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Potentials of botanicals, solar radiation, and muslin cloth for the management of cowpea bruchid (*Callosobruchus maculatus* F.) on stored cowpea (V*igna unguiculata* L.)

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Callosobruchus maculatus **is the major field-to-store insect pest of stored cowpea in the tropics and sub-tropics. Despite the serious hazards to humans, livestock, and the environment, fumigants and residual insecticides are the main control methods used by farmers for cowpea protection. This study aims at evaluating the efficacy of crude extracts of botanicals (neem, water hyacinth, and soursop) in combination with solar radiation (at 0-, 48-, and 72-h) and muslin cloth for the management of** ***C. maculatus*****. Fifteen grams of infested cowpea were treated with 0.3 ml of the botanicals leaf extracts, covered with either, a black, white muslin cloth, or net, and exposed to solar radiation. Adult mortality, the number of eggs laid, and the percentage of weight loss of seeds were evaluated. Results revealed 100% adult mortality on cowpea treated with botanicals, covered with black muslin, and net after 48-h of exposure. There were fewer eggs laid on seeds treated with botanicals after 48-h of exposure. It also revealed differences in weight loss of treated and untreated cowpea seeds after 48-h of exposure. The study shows that seeds treated with neem, covered with black muslin, and exposed to 72-h of solar radiation were effective in controlling** ***C. maculatus*****.**

Key words: *Callosobruchus maculatus*, botanicals, solar radiation, muslin cloth, neem, water hyacinth, soursop.

INTRODUCTION

Cowpea (*Vigna unguiculata* (L.) Walp.) is a dicotyledonous herbaceous crop in the order Fabaceae. growth forms vary and may be erect, trailing, climbing, bushy, or sub-erect usually indeterminate annual plant under favourable conditions, 15-80 cm in height with leaves that are alternate and trifoliate usually dark green and petioles 5-25 cm long (FAO, 2004, Doumbia et al., 2013). The seeds vary considerably in size, shape and colour, with sizes ranging from 2 to 12 mm long, and weighing 5 to 30 g/100 seeds and usually with 8 to 20 seeds/pod (FAO, 2004; Timko and Singh, 2008). The structure of a mature cowpea plant is influenced by the genotype and some environmental conditions which range from temperature and photoperiods which may cause the plant to be erect, prostrate, trailing or climbing (Timko and Singh, 2008).

Cowpea is a multipurpose crop, providing food for humans and feed for livestock. Cowpea is also a cash-

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generating commodity for farmers, and small and medium-sized entrepreneurs (Kristjanson et al., 2001).

Callosobruchus maculatus F. (Coleoptera: Bruchidae), a major insect pest of stored cowpea has been reported by various authors as cosmopolitan in distribution, polyphagous in nature, and found in the tropics and subtropics. It is commonly known as the cowpea weevil or bean beetle due to its affinity to stored legumes (Umeozor, 2005). Adult females lay eggs on the seed coat and the larvae develop exclusively within the seeds at the expense of the grain endosperm and embryo, causing damage to the seeds (Ouédraogo et al., 1996). Several generations of the flightless form of *C. maculatus* can therefore overlap in stocks during cowpea postharvest storage in West Africa (Murdock et al., 2003). Cowpea postharvest storage is constrained by the infestation of pods or seeds by *C. maculatus*, a major insect pest of cowpea (Sanon et al., 2005; Adedire et al., 2011). The attack by *C. maculatus* begins in the field such that at harvest the seed infestation rate is between 1 and 5%, subsequently causing significant losses after a few months of storage (Sanon et al., 2005). Annual losses by *C. maculatus* have been estimated to be from 10 to 50% during storage (Adedire et al., 2011). Udo and Henry (2013) pointed out that a loss of between 20 and 50% can result in stored cowpea due to an attack by *C. maculatus* and in extreme cases, the loss may be up to 100%. According to Caswell (1980), about 4% of the annual production of cowpea or about 30,000 tonnes valued at over $30 million is lost annually to the cowpea bruchids in Nigeria alone. Oluwafemi (2012) reported that *C. maculatus* is regarded as the major insect pest of cowpea, which causes serious losses in cowpea seeds by the perforation of the seed and reduction in weight, market value and germination ability.

Currently, the management of insect pests in stored cowpea relies primarily on the use of fumigants and residual insecticides (inorganic chemicals) both of which pose serious hazards to humans, livestock, and the environment.

The use of plant materials (botanicals) for the protection of crops and stored commodities against insect attack has been on the rise in the last decade because it is safe and benign to the environment (Sanon et al., 2005). Tissues of higher plants contain arrays of biochemicals, known as “secondary plant chemicals” (or allelochemicals), which are defensive in function, such as alkaloids, steroids, phenolics, saponins, resins, essential oils, various organic acids and other compounds. It is well known that secondary plant metabolites may act as kairomones, allomones, stimulants or deterrents of feeding and oviposition, and as antifeedants, insecticides and insect hormone mimics (Said and Pashte, 2015). In a study by Ilesanmi and Gungula (2010) on the preservation of cowpea using neem and moringa seed oils, cowpea was treated with pure concentrations of neem and moringa oils, and their mixtures resulted in better protection for cowpea against insect pest infestation. Ekeh et al. (2013) tested the effectiveness of botanical powders against *C. maculatus* on some stored leguminous grains (*V. unguiculata. Vigna subterranean*, and *Cajanus cajan)* under laboratory conditions. Their result showed that the powders of these botanicals were effective in suppressing damage caused by *C. maculatus*. In the study to evaluate five botanicals as protectants against cowpea bruchids, Asawalam and Anaeto (2014) showed that the botanicals gave protection to the stored cowpea seeds compared with the control. They further showed that the total number of *C. maculatus* adults that emerged from untreated control progressively increased with time of exposure compared to the other treatments. In another study on the repellence and toxicological activity of the root powder of the invasive alien plant, *Chromalaena odorata* against *C. maculatus*, Uyi and Igbinoba (2016) showed that the root powder of *C. odorata* significantly repelled *C. maculatus*. They found out that *C. odorata* root powder caused mortality of *C. maculatus* and that mortality was dependent on concentration and exposure time. While findings by Obembe and Ogungbite (2017) on the comparative insecticidal activities of some botanical powders and pirimiphos-methyl against *C. maculatus* infestation on cowpea seeds showed that insecticidal activities of their powders considerably reduced the number of adult *C. maculatus* that emerged and effectively protected the cowpea seeds during storage for five weeks. They concluded that the insecticide powders from the botanicals used were more effective in protecting *C. maculatus* compared to chemical insecticide. The research by Adebayo and Anjorin (2018) to assess the entomocidal effect of solar radiation on the management of cowpea weevil in stored cowpea, indicated that the exposure to solar radiation caused mortality, inhibited egg-laying and embryonic development of *C. maculatus* resulting in the inhibition of the emergence offspring. This led to the conclusion that solar radiation could be an effective method of postharvest management of cowpea seeds from cowpea bruchids. The findings of Yusuf et al. (2019) on the suppression of the damaging effects of *C. maculatus* by plant powders of *Azadirachta indica, Piper guineense* and *Cymbopogon citratus* showed that all the botanicals gave protection to the stored cowpea seeds and significantly reduced the mean adult emergence and seed weight loss caused by *C. maculatus* when compared with the untreated control. The study by Deme et al. (2019) on the insecticidal effects of *Cassia tora* and *Cassia alata* against the cowpea weevil showed that the mortality of adult *C. maculatus* was higher when treated with a powdered mixture of both plant materials. The result of the study also showed that the combination of these two plants can be used in the control of adult *C. maculatus* in the storage of cowpea.

Ajayi et al. (2021) evaluated the efficacy of solar heat treatment using double-layered black polypropylene sheets in suppressing the development of the cowpea

Table 1. Plant species used as botanicals in the current study.

Plant	Common Name	Family
A. indica	Neem	Meliaceae
A. muricata	Soursop	Annonaceae
P. crassipes	Water hyacinth	Pontederiaceae

Source: The tables where generated from data of the experiment.

bruchid eggs and the effect of the heat absorbed on the germination potential of the cowpea seeds. Their result showed that cowpea seeds exposed to solar radiation for 24 h resulted in 100% egg mortality. They, therefore, concluded that 24-hours exposure of cowpea to solar radiation could be the thermal death point of *C. maculatus* eggs. In the findings by Fawki et al. (2014) on the use of solar energy, lemon, orange and citrus peel powders to control cowpea beetles using a metal-box heater with different exposure times of between 5 and 20 min. The result showed 100% mortality with the box heater at 15 min. However, the lemon and citrus peel powder was more effective than orange peel powder due to their higher repellence activity. They concluded that the combination of solar energy and botanicals is good for the management of *C. maculatus* on stored cowpea.

The use of solar radiation to sun-dry pods and suppress pest damage on stored cowpea seeds are prevalent in farming communities in sub-Saharan Africa (Peter and Sule, 2019) where peasants sun-dry their produce/ products on mats, flat stones, etc (Ajayi et al., 2021). Exposure of cowpea infested by insect pests to solar radiation tends to kill them due to their sensitivity to heat and high temperature (Peter and Sule 2019). However, Ajayi et al. (2021) stated that exposing cowpea seeds to solar radiation alone in the open is less efficient due to constant air current, which may cause a fluctuation in the amount of heat absorbed by the seed making it less fatal to the insects. Thus, the use of enclosed containers can be effective as the air current encountering the seeds will be reduced. This study aims at evaluating the efficacy of crude extracts of selected botanicals in combination with solar radiation and different muslin cloth for the management of *C. maculatus* in stored cowpea.

MATERIALS AND METHODS

Experimental site

The experiment was conducted in the General Laboratory of the Department of Crop and Soil Science, University of Port Harcourt, Rivers State, Nigeria.

Experimental materials

Cowpea variety Bakologi, purchased in Jos, Plateau State, Nigeria was used in the study. Three (3) botanicals namely, Neem leaves (*A. indica*) obtained from the Oil Mill market in Port Harcourt, Soursop leaves (*Anona muricata*) obtained from the University of Port Harcourt Institute of Agricultural Research and Development Farm, and water hyacinth (*Pontederia crassipes*) obtained from a creek in Omoku, Rivers State, Nigeria shown in Table 1.

Culture and maintenance of *C. maculatus*

Adults *C. maculatus* was sourced from previously infested beans obtained from Rumuokoro market in Port Harcourt, Rivers State, Nigeria. The adult insects were cultured in eight 4-L plastic containers each with beans and were left for 7 days to allow the adult females *C. maculatus* to mate and oviposit. The containers were covered with a fine net holding them properly with the container lids to allow aeration and prevent possible escape of the adult bruchids. After oviposition, bruchids were sieved out and culture left until F_1 generation. The F_1 cohorts were used for the experiment.

Sterilization of cowpea seeds

Before the commencement of the experiment, about 1500 g of cowpea was sterilized in a refrigerator for about 4 weeks at -4°C. Before the experiment was set up, the cowpea seeds were removed from the refrigerator and kept on the laboratory bench to acclimatize for 48-h at room temperature.

Collection and extraction of botanicals

Fresh leaves of *A. indica*, *A. muricata* and *P. crassipes* were washed, air-dried and milled into a powder using a dry mill blender. The ground leaves weighed were 119.0 g for neem, 135.3 g for water hyacinth and 162.4 g for soursop. These were sent to the Plant Science and Biotechnology laboratory at the University of Port Harcourt for extraction using the Soxhlet extractor apparatus (Rani and Jamil, 1989). The botanical powders were placed in glass jars and the solvent (petroleum ether) was poured into the glass jars containing the extracts and left for an hour. After that, the solvent and extract in the jars were sieved into a cellulose thimble, which was then placed in the Soxhlet extractor. The mixture was heated until all the solvent evaporated through the condenser and it dripped into a conical flask. This process ran for about 8-h. Dried leaves yielded 13.5 g crude extract of neem, 47.0 g of soursop and 2.4 g of water hyacinth.

Experiment set-up

Fifteen grams of cowpea seeds were weighed and put in 4 ml plastic containers for the experiment. Each container was infested with 3 pairs of sexed *C. maculatus* adults. A total of 108 containers were infested. The adults could be easily sexed with their abdomen's distinctive shape and length. Males had comparatively

Table 2. Effect of botanicals on the percentage adult mortality of *C. maculatus* bred on stored cowpea covered with white, black muslin cloth and net exposed to 48- and 72-h of solar radiation.

Treatment	Exposure time								
	0 h			48 h			72 h		
	Black	White	Net	Black	White	Net	Black	White	Net
Neem	88.89±11.11[cd]	83.33±9.62[cd]	55.56±11.11[ab]	100.00±0.00[a]	100.00±0.00[b]	100.00±0.00[a]	100.00±0.00[a]	100.00±0.00[a]	100.00±0.00[a]
Soursop	61.11±5.56[ab]	61.11±5.56[ab]	50.00±9.62[ab]	100.00±0.00[a]	94.44±5.56[b]	100.00±0.00[a]	100.00±0.00[a]	100.00±0.00[a]	100.00±0.00[a]
W. hyacinth	66.67±0.00[bc]	66.67±9.62[abc]	61.11±11.11[bc]	100.00±0.00[a]	94.44±5.56[b]	100.00±0.00[a]	100.00±0.00[a]	100.00±0.00[a]	100.00±0.00[a]
Control	44.44±5.56[a]	44.44±5.56[a]	38.89±22.22[a]	100.00±0.00[a]	55.56±27.78[a]	100.00±0.00[a]	100.00±0.00[a]	100.00±0.00[a]	100.00±0.00[a]

Means followed by the same letter in a column are not significantly different at $p \leq 0.05$.
Source: The tables where generated from data of the experiment.

shorter abdomen and the dorsal side of the terminal segment was sharply curved downwards and inwards. In contrast, the females had comparatively longer abdomens, and the terminal segment's dorsal side was slightly bent downwards (Bandara and Saxena, 1994). This was done with the aid of a paintbrush, which easily conveyed the insects from the culture jars to the experimental containers. After infestation, some containers were covered with a white muslin cloth, black muslin cloth and none (covered with net) which served as a control. They were allowed to mate and oviposit for seven days on the cowpea seeds, after which the insects were removed from each container.

Application of crude extracts

The crude extracts of water hyacinth, *P. crassipes, A. indica*, and *A. muricata* each were dissolved in 100 ml of acetone giving a 0.25% concentration for each extract. The mixture was stirred continuously and applied on filter paper. This was left for about 5 min to ensure that all acetone had evaporated. It was then placed in the container, with the cowpea seeds and infested with the insects.

Exposure to solar radiation

Exposure of infested seed to solar radiation was conducted following the procedure described by Ajayi et al. (2021) with some modifications. White and black muslin cloths were used as a top cover for the experimental containers and held tightly with the lid of the plastic containers already cut open at the centre. These were exposed to solar heat for 48- and 72-h. A control (0 h exposure) was laid out in the laboratory and not exposed to solar heat. This was carried out in a complete randomized design and replicated 3 times. The exposure period was carried out from sunrise to sunset for each day and the treatment was removed and kept in the laboratory throughout the night and brought out the next day to continue the solar radiation treatment until the individual exposure period (48- and 72-h) were met.

Experimental design

The experiment was laid out in a 4×3×3 factorial design of which 3 botanicals (neem, soursop, and water hyacinth) were used, with a control (no botanical), 3 fabrics of a fine net, white and black muslin and 3 solar radiation regimes of 0- (no exposure to solar radiation. samples were left in the laboratory) 48- and 72-h solar radiation exposure.

Data collection

Data on adult mortality, the number of eggs laid, and the percentage of weight loss of cowpea seeds were collected.

Statistical analysis

Statistical analysis was done using the R-Software (4.1.1) base package and Agricole version (1.3.5) package.

RESULTS

Table 2 shows adult C. maculatus mortality on cowpea treated with crude extracts of the botanicals and covered with white and black muslin cloth exposed to 48- and 72-hours solar radiation. The result shows that all insects introduced into cowpea seeds treated with the different botanicals and covered with black muslin cloth and net died after 48-hours of solar radiation exposure. Although, the insects in cowpea treated with soursop, water hyacinth and control did not reach 100% mortality after 48-hours, however, all insects died after 72-hours of exposure to solar radiation. The result also shows that all untreated control and treated cowpea that were not exposed to solar radiation had lower mortality; however, it was not significantly different from cowpea treated with water hyacinth and covered with a white or black muslin cloth.

Table 3 shows the effect of crude extracts of the botanicals on the number of eggs laid by adult females of *C. maculatus* on cowpea covered with white, black muslin cloth and net exposed to 48- and 72-h solar radiation. The result shows that there were significant differences in the number of eggs laid on botanicals treated and untreated

Table 3. Effect of botanicals on the number of eggs laid by C. *maculatus* females on stored cowpea covered with white, black muslin cloth and net exposed to 48- and 72-h of solar radiation.

Treatment	Exposure time								
	0 h			48 h			72 h		
	Black	White	Net	Black	White	Net	Black	White	Net
Neem	1.00±1.00[a]	2.67±2.52[ab]	4.33±3.71[a]	1.00±0.58[a]	1.33±0.67[bc]	1.00±0.58[ab]	1.00±0.58[a]	1.67±1.53[ab]	2.00±0.58[bc]
Soursop	3.67±2.52[bc]	2.33±2.08[ab]	4.00±0.58[a]	1.67±2.08[a]	0.67±0.58[ab]	2.00±0.00[bc]	1.67±0.58[bc]	3.33±1.53[bc]	0.67±0.5[a]
W. hyacinth	2.33±0.88[b]	2.00±0.58[a]	4.33±0.88[a]	1.00±0.00[a]	1.67±0.88[c]	1.67±0.58[bc]	1.67±0.88[bc]	1.00±0.58[a]	1.00±0.58[ab]
Control	7.00±1.00[d]	5.67±0.88[c]	10.00±5.86[b]	6.33±2.33[b]	4.67±6.43[d]	4.33±3.71[d]	1.33±0.88[ab]	1.00±0.00[a]	0.33±0.58[a]

Means followed by the same letter in a column are not significantly different at p≤0.05.
Source:The tables where generated from data of the experiment.

Table 4. Effect of botanicals on the percentage weight loss (grams) of stored cowpea covered with white, black muslin cloth and net exposed to 48- and 72-h of solar radiation.

Treatment	Exposure time								
	0 h			48 h			72 h		
	Black	White	Net	Black	White	Net	Black	White	Net
Neem	22.98±0.73[a]	25.06±1.25[b]	23.78±0.99[ab]	11.15±1.04[ab]	10.30±1.39[b]	12.98±0.14[bc]	10.25±0.55[c]	8.48±0.21[b]	11.81±0.15[bc]
Soursop	23.74±1.52[a]	23.46±1.72[ab]	23.10±0.19[ab]	18.18±0.60[c]	15.62±0.51[c]	16.87±0.95[c]	10.90±1.30[c]	12.97±0.60[bc]	10.70±0.84[bc]
W. hyacinth	24.35±1.39[a]	23.18±1.59[ab]	25.02±0.95[bc]	9.92±1.48[a]	9.37±0.53[b]	9.09±0.98[ab]	7.49±0.23[b]	11.02±0.89[bc]	9.58±0.19[b]
Control	34.26±3.00[b]	36.21±1.41[c]	39.37±0.25[c]	11.02±5.17[ab]	5.15±1.54[a]	5.11±0.89[a]	2.20±1.41[a]	2.49±1.29[a]	3.84±0.79[a]

Means followed by the same letter in a column are not significantly different at p ≤ 0.05.
Source: The tables where generated from data of the experiment.

cowpea seeds left in the laboratory. Fewer eggs were laid on cowpea seeds treated with botanicals compared to the control without solar radiation. The result also showed that the cowpea seeds treated with soursop, covered with white muslin cloth had more eggs laid on them even when exposed to 72-h solar radiation compared to cowpea treated with neem and water hyacinth, covered with net with the same exposure time.

Table 4 shows the effect of crude extracts of the botanicals on the percentage weight loss of cowpea covered with white, black muslin cloth and net after exposure to 48- and 72-h of solar radiation. The result shows that all cowpea exposed to solar radiation had a lower weight loss compared to those kept in the laboratory.

Seeds without treatment and exposed for 48- and 72-h had a lower weight loss compared to those that were treated with botanicals irrespective of the colour of muslin cloth or net used. The result also showed that seeds without treatment kept in the laboratory had a greater weight loss than those treated with botanicals.

DISCUSSION

This study was on the efficacy of botanicals in combination with solar radiation and muslin cloths for the management of stored cowpea against the cowpea bruchid. Lale and Vidal (2003b) showed that exposing cowpea grains to a temperature of 50°C in an oven also killed all immature stages (eggs, larvae and pupae) of C. maculatus within the seeds.

Muslin cloth had a lethal effect on the adults and reduced oviposition by females of *C. maculatus*. Studies have shown that exposure to solar radiation alone is lethal to a wide range of insect pests of stored products. In general, insects have a temperature range with a lower and higher threshold, below or above which they do not survive (Fields, 1992; Lale and Maina, 2002).

In their study, Lale and Vidal (2003a) showed that total mortality of adult *C. maculatus* and *Callosobruchus subinnotatus* on cowpea was achieved after 6 h of exposure to solar radiation. The study also showed that there was an increase in the mortality of adult bruchids as exposure to solar radiation increased from 0- to 48-h with those covered with black muslin cloth and sieve achieving 100% mortality. Black as a colour absorbs heat because of specific properties of the colour and of the light. When light shines on an object, the object's colour either absorbs or reflects the light. Black absorbs light and white reflects it. Studies have also shown that the botanical *A*. *indica* contains Azadirachtin which has an extremely low mammalian toxicity and is the least toxic of the commercial botanical insecticides, with an LD50 of 13,000 mg/kg (Ekeh et al., 2013). It is considered a contact poison, with some systemic activity in plants when applied to the foliage, generally non-toxic to beneficial insects and mites, but has a broad mode of activity, working as a feeding deterrent, insect-growth regulator, repellent, and sterilant; and it may also inhibit oviposition (Ekeh et al., 2013, Rembold, 1989). One of the most effective essential oils (EO) for the protection of stored seeds is that of *Ocimum canum* which has been remarkable in all the studies conducted. It is mostly composed of 1,8-cineole (Nébié, 2006), a compound with previously known biological activity against many storage insect pests (Obeng-Ofori et al., 1997). Trials have been conducted using EO for the protection of cowpea in storage (Ilboudo, 2009; Ilboudo et al., 2015), and several factors can affect the effectiveness of EO in stored cowpeas (Sanon, 2018). Thus, Ilboudo et al. (2015) showed that the efficacy of *Hyptis spicigera* and *Lippia multiflora* EO is dependent on the amount of cowpea seed treated, whereas this factor does not influence the activity of *O. canum* and *Hyptis suaveolens* EOs using up to 7 applications of EO over 4 months of cowpea storage, it was shown that the efficiency of EOs does not depend on the number of applications but their specificity and their chemical composition (Ilboudo et al., 2015).

The difference in mortality between botanicals observed at 48 h may be a result of the combination of the chemical compound contained in the botanicals and the high temperature inside the container due to the materials they are covered with. The black material absorbs heat which increases the temperature in the container beyond the bruchid higher threshold. Similarly, the net material is perforated which allows solar radiation to pass through, also heating the container beyond the bruchid high threshold. However, the white-coloured muslin cloth reflects solar radiation, thus having a lower temperature within the container.

An increase in the solar radiation duration also reduced the egg lay of female *C. maculatus* compared to the control. This agrees with work by Adebayo and Anjorin (2018) which showed that increased exposure of *C. maculatus* to solar radiation reduced the eggs laid compared to those with shorter solar radiation duration and those not exposed at all. This low level of eggs laid by the insects with an increased solar radiation exposure could be explained by the behavioural response of the bruchids, seeking shelter from the heat underneath the cowpea seeds and the filter paper on which the seeds were placed. Although, Lale and Vidal (2003b) showed that exposing cowpea grains to a temperature of 50°C in pupae) of *C. maculatus* within the seeds. This temperature exposure time was recorded as the thermal point of *C*. *maculatus* (Murdock et al., 1991). It is also further explained by Doumma (2006) that the exposure of cowpea pods to solar radiations for up to four weeks considerably limits the evolution of populations of beetles and their parasitoids. According to Cruz et al. (1988), when the water content of the seeds is very low, the eggs' hatching is inhibited, and the larvae fail to develop. This also promotes the departure of adult beetles that cannot tolerate extreme heat or intense sunlight.

Weight loss was lower in cowpea seeds exposed to solar radiation for 48- and 72-h and treated with the botanicals, this was consistent with the result obtained by Sembene et al. (2006) on groundnut where the authors showed that under extreme temperatures over 33°C, weight loss caused by *Caryedon serratus* was reduced. In another experiment, 1 h of exposure to solar radiation in a device used by Murdock et al. (2003) was enough to kill all stages of *C. serratus*, which help reduce infestation on groundnut and prevented a significant weight loss.

The results also showed that seeds exposed to solar radiation and treated with neem leaf extract and water hyacinth leaf extract had high mortality in the adults and eggs laid. This is comparable to the results of Rani and Jamil (1989) who showed that cowpea treated with water hyacinth extract, was remarkably effective on the mortality of *C. maculatus*. The water hyacinth extract also had an immediate knockdown effect on the larvae of *Tribolium castaneum*. The study by Maina and Lale (2004) also shows that integrating solar radiation for 1 h or 2 h with 0.04 or 0.08 ml of neem seed oil reduced considerably the population of adult progeny that developed in cowpea seeds. No adult progeny developed in seeds exposed to solar heat for 4 h (Lale and Maina, 2002). The study also showed that the number of eggs laid was also reduced.

According to Shinichi et al. (2008), solar absorbance of fabrics does not depend on direct and diffuse solar radiation but the material and colour of the fabric hence the use of black and white muslin cloth, as black absorbs heat thus increasing the temperature and white reflecting heat thus not giving as much heat as the black muslin cloth. The combination of black muslin cloth and solar radiation gave high mortality with neem botanical, which reduced the emergence of adult bruchids. This result agrees with the findings of Ajayi et al. (2021) on the impact of solar heat enhanced with black propylene sheet in the development of *C. maculatus.* They recorded higher mortality of the adult and immature stages of the insect pests under solar radiation than when left under ambient temperature. This also corroborates the findings of Peter and Sule (2019) who showed that cowpea bruchids infesting cowpea seeds exposed to solar radiation in black polypropylene sheets had lesser progeny development than the control.

Conclusion

This study was limited by the non-identification of the active ingredients of the crude extracts of the botanicals. However, the study highlights the potential of the botanicals (*P. crassipes* and *A. muricata*), solar radiation and muslin (black and white) to effectively suppress the infestation of cowpea seeds by *C. maculatus* during storage. The results also showed that this treatment combination significantly suppressed the number of *C. maculatus* eggs laid and adults that emerged without adversely affecting the cowpea seed weight. Overall, the study suggests that with the combination of botanicals, 72-h solar radiation exposure, and the use of black muslin cloth, a 100% mortality of *C. maculatus* can be achieved without significantly reducing the weight of the cowpea seeds. Therefore, considering the ease, safety, and affordability of these botanicals, solar radiation and black muslin cloth, this technique is recommended for its adoption for the management of *C*. *maculatus* on cowpea seeds in the Niger Delta region of Nigeria.

RECOMMENDATION

Post-harvest losses caused by *C. maculatus* are a major constraint to cowpea production and storage and the improper use of synthetic insecticides by most farmers has resulted in environmental and health hazards and the development of insecticide resistance in insects. From the study, the use of neem, black muslin cloth and fine net with 72-h solar radiation exposure, have been found to inhibit the growth, development, oviposition, and most importantly caused severe mortality of adult *C. maculatus*. This study, therefore, recommends to farmers, especially subsistence farmers that, in a bid to find a safe, biodegradable and an inexpensive means or strategy to reduce or prevent post-harvest losses of cowpea, the use of botanicals, especially crude neem extract, in combination with solar radiation and black muslin cloth is recommendable. Further investigations should be conducted with the EOs of *P. crassipes* and *A. muricata* to identify their active ingredients and optimize their potential.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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