Original Research Article

ALLELOPATHIC POTENTIAL OF AQUEOUS EXTRACTS OF WILD SUNFLOWER (*Tithonia diversifolia* (Hemsl.) A.Gray) AND SORGHUM (*Sorghum bicolor* (L.) Moench) FOR CONTROLING WEEDS AND ENHANCING YIELD OF COWPEA (*Vigna unguiculata* (L.) Walp)

ABSTRACT

Cowpea is an important grain legume in Sri Lanka. Approximately 53–60% of yield losses in cowpea cultivation are attributed to weeds. Chemical weed control (herbicide), is one of the method in weed control in cowpea. Import of herbicide have been prohibited recently since of government policy and the nation's economic problems. As a result, it's critical to identify other suitable alternatives. In this context, a field experiment was conducted to study the effect of aqueous extract of wild sunflower and sorghum on weed control, growth and yield of cowpea. The experiment consisting of five weed control treatments viz T1 (aqueous extract of wild sunflower; 12 L ha^{-1} ,T2 (aqueous extract of sorghum; 12 L ha^{-1}), T3 (combined application of both wild sunflower and sorghum aqueous extract in a 1:1 ratio; 6+6 L ha^{-1}), T4 (hand weeding), and T5 (unweeded check-control) was conducted in Randomized Complete Block Design with four replication in the crop farm of Eastern University, Sri Lanka.. The experiment was conducted from September to November 2022. Hand weeding was done on 21 and 42 DAS while application of aqueous extracts were done on 2, 21, and 35 DAS. Minitab 17 software was used for the statistical analysis, and Tukey's test was used to compare the treatment means. The results revealed that the different weed control treatments had a substantial ($P<0.05$) impact on weed population & dry weight, growth and yield of cowpea. When compared to the control, hand weeding was found to be most effective to control weeds followed by combined application of aqueous extracts from wild sunflower and sorghum Hand weeding and the combined application of aqueous extracts significantly reduced the number of weeds by 82.98 and 54.39%, respectively. Further, the hand weeding and combined application of extract significantly enhanced yield by 45.09% and 62.85% respectively in comparison to the control (unweeded check). According to the study's findings, it can be concluded that under the condition of Sri Lanka, combined application of aqueous extracts was proved to be more remunerative and sustainable alternate option for weed control in cowpea crop.

Keywords: *Allelochemicals, Aqueous extract, Cowpea, Hand weeding, Sorghum and Wild sunflower, Weed control, yield.*

1. INTRODUCTION

In Sri Lanka, Cowpea (*Vigna unguiculata* L. Walp) is an important annual legume crop in the Fabaceae family [1]. The area and production under this crop is 10,431.2 hectares and 11,878.1 metric tons, respectively [2]. In addition to providing animals with food, hay, silage, and forage, it also maintain soil fertility through green manure and cover crops [3].In cowpea cultivation, infestation by different insect pests and diseases, lack of understanding of effective cultural practices, planting at a low density, low soil fertility and weeds infestation are some of the constraints for low yield [4].

The biggest biological barrier to global agricultural productivity is weeds. Weeds and crops compete against each other for water, sunlight, nutrients, and space [5]. When compared to diseases (which account for 25% of losses) and insect pests (20%), weeds represent the most significant category of agricultural risks, accounting for over 45% of economic losses in field crops [6]. Weeds decreased cowpea and other legume crop yields in Nigeria by 53–60% [7]. *Dactyloctenium aegyptium, Eleusine indica, Gnaphalium indicum, Cyperus rotundus, Echinochloa crusgalli, and Sorghum halepense* are the main weeds in cowpea fields [8].

Weed control is a type of pest management that aims to inhibit the growth of weeds, particularly noxious weeds, in order to lessen their competition with desirable flora and fauna, such as domesticated plants and livestock, and to keep nonnative species from displacing native species in natural settings. To achieve these targets five methods of weed control are preventive, physical, cultural, biological and chemical control [9].

Any form of weed control that tries to keep weeds out of cultivated crops, pastures, or greenhouses is referred to as a preventive weed control strategy. The physical approach of controlling weeds comprises hand removal as well as the use of hoes and cutlasses. There are always weeds in a farmland that need to be pulled by hand because other techniques of crop management don't get rid of them entirely. Any weed management strategy that entails keeping field conditions so that weeds are less likely to become established and/or multiply is referred to as the cultural method. By introducing a target weed's natural enemies—insects, mites, and pathogens—biocontrol attempts to lower the weed's density to a certain point. Any method of killing or preventing weed growth by the application of synthetic herbicides is referred to as chemical weed control. The weed is impacted by this by either losing its leaves or drying up the stems and leaves [9].

Several herbicides are used in chemical weed control, applied both PRE- and POST-emergence. Herbicide application has shown to be the most workable, affordable, and efficient way to eradicate even harmful or difficult-to-reach weeds [9]. However, if a human were to consume herbicide, exposure to it might be quite dangerous and result in health problems. Furthermore, some pests might get resistant to pesticides, which makes it more difficult to get rid of them. The environmental contamination caused by the chemicals could affect plants or groundwater.

Allelopathy, the direct or indirect effect of one plant species on another by chemical substances released into the root environment, could provide a different approach to controlling the weeds [10]. Many techniques, such as combination application with lower herbicide dosages, absorption into the soil, mix cropping/intercropping, surface mulching, and aqueous extracts, can be utilized to manage weeds in the field using allelopathic potentiality [11]. Substances with an allelopathic effect are known as allelochemicals. Allelochemicals includes substances like alkaloids, benzoxazinones, derivatives of cinnamic acid, cyanogenic compounds, ethylene, and other stimulants of seed germination.

Wild sunflower (*Tithonia diversifolia* A. Gray) is an aggressive weed with high invasive capacity because it is known to exhibit allelopathy. Flavonoids, tannins, glycosides, terpenoids, saponins, alkaloids, and phenols are the constituents of the methanolic and water extracts of wild sunflower. Wild sunflower allelochemicals are utilized to control weeds of *Amaranthus cruentus, Cleome gynandra,* and *Tridax procumbens* [12].

Likewise,the allelopathic plant Sorghum (*Sorghum bicolor* L. Moench) inhibits the growth of weeds such as *Phalaris minor* Retz, *Rumex dentatus* L, *Chenopodium album* L. Benzoic acid, p-hydroxy benzoic acid, vanillic acid, m-coumaric acid, p-coumaric acid, gallic acid, caffeic acid, ferulic acid, and chlorogenic acid are the allelochemicals found in *Sorghum bicolor* [13].Therefore, this present study was undertaken with the objective to find the effect of aqueous extract of wild sunflower and sorghum on weeds and growth and yield of cowpea.

2. MATERIALS AND METHODS

2.1. Experimental location

The field experiment was carried out in a crop farm of the Eastern University of Sri Lanka from September to November 2022. It is located at the latitude of 7° 42' 59.99" N and longitude of 81° 41' 59.99", which comes under the Agro-Ecological Zone of the Low Country Dry Zone (DL_2).

2.2. Experimental design

The experiment consisting of five weed control treatments viz T1 (aqueous extract of wild sunflower; 12 L ha^{-1} ,T2 (aqueous extract of sorghum; 12 L ha^{-1}), T3 (combined application of both wild sunflower and sorghum aqueous extract in a 1:1 ratio; 6+6 L ha^{-1}), T4 (hand weeding), and T5 (unweeded check-control) was conducted in Randomized Complete Block Design with four replication in the crop farm of Eastern University, Sri Lanka. Hand weeding was done on 21 and 42 DAS, while, Aqueous extract were applied as a soil application and foliar application at 2, 21 and 35 DAS.

2.3. Collection of seeds

The seeds of cowpea variety 'Waruni' were collected from the sales center of Crop farm, Eastern University, Sri Lanka.

2.4. Aqueous extract

2.4.1. Collection of Allelopathic plants

Sorghum [*Sorghum bicolor* (L.) Moench] plants were collected from the farmers' fields of district Batticaloa. Wild Sunflower [*Tithonia diversifolia* (Hemsl.) A.Gray L.] plants were collected from the crop farm of Eastern University, Sri Lanka. Sorghum and Wild Sunflowers plants were collected after harvesting the crops in the field. All the plant samples were cleaned to remove dust and other particles. The plants of sorghum and wild sunflower were cut into small pieces and were dried in a shaded area for 7 days. The dried samples of all these plants were kept in bags and labeled

2.4.2. Preparation of aqueous extracts

One kilogram of dry herbage to ten liters of water (weight/volume, or w/v) was the ratio used to prepare aqueous extracts from chopped dry sorghum and wild sunflower herbage, which were soaked in water separately for 24 hours [14].

2.5. Agronomic practices

The land was ploughed to a depth of 15-20 cm and harrowed twice. After cleaning the land, 20 beds of 1.125 m^2 were prepared. For ease of maintenance, 50cm was allowed between each bed and 16 planting holes were made in each bed. The seeds of cowpea were sown at spacing of 15 cm in 30 cm apart rows. The Department of Agriculture's recommendations were followed while carrying out agronomic activities including fertilizer application, irrigation, and pest and disease control.

2.6. Data Collection

Weed parameters such as weed density, weed fresh weight, weed control index, weed control efficiency, growth parameters such as germination percentage, plant height, fresh weight of shoot, dry weight of shoot, fresh weight of roots, dry weight of roots and yield parameters such as total number of pods per plant and total yield were recorded.

Weed density - Weed density was measured from each plot by counting the number of weeds manually at 35 and 50 days after the sowing of cowpea seeds.

Weed fresh weight (g) - Weeds were collected by uprooting the weeds from each plot after harvesting the cowpea pods and packed in separate polybags (50 DAS). Weeds were cut into small pieces and their fresh weight was measured using an electronic balance.

Weed Control Index (%) - Weed Control Index (WCI) was measured by taking the reduction in weed population in the treated plot over the weed population in an unweeded check (control).

Weed Control Efficiency (%) - Weed Control Efficiency (WCE) was measured by taking the reduction in weed dry weight in a treated plot over weed dry weight in an unweeded check (control).

Germination (%) Germination percentage was measured from each plot by physically counting the number of seeds that germinated 5 days after sowing.

Plant height (cm) - Plant height was measured by selecting two centre seedlings from each plot at 4 and 6 weeks after planting. The length of the plant was measured from the ground surface to the growing tip of the plant by using a meter scale.

Fresh weight of shoot (g) - The shoots of two center plants were uprooted from each plot after harvesting the pods (50 DAS). It was cut into small pieces by destructive sampling including leaves, stem and their fresh weight was measured using an electronic balance.

Dry weight of shoot (g) -The shoots of two center plants were uprooted from each plot after harvesting the pods (50 DAS). It was cut into small pieces by destructive sampling, including leaves, stem and placed in paper trays, where they were dried at 70°C in the oven until a constant weight was achieved, and their dry weight was measured using an electronic balance.

Fresh weight of roots (g) - The roots of two centre plants were uprooted from each plot after harvesting the pods (50 DAS). It was cut into small pieces by destructive sampling and their fresh weight was measured using an electronic balance.

Dry weight of roots (g) - The roots of two centre plants were uprooted from each plot after harvesting the pods (50 DAS). It was cut into small pieces by destructive sampling and placed in paper trays, where they were dried at 70°C in the oven until a constant weight was achieved and their dry weight was measured using an electronic balance.

Total number of pods per plant - The total number of pods was counted by selecting two centre plants from each plot in each plant at harvest.

2.7. Analysis of Data

Collected data were statistically analyzed using the statistical software Minitab 17, and the mean comparison within treatments was performed by Tukey's test at 5 % significant level.

2.8. Calculation

$$Weed\ Control\ Index = \frac{WPC - WPT}{WPC} \times 100$$

$$Weed\ control\ efficiency = \frac{WDC - WDT}{WDC} \times 100$$

WPC = Weed population in control (unweeded) plot (number of weeds)

WPT= Weed population in the treated plot (number of weeds)

WDC = Weed dry weight in the control (unweeded) plot (g)

WDT= Weed dry weight in treated plot. (g)

3. RESULTS AND DISCUSSION

3.1. Weed parameters

3.1.1. Weed density

Table 1 showed the effect of wild sunflower and sorghum aqueous extract on weed density at 35 and 50 DAS. *Richardia scabra* L., *Cyperus rotundus* L., *Digitaria sanguinalis* L. Scop, *Phyllanthus urinaria* L., *Cleome viscosa* L., and *Mollugo cerviana* L. Ser were identified as predominant weeds during the experimental period.

Table 1. The effect of aqueous extract of wild sunflower and sorghum on weed density at 35 and 50 DAS.

Treatments	35 DAS	50 DAS
Wild Sunflower extract	65.00 ± 1.83^{b}	117.50 ± 1.85^{b}
Sorghum extract	67.25 ± 1.25^{b}	120.75 ± 3.90^{b}
Wild Sunflower + Sorghum extract	55.00 ± 1.08^{c}	88.50 ± 4.05^{c}
Hand weeding	15.75 ± 2.29^{d}	33.00 ± 2.16^{d}
Control (unweeded check)	103.00 ± 3.54^{a}	194.00 ± 3.39^{a}
F-Test	*	*

DAS- Days After Sowing; The value is the average of four replicates. The mean value in a column with a different letter or letters indicates that the difference is significant by Tukey's test at the 0.05 level of probability.

Weed density was significantly (P<0.05) affected by different weed control treatments when compared with the control (unweeded check) at 35 and 50 DAS. Significantly lowest weed density was recorded in hand weeding and significantly highest weed density was recorded in control (unweeded check). After hand weeding, among the aqueous extract application significantly minimum weed density was recorded in the combined application of aqueous extracts of sunflower and sorghum followed by the alone application of aqueous extract from wild sunflower and sorghum.

Hand weeding was used to achieve these results because it eliminates weeds before they become mature and start to generate seeds. Furthermore, removing weeds by hand helps to get rid of their roots, rhizomes, and other underground components like tubers and stolons. Additional aqueous extract with allelochemical properties might have helped to modify or interfere with pathways that generate plant hormones necessary for seed germination. They might have also prevented weed seed germination by altering the permeability of the cell membrane and decreasing the amount of water that weed seedlings take in when exposed to allelopathic stress. Additionally, they affect the photosynthetic process, cell differentiation, and metabolite concentrations required for the weeds to develop their cellular machinery [15]. The synergistic effect of two aqueous extracts in combination might have reduced the weed population. However, the results are consistent with those of Awan et al., [14] who indicated that allelopathic crop water extracts of brassica, sunflower, and sorghum in wheat significantly reduced the density of weeds.

3.1.2. Weed control index (%)

Table 2 presented the effect of aqueous extracts of wild sunflower and sorghum on the weed control index at 35 and 50 DAS in cowpea. The results showed that weed control index was significantly (P<0.05) influenced by the different weed control treatments when compared with control at 35 and 50 DAS. Significantly highest weed control index was recorded in the hand weeding treatment and it was followed by combined application of wild sunflower and sorghum extract. Significantly lowest weed control index was recorded in unweeded plot. Among weed control treatments, aqueous extract of wild sunflower, sorghum, combined application of wild sunflower and sorghum aqueous extract and hand weeding had the weed control index by 39.37, 37.79, 54.39 and 82.98%, respectively at 50 days after sowing compared with the control (unweeded check).

Table 2. The effect of aqueous extract of wild sunflower and sorghum on weed control index at 35 and 50 DAS in cowpea.

Treatments	35 DAS	50 DAS
Wild Sunflower extract	36.41 ± 3.69^{bc}	33.37 ± 1.47^{c}
Sorghum extract	33.63 ± 3.42^{c}	37.79 ± 1.08^{c}
Wild Sunflower + Sorghum extract	46.36 ± 2.54^{b}	54.39 ± 1.90^{b}
Hand weeding	84.83 ± 1.95^{a}	82.98 ±1.17^{a}
Control (unweeded check)	0.00 ± 0.00^{d}	0.00 ± 0.00^{d}
F-Test	*	*

DAS- Days After Sowing; The value is the average of four replicates. The mean value in a column with a different letter or letters indicates that the difference is significant by Tukey's test at the 0.05 level of probability.

It might be due to the fact that a larger concentration of the allelochemicals interfered with membrane permeability, photosynthesis, respiration, protein metabolism, and plant/water relationships, which significantly reduced weed growth [15].

3.1.3. Weed fresh weight (g)

Table 3 described the impact of aqueous extracts of wild sunflower and sorghum on the fresh weight of weeds at 50 DAS. The results revealed that the fresh weight of weeds was significantly (P<0.05) influenced when compared with the control (unweeded check). Significantly lowest weed fresh weight was recorded in hand weeding and significantly highest weed fresh weight was recorded in control (unweeded check). After hand weeding, among the aqueous extracts, significantly lower weed fresh weight was recorded by all statistically similar treatments of aqueous extract applied either alone or in combination over weedy check.

Table 3. The effect of aqueous extract of wild sunflower and sorghum on the fresh weight of weeds at 50 DAS.

Treatments	Weed fresh weight (g)
Wild Sunflower extract	213.02 ± 5.68 ^{b}
Sorghum extract	215.86 ± 3.35 ^{b}
Wild Sunflower + Sorghum extract	188.85 ± 2.24 ^{b}
Hand weeding	30.36 ± 2.49 ^{c}
Control (unweeded check)	573.8 ± 73.4 ^{a}
F-Test	*****

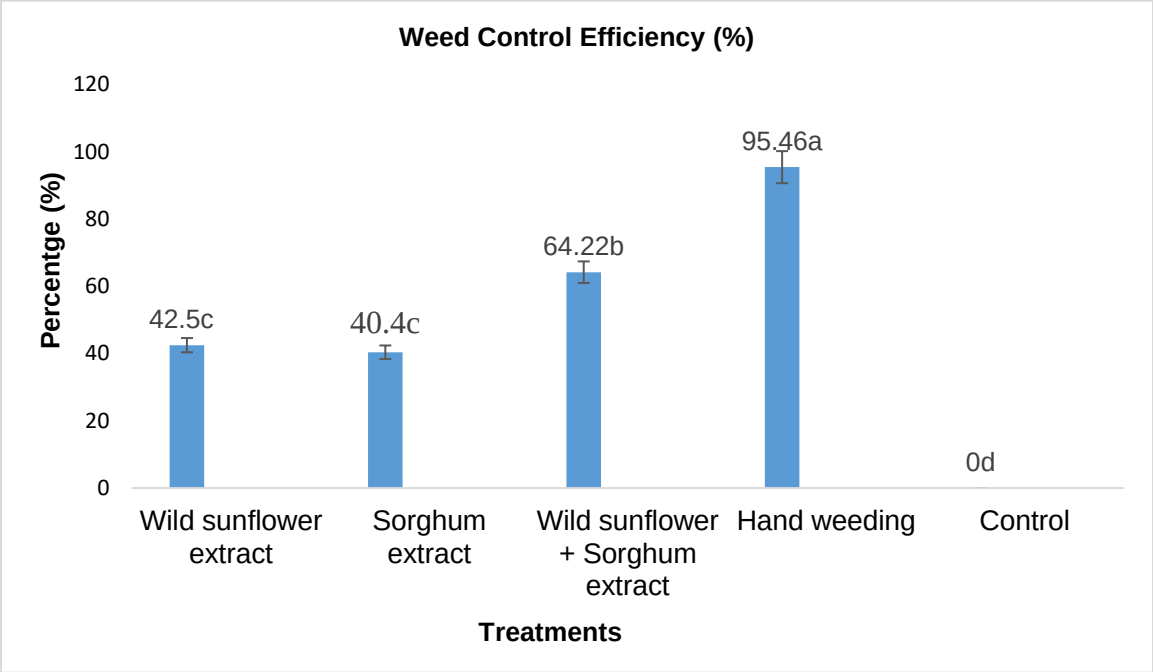
DAS- Days After Sowing; The value is the average of four replicates. The mean value in a column with a different letter or letters indicates that the difference is significant by Tukey's test at the 0.05 level of probability.

Numerically, among the aqueous extracts, sorghum extract is least effective for reducing the weed fresh weight. It might be due to the fact that allelochemicals from wild sunflower have a greater inhibitory impact than sorghum. These results are in conformity with the findings of Mubeen et al., [16] who reported more inhibitory effects of allelochemicals in the aqueous extract of sunflower than in sorghum.

3.1.4. Weed control efficiency (%)

Figure 1 depicted the effect of aqueous extracts of wild sunflower and sorghum on weed control efficiency. There were significant differences (P<0.05) in the weed control efficiency when compared with the control (unweeded check) at 50 DAS. The highest weed control efficiency was reported in hand weeding than other treatments when compared with the control (unweeded check). Among the aqueous extract application, the combined application of wild sunflower and sorghum recorded significantly more weed control efficiency when compared with control (unweeded check). The treatments of wild sunflower extract, sorghum extract, combined application of wild sunflower and sorghum aqueous extract and hand weeding enhanced the weed control efficiency by 42.58%, 40.40%, 64.22% and 95.46% compared with the control (unweeded check).

It might be due to the fact that a larger concentration of the allelochemicals interfered with membrane permeability, photosynthesis, respiration, protein metabolism, and plant/water relationships, which significantly reduced weed growth [17]. These results are in conformity with the findings of Ajayi et al., [18] who also found that hand weeding had more weed control efficiency followed by the application of wild sunflower and sorghum aqueous extract in cowpea.



Error bar denotes a standard error of four replicates. The mean value in a column with a different letter or letters indicates that the difference is significant by Tukey's test at the 0.05 level of probability.

Figure 1. The effect of aqueous extracts of wild sunflower and sorghum on weed control efficiency.

3.2. Growth parameters

3.2.1. Germination (%)

The effect of the aqueous extract of wild sunflower and sorghum on the germination of cowpea has been mentioned in Table 4. There were no significant differences (P>0.05) among the treatments. The germination percentages ranged from 98to 99%.

Table 4. The effect of an aqueous extract of wild sunflower and sorghum on the germination of cowpea.

Treatments	Germination (%)
Wild Sunflower extract	99.25 ± 0.75[a]
Sorghum extract	98.50 ± 0.86[a]
Wild Sunflower + Sorghum extract	99.25 ± 0.75[a]
Hand weeding	99.25 ± 0.75[a]
Control (unweeded check)	98.50 ± 0.86[a]
F-Test	**NS**

The value is the average of four replicates. The letter 'NS' denotes a difference that is not significant at the probability level of 0.05. The mean value in a column with a different letter or letters indicates that the difference is significant by Tukey's test at the 0.05 level of probability

Ajayi et al., [18] reported that 97% to 98% of germination was recorded using an aqueous extract of wild sunflower and sorghum in cowpea. These results are consistent with that of Oyerinde et al., [19] who found that the shoot extract of wild sunflower did not have an inhibitory effect on germination on maize. Similarly, Moosavi et al., [20] recorded that utilizing sorghum leaf, stem, and root extract had no significant effects on seed germination of green gram.

3.2.2. Plant height (cm)

The data on the effect of an aqueous extract of wild sunflower and sorghum on the plant height of cowpea have been presented in Table 5. Plant height was significantly varied (P<0.05) during 4 and 6 WAS when compared with a control (unweeded check). Significantly higher values of plant height were recorded with statistically alike treatments of the combined application of aqueous extract and hand weedings, while, significantly lowest plant height was recorded in the control (unweeded check) plot at 4 and 6 WAS.

Table 5. The effect of aqueous extracts of wild sunflower and sorghum on the plant height of cowpea.

Treatments	4 WAS	6 WAS
Wild Sunflower extract	40.29 ± 0.45^{b}	49.98 ± 0.65^{b}
Sorghum extract	40.78 ± 0.44^{b}	50.80 ± 0.45^{b}
Wild Sunflower + Sorghum extract	45.63 ± 0.46^{a}	54.49 ± 0.31^{a}
Hand weeding	44.26 ± 0.51^{a}	53.21 ± 0.29^{a}
Control (unweeded check)	37.27 ± 0.54^{c}	46.03 ± 0.36^{c}
F-Test	*	*

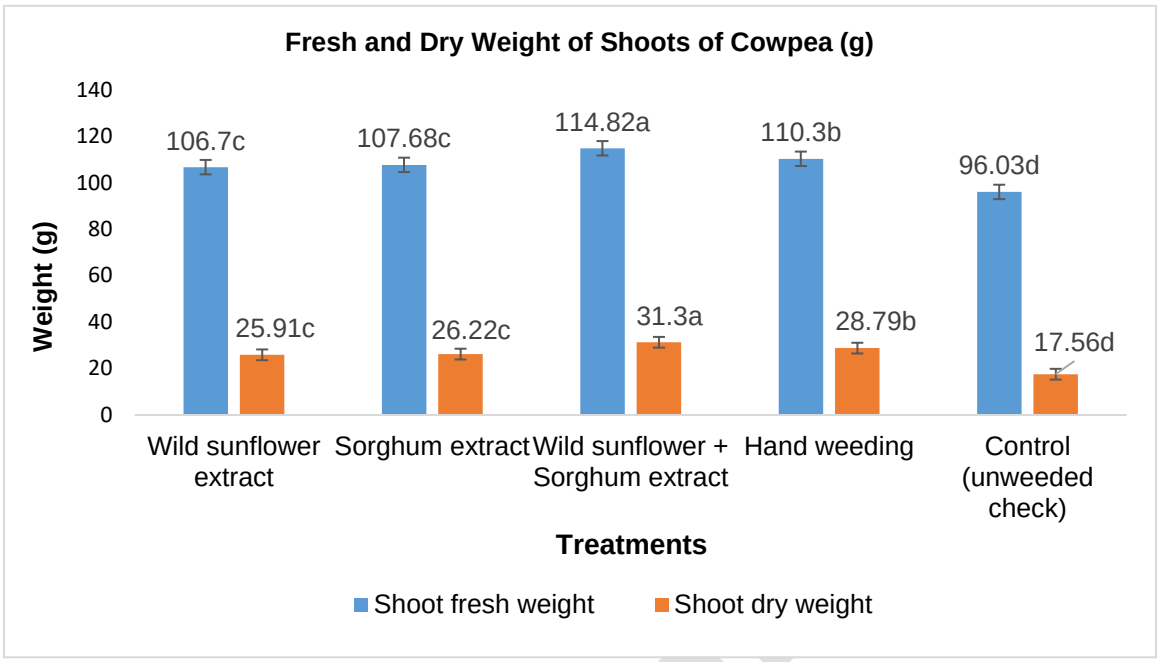
WAS- Weeks After Sowing; The value is the average of four replicates. The mean value in a column with a different letter or letters indicates that the difference is significant by Tukey's test at the 0.05 level of probability

These results might have been achieved as a result of more effective weed management, which allowed the cowpea plants to make the best use of theavailable resources, along with the nutrients present in the aqueous extract, which led to an increase in plant height. These results are consistent with the findings of Ajayi et al., [18] who reported that the allelopathic effect of wild sunflower and sorghum extract did not affect crop growth negatively.

3.2.3. Fresh and dry weight of Cowpea Shoots (g)

Figure 2 depicted the effect of aqueous extract of wild sunflower and sorghum on the fresh and dry weight of shoots of cowpea at 50 DAS. The fresh and dry weight of shoots were significantly (P<0.05) affected by the application of aqueous extract of wild sunflower and sorghum when compared with the control (unweeded check). Among the treatments, significantly highest shoot fresh and dry weight were recorded with the combined application of sunflower and sorghum plant extracts, and significantly lowest shoot fresh and dry weight were recorded in control (unweeded check).

It might be the result of positive interaction between soil microorganisms and the allelochemicals in the aqueous extracts, which might have helped in more availability of nutrients and increased the amount of fresh and dry weight shoot production. The results of this study corroborate with the findings of Oyerinde et al., [19] who found that an aqueous extract of wild sunflower greatly increased the shoot dry weight of maize, and Ajayi et al., [18] who found that an aqueous extract of sorghum and wild sunflower significantly enhanced shoot dry weight of cowpea



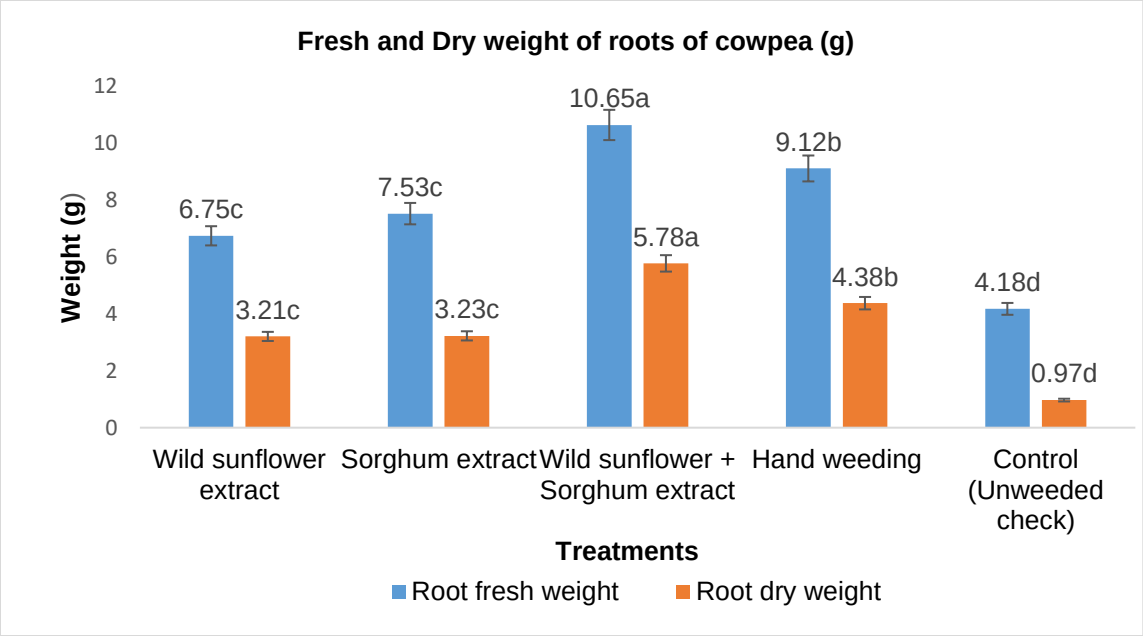
Error bar denotes a standard error of four replicates. The mean value in a column with a different letter or letters indicates that the difference is significant by Tukey's test at the 0.05 level of probability.

Figure 2. The effect of aqueous extract of wild sunflower and sorghum on the fresh and dry weight of shoots of cowpea at 50 DAS.

3.2.4. Fresh and dry weight of Cowpea roots (g)

The effect of an aqueous extract of wild sunflower and sorghum on the fresh and dry weight of roots of cowpea at 50 DAS has been shown in Figure 3. The fresh and dry weight of cowpearoots was significantly (P<0.05) affected by the application of aqueous extract of wild sunflower and sorghum when compared with the control (unweeded check). Among the treatments, significantly maximum shoot and fresh weight were recorded in the combined application of sunflower and sorghum extracts, and significantly lowest shoot and fresh weight were recorded in control (unweeded check).

These results have indicated higher stimulatory effects on the root fresh and dry weight than the shoot fresh and dry weight. The result might be due to the fact that roots have direct contact with the allelochemicals applied to the soil [21].



Error bar denotes a standard error.of four replicates. The letter 'ns' denotes a difference that is not significant at the probability level of 0.05. The mean value in a column with a different letter or letters indicates that the difference is significant by Tukey's test at the 0.05 level of probability.

Figure 3. The effect of aqueous extract of wild sunflower and sorghum on the fresh and dry weight of roots of cowpea at 50 DAS.

3.3. Yield parameters

3.3.1. Pods per plant

The data on the effect of an aqueous extract of wild sunflower and sorghum on the number of pods per plant of cowpea have been given in Table 6. The number of pods per plant was significantly (P<0.05) affected by the aqueous extract application of wild sunflower and sorghum when compared with the control (unweeded check). Significantly maximum number of pods was recorded with the combined application of sunflower and sorghum aqueous extracts followed by hand weedings, and significantly lowest number of pods was recorded in the control (unweeded check) plot.

Table 6. The effect of aqueous extract of wild sunflower and sorghum on the number of pods per plant of cowpea.

Treatments	Pods/plant
Wild Sunflower extract	19.12 ± 0.31^{c}
Sorghum extract	19.87 ± 0.42^{c}
Wild Sunflower + Sorghum extract	25.12 ± 0.31^{a}
Hand weeding	23.25 ± 0.14^{b}
Control (unweeded check)	15.87 ± 0.31^{d}
F-Test	*

The value is the average of four replicates. The mean value in a column with a different letter or letters indicates that the difference is significant by Tukey's test at the 0.05 level of probability

These resuls might be obtained due to the fact that the aqueous extract containing the allelochemicals might be responsible for controlling weeds. In addition, allelochemicals have improved the mineralization of nutrients and nutrient uptake, which led to greater nutrient absorption and an increase in the number of pods per plant [18] was recorded. These results are consistent with the findings of Ajayi et al., [18] who reported wild sunflower leaf extract had the highest number of pods compared with the control (unweeded check) plot.

3.3.2. Total yield (kg/ha)

The data on theeffect of an aqueous extract of wild sunflower and sorghum on the total yield of cowpea have been presented in Table 7. The total yield of cowpea was significantly (P<0.05) affected by the aqueous extracts application of wild sunflower and sorghum when compared with the control (unweeded check). The treatments of wild sunflower extract, sorghum extract, combined application of wild sunflower and sorghum aqueous extract and hand weeding increased the total yield by 20.5, 25.3, 62.84 and 45%, respectively compared with the control (unweeded check).

Table 7. The effect of aqueous extract of wild sunflower and sorghum on the total yield of cowpea.

Treatments	Total yield (kg/ha)
Wild Sunflower extract	1071.6 ± 18.7^{c}
Sorghum extract	1114.0 ± 19.7^{c}
Wild Sunflower + Sorghum extract	1447.4 ± 28.^{a}
Hand weeding	1289.6 ± 19.3^{b}
Control (unweeded check)	888.8 ± 16.2^{d}
F-Test	*

The value is the average of four replicates. The mean value in a column with a different letter or letters indicates that the difference is significant by Tukey's test at the 0.05 level of probability

The result might be obtained due to the fact that the aqueous extract of wild sunflower and sorghum controled the weed interference in cowpea plants during the critical period. According to Arif et al., [22] two foliar sprays of sorghum, sunflower, and brassica at 18 l/ha increased wheat grain yield. Ajayi et al., [18] reported that the wild sunflower and sorghum aqueous extract increased the yield of crop as compared to the unweeded check plot.

4. CONCLUSION

Different weed control treatments had a substantial impact on weed population & dry weight, growth and yield of cowpea. Hand weeding was found to be most effective for controlling weeds than the other treatments. After hand weeding, combined application of wild sunflower and sorghum aqueous extracts were found to be the effective treatment for suppressing weed. Hand weeding and the combined application of aqueous extracts of wild sunflower and sorghum significantly suppressed the weeds by 82.98 and 54.39%, respectively. Furthermore, when compared to the control (an unweeded check), hand weeding and combined application of aqueous extracts of wild sunflower and sorghum significantly improved yield by 45.09% and 62.85% respectively. The combined application of aqueous extract from different plants did not achieve the same level of weed reduction as the conventional methods (herbicide and hand weeding), however, had pronounced effect in increasing the yield attribute and yield of cowpea. From the present study, it can be concluded that combined application of aqueous extract of wild sunflower and sorghum could be an organic alternative to synthetic herbicides for achieving acceptable weed control, better growth and getting higher yield in cowpea, since it is less labor-intensive and have no negative impacts on the environment and human health.

Conference disclaimer:

Some part of this manuscript was previously presented and published in the conference: 3rd International Symposium on Agriculture 2023, Self-Sustaining Agriculture: Way Forward for Food Security and Safety dated from 9th March, 2023 in Sri Lanka, Web Link of the proceeding: https://www.fag.esn.ac.lk/sites/default/files/2023-03/Proceedings%20of%20the%20ISA-2023.pdf

REFERENCES

[1] Belay F, Gebreslasie A, and Meresa H. Agronomic performance evaluation of cowpea [*Vigna unguiculata* (L.) Walp] varieties in Abergelle District. Northern Ethiopia. Journal of Plant Breeding and Crop Science. 2017; 9(8):139-143.

[2] Anonymous. Department of Census and Statistics. Highland Crops Time Series Data. 2022. http://www.statistics.gov.lk/Agriculture/StaticalInformation/HighlandCrops.

[3] Alemu M, Asfaw Z, Woldu Z, Fenta B. A, and Medvecky B. Cowpea (*Vigna unguiculata* (L.) Walp.) (Fabaceae) landrace diversity in northern Ethiopia. International Journal of Biodiversity and Conservation. 2016; 8(11); 297–309.

[4] Adigun J, Osipitan A. O, Lagoke S. T, Adeyemi R. O, and Afolami S. O. Growth and yield performance of cowpea (*Vigna unguiculata* (L.) Walp) as influenced by row-spacing and period of weed interference in South-West Nigeria. Journal of Agricultural Science. 2014; 6(4): 188.

[5] Renton M, and Chauhan B. S. Modelling crop-weed competition: Why, what, how and what lies ahead?. Crop Protection. 2017; 95: 101-108.

[6] Monteiro A, and Santos S. Sustainable approach to weed management: The role of precision weed management. Agronomy. 2022; 12(1): 118.

[7] Madukwe D. K, Ogbuehi H. C, and Onuh M. O. Effect of weed control method on the growth and yield of cowpea (*Vigna unguiculata* (L) Walp) under Rain- fed condition Owerri. American-Eurasian Journal of Agriculture and Environment Sciences. 2012; 12(11):1426-1430.

[8] Tripathi S. S, and Singh G. Critical period of weed competition in summer cowpea [*Vigna unguiculata* (L.) Walp.]. Indian Journal of Weed Science. 2001; 33(1&2): 67-68.

[9] Yadav T, Nisha K. C, Chopra N. K, Yadav M. R, Kumar R, Rathore D. K, Sonil P.G, Makarana G, Tamta A, Kushwah M, Ram H, Meena R.K, and Singh M. Weed management in cowpea-A review. International Journal of Current Microbiology and Applied Sciences. 2017; 6(2); 1373-1385.

[10] Duke S. O. Proving allelopathy in crop–weed interactions. Weed Science. 2015; 63(SP1): 121-132.

[11] Cheema Z. A, Farooq M, and Khaliq A. Application of allelopathy in crop production: success story from Pakistan. In Cheema Z. A, Farooq M, and Wahid A (Eds.), Allelopathy (pp. 113-143). Springer, Berlin, Heidelberg, Germany.2013.

[12] Musyimi D. M, Kahihu S. W, Buyela D. K, and Sikuku P. A. Allelopathic effects of Mexican sunflower [*Tithonia diversifolia* (Hemsl) A. Gray] on germination and growth of spiderplant (*Cleome gynandra* L.). Journal of Biodeversity and Environmental Sciences. 2012; 2(8): 26-35.

[13] Mahmood A. R. I. F, and Cheema Z. A. Influence of sorghum mulch on purple nutsedge (*Cyperus rotundus* L.). International journal of agriculture and biology. 2004: 6(1): 86-88.

[14] Awan F. K, Rasheed M, Ashraf M, and Khurshid M. Y. Efficacy of brassica, sorghum and sunflower aqueous extracts to control wheat weeds under rainfed conditions of Pothwar, Pakistan. The Journal of Animal and Plant Sciences. 2012; 22(3): 715-721.

[15] Ghimire B. K, Hwang M. H, Sacks E. J, Yu C. Y, Kim S. H, and Chung I. M. Screening of allelochemicals in *Miscanthus sacchariflorus* extracts and assessment of their effects on germination and seedling growth of common weeds. Plants. 2020; 9(10); 1313.

[16] Mubeen K, Nadeem M. A, Tanveer A, and Zahir Z. A. Allelopathic effects of sorghum and sunflower water extracts on germination and seedling growth of rice (*Oryza sativa* L.) and three weed species. The Journal of Animal and Plant Sciences. 2012; 22(3): 738-746.

[17] Farooq M, Bajwa, A.A, Cheema S.A, and Cheema Z.A. Application of allelopathy in crop production. International Journal of Agriculture and Biology. 2013; 6: 1367-1378.

[18] Ajayi O. A, Akinola M. O, and Rasheed O. A. Allelopathic potentials of aqueous extracts of *Tithonia Diversifolia* (Hemsley) A. Gray in biological control of weeds in cowpea cropping system. International Journal of Agriculture and Economic Development. 2017; 5(1): 11 - 28.

[19] Oyerinde R. O, Otusanya O. O, and Akpor O. B. Allelopathic effect of *Tithonia diversifolia* on the germination, growth and chlorophyll contents of maize (*Zea mays* L.). Scientific Research and Essay. 2009; 4(12): 1553-1558.

[20] Moosavi A, Afshari R. T, Asadi A, and Gharineh M. H. Allelopathic effects of aqueous extract of leaf stem and root of *Sorghum bicolor* on seed germination and seedling growth of *Vigna radiata* L. Notulae Scientia Biologicae. 2011; 3(2): 114-118.

[21] Ilori O.J, Otusanya O, and Adelusi A. Phytotoxic effects of *Tithonia diversifolia* on germination and growth of *Oryza sativa*. Research Journal of Botany.2007; 2: 23-32.

[22] Arif M, Cheema Z.A, Khaliq A and Hassan A. Organic weed management in wheat through allelopathy. International Journal of Agriculture and Biology. 2015; 17 (1): 127-134.