RESEARCH ARTICLE

Pruning and Chemical Manipulation Influence Leaf Physiological Parameters and Pod Yield Parameters of Perennial Moringa (*Moringa oleifera* Lam.) cv. Kappalpatti Local During Off-Season

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ABSTRACT

Understanding and controlling the physiological processes that regulate flowering is crucial for producing crops in the off-season. To explore this, an experiment was conducted involving various pruning intensities and chemical sprays to induce off-season flowering and fruiting in moringa trees. The experiment followed a Factorial Randomized Block Design, with Factor I representing pruning at four levels: P-1 (No pruning), P-2 (Pinching off the previous year's growth of fruiting branches), P-3 (Light pruning, removing 33% of the previous year's growth), and P-4 (Severe pruning, removing 66% of previous year's growth). Factor II involved chemical sprays at seven levels: C-1 (Control-water spray), C-2 to C-7 (Different chemical treatments). A total of 28 treatment combinations were tested with two replications each. Pruning was performed in the second week of July, and chemicals were sprayed twice, with the first application 30 days after pruning and the second 15 days after that. Various physiological parameters such as nitrate reductase activity, total carbohydrate content, nitrogen content, carbohydrate: nitrogen ratio, soluble protein, IAA oxidase activity, and gibberellic acid content in leaves were measured using standard procedures. Pod yield-related characteristics such as number of panicles per tree, number of flowers per panicle, number of pods per panicle, and total pod yield per tree were also recorded. The results revealed significant effects on various physiological parameters by pruning, chemicals, or combinations. These alterations in physiological parameters induced flowering during the off-season in perennial moringa cv. Kappalpatti local. Notably, the interaction between pinching and foliar application of nitrobenzene at 0.5% (P2 × C7) resulted in 61.15 panicles per tree. In contrast, severe pruning combined with foliar application of paclobutrazol at 170.2 µM (P4 × C2) led to 125.45 flowers per panicle. Additionally, the interaction between light pruning and foliar application of paclobutrazol at 170.2 µM (P3 × C2) showed significantly higher mean numbers of pods per panicle (2.95) and pod yield per tree (14.14 kg).

Keywords: Moringa, Off-season, Pruning, Chemicals, Physiology, pod yield.

Highlights

- The pruning and chemical manipulations altered the physiological parameters of moringa.
- These alterations in physiological parameters induced flowering during the off-season in perennial moringa cv. Kappalpatti local.
- The interaction between pinching and foliar application of nitrobenzene at 0.5% resulted in an average of 61.15 panicles per tree.
- Severe pruning combined with foliar application of paclobutrazol at 170.2 µM (P4 × C2) led to on average of 125.45 flowers per panicle.
- The interaction between light pruning and foliar application of paclobutrazol at 170.2µM (P3 × C2) showed significantly higher mean numbers of pods per panicle (2.95) and pod yield per tree (14.14 kg).

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INTRODUCTION

India is leading in moringa production, accounting for 2.6 million tonnes of tender fruits annually from 43,600 hectares with a productivity of 63 tonnes per hectare in 2023. India is the principal provider of moringa, accounting for around 80% of global calls. Tamil Nadu contributes the highest in area and production, followed by Andhra Pradesh and Karnataka. (Samsai, 2023). In South Indian conditions, the performance of the moringa crop grown during the summer is recognized as the prime period for flowering and fruiting. Conversely, the winter season experiences minimal to negligible flowering and fruiting, constituting an off-season for these essential processes. The November to March period is the lean phase in moringa production due to the onset of the northeast monsoon, which brings about high soil moisture and lower temperatures.

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Cultivating moringa during the off-season in winter proves to be highly profitable due to the increased market prices. This price surpasses the profits garnered during the surplus production period from April to August. Managing the flowering physiology and fruiting cycles through pruning and strategic chemical sprays in the appropriate season holds immense potential for off-season yielding. Hence, an investigation was carried out to assess the influence of pruning and certain chemical sprays to get pod yield during the off-season of perennial moringa cv. Kappalpatti Local by altering the flowering physiology.

MATERIALS AND METHODS

The experiment was initiated by collecting limb cuttings of the perennial moringa variety, Kappalpatti local, from a farmer's field in the Dindigul District, Tamil Nadu, India. Kappalpatti Local is a type of perennial plant with a spreading branching habit. The pods have a long shelf-life, making them suitable for long-distance transportation.

Treatment Description

The experiment was conducted with different pruning intensities and chemical sprays to obtain the off-season flowering and fruiting in moringa trees. The design of experiment adopted was Factorial Randomized Block Design (FRBD), Factor I: Pruning (04 levels), P-1 – No pruning, P-2 – Pinching (Tipping off the previous year's growth of fruiting branches), P-3 – Light pruning (Removal of 33% of previous year growth of fruiting branches), P-4 – Severe pruning (Removal of 66% of previous year growth of fruiting branches). Factor II: Chemical spray (07 levels), C-1 – Control (water spray), C-2 – paclobutrazol 170.2 µM, C-3 – Mepiquat chloride – 406.14 µM , C-4 – Mono Potassium Phosphate – 1%, C-5 – Potassium Nitrate – 1%, C-6 – Potassium sulphate – 1%, C-7 – Nitrobenzene – 0.5%. There was a total of 28 treatment combinations, and there were two replications. The pruning was carried out during the second week of July, and chemicals were sprayed twice, the first 30 days after pruning and the second 15 days after that.

Physiological parameters

Nitrate reductase

The measurement of nitrate reductase activity in leaves was quantified using the approach suggested by Miranda *et al*. (2001). The activity is expressed as micromole nitrite produced per min per g of fresh tissue (µmol/min/g).

Total carbohydrate

The total carbohydrate content was determined using UV spectrophotometry, following the protocol outlined by Albalasmeh *et al*. (2013), and the results were expressed in milligrams per gram (mg/g).

Nitrogen

The nitrogen content was estimated using the Micro-Kjeldahl method and was expressed as a percentage. (Huang and Peng, 2004).

Carbohydrate: Nitrogen (C: N) ratio

The ratio was calculated by dividing the total carbohydrate by the nitrogen content of leaves. (Nicolardot *et al.* 2001).

Soluble Protein

The protein content of the leaves was determined by the Kjeldahl method, according to Beljkas (2010).

Indoleacetic acid oxidase (IAA oxidase)

The IAA activity was quantified using the procedures suggested by Pujari & Chanda (2002) and expressed as µg IAA destroyed/h/mg of sample.

Gibberellic acid content

The amount of GA produced can be estimated spectrophotometrically by Berrios *et al.* (2004). It is based on the conversion of gibberellic acid followed by measuring its absorption at 254 nm in a spectrophotometer. The concentration was quantified in Micro Molar (µM).

Yield parameters

Number of panicles per tree

Each panicle on the randomly selected trees was labeled, and the total number of panicles per tree was calculated. The average value is presented as the mean number of panicles.

Number of flowers per panicle

Flower counting was conducted on three randomly chosen panicles from each tree, and the average count was calculated and expressed as a numerical value.

Number of pods per panicle

In selected trees, the count of pods was conducted on three randomly chosen panicles, and the average count was presented as a numerical value.

Total pod yield per tree

The cumulative yield of pods per tree, encompassing all harvests during the off-season, was documented across randomly selected trees. The average value is expressed as kilograms per tree.

Statistical analysis

Statistical analysis was carried-out by following the procedure of Team (2013).

RESULTS

Leaf physiological parameters

Nitrate reductase activity

Nitrate reductase ensures efficient utilization of nitrate for plant growth and development, contributing to the overall health of moringa plants. Nitrate reductase enzyme activity in moringa cv. Kappalpatti Local was highly influenced during the off-season by pruning and chemical application. The enzyme activity was measured in µmol/min/g and presented in Table 1. Among the various levels of pruning intensity investigated, light pruning (P3) exhibited the highest enzyme activity of 8.85 µmol/min/g. A foliar spray of paclobutrazol at 170.2 µM (C2) displayed a higher enzyme activity level of 8.49 µmol/min/g among the chemical sprays. The interaction between chemical and pruning levels showed that light pruning (P3) and foliar application of

Table 1: Influence of different pruning intensities and chemicals on Nitrate reductase activity (µmol/min/g) of moringa cv. Kappalpatti Local during off-season

Pruning intensity/ Chemical	*P1-No pruning*	*P2-Pinching*	*P3-Light pruning*	*P4-Severe pruning*	*Mean*
C1-Control (water spray)	6.57^{LMN}	7.49^{HIJ}	8.03^{FGH}	6.67^{KLMN}	7.19^{e}
C2- Paclobutrazol - 170.2µM	6.20^{N}	9.38^{ABCD}	10.10^{A}	8.29^{EFG}	8.49^{a}
C3-Mepiquat chloride – 406.14µM	6.28^{N}	8.88^{BCDE}	9.50^{ABC}	7.71^{GHI}	8.09^{bc}
C4-Mono Potassium Phosphate – 1%	6.80^{JKLMN}	8.56^{EF}	7.74^{GHI}	8.04^{FGH}	7.78^{cd}
C5-Potassium Nitrate – 1%	7.29^{HIJKL}	7.42^{HIJK}	9.55^{AB}	8.55^{EF}	8.20^{ab}
C6-Potassium sulphate – 1%	6.56^{LMN}	8.32^{EFG}	8.35^{EFG}	8.74^{CDEF}	7.99^{bcd}
C7-Nitrobenzene – 0.5%	7.09^{IJKLM}	6.50^{MN}	8.70^{DEF}	8.49^{EFG}	7.69^{d}
Mean	6.68^{c}	8.08^{b}	8.85^{a}	8.07^{b}	
Factor	Chemical		Pruning		C × P
CD @ 5%	0.394		0.298		0.788

Table 2: Influence of different pruning intensities and chemicals on total leaf carbohydrate (mg/g) and nitrogen content (%) in moringa cv. Kappalpatti Local during off-season

Pruning intensity/chemical	*Total leaf carbohydrate content (mg/g)*					*Leaf nitrogen content (%)*				
	P1-No pruning	*P2-Pinching*	*P3-Light pruning*	*P4-Severe pruning*	*Mean*	*P1-No pruning*	*P2-Pinching*	*P3-Light pruning*	*P4-Severe pruning*	*Mean*
C1-Control (water spray)	0.42^{M}	0.76^{FGH}	0.63^{JK}	0.62^{JK}	0.61^{f}	2.61^{BC}	2.65^{ABC}	2.86^{AB}	2.85^{AB}	2.74^{a}
C2-Paclobutrazol - 50 ppm	0.76^{FG}	1.07^{C}	1.06^{C}	0.83^{EF}	0.93^{c}	2.81^{AB}	2.84^{AB}	2.73^{ABC}	2.65^{ABC}	2.75^{a}
C3-Mepiquat chloride – 50 ppm	0.51^{L}	0.96^{D}	1.12^{c}	1.38^{B}	0.99^{b}	2.81^{AB}	2.92^{A}	2.78^{AB}	2.82^{AB}	2.83^{a}
C4-Mono Potassium Phosphate – 1%	0.58^{KL}	1.09^{C}	0.66^{IJK}	0.74^{GH}	0.77^{d}	2.71^{ABC}	2.87^{AB}	2.61^{BC}	2.86^{AB}	2.76^{a}
C5-Potassium Nitrate – 1%	0.36^{M}	0.83^{EF}	0.72^{GHI}	0.83^{EF}	0.69^{e}	2.48^{C}	2.88^{AB}	2.82^{AB}	2.73^{ABC}	2.73^{a}
C6-Potassium sulphate – 1%	0.87^{E}	0.14^{N}	1.78^{A}	0.85^{E}	0.91^{c}	2.82^{AB}	2.60^{BC}	2.92^{A}	2.80^{AB}	2.78^{a}
C7-Nitrobenzene – 0.5%	0.68^{HIJ}	1.05^{C}	1.33^{B}	1.12^{C}	1.05^{a}	2.90^{A}	2.81^{AB}	2.87^{AB}	2.70^{ABC}	2.82^{a}
Mean	0.60^{d}	0.85^{c}	1.04^{a}	0.91^{b}		2.73^{a}	2.79^{a}	2.80^{a}	2.77^{a}	
Factor	Chemical		Pruning		CxP	Chemical		Pruning		C× P
CD @ 5%	0.040		0.030		0.080	0.143		0.108		0.287

paclobutrazol at a concentration of 170.2 µM (C2) exhibited a higher level of enzyme activity at 10.10 µmol/min/g. Likewise, the combination of light pruning (P3) with foliar application of potassium nitrate at a concentration of 1% recorded an enzyme activity of 9.55 µmol/min/g, showing a slight significant difference compared to P3 × C2 (Table 1).

Total leaf carbohydrate and nitrogen content

The nutritional composition of *Moringa oleifera* leaves, focusing on total carbohydrate content, holds significance in flower induction. Altering pruning intensities and applying different chemicals during the off-season significantly impacted the total carbohydrate levels in Moringa cv. Kappalpatti Local. During the off-season, light pruning (P3) of Moringa cv. Kappalpatti Local resulted in an increase in total carbohydrate content to 1.05 mg/g. Among the different chemicals tested, nitrobenzene at a concentration of 0.5% (C7) resulted in the highest total carbohydrate content of 1.05 mg/g in leaves. The interaction of pruning and chemicals, light pruning with the application of potassium sulfate at a concentration of 1% (P3 × C6) exhibited the highest amount of total carbohydrates, reaching up to 1.78 mg/g of leaf tissues (Table 2). Generally, medium to low leaf nitrogen levels favor flower induction. Pruning practices and chemicals did not exert any influence on the nitrogen composition of Moringa cv. Kappalpatti Local. Regarding the interaction between pruning intensity and chemical application (P × C), experimental Moringa plants subject to light pruning along with the foliar application of potassium sulfate at 1% (P3 × C6) exhibited the highest nitrogen content in leaves at 2.92% compared to other combinations. However, the statistical analysis did not indicate significant differences in nitrogen content among the various treatments and interactions (Table 2).

Carbohydrate: Nitrogen (C: N) ratio

An optimal to high C: N ratio in any crop can shift the vegetative phase to the reproductive phase. In the current research, altering pruning intensities and applying different chemicals during the off-season significantly impacted the C: N ratio in Moringa cv. Kappalpatti Local. The interaction between pruning intensities and foliar application of chemicals had a more excellent C: N ratio than the individual effects of both pruning and chemicals. The plants subjected to light pruning with potassium sulfate at 1% (P3

× C6) exhibited the highest C: N ratio, 0.63. This was followed by the interactions between P4 × C3 (severe pruning combined with Mepiquat chloride – 406.14µM), showing a C: N ratio of 0.51 (Fig. 1).

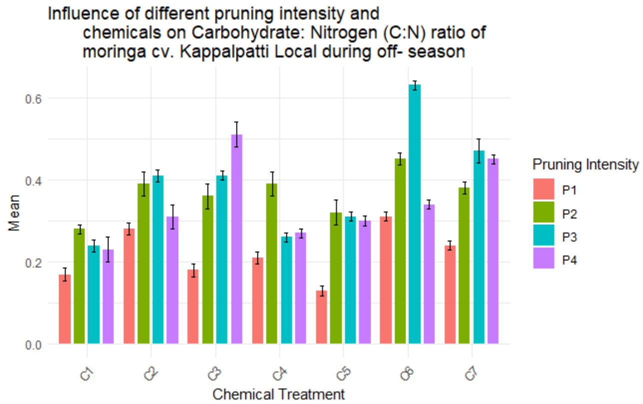

Fig. 1: Influence of different pruning intensities and chemicals on Carbohydrate: Nitrogen (C: N) ratio of moringa cv. Kappalpatti Local during off-season

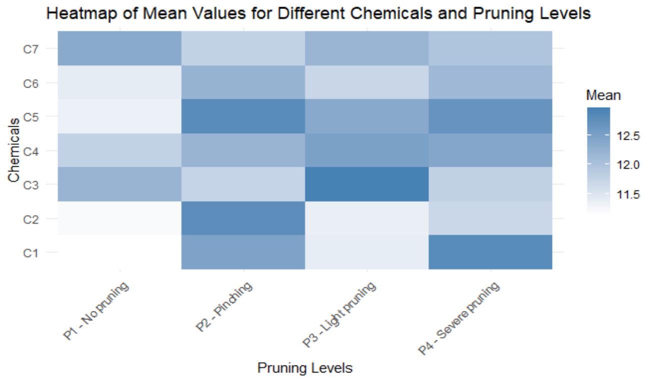

Fig. 2: Influence of different pruning intensities and chemicals on Soluble Protein (mg/g) of moringa cv. Kappalpatti Local during off-season

Soluble protein

Moringa leaves, seeds, and pods are valuable sources of protein. Besides contributing to nutritional makeup, soluble proteins are crucial components that indicate the plants' health status. A healthy status of plants is a prerequisite for flower induction. In the current study, pruning and chemical spraying statistically did not exhibit significant differences during the off-season. However, the interaction of light pruning combined with foliar application of 406.14 µM mepiquat chloride (P3 × C3) resulted in the highest soluble protein content of 12.97 mg/g of leaves. This was followed by the combination of severe pruning with the control (P4 × C1) and the combination of pinching with foliar application of 1% potassium nitrate (P2 × C5), which recorded 12.82 and 12.81 mg/g, respectively, and were statistically on par with each other. The lowest soluble protein content of 11.13 mg/g of leaves was observed in the combination of both control groups i.e., no pinching and water spray (P1 × C1) (Fig. 2).

Leaf IAA oxidase activity and gibberellic acid content

By regulating the levels of auxin, IAA oxidase contributes to the growth and flowering of plants. IAA oxidase (indole-3-acetic acid oxidase) activity indirectly measures auxin levels in leaves. Reduced auxin in leaves always induces flowering, as it is a well-known hormone for apical dominance. The higher the activity of IAA oxidase, the apical dominance is arrested by curtailing auxin biosynthesis, which induces flowering stimuli. The effect of various pruning intensities and chemical applications on IAA oxidase activity in moringa cv. Kappalpatti Local during the off-season was assessed and results are tabulated in Table 3. Severe pruning (P4) employed plants showed the highest activity of IAA oxidase (624.75 µg IAA destroyed/h/mg). Foliar spraying of paclobutrazol - 170.2 µM (C2) during the off-season showed significantly high IAA oxidase activity (624.75 µg IAA destroyed/h/mg). The combined treatment of light pruning and foliar spray at 170.2 µM (P3 × C2) showed the highest IAA oxidase activity, measuring 656.0 µg IAA destroyed/h/mg. Similarly, light pruning combined with a foliar spray of Mepiquat chloride at

Table 3: Influence of different pruning intensities and chemicals on IAA oxidase activity (µg IAA destroyed/h/mg) and Gibberellic acid content (µM) of moringa cv. Kappalpatti Local during off-season

Pruning intensity/chemical	*IAA oxidase activity (µg IAA destroyed/h/mg)*					*Gibberellic acid content (µM)*				
	P1-No pruning	*P2-Pinching*	*P3-Light pruning*	*P4-Severe pruning*	*Mean*	*P1-No pruning*	*P2-Pinching*	*P3-Light pruning*	*P4-Severe pruning*	*Mean*
C1-Control (water spray)	532.0^{J}	558.0^{FGHIJ}	616.5^{ABCDEF}	572.5^{DEFGHIJ}	569.75^{b}	0.144^{KLM}	0.173^{IJ}	0.173^{JKL}	0.173^{JK}	0.173^{e}
C2-Paclobutrazol - 170.2µM	553.0^{GHIJ}	644.0^{ABC}	656.0^{A}	646.0^{AB}	624.75^{a}	0.086^{P}	0.115^{OP}	0.115^{OP}	0.115^{NO}	0.115^{g}
C3-Mepiquat chloride – 406.14µM	548.0^{HIJ}	586.5^{BCDEFGHIJ}	649.5^{A}	624.0^{ABCDE}	602.00^{a}	0.115^{OP}	0.144^{MN}	0.115^{NO}	0.144^{LMN}	0.115^{f}
C4-Mono Potassium Phosphate – 1%	537.0IJ	610.5^{ABCDEFG}	636.5^{ABC}	633.5^{ABCD}	604.37^{a}	0.173^{JK}	0.202^{I}	0.288^{DE}	0.230^{H}	0.230^{d}
C5-Potassium Nitrate – 1%	562.5^{EFGHIJ}	598.0^{ABCDEFGHI}	620.5^{ABCDE}	644.5^{ABC}	606.37^{a}	0.230^{GH}	0.230^{FGH}	0.259^{EFG}	0.259^{EFGH}	0.259^{c}
C6-Potassium sulphate – 1%	558.0^{FGHIJ}	607.5^{ABCDEFGH}	584.0^{CDEFGHIJ}	651.0^{A}	600.12^{ab}	0.259^{EFGH}	0.259^{DEF}	0.288^{CD}	0.259^{DE}	0.259^{b}
C7-Nitrobenzene – 0.5%	570.5^{EFGHIJ}	621.0^{ABCDE}	618.5^{ABCDEF}	634.0^{ABCD}	611.00^{a}	0.317^{C}	0.375^{AB}	0.404^{A}	0.346^{B}	0.346^{a}
Mean	551.57^{c}	603.64^{b}	625.92^{ab}	629.35^{a}		0.202^{c}	0.202^{b}	0.230^{a}	0.230^{ab}	
Factor	Chemical		Pruning		CxP	Chemical		Pruning		C× P
CD @ 5%	30.763		23.255		61.526	0.004		0.003		0.008

406.14 µM (P3 × C3) resulted in an IAA oxidase activity of 649.5 µg IAA destroyed/h/mg. Both treatments are statistically on par with each other at a significance level of $p \geq 0.05$, as indicated by an LSD value of 61.526 (Table 3).

Gibberellic acid (GA3) stimulates internodal length, hypocotyl growth, enlargement of leaves, stress tolerance, ion homeostasis, and reproductive processes in moringa plants. Data in Table 3 represents the gibberellic acid content in moringa cv Kappalapatti Local plants experienced different intensities of pruning and foliar application of different chemicals. Pruning at various intensities affected the gibberellic content (µM). Plants that suffered light pruning (P3) exhibited the GA3 content at 0.230 µM, followed by those subjected to severe pruning (P4) at a mean 0.230 µM. Both values are statistically similar and do not display any significant difference. The GA3 content was recorded at 0.346 µM in moringa cv. Kappalpatti Local plants were treated with foliar application of nitrobenzene at 0.5% (C7), followed by moringa cv. Kappalpatti plants were treated with foliar application of potassium sulfate at 1% (C6) and potassium nitrate – 1% (C5), which recorded a mean value of 0.259 µM of GA3 content. The study found that moringa cv. Kappalpatti plants subjected to light pruning combined with nitrobenzene – 0.5% application (P3 × C7) exhibited a significantly higher GA3 content of 0.404 µM during the off-season. Following this, the combination of pinching with foliar application of nitrobenzene – 0.5% application (P3 × C7) recorded a substantially similar GA3 content of 0.375 µM.

Conversely, the interaction between no pruning and foliar application of paclobutrazol – 170.2 µM resulted in the lowest GA3 content of 0.086 µM. Generally, GA induces the modification of vegetative growth to the reproductive phase. Exogenous application of gibberellic acid stimulates the genes of circadian rhythms to regulate flowering. In some plants, it suppresses the GA antagonist protein (DELLA protein) to induce flowering, according to Dong *et al*. (2017) (Table 3).

Pod yield parameters

Number of panicles per tree and number of flowers per panicle

Applying different intensities on pruning and chemical treatments can significantly affect the number of panicles per tree in Moringa cv. Kappalpatti Local during the off-season and the data obtained were presented in Table 4. The significance of panicle numbers per tree was determined statistically by the LSD value of 2.012 at a significance level of $p \geq 0.05$ by pruning intensities, chemicals and their interaction. Pinching (P2) during the off-season significantly increases the number of panicles in Moringa plants by 53.62 per tree. This was followed by light pruning (P3), which recorded 44.87 panicles per tree. Potassium sulphate at 1% (C6) is applied as a foliar spray to Moringa cv. Kappalpatti Local plants during the off-season resulted in 47.01 panicles per tree. This was followed by the foliar application of potassium nitrate at 1% (C5), which recorded 46.77 panicles per tree. The interaction between pinching and the foliar application of nitrobenzene at 0.5% (P2 × C7) resulted in 61.15 panicles per tree. In comparison, the interaction of pinching with mono potassium phosphate at 1% (P2 × C4) recorded 58.95 panicles per tree. Table 4 presents data regarding the number of flowers per panicle of Moringa cv. Kappalpatti Local plants are subjected to various pruning intensities and foliar application of chemicals during the off-season. The pruning intensities, chemicals and their interaction exhibited statistically significant distinctions, with a significance level of $p \geq 0.05$ and an LSD value of 2.161. During the off-season, severe pruning (P4) increased the number of flowers per panicle by 72.69. Applying at 170.2 µM (C2) as a foliar spray during the off-season resulted in 84.00 flowers per panicle. The interaction between severe pruning and the foliar application of paclobutrazol at 170.2 µM (P4 × C2) resulted in 125.45 flowers per panicle. Following this, light pruning with the foliar application of potassium sulphate at 1% (P3 × C6) recorded 99.60 flowers per panicle. Conversely, the least number

Table 4: Influence of different pruning intensities and chemicals on number of panicles per tree and number of flowers per panicle of moringa cv. Kappalpatti Local during off-season

Pruning intensity/chemical	*Number of panicles per tree*					*Number of flowers per panicle*				
	P1-No pruning	*P2-Pinching*	*P3-Light pruning*	*P4-Severe pruning*	*Mean*	*P1-No pruning*	*P2-Pinching*	*P3-Light pruning*	*P4-Severe pruning*	*Mean*
C1-Control (water spray)	22.90^{N}	47.25^{FG}	42.75^{HIJK}	43.90^{GHIJ}	39.20^{e}	40.52^{L}	51.64^{JK}	48.64^{K}	77.16^{EF}	54.49^{de}
C2-Paclobutrazol - 170.2µM	28.25^{M}	45.80^{FGH}	47.90^{FG}	46.80^{FG}	42.18^{cd}	36.98^{LM}	85.25^{CD}	88.33^{C}	125.45^{A}	84.00^{a}
C3-Mepiquat chloride – 406.14µM	$39.60K^{L}$	52.00^{DE}	40.10^{JKL}	39.90^{JKL}	42.90^{bc}	53.11^{IJK}	81.69^{DE}	34.41^{MN}	57.81^{HI}	56.76^{cd}
C4-Mono Potassium Phosphate – 1%	23.75^{N}	58.95^{AB}	40.80^{IJK}	39.10^{KL}	40.65^{de}	60.60^{H}	40.25^{L}	40.80^{L}	73.78^{FG}	53.86^{e}
C5-Potassium Nitrate – 1%	36.35^{L}	57.00^{BC}	49.00^{EF}	44.75^{GHI}	46.77^{a}	29.47^{N}	74.76^{FG}	54.98^{HIJ}	75.88^{F}	58.77^{c}
C6-Potassium sulphate – 1%	40.00^{JKL}	53.20^{CD}	47.00^{FG}	47.85^{FG}	47.0^{1a}	71.52^{FG}	50.10^{JK}	99.60^{B}	51.15^{JK}	68.09^{b}
C7-Nitrobenzene – 0.5%	30.65^{M}	61.15^{A}	46.60^{FGH}	40.50^{JK}	44.72^{b}	69.75^{G}	74.01^{FG}	74.54^{FG}	47.60^{K}	66.47^{b}
Mean	31.64^{d}	53.62^{a}	44.87^{b}	43.25^{c}		51.71^{d}	65.38^{b}	63.04^{c}	72.69^{a}	
Factor	Chemical		Pruning		CxP	Chemical		Pruning		C× P
CD @ 5%	2.012		1.521		4.025	2.859		2.161		5.719

Level of significance is 0.05

Table 5: Influence of different pruning intensities and chemicals on number of pods per panicle and total pod yield per tree (kg) of moringa cv. Kappalpatti Local during off-season

Pruning intensity/chemical	*Number of pods per panicle*					*Total pod yield per tree (kg)*				
	P1-No pruning	*P2-Pinching*	*P3-Light pruning*	*P4-Severe pruning*	*Mean*	*P1-No pruning*	*P2-Pinching*	*P3-Light pruning*	*P4-Severe pruning*	*Mean*
C1-Control (water spray)	0.54^{M}	1.10^{K}	1.67^{DEFG}	1.54^{GH}	1.21^{e}	1.11^{P}	3.57^{M}	8.27^{FG}	7.08^{J}	5.01^{e}
C2-Paclobutrazol - 170.2µM	0.53^{M}	1.80^{D}	2.95^{A}	1.95^{C}	1.80^{a}	2.08^{NO}	5.80^{K}	14.14^{A}	11.46^{B}	8.37^{a}
C3-Mepiquat chloride – 406.14µM	0.82^{L}	1.75^{DE}	1.30^{IJ}	1.60^{FG}	1.36^{d}	2.19^{NO}	5.47^{K}	8.39^{F}	7.68^{HI}	5.93^{d}
C4-Mono Potassium Phosphate – 1%	0.91^{L}	1.22^{JK}	0.95^{L}	1.70^{DEF}	1.19^{e}	1.96^{O}	4.43^{L}	7.37^{HIJ}	9.18^{E}	5.74^{d}
C5-Potassium Nitrate – 1%	0.51^{M}	2.75^{B}	1.62^{EFG}	1.63^{EFG}	1.63^{c}	1.64^{OP}	9.53^{E}	7.77^{GH}	10.28^{D}	7.31^{c}
C6-Potassium sulphate – 1%	1.10^{K}	1.75^{DE}	2.77^{B}	1.10^{K}	1.68^{bc}	2.58^{N}	7.15^{IJ}	9.58^{E}	11.33^{B}	7.66^{b}
C7-Nitrobenzene – 0.5%	1.42^{HI}	2.80^{B}	1.55^{GH}	1.17J^{K}	1.73^{b}	3.27^{M}	10.65^{CD}	7.57^{HIJ}	11.05^{BC}	8.13^{a}
Mean	0.83^{d}	1.88^{a}	1.83.^{b}	1.52^{c}		2.12^{d}	6.66^{c}	9.01^{b}	9.72^{a}	
Factor	Chemical		Pruning		CxP	Chemical		Pruning		C× P
CD @ 5%	0.065		0.491		0.130	0.292		0.221		0.585

of flowers per panicle was observed in the interaction between no pruning and the foliar application of potassium nitrate at 1% (P1 × C5), which recorded 29.47 flowers per panicle.

The findings in Table 5 illustrate the significant impact of both pruning intensities and foliar application of chemicals on the number of pods per panicle in *Moringa* cv. Kappalpatti Local during the off-season. When examining the means of pruning intensities, it is evident that pinching (P2) and light pruning (P3) produced higher mean values of 1.88 and 1.83, respectively. The highest mean number of pods per panicle was observed with the foliar application of – 170.2 µM (C2) at 1.80, followed by nitrobenzene at 0.5% (C7) and potassium sulphate at 1% (C6), both with mean values of 1.73 and 1.68, respectively. Distinct variations were observed in the interaction between pruning intensities and chemicals. The interaction between light pruning and foliar application of paclobutrazol at 170.2 µM (P3 × C2) recorded a substantially higher mean number of pods per panicle of 2.95. Following this, the interaction between light pruning and foliar application of potassium sulphate at 1% resulted in a mean number of pods per panicle of 2.77. In contrast, the interaction between no pruning and foliar application of 170.2 µM resulted in a lower mean number of pods per panicle of 0.53 (Table 5).

The data in Table 5 elucidates the impact of different pruning intensities and chemical treatments on the total yield per tree of Moringa cv. Kappalpatti Local during the off-season, recorded in kg per plant. All the pruning intensities were statistically significant, with the LSD value of 0.221 at the significance level $p \geq 0.05$. Severe pruning (P4) is the most influential practice, and a yield of 9.72 kg per tree was recorded among the pruning intensities. Light pruning (P3) recorded 9.01 kg, and pinching (P2) recorded 6.66 kg per tree. The lowest yield was observed in plants subjected to no pruning (P1), which recorded 2.21 kg per tree. For instance, foliar application of paclobutrazol at 170.2 µM (C2) recorded the highest yield of 8.37 kg per tree, followed by nitrobenzene – 0.5% (C7) yielded the average yield of 8.13 kg per tree. Both are statistically on par with each other and the lowest yield recorded in foliar water application (C1 - Control) is 5.01 kg per tree. Moreover, the interaction between pruning intensities and chemical treatments significantly influences yield outcomes. The outcome suggested a synergistic effect between light pruning and – 170.2 µM (P3 × C2) in enhancing moringa pod yield, recorded at 14.14 kg per tree. Additionally, severe pruning combined with paclobutrazol– 170.2 µM (P4 × C2) also resulted in a substantial yield of 11.46 kg per tree. Conversely, the lowest yield was observed in plants subjected to no pruning when treated with foliar application of water (P1 × C1), yielding an average of 1.11 kg per tree. This finding highlights the importance of pruning with appropriate chemical applications to optimize moringa pod yield during the off-season.

Discussion

Pruning influences the growth; more side buds will be in the dormant stage, and when the tip is removed, auxin is redirected to activate those dormant buds, thus increasing the number of branches (Eve, 2016). Pruning determines the vegetative growth, canopy spread, flowering, and fruiting transition. Termination of the apical bud suppresses auxin content and increases the cytokinin content by inducing cytokinin biosynthesis and reducing the degradation (Tanaka, 2006). Number of flowers per panicle was higher in pruned trees. This is in line with the reports of (Santos *et al*., 2007; Asghari and Khokhar, 2013; Ekwu and Nwokwu, 2017). Pruning creates room for maximum carbohydrate storage and diverts the reserves to the inflorescence. The diverted food reserves encourage more flower bud formation in inflorescence (Ahmad *et al*.., 2007). The findings confirm the results of Tswanya and Olaniyi (2016) in tomato and Silva *et al*. (2009) in mango. The genetic and environmental factors greatly governed the number of pods per inflorescence and pods per tree. Those external factors could be manipulated to some extent by altering the tree architecture. Assimilation partitioning will be altered when the average growth is disturbed. Pruning the apical portion reduces the assimilation rate and influences the root system. The carbohydrates stored will be translocated to stabilize the lost region of a tree. Pruning will also transfer the assimilates from root to shoot growth (Bussi *et al.*2005). This translocation and respiration might be because it control the root-shoot ratio's equilibrium state. The reverse translocation of food reserve influences the water and nutrient uptake. Light and frequent pruning increases the stomatal conductance and functioning of the Phytosystem (Peter and Lehmann, 2000). Availability of sufficient nutrients regulates the C: N ratio, thus increasing the fruiting (Christiaens *et al.* 2016). This is in accordance with the observations of (Franco *et al*.., 2009) in cherry tomatoes, Mbonihankuye *et al.* (2013) in tomatoes and Kalicharan (2012) in annual moringa.

Nitrate reductase (NRase) plays a crucial role in converting nitrate to nitrite and initiating changes in root architecture. Light perception significantly affects nitrate assimilation (Lillo & Appenroth, 2001), with NRase activity being exceptionally high during the early stages of the photoperiod. In this study, NRase activity was higher in trees subjected to pruning. This increase in activity may be attributed to well-established lateral branches in the pruned trees, which likely enhance light perception by phytochromes. Additionally, the levels of auxin and cytokinin play a significant role in regulating NRase activity in crops. Soares *et al.* (2017) demonstrated that increased cytokinin synthesis stimulates nitrate reductase activity in rice. When the top of a plant is pruned, auxin moves downward from the growing point. The gravitational response of auxin causes it to accumulate near lateral buds, promoting cell division and the emergence of lateral shoots. Each shoot then experiences increased auxin production, further promoting nitrate reductase enzyme production. This observation aligns with the findings of Anbarasu (2009) in annual moringa and Joshi *et al.* (2011).

The flowering characters contributing to yield are panicle number per tree and flower number per panicle. Nitrobenzene treatment increased both the characters in annual moringa. Endogenous cytokinin, transported acropetally, will enter the auxiliary bud and promote the outgrowth. Endogenous auxin represses the biosynthesis of cytokinin and thus, the flowering stimulation is affected (Chatfield *et al*.., 2000). Synthetic auxin acts as an antiauxin and lowers the activity of native IAA. Plant oxidases will be generated at that time, and both the native and synthetic auxin will be removed, thereby controlling the duration of the competitive effect. That controlled duration creates room for cytokinin's action, which induces inflorescence formation and increases the number of flowers. This result is in line with the observations of (Geetharani and Manivannan., 2008). Also, mepiquat chloride increased the flower number per panicle. It lowers the concentration of native auxin governing the apical dominance, thus favoring the growth and development of auxiliary buds into side shoots. Retarded apical growth with increased branches increases the availability of photosynthates to the flowers. This might have caused the increased flower number per inflorescence, as opined by Elkoca and Kantar (2006) in peas, Sherif and Asaad (2014) in pears and Kalaimani *et al.* (2017) in jasmine.

Indole-3-acetic acid (IAA) oxidase indirectly indicates auxin levels and apical dominance in plants. It tends to be lower in regions with higher auxin concentrations and higher in regions with lower auxin concentrations (Pujari and Chanda, 2002). The activity of IAA oxidase showed significant variation with the application of chemicals. IAA oxidase activity decreased during flowering (Ebrahimzadeh and Abrishamchi, 2001). Growth retardants such as mepiquat chloride and inhibit IAA content by increasing IAA oxidase activity (Vijayakumar *et al.*, 2002). Compounds like nitrobenzene reduce IAA oxidase activity, as Alappat (2004) observed in bananas. Gibberellins (GAs) promote normal growth and development, including cell division and elongation. They also regulate developmental switches such as germination and the transition from vegetative to reproductive phases in certain species. Flower induction can occur once cell division has initiated and sufficient hormones are present. The physiologically active leaf can synthesize flowering hormones, and the accumulation of gibberellic acid in the shoot apex before floral transition stimulates the flowering stimulus (Eriksson *et al*.., 2006). Nitrobenzene spray increased gibberellic acid content, consequently increasing panicle and flower numbers. This heightened gibberellic acid content may induce florigen activity in plants, eliciting specific red and far-red light responses and promoting active cell division in buds (Shalit *et al.*, 2009).

CONCLUSION

Off-season crop production carries several advantages, impacting both farmers and consumers positively. Firstly, it significantly enhances farmers' income and elevates their living standards. Additionally, it ensures a consistent product supply to consumers throughout the year. Furthermore, this practice enables growers to acquire specialized techniques in crop production, fostering their expertise in the field. Moreover, off-season production strengthens foreign exchange by supporting continuous exports. It also aids in reducing wastage that occurs during on-season production surpluses, preventing glut in commodity markets.

Additionally, this practice generates year-round employment opportunities for farm laborers, contributing to stable livelihoods. In South Indian conditions, the summer season is recognized as the prime period for flowering and fruiting. Conversely, the winter season is considered off-season for these essential processes. During November to March period, the cost of pods can surge significantly, reaching as high as Rs.60 - Rs.120 per kilogram. This price surpasses the profits garnered during the surplus production period from April to August. Managing the flowering and fruiting cycles through pruning and strategic chemical sprays in the appropriate season holds immense potential for inducing flowering in moringa during the off-season. Hence, this study was taken up with the vital aim of studying the influence of different pruning intensities and chemicals to induce off-season Moringa production by manipulating various physiological parameters. These pruning and chemical manipulations altered physiological parameters. Besides, the interaction between pruning and chemicals, exceptionally light pruning and foliar application of paclobutrazol at 170.2μM recorded a substantially higher mean number of pods per panicle and pod yield per tree.

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Author Contribution

Mr. Mansih Kumar, the research scholar, conducted the field experiment, S. Srivignesh and Arumugam Harish assisted in conducting the field experiment and data collection, S. Manivannan and Thondaiman, V contributed to data analysis. Dinakar Challabathula contributed to laboratory analysis and A. Ramesh Kumar is the research supervisor, who framed the concept and prepared the synopsis, mentored the research activity and research paper writing.

Conflict Of Interest

No conflict of interest.

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