.24^{cde}	2.15±0.21^{cd}	2.35±0.08^{cd}
T_6	3.07±0.32^{f}	3.14±0.23^{e}	1.11±0.10^{f}	1.77±0.15^{g}	2.17±0.19^{c}	2.28±0.09^{cde}
T_7	3.25±0.23^{ef}	3.98±0.12^{cd}	1.34±0.10^{e}	2.09±0.18^{ef}	2.05±0.13^{cde}	2.09±0.10^{def}
T_8	3.82±0.42^{bcd}	4.31±0.19^{bc}	1.42±0.18^{de}	2.35±0.02^{cde}	2.02±0.13^{cde}	2.29±0.06^{cde}
T_9	3.66±0.22^{cde}	3.72±0.27^{d}	1.44±0.20^{cde}	2.17±0.04^{de}	2.12±0.18^{cd}	2.12±0.04^{def}
T_{10}	3.54±0.24^{def}	4.45±0.14^{bc}	1.46±0.16^{cde}	2.42±0.16^{bcd}	2.05±0.12^{cde}	2.00±0.02^{ef}
T_{11}	4.34±0.27^{ab}	4.57±0.26^{b}	1.56±0.03^{bcd}	2.50±0.14^{bc}	2.47±0.23^{ab}	2.31±0.11^{cde}
T_{12}	4.25±0.19^{ab}	4.74±0.20^{b}	1.63±0.03^{bcd}	2.67±0.16^{b}	2.60±0.14^{a}	2.86±0.12^{b}
T_{13}	4.34±0.28^{ab}	3.70±0.41^{d}	1.66±0.01^{bc}	2.46±0.10^{bcd}	2.30±0.16^{bc}	2.48±0.13^{c}
T_{14}	4.06±0.20^{abc}	3.64±0.29^{d}	1.71±0.15^{ab}	1.85±0.21^{fg}	2.09±0.17^{cd}	2.02±0.23^{ef}
T_{15}	0.71±0.00^{h}	0.71±0.00^{h}	0.71±0.00^{h}	0.71±0.00^{j}	0.71±0.00^{h}	0.71±0.00^{i}
T_{16}	4.50±0.38^{a}	5.41±0.23^{a}	1.90±0.25^{a}	3.19±0.23^{a}	2.73±0.18^{a}	3.76±0.14^{a}
F stat	66.18**	71.94**	27.96**	37.77**	26.37**	46.68**
SE(m)	0.16	0.16	0.07	0.10	0.09	0.10
CV(%)	9.14	8.19	8.78	8.40	8.18	8.35
Cohen's F	5.75	6.00	3.74	4.35	3.63	4.83

*: significance at 5% level; **: significance at 1% level; treatments with the same letter are not significantly different (p = 0.05); GDW30: grass dry weight at 30 days after transplanting; GDW60: grass dry weight at 60 days after transplanting; SDW30: sedge dry weight at 30 days after transplanting; SDW60: sedge dry weight at 60 days after transplanting; BLDW30: broadleaved weed dry weight at 30 days after transplanting; BLDW60: broadleaved weed dry weight at 60 days after transplanting.

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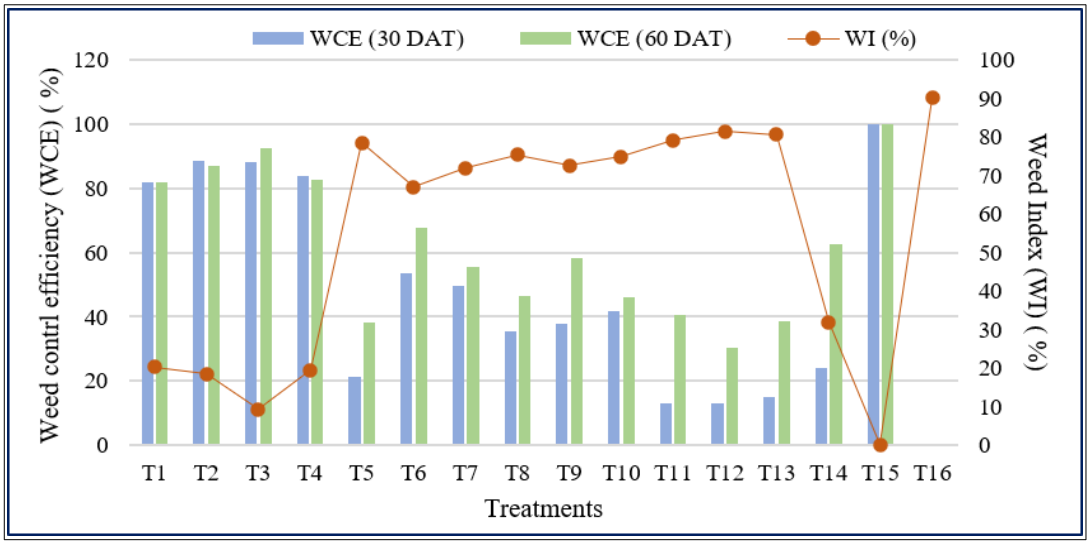


Fig. 3. Weed control efficiency at 30 and 60 days after transplanting (DAT) and weed index (WI).

Economics

Based on the findings of the experiment, among all the treatments, the soil solarisation along with one hand weeding at 30 days after planting treated plot (T_3) recorded gross return (₹673110 ha^{-1}), highest net return (₹396389 ha^{-1}), as well as a benefit-cost ratio of 2.4 (Table 4a, 4b, 4c). A different trend was observed compared to the results previously reported (9, 22), where the maximum net return and benefit-cost ratio were obtained under the use of herbicides. The rest of the soil solarisation-treated plots exhibited a decent benefit-cost ratio as compared to the weed-free plot, while gross return was maximum (₹711900 ha^{-1}) in the weed-free plot, though it is not economically viable in terms of the lower B : C ratio (1.92) due to repeated hand weeding operations leading to higher cost of cultivation. The weedy plot recorded the lowest benefit-cost ratio of 0.36 (Table 4c). Similar findings were also reported in brinjal (22). Moreover, the soil solarisation-treated plot was the best option as it boosted the net return as well as B : C ratio.

Multivariate analysis

Principal component analysis (PCA) is a multivariate statistical tool used to determine the source and structure of variations as well as the contribution of observable attributes to overall variability. It reduces the dimensionality of complex datasets by retaining the maximum possible variation present in the original variables. The PCA transforms correlated variables into a set of new, uncorrelated variables known as principal components (PCs). It helps in understanding the pattern of variation and the relationship among traits and treatments more effectively. In this experiment, PCA was carried out on growth, yield and weed parameters of brinjal. The analysis resulted in eight PCs, among which PC1 was found to be highly significant, exhibiting an eigenvalue of 22.10, accounting for 92.08 % of total variation (Table 5). PC2 contributed only 3.07 % of total variation and other components contributed negligibly to the overall variability (Table 5). Since PC1 and PC2 both contributed a major proportion of total variance, they were considered the most informative components for interpretation and graphical representation. Therefore, the PCA biplot was constructed based on PC1 and PC2 to represent the distribution of treatments and the relationship between traits.

Table 4a. Effects on different weed management practices on economics of brinjal (fixed cost)

Particular	Quantity	Rate $unit^{-1}$ (₹)	Total price (₹ ha^{-1})
Fixed cost (A)			
Rental value of land (ha)	1 ha	45000	45000
Depreciation on fixed assets (10 %)			4500
Sub-total (₹)			49500
Interest on fixed cost at 10 %			4950
Total fixed cost A (₹)			54450
Fixed cost B			
Seedlings	17500	1.4	24500
Machinery cost for land preparation (hours)	10 hours	1200	12000
Compost	25 tonnes	1500	37500
Chemical fertiliser			
Urea	100kg	5.42	542
Single super phosphate (SSP)	60kg	13	780
Muriate of potash (MOP)	50kg	29	1450
Plant protection chemical			10000
Intercultural operation (Man days)	30	462	13860
Harvesting (Man days)	10	462	4620
Transportation cost			30000
Miscellaneous charges			5000
Sub-total (₹)			140252
Interest on working capital at 7 % (₹)			9817
Total cost B (₹)			150069
Total fixed cost (A + B) (₹)			204519

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Table 4b. Effects on different weed management practices on economics of brinjal (variable cost)

Treatments details	Tillage	Labour charge for mulching at ₹350 (6 nos.)	Mulch material cost at ₹150 (400 kg)	Herbicide cost	Labour charge for weeding and spraying	Total variable cost (₹)
T_1: Soil solarisation	2500	2772	60000	0	0	65272
T_2: Soil solarisation + paddy straw mulch	2500	2772	60000	5000	1848	72120
T_3: Soil solarisation + hand weeding	2500	2772	60000	0	6930	72202
T_4: Soil solarisation + Metribuzine	2500	2772	60000	1875	924	68071
T_5: Paddy straw mulch	0	1848	5000	0	0	6848
T_6: Paddy straw mulch + hand weeding	0	1848	5000	0	6930	13778
T_7: Paddy straw mulch + Metribuzine	0	1848	5000	1875	924	9647
T_8: Oxyfluorofen	0	0	0	1493	924	2417
T_9: Oxyfluorofen + hand weeding	0	0	0	1493	7854	9347
T_{10}: Oxyfluorofen + Metribuzine	0	0	0	3368	1848	5216
T_{11}: Metribuzine	0	0	0	1875	924	2799
T_{12}: Intercropping (brinjal + cow pea)	2000	0	0	0	4620	6620
T_{13}: Intercropping (brinjal + cow pea) + Paddy straw mulch	2000	0	0	5000	6468	13468
T_{14}: Hand weeding at 30 and 60 DAT	0	0	0	0	27720	27720
T_{15}: Weed-free	0	0	0	0	166000	166000
T_{16}: Weedy	0	0	0	0	0	0

DAT: days after transplanting.

Table 4c. Effects on different weed management practices on overall economics of brinjal

Treatments details	Total cost of cultivation (₹)	Total yield ton ha^{-1}	Gross income (₹)	Net return (₹)	B : C
T_1: Soil solarisation	269791	19.72	591450	321659	2.19
T_2: Soil solarisation + paddy straw mulch	276639	20.16	604800	328161	2.19
T_3: Soil solarisation + hand weeding	276721	22.44	673110	396389	2.43
T_4: Soil solarisation + Metribuzine	272590	19.93	597990	325400	2.19
T_5: Paddy straw mulch	211367	5.31	159240	-52127	0.75
T_6: Paddy straw mulch + hand weeding	218297	8.14	244050	25753	1.12
T_7: Paddy straw mulch + Metribuzine	214166	6.94	208110	-6056	0.97
T_8: Oxyfluorofen	206936	6.08	182430	-24506	0.88
T_9: Oxyfluorofen + hand weeding	213866	6.76	202770	-11096	0.95
T_{10}: Oxyfluorofen + Metribuzine	209735	6.23	186750	-22985	0.89
T_{11}: Metribuzine	207318	5.14	154200	-53118	0.74
T_{12}: Intercropping (brinjal + cow pea)	211139	4.51	135300	-75839	0.64
T_{13}: Intercropping (brinjal + cow pea) + paddy straw mulch	217987	4.77	143130	-74857	0.66
T_{14}: Hand weeding at 30 and 60 DAT	232239	14.85	445440	213201	1.92
T_{15}: Weed-free	370519	23.73	711900	341381	1.92
T_{16}: Weedy	204519	2.44	73050	-131469	0.36

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Table 5. Eigen value and principal components (PCs) loadings for growth, yield and weed traits in brinjal

Variables	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8
eigenvalue	22.10	0.74	0.51	0.29	0.11	0.10	0.08	0.03
percentage of variance	92.08	3.07	2.11	1.22	0.48	0.41	0.32	0.13
cumulative percentage of variance	92.08	95.15	97.26	98.48	98.96	99.36	99.68	99.81
Correlation between variables and PCs								
PH120	0.97	0.18	0.01	0.14	0.04	-0.08	0.05	0.03
NOB120	0.99	0.05	0.09	0.07	0.09	-0.02	0.01	0.02
TPFW120	0.95	0.13	0.20	0.19	0.04	0.08	-0.02	0.02
TPDW120	0.99	0.10	0.08	0.08	0.02	0.05	-0.02	0.03
FL	0.99	0.07	0.07	0.08	0.08	0.00	0.01	0.00
FD	0.98	0.11	-0.01	0.06	0.02	-0.05	0.12	0.01
NFP	0.95	0.00	0.26	0.11	-0.09	0.08	-0.05	-0.04
FY.Plant	0.96	0.21	-0.11	-0.13	0.01	-0.01	0.03	-0.02
TY	0.96	0.21	-0.12	-0.11	-0.08	0.03	-0.01	-0.02
EY	0.96	0.22	-0.10	-0.13	0.01	-0.01	0.03	-0.02
BY	0.97	0.20	-0.09	-0.11	0.01	-0.01	0.03	-0.01
HI	0.95	0.30	-0.04	0.03	-0.02	0.03	-0.01	0.00
G30	-0.94	0.15	0.27	-0.07	0.05	-0.09	0.00	0.00
G60	-1.00	0.00	0.07	0.05	0.04	-0.01	0.04	0.01
GDW30	-0.94	0.11	0.27	-0.11	0.02	-0.10	0.05	0.00
GDW60	-0.97	0.07	0.13	0.03	0.05	0.11	0.12	-0.11
S30	-0.93	0.32	0.12	-0.07	-0.04	0.07	-0.09	-0.02
S60	-0.98	0.07	-0.11	0.08	-0.04	0.07	0.07	0.06
SDW30	-0.92	0.30	0.11	-0.18	0.04	0.06	-0.03	0.07
SDW60	-0.98	0.06	-0.12	0.01	-0.04	0.11	0.12	0.04
BL30	-0.95	0.25	0.04	0.17	-0.02	-0.06	0.01	0.00
BL60	-0.96	0.08	-0.17	0.10	0.15	0.04	-0.05	0.01
BLDW30	-0.93	0.22	-0.06	0.18	-0.19	-0.09	-0.01	-0.01
BLDW60	-0.92	0.21	-0.28	0.11	0.10	-0.03	-0.07	-0.05

PH120: plant height at 120 days after transplanting; NOB120: number of branches at 120 days after transplanting; TPFW120: total plant fresh weight at 120 days after transplanting; TPDW120: total plant dry weight at 120 days after transplanting; FL: fruit length; FD: fruit diameter; NFP: number of fruits per plant; FYP: fruit yield per plant; TY: total yield; EY: economic yield; BY: biological yield; HI: harvest index; G30: grass at 30 days after transplanting; G60: grass at 60 days after transplanting; GDW30: grass dry weight at 30 days after transplanting; GDW60: grass dry weight at 60 days after transplanting; S30: sedges at 30 days after transplanting; S60: sedges at 60 days after transplanting; SDW30: sedge dry weight at 30 days after transplanting; SDW60: sedge dry weight at 60 days after transplanting; BL30: broadleaved weed at 30 days after transplanting; BL60: broad-leaved weed at 60 days after transplanting; BLDW30: broadleaved weed dry weight at 30 days after transplanting; BLDW60: broad-leaved weed dry weight at 60 days after transplanting.

The PCA biplot depicted that the first PC1 explained 92.08 % of the total variation, separating distinctly crop growth and yield traits from weed parameters. Growth and yield attributes such as plant height, number of branches, plant fresh weight, dry weight, fruit length, fruit diameter, number of fruits per plant, fruit yield per plant, total yield, economic yield, biological yield and harvest index were negatively correlated with weed parameters. This indicates a strong inverse relationship between weed infestation and crop growth. Treatments on the positive side of PC1 exhibited better crop growth and yield (r = 0.95–0.99) with minimal weed infestation, whereas treatments on the negative side were influenced by high weed pressure and poor crop performance (r = -0.92 to -1.00). The biplot consisted of different vectors projected in different directions with different lengths, which indicate the nature and extent of variation present in the experiment. The angle between vectors represents the relationship between different traits. For e.g., number of fruits per plant (NFP) having an opposite direction vector towards G60, representing a negative correlation, which explains that an increase in grasses at 60 DAT directly impacts NFP. Similarly, if the vector angle is an acute angle, i.e.,

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less than 90°, this indicates positive correlations between the traits. In our experiment, the crop growth and yield traits are placed at acute angles, which indicates that these all are positively correlated. An increase in any plant value will facilitate an increase in the value of the other trait. Similarly, if the vector angle is placed at nearly 90°, this indicates an independent relationship. For e.g., S30 and harvest index have an independent relationship, which means that if S30 increases, there is no impact on harvest index. The traits projected towards treatments are significantly impacted, with all growth and yield traits being significantly impacted by T_1, T_2, T_3, T_4, T_{14} and T15, whereas the weed traits are projecting towards the treatments T_5, T_8, T_9, T_{10}, T_{11}, T_{12}, T_{13} and T_{16}. Among them, T_{15} and T_{16} showed their strong association with yield traits and weed traits respectively, due to their distant projection. The biplot clearly shows that there is a grouping of traits into two groups. In one group, growth and yield traits and in the other group, weed traits are there.

The correlation of traits on PC revealed that the PC1 had strong positive associations with growth and yield attributes such as plant height, number of branches, plant fresh weight and dry weight, fruit length, fruit diameter, number of fruits per plant, fruit yield per plant, total yield, economic yield, biological yield and harvest index. In contrast, weed density and biomass parameters, including grasses, sedges and broad-leaved weeds at different growth stages, exhibited strong negative correlations with PC1. This indicates that PC1 effectively differentiates weed pressure from crop performance. Subsequent components contributed minimally to the overall variation, suggesting that PC1 alone explains the majority of variability in the dataset (Fig. 4a).

The PC1 index plot (Fig. 4b), computed from the signed PC1 score of each treatment, places the weed-free check (T_{15}) at the highest end of the index, followed by the solarisation-based treatments (T_3, T_2, T_4, T_1), reflecting their combination of superior crop growth and yield with effective weed suppression in this trial. The weedy check (T_{16}) occupies the lowest end of the index, consistent with its poor crop performance and high weed load. This ordering is now fully concordant with the PCA loadings (Table 5) and the biplot (Fig. 4c). The PC2 index plot (Fig. 4b) is presented for completeness but was not used for treatment selection or ranking. PC2 explained only 3.07 % of total variance and none of the 23 traits showed a dominant loading on this axis (all $|r| \leq 0.32$). The highest PC2 score was recorded for T_{14} (hand weeding at 30 and 60 DAT), which appears as a clear outlier in the biplot (Fig. 4c) along the PC2 axis while showing a near-zero PC1 score; this indicates that PC2 largely reflects residual, treatment-specific variation rather than a generalisable weed-management or crop-performance gradient and it was therefore excluded from the treatment index used for selection. Taken together, treatment selection in this study was based on the PC1 index alone, which identified the weed-free check and the solarisation-based combinations as the top-performing treatments and the weedy check as the poorest, in agreement with the trait loadings and the PCA biplot.

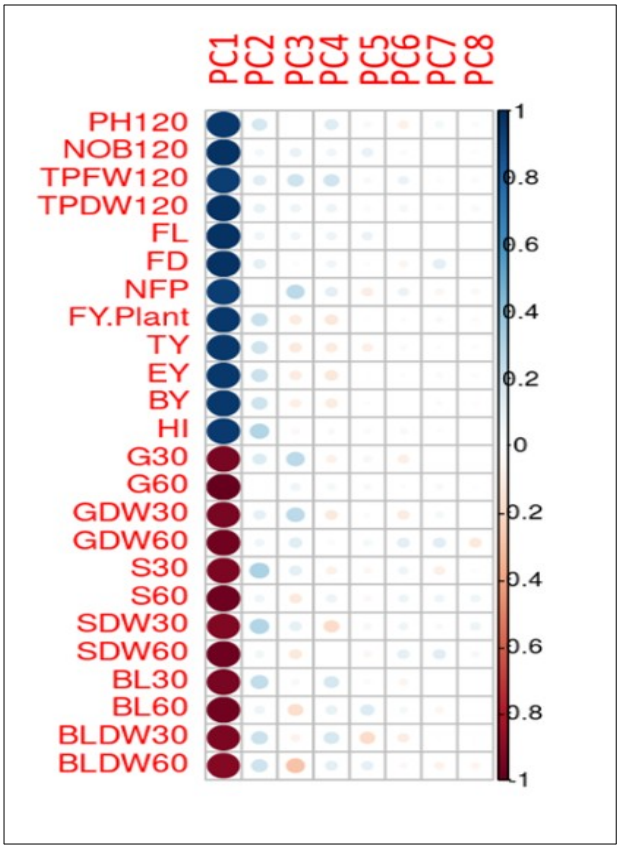


Fig. 4a. Correlation plot of variables vs principal components (PCs).

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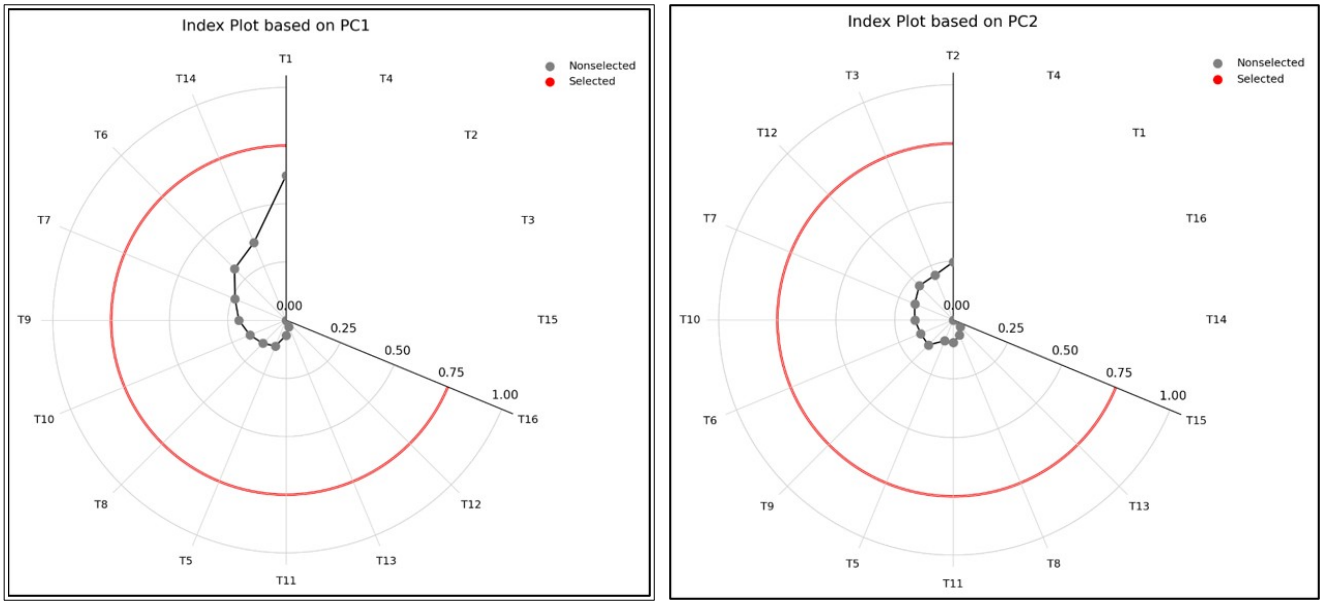


Fig. 4b. Index plot on the basis of principal components, PC1 and PC2.

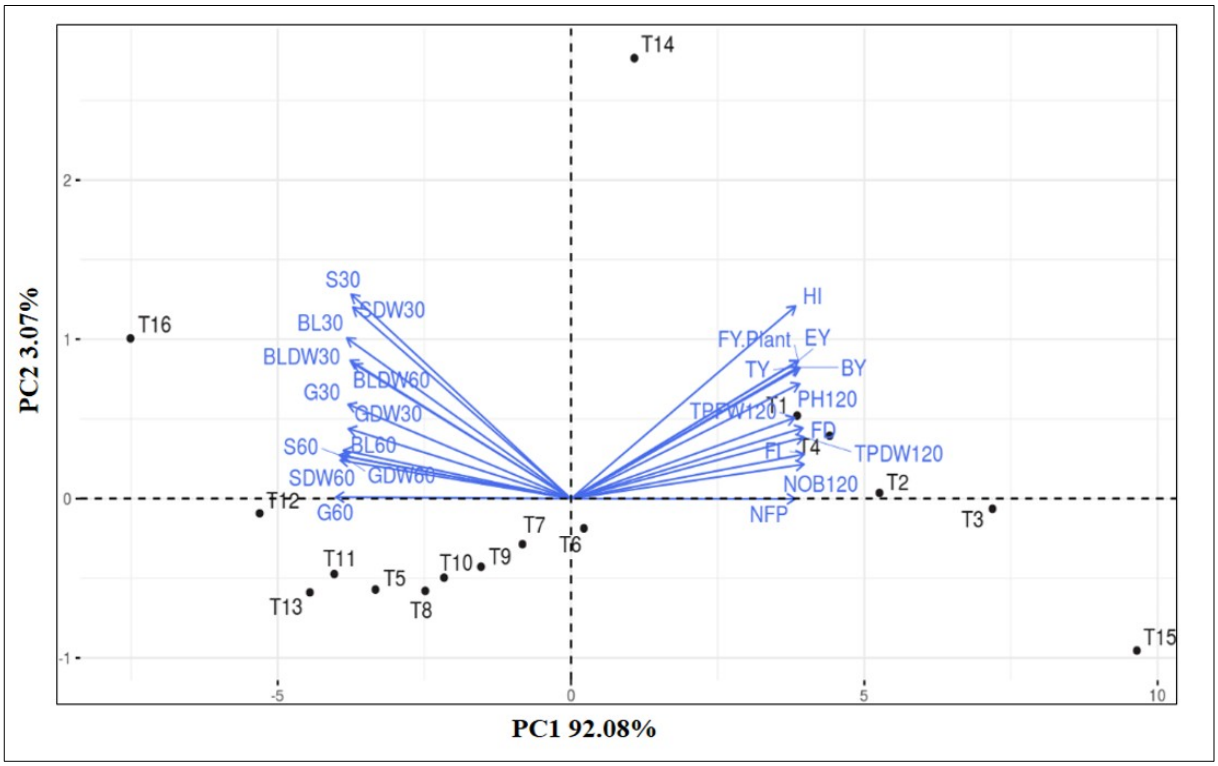


Fig. 4c. Principal component analysis (PCA) biplot showing contribution of principal components, PC1 and PC2 and allocation of traits and treatments.

Pearson correlation among growth, yield attributing traits and weed flora related traits

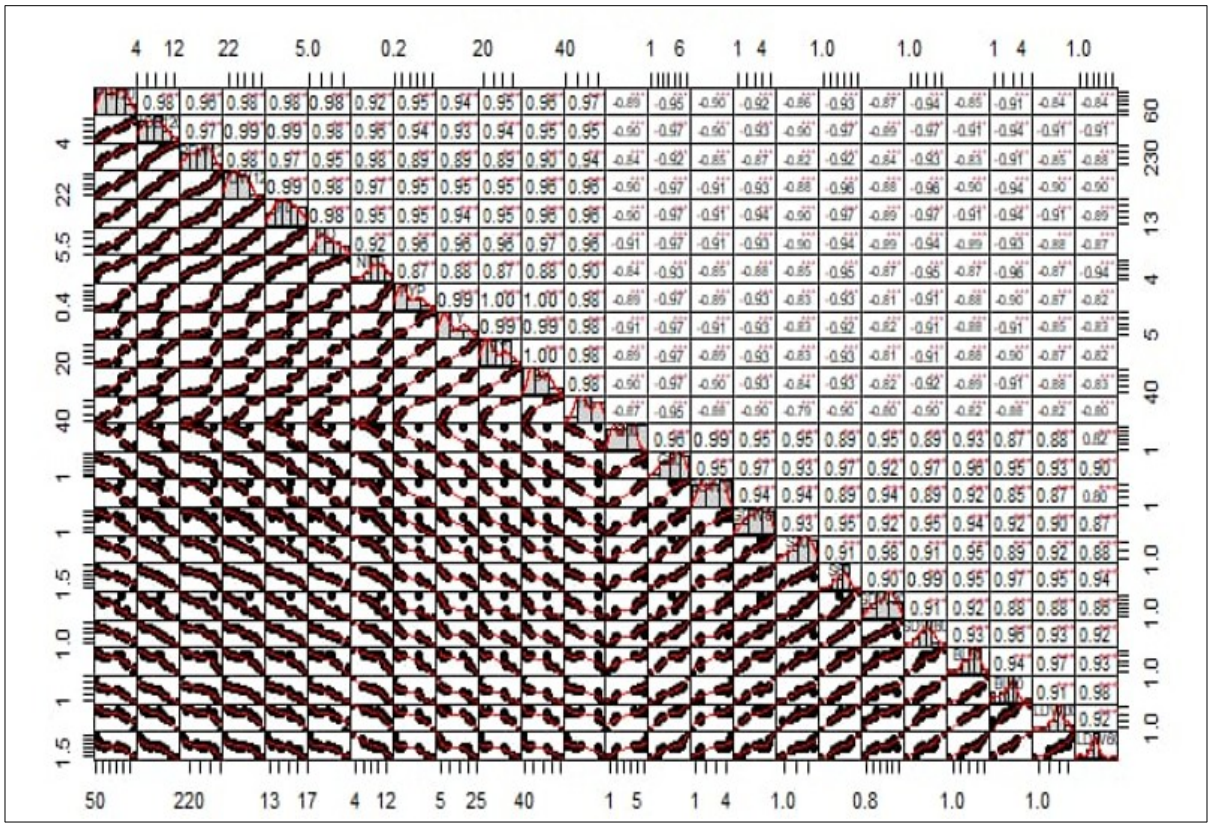
The correlation matrix plot represents the interrelationship among crop growth, yield and weed parameters. The combined correlation analysis revealed that growth and yield parameters including plant height, number of branches, plant fresh weight, plant dry weight, fruit length, fruit diameter, number of fruits per plant, fruit yield per plant, total yield, economic yield, biological yield and harvest index had strong positive correlations. The plant height had the highest positive significant correlation with fruit diameter (0.98) followed by number of branches (0.98), fruit length (0.98), plant dry weight (0.98), harvest index (0.97), plant fresh weight (0.96), biological yield (0.96), fruit yield per plant (0.95), economic yield (0.95), total yield (0.94) and number of fruits per plant (0.92) (Fig. 5a, 5b). Similarly, number of branches had a positive correlation with all the growth and yield traits. The result suggests that improved vegetative growth directly

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enhances the reproductive growth and fruiting in brinjal. The strong positive correlation between growth and yield traits may be attributed to increased photosynthetic efficiency and nutrient uptake, which leads to better fruit development. The positive association between plant fresh weight and dry weight suggests that vigorous vegetative growth directly contributed to biomass accumulation. Similarly, fruit yield per plant, total yield and economic yield are positively correlated with plant growth parameters, indicating that better crop growth enhances productivity. Total weeds, sedges and broad-leaved weed density along with their dry weight also revealed strong positive correlations among themselves (Fig. 5a, 5b). This strong positive association among weed traits may be due to favourable environmental conditions to grow in the field. On the other hand, growth and yield traits had highly significant negative correlations with weed density and weed dry weight, exhibiting a strong inverse relationship between crop growth and weed infestation (Fig. 5a, 5b). This is because of severe crop-weed competition for nutrient, light, moisture and space at the critical period. These findings are similar to those previously reported, who reported that an increase in grain yield in rice decreased weed density and biomass (26). The soyabean yield was strongly negatively correlated with weed dry matter at 30 and 60 DAS (27). The negative association between weed biomass and harvest index indicates that severe weed competition reduced assimilate partitioning towards economic yield (Fig. 5a, 5b).

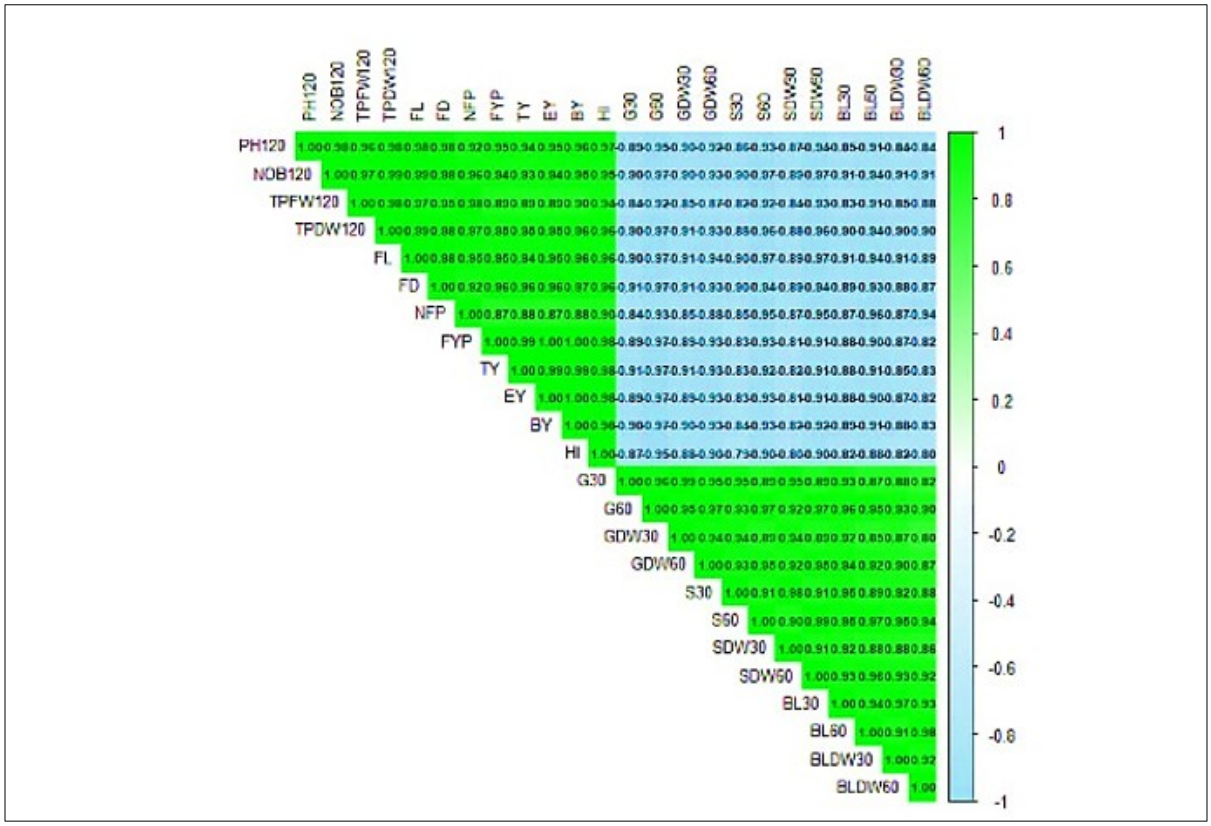
The box plot analysis of crop growth, yield and weed traits revealed considerable variation among the treatments in brinjal. Among the growth traits, plant fresh weight exhibited the highest median value with a relatively wider interquartile range, suggesting substantial variation among the treatments. Plant height and plant dry weight showed moderate variability, indicating the effects of differential treatments on vegetative growth and biomass production (Fig. 5c). In contrast, fruit length, fruit diameter, number of fruits per plant and fruit yield per plant showed a narrow interquartile range, indicating stable performance across the treatments (Fig.5c). Yield parameters such as total yield, economic yield and biological yield exhibited wider boxes with long whiskers, indicating more variation (Fig. 5c). This suggests that certain treatments significantly enhance crop productivity compared to other treatments. Harvest index showed less variability, indicating more consistent partitioning of assimilates towards economic yield. The weed-related traits exhibited lower median values with smaller boxes (Fig. 5c). The presence of extended whiskers and outliers in some traits indicates uneven weed infestation across treatments (Fig. 5c). This variation confirms that weed management treatments performed differently in suppressing weed population and biomass accumulation.

The histogram demonstrated the distribution of 24 traits and variation among the treatments (Fig. 5d). Most of the crop growth and yield traits exhibited a normal distribution, which indicates stable variation across the treatments. Weed-related traits showed skewed distributions, confirming uneven weed infestation under different treatments. Total yield and economic yield were slightly right-skewed, suggesting that only a few treatments achieved comparatively higher yield.

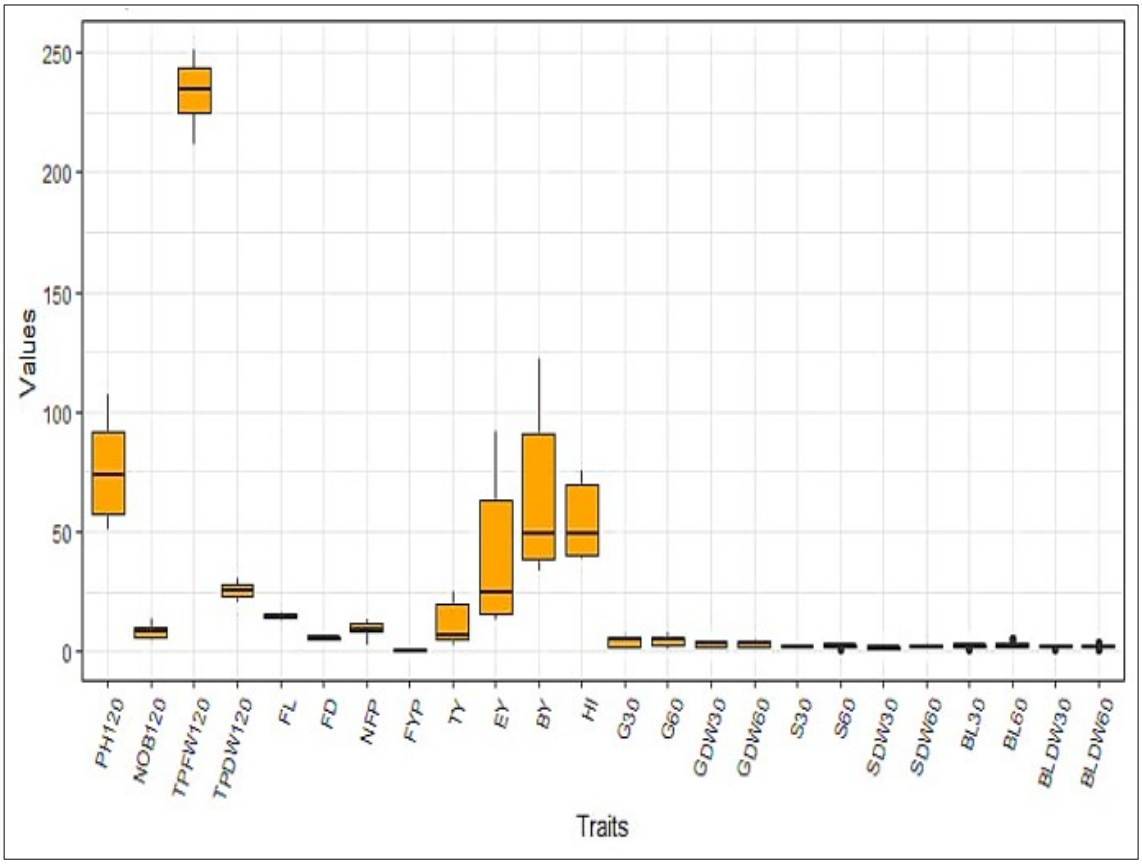


5a. Pearson correlation.

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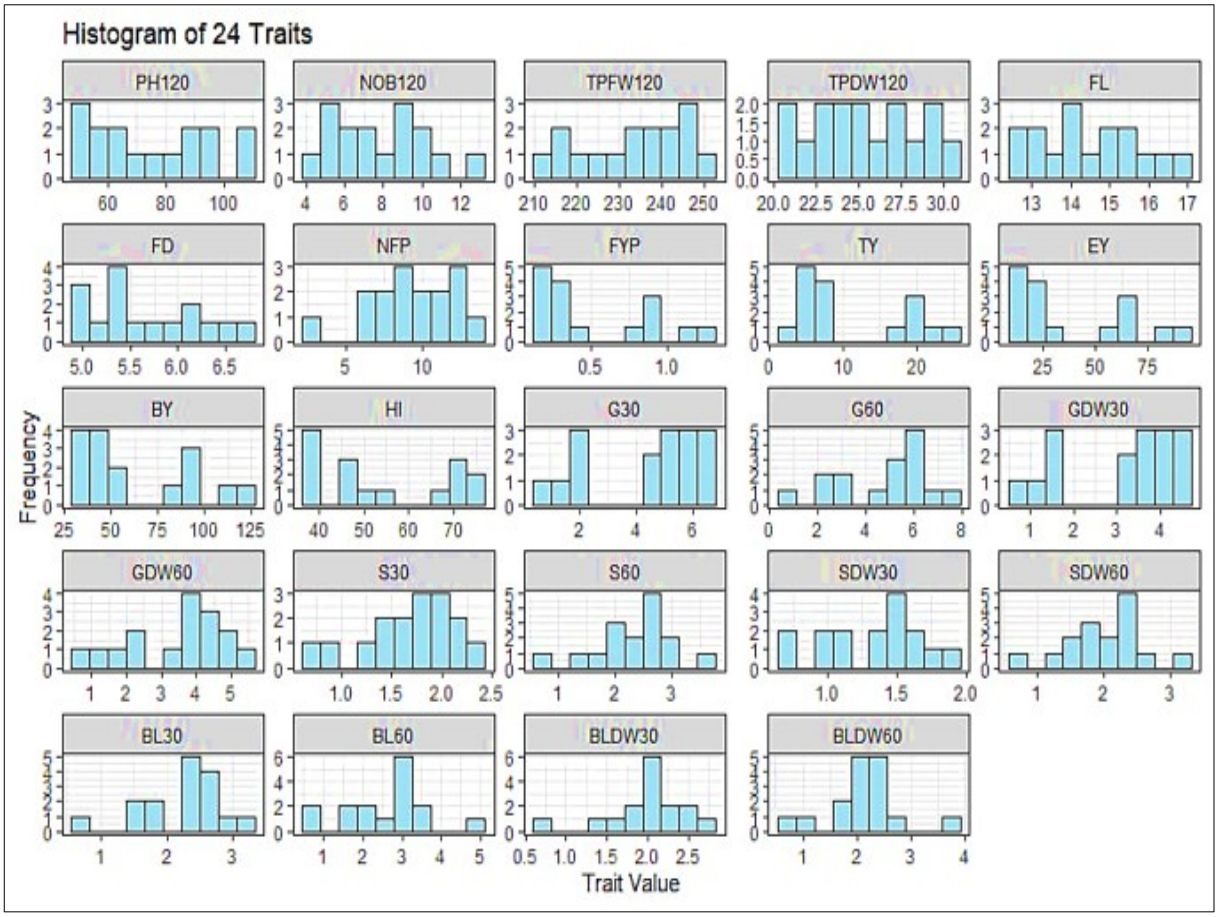


5b. correlation matrix.



5c. Box pot.

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5d. Histogram plots.

Fig. 5. Correlation matrix of growth, yield and weed traits in brinjal.

4. Conclusion

Based on the results of the present investigation, it can be concluded that weed management plays a vital role in improving crop growth, yield and overall productivity of kharif brinjal and uncontrolled weed growth significantly reduces the yield. Although the weed-free plot proved superior in terms of crop growth and yield as well as weed suppression in this study, it is not economically viable due to high labour wages and the unavailability of skilled labour, especially in kharif season. Therefore, there should be a new approach to control weeds, such as integrated weed management, which can be economically and environmentally viable. Therefore, keeping all these points in view, we can conclude that soil solarisation + 1 hand weeding at 30 days after transplanting (DAT) will be a better option for successful weed management since it resulted in the highest benefit-cost ratio. Among all the treatments, soil solarisation along with one hand weeding at 30 days after planting was found to be the best treatment, resulting in the highest net return of ₹396389 ha^{-1} and a benefit-cost ratio of 2.43. The study can be beneficial for brinjal growers who face many difficulties in managing the weed menace in kharif season.

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Authors' contributions

AKD, KP, AM and CJ conceptualised the article. AKD and SA collected and interpreted the research data. AKD, CJ and SP prepared the manuscript. VKG, SP and KP performed the data analysis and language editing. All authors have read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest

Authors do not have any conflict of interests to declare.

Ethical issues

None

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