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Effects of Pendimethalin on the Growth Parameters of Sesame (*Sesamum Indicum* L.) Varieties

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ABSTRACT
Sesame (Sesamum indicum L..*) is a high-value oilseed crop in Nigeria, yet weed competition during its slow early-growth phase causes 50–75% yield losses, threatening productivity and food security. Traditional manual hoe-weeding is labor-intensive and costly, while information on pendimethalin use in the Northern Guinea Savanna remains limited. This study evaluated the effects of pendimethalin concentrations on growth parameters of two sesame varieties (NCRIBEN 02M and E8). A field experiment was conducted in 2024 at the IAR farm, Samaru, Zaria, using a randomized complete block design in a split-plot arrangement with three replications. Main plots were the two varieties; sub-plots included pendimethalin at 0.5, 1.0, 1.5, and 2.0 kg a.i. ha $^{-1}$ (pre-emergence), hoe-weeding (twice), and unweeded control. Growth parameters (plant height, number of leaves, branches, leaf area, and chlorophyll content) were measured at 4, 6, 8, 10, and 12 weeks after sowing and analyzed with ANOVA and Duncan's test at $p \leq 0.05$. Hoe-weeding produced the highest values for most parameters, followed by 0.5 and 1.0 kg a.i. ha $^{-1}$ pendimethalin. Higher rates (1.5–2.0 kg) reduced growth due to phytotoxicity. NCRIBEN 02M outperformed E8 in height, leaf area, branches, and chlorophyll. Chlorophyll content was unaffected by treatments. Moderate pendimethalin rates provided effective weed control with minimal crop injury. The findings support integrated weed management using 0.5–1.0 kg a.i. ha $^{-1}$ pendimethalin or hoe-weeding, with NCRIBEN 02M recommended for the region. This enhances sesame productivity and sustainability.*

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INTRODUCTION
Sesame (*Sesamum indicum L.*) is one of the oldest cultivated oilseed crops and is believed to have originated in Africa. It belongs to the genus *Sesamum* under the family Pedaliaceae (Dossa *et al.,* 2017). The genus comprises about 20 species, which are predominantly distributed across Asia and Africa; however, *Sesamum indicum* is the most widely cultivated species due to its economic importance as a source of edible oil and food ingredients (Bedigian, 2015).

In West Africa, sesame is commonly referred to as benniseed. In Nigeria, it is known locally as *Ridi*, *Ekuku*, and *Isasa* among the Hausa, Yoruba, and Igbo ethnic groups, respectively (Abu *et al.,* 2012). The crop is widely grown in arid and semi-arid tropical and subtropical regions worldwide (Baghery *et al.*, 2022) and is well adapted to unfavorable climatic

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conditions, particularly drought stress. Historically, sesame has been cultivated mainly for its oil, earning it the title "Queen of Oilseeds" because of its exceptionally high oil content, which ranges from 50 to 60% (Chaudhuri & Ghosh, 2020). It is among the major oilseed crops produced in Nigeria (Singh, 2005; Audu *et al.,* 2021).

Sesame seeds are highly valued for their rich nutritional profile and multifunctional uses. The crop is widely utilized as an active ingredient in several food products and is also recognized as a traditional medicinal plant with high nutritional and therapeutic value. Its desirable flavor, attractive aroma, and resistance to oxidative deterioration further enhance its importance. Sesame is commonly processed into various food products such as bread, biscuits, burgers, cakes, dressings, snacks, flour, and edible oil, while the residual cake after oil extraction is often used as livestock feed or organic manure (Ghoei, 2009; Hansen, 2011; Torricelli *et al.,* 2020). In Nigeria, sesame seeds are consumed fresh, dried, fried, or mixed with sugar, and they are also processed into paste for use in some traditional soups (Fariku *et al.,* 2007; Zubair *et al.,* 2020).

Globally, sesame is cultivated on approximately 13.97 million hectares, of which Africa accounts for about 9.69 million hectares (FAOSTAT, 2023). In 2022, global sesame seed production was estimated at 6.74 million tonnes, with Africa contributing about 4.3 million tonnes, representing 69.2% of total global production (FAOSTAT, 2023). In recent years, sesame production in African countries has increased substantially, with Tanzania emerging as the leading producer, surpassing India.

In Nigeria, sesame is predominantly produced in the Northern region and in parts of the Southern, South-Eastern, and South-South zones (Mohammad, 2020). Two major sesame varieties are cultivated in the country: the brown or mixed variety, primarily used for oil extraction, and the white or food-grade variety, widely used in the bakery industry and consisting of 98–100% white seeds. Sesame production plays a significant role in Nigeria's agricultural export sector, and the crop is commonly intercropped with other arable crops by smallholder farmers (Hong *et al.,* 2020).

Weeds are among the most serious constraints on sesame production. They compete with the crop for essential growth resources such as light, water, nutrients, and space, thereby reducing growth and yield. In addition, weeds serve as alternative hosts for insect pests and disease-causing organisms (Bruno & Samson, 2014). Sesame is especially sensitive to weed competition during its early growth stages, making effective weed management a critical component of successful production (Rekhasree & Reddy, 2025). Severe weed interference during this period can significantly reduce growth performance, yield attributes, and final seed yield. Most sesame farmers in Nigeria rely on traditional production practices such as manual hoe weeding, Hoe pulling, and manual harvesting (Imoloami *et al.,* 2011). These methods are labor-intensive, time-consuming, and costly, and they increase the risk of mechanical damage to crop roots and branches, thereby further reducing yield (Tataridas *et al.,* 2022; Singh *et al.,* 2022; Kumar *et al.,* 2023).

Although herbicide-assisted weed management can increase sesame yield by up to 80%, inappropriate application rates may cause phytotoxic effects on the crop (Grichar *et al.,* 2001; Grichar & Dotray, 2007). Also, some herbicides may contain certain trace metals which may affects the physiology of plants (Upahi *et al.,* 2021; Upahi *et al.,* 2026). Pendimethalin acts by inhibiting weed seed germination and early seedling growth (Shan *et al.,* 2012; Getachew *et al.,* 2024). Therefore, it is necessary to evaluate its effects on sesame growth, yield, and biochemical composition to ensure safe and effective use. This study was conducted to assess the response of two sesame varieties to different concentrations of pendimethalin.

MATERIALS AND METHODS

Experimental Site

The field trial was conducted during the rainy season of 2024 at the Institute for Agricultural Research (IAR) farm in Samaru

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(Latitude 110 11' N, Longitude 70 38' E, and 686m above sea level) in the Northern Guinea Savanna ecological zone of Nigeria.

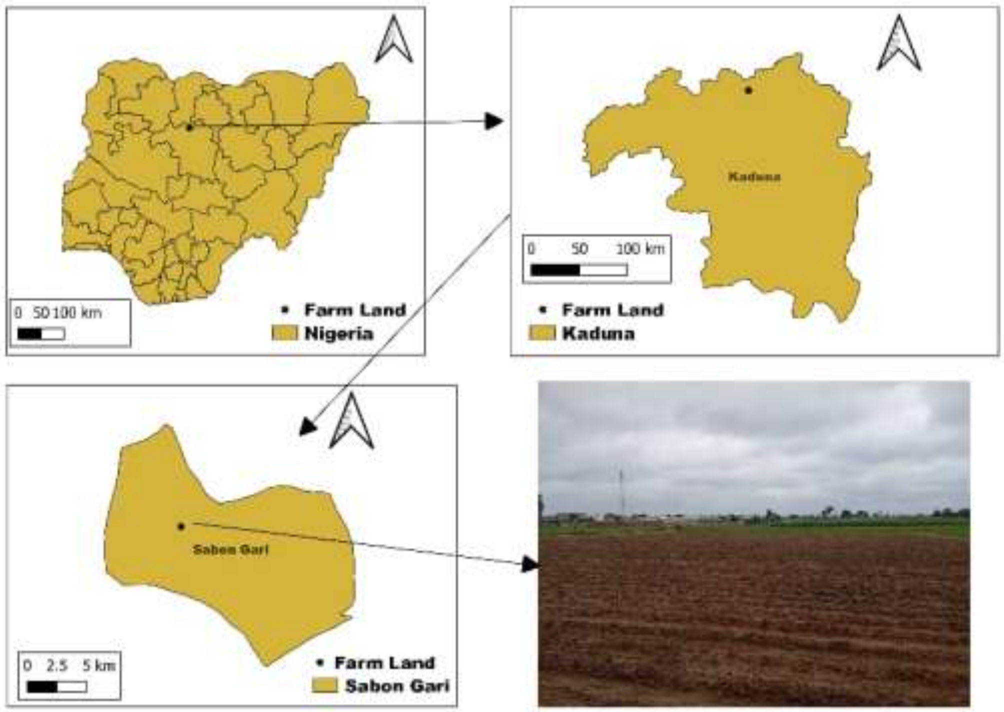

Figure 3.1 Map of Experimental Site

Seeds Sample Collection

Seeds of two sesame varieties (*Sesamum indicum* L.) were obtained from the National Cereals Research Institute (NCRI), Badeggi, Niger State, and transported aseptically to the Institute for Agricultural Research (IAR), Ahmadu Bello University, Zaria for the proper commencement of the research work.

Land preparation

The experimental field was ploughed and harrowed with a tractor to make a total of 36 plots. Each plot was 3.0 m x 4.0 m (12 m^2), with an inter-plot spacing of 1 m, in which ridges were made to separate the plots.

Treatments and Experimental Design

The experiment was laid out in a Randomized Complete Block Design (RCBD) with treatments arranged in a split plot design and replicated 3 times. The 2 sesame varieties were assigned to the main plot, and pendimethalin levels (0.5, 1.0, 1.5, 2.0 kg a.i / ha) were assigned to the sub-plot treatment and were replicated 3 times along with hoe-weeded and unweeded checks.

Seed dressing

Sesame seeds were dressed with Apron plus® (metalaxyl – M 20 % w/w, difenoconazole 2 % w/w, thiamethoxam 20% w/w) at the rate of one sachet (10 g) per 4 kg of seed, before sowing to protect the seeds from soil-borne pests and diseases.

Seed sowing

Sesame seeds were mixed with fine sand in 1: 2 proportions (one part of sesame seed and two parts of fine sand) and were sown

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manually at a shallow depth of about 2 cm by the drilling method at a spacing of 0.5 m x 0.5 m.

Herbicide application

The Pendimethalin herbicide was applied pre–emergence using a Cooper Pegler (CP3) Knapsack sprayer, 1 DAS. After calibration using the area–volume method, pendimethalin was applied at the rate of 0.5, 1.0, 1.5 and 2.0 kg a.i /ha. In addition to the above, there were also a Weedy (W) and hoe–weeding (H.W) treatments to serve as the first and second control (weeding was done at 4 and 6 weeks after emergence); these were summed up to a total of six treatments. The treatments were arranged in a randomised complete block design with three replications.

Fertiliser application

Nitrogen, phosphorus and potassium fertilizer was applied at 2 WAS and 6 WAS to all the subplots at the rate of 30 kg N/ha, 60 kg P/ha and 40 kg K/ha. Urea (46%), single superphosphate (18% P_2O_5) and muriate of potash (60% K_2O) fertilisers were used as sources of N, P and K, respectively, as recommended by National Cereals Research Institute, Badeggi (NCRI 2008).

Data collection

Plant height

Plant height was obtained following the instructions provided in Lavorel *et al.* (2003). Three plants were randomly selected on each plot for the height determination. The height (part of the plant from the soil surface to the tip of the apical bud) of each plant was measured with a meter rule. This was done at 4, 6, 8, 10 and 12 WAS.

Number of branches per plant

The number of branches from three randomly selected plants was counted and recorded at 4, 6, 8, 10 and 12 WAS.

Number of leaves per plant

The number of leaves from three randomly selected plants was counted and recorded at 4, 6, 8, 10 and 12 WAS.

Leaf area

Three plants were selected randomly and uprooted from the replicated plots of each treatment. All the leaf blades on each plant were removed from the petiole, washed and dried with 9 cm Whatman filter paper, and their area was measured with a leaf area meter, model Li – 300, for each sampled plant. This was done fortnightly at 4, 6, 8, 10 and 12 WAS.

Leaf chlorophyll content

The leaf chlorophyll content of three randomly selected plants in each plot was determined by the non-destructive method using the Chlorophyll meter (SPAD meter) fortnightly, as mentioned above. Healthy and fully developed leaves from the middle part of the plant were selected and measured. The SPAD meter sensor was placed on the leaf surface, and the SPAD value, which is an indirect measure of total chlorophyll content, was recorded in the field.

Data Analyses

The data generated were subjected to analysis of variance (ANOVA) using Statistical Analysis System (SAS). Treatment means found to be statistically significant were compared using Duncan's New Multiple Range Test (DNMRT) at 5 % level of probability.

RESULTS

The results in Table 1 showed the effects of pendimethalin concentration and weeding treatment on plant height of two sesame varieties over the period. The result revealed a significant difference ($p \leq 0.05$) between pendimethalin treatment and other weed management practices. In the NCRIBEN 02M variety, HW had the maximum height at week 6 (34.83cm), 8 (42.57cm), 10 (46.93cm), and 12 (54.37cm), while the 0.5 kg a.i ha^{-1} had the highest plant height at 4 weeks (28.57cm) compared to the control treatment (unweeded). A similar trend

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was observed for E8, where HW produced the tallest plants at week 6 (33.07cm), 8 (40.53cm), 10 (49.03cm), and 12 (52.00 cm), while 0.5 kg/ha had the highest plant height at 4 weeks (26.33cm) compared to the control treatment (unweeded).

Table 2 showed the effects of pendimethalin concentration and weeding treatment on the leaf area of two sesame varieties over time. The result revealed a significant difference ($p \le 0.05$) between pendimethalin treatment and other weed management practices. Hoe weeding resulted in the largest leaf area in NCRIBEN 02M across week 4 (47.67cm^2), 6 (53.9 cm^2), 8 (60.43cm^2), 10 (67.2 cm^2), 12 (73.73 cm^2), while E8 showed similar trend across week 4 (38.87 cm^2), 6 (44.70 cm^2), 8 (51 cm^2), 10 (57.33 cm^2), and 12 (63.6) however, unweeded and the 2kg.ai. ha^{-1} pendimethalin concentration resulted in the smallest leaf area for both varieties.

Table 3 showed the effects of pendimethalin concentration and weeding treatment on the number of two sesame varieties over time. The result revealed a significant difference ($p \le 0.05$) between pendimethalin treatment and other weed management practices. Hoe weeding resulted highest number of leaves in NCRIBEN 02M across week 4 about (11), 6 (16), 8 (23), 10 (28),12 (33), while E8 showed similar trend across week 4 about (12.67), 6 (17.33), 8 (23), 10 (29), and 12 (33.67) however unweeded and the 2 kg a.i. ha^{-1} pendimethalin concentration resulted in the smallest leaf area for both varieties.

Table 4 show effects of pendimethalin concentration and weeding treatment on the number of branches of two sesame varieties over time. The result revealed a significant difference ($p \le 0.05$) between pendimethalin treatment and other weed management practices. NCRIBEN 02M 1 kg a.i. ha^{-1} had the highest number of branches observed at week 4(5), 6(8), 10(12), except week 12 (14), which was noted at 0.5kg a.i/ha. A similar trend was observed for E8, where 1 kg a.i. ha^{-1} had the maximum number of branches at week 4 (5), 6 (7), 10 (12), while HW had the highest number of branches at week 12(14).

Table 5 showed the effects of pendimethalin concentration and weeding treatment on total chlorophyll content of two sesame varieties over time. The result revealed no significant difference ($p < 0.05$) between pendimethalin treatment and other weed management practices. In NCRIBEN 02M variety, 0.5 kg a.i. ha^{-1}, had the maximum total chlorophyll content across all weeks (week 4: 5.3, week 6: 6.03, week 8: 6.77, week 10: 7.5, and week 12: 8.07) while UW had the lowest content across all the weeks, in which no significant difference was noted across treatments. A similar trend was observed for E8, where 1 kg a.i. ha^{-1} produced the highest content at week 4 (5), 6 (5.7), 8 (6.4), 10 (7.07), and 12 (7.63).

Table 1: Effects of Pendimethalin Concentration and Weeding Treatment on Plant Height of Two Sesame Varieties Over the Period

Variety	Concentration	Week 4	Week 6	Week 8	Week 10	Week 12
NCRIBEN 02M	0.5 kg a.i. ha^{-1}	28.57±0.14^a	34.53±0.28^b	41.7±0.23^b	46.57±1.07^a	52.27±0.22^b
	1 kg a.i. ha^{-1}	25.33±0.72^c	31.57±0.72^c	38.9±0.68^c	46.5±0.61^a	50.27±0.44^c
	1.5 kg a.i. ha^{-1}	22.33±1.43^c	28.2±0.98^c	34.83±0.98^e	43.00±1.61^b	45.33±0.87^d
	2 kg a.i. ha^{-1}	21.83±0.36^c	26.67±0.36^d	33.17±0.36^f	37.23±0.45^d	43.507±0.44^e
	HW	27.67±1.19^b	34.83±1.19^a	42.57±1.02^a	46.93±1.04^a	54.37±0.62^a
	UW	22.83±0.36^c	28.47±0.36^c	35.17±0.21^d	40.67±2.97^c	45.73±0.38^d

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Variety	Concentration	Week 4	Week 6	Week 8	Week 10	Week 12
E8	0.5 kg a.i. ha⁻¹	26.33±1.19ᵃ	32.77±1.19 ᵃ	40.2±1.15ᵃ	47.97±0.23ᵇ	51.70±1.00ᵃ
	1 kg a.i. ha⁻¹	26.2±0.69ᵃ	33.07±0.69ᵃ	40.23±0.66ᵃ	45.53±0.55ᶜ	51.37±0.6ᵃ
	1.5 kg a.i. ha⁻¹	23.73±1.43ᵇ	29.83±1.44ᵃ	36.8±1.58ᵃ	40.77±1.08ᵉ	47.9±1.52ᵇ
	2 kg a.i. ha⁻¹	18.83±0.59ᵈ	24.6±0.59ᵈ	31.17±0.48ᶜ	38.77±0.35ᶠ	41.9±0.45ᵈ
	HW	26.33±1.19ᵃ	33.07±1.19ᵃ	40.53±1.19ᵃ	49.03±0.54ᵃ	52.00±0.94ᵃ
	UW	21.17±2.73ᶜ	27.17±2.73ᵇ	34.33±2.73ᵇ	40.93±0.33ᵈ	45.83±2.93ᶜ
P-value	Concentration	0.00	0.00	0.00	0.00	0.00
	Varieties	0.24	0.47	0.55	0.67	0.56
	Interaction	0.60	0.64	0.63	0.55	0.89

Key: Means that do not share a letter are significantly different ($p<0.05$). HW: Hoe weeding, UW: unweeded.

Table 2: Effects of Pendimethalin Concentration and Weeding Treatment on Leaf Area of Two Sesame Varieties Over Time

Variety	Concentration	Week 4	Week 6	Week 8	Week 10	Week 12
NCRIBEN 02M	0.5 kg a.i. ha⁻¹	37.82 ± 1.07ᵇ	44.1 ± 0.87ᵇ	50.77 ± 0.94ᵇ	56.53 ± 0.94ᵇ	62.27 ± 0.94ᵇ
	1 kg a.i. ha⁻¹	36.87 ± 0.24ᵇ	41.73 ± 0.31ᶜ	47.17 ± 0.35ᶜ	52.50± 0.36ᶜ	58.07 ± 0.35ᶜ
	1.5 kg a.i. ha⁻¹	33.07 ± 0.47ᶜ	39.53 ± 0.41ᵈ	46.03 ± 0.49ᶜ	51.60 ± 0.56ᶜ	57.27± 0.5ᵈ
	2 kg a.i. ha⁻¹	28.23 ± 0.23ᵈ	32.57 ± 0.28ᵉ	37.83 ± 0.31ᵈ	42.57 ± 0.28ᵉ	47.37± 0.28ᵉ
	HW	47.67 ± 0.28ᵃ	53.9 ± 0.31ᵃ	60.43 ± 0.28ᵃ	67.2 ± 0.31ᵃ	73.73±0.38ᵃ
	UW	26.22 ± 0.06ᵉ	30.27 ± 0.12ᶠ	34.77 ± 0.12ᵉ	39.03 ± 0.12ᵉ	43.6 ± 0.17ᶠ
E8	0.5 kg a.i. ha⁻¹	36.02 ± 0.06ᵇ	41.00± 0.09ᵇ	46.73 ± 0.10ᵇ	51.87 ± 0.07ᵇ	57.27 ± 0.12ᵇ
	1 kg a.i. ha⁻¹	30.90 ± 0.45ᶜ	36.00 ± 0.52ᶜ	41.27 ± 0.53ᶜ	46.17 ± 0.59ᶜ	51.17 ± 0.59ᶜ
	1.5 kg a.i. ha⁻¹	24.17 ± 0.07ᵈ	28.27 ± 0.12ᵈ	32.97 ± 0.12ᵈ	37.23 ± 0.12ᵈ	41.6 ± 0.17ᵈ
	2 kg a.i. ha⁻¹	21.43 ± 0.59ᵉ	25.10± 0.45ᵉ	29.40 ± 0.37ᵉ	33.67 ± 0.36ᵉ	37.83 ± 0.36ᵉ
	HW	38.87 ± 0.40ᵃ	44.70± 0.40ᵃ	51.00 ± 0.43ᵃ	57.33 ± 0.45ᵃ	63.6 ± 0.48ᵃ
	UW	20.00 ± 0.00ᶠ	23.50± 0.00ᶠ	27.80 ± 0.00ᵉ	32.00 ± 0.00ᵉ	36.5 ± 0.00ᵉ

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Variety	Concentration	Week 4	Week 6	Week 8	Week 10	Week 12
P- value	Concentration	0.00	0.00	0.00	0.00	0.00
	Varieties	0.00	0.00	0.00	0.00	0.00
	Interaction	0.00	0.00	0.00	0.00	0.00

Key: Means that do not share a letter are significantly different HW: Hoe weeding, UW: Unweeded.

Table 3: Effects of Pendimethalin Concentration and Weeding Treatment on the Number of Leaves of Two Sesame Varieties Over Time

Variety	Concentration	Week 4	Week 6	Week 8	Week 10	Week 12
NCRIBEN 02M	0.5 kg a.i. ha⁻¹	10.00±1.00[b]	14.33±0.34[b]	19.00±0.12[b]	24.00±3.13[b]	28.33±2.13[b]
	1 kg a.i. ha⁻¹	8.67±0.32[c]	12.33±0.56[c]	16.67±2.12[c]	21.00±0.78[c]	25.00±0.24[c]
	1.5 kg a.i. ha⁻¹	7.67±0.76[c]	10.33±0.12[d]	14.33±2.12[d]	18.33±2.12[d]	22.33±3.21[d]
	2 kg a.i. ha⁻¹	6.67±0.34[d]	9.67±1.12[d]	13.00±1.11[d]	17.23±2.12[d]	20.11±1.11[d]
	HW	11.33±0.23[a]	16.00±2.13[a]	23.00±2.12[a]	28.33±1.43[a]	33.33±0.78[a]
	UW	7.00±0.89[d]	11.00±0.43[c]	15.00±0.28[d]	19.00±1.2[d]	22.33±0.56[d]
E8	0.5 kg a.i. ha⁻¹	9.33±0.23[b]	14.00±0.24[b]	19.67±0.45[b]	24.33±1.23[b]	29.12±4.12[b]
	1 kg a.i. ha⁻¹	10.00±0.57[b]	14.00±0.24[b]	19.33±0.56[c]	24.33±0.57[b]	28.67±2.56[c]
	1.5 kg a.i. ha⁻¹	7.67±0.76[c]	11.00±0.56[c]	15.67±0.56[d]	20.00±3.11[c]	23.33±1.23[d]
	2 kg a.i. ha⁻¹	8.00±0.12[c]	10.67±0.90[d]	14.00±0.05[e]	17.67±3.12[d]	20.67±3.33[f]
	HW	12.67±1.11[a]	17.33±1.23[a]	23.00±0.89[a]	29.00±2.12[a]	33.67±3.08[a]
	UW	8.67±0.78[c]	12.33±0.12[c]	16.33±1.45[d]	20.00±1.44[c]	23.00±4.12[e]
P value	Concentration	0.00	0.00	0.00	0.00	0.00
	Varieties	0.07	0.03	0.03	0.03	0.09
	Interaction	0.58	0.75	0.75	0.65	0.70

Key: Means that do not share a letter are significantly different HW: Hoe weeding, UW: Unweeded.

Table 4: Effects of Pendimethalin Concentration and Weeding Treatment on The Number of Branches of Two Sesame Varieties Over Time

Variety	Concentration	Week 4	Week 6	Week 8	Week 10	Week 12
NCRIBEN 02M	0.5 kg a.i. ha⁻¹	5.00± 0.94[a]	7.67± 0.72[a]	8.00±0.72[c]	11.67± 0.72[b]	14.33± 0.72[a]
	1 kg a.i. ha⁻¹	5.33± 0.27[a]	8.00± 0.47[a]	11.00±0.47[a]	12.00± 0.47[a]	13.67± 0.27[b]

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Variety	Concentration	Week 4	Week 6	Week 8	Week 10	Week 12
	1.5 kg a.i. ha⁻¹	4.00± 0.94ᵃ	6.67± 0.72ᵃ	8.67±0.72ᵇ	10.67± 0.72ᶜ	13.33± 0.47ᶜ
	2 kg a.i. ha⁻¹	3.00± 0.00ᵃ	5.00± 0.00ᵃ	7.33±0.27ᵈ	7.67± 0.27ᵉ	12.00± 0.47ᵈ
	HW	4.00± 0.82ᵃ	7.00± 0.82ᵃ	8.00±0.82ᶜ	8.00± 0.82f	10.00± 0.72ᵉ
	UW	3.00± 0.00ᵃ	5.00± 0.00ᵃ	7.33±0.27ᵃ	12.00± 0.27ᵃ	9.00± 0.47ᵈ
E8	0.5 kg a.i. ha⁻¹	4.33± 0.94ᵃ	6.67± 0.27ᵃ	8.33±0.27ᶜ	8.67± 0.00ᵈ	12.67± 0.27ᵇ
	1 kg a.i. ha⁻¹	4.67± 0.27ᵃ	7.00± 0.47ᵃ	10.33±0.27ᵃ	11.33± 0.72ᵇ	12.33± 0.27ᶜ
	1.5 kg a.i. ha⁻¹	4.00± 0.94ᵃ	6.00± 0.82ᵃ	9.33±0.82ᵇ	11.00± 0.47ᶜ	10.67± 0.54ᵈ
	2 kg a.i. ha⁻¹	3.00± 0.00ᵃ	5.00± 0.00ᵃ	7.33±0.00ᵉ	9.67± 0.72ᵈ	8.33± 0.27ᵉ
	HW	4.00± 0.82ᵃ	7.00± 0.82ᵃ	8.00±0.82ᶜ	7.00± 0.27ᵉ	13.67± 0.72ᵃ
	UW	3.33± 0.27ᵃ	5.33± 0.27ᵃ	7.67±0.27ᵈ	12± 0.82ᵃ	10.33± 0.27ᵈ
P- value	Concentration	0.07	0.00	0.00	0.00	0.00
	Varieties	0.70	0.33	0.57	0.24	0.05
	Interaction	0.98	0.87	0.92	0.87	0.80

Key: Means that do not share a letter are significantly different HW: Hoe weeding, UW: unweeded.

Table 5: Response of Sesame Variety to Pendimethalin Treatment on Total Chlorophyll Contents

Variety	Concentration	Week 4	Week 6	Week 8	Week 10	Week 12
	0.5 kg a.i. ha⁻¹	5.30 ± 1.43ᵃ	6.03 ± 1.42ᵃ	6.77 ± 1.40ᵃ	7.50± 1.43ᵃ	8.07 ± 1.44ᵃ
	1 kg a.i. ha⁻¹	4.37 ± 1.36ᵃ	5.13 ± 1.28ᵃ	5.97 ± 1.28ᵃ	6.67 ± 1.32ᵃ	7.20± 1.30ᵃ
	1.5 kg a.i. ha⁻¹	3.43 ± 0.19ᵃ	4.13 ± 0.15ᵃ	4.93 ± 0.15ᵃ	5.50± 0.17ᵃ	6.07 ± 0.18ᵃ
NCRIBEN 02M	2 kg a.i. ha⁻¹	2.53 ± 0.44ᵃ	3.27± 0.43ᵃ	4.00± 0.42ᵃ	4.60± 0.41ᵃ	5.13 ± 0.40ᵃ
	HW	4.93 ± 0.55ᵃ	5.57± 0.58ᵃ	6.23 ± 0.55ᵃ	6.80± 0.52ᵃ	7.30± 0.57ᵃ
	UW	3.63 ± 0.58ᵃ	4.40± 0.6ᵃ	5.20± 0.60ᵃ	5.87 ± 0.63ᵃ	6.43 ± 0.61ᵃ
	0.5 kg a.i. ha⁻¹	3.77 ± 1.12ᵃ	4.37 ± 1.12ᵃ	5.07 ± 1.12ᵃ	5.67 ± 1.16ᵃ	6.23 ± 1.17ᵃ
E8	1 kg a.i. ha⁻¹	5.00± 1.2ᵃ	5.7 ± 1.17ᵃ	6.40± 1.17ᵃ	7.07 ± 1.23ᵃ	7.63 ± 1.20ᵃ
	1.5 kg a.i. ha⁻¹	2.90± 0.45ᵃ	3.5 ± 0.45ᵃ	4.20± 0.41ᵃ	4.83 ± 0.4ᵃ	5.37 ± 0.38ᵃ

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Variety	Concentration	Week 4	Week 6	Week 8	Week 10	Week 12
	2 kg a.i. ha⁻¹	2.63 ± 0.24ᵃ	3.27 ± 0.27ᵃ	3.90± 0.26ᵃ	4.50± 0.29ᵃ	5.07 ± 0.31ᵃ
	HW	3.33 ± 0.44ᵃ	4.03 ± 0.44ᵃ	4.73 ± 0.44ᵃ	5.37 ± 0.46ᵃ	5.90± 0.45ᵃ
	UW	2.17 ± 0.07ᵃ	2.73 ± 0.10ᵃ	3.30± 0.09ᵃ	3.83 ± 0.10ᵃ	4.30± 0.09ᵃ
P value	Concentration	0.96	0.96	0.96	0.95	0.95
	Varieties	0.21	0.16	0.11	0.11	0.11
	Interaction	0.13	0.11	0.10	0.10	0.09

Key: Means that do not share a letter are significantly different. HW: Hoe weeding, UW: unweeded.

DISCUSSION OF FINDINGS

The results of this study clearly demonstrate that pendimethalin concentration and weeding regime significantly influenced the growth and development of the two sesame varieties, NCRIBEN 02M and E8. This finding highlights the central role of effective weed management in determining crop growth performance, particularly in slow-growing crops such as sesame that are highly susceptible to early-season weed interference. The present results are consistent with Abdulmohsen *et al.* (2024), who reported that both herbicidal treatments and hoeing significantly enhanced agronomic traits of sesame by reducing weed pressure.

The improvement in growth parameters under effective weed management can be attributed primarily to the reduction or elimination of competition for essential growth resources, including nutrients, water, light and space. Weeds are known to exert their strongest competitive effects during the early stages of crop growth, when crop root systems and photosynthetic capacity are not yet fully developed (Zimdahl, 2018). Therefore, weed suppression during this critical period allows sesame plants to allocate assimilates more efficiently toward vegetative growth and structural development.

Hoe weeding consistently resulted in superior growth performance across most parameters, supporting earlier reports by Hossain *et al.* (2020) and Rekhasree *et al.* (2025), who demonstrated that physical weed removal enables sesame plants to maximize growth potential, leading to increased plant height, leaf area, and dry matter accumulation. The effectiveness of Hoe weeding is largely attributed to its non-selective and immediate removal of all weed species, thereby maintaining a near weed-free environment throughout the crop growth cycle. However, despite its agronomic superiority, Hoe weeding is often constrained by high labour demand and cost, particularly under large-scale production systems, which justifies the continued search for effective herbicide-based alternatives. According to Imoloame *et al.* (2011), an increase in herbicide rate induced a decrease in plant height regardless of the specific herbicide used.

The temporal pattern of plant height observed in this study revealed important stage-specific responses to weed management practices. The early height advantage recorded at the lowest pendimethalin rate (0.5 kg a.i. ha⁻¹) during weeks 4–6 suggests that early sesame growth is particularly sensitive to herbicide residues in the soil. At lower rates, pendimethalin appears to provide sufficient weed suppression with minimal phytotoxic effects on the crop, allowing faster initial vertical growth. Similar early-stage growth stimulation at low herbicide doses has been reported in sesame and other oilseed crops (Singh *et al.,* 2018; Kumar and Raja, 2019).

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In contrast, the eventual dominance of Hoe weeding from weeks 6–12 indicates that once sesame plants overcome early developmental constraints, sustained weed-free conditions become the primary determinant of continued growth. This shift suggests that different growth-limiting factors operate at different phenological stages, with early growth influenced by herbicide–crop interactions and later growth driven mainly by cumulative weed competition.

The progressive decline in plant height with increasing pendimethalin rates (HW > 0.5 > 1.0 > 1.5 > 2.0 kg a.i. ha^{-1}) reflects a classic dose-dependent phytotoxic response. Higher herbicide concentrations likely interfered with mitotic activity in root meristems, reduced lateral root proliferation, and impaired water and nutrient uptake, ultimately limiting shoot elongation. Similar reductions in plant height at higher pre-emergence herbicide doses have been reported in sesame by Singh *et al.* (2018), Sharma *et al.* (2020), Leela *et al.* (2022) and Kumar and Raja (2019). These findings collectively suggest that while pendimethalin is effective for weed suppression, excessive rates may compromise crop growth through indirect root-mediated stress.

Leaf area and number of leaves were particularly sensitive to weed management practices. Hoe weeding consistently produced significantly larger leaf area, approximately 15–20% greater than even the best-performing herbicide treatment by week 12, indicating that no pendimethalin rate fully replicated the favourable growth environment created by complete mechanical weed removal. This observation agrees with Hossain *et al.* (2020), who emphasized that even low levels of weed interference or mild herbicide stress can substantially reduce canopy development in sesame.

The similarity in poor leaf development between the unweeded control and the highest pendimethalin rate (2.0 kg a.i. ha^{-1}) is particularly noteworthy. It suggests that severe weed competition and excessive herbicide injury can result in comparable growth suppression, although through fundamentally different mechanisms: resource deprivation in the former and direct cellular toxicity in the latter. This finding aligns with the conceptual framework proposed by Monaco *et al.* (2002), which posits that both biotic and chemical stresses can converge on similar physiological growth limitations.

Number of leaf trends closely mirrored those of leaf area, indicating coordinated suppression of leaf initiation and expansion under stress conditions. The E8 variety consistently produced a higher number of leaves but with smaller individual leaf area compared to NCRIBEN 02M, suggesting inherent varietal differences in morphological plasticity. Under stress conditions, E8 appears to prioritize leaf initiation, potentially as a compensatory strategy to maintain photosynthetic surface area, whereas NCRIBEN 02M invests more in expanding fewer leaves. Such varietal differences in growth strategy have been reported in sesame and other oilseed crops and are often linked to genetic differences in assimilate partitioning and stress tolerance (Langham *et al.,* 2008; Sharma *et al.,* 2020).

Branching response exhibited a nuanced dose–response relationship. The early-stage superiority of the 1.0 kg a.i. ha^{-1} treatment during weeks 4–6 suggests that this rate provided an optimal balance between effective weed suppression and minimal phytotoxicity, thereby reducing competition-induced apical dominance while still allowing lateral bud initiation. This supports the hypothesis that moderate weed stress relief can promote branching by altering hormonal balance, particularly auxin–cytokinin interactions (Taiz *et al.,* 2015). However, Hoe weeding became dominant at later stages (weeks 8–12), indicating that sustained weed-free conditions are essential for continued branch initiation and development. The consistently poor branching observed at the highest pendimethalin rate (2.0 kg a.i. ha^{-1}) likely reflects direct inhibition of cell division in axillary meristems, compounded by overall plant stress.

Total chlorophyll content was not significantly affected by weed management practices, indicating that pendimethalin, within the tested concentration range, did not directly interfere with chlorophyll biosynthesis. This finding

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agrees with Chaudhuri (2020), Rakesh *et al.* (2025), and Dhanush *et al.* (2025), who reported that chlorophyll content in sesame remains relatively stable across different weed control treatments, even when growth and yield parameters vary significantly. The observed stability may be attributed to the physiological resilience of sesame or the timing of herbicide application, which may not coincide with critical phases of chlorophyll synthesis.

However, these results contrast with those of Abo Omar *et al.* (2018) and Kumar *et al.* (2020), who reported increased chlorophyll content at moderate herbicide doses and reduced pigmentation at excessive rates. Such discrepancies may be explained by differences in herbicide type, application timing, soil properties and varietal sensitivity. Although unweeded plots consistently recorded the lowest total chlorophyll values in the present study, the differences were not statistically significant, suggesting that total chlorophyll content was not the primary axis of stress response. Instead, growth suppression was more strongly associated with limitations in resource acquisition and meristematic activity rather than photosynthetic pigment degradation.

CONCLUSION

Growth parameters, including plant height, leaf area, number of leaves, number of branches, and chlorophyll content, were significantly influenced by weed management practices. Hoe-weeding and lower pendimethalin rates (0.5–1.0 kg a.i./ha) consistently produced superior growth performance. Higher herbicide rates negatively affected growth, indicating possible herbicide stress. NCRIBEN 02M exhibited better vegetative growth than E8 across most growth stages, demonstrating varietal differences in response to pendimethalin.

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