agronomy

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Efficacy of Eco-Friendly Bio-Pesticides against the Whitefly *Bemisia tabaci* (Gennadius) for Sustainable Eggplant Cultivation in Kebbi State, Nigeria

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Abstract: The eggplant (*Solanum melongena* L.) is among the vital fruit vegetables cultivated globally for its health and nutritional benefits. However, its production has been hindered by whiteflies (*Bemisia tabaci* G.) infestation worldwide. This study aims to assess the effect of some bio-pesticides in the control of whiteflies on eggplants under field conditions. The trial consists of seventeen (17) treatments replicated three times for 45 days. From the results obtained, neem leaf extract (60 mL/L) proved more effective against whiteflies, with 1.2 and 1.3 adults/leaf, while buttermilk and cow dung (50 mL/L) were less effective (10.1 and 10.8 adults/leaf) when compared to untreated plots (26.9 and 33.4 adults/leaf), two weeks after the third spray during the first and second trials. The highest reduction (%) in whitefly population was found using neem leaf extract (95.7 and 96.1%) and cow urine (85.8 and 96.1%), with cow dung and buttermilk exhibiting the least overall averages (65.9 and 62.3%), two weeks after the third spray during the respective trials. Neem extract and cow urine were more effective among the treatments examined and, thus, recommended to be incorporated into control strategies of whiteflies for the improved production of eggplants in the area.

Keywords: *Solanum melongena* L.; whiteflies; neem leaf extract; sustainable; pest management

Citation: Abubakar, M.; Yadav, D.; Koul, B.; Song, M. Efficacy of Eco-Friendly Bio-Pesticides against the Whitefly *Bemisia tabaci* (Gennadius) for Sustainable Eggplant Cultivation in Kebbi State, Nigeria. *Agronomy* **2023**, *13*, 3083. https://doi.org/10.3390/agronomy13123083

Academic Editor: Stefano Bedini

Received: 14 November 2023
Revised: 13 December 2023
Accepted: 15 December 2023
Published: 18 December 2023

1. Introduction

The eggplant (family: Solanaceae), also known as brinjal (*Solanum melongena* L.), is a vital fruit vegetable in Asia, Europe, and Africa, with an acreage of over 2 million hectares and an annual yield of 33 million tons, worth USD 10 billion [1,2]. This nutritious vegetable is abundant in dietary fiber, vitamins, and several essential elements [3,4]. Furthermore, it is enriched with valuable phytochemicals such as flavonoids, phenolics, and thiamin [5,6]. These contribute to its potential role in offering various health benefits, such as anticancer, anti-asthmatic, and antioxidant, as well as antidiabetic, effects.

The whitefly (*Bemisia tabaci* Gennadius; Hemiptera: Aleyrodidae) is a highly destructive sap-sucking pest that affects various crops, particularly solanaceous vegetables [7,8]. The eggplant is among the most affected crops by whitefly infestation, causing direct and indirect feeding effects that lead to a reduction in both the physiological and morphological parameters of the crop [9,10]. An infestation by a large whitefly density also leads to the release of honeydew and sooty mold development, which blackens the leaves, reduces the rate of photosynthesis, and, ultimately, the yield of the crop [11–15]. Whiteflies are also known as vectors of more than 350 species of viruses in different vegetables. Eggplant mild leaf mottle virus (EMLMV) [16], tomato torrado virus (ToTV) [17], and tomato yellow leaf curl virus (TYLCV), which are vectored by whiteflies and frequently seen in tomatoes, also affect eggplants [18]. Whiteflies are thus widely known agricultural pests, with both primary and secondary effects causing remarkable yield losses if not well managed [19,20].

The control regimes depend largely on synthetic insecticides. However, frequent application has caused *B. tabaci* species to develop a resistance to such chemicals [21]. Furthermore, their injudicious application has led to several negative consequences on humans and the ecosystem [22,23]. Considering these challenges, it is of great importance to deploy eco-friendly plant protection approaches to improve crop yields and ensure food security. At this point, indigenous technology and expertise in plant protection in agricultural production would be extremely useful [24]. The use of traditional treatments has been demonstrated to effectively reduce the whitefly population on several crops like cabbage, tomatoes, okra, and sugarcane [25]. This has been achieved by applying indigenous technology to reduce the effects of whiteflies and other sap-sucking pest infestations using locally available materials/techniques and expertise [9]. One of these approaches involves the application of plant extracts, which have been documented as successful in combating major insect pests, including whiteflies, on various crop plants [26,27]. For instance, Peres et al. [28] reported a 98% anti-oviposition effect using *Xylopia aromatic* (Lam.) essential oils on whiteflies, while Abubakar and Koul [29] found eucalyptus essential oil effective in reducing the whitefly density on brinjal crops, causing up to 95% reduction.

The application of wood ash [30], kerosene–soap–water emulsion [31], fermented curd water, cow dung and urine with plant extracts, liquid soap in plant extracts, and yellow stick traps [24,32–35] have been shown to have potential in whitefly management for different vegetables. These strategies have also been demonstrated to increase the yield of the crops with lower production costs. Despite their efficacy, these techniques are currently less practiced by both farmers and the scientific community in Kebbi State, Nigeria. As a result, the efficacy of some traditional formulations from chili pods, neem leaves, cow urine, cow dung, and fermented curd water was evaluated using the green round eggplant cultivar. This was done to identify a more robust eco-friendly approach using locally available materials that are easily obtainable and simple to prepare for sustainable eggplant cultivation.

2. Materials and Methods

2.1. Experimental Site

The experiment was conducted at the Agricultural Research Field, Kebbi State University of Science and Technology, Aliero (KSUSTA), Kebbi State, Nigeria, from January to April in 2022 and 2023. The geographical coordinates of the area are approximately 12°13′19.88″ N latitude and 4°22′46.67″ E longitude. This region experiences wet and dry seasons, with the wet season typically spanning from May to October and the dry season lasting from October to May. The area has an average of 13.3% and 29.5 °C of relative humidity and temperature, respectively.

2.2. Seed Procurement, Germination, and Viability Testing

The seeds of one of the most cultivated but susceptible eggplant varieties (green round) locally known as "Yalo-Bahaushe" were purchased from Afrimash Company Limited Ibadan, Nigeria. The germination capacity of the seeds was tested in 3 earthen pots filled with fertile soil. Each pot was planted with a hundred seeds and irrigated regularly as the germination potential was observed for two weeks, recording up to 75% germination capacity. Consequently, the seeds were chosen to develop the seedlings used to experiment. The seedling production process commenced with site clearance and plowing, which were done manually using a hoe. Nursery beds, measuring 1 × 3 m in dimensions, were prepared, and one wheelbarrow full of organic fertilizer was added to each of the beds and thoroughly mixed with the soil for adequate irrigation before sowing the seeds. Rice straws were placed on the beds to serve in retaining moisture, maintaining the optimal bed temperature, and protecting the germinating seedlings from potential damage by rodents and birds. A week after the seeds' germination, the organic mulches were carefully removed from the beds to expose the seedlings to sunlight, and regular irrigation was maintained until the seedlings developed 5 to 6 true leaves. One week prior to transplanting, the watering was reduced to help harden the seedlings. The seedlings, along with some soil, were then uprooted and immediately transplanted into the experimental plots.

2.3. Experimental Design and Agronomic Practices

The experiment was set up in a randomized block design (RBD) to determine the potential of traditional methods in the control of whiteflies on the eggplants. The trial consisted of seventeen experimental plots, including the control (3×3 m^2, separated by 0.5 m), replicated three times. A synthetic insecticide was applied as an absolute control, while a negative control group was sprayed with water only. The seedlings were transplanted in the experimental plots; spaced at 60×60 cm; and standard agronomic activities such as irrigation, weeding, and fertilizer application were uniformly implemented across all the plots throughout the trial [36]. Whiteflies were allowed to occur naturally in the experimental field, and a week before the application of the treatments, pretreatment whitefly counts were recorded from the plots.

2.4. Preparation and Spray of the Treatments

2.4.1. Chili Pod Extract

Fresh fruits of the red chili (*Capsicum annum* L.), commonly known as 'Cayenne long slim variety' (locally called 'Tanka Dan Fura'), were purchased from the local market (Dodoru, Gwandu LGA, Nigeria) in a polythene bag and taken to the botany laboratory, KSUSTA. About 1 kg of fresh fully matured chili pods measuring 7.6–10.4 cm in length with seeds intact were crushed using an electric mixer grinder machine. A small amount of water was added to the crushed product in a 3 L earthen pot and boiled for ½ an hour. Thereafter, ten L of water was added to make the final concentration 10% w/v [34]. About 0.5% of liquid soap was then added to the filtrate to serve as an emulsifier and surfactant and to enhance the effect of the treatment. The mixture was stirred vigorously for 5 min using a metal rod and filtered twice using a muslin cloth. The solution was then stored at 4 °C in an airtight clean container before use. The extract was sprayed at three different doses (20, 40, and 60 mL/L) [37].

2.4.2. Cow Dung

Fresh cow dung of the "White Fulani cattle breed (Diali)" was collected from the local cattle herders in the area. This breed is characterized by long horns and white fur, with red marks on their ears and legs. They were fed on a diet consisting of pearl millet straw, cassava peels mixed with wheat bran, cowpea (black eye pea) hay, and soybean husks, mixed in a ratio of 3:2:1:1:1, respectively. About 1.5 kg of fresh cow dung was collected in a clean polythene bag and placed in a 5 L earthen pot containing 3 L of tap water. The cow dung was allowed to ferment for 72 h with daily intermittent stirring. Thereafter, the slurry was strained thrice using a muslin cloth and stored at 4 °C in a 5 L plastic container before usage. The treatment was also sprayed at three different doses (50, 100, and 150 mL/L, respectively) [38].

2.4.3. Buttermilk

To prepare the fermented curd water, 4 L of fresh cow milk of the "White Fulani cattle breed (Diali)" was purchased from Fulani herdsmen in the study area and placed in a 5 L sterile plastic container. The fresh milk was allowed to ferment for one week, then 4 L of distasteful buttermilk (curd that has been stored for up to 7 days) were added to 8 L of water and mixed (50% v/v). The mixture was covered and allowed to ferment further for one week. It was then hand-shaken vigorously for 5 min. The solution was strained twice using a cotton muslin cloth, which was then used as a foliar spray at three different doses (50, 100, and 150 mL/L) [39].

2.4.4. Neem Leaf Extract

Fresh neem leaves (*Azadiracta indica* Juss), commonly known as Margosa/Indian lilac (locally called "Dogonyaro"), were obtained from the university farm and taken to the botany laboratory at KSUSTA for the extract preparation. The leaves were collected in a polythene bag from the upper regions of newly produced branches from the first to third internodes. They were carefully and thoroughly washed under tap water to remove the dust. About 400 g of the cleaned leaves were crushed in an electric grinding machine (Prestige 750 w grinder mixer, India). The crushed material was added to 4 L of tap water containing 0.5% liquid detergent. The mixture was thereafter boiled in an earthen pot for ½ hour. The mixture was allowed to cool, filtered thrice to obtain a clear extract, and then stored refrigerated to maintain the freshness and potency of the extract before use. The extract was sprayed at three different doses (20, 40, and 60 mL/L) [40,41].

2.4.5. Cow Urine

Fresh cow urine of the "White Fulani cattle breed (Diali)" was obtained from the local cattle herders in the study area in a 5 L sterile plastic container. The urine was then filtered using Whatman No. 1 filter paper to remove debris and precipitated substances. Subsequently, the strained urine was placed in an airtight container and allowed to ferment for seven days. Before application, the fermented concentrated urine was diluted in tap water (50% v/v), a concentration previously reported as effective for insect pests and disease management. The solution was hand-shaken vigorously for 5 min to ensure proper mixing, strained twice via Whatman No. 1 filter paper, and applied at 3 different doses (25, 50, and 75 mL/L) [42,43]. The details of the treatments are presented in Table 1.

Table 1. Various treatments for whitefly management.

Treatments	Type	Concentration %/Dosage (mL/L)
ChPo20 ChPo40 ChPo60	Chili pods	10% w/v (20) " " " (40) " " " (60)
CoDu50 CoDu100 CoDu150	Cow dung	50% w/v (50) " " " (100) " " " (150)
BuMi50 BuMi100 BuMi150	Buttermilk	50% v/v (50) " " " (100) " " " (150)
CoUr25 CoUr50 CoUr75	Cow urine	50% v/v (25) " " " (50) " " " (75)
NeLe20 NeLe40 NeLe60	Neem leaf	10% w/v (20) " " " (40) " " " (60)
CheIn6 Control	Malathion EC 50% Water	(6) ....

A 15 L Knapsack sprayer (MT-107, Zhejiang, China, Zhejiang Jinnong Medical Machinery Co., Ltd.) procured from Afrimash Company Ltd., Ibadan, Nigeria, was used for the foliar applications (1st, 2nd, and 3rd sprays) of different treatments at an interval of two weeks. Water and liquid detergent were used to clean the sprayer before its being refilled with another treatment [34]. The effectiveness of the treatments was assessed by recording data on the adult counts per eggplant leaves from 3 leaves (upper, middle, and lower regions) of 5 randomly selected plants from each of the three replications of the experimental plots. The data were recorded at several points (1st, 2nd, 3rd, 5th, 7th, and

15th days) after each spray. Additionally, the crop yield (g/plot) was assessed during the respective experiments (2022 and 2023), considering the weights of the fruits taken from the 5 randomly chosen plants in each of the experimental plots.

2.5. Statistical Analysis

Agricultural statistical software (STAR version 2.0.1) was deployed to analyze the data through ANOVA. To separate the means, Tukey's Honest Significant Difference (HSD) was used at a 5% level of significance. While performing the ANOVA, both the homogeneity of the variances and normality of the residuals were taken into consideration using the Bartlett's and Shapiro–Wilk tests.

The following equation was used to determine the efficacy (%) in the whitefly population.

$$\text{Efficacy } (\%) = \frac{\text{Control plots} - \text{Treated plots}}{\text{Control plots}} \times 100$$

where efficacy = percentage decrease in whitefly number in the respective blocks/plots; control plots = plots treated with water only, and treated plots = plots sprayed with the various biopesticides.

3. Results

3.1. Efficacy of Traditional Treatments against the Whitefly

The results on the effects of traditional treatments at different data recording periods (1st, 2nd, 3rd, 5th, 7th, and 15th days) after the various sprays during the 2022 and 2023 experiments are presented in Tables 2–4. The experimental plots were found with a similar whitefly population per eggplant leaf before the spraying of the treatment in the 2022 ($F(DF) = (1.0(16),\ P = 0.661)$) and 2023 ($F(DF) = (1.1(16),\ P = 0.340)$) experiments. In 2022, the treatments varied significantly (P < 5%) in all the data recording periods, except for day 1 ($F(DF) = (1.5(16), P = 0.155)$) after the first spray. NeLe60 (60 mL/L) had the highest effect with 38.0 adults/leaf, followed by ChPo60 (60 mL/L) with 42.7 adults/leaf, while CoDu50 (50 mL/L) had the least effect with 49.5 adults/leaf on day 1 after the first spray. NeLe60 (60 mL/L) had the highest effect, as a significant difference was observed among the treatments on the 2nd ($F(DF) = (2.3(16),\ P = 0.021)$), 5th, ($F(DF) = (2.3(16),\ P = 0.022)$), 7th ($F(DF) = (3.9(16),\ P = 0.0004)$), and 15th ($F(DF) = (5.6(16),\ P < 0.0001)$) days after the spray, recording 29.7, 25.8, 19.3, and 15.7 adults/leaf, respectively. CoUr75 (75 mL/L) had the highest effect (28.8 adults/leaf), with the treatments differing significantly ($F(DF) = (2.6(16),\ P = 0.032)$) on day 3 after the spray in the 2022 experiment. CoDu50 (50 mL/L) recorded the highest whitefly number in all the data recording periods during the same season, with up to 32.9 adults/leaf two weeks after the spray. In 2023, similar results were recorded as in 2022, with the treatments exhibiting varying effects on the 2nd ($F(DF) = (3.2(16),\ P = 0.003)$), 3rd ($F(DF) = (2.9(16), P = 0.004)$), 5th ($F(DF) = (3.6(16),\ P = 0.001)$), 7th ($F(DF) = (6.3(16),$ $P < 0.0001)$), and 15th ($(F(DF) = (3.9(16), P = 0.001)$) days after the spray. NeLe60 (60 mL/L) was the most effective with 30.7 and 16.9 adults/leaf, followed by NeLe60 (60 mL/L) with 32.1 and 18.7 adults/leaf, while ChPo20 (20 mL/L) was the least effective with 45.5 and 31.7 adults/leaf on the 1st and 15th days, respectively, after the first foliar spray of the treatments (Table 2).

Table 2. Effect of the treatments against the whitefly after the 1st foliar spray.

Treatments	**Average Adult Whiteflies/Leaf**							**Average Adult Whiteflies/Leaf**						
	2022							**2023**						
	D0	**D1**	**D2**	**D3**	**D5**	**D7**	**D15**	**D0**	**D1**	**D2**	**D3**	**D5**	**D7**	**D15**
ChPo20	53.8 ^{a}	48.3 ^{a}	47.1 ^{ab}	41.1 ^{a}	37.7 ^{ab}	30.3 ^{abc}	31.5 ^{abc}	49.9 ^{a}	45.5 ^{a}	41.1 ^{ab}	38.3 ^{ab}	35.9 ^{abc}	34.8 ^{ab}	31.7 ^{ab}
ChPo40	55.3 ^{a}	46.9 ^{a}	42.4 ^{ab}	36.0 ^{a}	35.1 ^{ab}	27.0 ^{abc}	24.1 ^{bcd}	51.9 ^{a}	38.9 ^{a}	37.8 ^{ab}	35.2 ^{ab}	33.4 ^{abc}	31.9 ^{bc}	24.4 ^{ab}
ChPo60	51.6 ^{a}	42.7 ^{a}	37.1 ^{ab}	32.8 ^{a}	30.7 ^{ab}	22.2 ^{bc}	21.6 ^{bcd}	54.2 ^{a}	32.9 ^{ab}	33.3 ^{b}	30.8 ^{b}	28.6 ^{bc}	27.7 ^{bc}	22.6 ^{b}
CoDu50	50.1 ^{a}	49.5 ^{a}	47.4 ^{ab}	44.1 ^{a}	38.6 ^{ab}	34.6 ^{ab}	32.9 ^{ab}	49.2 ^{a}	44.3 ^{a}	41.7 ^{ab}	38.8 ^{ab}	36.4 ^{abc}	33.4 ^{bc}	31.3 ^{ab}
CoDu100	51.5 ^{a}	48.9 ^{a}	43.8 ^{ab}	40.1 ^{a}	37.6 ^{ab}	29.7 ^{abc}	26.5 ^{abc}	49.4 ^{a}	41.1 ^{a}	39.4 ^{ab}	37.7 ^{ab}	37.9 ^{ab}	36.5 ^{ab}	32.5 ^{ab}
CoDu150	50.4 ^{a}	47.5 ^{a}	41.2 ^{ab}	38.7 ^{a}	33.6 ^{bc}	28.5 ^{abc}	27.6 ^{abc}	51.1 ^{a}	39.6 ^{a}	36.5 ^{ab}	33.5 ^{ab}	33.1 ^{bcd}	30.1 ^{bc}	30.9 ^{ab}
BuMi50	54.8 ^{a}	48.6 ^{a}	44.4 ^{ab}	42.3 ^{a}	37.1 ^{ab}	30.6 ^{abc}	26.8 ^{abc}	52.1 ^{a}	43.8 ^{a}	41.2 ^{ab}	40.4 ^{ab}	37.9 ^{abc}	33.0 ^{bc}	27.7 ^{ab}
BuMi100	55.2 ^{a}	46.9 ^{a}	42.2 ^{ab}	41.1 ^{a}	34.1 ^{ab}	29.6 ^{abc}	25.6 ^{abc}	56.6 ^{a}	40.4 ^{a}	35.4 ^{ab}	33.6 ^{ab}	31.9 ^{ab}	29.4 ^{bc}	29.1 ^{ab}
BuMi150	57.9 ^{a}	43.5 ^{a}	42.7 ^{ab}	35.6 ^{a}	31.8 ^{ab}	26.9 ^{abc}	23.9 ^{abc}	54.1 ^{a}	36.1 ^{a}	33.0 ^{b}	34.5 ^{ab}	30.0 ^{bcd}	25.7 ^{bc}	25.8 ^{ab}
CoUr25	50.1 ^{a}	48.9 ^{a}	43.2 ^{ab}	39.5 ^{a}	34.4 ^{ab}	29.3 ^{abc}	22.8 ^{bcd}	50.5 ^{a}	38.9 ^{a}	35.0 ^{ab}	33.6 ^{ab}	31.1 ^{bc}	31.3 ^{bc}	27.0 ^{ab}
CoUr50	53.9 ^{a}	44.4 ^{a}	41.6 ^{ab}	34.1 ^{a}	28.6 ^{bc}	23.4 ^{bc}	20.1 ^{cd}	51.7 ^{a}	37.3 ^{a}	35.4 ^{ab}	35.3 ^{ab}	32.2 ^{abc}	29.3 ^{bc}	23.2 ^{b}
CoUr75	56.2 ^{a}	42.7 ^{a}	35.2 a^{b}	28.8 ^{b}	26.3 ^{bc}	22.5 ^{bc}	15.8 ^{d}	53.5 ^{a}	35.9 ^{a}	33.2 ^{b}	31.5 ^{b}	29.1 ^{abc}	25.1 ^{bc}	20.6 ^{b}
NeLe20	54.2 ^{a}	44.2 ^{a}	41.4 ^{ab}	34.3 ^{a}	30.7 ^{bc}	26.3 ^{abc}	23.0 ^{bcd}	50.4 ^{a}	38.2 ^{a}	34.9 ^{ab}	32.9 ^{ab}	31.4 ^{abc}	28.0 ^{bc}	20.9 ^{b}
NeLe40	51.9 ^{a}	42.2 ^{a}	35.8 ^{ab}	32.7 ^{a}	26.7 ^{bc}	24.6 ^{bc}	21.6 ^{bcd}	53.7 ^{a}	32.1 ^{ab}	29.5 ^{b}	29.5 ^{b}	30.3 ^{bc}	26.5 ^{bc}	18.7 ^{b}
NeLe60	55.1 ^{a}	38.0 a	29.7 ^{b}	29.2 ^{b}	25.8 ^{c}	19.3 ^{c}	15.7 ^{d}	48.3 ^{a}	30.7 ^{ab}	28.9 ^{b}	27.9 ^{b}	23.7 ^{c}	21.6 ^{c}	16.9 ^{b}
CheIn6	52.6 ^{a}	40.7 ^{a}	34.2 ^{ab}	31.6 ^{a}	26.4 ^{bc}	21.9 ^{bc}	22.6 ^{bcd}	55.9 ^{a}	35.0 ^{a}	32.4 ^{b}	30.7 ^{b}	26.6 ^{bc}	20.5 ^{c}	20.5 ^{b}
Control	52.3 ^{a}	50.2 ^{a}	50.3 ^{a}	44.8 ^{a}	40.0 ^{a}	38.4 ^{a}	35.6 ^{a}	54.2 ^{a}	47.5 ^{a}	48 ^{a}	45.5 ^{a}	43.8 ^{a}	47.0 ^{a}	40.4 ^{a}
C.D.	0.0	0.0	10.0	8.9	9.1	7.1	6.5	0.0	9.4	8.0	7.4	7.3	7.1	8.9
SEM±	3.8	2.9	3.5	3.1	3.1	2.4	2.3	3.2	3.3	2.8	2.6	2.5	2.5	3.1
F-value	1.0	1.5	2.3	2.6	2.3	3.9	5.6	1.1	2.1	3.2	2.9	3.6	6.3	3.9
p-value (5%)	0.661	0.155	0.021	0.01	0.022	0.0004	<0.0001	0.370	0.033	0.003	0.004	0.001	<0.0001	0.001

Means in the same column with the same common letter are not significantly different from each other ($p \leq 0.05$). D0 = day before the spray, D1–D15 = days after the spray, C.D. = critical difference, and SEM = standard error of the mean.

Table 3. Effect of the treatments against the whitefly after the 2nd foliar spray.

Treatments	Average Adult Whiteflies/Leaf						Average Adult Whiteflies/Leaf					
	2022						2023					
	D1	**D2**	**D3**	**D5**	**D7**	**D15**	**D1**	**D2**	**D3**	**D5**	**D7**	**D15**
ChPo20	22.9 ^{abc}	18.2 ^{abc}	13.5 ^{bcd}	10.0 ^{bc}	9.4 ^{bcd}	12.0 ^{b}	27.3 ^{b}	28.4 ^{ab}	23.5 ^{bc}	21.7 ^{ab}	17.7 ^{b}	12.9 ^{bcd}
ChPo40	18.9 ^{bcd}	17.3 ^{abc}	10.2 ^{bcd}	7.4 ^{bc}	7.3 ^{bcd}	5.8 ^{def}	22.4 ^{bcd}	20.4 ^{bcd}	16.7 ^{bcd}	13.6 ^{bcd}	12.8 ^{bcd}	11.0 ^{bcd}
ChPo60	17.1 ^{cd}	11.3 ^{bc}	9.2 ^{bcd}	5.8 ^{c}	4.8 ^{bcd}	5.7 ^{def}	20.2 ^{bcd}	16.7 ^{cde}	12.1 ^{def}	10.1 ^{def}	6.6 ^{d}	5.1 ^{efg}
CoDu50	27.5 ^{ab}	21.1 ^{ab}	16.2 ^{b}	12.9 ^{b}	10.8 ^{bc}	10.4 ^{bc}	26.5 ^{bc}	23.9 ^{bcd}	20.7 ^{bcd}	21.3 ^{bc}	18.8 ^{b}	18.0 ^{b}
CoDu100	21.6 ^{abc}	16.9 ^{abc}	13.4 ^{bcd}	9.7 ^{bc}	7.7 ^{bcd}	7.3 ^{cde}	28.8 ^{b}	28.5 ^{ab}	24.5 ^{b}	18.9 ^{bcd}	15.6 ^{bc}	14.3 ^{bc}
CoDu150	19.9 ^{bcd}	12.6 ^{bc}	11.1 ^{bcd}	10.0 ^{bc}	5.3 ^{bcd}	3.8 ^{efg}	27.9 ^{b}	22.6 ^{bcd}	19.6 ^{bcd}	15.6 ^{bcd}	11.3 ^{bcd}	9.4 ^{cde}
BuMi50	25.0 ^{abc}	16.8 ^{abc}	14.6 ^{bcd}	10.7 ^{bc}	11.8 ^{b}	9.9 ^{bcd}	29.9 ^{ab}	26.9 ^{abc}	23.1 ^{bc}	23.7 ^{ab}	18.5 ^{b}	15.3 ^{bc}
BuMi100	17.7 ^{bcd}	13.7 ^{bc}	13.2 ^{bcd}	8.9 ^{bc}	9.6 ^{bcd}	7.0 ^{cde}	26.8 ^{bc}	24.1 ^{bcd}	21.9 ^{bc}	14.2 ^{bcd}	12.7 ^{bcd}	10.2 ^{bcd}
BuMi150	21.5 ^{abc}	12.1 ^{bc}	11.8 ^{bcd}	8.0 ^{bc}	7.7 ^{bcd}	4.2 ^{efg}	23.3 ^{bcd}	19.3 ^{bcd}	16.3 ^{bcd}	14.1 ^{bcd}	12.7 ^{bcd}	11.9 ^{bcd}
CoUr25	20.6 ^{abc}	10.1 ^{bc}	9.4 ^{bcd}	6.4 ^{c}	7.3 ^{bcd}	3.3 ^{efg}	22.8 ^{bcd}	18.9 ^{bcd}	14.8 ^{cde}	10.8 ^{cde}	12.6 ^{bcd}	13.3 ^{bcd}
CoUr50	17.9 ^{bcd}	9.4 ^{c}	8.0 ^{bcd}	6.1 ^{c}	4.8 ^{bcd}	4.0 ^{efg}	20.5 ^{bcd}	22.6 ^{bcd}	15.2 ^{cde}	14.4 ^{bcd}	10.3 ^{bcd}	10.4 ^{bcd}
CoUr75	15.6 ^{cd}	8.4 ^{c}	6.5 ^{cd}	4.9 ^{c}	3.3 ^{cd}	2.7 ^{g}	17.8 ^{bcd}	13.7 ^{de}	8.9 ^{efg}	6.7 ^{h}	4.9 ^{d}	5.6 ^{def}
NeLe20	16.9 ^{cd}	12.2 ^{bc}	9.1 ^{bcd}	7.0 ^{c}	4.2 ^{cd}	7.7 ^{bcd}	19.0 ^{bcd}	20.7 ^{bcd}	16.6 ^{bcd}	16.7 ^{bcd}	12.0 ^{bcd}	10.5 ^{bcd}
NeLe40	15.3 ^{cd}	13.2 ^{bc}	7.1 ^{cd}	5.7 ^{c}	3.2 ^{d}	3.6 ^{efg}	16.6 ^{bcd}	13.0 ^{de}	9.9 ^{efg}	8.5 ^{def}	6.5 ^{d}	5.1 ^{efg}
NeLe60	13.7 ^{d}	9.9 ^{bc}	5.4 ^{d}	5.2 ^{c}	2.4 ^{d}	2.8 ^{fg}	13.5 ^{cd}	10.7 ^{e}	7.1 ^{fg}	4.9 ^{fg}	4.3 ^{d}	3.4 ^{fg}
CheIn6	16.2 ^{cd}	16.1 ^{bc}	10.3 ^{bcd}	7.4 ^{bc}	7.8 ^{bcd}	5.2 ^{efg}	11.6 ^{d}	10.2 ^{e}	6.6 ^{g}	4.5 ^{g}	7.5 ^{cd}	2.9 ^{g}
Control	30.1 ^{a}	27.6 ^{a}	27.9 ^{a}	26.2 ^{a}	26.7 ^{a}	21.8 ^{a}	43.2 ^{a}	37.4 ^{a}	39.7 ^{a}	32. ^{a}	36.4 ^{a}	36.4 ^{a}
C.D.	5.9	6.2	4.8	3.2	4.1	2.5	7.3	6.2	5.1	5.9	4.6	4.2
SEM±	2.0	2.1	1.7	1.1	1.4	0.9	2.5	2.1	1.7	2.1	1.6	1.5
F-value	5.7	5.3	9.6	14.9	15.4	31.1	8.5	11.1	21.5	13.1	22.1	25.6
p-value (5%)	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

Means in the same column with the same common letter are not significantly different from each other ($p \leq 0.05$). D0 = day before the spray, D1–D15 = days after the spray, C.D. = critical difference, and SEM = standard error of the mean.

Table 4. Effect of the treatments against the whitefly after the 3rd foliar spray.

Treatments	Average Adult Whiteflies/Leaf							Average Adult Whiteflies/Leaf						
	2022							2023						
	D1	**D2**	**D3**	**D5**	**D7**	**D15**	**Yield (kg/ha)**	**D1**	**D2**	**D3**	**D5**	**D7**	**D15**	**Yield (kg/ha)**
ChPo20	8.4 ^{bc}	8.5 ^{bcd}	5.5 ^{bcd}	6.9 ^{bc}	5.8 ^{bc}	8.8 ^{bc}	820.8 ^{e}	10.6 ^{bcd}	9.7 ^{b}	11.6 ^{bc}	9.9 ^{bc}	9.2 ^{bc}	8.9 ^{bc}	803.6 ^{f}
ChPo40	5.5 ^{bc}	5.9 ^{bcd}	3.2 ^{cd}	3.5 ^{bcd}	2.3 ^{cd}	5.5 ^{bcd}	805.3 ^{e}	7.5 ^{bcd}	6.2 ^{b}	9.3 ^{bc}	9.3 ^{bc}	8.3 ^{bc}	7.2 ^{bc}	812.9 ^{fg}
ChPo60	4.7 ^{bc}	3.6 ^{cde}	2.2 ^{cd}	2.2 ^{bcd}	1.3 ^{d}	2.9 ^{de}	898.4 ^{cd}	4.2 ^{de}	3.6 ^{b}	2.7 ^{c}	3.2 ^{e}	1.3 ^{c}	2.1 ^{f}	908.4 ^{cd}
CoDu50	10.9 ^{b}	9.0 ^{bcd}	9.7 ^{b}	7.5 ^{b}	4.8 ^{bcd}	10.6 ^{b}	747.3 ^{f}	15.3 ^{bc}	13.4 ^{b}	10.9 ^{bc}	9.3 ^{bc}	12.1 ^{b}	10.8 ^{bc}	923.8 ^{c}
CoDu100	7.9 ^{bc}	7.7 ^{bcd}	4.1 ^{bcd}	4.4 ^{bcd}	3.3 ^{bcd}	8.4 ^{bcd}	751.9 ^{f}	12.3 ^{bcd}	11.1 ^{bc}	11.9 ^{bc}	11.9 ^{bc}	10.4 ^{b}	11.4 ^{b}	769.7 ^{g}
CoDu150	5.8 ^{bc}	5.7 ^{bcd}	2.4 ^{cd}	2.5 ^{bcd}	1.5 ^{d}	5.2 ^{bcd}	919.9 ^{cd}	9.6 ^{bcd}	8.1 ^{b}	7.8 ^{bc}	7.8 ^{cde}	6.8 ^{bc}	7.0 ^{bc}	877.3 ^{e}
BuMi50	8.8 ^{bc}	9.4 ^{b}	7.5 ^{bc}	6.6 ^{bcd}	4.8 ^{bcd}	8.4 ^{bcd}	879.0 ^{d}	16.3 ^{b}	12.6 ^{b}	14.3 ^{b}	14.0 ^{b}	12.5 ^{b}	9.3 ^{bcd}	892.2 ^{de}
BuMi100	6.0 ^{bc}	4.2 ^{bcd}	2.9 ^{cd}	3.2 ^{bcd}	4.0 ^{bcd}	3.5 ^{cde}	820.2 ^{e}	10.3 ^{bcd}	8.2 ^{b}	11.3 ^{bc}	10.5 ^{bcd}	6.2 ^{bc}	3.9 ^{cde}	896.1 ^{de}
BuMi150	3.6 ^{bc}	3.3 ^{de}	2.6 ^{cd}	2.9 ^{bcd}	10.9 ^{b}	2.3 ^{e}	912.6 ^{cd}	8.8 ^{bcd}	11.7 ^{b}	5.8 ^{bc}	5.8 ^{cde}	3.6 ^{bc}	3.1 ^{ef}	992.4 ^{b}
CoUr25	3.7 ^{bc}	3.2 ^{de}	3.6 ^{bcd}	2.9 ^{bcd}	2.2 ^{cd}	6.4 ^{bcd}	919.0 ^{cd}	10.4 ^{bcd}	8.1 ^{b}	7.3 ^{bc}	7.3 ^{cde}	6.5 ^{bc}	5.8 ^{bcd}	880.4 ^{de}
CoUr50	3.1 ^{c}	2.7 ^{e}	2.1 ^{cd}	1.7 ^{bcd}	1.4 ^{d}	2.2 ^{e}	905.7 ^{cd}	6.9 ^{cde}	4.7 ^{b}	4.1 ^{bc}	4.2 ^{de}	2.4 ^{bc}	3.6 ^{efg}	1001.2 ^{b}
CoUr75	2.7 ^{c}	3.3 ^{de}	2.2 ^{cd}	1.9 ^{bcd}	1.1 ^{d}	2.1 ^{e}	1082.4 ^{a}	3.5 ^{de}	2.5 ^{b}	1.8 ^{c}	1.8 ^{e}	1.1 ^{c}	1.3 ^{f}	1061.6 ^{a}
NeLe20	5.9 ^{bc}	5.9 ^{bcd}	3.7 ^{bcd}	3.8 ^{bcd}	3.2 ^{bcd}	3.4 ^{cde}	889.2 ^{d}	10.7 ^{bcd}	8.7 ^{b}	7.4 ^{bc}	6.8 ^{cde}	4.6 ^{bc}	4.6 ^{bcd}	910.4 ^{cd}
NeLe40	4.0 ^{bc}	3.0 ^{e}	2.9 ^{cd}	1.4 ^{cd}	1.5 ^{d}	2.1 ^{e}	891.8 ^{d}	5.0 ^{de}	3.3 ^{b}	1.9 ^{c}	1.9 ^{e}	2.8 ^{bc}	3.9 ^{cde}	1013.3 ^{b}
NeLe60	3.2 ^{cd}	2.7 ^{e}	1.2 ^{d}	2.0 ^{bcd}	0.7 ^{d}	1.6 ^{e}	999.2 ^{b}	2.7 ^{e}	2.7 ^{b}	2.0 ^{c}	2.0 ^{e}	1.6 ^{c}	1.3 ^{f}	1051.0 ^{a}
CheIn6	5.1 ^{bc}	4.6 ^{bcd}	5.9 ^{bcd}	3.5 ^{bcd}	3.9 ^{bcd}	1.8 ^{e}	988.0 ^{bc}	3.9 ^{de}	2.4 ^{b}	2.5 ^{c}	2.4 ^{e}	1.5 ^{c}	0.9 ^{f}	1008.6 ^{b}
Control	24.5 ^{a}	28.0 a	28.0 ^{a}	20.8 ^{a}	21.1 ^{a}	26.2 ^{a}	570.9 ^{g}	34.6 ^{a}	32.5 ^{a}	30.8 ^{a}	32.6 ^{a}	31.5 ^{a}	33.4 ^{a}	654.8 ^{b}
C.D.	4.0	3.0	3.5	4.1	5.6	3.0	13.4	5.1	6.2	5.7	5.9	5.4	3.9	11.7
SEM±	1.4	1.0	1.2	1.4	1.9	1.0	11.1	1.8	2.1	2.0	2.0	1.9	1.4	7.4
F-value	13.9	34.3	27.5	27.8	39.9	33.9	170	18.0	11.1	12.9	13.8	14.6	32.1	146.2
p-value (5%)	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

Means in the same column with the same common letter are not significantly different from each other ($p \leq 0.05$). D0 = day before the spray, D1–D15 = days after the spray, C.D. = critical difference, and SEM = standard error of the mean.

The treatments lowered the whitefly counts further as they differed significantly ($P \leq 0.05$) after the second spray, NeLe60 (60 mL/L) having the highest effect in most of the data-taking periods. It was found that the least whitefly numbers (13.7, 2.4, and 2.8 adults/leaf) were statistically significant from the remaining treatments on the 1st $(F(DF) = (5.7(16),\ P < 0.001))$, 7th $(F(DF) = (15.4(16),\ P < 0.001))$, and 15th $(F(DF) = (31.1(16)), P < 0.001)$ days after the spray in the 2022 experiment. It was followed by CoUr75 (75 mL/L) with 15.6, 3.3, and 2.7 on days 1, 7, and 15 after the second spray in the 2022 experiment, while the least effect was found using CoDu50 (50 mL/L) and ChPo20 (20 mL/L) with 27.5 and 12.0 adults/leaf on days 1 and 15, respectively. CoUr75 (75 mL/L) was found to be more effective, differing significantly from the rest of the treatments on the 2nd $(F(DF) = (5.3(16),\ P < 0.0001))$ and 5th $(F(DF) = (14.9(16),\ P < 0.0001))$ days after the spray with 8.4 and 4.9 adults/leaf on the respective days. The control plot differed significantly from all the treated plots in all the data recording periods with up to 30.1 and 21.8 adults/leaf on the 1 and 15 days, respectively, in the 2022 trial. The results in 2023 were similar to those of the 2022 experiment, demonstrating NeLe60 (60 mL/L) to have a more significant effect $(P < 0.0001)$ than most of the treatments, recording 13.5, 10.7, 7.1, 4.9, 4.3, and 3.4 adults/leaf on days 1, 2, 3, 5, 7, and 15, respectively. BuMi50 and CoDu100 (50 and 100 mL/L) had similar effects after the second spray, being less effective in the 2023 experiment, recording 29.9 and 28.8 adults/leaf on day 1. BuMi50 and CoDu50 (50 mL/L) also recorded 13.8 and 18.0 adults/leaf on the 15th day, and both were less effective than ChPo20 (20 mL/L) with 27.3 and 12.9 adult/leaf on the 1st and 15th days, respectively, after the second spray (Table 3).

CoUr75 (75 mL/L) recorded the least whitefly count, being highly significant on the 1st $(F(DF) = (13.9(16),\ (P < 0.0001))$ day after the third spray with 2.7 adults/leaf, followed by CoUr50 (50 mL/L) with 3.1 adults/leaf, while CoDu50 (50 mL/L) had the highest (10.9 adults/leaf) on the 1st day after the spray. NeLe60 (60 mL/L) was more effective in the remaining data record periods, with the least whitefly number (0.7 adults/leaf) recorded on the 7th day, having a significant statistical effect $(F(DF) = (39.9(16),\ P < 0.0001))$ compared to the rest of the treatments in 2022. CoDu50 (50 mL/L) was found to have the least effect with 10.9, 9.7, 14.5, and 10.6 adults/leaf on the 1st, 3rd, 7th, and 15th days after the spray during the same year experiment. Similar results were obtained in the 2023 experiment, with CoUr75 (75 mL/L) and NeLe60 (60 mL/L) having the highest effects while BuMi50 (50 mL/L) and CoDu50 (50 mL/L) had the least effects as the treatments varied significantly $(P < 0.0001)$ after the third spray. The highest densities (16.3 and 11.4 adults/leaf) were found with BuMi50 (50 mL/L) and CoDu50 (50 mL/L), while the least (2.7 and 1.3 adults/leaf) were recorded with NeLe60 (60 mL/L) on the 1st and 15th days, respectively, after the third spray (Table 4). The treatments were crucial in increasing the yield of the crop during the experiments. In 2022, CoUr75 (75 mL/L) recorded a higher yield of 1082.4 kg/ha, having a significant effect $(F(DF) = (170(16),\ P < 0.0001))$ compared to the rest of the treatments. It was followed by NeLe60 (60 mL/L) with 999.2 kg/ha, and CoDu50 (50 mL/L) recorded a lower yield (747.3 kg ha^{-1}) but higher than the control (570.9 kg/ha). In 2023, CoUr75 (75 mL/L) and NeLe60 (60 mL/L) exhibited similar effects, having the highest yields of 1061.6 and 1051.0 kg/ha, respectively, differing significantly from the remaining treatments $(F(DF) = (146.2(16),\ P < 0.0001))$, with CoDu50 (50 mL/L) having the lowest yield (769.7 kg/ha) just after the control (654.8 kg/ha) (Table 4).

Efficacy (%) of the Treatments against Whiteflies

The treatments examined substantially reduced the adult whitefly population over various data-taking periods during the two respective seasons, and the overall average reduction (%) for all three sprays is presented in Figures 1–3. The results showed that NeLe60 (60 mL/L) was the most effective on the 15th day after the initial spray with a 58.1% reduction, similar to CoUr75 (75 mL/L) and ChPo60 (60 mL/L) with 56.7% reduction each, as the treatments recorded significant statistical effects $(F(DF) = (98.0(15),\ P < 0.0001))$ in 2022. In 2023, neem leaf extract CoDu50 (50 mL/L) also had the highest reduction (58.2%), being significantly different $(F(DF) = (32.6(15),\ P < 0.0001))$ from the rest of the treatments

15 days after the first spray. CoDu50 (50 mL/L) was found to have the least effect (7.7 and 19.6%) 15 days after the foliar spray during the 2022 and 2023 trials respectively (Figure 1).

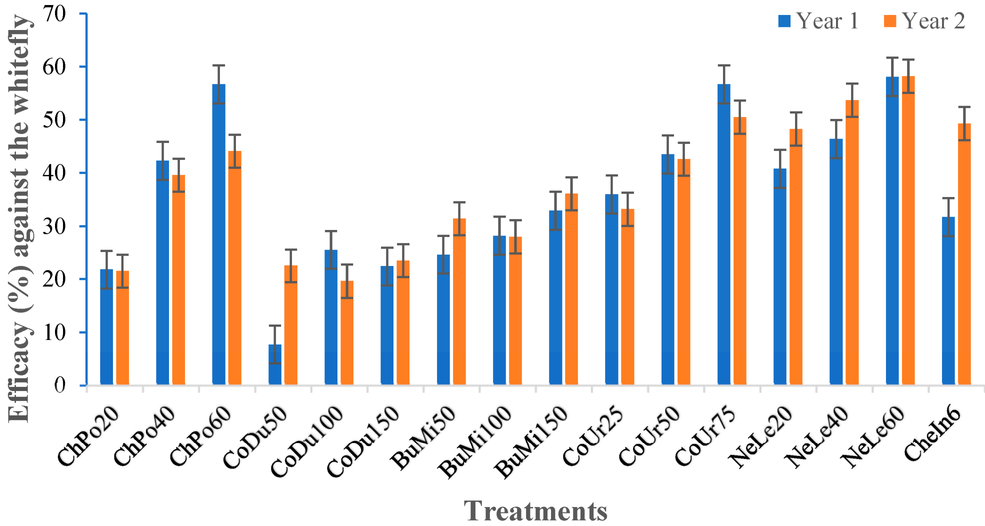

Figure 1. Efficacy (%) against the adult whiteflies 15 days after the 1st spray of the treatments.

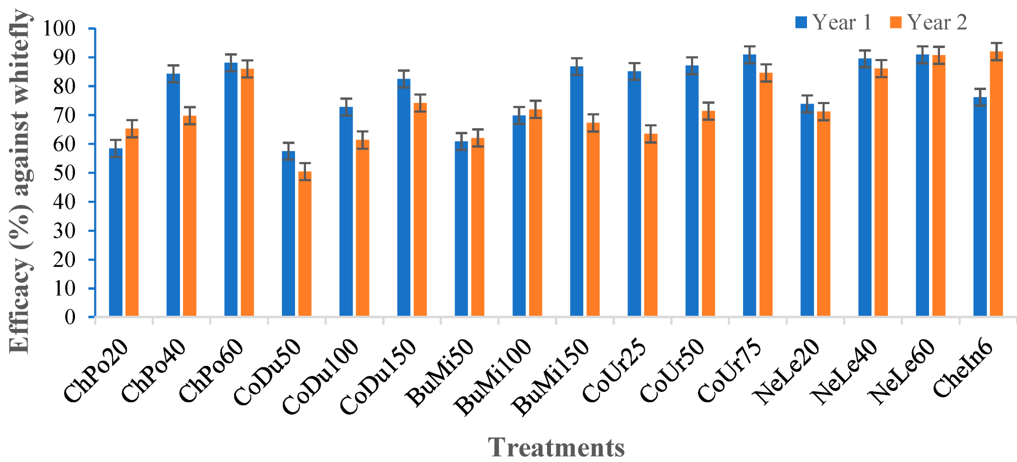

Figure 2. Efficacy (%) against adult whiteflies 30 days after the 2nd foliar sprays of the treatments.

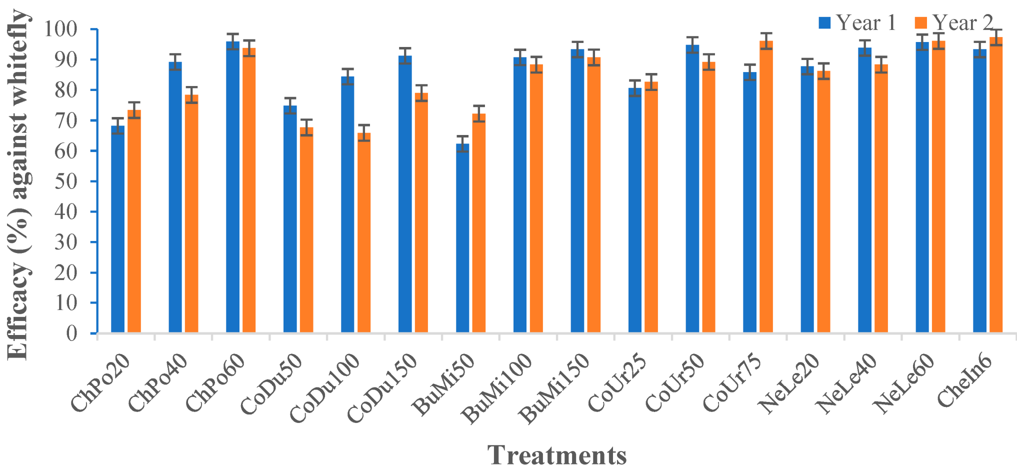

Figure 3. Efficacy (%) against the adult whiteflies 45 days after the 3rd spray of the treatments.

The treatments also differed significantly in 2022 $(F(DF) = (33.7(15),\ P < 0.0001))$ and 2023 $(F(DF) = (21.6(15),\ P < 0.0001))$, as they reduced the whitefly density further after the second spray. NeLe60 (60 mL/L) was highly effective, causing 91.0 and 90.7% reduction in the adult population in the 2022 and 2023 trials, respectively, 30 days after the subsequent spray. It was followed by CoUr75(75 mL/L) with 90.9 and 84.6%, while CoDu50 (50 mL/L) remained the least with 57.5 and 50.5% reduction 30 days after the second spray in the 2022 and 2023 experiments (Figure 2).

The treatments reduced the adult population further after the third spray, with NeLe60 (60 mL/L) also being the most effective (96.0 and 96.1%), as it differed significantly from the remaining treatments in 2022 $(F(DF) = (19.4(15),\ P < 0.0001))$ and in 2023 $(F(DF) = (22.4(15),\ P < 0.0001))$, respectively, while BuMi50 and CoDu50 (50 mL/L) were the least effective (62.3 and 65.9%) 45 days after the third spray during the 2022 and 2023 experiments (Figure 3).

4. Discussion

The current research examined the potential of some traditional treatments against the whitefly, a destructive sap-sucking insect pest ravaging various crops, using eggplant as the experimental species. The treatments deployed included chili pods, cow dung, cow urine, buttermilk, neem leaf extract, and a synthetic insecticide. From the results obtained, NeLe60 (60 mL/L) had the greatest effect against the whitefly among all the biopesticides evaluated, causing up to 96.1% reduction in the whitefly population at the end of the experiment. Previous studies [44] have demonstrated the potency of neem extracts in insect control and reported up to 94.1% reduction in whitefly populations using 0.05 g/L a week after the treatment. This was higher than the effect recorded in the current study (58.1%) 15 days after the first spray but lower than what was recorded (96.1%) 45 days after the third spray. The higher effect at 7 days may be due to the application of the main bioactive compound (azadirachtin), which is known to be more effective than the whole extracts, while the repeated sprays might have caused more reduction observed at 45 days. The results reported by Lynn et al. [41] using neem-based products aligned with the current report, causing a reduction in adult colonization, egg hatching, and oviposition by 78.2, 71.2, and 47.0%, respectively. A lower adult whitefly number (0.707 adult/leaf) was reported by [40] compared to the control (2.691 adult/leaf) using neem leaf extract in okra plant, which is comparable to the current results two weeks after the last spray, indicating the presence of extractible intoxicants in the neem leaf product. Castillo-Sánchez et al. [45] examined the effect of neem seed extracts (NEEM-1 and NEEM-2) at 10% *w/v*, which caused up to 100% whitefly mortality, 5 h after the treatment. This was more effective than the current (58.1%) reduction 15 days after the first foliar spray. The higher effect may be due to the application of concentrated bioactive compounds, the experimental setting, and the crop involved. Similarly, Ali et al. [46] proved that neem extract was potent against whiteflies, reporting up to 82.60% reduction in the whitefly population in brinjal at 50% *w/v* two weeks after application. This was higher than our findings, with 58.1% reduction at 10% *w/v* two weeks after the first spray, and the higher effect could be due to the higher concentration applied in their studies. Asare-Bediako et al. [40] also examined the effect of neem seed extract (10% *w/v*) and Flanicamid, which led to a 79% and 92% reduction in the whitefly count, demonstrating the chemical insecticide to be more effective than neem extract [44]. This aligns with the present study, demonstrating malathion as being more effective than neem leaf extract. In another study, up to 80% reduction in whitefly density was reported when using neem leaf extract at (5% *w/v*) on cotton [47]. This was lower than the 96.1% recorded in this study, which was probably due to variations in the concentrations used. Similarly, neem leaf and seed extracts led to 1.35 and 1.10 adults/leaf 10 weeks after sowing [48] as compared to the control (3.56 adults/leaf) in the cowpea plant. The combined effect of neemactin 0.15 EC and floral extracts of spilanthes (at 1.5 and 40 mL/L) led to 62.39% suppression in whitefly numbers, lower than the results in the current findings, which might be due to the higher dosage (60 mL/L) and spray periods (45 days) in the current study. Neem leaf extract in cow urine was also shown to be substantial against not only whiteflies (95.2%) but also leafhoppers (94.6%) and blister beetles (94.6%) in okra plants [37], similar to the effects recorded against the whiteflies in the present study. Several reports [47–49] revealed that neem extracts were potent against several insect pests, including pod borers (*Maruca vitrata* Geyer), pod-sucking bug complex (*Clavigralla tomentosicollis* Stal), and other insect pests. These agreed with the reports of [49–51], demonstrating that neem extracts possess toxic organic components that are effective in minimizing the density of diverse insect pests of agricultural importance in different crop plants. The efficacy of neem extract as an insecticide is due to its diverse compound composition, with azadirachtin serving as the primary active element. These compounds, including methyl isoheptadecanoate, butyl palmitate, eicosane, 7-hexyl, oxalic acid, 2-ethylhexyltetradecylest, nonadecane, 2-Methyl-5-ethylfuran, heptacosane, and octacosane, collectively disrupt insect feeding and growth, interfering with molting, pupation, and reproduction, ultimately reducing pest populations. The bitter taste and odor of neem deter pests from feeding, and it also affects insect larvae, impeding their development and lowering their reproductive capacity, resulting in reduced egg-laying and, subsequently, pest population reduction [52].

The second most effective treatment was cow urine, and its potential in insect control has been demonstrated by previous reports. Mandal et al. [53] in their experiment on the application of traditional methods for the management of sap-sucking insects on brinjal reported that cow urine at a ratio of 1:10 urine–water caused a reduction in the whitefly population by 3.92 adult/leaf (31.0%) and 3.47/leaf (38.5%) in two consecutive trial seasons. This was less than our (91.1 and 94.0%) reduction at 50% (75 mL/L) 45 days after the third spray. The higher effect may be due to variations in the concentration, duration of the experiment, and the number of sprays. Cow urine has also been reported to be used for various agricultural practices, as it has been used as an insecticide against sap-sucking insects like whiteflies and aphids [54]. Patel et al. [55] reported that cow urine applied at 20% fortified with neem leaf extract led to a reduction in whiteflies to 2.22 adults/leaf with the highest yield (287.89 q/ha). This result was higher than the present finding (6.30 adults/leaf) at 50%, and this may be due to fortification of the urine with neem extract. However, the results of [42] proved less effective using a similar concentration, with up to 13.26 adults/leaf. This may be due to variations in the crop deployed and climatic conditions of the experimental sites. Moreover, the use of cow urine at 10% *w/v* along with plant extracts has led to a higher efficacy of 95.2% reduction [37]. The higher potential could be related to the deployment of the treatments in an integrated setting along with plant extracts. The application of 10% cow urine along with neem and *Jatropha curcas* extracts led to 82 to 98% mortality of sucking pests on a 50-day-old potato crop two weeks after the spray [33]. This was higher than the current findings, with a 32.9 to 56.7% reduction two weeks after the spray, but similar to the results obtained 45 days after the third spray (94.8 to 96.1%). The variations might be attributed to the incorporation of plant extract in cow urine, while the higher effect at 45 days indicates the effect of repeated long-term sprays. This is because different combinations of cow urine, various plant parts, and commercially available neem-based products have demonstrated a significant synergistic effect against whiteflies, and this synergy enhances the toxicity of the product, resulting in a higher rate of pest mortality [56,57]. A similar report also demonstrated that cow urine in garlic paste caused 75.96% reduction 10 days after the spray [58]. Several other reports have described the effectiveness of cow urine in insect pest management on different crop plants [25,59–61]. Besides crop protection against insect pests, cow urine (50%) was also shown to increase the chlorophyll and protein content in Bhindi crops, as it enhances the NPK uptake through the foliar spray and, thus, the crop yield [57,62]. This complied with the current reports demonstrating the highest yield recorded in the cow urine-treated plots. The effectiveness of cow urine in whitefly control can be attributed to multiple factors. These include the presence of ammonia, which serves as an insect repellent and disrupts insect behavior. Additionally, the nitrogen compounds in cow urine deter insects, and its alkaline nature with a high pH is detrimental to certain pests and their larvae. The smell and taste of cow urine act as a natural repellent, discouraging insects from landing on or feeding on plants. These properties collectively make cow urine an effective and natural method for whitefly control [63,64].

Chili pod extract was similarly effective against the whitefly, causing a 68.2 to 95.9% reduction in whitefly density 45 days after the third spray. Previous studies demonstrated that the whitefly population was reduced to 1.0 adult/leaf 63 days after spraying [40]. This complied with the current findings reporting an average adult population (1.10 and 2.1 adult/leaf) 45 days after repeated sprays, indicating the effect of bioactive compounds like capsaicin and its pungent odor, which are known to serve as a barrier that makes it difficult for whiteflies to settle and feed on plants [65,66]. This complied with results of Fening et al. [67], in which pepper extract was shown to be effective in controlling insect pests of cabbage and French beans while conserving their natural enemies. Legaspi and Simmons [68] evaluated the anti-oviposition effects of hot pepper wax, and their results showed that it was substantial in reducing whitefly numbers (32.9 adult/leaf) as compared to the control (42.9 adult/leaf) 2 days after application. This was also similar to our results, with 30.2 adults/leaf compared to the control (51.5 adults/leaf) two days after the spray. Sumaili et al. [69] reported a 73.3% (chili extract only) and 77.6% (chili extract + *Erectomocerus eremicus*) reduction in the whitefly population on tomato crops 28 days after the spray. This was lower than our results (86.0 to 88.1% reduction), probably due to variations in dosage, the crop involved, and environmental conditions of the experimental sites. They showed that the use of chili extracts and *E. eremicus* were effective against whitefly infestations and improved the growth and yield of greenhouse tomato plants, similar to the yield effect in this study. This complied with the work of Singh et al. [37], in which the use of plant extracts involving chili caused more than a 95% reduction in whitefly density with a higher yield in okra plants. Rosulu et al. [70] demonstrated that chili extracts at 200 and 250 l/ha significantly reduced the population of insect pests other than whiteflies, including thrips, legume pod borers in various life stages, and pod-sucking bug adults. The treatment also resulted in decreased pod damage and increased grain yields when compared to an untreated control group. However, a 250 L/ha extract caused higher levels of a phytotoxic effect compared to a 200 L/ha extract. They suggested that chili pepper extracts can be effective in managing cowpea insect pests and improving crop yields. The effectiveness of chili pod extract as an insecticide is attributed to its diverse compound composition, including capsaicin, pentadecanoic acid, dihydrocapsaicin, homodihydrocapsaicin, homodihydrocapsaicin II, β-amyrin α-amyrin, and quercetin. They disrupt insects' nervous systems, potentially leading to paralysis or death. The extract's pungent odor and taste act as a natural repellent, deterring insect feeding. When sprayed on plant leaves, it creates a physical barrier that hinders insect settlement, feeding, and egg-laying, reducing infestations [65,66].

Buttermilk was found to be more effective against whiteflies than the untreated control plots in the present study, causing a high reduction 45 days after repeated sprays. A previous study reported up to 60% whitefly reduction in Bhindi crops in India [24]. This was higher than the results in our study (32.87%) 15 days after the first spray but lower than the values recorded 45 days after the third spray (90.7 and 93.3%) in the two respective seasons. This indicates the efficacy of repeated applications over time. Tagger and Singh [71] evaluated the effects of different insecticides against whiteflies in black gram, with thiamethoxam at 100 g/ha being the most effective, resulting in a 71.17% reduction in the whitefly population, while nonconventional treatments, such as buttermilk, lisapol detergent, and detergent soap, showed lower reductions (26.50–27.35%) in whitefly populations [72]. They concluded that these nonconventional treatments (buttermilk and detergent soap), while not as potent as Actara, still contributed to satisfactory grain yields. Kumari et al. [72] also examined the effect of organic insecticides with fermented buttermilk at 40% *v/v*, causing 61.11% whitefly mortality 3 days after the spray. This was higher than our results (36.1%) 15 days after the first spray at 50% *v/v*, and this could be due to variations in the whitefly life stages treated (nymphs and adults) and the experimental conditions (laboratory and field). Sood and Ghongade [73] evaluated the efficacy of some natural products, in which they reported fermented curd water caused a 22.68% reduction in whitefly density at 10% 2 days after spraying under control conditions [73]. This was lower than that of Kumari et al. [72] and of the current report, which was probably due to the lower concentration applied in their experiment, as the effectiveness of insecticides is concentration-dependent. While deploying safer approaches for managing pest populations on chili plants, Chakraborti et al. [74] reported that the spraying of plant extracts (giant milkweed, neem, and lemon) and cow-based products (cow urine and buttermilk) were found potent in suppressing the growth and development of thrips, yellow mites, and whiteflies and also substantial in reducing the incidence of leaf curl disease. Jain et al. [75] demonstrated that butter was effective against whiteflies and jassids, causing 64.24 and 66.12% reduction, respectively, in okra 14 days after the second spray. This was lower than the results in the current findings (67.3 to 86.8%) 15 days after the second spray. The highest effects could be attributed to higher doses applied in the present experiment. Buttermilk's effectiveness as an insecticide can be attributed to its rich composition, including casein protein, fat, galactose, lactose, glucose, uric acid, acetic acid, α-ketoglutaric acid, and orotic acid. These components offer essential nutrients to plants, bolstering their health and reducing their vulnerability to insect attacks. Buttermilk's slight acidity creates an unfavorable environment for some pests and their larvae. Additionally, it may possess antifungal properties, guarding against fungal diseases that can attract insects. The distinct smell and taste of buttermilk serve as natural repellents, discouraging insects from landing on treated plants [53,76].

Cow dung was found the least effective among the treatments evaluated in the current study. Mallick et al. [77] examined some biorational strategies against jassids and whitefly populations, with 3.0/three leaves in cow dung-treated plots, similar to the untreated control with 3.25/three leaves as per the whitefly population. They further concluded that, despite significant variations in population density of the target insects, none of the treatments examined was potent in lowering the density of the sucking pests. This was similar to our results, with cow dung having a higher whitefly number in most of the data recoding times throughout the trials. However, it has been reported to lower pest densities, increase yields, and reduce the cost of production with less effect on nontarget arthropods [25]. This complied with our results 45 days after the third spray, with cow dung causing 68.2% whitefly reduction and a higher yield at harvest than the control plot. This could be due to the higher concentration (50%) and triple sprays used during the experiments. A similar report by Mandal et al. [54] demonstrated that cow dung slurry reduced the whitefly density to 4.0 adults/leaf as compared to 5.68 adults/leaf in the untreated plots. This represented a 28.9% reduction, which indicated the lower efficacy of cow dung against the sap-sucking pests, similar to the current results. The potential of cow dung in whitefly control could be due to the presence of different chemicals, including chloride, sulfate, nitrite and phosphorus pentoxide, magnesium, copper, cobalt, sodium, manganese, nitrogen, sulfur, and potassium, as being rich in nutrients like nitrogen, phosphorus, and potassium can improve plant health and growth, potentially reducing their attractiveness to pests [78].

5. Conclusions

In conclusion, the results of the present study demonstrated the high potential of traditional treatments in the control of whiteflies (*Bemisia tabaci* Genn.) on eggplants in Northwestern Nigeria. The effectiveness of the treatments tended to rise with an increase in the number of sprays and their dosages, as the treatments yielded better results at higher doses. From the results recorded, it was evident that NeLe60 (60 mL/L) and CoUr75 (75 mL/L) proved to be highly effective among all the treatments evaluated, as they led to the least number of whiteflies and the highest efficacy (%) during the trials. The capacity of these treatments to reduce the adult population by up to 96.1% suggests that they can be deployed to efficiently manage the effects of the notorious sap-sucking insect pest (*Bemisia tabaci* Genn.) for sustainable eggplant cultivation in Northern Nigeria.

Author Contributions: Conceptualization was done by B.K. and M.A., B.K., D.Y. prepared the treatments, conducted the experiments, analyzed the data, and drafted the initial manuscript. B.K. and M.S. revised the manuscript. All authors have read and agreed to the published version of the manuscript.

Funding: This research was financially supported by Tertiary Education Trust Fund (TETFUND) Nigeria with grant number: TEFF/ES/UNIV/ALIERO/TSAS/2020.

Data Availability Statement: Data is available with the corresponding author on request.

Acknowledgments: We are thankful to KSUSTA and Lovely Professional University (LPU), Punjab, India, for the infrastructural support. The efforts of Adamu Muhammad and Mustapha Sale Na'Allah, Crop Science Department, KSUSTA in providing technical assistance is highly appreciated.

Conflicts of Interest: The authors have no financial or any other conflict of interest related to this article to declare.

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