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RESEARCH ARTICLE

Influence of manual and chemical nipping and different castor hybrids on physiological and yield attributes and yield under irrigated ecosystem of South India

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Abstract

A field experiment was carried out in Tapioca and Castor Research Station, Yethapur Salem, Tamil Nadu, India, to study the effect of castor hybrids and nipping practice on the physiological and yield of castor in irrigated conditions. The experiment was laid out in a split-plot design with three replications. The main plot treatments comprised four castor hybrids of M_1- YRCH -1, M_2-YRCH-2, M_3- ICH-66, M_4-DCH-519 and sub-plot treatments have various nipping of S_1-no nipping, S_2-manual nipping @10th node, S_3-manual nipping @ 12th node and S_4-Chemical nipping @ 12th node mepiquat chloride 200 g/ha have been imposed. Among the castor hybrids, M_2-YRCH -2 recorded significantly highest physiological parameters., chlorophyll content 53.0 (spade value), Photosynthetic rate (22.0 μ mol/m^2/sec), Transpiration rate (10.5 mmol/m^2/sec) and stomatal conductance (269 mmol/m^2/sec), Concerning yield attributes, highest number of spike/plant of 7.9, spike length of 73.6 cm, number of capsules /spike 158.6 were recorded with YRCH2 (M_2), spike yield of 2327 kg/ha seed yield of 1820 kg/ha over the other hybrids. About nipping practices, S_4- chemical nipping with mepiquat chloride 200 g/ha recorded, Significantly highest physiological parameters Viz., chlorophyll content 57.0 (spade value), Photosynthetic rate (27.2 μ mol/m^2/sec), Transpiration rate (11.2 mmol/m^2/sec) and stomatal conductance (387.6 mmol/m^2/sec) and yield attributes like., number of spike /plant of 9.0, number of capsules /spike 167.7, spike length of 75.4 cm, spike yield 2487 kg/ha and seed yield of 1975 kg/ha. From this experiment, it is concluded that raising YRCH-2 castor hybrid combined with chemical nipping of mepiquat chloride @ 200 g/ha (M_2S_4) recorded the highest yield of 2198 kg/ha, net return of 92849 Rs/ha and benefit-cost ratio of 3.31. Hence, adopting nipping under conditions can enhance the physiological parameters and yield of the castor.

Keywords: castor hybrids; mepiquat chloride; nipping; photosynthetic rate; transpiration rate; yield attributes

Introduction

Castor (*Ricinus communis L.*), a member of the Euphorbiaceae family, is a perennial crop valued for its oil seed production. It is cultivated in warm tropical and temperate regions, contributing significantly to industrial purposes (1,2). The top castor-producing countries globally include India, China, Brazil, Russia, Thailand, Ethiopia and the Philippines (2). Indias' castor seed production to reach 20.54 lakh tonnes in 2023-24, an increase from 18.81 lakh tonnes in 2022-23. The estimated average productivity during 2023-24 is 2044 kg/ha, slightly lower than the 2048 kg/ha recorded in 2022-23 (SEAs' castor crop survey 2023-24). A notable challenge castor farmers face is the limitation on cultivating a second crop, as the existing cultivars necessitate a growth period of 6 to 7 months for the tertiary spikes to mature for harvest, thereby hindering actual annual cultivation (3). Castor is an indeterminate growth pattern characterized by substantial vegetative development and multiple spikes, including primary, secondary, tertiary and quaternary. This leads to an imbalanced source-sink relationship. To manage the physiological parameters effectively, periodic and staggered nipping is employed (4). Nipping is an essential agricultural practice that curtails the vertical growth of the main stem, ultimately enhancing the pod count. Nipping at 35 days, post-sowing can significantly improve crop yield (5). Nipping can be executed through two main techniques: manual nipping and chemical nipping. Manual nipping consists of pinching the terminal portion of the crop, whereas chemical nipping involves the application of growth retardants such as mepiquat chloride (6). In numerous developing nations, the harvesting of castor is a labour-intensive endeavour, predominantly performed by hand. In

India, this process generally requires two to three rounds of picking, with manual harvesting proving to be more expensive than other agricultural practices.

Furthermore, hand harvesting of castor presents various health hazards for workers. Recently, there has been a significant increase in the adoption of mechanized harvesting due to substantial labour shortages (7). This mechanization effectively addresses the challenges linked to manual harvesting, facilitates the timely planting of subsequent crops and requires that the plants maintain a consistent and reduced height. The primary objective is to influence the physiological functions of the castor plant to manage foliage, induce defoliation or desiccation and encourage the synchronized opening of castor capsules. Appropriate concentrations of growth regulators have shown beneficial effects in enhancing seed yield and reducing shattering (8).

Additionally, these compounds may aid in decreasing plant height in castor; however, previous research has indicated inconsistent results regarding the efficacy of gibberellic acid inhibitors in this specific crop (9). The combination of manual nipping and mepiquat chloride aims to improve the mechanical harvesting of castor by altering the plants' physiological processes. Therefore, it is essential to explore this area further. Consequently, this study focused on the performance of different castor hybrids on manual and chemical nipping with different internodes on physiological and yield attributes.

Materials and Methods

A field experiment was conducted at Tapioca and Castor Research Station in Yethapur, Salem, part of Tamil Nadu Agricultural University located in Coimbatore, Tamil Nadu, India. The site is positioned at a latitude of 11°39' N and a longitude of 78°28' E, with an elevation of 282 meters above mean sea level. The research occurred during the Rabi season, from December 2023 to April 2024. The soils' physico-chemical characteristics in the experimental field revealed that it is classified as red sandy loam. The chemical properties included a pH of 7.14, an electrical conductivity (EC) of 0.82 dSm^{-1}, available nitrogen at 206 kg/ha (medium), available phosphorus at 10.4 kg/ha (low) and available potassium at 282 kg/ha (high). The experimental design utilized a split-plot arrangement with three replications and sixteen treatments. The treatments included four hybrid castors in main plot: M_1-YRCH-1, M_2-YRCH-2, M_3-ICH-66 and M_4-DCH-519, along with four sub-plot treatments: S_1-No Nipping, S_2-Manual Nipping at the 10^{th} node, S_3-Manual Nipping at the 12^{th} node and S_4- Chemical Nipping using mepiquat chloride at a rate of 200 g/ha.

Chlorophyll content

SPAD measurements were obtained utilizing a chlorophyll meter (SPAD 502) developed by the Soil Plant Analytical Development (SPAD) Section of Minolta, Japan. The Minolta SPAD-502 quantifies chlorophyll content by assessing the light transmittance ratio at 650 nm and 940 nm. Five readings were collected from each replication in each net plot, with measurements taken from the top, middle and bottom leaves. The average value was subsequently calculated (10, 11).

Stomatal conductance

Stomatal Conductance was measured by (60 and 90 DAS) portable photosynthetic system (PPS) and expressed as mmol/ m^2/Sec.

Photosynthetic rate

The photosynthetic rate was measured by (60 and 90 DAS) using a portable photosynthetic system (PPS) and expressed as μ mol/m^2/sec.

Transpiration rate

The transpiration rate was recorded using (60 and 90 DAS) portable photosynthetic system (PPS) and expressed as m mol/m^2/sec.

Yield attributes and yield

The total number of spikes per plant was recorded for each plot, including primary, secondary and tertiary spikes. Furthermore, the number of capsules per spike was evaluated by counting the capsules on five tagged plants within each plot at every harvest. Spike length was measured in centimetres on five tagged plants, from the emergence point of the primary, secondary and tertiary spikes to their tips. After the final harvest, the spikes from each net plot were collected and weighed to determine the spike yield, which was expressed in kilograms per hectare (kg/ha). Likewise, following the final harvest, the seed yield was assessed by separating and weighing the seeds from the spikes, with the seed yield also reported in kilograms per hectare (kg/ha) for each specific treatment.

Statistical analysis

The data collected on multiple parameters from field experiments underwent statistical analysis utilizing a split-plot design through AGRES software. The critical difference (CD) was determined at a 5 % probability level.

Results

Effect of nipping on physiological parameters

Physiological parameters such as stomatal conductance, transpiration and chlorophyll content are crucial for understanding plant performance under different environmental conditions and treatments, especially in field experiments. These parameters help determine the optimal practices that maximize water use efficiency, improve photosynthesis and enhance yield.

Chlorophyll content

The SPAD value measures the chlorophyll content in leaves. In this experiment, the SPAD value of castor varied significantly on different days after sowing due to the cultivation of different castor hybrids (Fig. 1.).The experimental results showed that the M_2 hybrid(YRCH-2) had the highest SPAD values (48.4, 53.0, at 60 and 90 DAS, respectively). In contrast, the M_1 hybrids (YRCH-1) had the lowest SPAD values for all growth stages. The finding revealed that YRCH-2 provided significantly higher chlorophyll content compared to ICH-66 cm and, DCH-519 and YRCH-1. This might be due to the significant variation in SPAD values across different genotypes affected by stress, with the DRSF-113 genotype showing the highest SPAD chlorophyll meter reading of 31.5, similar to other sunflower varieties (12).

This is apparent due to different nipping practices treatments had increased than the chlorophyll content (Fig.1.). Among the chlorophyll content measures, chemical nipping @ 12th mepiquat chloride 200 g/ha (S_4) significantly recorded the highest SPAD values (53.4, 57.0 and at 60 and 90 DAS respectively). The no-nipping treatment recorded the lowest chlorophyll content (S_1). Their findings discovered the highest chlorophyll content to chemical nipping using 200 g ha^{-1} mepiquat chloride at the 12th node compared to manual nipping at the 10th and 12th node and no nipping (60 and 90 DAS, respectively). This might be due to enhancing leaf chlorophyll content by controlling the expression of crucial enzymes involved in chlorophyll biosynthesis (13). Additionally, the production of endogenous cytokinins promotes chloroplast differentiation, which helps delay their degradation (14).

In terms of interaction effects (Fig. 2.), the combination of the main plot and subplot had the highest chlorophyll content of SPAD values (55.2, 61.2, at 60 and 90 and DAS, respectively) observed with YRCH-2 and chemical nipping of mepiquat chloride at a rate of 200 g ha^{-1} (M_2S_4), which were statistically similar to the ICH-66 and chemical nipping @ 12th node (M_3S_4) treatment at 60 and 90 DAS. The lowest SPAD values (40.0, 41.0 and 60 and 90 DAS, respectively) were recorded in the YRCH-1 and no nipping (M_1S_1) treatment. This might be due to increased leaf chlorophyll content by regulating the expression of key enzymes involved in chlorophyll biosynthesis. It promotes the production of endogenous cytokinins, which enhance chloroplast differentiation and delay their degradation (14, 15).

Photosynthetic rate

The treatment involving various castor hybrids at different stages after sowing significantly impacted the plants' photosynthetic rate (μmol/m^2/s) (Table 1). The results showed that YRCH-2 (M_2) had the highest photosynthesis rates of 19.1, 22.0 μmol/m^2/s at 60 and 90 DAS., statistically on par with ICH-66 and(At 60 and 90 DAS). In contrast, YRCH-1 (M_1) recorded the lowest rates, with values of 17.5 and 18.5

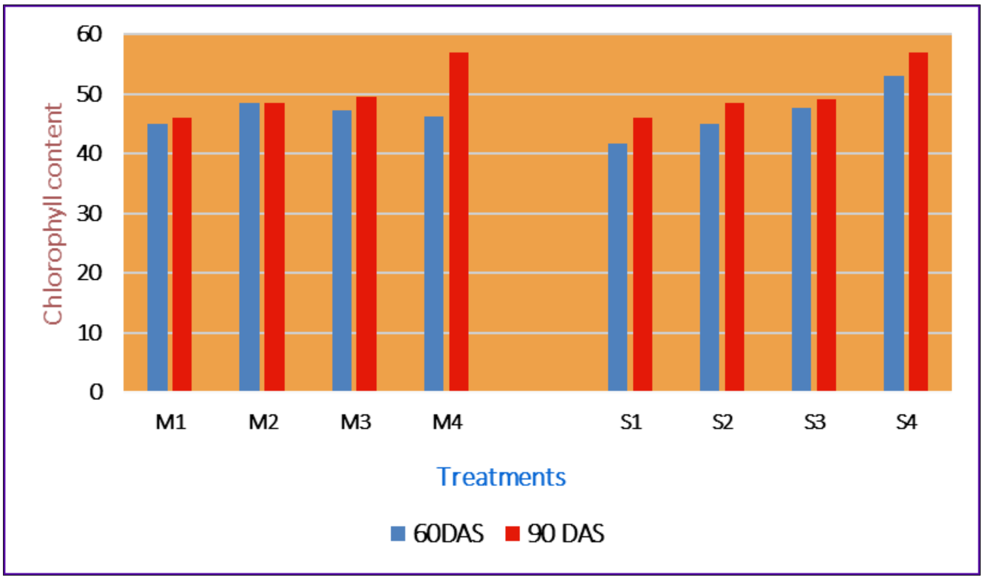

Fig. 1. Effect of castor hybrids and nipping practice on chlorophyll content at 60 and 90 DAS.

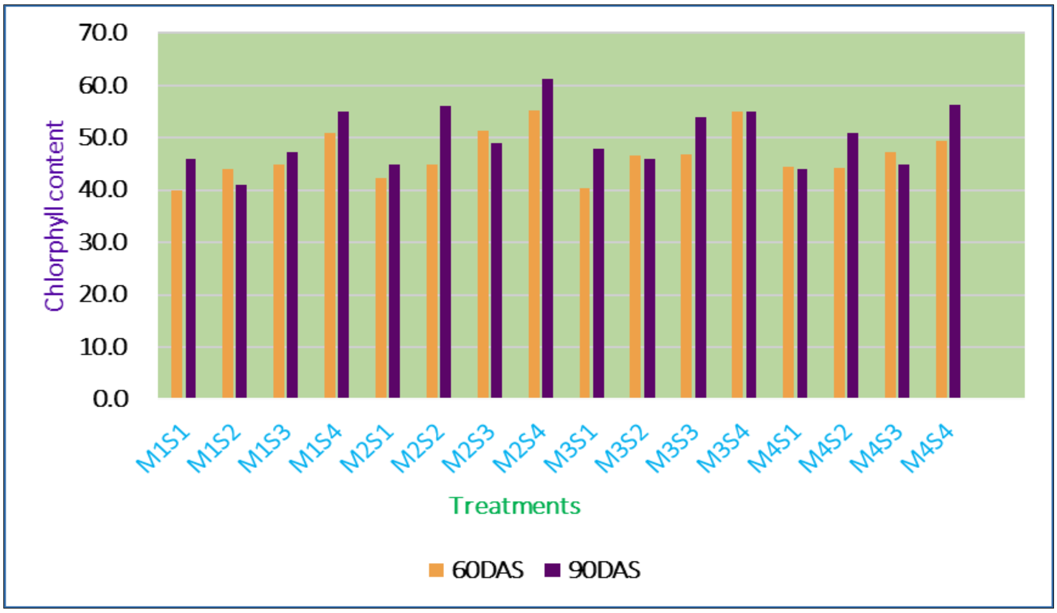

Fig. 2. Effect of castor hybrids and nipping practice on chlorophyll content at 60 and 90 DAS.

Table 1. Effect of castor hybrids and nipping practice on photosynthetic rate µ mol/m²/sec at 60 and 90 DAS were significantly highest YRCH-2 and chemical nipping

60DAS					90DAS				
M1	M2	M3	M4	Mean	M1	M2	M3	M4	Mean
17.0	16.4	15.3	15.0	16.0	17.3	17.1	16.8	16.1	16.8
16.0	17.0	17.0	16.5	17.0	16.0	18.3	17.5	17.0	17.2
17.0	19.0	19.0	18.5	18.3	17.0	19.1	18.3	19.0	18.0
20.0	25.0	23.0	23.1	23.0	23.3	33.0	27.0	26.0	27.2
17.5	19.1	18.5	18.3		18.4	22.0	19.9	19.5	
M	S	M at S	S at M		M	S	M at S	S at M	
0.3	0.4	0.1	1.0		0.2	0.3	0.7	0.7	
0.7	0.8	1.0	2.0		0.5	0.6	1.4	1.5	

(Significant at $P < 0.05$)

µmol/m²/s at the same stages. The reason for the increase in photosynthetic and metabolic activity in cotton plants after mepiquat chloride treatment explains the observed effects (16, 17).

Among the various nipping practices, the application of chemical nipping @ 12th node mepiquat chloride at 200 g/ha (S_4) recorded the highest photosynthesis rates of 23.0 and 27.2 µmol/m²/sec at60 and 90 DAS, respectively. The lowest photosynthesis rates were observed in the no-nipping treatment (S_1), with 6.0 and 16.7 µmol/m²/sec values. This was followed by manual nipping at the 12th node (S_3) across all growth stages. Regarding interaction effects, combining four castor hybrids and nipping practices resulted in a significantly enhanced photosynthesis rate (25.0, 33.0 µmol/m²/Sec)(M_2S_4). This might increase light exposure and improve plant nutrient availability, boosting photosynthetic activity and greater dry weight (18). This could be attributed to the fact that NAA, part of the auxin group, plays a key role in root development. The increase in plant height following foliar application of NAA may be due to enhanced cell elongation, cell division and the growth-promoting effects of this hormone. It also leads to increased photosynthetic activity, better mobilization of photosynthates and enhanced membrane permeability (19- 21).

Stomatal conductance

The analysis conducted on various castor hybrids at different intervals post-sowing demonstrated a notable impact on the stomatal conductance of castor plants (Table 2.). The findings indicated that the highest stomatal conductance was observed in YRCH-2 (M_2) with 259.1 and 269.9 m mol/m²/sec values at the 60 and 90 DAS, respectively. Conversely, the lowest measurements were recorded for YRCH-1 (M_1) at 17.5 and 18.5 m mol/m²/sec for the same intervals. The improved performance of the castor hybrids may be linked to their superior leaf reflectance and transmission characteristics, which facilitate a more rapid stomatal conductance (22).

Among the various nipping techniques, the application of chemical nipping @ 12th node mepiquat chloride at 200 g/ha (S_4) demonstrated the highest stomatal conductance, measuring 346.7 and 387.6 m mol/m²/sec at 60 and 90 days after sowing (DAS), respectively. In contrast, the lowest stomatal conductance was recorded for the treatment with no nipping (S_1), which yielded 169.8 185.3 m mol/m²/sec values at the same intervals. With the interaction of higher stomatal conductance YRCH-2 and chemical nipping @ 12th node mepiquat chloride at 200 g/ ha (M_2S_4) (379.3,402.3 m mol/M²/Sec at 60 and 90DAS, respectively). It was followed by YRCH-2 (M_2) (259.3, 389.3 m mol/M²/Sec and at 60 and 90 DAS). The MC application increased the leaf CO_2 exchange rate and Pn compared with control plants. This might be due to the rise in the CO_2 exchange rate, which may also be linked to enhanced stomatal conductance of cotton leaves (23). Environmental elements like light, temperature, moisture, nutrients and others impact the effectiveness of plant growth regulators (24). This technique increases chlorophyll content in plants, reduces plant height and inhibits cell elongation. Under these conditions, applying mepiquat chloride causes the plant to grow progressively shorter (21).

Transpiration rate

The treatment involved various castor hybrids on different days after sowing, significantly affecting the results, which revealed the highest transpiration rate of 9.2, 10.5 (YRCH-2) (M_2) at 60 and 90 DAS. It was statistically followed by ICH-66 (M3) (60 and 90 DAS, respectively) (Table 3). YRCH-1 (M1) recorded the lowest value, 7.0, 7.7 (60 and 90 DAS). Among the various nipping practices, chemical nipping at the 12th node using mepiquat chloride at 200 g/ha(S_4) resulted in the highest transpiration rates (10.5, 11.2 µmol/M²/Sec 60 and 90 DAS, respectively). This was followed by manual nipping 12th node (S_3) (60 and 90 DAS, respectively). In terms of interaction effects, the comparison between the main plot and subplot revealed that the highest transpiration rate was observed

Table 2. The effect of castor hybrids, nipping practice and practice on stomatal conductance m mol/m2/sec at 60 and 90 DAS showed significantly higher YRCH-2 and chemical nipping

60DAS					90DAS				
M_1	M_2	M_3	M_4	Mean	M_1	M_2	M_3	M_4	Mean
122.0	185.0	175.0	197.3	169.8	184.7	203.7	190.0	162.7	185.3
142.7	221.0	199.0	196.0	189.6	221.0	229.7	215.7	186.0	213.1
153.3	251.7	228.0	211.3	211.1	251.7	244.0	265.3	197.3	239.6
259.3	379.3	378.3	369.7	346.7	379.1	402.3	379.3	389.3	387.6
169.3	259.1	245.1	243.5		259.2	269.9	262.6	233.8	
M	S	M at S	S at M		M	S	M at S	S at M	
1.8	2.8	6.4	6.8		9.3	6.3	16.9	15.4	
3.9	5.5	12.9	13.5		20.6	12.6	35.0	30.1	

(Significant at $P < 0.05$) (Stomatal conductance m mol/m2/sec)

Table 3. Effect of castor hybrids, chemical nipping practice on transpiration rate µ mol/m²/sec at 30, 60 and 90 DAS, significantly highest YRCH-2 and chemical nipping

60DAS					90DAS				
M_1	M_2	M_3	M_4	Mean	M_1	M_2	M_3	M_4	Mean
4.0	7.3	6.4	6.1	5.9	6.5	8.0	7.0	5.0	6.6
7.0	8.2	7.0	7.9	7.5	8.0	10.0	8.0	7.0	8.2
8.0	9.0	8.2	8.0	8.3	8.6	11.0	8.5	8.0	9.0
9.0	12.3	9.9	10.7	10.5	13.3	13.0	10.6	11.0	11.2
7.0	9.2	7.8	8.2		9.0	10.5	8.5	7.7	
M	S	M at S	S at M		M	S	M at S	S at M	
0.1	0.1	0.3	0.3		0.1	0.2	0.4	0.5	
0.3	0.2	0.6	0.6		0.3	0.4	0.9	0.1	

(Significant at $P < 0.05$) (Transpiration rate µ mol/m2/sec)

with the combination of YRCH-2 and chemical nipping using mepiquat chloride at a rate of 200 g/ha (M_2S_4) (60 and 90 DAS, respectively). This might be because mepiquat chloride increases transpiration rates in oil seed crops by controlling plant growth, enhancing water use efficiency and altering leaf physiology. Heres' how it influences transpiration in oil seeds (16).

Effect of nipping on yield attributes

Number of spikes/plant

The various treatments applied in castor hybrids significantly influenced the number of spikes per plant at the time of harvest (Fig. 3.). The highest count of 7.9 spikes per plant was observed in the YRCH-2 hybrid (M_2), followed by ICH-66 with 7.0 spikes (M_3) and DCH-519, which recorded 6.9 spikes (M_4). The lowest count of 6.8 spikes per plant was noted in the YRCH-1 hybrid (M_1). The various treatments of subplots, precisely the number of spikes per plant, are significantly affected by nipping practices during harvest. The highest recorded number of spikes per plant was 9.1, achieved through chemical nipping at the 12th node using mepiquat chloride at a rate of 200 g/ha (S_4). This was followed by manual nipping at the 12th node(S_3), which yielded 8.3 spikes per plant. A count of 7.4 spikes per plant was also noted with manual nipping at the 10th node (S_2). Conversely, the lowest number of spikes per plant, recorded at 3.3, was observed in the no-nipping (S_1). The finding revealed that the application of chemical nipping with 200 g ha^{-1} of mepiquat chloride resulted in the highest number of spikes at the 12th node (Fig. 4.), in contrast to manual nipping at the 10th and 12th nodes, as well as the no nipping. This might be influenced by the accumulation and photosynthetic of photo-assimilates in the plants' reproductive parts. An increase in spikes can be attributed to higher seed yield (25).

Regarding interaction effects, the combination of castor hybrids and nipping practices yielded the highest number of spikes per plant, with a notable count of 10.0 recorded for YRCH-2 when subjected to manual nipping at the 12th node (M_2S_3). This result is comparable to the 9.0 spikes observed with YRCH-2 using chemical nipping at the 12th node with mepiquat chloride at 200 g ha^{-1}(M_2S_4). Additionally, DCH-519 and ICH-66 recorded 9.3 spikes when treated with chemical nipping at the 12th node using mepiquat chloride at 200 g/ha (M_4S_4 and M_3S_4, respectively). YRCH-1 also achieved 8.7 spikes with chemical nipping at the 12th node using mepiquat chloride (M_1S_4), while YRCH-2 recorded 8.7 spikes with manual nipping at the 10th node (M_2S_2). YRCH-1 with manual nipping at the 12th node and the same chemical applications recorded 8.1 spikes (M_1S_3). DCH-519 and ICH-66, with manual nipping at the 12th node and the same chemical treatments, yielded 7.6 spikes (M_4S_3 and M_3S_3, respectively). Lastly, DCH-516, with manual nipping at the 10th node and the same chemical applications, recorded the lowest count of 7.3 spikes (M_4S_2). The lowest number of spikes per plant, 3.4 was noted for DCH-519 with no nipping (M_4S_1). The findings indicated that the application of castor hybrids of YRCH-2 + chemical nipping at the 12th node using mepiquat chloride at a rate of 200 g/ha (M_2S_4) resulted in the highest number of spikes when compared to the no nipping. The

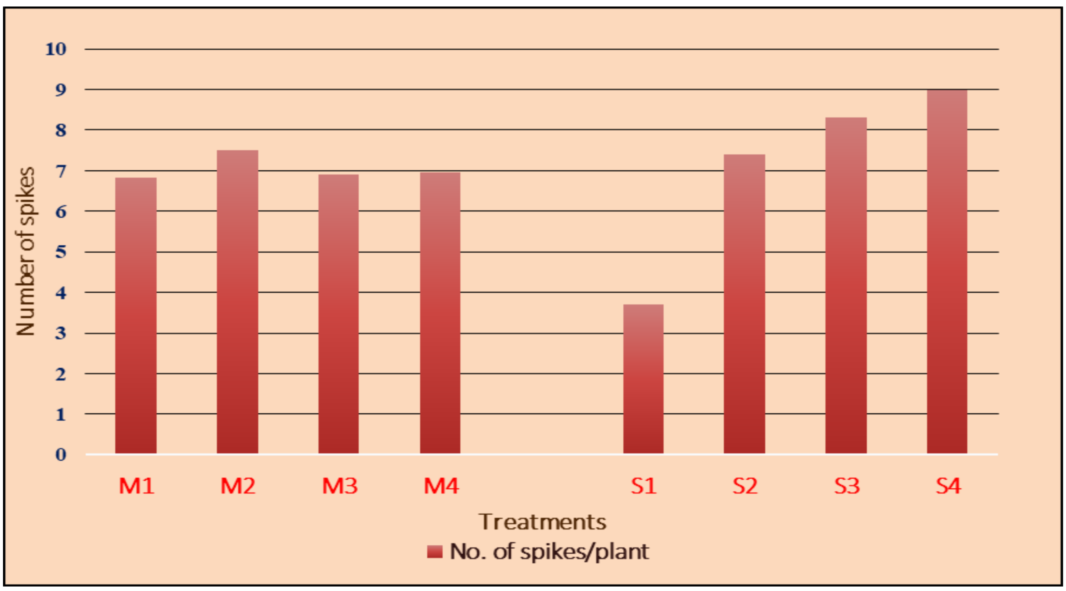

Fig. 3. Effect of castor hybrids and nipping practice on the number of spikes/plant at harvest stage.

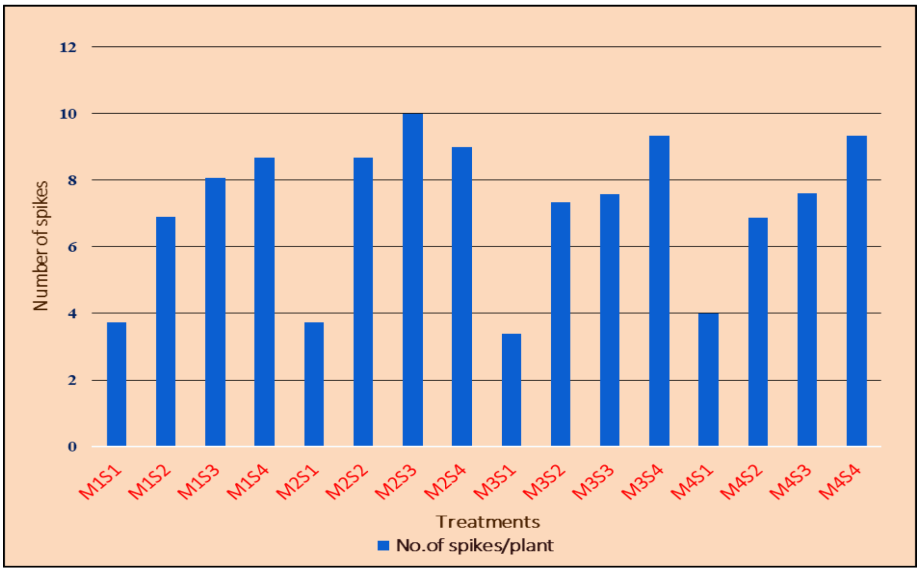

Fig. 4. Effect of castor hybrids and nipping practice on the number of spikes/plant at the harvest stage.

higher yield attributes observed with NAA application may be due to its role in promoting cell elongation and division and reducing flower and pod drop, which enhances pod and fruit set. This ultimately increases chickpeas yield (kg/ha) (26, 27).

Spike length/spike

Among the various primary plot treatments, the spike length/spike was notably influenced by castor hybrids at the time of harvest (Fig. 3). The maximum spike length/spike of 73.6 cm was observed in YRCH-2 (M_2), which is comparable to the 70.3 cm recorded for ICH-66 (M_3), followed closely by DCH-519 (M_4) at 69.1 cm. Conversely, the minimum spike/length of 62.1 cm was noted in YRCH-1 (M_1). The various treatments of the subplot, specifically spike length/spike, are significantly influenced by nipping practices during harvest (Fig. 3.). The maximum spike length $^{-1}$ recorded was 75.4 cm, achieved through chemical nipping at the 12th node using mepiquat chloride at a rate of 200 g/ha (S_4). This was closely followed by manual nipping at the 12th node (S_3), which resulted in a spike/length of 71.1 cm. A spike length of 66.3 cm was also noted with manual nipping at the 10th node (S_2). In contrast, the lowest spike length/spike of 62.2 cm was observed in the no nipping (S_1).

In terms of interaction effects (Fig. 4), the combination of castor hybrids and nipping practices yielded the highest spike length of 80.6 cm, achieved with the YRCH-2 hybrid and chemical nipping using mepiquat chloride at a rate of 200 g/ha (M_2S_4). This result is comparable to the 75.2 cm spike length observed with the YRCH-1 hybrid under the same chemical nipping conditions (M_1S_4). Additionally, a spike length of 75.9 cm was recorded for the DCH-519 hybrid with the same chemical nipping treatment (M_4S_4). Following closely, the YRCH-2 hybrid again showed a spike length of 74.4 cm with the chemical nipping treatment (M_2S_4). A spike length of 71.5 cm was noted for the DCH-519 hybrid when subjected to manual nipping at the 12th node (M_4S_3).

Furthermore, the ICH-66 hybrid exhibited a spike length of 72.9 cm under manual nipping at the 10th node (M_3S_2). Conversely, the lowest spike length of 55.3 cm was recorded for the YRCH-1 hybrid with manual nipping at the 10th node (M_1S_2). This could be due to the increased vigour and strength gained by the plants from enhanced photosynthetic activity, supported by adequate light and optimal nutrient supply. Additionally, wider crop spacing allows for better crop development, providing more plant space and reducing competition for nutrients and moisture, ultimately leading to improved yield attributes. Similar findings were reported by(28).

Number of capsules/Spike

The analysis of the primary plot treatments revealed that the castor hybrids significantly affected the number of capsules per plant at harvest time (Table 4). The highest count of capsules per plant, totalling 159.0, was observed in YRCH-2 (M_2), which was comparable to the 156.0 recorded for ICH-66

Table 4. The effect of castor hybrids, manual and chemical nipping practices on no. of capsules /spike, spike length/spike at harvest stage was significantly highest YRCH-2 and chemical nipping

No. of capsules /spike					Spike length/Spike				
M_1	M_2	M_3	M_4	Mean	M_1	M_2	M_3	M_4	Mean
143.7	144.6	141.1	145.0	143.6	56.2	66.9	61.4	64.4	62.2
154.0	153.3	157.0	149.3	153.4	55.3	72.5	72.9	64.6	66.3
157.3	162.6	161.0	158.0	159.7	62.0	74.4	70.6	71.5	69.6
160.0	174.0	166.0	171.1	167.7	75.2	80.6	76.2	75.9	76.9
153.7	158.6	156.3	155.8		62.2	73.6	70.3	69.1	
M	S	M at S	S at M		M	S	M at S	S at M	
2.1	1.3	3.3	2.7		1.4	1.3	2.6	2.3	
5.3	2.8	6.7	5.7		3.5	2.6	5.4	5.2	

(Significant at $P < 0.05$)

(M_3) and the 155.8 recorded for DCH-519 (M_4). Conversely, the lowest count of capsules per plant, at 154.0, was found in YRCH-1 (M_1). The development of castor racemes is influenced by genetic traits, environmental conditions and the plants' physiological status, with some characteristics determined even before the raceme develops (29).

Various nipping treatment practices significantly influenced the number of capsules per plant at harvest (Table 4.). The highest count of capsules per plant, totalling 168.0, was observed by applying chemical nipping at the 12th node using mepiquat chloride at a rate of 200 g/h (S_4). This was closely followed by manual nipping at the 12th node (S_3), which yielded 159.8 capsules. Additionally, a count of 153.4 capsules was recorded with manual nipping at the 10th node (S_2). In contrast, the lowest number of capsules per plant, recorded at 143.6, occurred in the no-nipping (S_1). The results corroborate a significant increase in capsules by nipping apical buds in different crops (30). comparatively, mepiquat chloride application is influenced by the accumulation and distribution of photo-assimilates in the plants' reproductive parts. An increase in seed yield can be attributed to more capsules (31).

In terms of interaction effects (Table 4), the combination of the main plot and subplot yielded the highest number of capsules per plant, 174.0, with the YRCH-2 variety and chemical nipping at the 12th node using mepiquat chloride at a rate of 200 g/ha (M_2S_4). This result is comparable to the 171.1 capsules recorded for the DCH-519 variety under the same chemical nipping conditions (M_4S_4). Following closely was the combination of ICH-66 with chemical nipping at the 12th node using mepiquat chloride at 200 g/ha (M_3S_4), which produced 166 capsules. The YRCH-1 hybrid, also with chemical nipping at the 12th node using mepiquat chloride at 200 g/ha, recorded 160 capsules (M_1S_4). Additionally, a combination of YRCH-2 with manual nipping at the 12th node (M_2S_3) resulted in 162.7 capsules. Conversely, the lowest number of capsules per plant, 141.1, was observed with ICH-66 and no nipping (M_3S_1). The findings revealed that the application of castor hybrids of YRCH-2 + chemical nipping at the 12th node using mepiquat chloride at a rate of 200 g/ha (M_2S_4) resulted in the highest number of spikes when compared to the no nipping. In this study, growth regulator application increased the number of capsules per plant. This finding underscores the potential of a tailored approach in applying growth regulators to enhance sesame productivity beyond traditional practices (32).

Spike yield

The various primary plot treatments significantly impacted spike yield, which was notably affected by the castor hybrids at the time of harvest (Table 5). The highest recorded spike yield was 2327 kg/ha for the hybrid YRCH-2 (M_2), followed by ICH-66 (M_3) with a yield of 2186 kg/ha and DCH-519 (M_4) with 2162 kg/ha. Conversely, the lowest spike yield was observed in YRCH-1 (M_1), which yielded 1932 kg/ha. The variations observed in the yield components of the castor accessions suggest that castor spike yield could be enhanced through selective breeding programs, provided there is genetic information on how these traits are inherited (33).

The harvest timing significantly influences the various nipping techniques and the overall spike yield (Table 5). The highest recorded total spike yield was 2487 kg/ha, achieved through chemical nipping at the 12th node using mepiquat chloride at a rate of 200 g/ha (S_4). This was followed by manual nipping at the 12th node combined (S_3), which yielded 2149 kg/ ha. A 2057 kg/ha yield was also obtained from manual nipping at the 10th node (S_2). In contrast, the no-nipping treatment observed the lowest total spike yield of 1915 kg/ha (S_1). The study demonstrated that chemical nipping with 200 g/ha of mepiquat chloride led to the most significant spike yield at the 12th node, compared to manual nipping performed at the 10th and 12th nodes and no nipping. The utilization of MC rates ranging from 98.8 to 105.7 g a.i./ha should be implemented at the onset of the second raceme production to enhance the physiological efficiency, including photosynthetic capability (34).

In terms of interaction, the combination of the main plot and subplot yielded the highest spike production of 2698 kg/ha, achieved by YRCH-2 with chemical nipping at the 12th node using mepiquat chloride at a rate of 200 g/ha (M_2S_4) (Table 5.). This result is comparable to the 2590 kg/ha recorded for the combination of ICH-66 and chemical nipping at the 12th node with the same application of mepiquat chloride (M_3S_4). Additionally, DCH-519 demonstrated a yield of 2489 kg/ha with chemical nipping at the 12th node using mepiquat chloride at 200 g/ha (M_4S_4). The combination of YRCH-2 with manual nipping at the 12th node resulted in a yield of 2398 kg/ha (M_2S_3). Conversely, the lowest yield of 1764 kg/ha was observed in YRCH-1 when no nipping was applied (M_1S_1). The findings observed that applying castor hybrids of YRCH-2 + chemical nipping at the 12th node with the same application of mepiquat chloride (M_2S_4) resulted in the highest spike yield compared to the no

Table 5. Effect of castor hybrids, manual and chemical nipping practice on spike yield, seed yield at harvest stage and significantly highest YRCH-2 and chemical nipping

	Spike yield (kg/ha)					Seed yield (kg/ha)				
	M_1	**M_2**	**M_3**	**M_4**	**Mean**	**M_1**	**M_2**	**M_3**	**M_4**	**Mean**
S_1	1764	1970	1996	1930	1915	1412	1597	1592	1579	1545
S_2	1881	2244	2024	2079	2057	1516	1741	1718	1657	1658
S_3	1912	2398	2133	2150	2149	1534	1742	1770	1787	1708
S_4	2172	2698	2590	2489	2487	1652	2198	2033	2018	1975
Mean	**1932**	**2327**	**2186**	**2162**		**1529**	**1820**	**1778**	**1761**	
	M	S	M at S	S at M		M	S	M at S	S at M	
SEd	27.2	51.9	119.3	127.2		22.2	24.9	59.9	60.9	
CD (P=0.05)	60.8	103.9	240.4	254.5		49.6	49.7	122.2	121.9	

(Significant at $P < 0.05$)

nipping.

Seed yield

The seed yield at the harvest stage was significantly affected among the four castor hybrids (Table 5.). The highest yield was observed in YRCH-2 (M_2), reaching 1820 kg/ha, statistically comparable to ICH-66 (M_3) at 1778 kg/ha. Following closely was DCH-519 (M_4) with a 1761 kg/ha yield. In contrast, the lowest seed yield was recorded for the YRCH -1 (M_1) hybrid, which amounted to 1529 kg/ha. Their unique genetic characteristics shape the growth and yield of various sunflower varieties. These findings are consistent with notable differences in agronomic traits and seed yield among cultivars attributed to variations in genotype and environmental factors.

The various subplot treatments significantly influenced seed yield, particularly the harvesting nipping practices (Table 5.). The highest seed yield of 1975 kg/ha was achieved through chemical nipping at the 12th node using mepiquat chloride at a rate of 200 g/ha (S_4). This was followed by a yield of 1708 kg/ha from manual nipping at the 12th node (S_3). A yield of 1658 kg/ha was also obtained from manual nipping at the 10th node (S_2). Conversely, the lowest seed yield of 1545 kg/ha was recorded in the no nipping (S_1). The research indicated that applying chemical nipping with 200 g/ha of mepiquat chloride resulted in the highest spike count at the 12th node, in contrast to manual nipping conducted at the 10th and 12th nodes and no nipping. Because of the efficient transfer of photosynthates accumulated during vegetative growth to the reproductive part, a significantly higher yield was recorded in nipping plots against non-nipping (36). The utilization of MC resulted in an enhanced yield of common beans, attributed to an increase in seed quantity and weight compared to alternative regulators. It is posited that MC may have affected shoot architecture by regulating assimilate distribution for vertical growth, thus facilitating a more uniform canopy structure, which can reduce the likelihood of lodging (37).

Regarding interaction effects, the combination of castor hybrids and nipping practices significantly influenced the various treatments (Table 5.). The highest seed yield of 2198 kg/ha was achieved with the YRCH-2 hybrid, which utilized chemical nipping at the 12th node with mepiquat chloride at a rate of 200 g/ha (M_2S_4). This was closely followed by the ICH-66 hybrid, which also employed chemical nipping at the 12th node (M_3S_4), yielding 2033 kg/ ha. Additionally, the DCH-519 hybrid recorded a seed yield of 2018 kg/ha under the same nipping treatment (M_4S_4). Conversely, the lowest seed yield of 1412 kg/ha was observed with the YRCH-1 hybrid when no nipping was applied (M_1S_1). Their findings interaction observed that the application of castor hybrids of YRCH-2 + chemical nipping at the 12th node using mepiquat chloride at a rate of 200 g/ ha (M_2S_4) resulted in the highest seed yield when compared to the no nipping. This might be due to enhancing physiological efficiency, including photosynthetic capability and significantly achieving higher crop yields (31). Such findings are pivotal, indicating that MCs' role extends beyond plant stature regulation to potentially influencing seed development processes, thereby impacting seed quality and market value. By retarding rapid cell division, MC allows for more extended nutrient accumulation in individual seeds, leading to heavier seeds (29).

Effect of hybrid castor and nipping practices on Economics

The economic parameters have been calculated based on the prevailing market prices of both inputs and outputs, as presented in (Fig. 5). Among the four castor hybrids and nipping treatments, the combination of YRCH-2 with chemical nipping at the 12th node, along with the application of mepiquat chloride at 200 g/ha, yielded the highest net return of Rs. 92849 (M_2S_4). This was followed by the combination of YRCH-2 with manual nipping at the 12th node (M_2S_3), which resulted in a net return of Rs. 72292. The combination of YRCH-2 with manual nipping at the 10th node (M_2S_2) recorded a net return of Rs. 67296. The lowest net return, Rs. 48711.3, was observed in YRCH-1 with no nipping (M_1S_1).

Regarding the benefit-cost ratio, the highest value of 3.31 was recorded in YRCH-2 with chemical nipping at the 12th

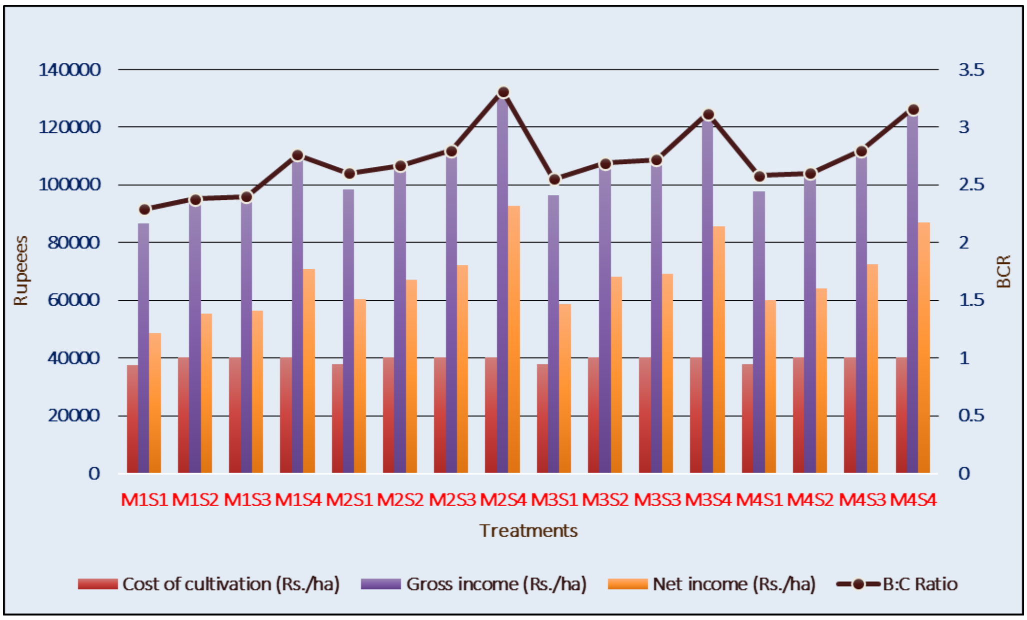

Fig. 5. Effect of castor hybrids, nipping practices on cost of cultivation (Rs./ha), gross income (Rs./ha) and benefit cost ratio at harvest stage.

node

Fig. 6. Effect of castor hybrids, chemical nipping sprayer.

(M_2S_4), while the lowest value of 2.2 was found in YRCH-1 with no nipping (M_1S_1). These results align with the findings in soybeans (38,39). The treatment involving nipping at 30 DAS and a foliar spray of MC @ 1000 ppm significantly impacted net returns, mainly due to the highest yield achieved and the lower cultivation costs than other treatments, which had similar yields but incurred higher costs.

Conclusion

From the experiment, it is concluded that castor hybrids combined with chemical nipping(12th node application of MQ at 200 g/ha) are significantly influenced by physiological, yield attributes and yield. Based on the field studies, it is revealed that YRCH-2 hybrid castor combined with chemical nipping by use of mepiquat chloride at the rate of 200 g/ha (M_2S_4) have recorded the highest physiological parameters like., chlorophyll content (measured by SPAD value) (61.2), stomatal conductance (402.3 m mol/M^2/Sec), photosynthetic rate (33.0 μmol/m^2/Sec) and yield parameters like Spike length (80.6 cm), number of capsules per spike(174.0), seed yield (2198 kg/ha). The combination of YRCH-2 and chemical nipping at the 12th node, application of mepiquat chloride at 200 g/ha to influence yielded the highest net return of Rs. 92849 benefit-cost ratio value of 3.31 (M_2S_4). Comparing manual and chemical nipping cultivation and applying growth regulators like mepiquat chloride can effectively improve the physiological parameters and yield, improving the feasibility of mechanized harvesting. Further investigations on optimizing the timing and concentration of growth regulators could further enhance the potential of castor hybrids for sustainable and efficient production.

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Authors' contributions

NK designed the work outline. RR executed the work. VR supervised the work. RS and SR helped in writing the manuscript. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors have no conflict of interest.

Ethical issues: None

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