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Research Article

COMPARATIVE EFFICACY OF FIVE INSECTICIDES AGAINST KEY INSECT PESTS OF DRY-SEASON ONION (*ALLIUM CEPA* L.) IN MESKINE, FAR NORTH CAMEROON

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ABSTRACT

The aim of the current study was to evaluate the efficacy of five insecticides for controlling the primary insect pests of dry-season onions in Meskine, Far North of Cameroon. The goal was to identify the insecticide that ensures a better yield for late-transplanted dry-season onion crops. To achieve this objective, a trial was conducted using a completely randomized experimental block design, with six treatments replicated three times. The treatments consisted of Cypercal (Cypermethrin 120 g/L, Profenofos 600 g/L), Neem oil solution + Neem cake (Azadirachtin), Optimal (Acetamiprid 200 g/Kg), Pacha (Lambda-cyhalothrin 15 g/L, Acetamiprid 10 g/L), Rapax (*Bacillus thuringiensis*), and a control. Applications of the treatments were carried out using an ULVA sprayer on the leaves between 6 a.m. and 7 a.m. Observations focused on growth and yield parameters, which were evaluated based on the various treatments applied. Data collected were analyzed using STATGRAPHIC Centurion XVI.I software at a 5% significance rate. Results showed that among the four insect species recorded on the leaves, thrips were the most prevalent, constituting 33.37% of the total population, followed by caterpillars (23.82%), aphids (22.32%), and locusts (20.48%). The analysis of variance revealed that among the growth parameters, only plant height was significantly affected by the application of the different insecticides. The highest marketable bulb yield was achieved with Cypercal, yielding 13.53 tons per hectare, compared to the control's 6 tons per hectare. Consequently, Cypercal has been identified as an effective alternative to Optimal, which is commonly used by growers to enhance yields of this dry-season crop.

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INTRODUCTION

In Sub-saharan Africa, more than 70% of the population is engaged in agriculture but performance is well below its potential (BAD, 2016). This low potential is due to several production constraints that generally lead to poor harvests. However, this agricultural sector is a source of employment which means 48.7% of the population in Africa practices agriculture (FAOSTAT, 2022). In Cameroon, it employs nearly 42.9% of the active population (FAOSTAT, 2022) and contributes more than 19.91% to GDP (OCDE and BM, 2021). In this agricultural sector, market gardening plays a key role in most of the human nutrition and poverty alleviation programs and contributes significantly to family incomes (James et al., 2010; FAO, 2012; Yolou et al., 2015). Among these crops, onions are the second most widely grown vegetable in the world after tomatoes, with an estimated global production of 97 million tons of dry onion form (FAOSTAT and CIRAD, 2021). In Cameroon, specifically in the northern region, onions are ranked as the third most valuable cash crop following cotton and groundnuts, and are the first vegetable crops in this area (Cathala et al., 2003).

This plant is grown for its leaves or bulbs for human consumption (Abdou et al., 2015). Onion cultivation is practiced at all times of the year, thus contributing not only to economic growth in general, but above all to the immediate improvement of the incomes of a large number of households in rural areas (Rameez et al., 2014). In Cameroon, onion production was estimated at 362,185 and 469,865 tons in 2018 and 2019, respectively (MINADER/DESA, 2020). The traditional production method yields between 7.9 and 11 tons per hectare (Kamga et al., 2016), while supported producers can achieve yields of up to 38 tons per hectare (Fleissner et al., 2015; AFSA, 2019). The landrace variety exhibits a highly variable bulb yield ranging from 10 to 35 t/ha (Dinissia et al., 2021). Conversely, the local Goudami variety demonstrates significantly higher economically profitable yields, reaching values of 49.53 t/ha and 42.98 t/ha, respectively, with the application of 21-9-11-5S-1.5MgO-0.15B2O3 and 12-14-19-3.5MgO-0.15B fertilizers (Sakatai et al., 2022). Despite these efforts made by onion production in Cameroon, the volume of production does not always cover the needs of national consumption (Cathala et al., 2003). In onion production in the Far North of Cameroon, there is still much to be improved in terms of pest control methods, especially for late-transplanted dry-season onion crops. Onion cultivation, like the majority of vegetable production, faces several constraints, namely the pressure of pests, which has been identified as the major constraint due to the crop losses inflicted on this crop (Kanda et al., 2013; Mondédji et al., 2015). Among these pests, onion thrips is the most formidable (Leblanc, 2010). It leads to the destruction of foliage by the removal of its food and the transmission of viruses with repercussions on the growth and maturation of the onion (Biao et al., 2019). This damage can result in yield losses of up to 60% (Cliniques des Plantes, 2018) and if the attack is early, the entire crop can be destroyed (Leblanc, 2010). Methods of control of these insect pests have been adopted over the years by farmers.

Initially, farmers used broad-spectrum chemical insecticides to control insects (Yarou et al., 2017). However, excessive use of these chemical products has led to insect resistance. In addition, insecticides can have detrimental effects on beneficial insects, such as pollinators, natural predators of pests, and microorganisms that regulate pest populations (Dufaure, 2012). These side effects can cause significant disruption in agricultural ecosystems and prevent insecticides from being an effective means of pest control (Fortier and Phytodata Inc, 2016).

As a result, farmers began to look for alternative solutions to insect pest control. Neem leaves, plant extracts, and essential oils have been widely used to repel insects (Schmutterer, 2002; Isman, 2006). Studies by Aminou et al. (2022) have demonstrated that the oil and bark of *Khaya senegalensis* (African mahogany) are effective against late mildews and certain onion pests. However, these methods have also shown their limitations, as insects have developed resistance to certain molecules used in these natural products. From this observation, it appears that the problem of the effectiveness of insecticides on insect pests remains a matter of concern. Farmers are facing increasing difficulty in controlling insect pests when late-transplanted dry-season onion crops are involved. Studies are necessary to develop more effective methods by making greater use of the local products (available and accessible in the market) to combat these insect pest and improve the yield of onion crop. The current study is focused on growth and yield parameters while identifying the insecticide that offered a better yield score among the local insecticides used.

MATERIALS AND METHODS

Presentation of the study site

The experiment was carried out at the application farm of the Center for Agricultural Research for Development (CRAM) in Maroua on an experimental plot with a length of 9 m and a width of 6.50 m (Figure 1). The farm is located in the Mangalaré village of Meskine, about 10 km from the center of the city of Maroua. Meskine is a township bounded on the east by Makabaye, on the west by Katouwal, and on the north and south by the Gazawa district. The test site has geographical coordinates of 10°54.26 North and 14°25.04 East. It is located at an altitude of 414 m and covers an area of 10 ha.

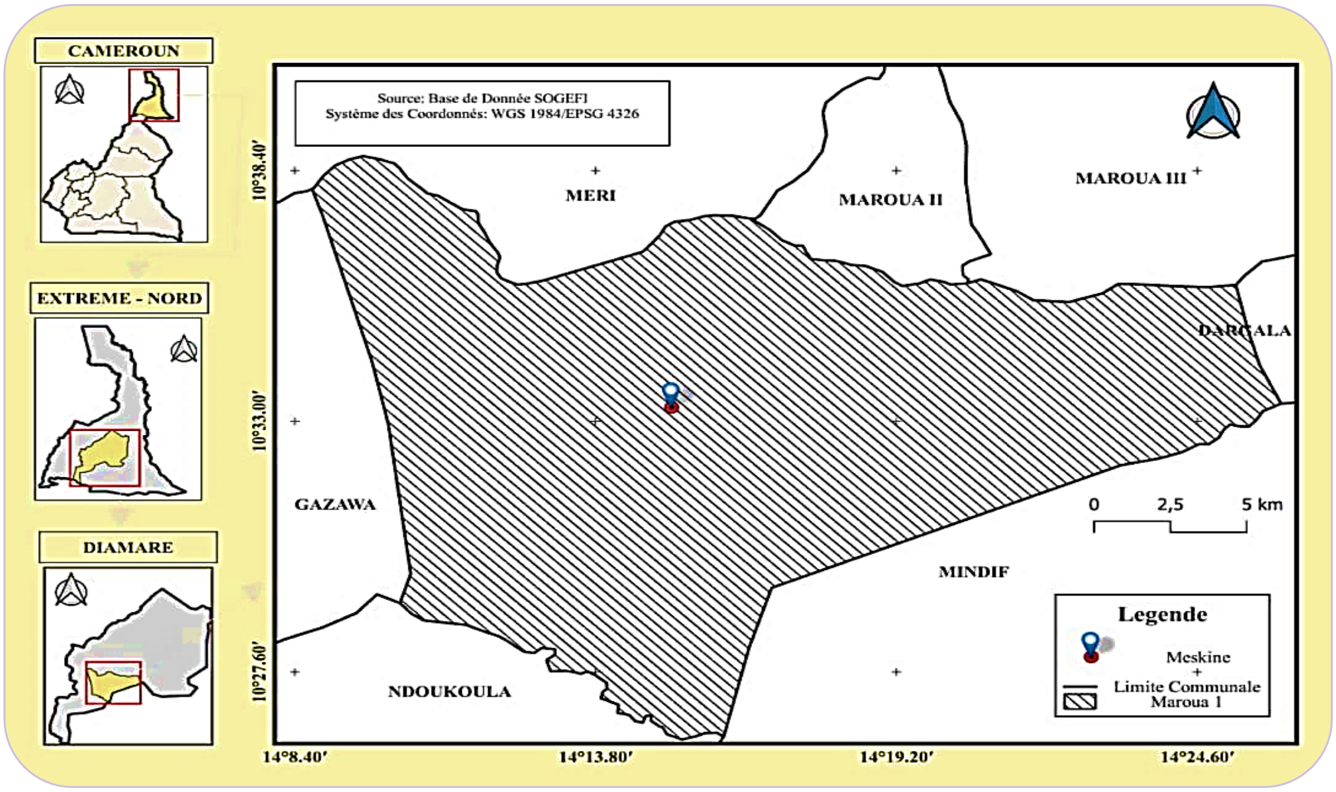


Figure 1. Location of the study site.

Materials

The plant materials comprised plants grown from seeds of *Allium cepa* var. local Goudami selected by IRAD in Maroua. The objective was to utilize alternative solutions accessible to local producers for more effective insect pest control, as certain molecules used in chemical and natural products were becoming increasingly resistant. Table 1 provides a summary of information (trade names, active ingredients, rates, and classes) on the insecticides utilized.

Table 1. Commercial names, active ingredients, rates and classes of products used in the studies.

Sr. No.	Commercial Names of Products	Active ingredients*	Applied doses	Class
1	Rapax ® AS	*Bacillus thuringiensis* var. *kurstaki* stump EG 2348; 188 g/kg 24.000 UI/mg	1.5 L/ha for 300; L/ha of water	Bio III
2	Cold extracted oil + Neem cake	*Azadirachtin*	Oil: 1 L/ha; Cake: 13 Kg/ha	Bio
3	Pacha® 25 EC	*Lambda-cyhalothrin* 15 g/L *Acetamiprid* 10 g/L	1 L/ha for 300; L/ha of water.	II
4	Cypercal ® P 720 EC Coton Tchad	*Cypermethrin* 120 g/L *Profénofos* 600 g/L	0.25 L/ha for 15 L of water	II
5	Optimal ® 20 SP	*Acetamiprid* 200 g/Kg	25 g for 1/4ha in 10 L of water	II

Source: (MINADER, 2021); Note: * Foliage spraying was applied using the sprayer between 6 a.m. and 7 a.m.

Preparation of oil-based extract and neem cake

In the preparation of the T2 treatment based on enriched neem meal, 50 g of soaked and macerated neem cake, sieved after 24 hours in 1 liter of water, were used. The slurry obtained after sieving was mixed and added to 37.5 ml of neem oil and 2.5 g of soap, then everything was mixed until homogenized or the total dissipation of the oil before application (Guet, 2002; Sana et al., 2018). *Azarachta indica*, better known as neem, is primarily used as a crop protection product (Guet, 2002; Sana et al., 2018). Its extracts have demonstrated their effectiveness in controlling harmful arthropods and certain diseases (Guet, 2002; Sana et al., 2018). It is used to protect crops against pests while promoting organic crop production. By replacing synthetic chemical products with neem cake, we contribute to the sanitation of water, the environment, soil, and, most importantly, reduce contamination of crops and animals.

Experimental design

The experimental design was a completely randomized block design with six treatments, repeated three times (Figure 1). Each replicate consisted of six elementary plots corresponding to the six treatments. That was a total of 18 unit plots for the entire experimental field. Each dimension of this unit plot (lockers) was 2 m × 1.5 m or 03 m^2. The elementary units consisted of 19 onion lines in a locker with a spacing of 10 cm on the line and between the lines. The blocks and elementary plots were separated by the rows of maize occupying the spaces of 0.5 m and 50 cm respectively. All the experimental plots were delimited from the maize rows in order to avoid mixing the products on each experimental unit during application. The total area of the test was 58.5 m^2. Figure 2 shows the parcel distribution.

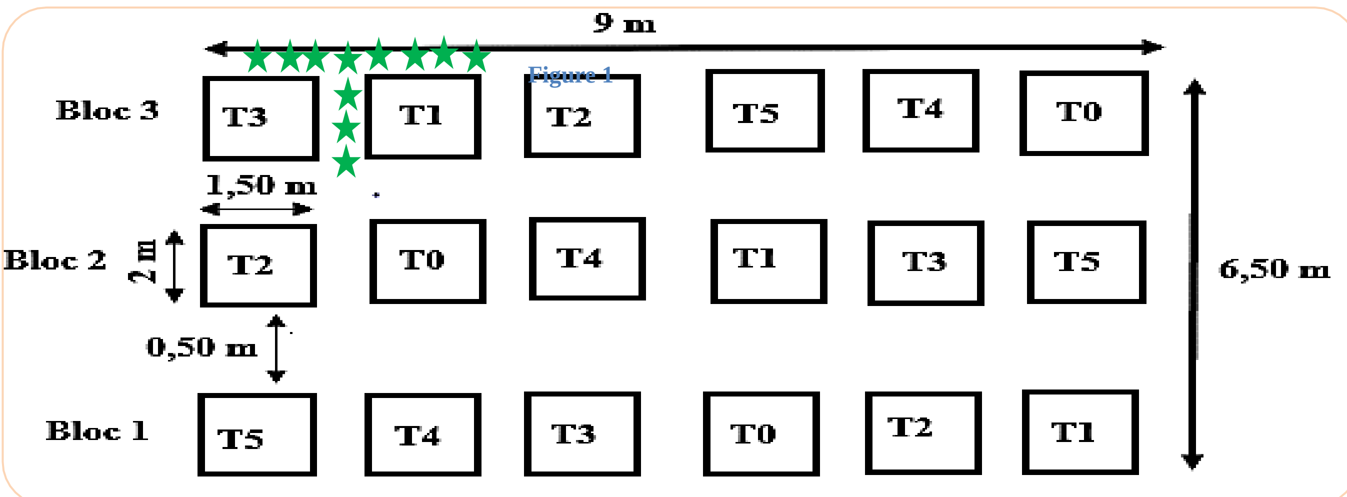


Figure 2. Plot distribution of treatment; the green stars show corn lines.

Conduct and implementation of the test

For the conduct of the test, an onion nursery was built using seeds of the local Goudami variety. Animal traction was carried out before hand for the ploughing of the plot. Once the plot has been disturbed, the corners of the sub-plots were made with the help of stakes in order to mark the boundaries. Making the lockers with a dimension of 2 m × 1.5 m was made using a decameter and a string. The rake was used to level the area of each plot. Irrigation was done according to a schedule, once a week for the first month (5 days after transplanting) if necessary and 2 times a week from the beginning of the formation of bulb until harvest (117 days after transplanting).

The maintenance work consisted of weeding (3 times) depending on the state of grass cover of the plot. The fertilization phase was carried out in three applications. During transplantation, a base fertilization based on mineral fertilizer at a rate of 50 kg/ha was applied. Then, at 20 days after transplanting, a fertilizer application consisting of NPK (20-15-15) and urea (46% N) at rates of 150 kg and 100 kg per hectare respectively was applied. And finally, a dose of 100 kg/ha of NPK (20-15-15) was applied at 60 days after transplanting.

Data collection

Assessing and determining the frequency of each insect pest in the entomofauna diversity of landrace goudami onion

To record all insects in the field, observations were made after every two days. These operations began from 23 to 81 days after transplanting on each experimental unit for different treatments. The passage was made on each plot that had received different treatments, this made it possible to determine and count the different insects encountered on the plants that were identified and marked. Each time insects were counted; the cumulative results were expressed in numbers according to the method of Tchindebe et al. (2021).

These data were used to determine the frequency of each insect species (Fi) in the entomofauna of *A. cepa*, using the given below formula adapted from Tchindebe et al. (2021).

$$\mathrm{Fi} = \frac{\mathrm{Pi}}{\mathrm{Pt}} \times 100$$

Where Pi = number of insects i at the level of treatments and Pt the number of all insects at the level of the attacked organs.

Growth and yield parameters

Plant height

The size of an onion plant was measured in centimeters from the base of the stem to the tip of the longest leaf. To get an accurate measurement, it is important to make sure the longest sheet is not damaged or bent. Size was taken using measuring tape (Sawadogo et al., 2020). Measurements were based on 10 randomly selected plants from each locker using the method of Sawadogo et al. (2020). This parameter was measured every 14 days until the leaves began to fall (during the bulb maturation phase).

Collar diameter of plants

The collar represents the widest section of the false stem, situated superficially once the bulbs have formed. This measurement was conducted using a caliper, where the process involved sliding the caliper's wheel to the level of the plant stem's collar and recording the values in millimeters displayed on the screen. This measurement was taken every 14 days until the onset of fall leaves, with 10 randomly selected individuals assessed at each stage (Sawadogo et al., 2020).

Number of leaves

Leaf counts were manually conducted on 10 randomly selected individuals from each locker (Sawadogo et al., 2020). This measurement was taken every 14 days until the leaves fell.

Yield of marketable and non-marketable bulbs onion

An evaluation of bulb weight was conducted following the methodology outlined by Sakatai et al. (2019). After harvest, the bulbs from each subplot were weighed and counted. The weight of both marketable and non-marketable bulbs for each treatment was determined using an electronic scale.

Identification of the promoter insecticide

The insecticide promoter was identified by calculating the Acceptability Index (AI), which represents the ratio of benefits obtained. This index measures the ratio between the treatments tested and the control treatment (negative or positive). Prospective studies have revealed a high usage of Optimal among producers. The reasons justifying its excessive use include its availability and notably it's lower cost (500 CFA F for a 25g bag covering an area of 0.25 hectare).

To do this, the acceptability index was calculated using the method of Nyembo et al. (2013). This helps to identify the best treatment that can be replaced and easily adopted by growers. This index compares the cost-effectiveness of the new treatments with the standard treatment that is well known by farmers. The formula suggested by Nyembo et al. (2013) presents the ratio of the calculations which is given below.

$$\mathrm{AI} = \frac{\text{Treatment Benefit}}{\text{Witness Benefit}}$$

Thus, a technology can only be easily adopted if the value of AI is equal to or greater than 2. Adoption is reluctantly done if this value is between 1.5 and 2; and below 1.5 there is rejection.

For the evaluation of profits and expenses related to production costs, the following elements were taken into consideration in CFA F: production operations (labor), insecticides, seeds, location of the plot, fuels (essence and motor oil), fertilizing elements, depreciation, other expenses (packaging, storage, transport, string).

The yield (tons/hectare) was assessed according to formula described by Sakatai et al. (2019) which is given below

$$\text{Profit (CFA F)} = [\text{Yield (t/ha)} \times 100] - \text{Total cost (CFA F)}$$

Pi = selling price of a 100 kg bag of bulbs in CFA F. All input and output prices (bags of onion bulbs) were valued at market prices at the time of operations.

Data processing and analysis

Data were entered using the Microsoft Office EXCEL 2016. The data were analyzed for variance (Turkey test) using the analysis STATGRAPHIC Centurion XVI.I software. At only 5% significance, Turkey's test was used to separate the mean values from the measured parameters.

RESULTS AND DISCUSSION

Inventory of each insect pest during the development stages of *A. cepa* local Goudami variety

From 23 to 81 days after transplanting, four insect species belonging to four orders and four families were counted on *A. cepa* leaves. Table 2 shows the insects recorded on *A. cepa* leaves, their numbers and percentages of individuals. Figure 3 shows the four insect species observed on *A. cepa* leaves.

Table 2. Insects recorded on *A. cepa* leaves, absolute numbers and percentages of presence of different insects.

Order	Family	Gender and species	Mouthpart of the type	n	p (%)
Hemiptera	Aphididae	*Aphis* spp.	Sucker-biter	178	22,32
Lepidoptera	Glyphipterigidae	*Acrolepiopsis assectella*	Crusher	207	23,82
Orthoptera	Acrididae	*Acrida cinerea*	Crusher (Larva)	194	20,48
Thysanoptera	Thripidae	*Thrips tabaci*	Rostrum biter	290	33,37
Total	4 species			869	100

$p = \frac{n}{869} \times 100$, Where n = number of individuals; p = percentage of effectiveness.

Table 2 illustrates that *Thrips tabaci* has the highest frequency of 33.37%, followed by *Acrolepiopsis assectella* (23.82%), *Aphis* spp. (22.32%), and *Acrida cinerea* (20.48%). Our findings align with the research by Savadogo et al. (2020), which identified *T. tabaci* as the primary insect pest affecting onion cultivation. These various insect species appeared chronologically in accordance with the plant's developmental stages: during the leaf growth stage (4 to 7 leaves), which spans 23 to 55 days after transplanting, locusts (*Acrida cinerea*) were the identified insects. Moreover, Saima et al. (2023) observed insect pests such as jassids, thrips, aphids, helicoverpa, and spotted bollworm in all treatments applied to okra cultivation at the Plant Pathology Research Institute in Pakistan.

Aphis spp

Acrolepiopsis assectella

Acrida cinerea

Thrips tabaci

Figure 3. Four insect species surveyed in *Allium cepa* leaves.

Furthermore, figure 4 illustrates the emergence of locusts 23 days after transplantation, followed by a decline starting at 40 days post-transplantation. The peak appearance of these insects was observed between 26 and 37 days after transplantation. Additionally, other insects, namely aphids, appeared during this stage, specifically between 32 and 34 days after transplantation. Figure 5 shows that aphids emerged between 32 and 34 days after transplanting, peaking at 32 days post-transplant. During this stage (4 to 7 leaves), the plant exhibited tolerance to damage caused by locusts and aphids. The stage of maximum growth and leaf development (4 to 8 leaves) is characterized by the appearance of caterpillars.

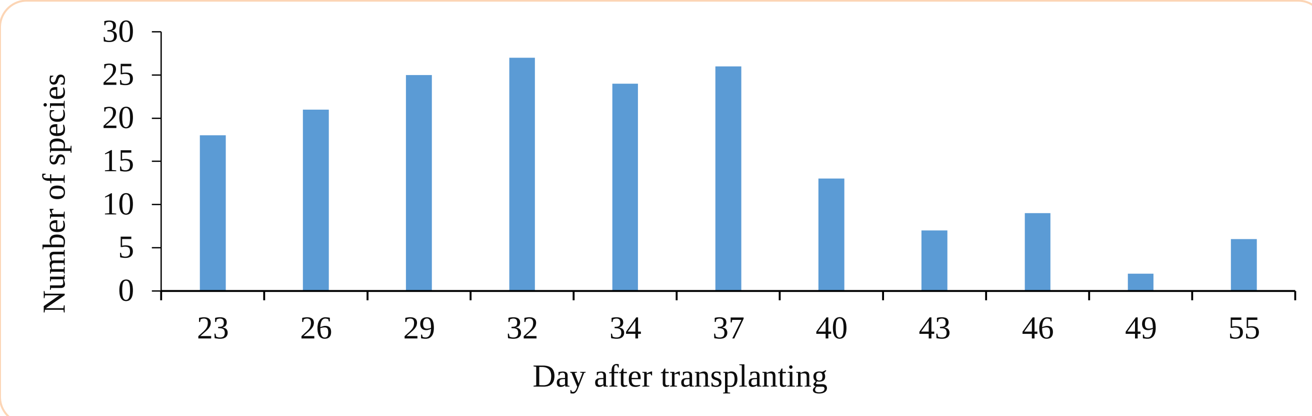


Figure 4. Evolution of *Acrida cinerea* numbers between 23 and 55 days after transplanting.

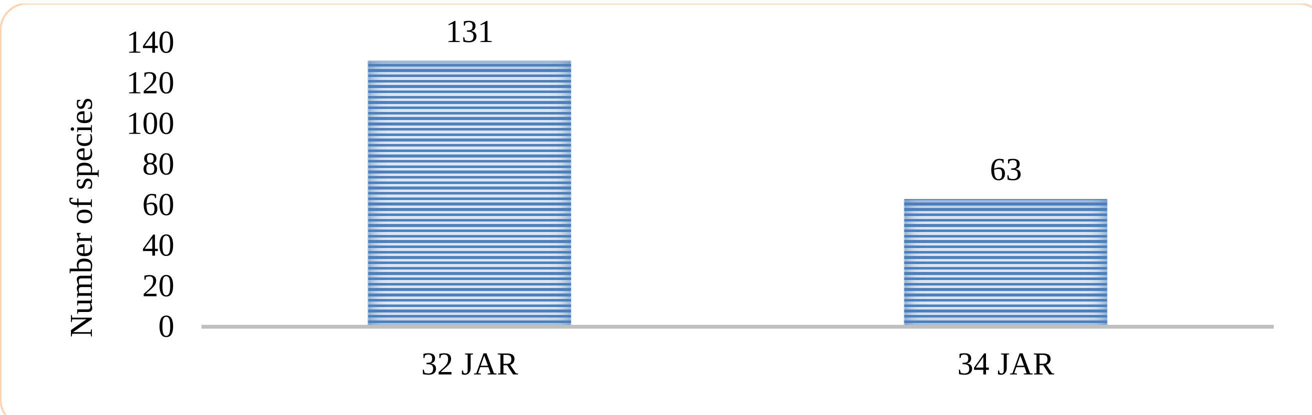


Figure 5. Evolution of *Aphis spp* numbers between 32 and 34 days after transplanting.

Figure 6 illustrates that the larvae emerge 26 days after transplanting and persist until 64 days post-transplanting. These insects reach their peak appearance between days 34 and 49 post-transplanting. At this stage, the damage inflicted by the caterpillars becomes significant. Specifically, the leek moth caterpillars settle directly inside the central cavity of the leaf upon hatching from their eggs. They proceed to consume the leaf tissue from within, leaving the outer epidermis intact (Céline et al., 2016). Consequently, the damage manifests as "windows" on the leaf surface. The most severely affected leaves eventually desiccate (Figure 6), leading to reduced photosynthesis and potentially affecting bulb yield.

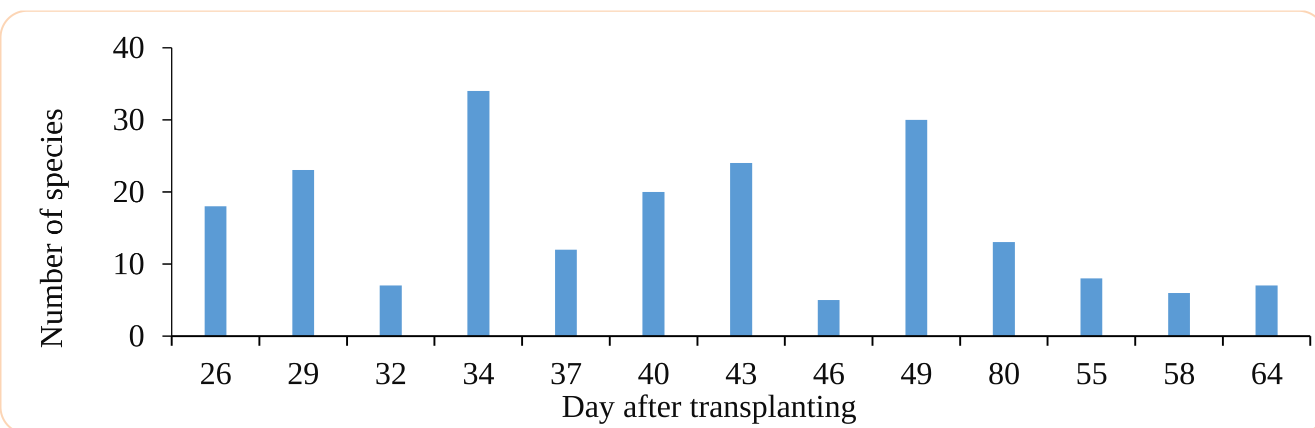


Figure 6. Counting of *Acrolepiopsis assectella* between 26 and 64 days after transplanting.

Figure 7 illustrates the progression of damage inflicted by the leek moth on onion leaves. During late leaf development and the early bulb stage (occurring 37 days after transplanting), thrips are the last pests to emerge. In Figure 8, the evolution of thrips is depicted between 72 and 81 days after transplanting.

Figure 7. Progression of damage caused by leek moth on onion leaves.

Figure 8 indicates that thrips reach their peak population 72 days after transplanting. Their presence at the collar was first noted 37 days after transplanting. Starting from this point, the plant's above-ground growth slows down, favoring underground growth due to collar swelling, which initiates bulb formation. This stage is critical as thrips attacks intensify, potentially leading to complete crop destruction if left untreated (Leblanc, 2010).

During thrips feeding, they use their rostrum to pierce the leaf, causing tissue laceration and separation, and then extract leaf contents through a feeding tube formed by the maxillary stylet. According to Bournier (1983) and Allache (2021), this feeding can result in silver scratches or stripes on leaves (Figure 9 A), and in high populations, it causes leaf deformities and stunted growth (Figure 9 B). Thrips damage various plant organs, notably leaves, reducing photosynthesis activity due to mechanical destruction of chlorophyll-containing mesophyll cells (Allache, 2021). This reduction in photosynthetic capacity ultimately leads to decreased yields. Moreover, these wounds can serve as entry points for pathogenic bacteria and fungi.

Figure 9 illustrates thrips' feeding marks on leaves (A), as well as leaf deformities and stunted growth (B) of onion plants in the field at Meskine, 2023.

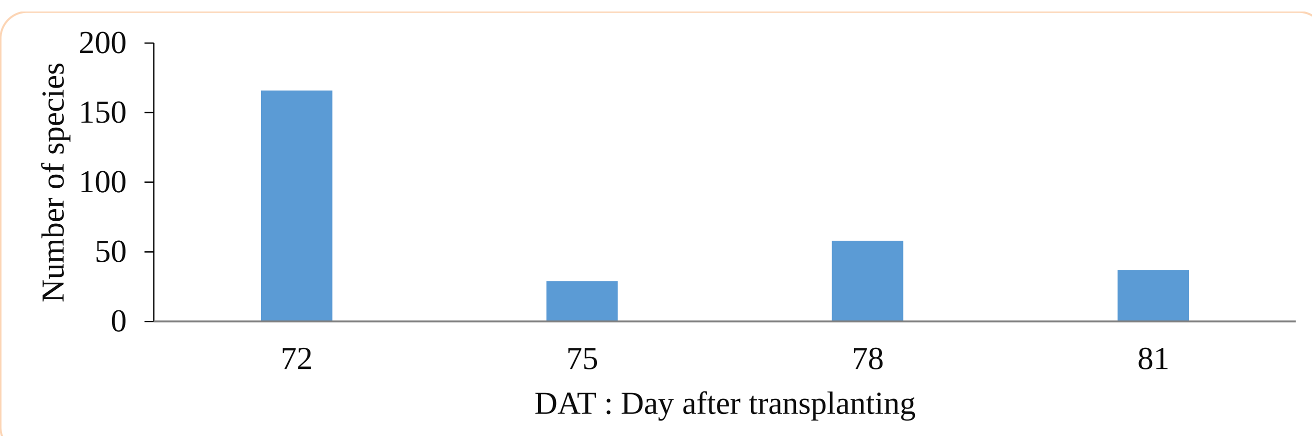
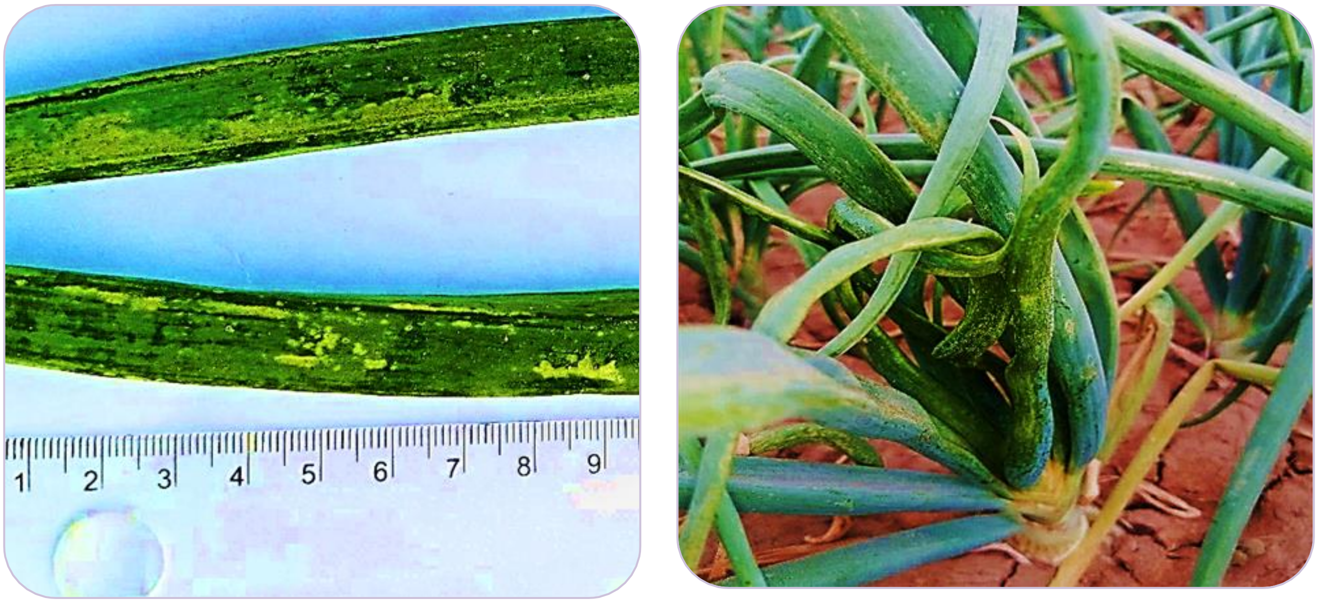


Figure 8. Evolution of *Thrips tabaci* number between 72 and 81 days after transplanting.



A B

Figure 9. Thrips feeding marks on leaves (A), leaf deformations and stunting (B) of the onion plant at Meskine 2023.

Overall, the observed regression of different insects can be explained by several factors. First, there is a hypothesis that the decrease in nutrient availability in the plant's leaves during its life cycle may lead to a reduction in the abundance of insects that feed on them. Second, it is hypothesized that the application of insecticides may have adverse effects by reducing the number of insects in the experimental field. Therefore, it is crucial to conduct insecticide treatments to identify the active ingredient(s) that can significantly reduce the number of organic pests on onions.

Effect of insecticide efficacy on growth and yield parameters

Effect of treatments on growth and development parameters

Table 3 displays the mean values of collar diameter and leaf count 65 days after transplanting onion plants. It is evident from Table 3 that the analysis of variance at the 5% significance level revealed no differences in mean values concerning collar diameter and leaf count at 65 days after transplanting. This can be attributed to the fact that the application of different treatments had no effect on the mean values of collar diameter and number of leaves. However, a slight variation in collar diameter was observed between the control (7.83 mm) and Rapax (9.32 mm). Meanwhile, the average number of leaves remained consistent across the tested treatments, with 6 ± 0.00 for Rapax and 6 ± 0.58 for Cypercal, HN + TDN, Optimal, Pacha, and the control.

Table 3. Collar diameter and leaf count of plants under different applied treatments at 65 days after transplanting.

Treatments	Collar diameter (mm)	Number of leaves
Cypercal	8.26 ± 0.35 [a]	6 ± 0.58 [a]
HN + TDN	8.05 ± 0.91 [a]	6 ± 0.58 [a]
Optimal	8.74 ± 0.66 [a]	6 ± 0.58 [a]
Pacha	8.50 ± 1.68 [a]	6 ± 0.58 [a]
Rapax	9.32 ±1.27 [a]	6 ± 0.00 [a]
Not treatment	7.83 ± 1.45 [a]	6 ± 0.58[a]
Probability value	NS (0.621)	NS (0.721)

HN + TDN: Neem oil + neem cake; NS: Not significant.

Table 4 presents the average plant heights at 23 and 65 days after transplanting (DAT). The results of the analysis of variance, shown in table 4, indicate that there is no significant difference (NS) in mean plant sizes at 23 days after transplanting among the different treatments applied. However, a variation in height between 13.25 for Pacha and 12.17 for Rapax has been recorded at this stage of development. On the other hand, there was a significant difference (P (5%) = 0.002) in mean plant size at 65 days after transplanting. The multiple comparisons (Tukey test) between the average sizes also revealed two groups of insecticides at 65 DAT: Group 1 comprised HN + TDN, Rapax, and Control; Group 2 consisted of Cypercal, Optimal, and Pacha. Between these two groups, the largest and smallest height values were recorded by Optimal (33.28 ± 0.48 cm) and the Control (27.75 ± 0.27 cm) respectively. This difference may be explained by the possibility that using insecticides after 23 days post-transplanting helped the plants develop better by eliminating insect pests that had begun to damage them. Insects such as aphids and thrips can cause significant damage to plants by sucking sap, leaving spots or scars on leaves, and disrupting normal growth (Bournier, 1983). It can be observed that there is a highly significant negative correlation between height parameters from 40 DAT and insect damage caused to plants at the 1% level of significance (Table 5).

Table 4. Mean plant heights at two dates (23 and 65 DAT) of the life stage according to the different treatments applied.

Treatments	Mean Plant height (cm)	
	23 DAT	65 DAT
Cypercal	12,50 ± 0,55 [a]	32,96 ± 1,53 [b]
HN + TDN	12,27 ± 1,15 [a]	28,28 ± 0,79 [a]
Optimal	13,21 ± 1,81 [a]	33,28 ± 0,48 [b]
Pacha	13,25 ± 0,31 [a]	32,99 ± 1,05 [b]
Rapax	12,17 ± 1,60 [a]	28,13 ± 1,33 [a]
Control	12,70 ± 0,81 [a]	27,75 ± 0,27 [a]
Probability value	NS (0,561)	VHS (0,002)

HN + TDN: Neem oil + neem cake; NS: not significant; VHS: Very highly significant.

Table 5 indicates that starting from 40 days after transplanting (DAT), the use of insecticides likely led to a significant reduction in insect damage. This reduction allowed plants to prioritize their growth and development. In the absence of insect pests, plants efficiently utilized available nutrients and water, leading to faster growth. Consequently, the use of insecticides notably decreased pest pressure during these critical stages of plant growth and development. This impact extended to the average yields of onion cultivation.

Abdoul et al. (2016) and Bonni et al. (2018) observed that neem oil and *Bacillus thuringiensis* effectively controlled *Helicoverpa armigera* and *Bemisia tabaci* in tomato plantations in Niger and cotton pests in Benin. Similarly, studies by Traore et al. (2019) demonstrated the efficacy of neem oil against *Maruca vitrata* Fabricius eggs, a cowpea pod borer, under laboratory conditions in Burkina Faso. In Pakistan, Saima et al. (2023) noted a progressive decrease in pest populations with treatment applications, with post-treatment measurements taken 48 hours after each spray. The biosal treatment resulted in the minimum average populations of aphids, thrips, jassids, and spotted bollworm, leading to a maximum agronomic yield of okra.

Table 5. Pearson's bilateral correlation coefficients between average plant sizes and insect damage.

Height on different dates	r (correlation coefficient)	
	Incidence (%)	Severity (%)
Height at 26 DAT	- 0.30	- 0.21
Height at 40 DAT	- 0.69 **	- 0.66 **
Height at 54 DAT	- 0.83 **	- 0.76 **
Height at 68 DAT	- 0.93 **	- 0.82 **

** Correlation is significant at the 1% level (student test).

Effect of insecticides on yields of local Goudami onion variety

Table 6 shows the average yields of marketable and non-marketable bulbs at harvest (147 DAT) according to the different treatments applied. In Table 6, the results of the analyses of variance indicate a highly significant difference (P at 5% = 0.000) in the average weight of marketable bulbs (tons/hectare) across the different treatments tested. Conversely, there was no significant difference in the average weight of non-marketable bulbs among the treatments. The comparison of marketable bulb yields reveals three distinct groups: Rapax, Optimal, and Control form the first group; HN + TDN and Pacha make up the second group, while Cypercal constitutes the third group. Cypercal exhibited the highest marketable bulb weight at 13.53 tons/hectare, while the lowest weight of 3.98 tons/hectare was observed with Neem oil enriched with its meal (HN + TDN). Regarding non-marketable bulb yield, HN + TDN showed the highest yield at 8.88 tons/hectare, while Pacha had the lowest yield at 6.62 tons/hectare.

These observations suggest that Cypercal treatment leads to superior yields compared to other insecticides, likely due to the effective control of insect pests by its active ingredients (cypermethrin and profenofos). This finding aligns with a similar study by Muhammad et al. (2021) in Pakistan, where cypermethrin demonstrated maximum efficacy against *V. isocrates*, followed by chlorpyrifos. Traditional onion cultivation yields between 7.9 to 11 t/ha, highlighting the significant improvement in bulb production with Cypercal.

The lower yield of marketable bulbs with the bio-insecticide HN + TDN (3.98 t/ha) compared to the control (6.01 t/ha) may be attributed to its impact on plant photosynthesis, particularly in the morning. This treatment likely affected stomatal function, leading to reduced gas exchange and subsequent leaf burns, as depicted in Figure 10. Stomata are crucial for regulating gas exchange during respiration and photosynthesis. Their closure, possibly induced by Neem oil in the HN + TDN treatment, limits CO_2 absorption and thus affects photosynthetic efficiency, explaining the observed decrease in performance compared to the control.

Table 6. Yield in t/ha of marketable and non-marketable bulbs of the different treatments applied to the local Goudami variety.

Treatments	Weight of bulbs in tons/hectare	
	Marketable	Non-marketable
Cypercal	13.53 ± 0.76 [c]	8.07 ± 1.03 [a]
Optimal	3.98 ± 0.88 [a]	8.19 ± 0.34 [a]
HN + TDN	8.86 ± 1.15 [b]	8.89 ± 0.60 [a]
Pacha	9.98 ± 1.42 [b]	6.62 ± 0.93 [a]
Rapax	5.31 ± 1.30 [a]	8.00 ± 0.87 [a]
Control	6.00 ±1.31 [a]	7.65 ± 1.15 [a]
Probability value	VHS (0,003)	NS (0,672)

HN + TDN: Neem oil + neem cake; VHS: Very highly significant; NS: Not significant.

Figure 10. Appearance of the plants that received the Neem oil + Neem cake treatment.

The lower marketable bulb yield (5.31 t/ha) in the Rapax treatment compared to the control (6.01 t/ha) can be attributed to the fact that the active ingredient in this bio-insecticide is more effective against larval stages of caterpillars than thrips. Thrips, due to their small size, can hide in leaf folds and tissues (Figure 11), making it challenging for them to come into contact with the "cry toxins" produced by *B. thuringiensis* microorganisms. When thrips larvae ingest these cry toxins, they bind to specific receptors in their gut (Bravo et al., 2011), leading to gut wall destruction, loss of digestive secretions, and eventual insect death (Bravo et al., 2011). However, this process is limited by the thrips; location on the plant, thereby reducing the effectiveness of the treatment against thrips and resulting in decreased marketable bulb yield. This highlights the limitations of this bio-insecticide's mode of action against thrips. Figure 11 illustrates thrips hiding in plant leaf folds and tissues. While certain insecticides have been shown to reduce pest pressure compared to control treatments, their use must align with product cost considerations.

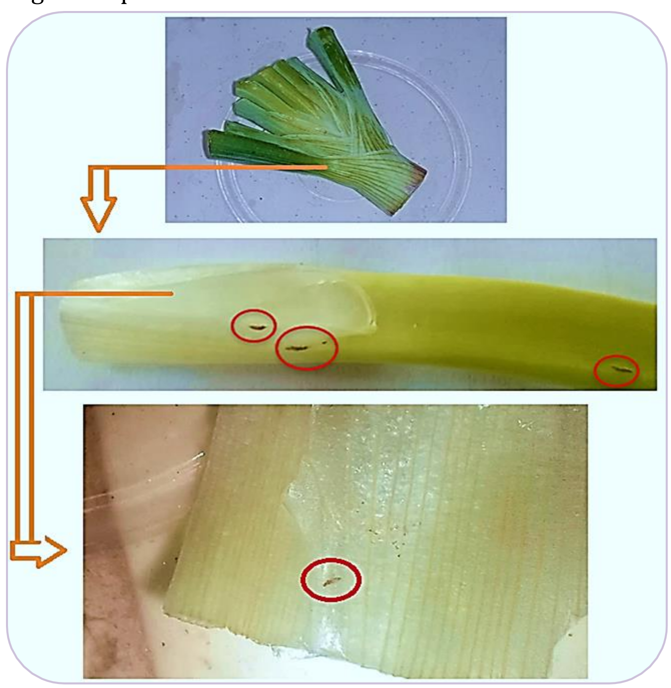


Figure 11. Thrips hiding in leaf folds and plant tissues. Individuals of thrips inside red circle.

Identification of the promoter insecticide for the treatment of onion production

Table 7 summarizes the various levels of resources, profits, and acceptability indices based on the different treatments applied. It shows that the total cost of production without the application of insecticides (control) is 670.370 CFA francs, with a profit of 832.130 CFA francs. All other things being equal, the resource levels for the other treatments are derived from the total cost of producing the negative control. Only insecticides (Cypercal, Neem oil + Neem cake, Optimal, Pacha, and Rapax) are the controlled factor modalities/treatments. Therefore, the acceptability index of each treatment can be summarized based on the control considered in Tables 8 and 9.

Table 8 reveals that when comparing the treatments applied with the negative control, Cypercal emerges as the most suitable insecticide for cost-effective production. Neem oil + Neem cake and Rapax are insecticides that should be rejected. Conversely, considering the positive control (Optimal), Table 9 presents the acceptability index of the different treatments based on the optimal treatment.

Table 7. Resource levels and acceptability index of different treatments.

Resource levels	Treatments						
	Control	Cypercal	HN + TDN	Optimal	Pacha	Rapax	Total
Insecticide purchase price /ha and transport (CFA F)	-	41 000	94 000	17 000	65 000	57 000	21 7000
Spray cost (CFA F)	-	16 000	16 000	16 000	16 000	16 000	80 000
Production cost	670 370	670 370	670 370	670 370	670 370	670 370	4 022 220
Total cost (CFA F)	670 370	727 370	780 370	703 370	751 370	743 370	4 376 220
Yield in tons/hectare	6,01	13,53	3,98	8,86	9,98	5,31	47,67
Number of bags	60,1	135,3	39,8	88,6	99,8	53,1	476,7
Gross revenue (CFA F)	1 502 500	3 382 500	995 000	2 215 000	2 495 000	1 327 500	11 917 500
Profit (CFA F)	832 130	2 655 130	214 630	1 511 630	1 743 630	584 130	7 541 280
AI	-	3,2	0,3	1,8	2,1	0,7	8,1

NB: HN + TDN: Neem oil + Neem cake; all prices are realized at the time of operations with Pi = 25,000 CFA F selling price of a 100 kg bag of bulbs; the purchase price of the insecticide/ha and transport (CFA F); the cost of spraying (CFA F) as a function of the number of times were evaluated.

Table 8. Acceptability index of different treatments according to the negative control.

Treatments	AI	Decision making
Cypercal	3.2	Accepted
HN + TDN	0.3	Rejected
Optimal	1.8	Accepted with reluctance
Pacha	2.1	Accepted
Rapax	0.7	Rejected
Zero treatment (control -)	-	-

HN + TDN: Neem oil + neem cake; AI: Acceptability Index.

Table 9. Acceptability index of treatments applied based on positive control.

Treatments	AI	Decision making
Cypercal	1.8	Accepted with reluctance
HN + TDN	0.1	Rejected
Pacha	1.2	Rejected
Rapax	0.4	Rejected
Optimal (control +)		Rejected

HN + TDN: Neem oil + neem cake, AI: Acceptability index.

It can be observed that, by comparing the acceptability index of different treatments with the optimal positive control, only Cypercal could be suggested instead of the optimal insecticide for better production in bulb onions. In Pakistan, the application of biosal on okra after treatment demonstrated superior efficacy as a control approach compared to alternative treatments (Seima et al., 2023). Muhammad et al. (2021) in Pakistan also showed that Neem oil was evaluated as an effective treatment to reduce infestation in pomegranate orchards.

CONCLUSION

At the conclusion of this study conducted at the Center for Agricultural Research for Development (CRAM) farm in Maroua, the objective of which was to evaluate the effectiveness of five insecticides in controlling the main insect pests of onions during late plant transplantation to identify the most effective insecticide promoting better onion bulb yield, several key findings were observed. The inventory of bio-pests revealed four major insect species infesting the leaves, with thrips being the most prevalent at 33.37% of the total population, followed by caterpillars (23.82%), aphids (22.32%), and locusts (20.48%) within the experimental field.

The application of insecticides effectively reduced pest pressure starting from 40 days after transplanting, facilitating optimal plant growth. The Cypercal insecticide yielded the highest marketable bulb yield at 13.53 t/ha, while other insecticides including Optimal, Pacha, Rapax, and Neem oil + Neem cake also contributed to reducing insect pest populations to varying degrees. Among these, Cypercal, Optimal, and Pacha showed better results in reducing thrips populations compared to the bio-pesticides Neem oil + Neem cake and Rapax.

Cypercal emerged as a key promoter insecticide capable of enhancing onion crop yields during the dry season, potentially replacing Optimal for improved outcomes. However, it is worth noting that this study has limitations due to its single-site nature. Nuances related to pedo-climatic conditions can significantly influence agronomic parameters and the efficacy of insecticides. To enhance the study's comprehensiveness, conducting similar research in a controlled environment targeting specific pests while varying insecticide doses would be crucial.

AUTHORS CONTRIBUTIONS

SD conducted the experiments, collected data, and wrote the first draft of the paper. SPD performed data analysis, contributed materials and tools, and wrote the final paper.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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