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Efficiency of Botanical and Chemical Pesticides on the Control of Field Insect Pests under Cowpea Production

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Abstract

The pulse cowpea [*Vigna unguiculata* (L.) Walp] holds a significant agricultural position in Uganda, ranking fourth among legume crops, following common beans, groundnuts, and soybeans. Known for its versatility, cowpeas are consumable at various developmental stages, from early seedling to maturity. However, the crop faces persistent pest challenges at each stage, leading to substantial yield losses. In Uganda, chemical insecticides are the primary pest control means, but their increased and excessive use raises environmental, health, and economic concerns. This has prompted a quest for alternative and sustainable solutions, prompting an exploration of botanical insecticides. This study, conducted at Makerere University Agricultural Research Institute (MUARIK), aimed to evaluate the effectiveness of three selected botanical insecticides versus four established chemical insecticides for managing cowpea insect pests under field conditions. The treatments included: Carbofuran, Cypermethrin 10% EC, Dimethoate, Pestwin, Pyrethrum ewc+, Pyrethrum 5ew, Profenofos 40% + Cypermethrin 4% EC mix, and Untreated, arranged in a randomized complete block design with three replications. The significant pests studied were aphids, thrips, pod-sucking bugs, and legume pod borer. Results indicated substantial impacts of the treatments on pest infestation, with Profenofos 40% + Cypermethrin 4% EC being the most effective against most pests. The plant parameter, plant height, was significantly affected by treatments in 2016B, while the number of pods was impacted in 2017A. Pestwin, a botanical insecticide blend (containing *Azadirachtin indica*, *Pongamia pinnata*, and *Ricinus communis* extracts) demonstrated superior efficacy against cowpea aphids. Moreover, it positively influenced plant height, number of pods, and pod biomass, surpassing many chemical insecticides. Pestwin's environmental friendliness positions it as a potential contributor to reducing environmental pollution, making it a promising candidate for inclusion in IPM programs. Overall, the study underscores the importance of exploring botanical alternatives to chemical insecticides for sustainable pest management in cowpea cultivation.

Keywords

Cowpea, Pest Management, Botanical Solutions, Profenofos, Sustainability

1. Introduction

Cowpea [*Vigna unguiculata* (L.) Walp] is a valuable legume crop grown in the tropics, especially the semi-arid tropics of Africa [1] [2] [3] [4] [5]. In Uganda, the crop is mainly suited for growth in the drier and warmer areas in the Eastern and Northern regions of the country, where it is grown for both its leafy and grains as food [6] [7] [8] [9]. To a lesser extent, the smallholder farmers in central Uganda depend on leafy cowpeas as part of their traditional daily meal [10]. This crop is ranked the fourth (4th) most crucial legume after common beans (*Phaseolus vulgaris* L.), groundnuts (*Arachis hypogea* L.), and soybean (*Glycine max*), despite being cultivated mainly by smallholder farmers owing only about 3 ha of land [9]. Cowpea can be consumed at different stages of development, right from early seedling to physiological maturity [11]. When consumed as leafy, cowpea provides a cheap supply of proteins, iron (Fe), calcium (Ca), and β-carotene, all of which improve the nutritional status of resource-constrained families [10] [11] [12]. Similarly, immature pods and immature cowpea grains contain high contents of proteins and minerals, specifically Ca, Fe, zinc (Zn), and potassium (K) [13] [14] [15] [16]. The high protein content of these two products provides a suitable alternative to the consumers' diet by granting a valuable source of a high level of plant protein [11] [13]. Therefore, the crop is regarded as poor men's meat due to the high protein content in leaves, pods, and grains [2].

Despite its enormous importance, in Uganda, the grain yield of cowpea is still too low, averaging between 50 - 500 $kgha^{-1}$ [4] despite a grain yield potential of 1200 - 2400 $kgha^{-1}$ for most cowpea genotypes [7] [17] [18]. The high incidence of myriad field insect pests and viral diseases in cowpea growing regions could be responsible for the reduced grain yield potential of the crop [8] [19]. Several field insect pests infest all crop growth stages from early emergence until pod formation [19]. The notable pests identified are the aphids (*Aphis craccivora* Koch) that can damage the crop as early as ten (10) days after emergence (DAE), thrips (*Megalurothrips sjostedti* Trybom: Thysanoptera; *Thripidae*) the most critical cowpea pest that causes irreversible damage to the floral structures [20] in the form of flower browning, distortion, abscission, and abortion of flower buds, which can result into 100% yield loss [21], Maruca pod borer (*Maruca vitrata* Fabricius: Lepidoptera; *Pyralidae*) that attacks the stems, flowers, and pods, and a complex of pod-sucking bugs that damage the cowpea pods [2] [19]. Among the pod-sucking bugs, the spiny brown bug (*Clavigralla tomentosicollis* Stal: Hemiptera: *Coreidae*) is the most notorious with the *Riptortus dentipes* Fabricius bugs (Hemiptera: *Aldidae*) and green stink bugs (*Nezara viridula* Linnaeus: Hemiptera: *Pentatomidae*) only occurring sporadically in cowpea fields [2]. These pests have also been identified as the most problematic in other parts of Africa growing cowpeas [22].

Given the devastating effects of the activities of these pests, different options are employed to manage field pests of cowpea in Uganda [20] [23]. Evaluating cowpea genotypes for resistance to field insect pests and stability in different locations is one of the management options. However, such resistance is specific to one pest, such as flower thrips [20] or aphids [24], and occurs more in a few genotypes than others, and there is variation in cowpea resistance to such pests in the different locations [20] [24]. Thus, synthetic pesticides (or pesticide mixes) like cypermethrin, lambda-cyhalothrin, dimethoate, chlorpyrifos, fenitrothion, cypermethrin, and endosulfan form a primary management tactic pursued vastly by farmers in cowpea growing districts of Uganda [25]. Unfortunately, some chemical insecticides are expensive, toxic, and, when used excessively, may present very harmful threats to human health and the environment [25] [26] [27]. Furthermore, the unselective use of synthetic pesticides can be associated with target pests developing resistance, eliminating useful natural enemies, and killing non-target beneficial insects [25] [26]. Once resistance renders an insecticide ineffective, it may be lost from an Integrated Pest Management (IPM) toolbox forever.

Conversely, because cowpea consumers mind about the food safety and consequences of the toxic effects of synthetic pesticides in cowpea production by demanding pesticide-free young tender leaves [25], calls for evaluating the concert of botanical pesticides as safer alternatives to synthetic insecticides in the management of cowpea pests. Evidence from Nigeria shows that extracts from the seeds of four different plants present a vast untapped reservoir of chemical compounds effective against most key field pests of cowpeas [27]. An earlier study in Uganda by [28] also revealed that applying tobacco to cowpea plants at budding and flowering stages and then with cypermethrin was effective against the field pod infesting pests and *Callosobruchus maculatus* in storage. Thus, the current research study was therefore conducted to examine the effectiveness of botanical insecticides versus selected conventional chemical insecticides (**Table S1**) in the management of cowpea aphids, flower thrips, pod-sucking bugs, and legume pod borer.

2. Materials and Methods

2.1. Experimental Site

The experiment was set up at Makerere University Agricultural Research Institute Kabanyolo (MUARIK) in Central Uganda, North Kyaddondo constituency, Wakiso District. MUARIK is located approximately 2.5 kilometers northeast of Kasangati, on the road from Kampala, Uganda's capital city. This location lies about 18 kilometers by road northeast of Kampala. The coordinates of the area are latitude (0˚28'N) and longitude (32˚37'E), with an elevation of over 1200 m above sea level [20] [24]. MUARIK has a bimodal rainfall pattern, with the first rains coming between March and June (285.10 mm). In most cases, the first rains are more reliable than the second rains, which occur from September to December (215.1 mm). The area has a warm climate receiving an annual average rainfall of about 1150 mm and an average annual temperature of about 21.5˚C [20], with a relative humidity ranging between 52% and 70%. Winds are generally less destructive; dew forms every morning with occasional mist. The soils in the area are sandy clay loam [20] [24].

2.2. Experimental Design

The experimental field was prepared through primary and secondary tillage using a tractor-driven disc plough, followed by harrowing to achieve a smooth and level seed bed. The experiment was done in two rainy seasons: 2016B (October 04-December 21, 2016) and 2017A (March 02-June 04, 2017).

The experiment was conducted as a Randomized Complete Block Design (RCBD) with three (3) replications. The treatments were: T1—Carbofuran, T2—Cypermethrin 10% EC, T3—Dimethoate, T4—Pestwin, T5—Pyrethrum ewc+, T6—Pyrethrum 5ew, T7—Profenofos 40% + Cypermethrin 4% EC mix, and T0—Untreated (control). The application rate was 24 mls/6litres of water for pyrethrum ewc+ and Pyrethrum 5ew and 2.5 mls/6litres of water, 4.5 mls/6litres of water, 15 mls/6litres of water and 7.5 mls/6litres of water for Dimethoate, Cypermethrin 10% EC, Profenofos 40% + Cypermethrin 4% EC and Pestwin, respectively.

Spraying was carried out using a knapsack sprayer. Spraying was done weekly for four consecutive weeks, starting from the 10 Days after emergence (DAE). Carbofuran was applied as a soil drench before planting at a rate of 45 g per plot. Treatment plots measured 3 m × 3 m with 2 m alleys between replications and a 1 m walking space between treatments. A local determinate, white-seeded cowpea cultivar, Ebelat, with a 70-day maturity period, was used as experimental material [28]. Cowpea was planted at a spacing of 60 cm × 10 cm with two seeds planted per hole; this gave a plant density of about 300 plants per plot. Each plot had (6) six rows measuring 3 m long. Spraying was done weekly for six consecutive weeks, starting from the 10 DAE.

2.3. Data Collection

Data were collected at different stages of growth of cowpeas, beginning at the vegetative phase early in the morning (6:30 to 9:30 AM).

1) Aphid densities, *A. craccivora* population densities were estimated using a visual rating scale of 1 - 6, where 1 = no aphids, 2 = 1 - 20 aphids per plant, 3 = 21 - 40 aphids per plant, 4 = 41 - 60 aphids per plant, 5 = 61 - 80 aphids per plant, 6 ≥ 80 aphids per plant. The aphid infestation was assessed once every starting at 10 Days after Emergence (DAE). At every sampling, visual ratings of

aphid densities were taken on ten (10) randomly selected cowpea plants per plot, and this sampling was stopped at 40 DAE [28] for 2016B, while for 2017A, aphid densities were taken two times at 30 and 40 DAE, hence an unbalanced data for this rating.

2) Number of *M. sjostedti* (thrips); counts of thrips were got right from 30 DAE, and estimates were obtained by randomly picking ten (10) plants and taking two (2) flower buds or flowers of cowpea per plant per plot, depending on the stage of growth. The flower buds/flowers were placed in glass vials containing 50% ethanol as a preservative. Later, the nymphs and adults of *M. sjostedti* were isolated from the plant tissue, and their numbers were counted and recorded. This was done once every ten (10) days starting 30 DAE until 50 DAE [28].

3) Plant height taken at 45 DAE, using a 1-metre ruler, once on ten (10) randomly selected plants per plot.

4) Population densities of *M. vitrata* were also assessed from twenty (20) flowers randomly picked from ten (10) plants in each plot. *Maruca* were counted every ten (10) days, beginning at 30 DAE till 50 DAE.

5) Population densities of pod-sucking bugs (PSB) were recorded by visual counting after ten (10) days, beginning at 40 DAE from each plot and continuing till 60 DAE. However, there was no attempt to separate the different PSB species.

6) Pod number: for ten (10) randomly selected plants per plot, the pods were counted at 50 and 60 DAE.

7) Number of pods damaged by the legume pod borer; this was done once after 68 DAE. Ten (10) plants were sampled per plot, and all pods were checked for damage. The number of pods bored and damaged by the pod borer was ascertained and recorded.

8) Pod biomass per plot was determined at harvest. All pods per plant in each plot were harvested and weighed using a portable weighing balance to obtain pod biomass per plot. The pod biomass obtained per plot was then used to calculate yield in a hectare ($Kgha^{-1}$) for each treatment. The experiments were harvested on December 21, 2016, and June 04, 2017, for seasons 2016B and 2017A, respectively.

2.4. Statistical Analyses

All data collected on pest population densities, plant growth parameters, and pest damage from different treated plots were entered in Microsoft Excel spreadsheets [29], saved as comma delimited (CSV) files, and imported to R software (R version 4.3.3) [30] for all statistical analyses. Data were analyzed by fitting a linear mixed effects model using the "lme4" package [31]. No statistical tests were executed to establish the sample size in advance [32]. Before analysis, data were inspected for distribution normality using quantile (QQ)-plots [29] and equal variances using residual plots; no normalization was necessary. Then, analysis of variance (ANOVA) tables were generated with the help of "lmerTest" package [33], and these ANOVAs were used to compare means of treatments for all parameters. Post-hoc tests for separation of the means were done using Fisher's least significant difference (LSD) test at $p < 0.05$ achieved by using a "multcomp" package [34]. The means for pest populations, plant parameters, and pest damage to cowpeas were presented in tables as means and respective standard deviations of three replicates.

3. Results

3.1. Effect of Treatments on Insect Pest Occurrence

The counts for the cowpea legume pod borer remained very low and were affected by the different treatments (*data not presented*). On the other hand, there was no significant effect of treatments on counts of the Pod-sucking bugs (PSB) per plant ($F_{7,704} = 0.492$, $p = 0.8410$) and number of bored pods per plant ($F_{7,230} = 1.836$, $p = 0.0813$) in season 2016B. Conversely, there were significant effects of treatments on aphid ratings per plant ($F_{7,941} = 15.852$, $p < 0.0001$), and counts of thrips per plant ($F_{7,704} = 5.025$, $p < 0.0001$)in season 2016B (**Table 1**). In 2017A, there were significant effects of treatments on aphid ratings per plant ($F_{7,467} = 5.853$, $p < 0.0001$), counts of thrips per plant ($F_{7,704} = 5.887$, $p < 0.0001$), counts of PSB per plant ($F_{7,704} = 11.660$, $p < 0.0001$), and number of bored pods per plant ($F_{7,230} = 3.044$, $p = 0.0044$) (**Table 1**). Generally, pest count was highest in season 2016B compared to 2017A (**Table 1**). In the two seasons, plots treated with T7 best-controlled cowpea aphids with averages of 1.05 and 1.07 aphid

Table 1. Effect of botanical mixtures and chemical insecticides on pest infestation on cowpea.

Treatments	*Mean insect ratings/ counts in 2016B*				*Mean insect ratings/ counts in 2017A*			
	Aphids	*Thrips*	*PSB*	*bored pods*	*Aphids*	*Thrips*	*PSB*	*bored pods*
	rating/ plant	*counts/ plant*	*counts/ plant*	*counts/ plant*	*rating/ plant*	*counts/ plant*	*counts/ plant*	*counts/ plant*
T0	2.03^{d}	11.94^{ab}	0.06	0.87	1.68^{ab}	5.13^{c}	0.69^{b}	2.27^{b}
T1	1.23^{ab}	13.61^{b}	0.08	0.53	1.33^{a}	4.98^{c}	0.08^{a}	1.47^{ab}
T2	1.18^{a}	7.23^{a}	0.07	0.40	1.28^{a}	4.29^{bc}	0.23^{a}	1.20^{a}
T3	1.62^{c}	11.46^{ab}	0.02	0.47	1.30^{a}	2.99^{ab}	0.27^{a}	1.60^{ab}
T4	1.19^{ab}	10.93^{ab}	0.06	0.47	1.50^{ab}	4.47^{bc}	0.14^{a}	1.13^{a}
T5	1.35^{abc}	13.39^{b}	0.03	0.60	2.00^{b}	2.62^{a}	0.08^{a}	0.90^{a}
T6	1.52^{bc}	7.79^{a}	0.08	0.23	2.07^{b}	4.09^{abc}	0.27^{a}	1.30^{ab}
T7	1.05^{a}	8.50^{a}	0.08	0.33	1.07^{a}	3.26^{ab}	0.06^{a}	1.53^{ab}
SE±	0.15	3.07	0.03	0.14	0.18	0.88	0.06	0.24

Means followed by the same character(s) in a column are not significantly different at ($p < 0.05$). Keys: T0—Untreated, T1—Carbofuran, T2—Cypermethrin 10% EC, T3—Dimethoate, T4—Pestwin, T5—Pyrethrum ewc+, T6—Pyrethrum 5ew, T7—Profenofos 40% + Cypermethrin 4% EC, PSB-Pod sucking bug complex. Treatments did not differ significantly in control of PSB and on the effect on the number of bored pods per plant in 2016B.

ratings per plant, respectively, for seasons 2016B and 2017A. In season 2016B, T2, and T6 were the most effective against thrips infestation, with treated plots averaging 7.23 and 7.79 thrips per plant, respectively. Conversely, T1 and T5 were not significantly different from untreated control and were least effective in controlling thrips, with average thrip count per plant recorded as 13.61, 13.39, and 11.94, for T1, T5, T0 plots respectively. In 2017A, T5 and T3 were best at controlling the thrips, with an average of 2.62 and 2.99 thrips per plant. Plots Treated with T7, T1, and T5 had better control of PSB with negligible infestation levels, while T5 and T4 treated plots with average 0.9 and 1.13 bored pods per plants were most effective in controlling pod borer damage in 2017A (**Table 1**). Generally, season 2017A had less control of legume pod borer damage compared to season 2016B (**Table 1**).

3.2. Effect of Treatments on Plant Parameters

There was no significant effect of the treatments ($F_{7,467} = 1.447$, $p = 0.1846$) on the number of pods per plant in 2016B (**Table 2**). In this season, the number of pods was highest in plots treated with T7 and least in T5 treated plots with 11.40 and 8.95 pods per plant, respectively. For Season 2017A, treatments differed significantly in their effect on the number of pods per plant ($F_{7,467} = 1.447$, $p = 0.0158$), with plots treated with T7 having the highest pod number recorded as 15.62. In contrast, T5 treated plots had the least number of pods, recorded as 11.77 pods per plant (**Table 2**). The plant height was significantly affected by treatments ($F_{7,230} = 3.545$, $p = 0.012$) in season 2016B, with plants treated with T4

Table 2. Effects of botanical mixtures and chemical insecticides on plant parameters.

Treatments	2016*B*			2017*A*		
	Plant height (cm)	No. of pods/ plant	Pod biomass ($Kgha^{-1}$)	Plant height (cm)	No. of pods/ plant	Pod biomass ($Kgha^{-1}$)
T0	56.5^{abc}	9.53	2.67	51.9	12.78^{ab}	2.35
T1	55.1^{abc}	9.60	2.83	54.4	14.77^{ab}	1.84
T2	60.3^{bc}	9.78	2.60	59.0	14.10^{ab}	2.15
T3	57.2^{abc}	10.02	2.60	51.5	12.78^{ab}	2.26
T4	64.6^{c}	11.33	3.20	53.1	14.92^{ab}	2.09
T5	45.4^{a}	8.95	1.57	50.9	11.77^{a}	2.36
T6	49.4^{ab}	9.87	1.57	52.3	13.02^{ab}	1.99
T7	62.7^{bc}	11.40	4.10	56.3	15.62^{b}	2.41
SE±	3.81	0.82	0.58	5.12	1.51	0.42

Means followed by the same character(s) in a column are not significantly different at ($p < 0.05$). Keys: T0—Untreated, T1—Carbofuran, T2—Cypermethrin 10% EC, T3—Dimethoate, T4—Pestwin, T5—Pyrethrum ewc+, T6—Pyrethrum 5ew, T7—Profenofos 40% + Cypermethrin 4% EC. PSB-Pod sucking bug complex. Treatments did not differ significantly in their influence on number of pods per plant in 2016B, on their influence on pod biomass in both 2016B and 2017A, and on their effect on plant height in 2017A.

being the tallest with an average height of 64.6 cm, and T5 treated plants were the shortest plants having an average height of 45.4 cm. In 2017A, plant height did not differ significantly between treatments ($F_{7,230}$ = 1.013, p = 0.4227) with T2 treated and T5treated plants being the tallest and shortest at 59.0 cm and 50.9 cm, respectively (**Table 2**). The treatments did not differ significantly in their effect on pod biomass in the two seasons, 2016B ($F_{7,14}$ = 2.469, p = 0.0711) and 2017A ($F_{7,14}$ = 0.480, p = 0.8335). Pod biomass in season 2016B was higher compared to that in season 2017A (**Table 2**). In both seasons, T7 treated plots had the highest mean pod biomass of 4.10 $kgha^{-1}$ and 2.41 $kgha^{-1}$, in 2016B and 2017A, respectively. In season 2016B, T6 and T5 treated plots had the least pod biomass of 1.57 $kgha^{-1}$ each, while T1 treated plots produced the least pod biomass of 1.84 $kgha^{-1}$ in 2017A (**Table 2**).

4. Discussion

Given the haunted negative impacts on man, the environment, and untargeted organisms resulting from using common pesticides to manage crop pests, assessing pesticide efficacy is vital to inform their judicious application. The present study evaluated the efficiency of four (4) chemical and three (3) botanical insecticides against cowpea *A. craccivora*, *M. sjostedti*, pod-sucking bug complex, and *M. vitrata* under field conditions (**Table 1**). The studied chemical insecticides were Carbofuran, Cypermethrin 10% EC, Dimethoate, and Profenofos 40% + Cypermethrin 4% EC ready mix, while the botanical insecticides included Pestwin, Pyrethrum ewc+, and Pyrethrum 5ew (**Table 1** and **Table 2**, **Table S1**). Our findings support an earlier suggestion that the use of pesticides in the production of cowpeas may not be inevitable [35]. Among the studied treatments, a chemical pesticide, Profenofos 40% and Cypermethrin 4% EC mix, was the most effective against most field insect pests of cowpea. The findings by [36] are supportive of present investigations as they observed that Profenofos 40% and Cypermethrin 4% EC was the most effective pesticide against pink bollworm [*Pectinophora gossypiella* (Saunders)] pest infestation in cotton (*Gossypium hirsutum*).

Similarly, in rice (*Oryza sativa*), a combination of Profenofos 40% and Cypermethrin 4% EC was most effective against most field pests [37]. In the management of gram pod borer [*Helicoverpa armigera* (Hubner)] in chickpeas, the study revealed that, among the different treatments, the lowest larval population of chickpea pod borer was recorded in Profenofos 40% + Cypermethrin 4% EC @ 0.1 mL/litre treated plots [38]. We attribute the efficacy of this pesticide mixture to a synergistic interaction between Profenofos 40% and Cypermethrin 4% EC that enhances the insecticidal properties of this pesticide in managing cowpea field pests. Even then, a pesticide mixture probably increases the commercial lives of the pesticide given that use in combinations complements the efficacy of the individual products, simultaneously lowers their use pressure, and widens the spectrum activity of the pesticides, let alone overcoming pest resistance to particular pesticide in the combination [39].

Compared to the untreated control, Carbofuran had the best control of aphids, the number of legume-bored pods in both seasons, and pod-sucking bugs in season 2017A (**Table 1**). Results by [35] indicated plots that had Carbofuran applied by seed dressing recorded the lowest aphid infestation levels across two seasons, but not pod-sucking bugs infestation and seed eaten due to *Maruca vitrata*. Therefore, the current study agrees with the above findings with a contrary finding for pod-sucking bug infestation and seeds eaten due to the activity of *M. vitrata*. Carbofuran has a relatively high residual time in soil and is a systemic pesticide. Therefore, the efficacy of Carbofuran can be attributed to its systemic nature and ability to persist in soil for a reasonable time (up to 50 days) from the time of application [40], which time is reasonable given the short gestation period of cowpeas. Recently, a study by [41] showed that when the effect of Carbosulfan, another carbamate similar to Carbofuran with a slight different chemical structure but the same mode of action, was assessed on the generations of Bird Cherry Oat aphid, *Rhopalosiphum padi* (L.), under laboratory conditions by exposing adult *R. padi* aphids to three different concentrations (1.4×10^{-7} ppm, 1.4×10^{-10} ppm, 1.4×10^{-13} ppm) of Carbosulfan (Advantage® EC), all three concentrations considerably lowered the pre-adult survival rate of resulting aphid progeny. Based on this, we conclude that Carbofuran is very effective against aphids.

For both seasons, compared with the untreated control, Dimethoate-treated plots had lower aphid counts at 1.62 and 1.30 aphids per plant vs. 2.03 and 1.68 aphids per plant in control plots during 2016B and 2017A, respectively (**Table 1**). Similarly, Dimethoate-treated plots had, on average, a lower thrip count per plant in both seasons compared to the untreated control plots at 11.46 and 2.99 vs. 11.94 and 5.13, respectively. The present investigation corroborates with other studies. The findings by [42] revealed that when compared to control, Dimethoate 30 EC @ 300 g a.i./ha was most effective at managing cowpea aphid. Similarly, a study by [22] revealed that thrips were considerably checked in plots treated with Dimethoate three times at bud initiation, 50% flowering, and 50% podding. Although some pests, especially the fruit fly species *Bactrocera oleae*, have been detected to be resistant to Dimethoate [43], this insecticide remains very effective against cowpea pests, with no cases of resistance reported so far [22]. Hence, our results agree with this postulation.

Among the three studied botanical insecticides, Pestwin had better control of aphids in both seasons (**Table 1**) at 1.35, 1.52, 1.19, and 2.07, 2.00, and 1.50 aphid rating for the Pyrethrum 5ew, Pyrethrum ewc+, and Pestwin insecticides in 2016B and 2017A, respectively. We attributed the efficacy of Pestwin on aphid management to the insecticidal effects of its component extracts from *Pongamia pinnata* L., *Ricinus communis*, and *Azadirachtin indica* on the aphids. A study by [44] revealed that *Pongamia* oil soap at 2 % and 1% and neem oil soap at 0.6% were effective against cowpea aphids. In another study carried out to determine the efficacy of leaf extract from the pongam tree, *P. pinnata* L. against the turnip aphid [(*Lipaphis pseudobrassicae* (Davis) (Hemiptera: *Aphididae*)] in the laboratory, pongam leaf extract showed very acute toxicity to the turnip aphid with low lethal concentration 50 (LC50) values of 0.585%, 0.151% and 0.113% at 24, 48 and 72 hours, respectively [45]. Thus, the results of our study showing that Pestwin controlled the *A. craccivora* to a greater extent could be due to the mortality of aphids given the toxicity of its ingredients. Even then, *A. indica* has intricate chemical fortifications that provide a rich source of biologically active chemical compounds that ably suffocate insect pests [27]. As reviewed by [46], *Azadirachtin* serves as both an antifeedant and a regulator of crucial insect growth and development processes by affecting 20-hydroxyecdysone (20E) and juvenile hormone (JH) levels. This is attributed to the ability of *A. indica* to impede the hemolymph ecdysteroids and JH levels, achieved through the downregulation of morphogenetic peptide hormone (PTTH) and allatotropins secretion from corpus cardiacum. Consequently, this leads to decreased pupation, potential deformities, and hindered adult emergence [46]. Thus, *A. indica* could have caused growth retardation to aphids in Pestwin-treated plots. Furthermore, in another study, pongam leaf extracts showed acute lethal toxicity against the two armyworm species, the LC50 values being 1.94%, 1.52%, and 1.10% at 24, 48 and 72 hours, respectively, for *Spodoptera litura*. In contrast, the values for *S. exigua* larvae were 3.18%, 2.57%, and 1.89% at 24, 48, and 72 hours, respectively [47]. This acute toxicity is embedded in the two significant flavonoids, *karanjin* and *pongapin*, in pongam extracts containing insecticidal properties [47] [48]. Thus, *Pongamiapinnata* further gives Pestwin excellent insecticidal efficiency, rendering it practical to combat insect pests.

Our results show that aphids and thrips were most abundant in 2016B (**Table 1**). At MUARIK, the first rains from March to June (season A) are more reliable and consistent than season B rains [20]. We attribute the reduced number of aphids in season 2017A to the higher intensity of rains that likely interfered with the aphid life cycle and washed them off the plants. This contradicts an earlier study by [35] that showed a higher count of aphids and thrips during 2016B rains. Thrips were the most abundant pests studied, even with the application of insecticides (**Table 1**). This is not shocking to us, given that MUARIK is one of the hotspots for *M. sjostedti* in Uganda [20].

We next assessed the influence of treatments on plant parameters, plant height, number of cowpea pods per plant, and pod biomass per treated plot (**Table 2**). Overall, plots treated with a chemical insecticide, Profenofos 40% and Cypermethrin 4% EC ready mix, had the highest number of pods and pod biomass. This superior yield is probably because the plants in plots treated with this ready-mix insecticide had minimal damage from the pests since fewer insect pests were recorded in these plots. Our results agree with the findings by [38], who noted a superior yield from chickpea plots treated with Profenofos 40% and Cypermethrin 4% EC compared to other botanical insecticides. Furthermore, plots treated with Pestwin had a better influence on the plant height, number of pods, and pod biomass compared to other botanical insecticides and some chemical insecticides (**Table 2**). Our findings are not any different from the findings by [38], who reported that Neem extracts, Neem oil, and Karanj oil treated plots were subsequent best high yielding after Profenofos 40% and Cypermethrin 4% EC treated plots when applied to manage gram pod borer [*Helicoverpa armigera* (Hubner)] in chickpea. This is probably because apart from the acute lethal toxicity of *karanjin*, *pongapin*, and *ricin* (insecticidal ingredients in Pestwin) on insects, extracts contain harmless but adverse effects against insect activities. For example, *karanjin* has a dramatic antifeedant or repellent impact, with many insects dodging treated crops. This ingredient destroys ecdysteroids, thus acting as an insect growth regulator and antifeedant, let alone inhibiting cytochrome P-450 in susceptible insects and mites [49]. The cytochrome P-450s in insects are crucial in the detoxification of pesticides, which alters the toxicological effects of the pesticides on insects [50]. In a study by [47], low concentrations of a pongam leaf extract significantly delayed the larval developmental time of the *S. litura* and *S. exigua*. This was attributed to the antifeedant potential of the pongam leaf extract. Thus, the better plant parameters could reflect an indirect reduction of overall pest numbers per plot treated with the *karanjin*-rich insecticide (Pestwin). We suspected the cowpea plants might have absorbed the extract mixtures through osmotic pressure, causing the insects to stop feeding. It is also possible that as the plants absorbed the spray liquid, the invading insects living and feeding in the preferred plant parts could have absorbed the extract mixtures, resulting in the death of the insects with eventual fast and enhanced growth of the plants.

Collectively, our findings demonstrate that the combination of Profenofos 40% and Cypermethrin 4% in a ready-to-use insecticide mixture proves to be highly effective against a variety of field insect pests affecting cowpeas. Furthermore, it exerts a positive influence on key plant growth parameters. Given the increasing consumer preference for pesticide-free cowpea products [26] and the potential negative consequences associated with chemical pesticide use, it is imperative for farmers to apply this mixture with caution. Additionally, it is crucial to time the harvest of cowpea produce so as to mitigate any residual toxic effects of Profenofos 40% and Cypermethrin 4%. This is particularly important due to the moderate persistence of this ready-to-use mixture in fruits and vegetables [26] [51]. Maximum residue levels permitted in tomato fruits treated with Profenofos and Cypermethrin are set at 10.00 ppm and 0.50 ppm, respectively. Analysis of tomato plants harvested 14 days post-application of Profenofos and Cypermethrin revealed detectable residue levels of 0.08614 ppm, 0.01073 ppm, and 0.00253 ppm in leaves, stems, and roots, respectively, as well as 0.00340 ppm across all parts [26]. Similarly, research conducted by [51] established waiting periods of 13.82 and 5.16 days for Profenofos 40% and Cypermethrin 4%, respectively, to ensure residue-free fruits when using a standard dose of 162 g a.i. ha^{-1} + 106 g a.i. ha^{-1}. Consequently, harvesting cowpea produce 14 days after the final application of this ready-to-use mixture ensures that the product is free of pesticides, rendering it suitable for human consumption.

5. Conclusions

According to the findings of this investigation, cowpea pests' infestation levels were influenced differently by chemical and botanical insecticides. The chemical and botanical insecticides utilized also exhibited variations in plant parameters such as plant height in the 2016B season, and the number of pods in the 2017A season. Profenofos 40% and Cypermethrin 4% EC ready mix demonstrated the highest efficacy against field insect pests especially cowpea aphids. For this ready mix, we recommend exploring appropriate spraying regimes to establish the number of sprays needed to effectively control aphids.

Within the category of botanical pesticides, Pestwin-treated plots outperformed others in controlling cowpea aphids, showcasing taller plants, a higher number of pods, and increased pod biomass in both seasons compared to most chemical insecticides.

Based on these study outcomes, we propose further investigations into Pestwin, considering its high potential in pest management and its positive impact on plant growth. Additionally, we recommend exploring appropriate spraying regimes and assessing efficacy on other crops. Given its environmentally friendly nature, this pesticide can significantly contribute to reducing environmental pollution and can be seamlessly integrated into an IPM program.

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Conflicts of Interest

The authors assert that there are no conflicts of interest about the publication of this paper.

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Supplementary Table

Table S1. Brief review of insecticides used in the study.

Insecticides	Pertinent details
Carbofuran	Carbofuran, chemical name 2,3-dihydro-2,2-dimethyl-7-benzofuranyl N-methylcarbamate [52], has a molecular formula $C_{12}H_{15}N0_{3,}$ a relative molecular weight of 221.25 gmol$^{-1,}$ and belongs to the class of insecticides called carbamates (CMs). As a systemic insecticide, when applied, it readily enters into a plant, gets transported by the sap, and feeding insects pick it up as they feed on the plants and become poisoned [52]. Like other CMs, the Carbofuran mode of actin involves reversible inhibition of cholinesterase enzyme activity in insects, mammals, and birds [52] [53]. For this reason, they were branded as anti-cholinesterases [52]. Cholinesterase enzyme is integral to all physiological responses and mechanisms, with no substitute enzyme thought to perform such an intricate set of functions in animals [52]. Thus, cholinesterase inhibition leads to a permanent overlay of acetylcholine neurotransmitters across a synapse [52]. Increased acetylcholine accumulation is associated with confusion, delirium, hallucinations, tremors, seizures, eventual collapse, and death [53]. Being a broad-spectrum insecticide, Carbofuran was dubbed an ideal insecticide, acaricide, and nematicide [52].
Cypermethrin 10% EC	Cypermethrin, chemical name, ([cyano-(3-phenoxyphenyl)methyl] 3-(2,2-dichloroethenyl)-2,2-dimethylcyclopropane-1-carboxylate [24], has molecular formula $C_{22}H_{19}Cl_2NO_3$ with a relative molecular mass of 416.3 mol^{-1}. Cypermethrin insecticide is a synthetic pyrethroid from natural pyrethrins extracted from plants, especially *Chrysanthemum cinerariaefolium* [54] [55]. Cypermethrin 10% EC is an emulsifiable concentrate (EC) formulation based on cypermethrin technical 10% w/w EC. It is a class II synthetic pyrethroid [55] [56]. Like other class II synthetic pyrethroids, an alpha-cyano group attached to the benzylic carbon in cypermethrin synergizes its toxicity [55] [56]. As reviewed by [55], pyrethroids antagonize sodium voltage-dependent channels (SVDC) in insects. Furthermore, [55] shows that SVDC and potassium voltage-dependent channels (PVDC) are necessary for the movement of Na^+ and K^+ across the membrane, resulting in electrical impulses trailing along the neurons. The antagonism of SVDC downs the peak of Na+ ions and prolongs the SVDC opening time, all of which cripple neurotransmission [55]. When the insect absorbs the insecticide molecule through the cuticle, the neurotransmission ceases, gets paralyzed, and dies within a few seconds or minutes [55].
Dimethoate	Dimethoate, chemical name, ([O, O-Dimethyl S-(N-methylcarbamoylmethyl) phosphorodithioate]), has a molecular formula$C_5H_{12}NO_3PS_2$ with a relative molecular mass 229.3 g/mol. Dimethoate insecticide belongs to the class of organophosphorus insecticides and is used worldwide in agriculture and urban areas due to its high efficacy and rapid environmental degradation [43]. Unlike carbamates, organophosphates act in an irreversible way in insects, birds, and mammals to inhibit Acetylcholinesterase (AChE) activity, resulting in nerve damage, which may lead to death [43] [57]. AChE initiates the hydrolysis of acetylcholine (ACh), a neurotransmitter, into inactive choline and acetic acid [53] [58]. Inhibition of AChE leads to a buildup of ACh at the nerve synapses causing destabilization of AChE that is vital for a functioning central nervous system [53] [58] [59]. The increased levels of ACh in the synapses circumvents into permanent stimulation of the muscles, eventually leading to seizures, exhaustion, and possibly death . Dimethoate is judged to be highly toxic to insects, although resistance has been observed in fruit fly species *Bactrocera oleae*, as reviewed by [43].
Pestwin	Pestwin is a botanical pesticide blend of plant-derived insecticidal components, *Azadirachtin indica, Pongamia pinnata,* and *Ricinus communis*. This botanical concoction has been registered in Uganda by the Ministry of Agriculture, Animal Industry and Fisheries (MAAIF) [60]. *Pongamia pinnata* (also known as Karanj) is a tropical tree native to southeast Asia [61], its oil is rich in medicinal properties and can be used as a biopesticide and insect repellent [61]. Although its seeds are highly rich in ricinoleic acid, a polyunsaturated fatty acidharvested for industrial work [62]*, Ricinus communis*is a castor bean plant whose toxicity is attributed to the presence of ricin, a water-soluble glycoprotein concentrated in seed endosperm but does not partition in seed oil [63] and is found in lesser concentration in other plant parts. Ricin is dubbed one of the most naturally poisonous and acts through the inactivation of a ribosome in the affected organisms [63], which affects protein synthesis. *Azadirachtin*, a tetranortriterpenoid, is a chemical compound derived from neem and is a tremendous antifeedant and insect growth disruptor with negligible residual effect and minimal toxicity to biocontrol agents, predators, and parasitoids [46] [64].

Continued

Pyrethrum ewc+ and Pyrethrum 5ew	Pyrethrum is a crude flower dust product extracted with organic solvents from mature inflorescence [55] of *Chrysanthemum species*. The natural active ingredient in pyrethrum extracts is pyrethrin. Pyrethrins are six related insecticidal esters occurring naturally in the crude material of *Chrysanthemum* flowers, formed by the combination of the acids, chrysanthemic and pyrethric acid, and the alcohols pyrethrolone, cinerolone, and jasmolone [55] [64]. As reviewed by [55], the natural pyrethrin compound has a reduced photostability and is more biodegradable than the synthetic pyrethroids. Pyrethrins exert their toxic effects by disrupting voltage-gated SDVC and PVDC, which negates the Na^+ and K^+ ion exchange process in insect nerve fibers, which knocks down normal transmission of nerve impulses [55] [64], causing paralysis. However, despite their rapid toxic action, many insects can digest pyrethrins quickly and, after a period of paralysis, recover instead of dying [64]. To increase their killing power, a synergist, piperonyl butoxide (PBO), can be added to natural pyrethrins [65], which prevents insects from metabolizing pyrethrins and recovering from poisoning. Pyrethrum ewc+ is an advanced natural insecticide oil in water formulated containing 21.9 g/L pyrethrin synergized with Sesame (*Sesamum indicum*) oils. It is a contact insecticide for use on all outdoor, protected crops and non-edible plants, such as ornamentals, to protect them against chewing and sucking pests throughout the season. This is a natural insecticide that contains 5% (w/v) pyrethrin. Conversely, Pyrethrum 5ew is a unique water-based formulation containing a blend of pyrethrum and natural food oils formulated to optimize natural Pyrethrum's spectacular insect-killing power. Pyrethrum 5ew is a very crop-safe insecticide and can be used in a wide range of crops, including vegetables, fruits, coffee, cocoa, and broad acre crops such as maize and wheat.
Profenofos 40% + Cypermethrin 4% EC	This is a ready mix of Profenofos 40% and Cypermethrin 4% EC. Profenofos, chemical name [O-(4-bromo-2-chlorophenyl) O-ethyl S-propyl phosphorothioate], has a molecular formula $C_{11}H_{15}BrClO_3PS$, a molecular weight of 373.60 $gmol^{-1}$. Profenofos is an organophosphate insect that acts by inactivating AChE activity, accumulating ACh at the synapse junction, leading to neuronal dysfunction [66]. As stated above, Cypermethrin is a class II synthetic pyrethroid that modifies voltage-gated ion channels.