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Orange peel powder and cypress ash affecting bean weevil (*Acanthoscelides obtectus*) and preserving seed viability

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Common bean *Phaseolus vulgaris* is highly attacked during storage by *Acanthoscelides obtectus* which reduces seeds quantity, quality and germination rate. Due to the hazards of synthetic chemicals to humans and the environment, there is a need to promote the application of phytochemicals. Orange peel powder, cypress leaf ash and their mixture were assessed against *A. obtectus* and to determine their influence on seed germination. Four concentrations (5, 10, 20 and 30 g/kg) of the botanicals were applied. Analysis of essential oil extracted from *Citrus sinensis* revealed limonene as the main volatile (90.77%). Orange peel powder was less effective against *A. obtectus* with 12.5 % mortality at the content of 30 g/kg within 5 days post exposure. Cypress ash and its combination with orange peel powder recorded 98% and 86% mortality respectively within the same period. The tested formulations were effective in inhibiting F_1 progeny thereby leading to less grain damage and weight loss. In addition, there was no significant effect of botanicals on stored seeds about the germination rate. Both plant products could be a major component for the protection of beans against *A. obtectus* attacks because it is easy to wash the treated seeds to remove residue of botanicals.

Key words: Botanicals, bioactivity, *Acanthoscelides obtectus*, common beans, germination.

INTRODUCTION

Crop cultivation is integral to the economy of every African nation and plays a crucial role in the overall development of a significant portion of the population (Giller et al., 2021). Over half of sub-Saharan Africa (SSA) relies on agriculture for subsistence (Kenko et al., 2017), and the primary challenge is to meet the growing demand for food. Consequently, substantial efforts are required to enhance food availability and access for the successful accomplishment of Sustainable Development Goal (SDG) 2 in SSA. Increasing crop productivity is

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essential for ensuring food security. Crop cultivation is typically confined to the short wet season, spanning less than half of the year, while the produced goods are consumed and marketed throughout the entire year (Bonuedi et al., 2022). This agricultural context complicates the achievement of SDG 2.

The common bean, *Phaseolus vulgaris*, holds a pivotal position as the most important legume globally for direct human consumption due to its protein content and high commercial value compared to other legumes. Half of the world's common bean production takes place in low-income, food-deficit countries where this staple crop significantly contributes to food security (Porch et al., 2013). Unfortunately, the common bean faces challenges during storage, as it is susceptible to attacks by *Acanthoscelides obtectus* (Coleoptera: Chrysomelidae). This pest initiates damage to mature bean pods on the farm, leading to approximately 10 to 40% weight loss and 70% seed damage within less than 6 months of storage (Paul et al., 2009). The larvae of *A. obtectus* feed inside the beans, and when present in large numbers within a seed, they cause its destruction, leaving only the outer coat (Njoroge et al., 2017).

This study addresses the significant reduction in the food value and germination potential of beans caused by the bean weevil *A. obtectus*. Combatting pests is imperative for food security, as without protection, farmers are essentially working for insects. The current encouragement of using botanicals, which are reduced-risk pesticides of plant origin, stems from the biodegradability of phytochemicals, potentially posing fewer human and environmental hazards. The widespread historical and current use of crude plant-based materials, such as powders, crushed leaves, bark, and extracts by smallholders in Africa, is noted (Stevenson et al., 2017). Currently, botanicals like pyrethrum, rotenone, neem, and essential oils are employed for insect management (Lengai et al., 2020).

Citrus sinensis, belonging to the Rutaceae family, contains secondary metabolites with insecticidal properties. The ethanolic extract of *C. sinensis* peel exhibits high insecticidal activity against the larvae of the yellow fever mosquito *Aedes aegypti* (Amusan et al., 2005). Orange peel powder has been reported to significantly affect the mortality of the wheat flour beetle *Tribolium confusum* (Yunis, 2014). Despite the high consumption of oranges in the North West Region of Cameroon, orange peels are often discarded as waste.

Cupressus sempervirens, an ornamental plant widely available in the North West Region, sees local use in villages, where fresh cypress leaves are employed for grain preservation after harvest, applied in storage facilities to prevent weevil infestation. While the efficacy of cypress leaf in this regard is not well known, scientific tests are crucial to establish the bioactivity of cypress against *A. obtectus*. The study specifically investigates the effectiveness of orange peel powder and cypress leaf ash against the bean weevil *A. obtectus* and their impact on seed germination.

MATERIALS AND METHODS

Collection and processing of botanicals

Cypress branches, featuring fresh and green leaves, were gathered from a tree located at Mile 3 Nkwen Bamenda. Subsequently, the collected branches underwent a two-week drying period under shade in a room. After this drying period, the branches were burnt on a metal zinc surface to facilitate collection and prevent the mixing of ash with other materials. Following the burning process, a three-hour cooling period was allowed before sieving the ash through a 0.2 mm mesh sieve to eliminate coarse particles. The resulting ash was stored in a cool and dry place until required for bioassays.

Oranges were procured from a local market, thoroughly cleaned, and then peeled. The peels were laid out on a clean surface and left to dry under shade in a room at ambient temperature for seven days in Bamenda. Following the drying period, the peels were ground into a powder using a common mill typically employed for grinding maize. To ensure the purity of the powder and prevent contamination, the milling machine was thoroughly cleaned before the grinding process. The obtained powder was then sieved through a 0.2 mm mesh sieve and stored in a cool and dry place until it was needed for bioassays.

Origin of common beans

Newly harvested beans of the "Merengue" variety, untreated, were purchased from local farmers in Bamenda. The beans underwent a selection process to eliminate off-types and debris, ensuring the use of pure beans. Subsequently, they were disinfected by placing them in a refrigerator at a temperature of -5ºC for one month.

Commercial insecticide used as a positive control

The homologated synthetic chemical in Cameroon, poudrox with 5% malathion active ingredient was bought from a farmers shop at Nkwen in Bamenda III Municipality and used as positive control.

Insect

Adults *A. obtectus* were obtained from the culture maintained in the laboratory of Applied Zoology of the University of Bamenda. Five hundred grammes of beans were infested for one week and sieved to remove adult insects. After five weeks of storage new progenies started to emerge and were used for bioassays. The adult insects used for experiments were one day old.

Bioassay of plant products on adult *Acanthoscelides obtectus* mortality

A sample of 50 g seeds was introduced into Petri dishes. Powder masses of 0.25, 0.5, 1, and 1.5 g of cypress ash, orange peel powder and a mixture of 50-50 of both powders were separately added to 50 g of beans giving the doses of 5, 10, 20 and 30 g/kg of beans. Poudrox at its recommended dose (0.5 g/kg) was used as the positive control and untreated seeds as the negative control. Groups of 20 adult *A. obtectus* were separately added to Petri dishes containing the treated beans and controls. All treatments

Table 1. *Citrus sinensis* essential oil chemical compounds.

Retension time (min)	Compounds	%
9.87	Myrcene	2.79
11.22	Limonene	90.77
25.57	Linalool	1.38
31.40	AlphaTerpineol	5.35
33.53	Delta Cadinene	0.40

were arranged in a completely randomised design on shelves in the laboratory (25 ± 1ºC and 60 ± 3% r.h.) and each treatment had four replications. Mortality was recorded 1, 3 and 5 days after treatment. Insects were considered dead when no movement was observed after touching them carefully with entomological forceps.

Progeny emergence, weight loss and seed damage

After the 5-day mortality recording, all insects and powders were separated from the seeds and discarded. The grains were left inside the petri dishes and all progeny were counted after two months of storage. All treated and untreated bean samples were weighed after counting the newly emerged adults. In addition, beans with holes and those without holes were counted and weighed separately so as to determine seed damage and weight loss. Percent weight loss (%WL) was computed using the FAO (1986) method as follows:

$$\%WL = [(U \times Na) - (Ua \times Ne)] / U (Na + Ne) \times 100$$

Where U is the weight of undamaged seeds, U*a* is the weight of the damaged seeds, N*a* is the number of damaged seeds; N*e* is the number of undamaged seeds. The Percentage seed damage (%D) was calculated using the formula:

$$\%D = (B/A) \times 100$$

Where: B is the number of grains with holes and A is the total number of grains.
From the undamaged seeds, 50 seeds were taken to evaluate seed viability after being in contact with insects and stored for two months.

Effect of cypress ash, orange peel powder and their mixture on seed viability and germination

Similar dosages of powders as applied as above were used for this assay. Each treatment was replicated four times and every petri dish (9 cm diameter) shaken manually for approximately 2 min to ensure uniform distribution of the powder to the entire seed mass. To assess seed viability, 50 seeds were taken at 1, 15, 30, 45 and 60 days after treatment and viability test was carried out. The 50 seeds of each treatment were sown under sterile sand in the germination trays, watered and covered with transparent plastic paper to ensure similar germination conditions. After 7 days of sowing, the number of germinated, abnormal, rotten, and non-germinated seeds was recorded.

$$PG = (\text{Number of germinated seeds} / \text{Total number of seeds}) \times 100$$

Data analysis

Data on corrected mortality, percentage germination, reduction in F_1 progeny and weight loss were arcsine [(square root(x/100)] transformed and the number of F_1 progeny produced and seed damage were log (x + 1) transformed to homogenise the variance. The transformed data were subjected to ANOVA using the Statistical Analysis System (SAS Institute, 2008). Tukey (HSD) test (P = 0.05) was applied for mean separation. Abbott's formula (Abbott, 1925) was used to correct mortality in control before ANOVA.

RESULTS

Composition of the essential oil of *Citrus sinensis*

Five compounds were found in the essential oil of *C. sinensis* peels (Table 1) with limonene being the main compound with 90.77% followed by alpha terpeneol 5.35%. Myrcene, linalool and delta cadinene are the minor compounds.

Effect of plant products on adult *Acanthoscelides obtectus* mortality

All botanical powders generally caused significant mortality to adult *A. obtectus* (Table 2) compared to the negative control. Mortality increased with ascending dose and time, irrespective of the products, except for orange peel powder and its binary combination with cypress ash after one day of application. Cypress ash (20 g/kg) led to a higher mortality (98.75 %) of *A. obtectus* five days post exposure. The commercial insecticide caused 100% mortality at its recommended dose within one day after infestation while orange peel powder registered the lowest mortality of 12.50% at a dose of 30 g/kg five days after application. For the mixture of ash and orange peel, a maximum weevil mortality of 86.25% was recorded at a dosage of 30 g/kg 5 days after exposure.

Acanthoscelides obtectus progeny inhibition in beans treated with plant products

Overall, there was a decrease in the rate of progeny emergence with increasing concentrations of powders. This trend was evident starting from the lowest powder contents (5 g/kg) of cypress ash and the binary combination of orange peel (refer to Table 3). However, the rate of progeny inhibition remained generally consistent among the powders, regardless of the plant species. Notably, the binary combination of powders demonstrated greater efficiency in inhibiting progeny production compared to adult mortality. Specifically, at powder contents of 5 g/kg for cypress ash, orange peel powder, and their mixture, progeny production was reduced by 78.10, 76.94 and 86.69%, respectively. Furthermore, the highest tested powder content (30 g/kg) led to a significant suppression of progeny production by 89.28, 94.29, and 97.97%, respectively, for cypress ash, orange peel powder, and their mixture.

Table 2. Corrected cumulative mortality (mean ± SE) of adult *Acanthoscelides obtectus* treated with orange peel powder, cypress ash and their binary combination.

Product/doses (g/kg)	Percentage mortality (means ± SE) / Days after exposure		
Cypress leaf ash	**Day1**	**Day3**	**Day5**
0	0.00 ±0.00[b]	0.00 ±0.00[b]	0.00 ±0.00[b]
5	5.00 ±22.04[ab]	78.75 ±3.75[a]	93.75 ±4.70[a]
10	7.50 ±1.44[ab]	86.25 ±3.15[a]	97.50 ±2.50[a]
20	6.25 ±2.39[ab]	91.25 ±5.54[a]	98.75 ±1.25[a]
30	8.75 ±3.15[a]	92.50 ±3.23[a]	98.75 ±1.25[a]
$F_{(4,15)}$	3.20*	66.92***	87.71***
Orange peel powder			
0	0.00±0.00[a]	0.00±0.00[a]	0.00 ±0.00[b]
5	0.00±0.00[a]	0.00±0.00[a]	6.15±3.75[ab]
10	0.00±0.00[a]	0.00±0.00[a]	6.35±1.25[ab]
20	2.50±1.44[a]	6.25±3.75[a]	10.00±3.54[ab]
30	1.25±1.15[a]	3.75±2.39[a]	12.50±3.25 [a]
$F_{(4,15)}$	1.71[ns]	2.20[ns]	3.85*
Cypress leaf ash +orange peel powder			
0	0.00 ±0.00[b]	0.00 ±0.00[b]	0.00 ±0.00[b]
5	1.25 ±1.25[a]	35.75 ±5.54[a]	76.25 ±8.26[a]
10	0.00 ±0.00[b]	35.00 ±5.40[a]	80.00 ±4.56[a]
20	8.75 ±1.25[a]	51.25 ±3.75[a]	83.75 ±6.57[a]
30	0.00 ±0.00[b]	42.50 ±9.24[a]	86.25 ±3.75[a]
$F_{(4,15)}$	22.20*	28.69*	45.94*
Poudrox	100	100	100

*Means ±SE in the same column followed by the same lower case letter or in the same line followed by the same upper case letter, do not differ significantly (Tukey's test; p<0.05). **p<0.001; ***p<0.001.

Table 3. Progeny emergence and percentage inhibition of *A. obtectus* in beans treated with cypress ash, orange peel powder and their mixture.

Products /doses	Mean number (±SE) of emerged *A. obtectus*	Percentage (±SE) of inhibited *A. obtectus*
Cypress leaf ash		
0	32.00±1.78[a]	0.00±0.00[b]
5	6.50±4.25[b]	78.00±14.75[a]
10	5.10±2.48[b]	84.97±7.08[a]
20	5.50±2.18[b]	83.58±6.32[a]
30	3.50±1.32[b]	89.28±4.19[a]
$F_{(4,15)}$	21.47***	21.92***
Orange peel powder		
0	32.00±1.78[a]	0.00±0.00[b]
5	7.25±2.66[b]	76.94±8.34[a]
10	8.00±3.49[b]	73.97±12.41[a]
20	5.75±2.06[b]	82.02±6.52[a]
30	1.75±0.48[b]	94.29±1.78[a]
$F_{(4,15)}$	26.87***	25.98***
Cypress leaf ash+ orange peel powder		
0	32.00±1.78[a]	0.00±0.00[b]

Table 3. Contd.

5	4.75±3.82[b]	86.69±10.25[a]
10	7.75±2.17[b]	76.62±5.12[a]
20	0.75±0.48[b]	97.66±1.58[a]
30	0.75±0.75[b]	97.97±2.03[a]
$F_{(4,15)}$	36.80***	61.21***
Poudrox	0.75±0.75	97.97±2.03

Means ±SE in the same column followed by the same lower do not differ significantly (Tukey's test) ***p<0.001.

Table 4. Bean damage and weight loss caused by *Acanthoscelides obtectu*s after treatment with cypress ash, orange peeling powder and their mixture.

Doses (g/kg)	Cypress leaf ash	Orange peel powder	Cypress leaf ash + Orange peel powder	$F_{(2, 9)}$
Mean percentage (±SE) seed damage				
0	16.83±4.91[a]	16.83±4.91[a]	16.83±4.91[a]	
5	3.30±2.04[baA]	4.34±2.59[bA]	0.22±0.13[bA]	2.56[ns]
10	4.05±0.28[baA]	2.62±1.19[bA]	3.97±1.45[bA]	0.14[ns]
20	4.05±2.03[baA]	1.75±0.73[bA]	0.55±0.28[bA]	1.88[ns]
30	0.81±0.35[Ba]	2.52±1.35[bA]	0.65±0.28[bA]	1.84[ns]
$F_{(4,15)}$	4.41*	16.35***	6.31***	
Mean percentage (± SE) weight loss				
0	3.41±1.01[a]	3.41±1.01[a]	3.41±1.01[a]	
5	0.40±0.16[Ba]	0.43±0.18[bA]	0.15±0.10[bA]	1.22[ns]
10	0.22±0.13[Ba]	0.24±0.06[bA]	0.48±0.16[bA]	1.52[ns]
20	0.38±0.17[Ba]	0.20±0.07[bA]	0.27±0.13[bA]	0.27[ns]
30	0.38±0.17[Ba]	0.21±0.05[bA]	0.23±0.17[bA]	0.16[ns]
$F_{(4,15)}$	9.65***	16.53***	12.32***	

Mean ± SE in this column followed by the same letter do not differ significantly at p=0.05 (Tukey's test), ns p > 0.05; *P < 0.05; ***P < 0.001.

Effects of tested plant products on seeds damage and weight loss

The infested common bean that were treated with plant products and subjected to 60 days storage after removing the insects and discarding of the powders, ash and their mixture recorded less damage and weight loss on seeds compared to the negative control (Table 4). There was no significant difference among the different concentrations of the botanicals.

Impact of plant products on seed germination

Table 5 shows that there was no variation in the germination rate within doses, products and days after treatments compared to the negative and positive controls. Percentage germination ranged from 95 to 100%. The lowest viability rate of 95.50% was registered with the mixture of orange peel powder and cypress ash (20 g/kg) 1-d after treatment and did not decrease with time, indicating a high viability of the seeds. After 60 days of storage, negative and positive controls recorded 100% germination rate indicating that the viability of seeds was not affected during storage. Moreover, as there was no significant difference among controls and the botanicals, it can be conclude that the tested phytochemicals do not influence common beans germination up to two months after storage.

Viability of infested and treated common beans after two months of storage

The presence of adult insects and their progeny production had no significant influence on treated beans regarding the viability of the seeds as shown in Table 6.

DISCUSSION

According to the results, limonene was identified as the

Table 5. Percentage germination of common beans treated with cypress ash, orange peel powder and their mixture during two months of storage.

Products/ doses	Mean percentage (± SE) germination after days of treatment					
	Day 1	Day 15	Day 30	Day 45	Day 60	$F_{(4,15)}$
Cypress ash						
0	99.50±0.50	100.00±0.00	99.50±0.50	99.50±0.50	100.00±0.00	0.75^{ns}
5	97.00±0.58^{aA}	99.00±0.58	99.00±0.58^{aA}	99.00±0.58^{aA}	99.50±0.50^{aA}	2.00^{ns}
10	96.50±1.25^{aA}	99.50±0.50	98.50±0.96^{aA}	99.00±0.58^{aA}	99.00±0.58^{aA}	1.08^{ns}
20	99.00±0.58^{aA}	99.00±0.50	99.00±1.00^{aA}	99.50±0.50^{aA}	98.50±0.96^{aA}	0.20^{ns}
30	97.50±0.96^{aA}	99.50±0.50	99.50±0.50^{aA}	100.00±0.00^{aA}	99.00±0.58^{aA}	2.06^{ns}
$F_{(4,15)}$	2.08^{ns}	0.75^{ns}	0.27^{ns}	0.75^{ns}	0.84^{ns}	
Orange peeling powder						
0	99.50±0.50	100.00±0.00	99.50±0.50^{aA}	99.50±0.50^{aA}	100.00±0.00	0.75^{ns}
5	98.50±0.96^{aA}	99.00±0.58^{aA}	98.50±0.96^{aA}	98.50±0.96^{aA}	99.50±0.50^{aA}	0.03^{ns}
10	97.50±0.96^{aA}	98.50±0.96^{aA}	99.00±0.58^{aA}	98.50±0.96^{aA}	98.50±0.50^{aA}	2.74^{ns}
20	98.00±0.82^{aA}	98.00±0.82^{aA}	99.50±0.50^{aA}	98.50±0.96^{aA}	99.50±0.50^{aA}	2.10^{ns}
30	97.00±1.29^{aA}	99.50±0.50^{aA}	99.50±0.50^{aA}	97.50±0.50^{aA}	99.00±0.58^{aA}	2.93^{ns}
$F_{(4,15)}$	0.95^{ns}	1.48^{ns}	0.36^{ns}	0.51^{ns}	0.50^{ns}	
Orange peeling powder +Cypress ash						
0	99.50±0.50	100.00±0.00	100.00±0.00^{aA}	99.50±0.50	100.00±0.00^{aA}	0.75ns
5	99.00±0.58^{aA}	98.50±0.96^{aA}	99.00±0.58^{aA}	99.00±0.58^{aA}	98.50±0.96^{aA}	0.22^{ns}
10	96.50±0.50^{aA}	98.50±0.96^{aA}	99.50±0.50^{aA}	99.50±0.50	99.00±0.58^{aA}	0.31^{ns}
20	95.50±1.89^{aA}	98.50±0.50^{aA}	98.50±0.96^{aA}	98.50±0.82^{aA}	99.50±0.50^{aA}	1.05^{ns}
30	95.50±1.89^{aA}	99.50±0.50^{aA}	99.50±0.50	98.50±0.96^{aA}	99.50±0.50^{aA}	1.46^{ns}
$F_{(4,15)}$	5.22^{ns}	1.24^{ns}	0.84^{ns}	0.76^{ns}	0.84^{ns}	
Poudrox	99.50±0.50	100.00±0.00	99.50±0.50	98.50±0.96	100.00±0.00	

*Means ±SE in the same column followed by the same lower case letter or in the same line followed by the same upper case letter, do not differ significantly (Tukey's test; p<0.05), **p<0.001; *** p<0.001.

predominant constituent in the orange rind. Kammegne et al. (2015) had previously reported limonene as the major compound found in orange rind, and the toxicity of *C. sinensis* peel has been attributed to d-limonene. This finding holds promise for resource-poor farmers in developing countries, as powder or oil extracted from orange rind could significantly contribute to combating food insecurity by reducing postharvest losses, considering the local availability of orange rind.

The observed significant mortality caused by all powders compared to the negative control may be attributed to the fact that insects typically breathe through their trachea, leading to the opening of their spiracles. The powders may have blocked the spiracles, resulting in suffocation, as reported by Komabonta and Falodu (2013). Notably, cypress ash exhibited the highest mortality, possibly linked to the presence of silica in the ash. Silica-based products are known alternatives to chemical insecticides (Otitodun et al., 2017). Additionally, cypress powder's reported repellence behavior (Achiri and Njweng, 2015) may be associated with the inhibition of various biosynthetic processes in the insect's metabolism, similar to the potential mechanism of cypress ash.

The superior performance of the binary combination of cypress ash and orange rind powder compared to orange rind powder alone suggests synergistic or additive effects of their constituents. The presence of silica in both ash and orange peel, along with limonene in orange peel, may contribute to an additive effect when combined. This binary combination demonstrated a synergistic effect on the bean weevil. Conversely, the lower mortality recorded by orange rind aligns with Abdullahi et al. (2019), who reported moderate effectiveness of *C. sinensis* rind extracts against the cowpea beetle. Similar findings were reported by Edu et al. (2019), where orange rind powder recorded moderate mortality against the maize weevil *Sitophilus zeamais*, possibly due to the evaporation of some active ingredients in orange rind during the drying process.

Reports suggest that when stored grains are combined with leaf, bark, seed powder, or oil extracts of plants, they can reduce the oviposition rate, suppress the adult emergence of stored product insects, and decrease seed damage rates (Hiruy and Getu, 2018; Mehta and Kumar, 2020). This effect may be attributed to the mortality of

Table 6. Viability rate of seeds treated with cypress ash, orange peel powder and their mixture after two months of storage.

Doses (g/kg)	Means Percentage (±SE) viability		
	Cypress leaf ash	Orange peel powder	Cypress ash + Orange peel powder
0	99.00±0.58[a]	99.00±0.58[a]	99.00±0.58[a]
5	100.00±0.00[a]	97.50±1.26[a]	99.50±0.50[a]
10	99.50±0.50[a]	99.50±0.50[a]	100.00±0.00[a]
20	99.00±0.58[a]	98.50±0.96[a]	99.50±0.50[a]
30	99.00±0.58[a]	97.50±0.96[a]	99.00±0.58[a]
$F_{(4,15)}$	0.80[ns]	1.55[ns]	0.58[ns]

Means ±SE in the same column followed by the same lower case letter do not differ significantly (Tukey's testp<0.05).

adult weevils before they can lay eggs, induced by the plant powders. Notably, *Fagus sylvatica* wood ash at a rate of 5% significantly reduced the emergence of *Sitophilus granarius* on wheat (Bohinc and Trdan, 2017). Coffee wood ash has been shown to prevent the population growth of *S. zeamais* and *Sitotroga cerealella* (Gemu et al., 2013). Additionally, Credland (1992) mentioned that orange rind acts as a physical barrier to the respiration of eggs and young larvae, exhibiting both toxicity and repellence due to its constituents. Musa and Adewale (2014) demonstrated that plant powders interfere with the developmental process of insects by reducing the number of eggs laid and exerting ovicidal effects.

The observed reduction in weight loss in this study may be attributed to the early mortality of weevils. Cypress ash's ability to reduce weight loss and damage may result from the desiccation of insects by the ash. The binary combination of cypress ash and orange peel powder may exhibit an additive effect due to the presence of constituents such as d-limonene and silica, aligning with Bohinc and Trdan (2017), who reported that botanical combinations can have additive and/or synergistic effects on their target pests.

Regarding germination rate and seed viability, no significant differences were observed among the various powders compared to the negative control. This finding aligns with Fotso et al. (2019), who reported that *Hemizygia welwitschii* extracts protected cowpea seeds for three months without adversely affecting seed germination. Similarly, Nsobinenyui et al. (2020) reported that binary combinations of fresh orange rind and rice husk ash had no adverse effects on seed germination. The lack of impact on seed germination by the different treatments aligns with the primary purpose of storage by small-scale farmers in Africa, ensuring household food supplies and viable seeds for the next planting season.

Conclusion

Overall, the efficacy of cypress leaf ash was higher than that of orange peel powder in terms of adult mortality. However, both products effectively prevented adult emergence, seed damage, and did not influence seed viability after two months of storage. Therefore, it is recommended to use both orange peel powder and cypress leaf ash for the protection of beans. It is practical to wash the seeds treated with these powders to remove residues of botanicals. Cypress leaf ash and orange peel powder could be integral components of an integrated storage protection package for beans against *A. obtectus* attacks.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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