Heliyon 10 (2024) e36855

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Research article

Determination of critical crop-weed competition period: Impact on growth, nutrient dynamics and productivity of green gram (*Vigna radiata*)

Akshay Kanjibhai Hirani [a], Santosh Korav [a,*], G.A. Rajanna [b], Hosam O. Elansary [c], Eman A. Mahmoud [d]

[a] *Department of Agronomy, School of Agriculture, Lovely Professional University, Phagwara, Jalandhar, 144411, Punjab, India*
[b] *ICAR-Directorate of Groundnut Research, Junagadh, 362001, India*
[c] *Plant Production Department, College of Food and Agriculture Sciences, King Saud University, P.O. Box 2460, Riyadh, 11451, Saudi Arabia*
[d] *Department of Food Science, Faculty of Agriculture, Damietta University, Damietta, 34511, Egypt*

A R T I C L E I N F O

Keywords:
Chlorophyll content
Crop-weed competition
Dry matter accumulation
Nutrient content
Relative yield loss

A B S T R A C T

The critical period of crop-weed competition (CPCWC) varies by cultivars, management strategies, cropping seasons, soil, and climate. Hence, a study was done to assess CPCWC in green gram under different cropping seasons and its impact on nutrient mining, agro-physiological characteristics, and productivity of green gram during the summer and rainy seasons. The experiment comprised of 12 treatments (weed interference until 10, 20, 30, 40, 50 days after sowing (DAS) and crop maturity, weed-free until 10, 20, 30, 40, 50 DAS and crop maturity). The treatments were placed in a randomized complete block design (RCBD) with three replications. Results revealed that, summer green gram outperformed rainy green gram by boosting nutrient uptake, growth and productivity. Weed interference up to crop harvest lowered the green gram dry matter accumulation by 34.11 %, seed index by 8.98 %, grain yield by 76.21 % and biological yield by 31.06 %. However, weed-free until crop harvest boosted nitrogen content by 50.4 %, phosphorus by 87.7 % and potassium by 42.9 %. Similarly, weed-free environment until harvest of the crop raised chlorophyll-a content by 2.9–6.6 fold and 2.7–7.0 fold, chlorophyll-b by 3.8–5.8 fold and 3.8–6.5 fold over season-long weedy plots during summer and rainy season, respectively. This study suggested that the critical duration for crop-weed competition under 5 % relative yield loss (RYL) was 11–43 DAS in summer and 4 to 36 DAS in rainy. Whereas, critical duration for the crop-weed competition at 10 % RYL was 21–36 DAS in summer and 8 to 27 DAS in rainy seasons.

1. Introduction

Pulses play a vital role in Indian Agriculture. India is the largest producer as well as consumer of pulses in the world. Globally, the annual production of green gram (*Vigna radiata* L.) is more than 5.3 MT [1]. It is a short-duration, self-pollinated, diploid legume with high nutritive significance and nitrogen-fixing capacity. It consists 21–27 protein, and other chemical compounds like flavonoids, phenolic acids, organic acids, and lipids [2]. Green gram is cultivated in India, Myanmar, Sri Lanka, Pakistan, China, Fiji, Queens's

* Corresponding author.
E-mail address: santoshkorav@gmail.com (S. Korav).

https://doi.org/10.1016/j.heliyon.2024.e36855
Received 6 July 2024; Received in revised form 22 August 2024; Accepted 23 August 2024
Available online 29 August 2024
2405-8440/

Land, and Africa. It can be cultivated in the *rainy* and summer seasons in India. It is grown in about 1.56 million hectares of area with the highest-ever production of 2.1 MT during 2022-23 [3]. The important green gram growing States in India are Rajasthan, Odisha, Maharashtra, Andhra Pradesh, Madhya Pradesh, Gujarat, and Bihar. A large majority of the country's green gram production comes from summer cultivation, which is primarily grown in Rajasthan, Madhya Pradesh, Punjab, Haryana, western Uttar Pradesh, Gujarat, Assam, and Bengal. In Punjab, green gram is cultivated in 0.024 million hectare area with a production of 0.023million tonnes and with a productivity of 969 kg ha^{-1} during 2020-21. The average highest productivity was recorded in the state of Madya Pradesh (1179 kg ha^{-1}) [4]. The study of critical weed competition periods in green gram is crucial for Punjab's agriculture. It enables farmers to optimize yields, use resources efficiently, and implement regionally-specific practices. This research directly impacts the economic viability of green gram cultivation, promotes sustainable farming, and improves crop quality. Understanding these critical periods is essential for developing effective weed management strategies tailored to Punjab's unique agricultural conditions.

Growth and productivity of green gram are substantially reduced by weed competition for nutrients, light, moisture and space etc. The significant weed infestation that arises from initial crop growth stages. Weed control during the early stages of green gram is critical for maintaining optimal crop growth. Weeds grow profusely and obstruct the crop's ability to absorb water and nutrients. They restrict the crop's access to light and space as well. Weeds reach maturity earlier than crops and drop their seeds into the soil, thus increasing the weed seed bank there [5]. Similarly, the economic value of the crop is decreased by weed seeds that are mixed up with it, which helpstheir spread to other places. The sedges viz., *Cynodondactylon, Dactylocteniumaegyptium, Celotiaargentia Cyperus rotundus*and broadleaf weeds *viz.,Digera arvensis, Trianthemaportulacastrum, Commelina bengalensis, Parthenium hysterphorus, Euphorbia hirta, Hemidismus indica* are major weeds of green gram in southern regions of India [6]. *Ageratum conyzoids, Boreriahispida, Commelinabanghalensis, Echinochloacolona, Cynodondactylon, Paspalum scrobiculatum, Digiteriasanguinalisand Cyperus rotundus*in eastern parts of India [7], *Cyperus rotundus, Echinochloacrusgalli, Digitariasanguinalist, Sorghum halepense, Cynodondactylon, Amaranthus viridis, Alternanthera sessillis, Digeraarvensiss,* and *Convolvulus arvensis* in western parts of India [8]. Pendimethalin, which controls grassy and broadleaf weeds, is registered in India for weed management in green gram. Hand weeding is another common practice. These techniques are the labor-intensive and costly. Herbicides pose a threat to ecosystems. Therefore, integrated weed management strategies are recommended for developing optimal weed control strategies and efficient herbicide use. The critical period of crop-weed competition (CPCWC) is an important factor to consider while developing an integrated weed management system and alternative weed management strategies. Zimdahl [9,10] defined CPCWC as the intervening time period following seeding or emergence when weed competition does not reduce crop yield and the time period after which weed competition no longer reduces crop yield. Knezevic et al. [11] defined CPCWC as a "window" in the crop growth cycle during which weeds must be controlled in order to avoid unacceptable yield losses.

At initial crop growth of 25–30 days after sowing (DAS), crop-weed competition is more [12]. Thus, CPCWC has been established for a range of crop species and environments. However, there are limited published studies on the critical period for weed control in pulses. CPCWC in chick pea was 17–49 days after emergence (DAE) Mohammadi et al. [13]; 30 to 60 DAS in pigeon pea and 30 to 45 DAS in black gram [14,15]); 15 to 60 DAS in *rainy* groundnuts [16], 15 to 63 DAE in *rabi* groundnut [17]. There are very few reports on CPCWC in green gram and a study from Punjab has reported CPCWC in the range of20–40 DAS [18]. Weed infestation in green gram can reduce the grain yield by 30–90 % due to poor weed management practices [19–22]. The degree of yield losses in green gram induced by weeds depend on the weed type, weed density, and the length of the crop-weed competition. As a result, targeting the critical weeding window is crucial for effective weed control. Therefore, this study was planned with the objective to investigate the competitive effect of growing seasons and weeds on green gram growth dynamics and productivity as well as to determine the CPCWC in green gram under different cropping seasons. Mixed natural weed populations were used to estimate the critical period applicable to typical field situations, and weed control timing was related to days after green gram emergence.

2. Materials and methods

2.1. Weather of experimental site

The experiment was carried out at the research farm of Lovely Professional University's School of Agriculture at Jalandhar, Punjab. It was located at $75^0.42'$ E longitude and $31^0.1'$N latitude, at an elevation of 235 m above mean sea level (MSL). The topography of the experimental site was found to be nearly homogeneous, with good surface drainage. Summertemperatures ranged from 27 °C to 41 °C, with relative humidity ranging from 21 to 64 % and total rainfall of 192 mm. While the *Rainy*season had temperatures ranging from 25 °C to 37 °C, a relative humidity of 62–76 %, and a total rainfall of 285 mm, respectively during experimentation.

2.2. Experimental design

The experiment was carried out in a randomized block designwith three replicationhaving twelve treatments, namely weedy until maturity (T1), weedy up to 10 days after sowing (DAS) (T_2), weedy up to 20 DAS (T_3), weedy up to 30 DAS (T_4), weedy up to 40 DAS (T_5), weedy up to 50 DAS (T_6), weed-free until maturity (T_7), weed-free up to 10 DAS (T_8), weed-free up to 20 DAS (T_9), weed-free up to 30 DAS (T_{10}), weed-free up to 40 DAS (T_{11}) and weed-free up to 50 DAS (T_{12}) during summer (February–May) and *rainy* (June–September) seasons of 2022. The 'Vishwas Magic' variety of green gram (total duration 90 days) was sown on April 12, 2022, and July 4, 2022, during summer and *rainy* seasons, respectively, with a spacing of 30 × 10 cm. At the time of sowing, the recommended NPK doses (20:40:20 kg ha^{-1}) were supplied through Urea, DAP, and MOP. Manual weeding was used to control weeds according to the treatment details.

2.3. Floristic distribution of weeds at the experimental site

The details of species-wise weeds observed in the experimental plot are summarized in Table 1.

2.4. Observations

2.4.1. Weed density

The total density of weeds was recorded at each stage i.e., 10, 20, 30, 40, and 50 DAS, and at maturity using 1 m^2 quadrat in each plot and counting the total number of weed species, and expressed as number of weeds per m^2.

2.4.2. Crop growth rate

The crop growth rate (CGR), rate of dry matter production per unit land area per unit time, was worked out by using the formula proposed by Watson [23] and expressed as g m^{-2} day^{-1}.

$$CGR = \frac{W2 - W1}{t2 - t1} \times \frac{1}{p}$$

where, W1 and W2 are dry matter production (g) per plant at time t1 and t2, respectively,

p = Ground area covered by the plant (m^2)

2.4.3. Chlorophyll estimation

The third leaf of the green gram plant from the top was sampled and ground with an 80 % acetone solution for chlorophyll estimation. The final 25 ml aliquot was taken, and absorbance at 645 and 663 nm or Spectronic-20 for chlorophyll 'a' and chlorophyll 'b' was measured. Arnon [24] formulae were used to compute Chlorophyl-a and Chlorophyl-b. It was estimated at two growth stages of green gram i.e., 30 and 50 DAS.

Chlorophyll 'a' (mg g^{-1}FW) = [(12.72 x A663) – (2.58 x A645)] x V/1000 x 1/W

Chlorophyll 'b' = [(22.87 x A645) – (4.67 x A663)] x V/1000 x 1/W

Where, FW- fresh weight, V- volume, W- sample weight.

2.4.4. Nutrient content of crop and weeds

For estimation of crop nutrient content, crop plants were harvested at maturity, washed in running water, and dried in the sun. Similarly, weeds from the net plot area were harvested close to the ground at 15-day intervals, washed in running water, and dried in the sun. Following a week of shade drying, both plant and weed samples were placed in a hot air oven at 60 ± 5 °C until they reached a constant weight. Plant and weed samples were ground separately in a mechanical grinder. The grounded sampleswere used to analyze total N, P, and K using the standard procedures outlined in Table 2.

Table 1
Weed flora of green gram during *summer* and *rainy* seasons of 2022.

Scientific name	Common name	*Summer*	*Rainy*
Digitaria sanguinalis	Large crabgrass	+	+
Portulaca oleracea	Common purslane	+	+
Cyperus rotundus	Purple nutsedge	+	-
Phyllanthus niruri	Stonebreaker	+	-
Sorghum happens.	Johnson grass	-	+
Chenopodium album	Common lambsquarter	+	+
Amaranthus viridis	Slender amaranth	+	+
Eleusine indica	Goosegrass	+	+
Mollugo nubicaulis	Nakedstem carpetweed	+	-
Trianthema portulacastrum	Horse purslane	+	+
Cyperus tenuis pica	Slender spiked sedge	+	+
Boerhavia erecta	Erect spiderling	+	+
Cynodon dactylon	Bermuda grass	+	-
Parthenium hysterphorus	Congress grass	-	+
Echinochloa colona	Jungle rice	-	+
Sinapis arvensis	Wild mustard	+	-
Euphorbia hirta	Snake weed	-	+
Physalis minima	Bladder cherry	-	+
Celosia argentea	Red fox	-	+

(+) weed present and (−) weed missing.

Table 2
Methodology for nutrient content estimation of crop and weeds.

Nutrient Content	Methodology	References
N	Kjeldahl's method	[25]
P	Olsen's method	[26]
K	Flame photometer	[27]

2.5. Statistical analysis

The data were analyzed and interpreted using Fisher's method of analysis of variance, as reported by Ref. [28]. A separate analysis of the field data was done for each season to explain the twelve different treatments for estimation of critical period of crop-weed competition. The means of treatments were compared on Duncan Multiple Range Test (DMRT) at $p \leq 0.05$ with the standard deviation and least significant difference (LSD) computed by SPSS window version 21.0 (SPSS Inc., Chicago, IL, USA) and Statistix 10 [29]. RStudio was used to depict graphical representation of the data [30].

2.6. CPCWC estimation

The effect of increasing the weed-free period on crop yield was described using the Gompertz equation, as suggested by Hall et al. [31], Knezevic et al. [11], and Johnson et al. [32].

$$RY = y0 + a \times \exp\left[-\exp\left(-\frac{(x - x0)}{b}\right)\right] \tag{1}$$

Where,
RY = indicates relative yield (% season-long weed-free yield),
y0 = lower limit,
a = upper limit, and b = slope
x0 = days to give 50 % yield,
x = number of days.

The seed yield of each weed-free period treatment was converted to a percentage and regarded as a relative yield. Statistical analysis was performed separately for each year in regression analyses due to differences in growing degree days (GDD), which was

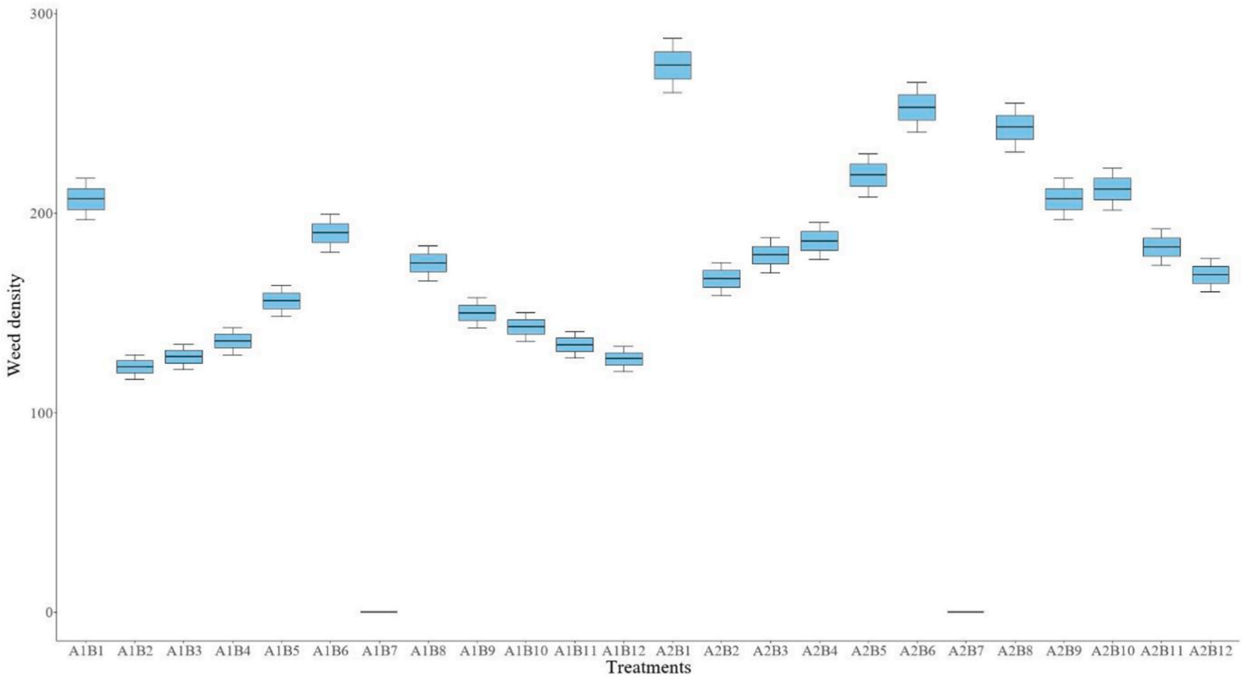


Fig. 1. Effect of growing seasons and critical period of crop-weed competition interaction on mean weed density of green gram during the *summer* and *kharif* seasons of 2022. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

used as an explanatory variable. A four-parameter log-logistic model with the D term set to 100 was used to analyze data on relative yield (% weedy) [33].

$$Y = \frac{D}{(1 + \exp[B(\log X - \log E])} \quad (2)$$

Where,

Y = response (e.g., relative yield),
D = upper limit.
X = calculated GDD after crop emergence,
E = GDD giving a 50 % response between the upper and lower limit (also known as the inflection point, $I50$)
B = slope of the line at the inflection point (the rate of change).

3. Results

Yield is eventually a result of crop growth. Crop growth is the net result of interplay of diverse metabolic activities taking place in different parts of a plant during its growth and development. It is well defined that; the infrastructure of plant is decided by plant height and dry matter accumulation. The metabolic activities and synthesis, accumulation and translocation of metabolites to the economic part are decided by the infrastructure of plant which is often influenced by different agronomic practices including weed management.

3.1. Distribution of weed flora, and their density in the experimental area

During experimentation, total of 19 different weed species were observed. Whereas 13 and 14 weed species were observed during summer and *rainy*, respectively. The details of species-wise weeds observed and its density observed in the study were calculated and summarized in Table 1 and Fig. 1. In both seasons *Digitaria sanguinalis*, *Cynodon dactylon, Phyllanthus niruri, Chenopodium album,* and *Eleusine indica* were predominant weeds. The *rainy* season had higher weed density (169–274 weeds m^{-2}) as compared to summer (Fig. 1). The maximum weed density(207 and 274weeds m^{-2} in summer and *Rainy,* respectively) was recorded in weedy until maturity (T_1) followed by the T_6 (weedy up to 50 DAS).

3.2. Plant height

The plant height of green gram through-out the crop growth period found significantly superior in summer season (5.06 cm at 10 DAS to 40.01 cm at maturity) as compared to *rainy* season (4.85 cm at 10 DAS to 39.77 cm at maturity) (Table 3). Similarly, effect of

Table 3
Effect of a cropping season and critical period of crop-weed competition on plant height (cm) of green gram during the summer and *Rainy* seasons of 2022.

Treatment	10 DAS	20 DAS	30 DAS	40 DAS	50 DAS	Maturity
A. Season						
Summer	5.06a±0.31	7.26a±0.55	14.46a±0.64	28.15a±1.68	33.06a±1.27	40.01a±1.32
Rainy	4.85b ± 0.51	5.96b ± 0.66	6.97b ± 0.65	14.47b ± 0.58	32.84b ± 1.24	39.77b ± 1.17
CD	0.119	0.16	0.269	0.524	0.531	0.539
B. Critical period of crop-weed competition						
T1: Control (weedy up to crop maturity)	4.23g ± 1.82	5.70i±3.39	9.65h ± 16.57	19.54f±24.21	30.94g ± 0.47	37.87g ± 0.30
T2: Weedy up to 10 DAS	4.91cde ± 0.13	6.42e±2.40	11.46a±18.94	20.98cde ± 27.26	32.81d ± 0.55	39.80de ± 0.11
T3: Weedy up to 20 DAS	4.77e±0.62	6.29ef±2.44	10.49defg±15.63	20.83de ± 27.35	32.54de ± 0.47	39.59de ± 0.02
T4: Weedy up to 30 DAS	4.68ef±0.89	6.17 fg ± 2.84	10.42efg±15.68	20.63def±27.66	32.07ef±0.42	38.95ef±0.25
T5: Weedy up to 40 DAS	4.53f±1.40	6.04gh ± 2.93	10.24 fg ± 16.31	20.24def±27.64	31.74f±0.47	38.69 fg ± 0.28
T6: Weedy up to 50 DAS	4.86de ± 0.34	5.895h ± 3.20	9.99gh ± 16.36	19.99ef±27.32	31.59f±0.17	38.33 fg ± 0.38
T7: Weed-free (up to maturity)	5.79a±0.40	7.45aa±2.23	11.01abcd±13.70	22.70a±31.40	34.87a±0.85	41.80a±1.38
T8: Weed-free up to 10 DAS	5.06bcd ± 0.02	6.77d ± 3.14	10.69cdef±15.58	21.33bcd ± 28.75	32.92d ± 0.36	39.96cd ± 0.21
T9: Weed-free up to 20 DAS	5.10bc±0.11	6.94c±2.86	10.90bcde ± 15.32	22.11abc±31.47	33.43c±0.59	40.17cd ± 0.19
T10: Weed-free up to 30 DAS	5.15bc±0.08	7.04c±2.67	11.08abc±15.44	22.29 ab ± 32.08	33.77bc±0.49	40.68bc±0.64
T11: Weed-free up to 40 DAS	5.17b ± 0.11	7.21b ± 2.76	11.24 ab ± 15.32	22.50a±31.62	34.06b ± 0.36	41.21 ab ± 1.46
T12: Weed free up to 50 DAS	5.2b ± 0.04	7.40a±2.38	11.47a±15.74	22.62a±31.33	34.72a±0.36	41.64a±1.48
CD	0.293	0.393	0.659	1.283	1.302	1.319
AxB	0.415	NS	NS	NS	NS	NS

The figures for seasons and CPCWC within columns with different letters differed significantly from each other (P ≤ 0.05 least significant difference with ±SE).

different crop-weed competition periods was significant on plant height of green gram. At maturity, plant height of the green gram was significantly higher (41.80 cm) when crop was weed free up to maturity (T_7) when compared to other treatments. However, it was on par with weed free up to 50 and 40 DAS ($T_{11}$and T_{12}). Contrarily, significantly lower plant height was noticed under control-weedy check (T_1) as compared to rest of the treatments. Season long weedy treatment produced 9.40% lowest plant height at maturity over season long weed free treatment.

3.3. Plant dry matter accumulation

Significantly higher dry matter was accumulated during summer season as compared to *Rainy*. At maturity, plant dry matter was 19.19 g plant^{-1} in summer and 16.91 g plant^{-1} in *Rainy*. The dry matter accumulation of green gram was highest at maturity which ranged from 13.99 to 21.24 g plant^{-1}. At maturity, the significantly superior dry matter accumulation was observed when crop was weed-free until maturity (T_7), however, it was statistically similar to the weed-free up to 40 DAS (T_{11}) and 50 DAS (T_{12}). On the other side, the lowest dry matter accumulation (13.99 g plant^{-1}) was found when crop was weedy until maturity (T_1). The weed interference in weedy check (T_1) reduced dry matter accumulation by 34.11 % over weed free up to maturity(Table 4).

3.4. Chlorophyll a and b

Summer season performed well and achieved higher chlorophyll content over *Rainy*season. Weed competition leads to a decrease in the chlorophyll content and vice-versa at all stages of the green gramduring both summer and *Rainy*seasons. The season-long weed-free plots accumulated maximum chlorophyll *a* (CHL-a) (0.5–0.67 mg g^{-1} and 0.47–0.55 mg g^{-1} in summer and *Rainy,* respectively) and chlorophyll *b* (CHL-b) (0.27–0.36 mg g^{-1} and 0.25–0.33 mg g^{-1} in summer and *Rainy,* respectively). The lowest chlorophyll content was found in season-long weedy plots. Similarly, at 50 DAS, weed-free plots accumulated chlorophyll-a by 2.9–6.6 fold and 2.7–7.0 fold, chlorophyll-b by 3.8–5.8 fold and 3.8–6.5 fold over season-long weedy plots during summer and *Rainy* seasons, respectively (Fig. 2a and b).

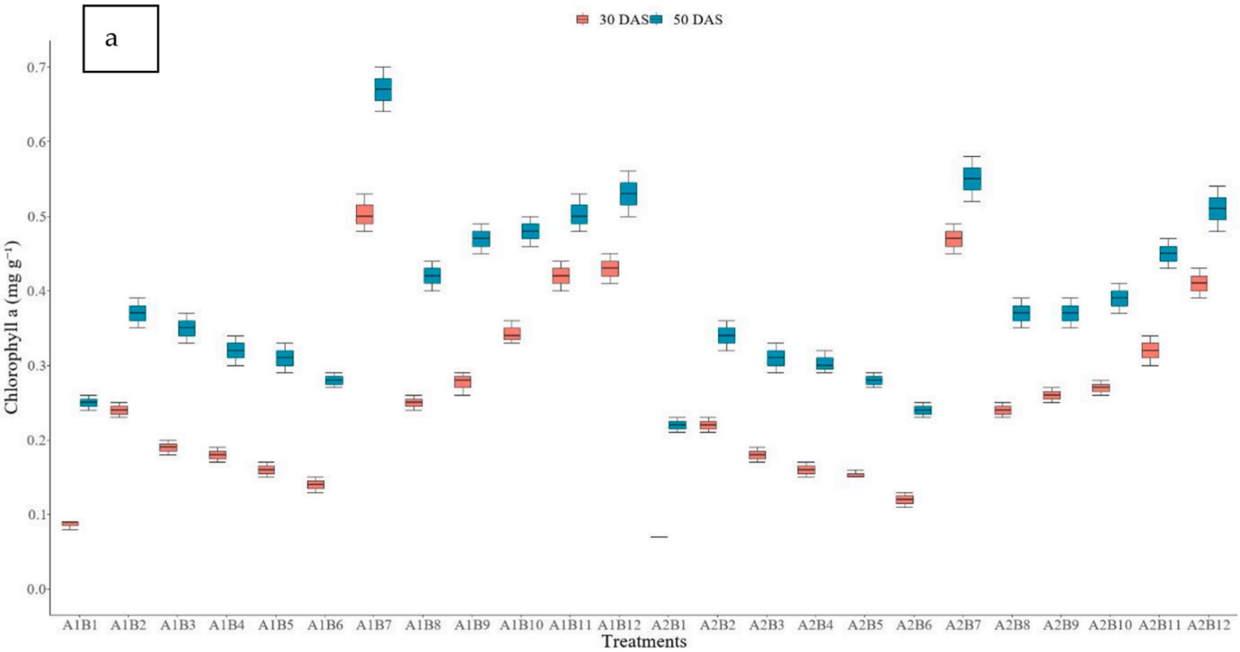
3.5. Crop growth rate (CGR)

At maturity, summer green gram recorded 15.34 % higher CGR (2.24 g m^{-2} day^{-1}) over *rainy* green gram (1.94 g m^{-2} day^{-1}). Among different periods of crop-weed competition, maximum CGR was noticed at 30–40 DAS. Further, weed-free periods until maturity (T_7) accounted significantly higher CGR (3.51 g m^{-2} day^{-1}) as compared to rest of the treatments except weed-free up to 40 DAS (T_{11}) and 50 DAS (T_{12}), which were on par with each other. Whereas, weedy until maturity (T_1) resulted in the lowest crop growth rate (2.71 g m^{-2} day^{-1}). Furthermore, the weed interference for longer periods reduced the crop growth rate in both seasons. Season-long weed interference reduced CGR by 22.63 percent over season-long weed-free plots (Table 5).

Table 4
Effect of cropping season and critical period of crop-weed competition on plant dry weight (g plant^{-1}) of green gram during summer and *Rainy* seasons of 2022.

Treatment	20 DAS	30 DAS	40 DAS	50 DAS	Maturity
A. Season					
Summer	0.61a±0.12	1.40 ± 0.20	2.21a±0.26	12.47a±1.08	19.19a±2.46
Rainy	0.59b ± 0.14	1.21b ± 0.20	2.11b ± 0.28	11.08b ± 1.07	16.91b ± 2.28
CD	0.015	0.032	0.053	0.285	0.438
B. Critical period of crop-weed competition					
T1: Control (weedy up to crop maturity)	0.39j±0.15	0.95l ± 0.31	1.66k±0.19	9.82j±2.16	13.99i±0.57
T2: Weedy up to 10 DAS	0.59e±0.10	1.30g ± 0.40	2.16f±0.23	11.77e±3.14	18.00e±5.07
T3: Weedy up to 20 DAS	0.55f±0.08	1.26h ± 0.52	2.098g ± 0.35	11.45f±3.14	17.33f±5.01
T4: Weedy up to 30 DAS	0.51g ± 0.07	1.20i±0.47	2.01h ± 0.35	11.20g ± 3.54	16.66g ± 6.05
T5: Weedy up to 40 DAS	0.47h ± 0.08	1.13j±0.37	1.92i±0.36	10.80h ± 3.03	15.75h ± 6.39
T6: Weedy up to 50 DAS	0.43i±0.06	1.07k±0.50	1.83j±0.23	10.37i±3.01	15.19h ± 4.84
T7: Weed-free (up to maturity)	0.78a±0.07	1.62a±0.42	2.56a±0.18	13.10a±2.55	21.24a±3.78
T8: Weed-free up to 10 DAS	0.61e±0.11	1.35f±0.35	2.19f±0.17	12.00d ± 3.22	18.39de ± 5.41
T9: Weed-free up to 20 DAS	0.66d ± 0.05	1.38e±0.32	2.26e±0.17	12.39c±3.12	18.97d ± 5.98
T10: Weed-free up to 30 DAS	0.70c±0.03	1.42d ± 0.37	2.34d ± 0.07	12.67b ± 2.82	19.72c±5.88
T11: Weed-free up to 40 DAS	0.73b ± 0.02	1.48c±0.39	2.39c±0.02	12.81b ± 2.93	20.43b ± 4.67
T12: Weed free up to 50 DAS	0.76a±0.06	1.53b ± 0.35	2.50b ± 0.23	12.96a±2.78	20.96 ab ± 4.45
CD	0.037	0.078	0.129	0.698	1.074
AxB	NS	NS	NS	NS	NS

The figures for seasons and CPCWC within columns with different letters differed significantly from each other (P ≤ 0.05 least significant difference with ±SE).



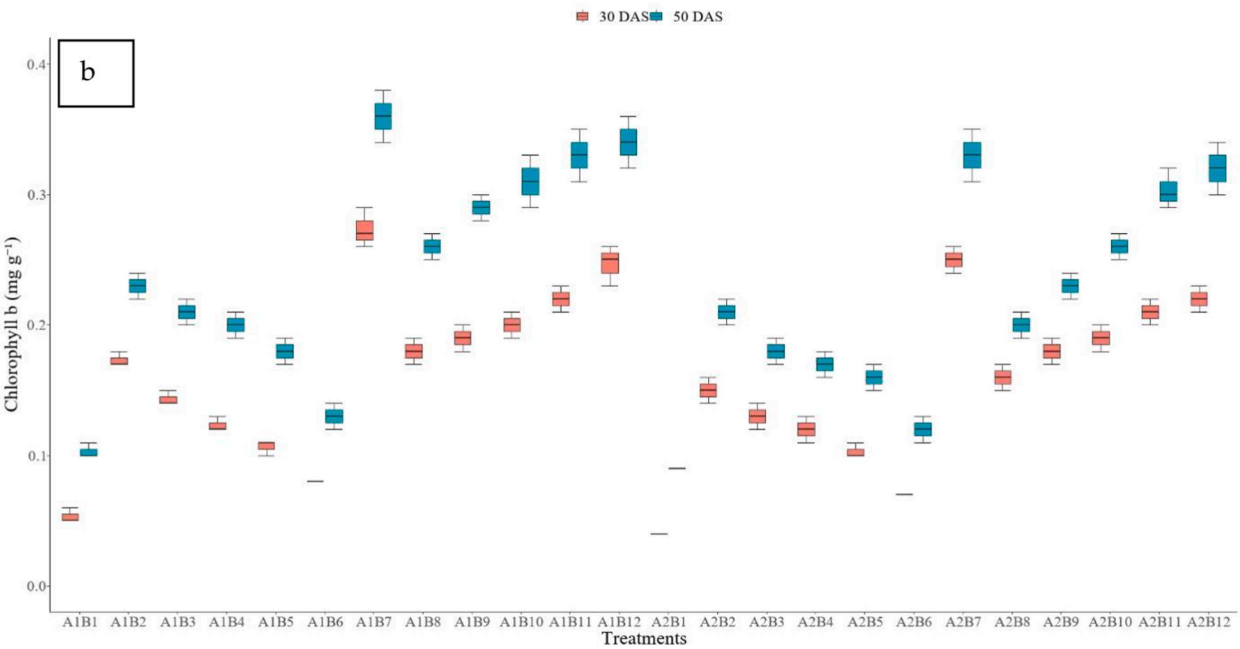


Fig. 2. (a–b) Effect of growing seasons and critical period of crop-weed competition interaction on chlorophyll (a and b) of green gram during the *summer* and *kharif* seasons of 2022. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

3.6. Yield attributes

Summer green gram out performed *Rainy*season with respect to yield attributes i.e. number of pods plant^{-1} (24.71 no.), pod length (8.47 cm), grain pod^{-1} (9.31 no.) and seed index (45.11 %) over Rainy. Further, among the varying periods of crop weed competition, significantly the highest number of pods plant^{-1} (33.54 no.), pod length (9.98 cm), grain pod^{-1} (11.16 no.) and seed index (47.21 %) were recorded when crop was weed-free until maturity (T_7) as compared to weed-free up to 50 DAS (T_{12}). Contrarily, the lowest yield

Table 5
Effect of cropping season and critical period of crop-weed competition on crop growth rate (CGR) (g m^{-2} day^{-1}) of green gram during summer and *Rainy* seasons of 2022.

Treatment	0-10 DAS	10-20 DAS	20-30 DAS	30-40 DAS	40-50 DAS
A. Season					
Summer	0.20a±0.04	0.26a±0.03	0.27a±0.05	3.42a±0.28	2.24a±0.46
Rainy	0.19b ± 0.05	0.20b ± 0.02	0.29b ± 0.03	2.99b ± 0.26	1.94b ± 0.41
CD	0.005	0.006	0.008	0.078	0.051
B. Critical period of crop-weed competition					
T1: Control (weedy up to crop maturity)	0.13i±0.05	0.18h ± 0.05s	0.23d ± 0.04	2.71 j ±0.66	1.39h ± 0.53
T2: Weedy up to 10 DAS	0.20d ± 0.03	0.23de ± 0.10	0.32a±0.09	3.20e±0.97	2.07de ± 0.64
T3: Weedy up to 20 DAS	0.18e±0.03	0.23de ± 0.15	0.30 ab ± 0.06	3.11f±0.93	1.95ef±0.62
T4: Weedy up to 30 DAS	0.17f±0.02	0.23ef±0.13	0.27c±0.04	3.06g ± 1.06	1.82f±0.83
T5: Weedy up to 40 DAS	0.16g ± 0.03	0.22 fg ± 0.10	0.23d ± 0.12	2.96h ± 0.89	1.65g ± 1.12
T6: Weedy up to 50 DAS	0.14h ± 0.02	0.21g ± 0.15	0.22d ± 0.24	2.84i±0.93	1.60g ± 0.61
T7: Weed-free (up to maturity)	0.26a±0.02	0.28a±0.16	0.31a±0.08	3.51a±0.79	2.71a±0.41
T8: Weed-free up to 10 DAS	0.20d ± 0.04	0.24bcd ± 0.08	0.28BCE±0.06	3.27d ± 1.02	2.13d ± 0.73
T9: Weed-free up to 20 DAS	0.22c±0.02	0.24cde ± 0.09	0.29abc±0.05	3.37c±0.98	2.19cd ± 0.95
T10: Weed-free up to 30 DAS	0.23b ± 0.01	0.23de ± 0.11	0.30 ab ± 0.10	3.44b ± 0.92	2.35c±1.02
T11: Weed-free up to 40 DAS	0.24b ± 0.01	0.25bc±0.14	0.30 ab ± 0.12	3.47 ab ± 0.97	2.53b ± 0.58
T12: Weed free up to 50 DAS	0.25a±0.02	0.25bc±0.14	0.32a±0.04	3.48 ab ± 0.85	2.66 ab ± 0.56
CD	0.013	0.015	0.021	0.19	0.126
AxB	NS	0.021	0.029	NS	0.178

The figures for seasons and CPCWCwithin columns with different letters differed significantly from each other($P \leq 0.05$ least significant difference with ±SE).

attributes were recorded when crop was weedy until maturity (T_1). Extent of reduction in yield attributes due to weedy condition until maturity was 53.08 % in pods $plant^{-1}$, 35.02 % in pod length, 34.76 % in grains pod^{-1} and 8.98 % in seed index as compared to weed-free condition until maturity of the crop(Table 6).

3.7. Grain yield and biological yield

Significantly superior grain yield (9.01 q ha^{-1}) and biological yield (40.30 q ha^{-1}) was realized in summer over *Rainy*. Further, season-long weed-free crop (T_7) achieved significantly higher grain yield (13.70 q ha^{-1}) and biological yield (46.95 q ha^{-1}) over rest of the treatments. However, it found on par with weed-free up to 50 DAS (T_{12}). Conversely, weedy plots through-out the crop season exhibited significantly lower grain and biological yields. Crops kept weed free up to its maturity produced 320 % and 45 % more grain

Table 6
Effect of cropping season and critical period of crop-weed competition on yield and attributes of green gram during summer and *Rainy* seasons of 2022.

Treatment	Pods $plant^{-1}$	Pod length (cm)	Grains pod^{-1}	Seed index
A. Season				
Summer	24.71a±6.47	8.47a±1.09	9.31a±1.20	45.11a±1.39
Rainy	23.52b ± 6.19	8.20b ± 1.17	9.06b ± 1.26	44.83b ± 1.30
CD	0.601	0.203	0.223	0.576
B. Critical period of crop-weed competition				
T1: Control (weedy up to crop maturity)	15.74k±1.27	6.48j±1.51	7.28k±0.74	42.97h ± 0.28
T2: Weedy up to 10 DAS	22.95g ± 4.62	8.22f±0.55	8.97g ± 0.57	44.74e±0.61
T3: Weedy up to 20 DAS	21.16h ± 3.18	7.87g ± 0.13	8.63h ± 0.45	44.60e±0.13
T4: Weedy up to 30 DAS	19.12i±1.48	7.70g ± 0.38	8.41i±0.74	43.98f±0.78
T5: Weedy up to 40 DAS	16.97j±0.17	7.32h ± 0.91	7.96j±0.64	43.70 fg ± 0.38
T6: Weedy up to 50 DAS	16.17k±3.12	6.96i±0.70	7.74k±0.78	43.39g ± 0.66
T7: Weed-free (up to maturity)	33.54a±2.44	9.98a±0.72	11.16a±0.57	47.21a±1.22
T8: Weed-free up to 10 DAS	25.75f±2.76	8.48e±0.30	9.45f±0.36	44.77e±0.15
T9: Weed-free up to 20 DAS	27.12e±0.91	8.78d ± 0.72	9.71e±0.30	45.47d ± 0.70
T10: Weed-free up to 30 DAS	28.65d ± 1.51	9.00c±0.55	9.79d ± 0.34	45.91c±0.19
T11: Weed-free up to 40 DAS	30.58c±4.14	9.49b ± 1.06	10.32c±0.36	46.31BCE±0.83
T12: Weed free up to 50 DAS	31.66b ± 4.73	9.81a±0.06	10.80b ± 0.38	46.60b ± 1.00
CD	1.471	0.496	0.547	1.412
AxB	NS	NS	NS	NS

The figures for seasons and CPCWC within columns with different letters differed significantly from each other($P \leq 0.05$ least significant difference with ±SE).

and biological yield, respectively, over the season long weedy situations. Besides, weed infestation reduced the grain yield by 1.62–76.21 % and biological yield by 1.85–31.06 % (Table 7).

3.8. Nutrient content of green gram

Summer season green gram accumulated significantly higher NPK over r*ainy* season green gram. Weed-free conditions up to maturity (T_7) significantly increased NPK accumulation in crop when compared to rest of the treatments. Increased uptake of NPK in weed free up to maturity (T_7) was to an extent of 50.4 %, 87.7 % and 42.9 %, respectively, over control or weedy check (T_1) which accumulated the lowest nutrients(Table 8).

3.9. Nutrient content of weeds

Rainy season weeds accumulated the maximum NPK content over the summer season crop. Increased accumulation in *Rainy* crop was to an extent of 9.76 %, 8.08 % and 7.33 % N, P and K respectively. Further, weedy crop until 10 DAS (T_2) accumulated significantly maximum nitrogen (2.31 %), phosphorus (1.225 %) and potassium (2.09 %) than other treatments (Table 8).

3.10. Critical period of crop-weed competition

The CPCWC significantly differed during the summer and *Rainy* seasons (Figs. 3 and 4). The critical duration for crop-weed competition under 5 % relative yield loss (RYL) was 11–43 DAS in summer and 4 to 36 DAS in *rainy*. Similarly, at 10 % RYL, the CPCWC was 21–36 DAS and 8 to 27 DAS, respectively, during summer and *Rainy* seasons.

3.11. Relationship between crop season, and weed interference period with crop growth, productivity nutrient content of green gram

Cropping season and weed interference periods showed significant correlation with crop growth, productivity and its nutrient content of green gram during 2022 (Fig. 5). Growth parameters like, plant height (0.74 and 0.83) dry matter accumulation (0.79 and 0.86), crop growth rate (0.82 and 0.87), yield attributes like seed index (0.76 and 0.87), grain per pod (0.85 and 0.92), pod length (0.86 and 0.92), pods per plant (0.87 and 0.91) and plant nutrients content like nitrogen (0.75 and 0.82), phosphorus (0.85 and 0.74) and potassium (0.79 and 0.88) of green gram was found to show significant positive strong correlation ($p < 0.01$ and $p < 0.05$) for grain and biological yield of green gram, respectively.

Table 7
Effect of cropping season and critical period of crop-weed competition on grain yield (q ha^{-1}) of green gram during the summer and*Rainy* seasons of 2022.

Treatment	Grain yield		Biological yield	
	Yield (q ha^{-1}) (±SD)	Yield loss (%)	Yield (q ha^{-1}) (±SD)	Yield loss (%)
A. Season				
Summer	9.01a±3.99	–	40.30a±4.96	–
Rainy	8.71b ± 4.03	3.32	39.61b ± 4.99	1.71
CD	0.23		0.97	
B. Critical period of crop-weed competition				
T1: Control (weedy up to crop maturity)	3.26g ± 0.32	76.21	32.36h ± 0.71	31.06
T2: Weedy up to 10 DAS	11.45e±2.78	16.41	42.86de ± 3.67	8.70
T3: Weedy up to 20 DAS	9.75f±7.42	28.84	40.58f±7.89	13.57
T4: Weedy up to 30 DAS	5.85f±4.88	57.30	36.19g ± 5.41	22.91
T5: Weedy up to 40 DAS	3.85g ± 1.06	71.89	33.42h ± 2.18	28.81
T6: Weedy up to 50 DAS	3.42g ± 0.53	74.99	32.46h ± 0.91	30.85
T7: Weed-free (up to maturity)	13.70a±0.62	–	46.95a±3.18	–
T8: Weed-free up to 10 DAS	5.25de ± 5.30	61.67	36.84g ± 4.29	21.53
T9: Weed-free up to 20 DAS	10.75cd ± 3.18	21.54	42.23e±2.95	10.04
T10: Weed-free up to 30 DAS	12.40bc±1.27	9.50	44.14cd ± 1.10	5.98
T11: Weed-free up to 40 DAS	13.14 ab ± 0.59	4.21	45.37bc±0.49	3.35
T12: Weed free up to 50 DAS	13.48 ab ± 0.08	1.62	46.08 ab ± 1.36	1.85
CD	0.58		2.38	
AxB	0.81		3.36	

The figures for seasons and CPCWC within columns with different letters differed significantly from each other ($P \leq 0.05$ least significant difference with ±SD).

Table 8
Effect of cropping season and critical period of crop-weed competition on % NPK in a plant of green gram and weed during the *summer and Rainy* seasons of 2022.

Treatment	Green gram			Weed		
	% N	% P	% K	% N	% P	% K
A. Season						
Summer	1.57a±0.28	0.68a±0.23	1.70a±0.19	1.06a±0.78	0.71a±0.38	1.24a±0.84
Rainy	1.59b ± 0.20	0.68a±0.21	1.64b ± 0.18	1.16b ± 0.79	0.77b ± 0.37	1.33b ± 0.83
CD	0.039	NS	0.041	0.031	0.02	0.035
B. Critical period of crop-weed competition						
T1: Control (weedy up to crop maturity)	1.33f±0.04	0.53e±0.04	1.44h ± 0.11	0.67f±0.76	0.77e±0.23	1.81e±0.23
T2: Weedy up to 10 DAS	1.52cd ± 0.19	0.74c±0.06	1.62e±0.13	2.31a±0.25	1.22a±0.06	2.09a±0.08
T3: Weedy up to 20 DAS	1.50de ± 0.15	0.71cd ± 0.02	1.57f±0.13	1.98b ± 0.17	1.19a±0.06	2.03b ± 0.11
T4: Weedy up to 30 DAS	1.44e±0.13	0.67d ± 0.13	1.63e±0.13	1.89c±0.06	1.11b ± 0.06	1.99BCE±0.17
T5: Weedy up to 40 DAS	1.35f±0.17	0.54e±0.13	1.53g ± 0.08	1.83c±0.13	0.93c±0.04	1.96cd ± 0.15
T6: Weedy up to 50 DAS	1.33f±0.06	0.15f±0.15	1.41i±0.11	1.67d ± 0.25	0.87d ± 0.06	1.92d ± 0.19
T7: Weed-free (up to maturity)	2.00a±0.55	0.99a±0.06	2.06a±0.23	0.00j±0.00	0.00i±0.00	0.00k±0.00
T8: Weed-free up to 10 DAS	1.58bcd ± 0.13	0.57e±0.17	1.63e±0.13	0.19i±0.08	0.29h ± 0.17	0.11j±0.06
T9: Weed-free up to 20 DAS	1.62b ± 0.02	0.72c±0.28	1.72d ± 0.15	0.41h ± 0.06	0.38g ± 0.25	0.41i±0.47
T10: Weed-free up to 30 DAS	1.64b ± 0.08	0.85b ± 0.13	1.745c±0.11	0.57g ± 0.15	0.55f±0.08	0.56h ± 0.42
T11: Weed-free up to 40 DAS	1.6BCE±0.13	0.83b ± 0.04	1.84b ± 0.11	0.92e±0.49	0.79e±0.38	0.80g ± 0.30
T12: Weed free up to 50 DAS	2.06a±0.15	0.87b ± 0.02	1.85b ± 0.13	0.94e±0.23	0.83d ± 0.06	1.72f±0.15
CD	0.094	0.043	0.099	0.077	0.048	0.086
AxB	0.134	0.061	NS	0.109	0.069	NS

The figures for seasons and CPCWC withincolumns with differentletters differed significantly from each other (P ≤ 0.05 least significant difference with ±SE).

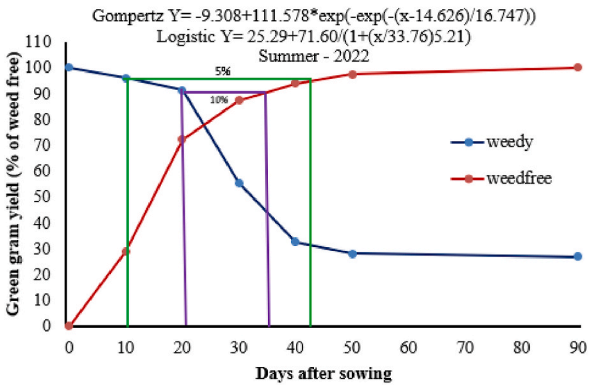


Fig. 3. The critical period for crop-weed competition during the *summer* season of 2022.

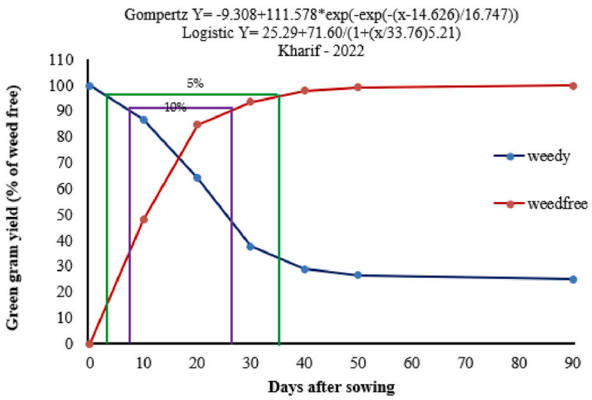


Fig. 4. The critical period for crop-weed competition during the *rainy* season of 2022.

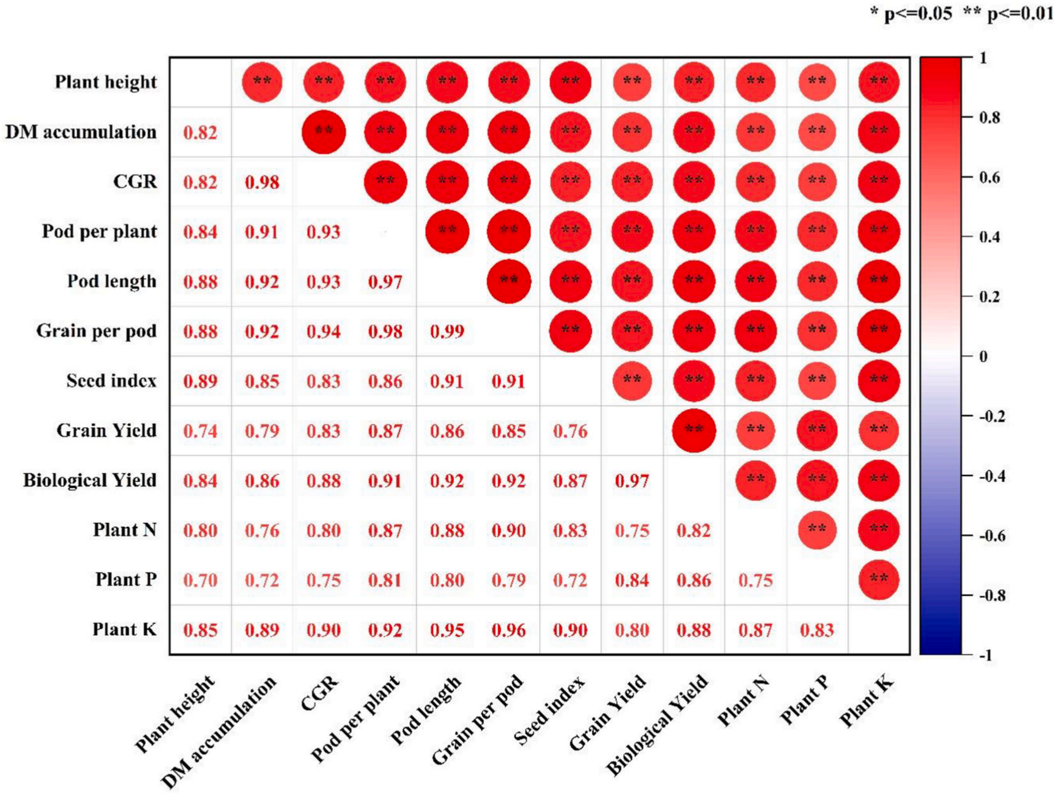


Fig. 5. Relationship between crop growth, yield attributes and nutrient content with productivity of green gram. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

4. Discussion

4.1. Plant height, DM, Chlorophyll, CGR and weed density

Green gram grows slowly at early growth phase and covers the soil slowly, resulting in intense weed competition. Rapid canopy establishment is important because it contributes to increased total light interception throughout the growing season and effective crop-weed suppression. Thus, increased weed interference period drastically reduced the plant height, dry matter accumulation, crop growth rate, and chlorophyll content (a and b) by increasing weed density during the summer and *rainy* seasons of 2022. Due to adequate rainfall and moderate temperature, intense weed population and their density during *rainy* season accelerated the crop-weed competition which led to reduced crop growth during *rainy* as compared to summer. Further, increased weed population produced allelochemicals leading to reduced crop growth [34]. Similarly, elevated temperature during summer which accelerated the crop physiological processes such as photosynthates translocation, flowering, maturity etc. lead to increased green gram growth and development. Furthermore, in both seasons, weed-free up to the maturity of green gram resulted in better agro-physiological parameters. This might be due to better availability of moisture and nutrients to the crop under better control of weeds throughout the crop growth period resulting in more favorable conditions for the crop, consequently, the crop attained more growth having a smothering effect on weeds. Similar findings by Seyyedi et al. [35] indicated that weed-free until maturity results in an increase in the height of black seed by 30 %. Increased weed-free duration increased the dry matter accumulation of sorghum Laha et al. [36], and groundnut also [17]. However, season-long weedy plots reduced the crop growth, which might be due to severe crop-weed competition for resources like solar radiation, nutrients uptake, space, moisture etc., consequently plant height, dry matter accumulation, CGR, and chlorophyll content were adversely affected. These results are correlated with earlier findings in fenugreek [37], sorghum [36], parsley [38–40]. Also, early-grown weeds cover the canopy of crops due to their shading effect, reducing the crop chlorophyll content [41–43]. The highest CGR was recorded at 30 DAS in green gram from weed-free conditions [44].

4.2. Yield attributes and yield of green gram

Weed interference reduced green gram yield during both seasons. Weed flora, density, and dry matter content were all higher in *rainy* than in summer season. Similarly, weeds are secondary host forpest infestation like aphids and thrips. During r*ainy* season, many of the green gram plants were turned into yellow color due to yellow mosaic virus infestation which was transmitted by aphids. For some reason, this might be responsible for the decline in *Rainy*green gram yield attributes and yield. Weeds reduced crop yield by competing for nutrients, moisture, space, CO_2, and light and also by harboring the insects like aphid. Weed interference during crop development increased yield loss, so early weed competition is thought to be the main cause of yield loss. Yield reduction was associated with a decrease in LAI and pod number, whereas weed interference primarily caused a decrease in the number of branches, seed weight, and biomass, in addition to a decrease in pod number. Pod number has been shown to be the most sensitive yield component to weed competition in green gram. The crop competes with weeds for resources more during the initial periods of weedy situations. Shortage of resources under weedy situations hampered green gram growth, resulting in lower growth and yield attributes. These findings are consistent with those of Bhalerao et al. [45], Husain et al. [46], Seyyedi et al. [35,47]. They observed that weed-free plots had the highest value of growth and yield attributes like total pods, 100 kernel weight, shelling percentage of groundnut, and volume weight, followed by two-hand weeding, and the lowest in increased weedy duration. Grain and biological yields decreased as the weed infestation period lengthened and increased as the weed-free period lengthened [35]. These findings are consistent with Singh et al. [48] in sesame, Karnas et al. [49] in groundnut, and Safdar et al. [50] in maize.

4.3. Plant and weed NPK content

In both seasons of study, NPK content in weeds increased significantly with an increased weed interference period. Adequate rainfall during the *rainy* season can promote vigorous weed growth, leading to increased nutrient uptake by weeds over summer season. Weeds may compete with green gram for essential nutrients, potentially impacting the nutrient status of the crop. Younger weeds absorbed more nutrients than older and their nutrient absorption capacity is reduced at crop harvest. Weed interference with varying durations accumulated more NPK content than those allowed to grow at later stages of crop growth. This phenomenon is consistent with the findings of Karkanis*et al.* [39] Stagnari and Pisante [51], and Seyyedi et al. [35], who found that longer weed interference periods were associated with higher weed N, P, and K content. Weeds have a deeper rooting system that absorbs soil moisture and nutrients from different layers of soil. Weed interference and faulty weed management practices reduced green gram yield [37,52,53].

The presence of weeds throughout the crop's life cycle will alter both available nutrients and dry matter allocation within the plant. A reduced N pool in the soil promotes the development of N deficiency symptoms such as general chlorosis and increased leaf senescence in older leaves. Under high weed pressure, crop leaf senescence develops faster than under weed-free conditions. Under limited nitrogen supply, a decrease in chlorophyll concentration and acceleration of leaf senescence will reduce total dry matter production and, eventually the yield [54]. During summer, less weed density and elevated temperature may lead to higher evapotranspiration rates in green gram, potentially increasing the demand for water and nutrients over *rainy*. Similarly, in both seasons, the season-long weed-free plots of green gram harvested the highest NPK content when compared to the weeds in the season-long weedy plot. However, weedy until 10 DAS had the highest NPK content in weeds compared to crops,due to slow initial growth of green gram which provided more space to weeds for absorption of moisture and nutrients. These findings were consistent with findings of Everaarts [55] that crop NPK content was lower in weedy plots than in weed-free plots. Seyyedi et al. [35] also observed that crop-weed competition reduced the N, P, and K contents of black seed grain and tissue during the weed interference period. These findings agreed with those of Korav et al. [56] in the Meghalaya region for groundnut. Increased crop-weed competition reduced N, P, and K content and uptake by crop, implying that more research into how crop-weed competition affects nutrient mining by crop and weed may aid in the development of better weed management decisions [57–60].

4.4. Critical period of crop weed competition

At the beginning and end of the critical period of crop-weed competition, different weed interference periods and cultivation seasons interacted significantly. The duration of weed interference or weed-free periods influenced green gram relative yield. Increased weed interference significantly reduced green gram yield in both seasons. When compared to summer, the CPCWC began earlier in *rainy*. The soil and weather conditions, particularly temperature and moisture, would have influenced the CPCWC starting a little earlier in *rainy* than in summer. Unchecked crop-weed competition in green gram lowered grain production by 53.7 %. This loss was maximum between 20 and 40 DAS, hence, this period is regarded as the most crucial for weed control. The yield drops before 20 DAS and after 40 DAS were minimal [61]. Based on a 5 % yield loss threshold, Erman et al. [62] estimated a CPCWC beginning before crop emergence and lasting until eight weeks after crop emergence in India. Extended weed competition beyond 15 DAS resulted in significant grain yield reduction in groundnut [17]. Similarly, 16 to 32 DAS was the critical period of crop-weed competition in fenugreek [37], 25 to 57 DAS in forage cowpea [63], and 3–6 weeks after planting in green gram [64]. Similarly, the critical weeding time in green gram was between 10 and 20 DAS and 30 to 40 DAS [65] and weed-free from 7 to 14 DAS [66].

4.5. Relationship between yield and other parameters

Effect of cropping seasons and weed interference periods on growth and nutrient content of green gram positively correlated with grain and biological yield (Figs. 4 and 5). The existence of significant relationship between growth, nutrient and grain and biological yield of green gram indicates that reduced weed interference period had significant role in improvement of crop growth and nutrient uptake of plant by reducing competition with weeds.

5. Conclusions

The *Rainy* season had maximum weed flora, density and dry matter accumulation than the summer. Furthermore, the increased weed interference period decreased the plant growth and productivity, and nutrient content of the crop but increased the nutrient content of weeds. For *Rainy* season grown green gram, critical period of crop-weed competition (CPCWC) was earlier than summer, and it should be kept weed-free between 11 and 43 DAS and 4 to 36 DAS, respectively, during summer and *Rainy* at 5 % relative yield loss (RYL). Similarly, CPCWC at 10 % RYL was between 21 and 36 DAS and 8 to 27 DAS, respectively, for summer and *Rainy* seasons. Beyond this period, weeds do not affect crop growth and yield significantly.

Future line of work

To minimize weed control expenses and reduce the impact of herbicides on the environment, farmers may adopt precision weed management techniques such as use of weed sensors, site-specific weed management, weed competition models based on CPCWC. There is a need for farmers, researchers, and stakeholders to adapt to the changing weed management scenario to ensure a sustainable crop production system.

Ethics statement

This research falls outside of human or animal studies and institutional ethical approval was not required.

Funding

Researchers Supporting Project number (RSP2024R118), King Saud University.

Data availability statement

All data generated or analyzed during this study are included in this published article or are otherwise publicly available.

CRediT authorship contribution statement

Akshay Kanjibhai Hirani: Writing – review & editing, Writing – original draft, Validation, Supervision, Software, Methodology, Formal analysis, Conceptualization. **Santosh Korav:** Writing – review & editing, Writing – original draft, Visualization, Supervision, Software, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **G.A. Rajanna:** Writing – review & editing, Supervision, Resources, Methodology, Investigation, Formal analysis, Conceptualization. **Hosam O. Elansary:** Writing – review & editing, Visualization, Software, Resources, Investigation, Data curation. **Eman A. Mahmoud:** Writing – review & editing, Visualization, Validation, Software, Resources, Formal analysis, Data curation.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:Santosh Korav reports financial support was provided by King Saud University. Santosh Korav reports a relationship with Lovely Professional University that includes: employment. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

The authors are grateful to Lovely Professional University (Phagwara) Jalandhar, Punjab. Also, the authors would like to thank Researchers Supporting Project number (RSP2024R118), King Saud University, Riyadh, Saudi Arabia.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2024.e36855.

References

[1] FAOSTAT. https://www.fao.org/3/a-br622e.pdf, 2022.
[2] D. Hou, J. Chen, X. Ren, C. Wang, X. Diao, X. Hu, Q. Shen, A whole foxtail millet diet reduces blood pressure in subjects with mild hypertension, J. Cereal. Sci. 84 (2018) 13–19, https://doi.org/10.1016/j.jcs.2018.09.003.
[3] MAFW. https://www.pib.gov.in/PressReleaseIframePage.aspx?PRID=1899193, 2023.

[4] DES, Directorate of Economics and Statistics, Department of Agriculture and Farmers Welfare, Ministry of Agriculture and Farmers Welfare, Govt. of India, 2021.
[5] B.S. Chauhan, R.G. Singh, G. Mahajan, Ecology and management of weeds under conservation agriculture: a review, Crop Protect. 38 (2012) 57–65, https://doi.org/10.1016/j.cropro.2012.03.010.
[6] T. Nagender, A. Srinivas, P.L. Rani, J. Narender, Evaluation of efficacy of different pre and post emergence herbicides for efficient weed control in green gram (*Vigna radiata* L.), Environ. Ecol. 35 (1B) (2017) 595–600.
[7] D. Tamang, R. Nath, K. Sengupta, Effect of herbicide application on weed management in green gram [*Vigna radiata* (L.) Wilczek], Advances in Crop Science and Technology 3 (2) (2015) 1000163, https://doi.org/10.4172/2329-8863.1000163.
[8] V.D. Chaudhari, L.J. Desai, S.N. Chaudhari, P.R. Chaudhari, Effect of weed management on weeds, growth and yield of summer greengram (*Vigna radiata* L.), Int. J. Life Sci. 11 (1) (2016) 531–534.
[9] R.L. Zimdahl, K. Moody, R.T. Lubigan, E.M. Castin, Patterns of weed emergence in tropical soil, Weed Sci. 36 (5) (1988) 603–608, https://doi.org/10.1017/S0043174500075482.
[10] R.L. Zimdahl, G. Foster, Canada thistle (Cirsium arvense) control with disking and herbicides, Weed Technol. 7 (1) (1993) 146–149, https://doi.org/10.1017/S0890037X00037027.
[11] Stevan Z. Knezevic, Sean P. Evans, Erin E. Blankenship, Rene C. Van Acker, John L. Lindquist, Critical period for weed control: the concept and data analysis, Weed science 50 (6) (2002) 773–786, https://doi.org/10.1614/0043-1745(2002)050[0773:CPFWCT]2.0.CO;2.
[12] K. Singh, H. Ram, R. Kumar, R.K. Meena, R. Kumar, Fodder quality and yields of green gram as influenced by different weed management practices, Indian J. Anim. Nutr. 38 (3) (2021) 233–239, https://doi.org/10.5958/2231-6744.2021.00034.7.
[13] G. Mohammadi, A. Javanshir, F.R. Khooie, S.A. Mohammadi, S. Zehtab Salmasi, Critical period of weed interference in chickpea, Weed Res. 45 (1) (2005) 57–63, https://doi.org/10.1111/j.1365-3180.2004.00431.x.
[14] Vivek, N.S. Rana, R. Singh, S.S. Tomar, Effect of weed interference on weeds and productivity of blackgram (Phaseolus mungo), Indian J. Weed Sci. 40 (1and2) (2008) 65–67.
[15] Vivek, S.S. Tomar, G. Singh, S.S. Tripathi, Crop weed competition in arhar (Cajanus cajan L.) under Northern west plain zone, Indian J. Weed Sci. 35 (3and4) (2003) 217–220.
[16] B.R. Raghvani, S.N. Goyal, J.C. Patel, D.D. Malavia, Weed competition in Mungbean1, Indian J. Weed Sci. 17 (1) (1985) 18–21.
[17] S. Korav, V. Ram, L.I.P. Ray, Critical period for crop-weed competition in groundnut (Arachis hypogaea L.) under mid altitude of Meghalaya, Journal of Crop and Weed 16 (1) (2020) 217–222, https://doi.org/10.22271/09746315.2020.v16.i1.1296.
[18] P. Sheoran, S. Singh, V. Sardana, S.S. Bawa, Studies on critical period of crop-weed competition in green gram in kandi region of Punjab, Indian Journal of Dryland Agricultural Research and Development 23 (1) (2008) 19–22.
[19] M. Dash, M. Tandon, M. Suvasmita, A review on integrated weed management in green gram, International Journal of Current Microbiology and Applied Sciences 7 (6) (2018) 1865–1871, https://doi.org/10.20546/ijcmas.2018.707.222.
[20] R. Raman, G. Kuppuswamy, R. Krishnamoorthy, Response of weed management practices on the growth and yield of urdbean (*Vigna mungo* L. Hepper), Legume Research-An International Journal 28 (2) (2005) 122–124.
[21] P.R. Mirjha, S.K. Prasad, M.K. Singh, R.H. Paikra, S. Patel, M. Majumdar, Effect of weed control measures on weeds, nodulation, growth and yield of green gram (*Vigna radiata*), Indian J. Agron. 58 (4) (2013) 615–617, https://doi.org/10.59797/ija.v58i4.4249.
[22] S.G. Algotar, V.C. Raj, D.D. Patel, D.K. Patel, Integrated weed management in green gram, in: 25th Asian- Pacific Weed Science Society Conference on "*Weed Science For Sustainable Agriculture Environmental Biodiversity*, 2015, pp. 13–16. Hyderabad, India.
[23] D.J. Watson, Comparative physiological studies on the growth of field crops: I. Variation in net assimilation rate and leaf area between species and varieties, and within and between years, Annals of botany 11 (41) (1947) 41–76. https://www.jstor.org/stable/42907002.
[24] D.I. Arnon, Copper enzymes in isolated chloroplasts. Polyphenoloxidase in *Beta vulgaris*, Plant physiology 24 (1) (1949) 1, https://doi.org/10.1104/pp.24.1.1.
[25] W.A. Jackson, D. Flesher, R.H. Hageman, Nitrate uptake by dark-grown corn seedlings: some characteristics of apparent induction, Plant Physiology 51 (1) (1973) 120–127, https://doi.org/10.1104/pp.51.1.120.
[26] S.R. Olsen, Estimation of Available Phosphorus in Soils by Extraction with Sodium Bicarbonate, No. 939, US Department of Agriculture, 1954.
[27] J.J. Hanway, H. Heidel, Soil analysis methods as used in Iowa state college of soil testing laboratory, Iowa State College of Agriculture Bulletin 57 (1952) 1–31, https://doi.org/10.12691/ajwr-7-1-5.
[28] K.A. Gomez, A.A. Gomez, Statistical Procedures for Agricultural Research, John Wiley and Sons, 1984.
[29] Statistix Team, Statistix 10.0 computer softwere. https://statistix.informer.com/10.0, 2012.
[30] RStudio Team, RStudio Desktop IDE (Version 2023.06.0-421), PBC, 2023 [Computer software], https://posit.co/products/open-source/rstudio/.
[31] M.R. Hall, C.J. Swanton, G.W. Anderson, The critical period of weed control in grain corn (Zea mays), Weed Sci. 40 (3) (1992) 441–447, https://doi.org/10.1017/S0043174500051882.
[32] D.E. Johnson, M.C.S. Wopereis, D. Mbodj, S. Diallo, S. Powers, S.M. Haefele, Timing of weed management and yield losses due to weeds in irrigated rice in the Sahel, Field Crops Res. 85 (1) (2004) 31–42.
[33] S.Z. Knezevic, J.C. Streibig, C. Ritz, Utilizing R software package for dose-response studies: the concept and data analysis, Weed Technol. 21 (3) (2007) 840–848, https://doi.org/10.1614/WT-06-161.1.
[34] R.S. Jat, H.N. Meena, A.L. Singh, J.N. Surya, J.B. Misra, Weed management in groundnut (Arachis hypogaea L.) in India-a review, Agric. Rev. 32 (3) (2011) 155–171.
[35] S.M. Seyyedi, P.R. Moghaddam, M.N. Mahallati, Weed competition periods affect grain yield and nutrient uptake of black seed (*Nigella Sativa* L.), Horticultural Plant Journal 2 (3) (2016) 172–180, https://doi.org/10.1016/j.hpj.2016.08.005.
[36] S.L. Ka, M.S. Mbaye, M. Gueye, R. Mballo, B. Bamba, C. Bassène, K. Noba, Assessment of critical period of crop-weed competition in grain sorghum under Sudanian conditions of southern Senegal, Journal of Research in Weed Science 3 (2) (2020) 188–199, https://doi.org/10.26655/JRWEEDSCI.2020.2.6.
[37] K. Singh, H. Ram, R. Kumar, R.K. Meena, R. Kumar, Effect of weed management practices on weed dynamics, nutrient depletion, productivity and profitability of summer green gram (*Vigna radiata*) under zero tillage condition, Legume Research-An International Journal 45 (6) (2022) 762–768, https://doi.org/10.18805/LR-4497.
[38] M. Begum, A.S. Juraimi, A. Rajan, S.R. Syed Omar, M. Azmi, Critical period competition between Fimbristylismiliacea (L.) Vahl and rice (MR 220), Plant Protect. Q. 23 (4) (2008) 153–157, https://doi.org/10.3316/ielapa.500084036621861.
[39] A. Karkanis, D. Bilalis, A. Efthimiadou, N. Katsenios, The critical period for weed competition in parsley (Petroselinum crispum (Mill.) Nyman ex AW Hill) in Mediterranean areas, Crop Protect. 42 (2012) 268–272, https://doi.org/10.1016/j.cropro.2012.07.003.
[40] A.K. Yogi, B. Singh, R. Singh, Critical stages of plant weed competition affecting plant growth and yield in ajwain (*Trachyspermumammi Sprague*), International Journal of Seed Spices 5 (1) (2015) 41–48, https://doi.org/10.18805/LR-4369.
[41] K.S. Olorunmaiye, Time of weed removal influence on vegetative and reproductive yield of two Cowpea (*Vigna unguiculata* (L) Walp) varieties, Ife Brown and TVX3236, Ethnobotanical Leaflets 14 (2010) 327–343. https://opensiuc.lib.siu.edu/ebl/vol2010/iss3/10.
[42] M.A. Hakim, A.S. Juraimi, M.H. Musa, M.R. Ismail, M.M. Rahman, A. Selamat, Impacts of weed competition on plant characters and the critical period of weed control in rice under saline environment, Aust. J. Crop. Sci. 7 (8) (2013) 1141–1151. https://search.informit.org/doi/10.3316/informit.409331668615013.
[43] S. Korav, V. Ram, R. Krishnappa, N. Premaradhya, Agro-physiological assessment of weed interference in groundnut (*Arachis hypogea* L.) at Sub-Himalayan hill region of Meghalaya, Bangladesh J. Bot. 49 (2) (2020) 313–327, https://doi.org/10.3329/bjb.v49i2.49312.
[44] R. Punia, S.S. Punia, S. Devi, V.S. Hooda, N.K. Kamboj, S.K. Thakral, Phenological behaviour, weed dynamics and productivity of green gram influenced by weed control treatments, International Journal of Current Microbioly and Applied Sciences 7 (2) (2018) 1795–1804, https://doi.org/10.20546/ijcmas.2018.702.217.

[45] S.N. Bhalerao, A.R. Shaikh, B.D. Romade, S.A. Landge, Impact source of treatments on yield performance of groundnut, Adv. Res. J. Crop Improv. 2 (1) (2011) 15–17.

[46] H. Abrar, N. Athar, A. Imran, A. Masood, Effect of weed competition periods on the growth and yield of black seed (Nigella sativa L.), Pakistan Journal of Weed Science Research 15 (1) (2009) 71–81.

[47] R. Absy, I.H. Yacoub, Prediction of critical periods for weed interference in soybean, Journal of Plant Production 11 (1) (2020) 25–34, https://doi.org/10.21608/JPP.2020.77988.

[48] M. Singh, R. Kumar, S. Kumar, V. Kumar, Critical period for weed control in field pea, Legume Research-An International Journal 39 (1) (2016) 86–90, https://doi.org/10.18805/lr.v0iOF.6787.

[49] Z. Karnas, D. Isik, N. Tursun, K. Jabran, Critical period for weed control in sesame production, Weed Biol. Manag. 19 (4) (2019) 121–128, https://doi.org/10.1111/wbm.12188.

[50] M.E. Safdar, A. Tanveer, A. Khaliq, R. Maqbool, Critical competition period of parthenium weed (*Parthenium hysterophorus* L.) in maize, Crop Protect. 80 (2016) 101–107, https://doi.org/10.1016/j.cropro.2015.11.002.

[51] F. Stagnari, M. Pisante, The critical period for weed competition in French bean (*Phaseolus vulgaris* L.) in Mediterranean areas, Crop Protect. 30 (2) (2011) 179–184, https://doi.org/10.1016/j.cropro.2010.11.003.

[52] S.P. Singh, R.S. Yadav, Effect of weed management on growth, yield and nutrient uptake of greengram, Indian J. Weed Sci. 47 (2) (2015) 206–210.

[53] G. Kaur, H.S. Brar, G. Singh, Effect of weed management on weeds, nutrient uptake, nodulation, growth and yield of summer mungbean (*Vigna radiata*), Indian J. Weed Sci. 42 (1) (2010) 114–119.

[54] I. Rajcan, C.J. Swanton, Understanding maize–weed competition: resource competition, light quality and the whole plant, Field Crops Res. 71 (2) (2001) 139–150, https://doi.org/10.1016/S0378-4290(01)00159-9.

[55] A.P. Everaarts, Effects of competition with weeds on growth, development and yield of soyabeans, Neth. J. Agric. Sci. 40 (1) (1992) 91–107, https://doi.org/10.18174/njas.v40i1.16531.

[56] S. Korav, A.K. Dhaka, R. Singh, N. Premaradhya, G.C. Reddy, A study on crop weed competition in field crops, J. Pharmacogn. Phytochem. 7 (4) (2018) 3235–3240.

[57] R.E. Blackshaw, R.N. Brandt, Phosphorus fertilizer effects on the competition between wheat and several weed species, Weed Biol. Manag. 9 (1) (2009) 46–53, https://doi.org/10.1111/j.1445-6664.2008.00317.x.

[58] J.L. Lindquist, S.P. Evans, C.A. Shapiro, S.Z. Knezevic, Effect of nitrogen addition and weed interference on soil nitrogen and corn nitrogen nutrition, Weed Technol. 24 (1) (2010) 50–58, https://doi.org/10.1614/WT-09-070.1.

[59] R. Ghasemi-Fasaei, Y. Mansoorpoor, Metal micronutrients relationships in crop, soil, and common weeds of two maize (*Zea mays* L.) fields, Arch. Agron Soil Sci. 61 (12) (2015) 1733–1741, https://doi.org/10.1080/03650340.2015.1030612.

[60] N. Tursun, A. Datta, E. Tuncel, Z. Kantarci, S. Knezevic, Nitrogen application influenced the critical period for weed control in cotton, Crop Protect. 74 (2015) 85–91, https://doi.org/10.1016/j.cropro.2015.04.007.

[61] P. Sheoran, S. Singh, V. Sardana, S.S. Bawa, Studies on critical period of crop-weed competition in green gram in kandi region of Punjab, Indian Journal of Dryland Agricultural Research and Development 23 (1) (2008) 19–22.

[62] M. Erman, I. Tepe, B. Bukun, R. Yergin, M. Taskesen, Critical period of weed control in winter lentil under non-irrigated conditions in Turkey, Afr. J. Agric. Res. 3 (8) (2008) 523–530.

[63] T. Yadav, N.K. Chopra, N.K. Chopra, R. Kumar, P.G. Soni, Assessment of critical period of crop-weed competition in forage cowpea (*Vigna unguiculata*) and its effect on seed yield and quality, Indian J. Agron. 63 (1) (2018) 124–127, https://doi.org/10.59797/ija.v63i1.5391.

[64] I.H. Utomo, Critical period of mungbean (*Phaseolus radiatus* L.) to weed competition, BIOTROPIA-The Southeast Asian Journal of Tropical Biology (2) (1989) 8–11. https://doi:10.11598/btb.1989.0.2.91.

[65] G. Teame, G. Gebregergs, Z. Gebremedhin, D. Gramy, Determining critical weeding period in mungbean (*Vigna radiata* (L.) wilczek) under rain fed condition in western tigray, Ethiopia, Journal of Agriculture and Ecology. Research International 20 (3) (2020) 1–6, https://doi.org/10.9734/jaeri/2019/v20i330113.

[66] D. Mandal, A. Khuntia, S. Ghosh, D. Pal, R.K. Ghosh, Determination of critical period of crop weed competition in green gram (*Vigna radiata* L. Wilczek) in the Gangetic alluvial soil of India, Journal of Crop and Weed 2 (2006) 13–14.