__Original Research Article__

UTILIZING *Eucheuma denticulatum* EXTRACT AND*Azadirachta indica* POWDER AS ORGANIC AGENTS TO CONTROL MAIZE WEEVIL *(Sitophilus Zeamais)* INFESTATION IN STORED MAIZE GRAINS

Abstract

Storage insect pests destroy food grains in storage. In the present study, the insecticidal activity of red seaweed extract (*Eucheuma denticulatum*) and neem (*Azadirachta indica)* was examined against maize weevils (*Sitophilus zeamais*) and the quality of the stored maize was assessed for a three months storage period. Three rates (0.0, 3.2, and 4.8% w/w) of neem powder and seaweed extract were used as treatments. The collected data were subjected to analysis of variance (ANOVA) using General Linear Model in SPSS computer software packages (version 25) and mean comparisons were conducted using Turkey's (HSD) test at the 5% level of significance. *Sitophilus zeamais,* mortality, grain weight loss, and rate of germination were recorded for each treatment. The 4.8%w/w mixture of seaweed extract and neem seed powder was more toxic, followed by the mixture of the extract and neem leaf powder (84.5% and 73.3% mortality rates, respectively), while in the control, mortality was 20%. In all treatments, *Sitophilus zeamais* mortality increased with increasing doses. Grain weight loss was high in the control (5.6%), followed by grains treated with 1.6% extracts of *Eucheuma denticulatum* alone (2.8%). The percentage of damaged maize grains was high in the control (14%) and low in grains treated with 4.8% seaweed extract and neem leaf powder (3.3%). Percentage germination was high in grains treated with 4.8% and 1.6% seaweed extracts alone (96% and 87% respectively) and in control (91%). Additionally, sensory evaluation showed no significant difference ($p>0.05$) in the intensity of color, odour, and overall acceptability and the grains treated with both botanicals could be accepted by the general public for consumption. The results indicate promising potential for seaweed extract and neem powder in controlling maize weevils, offering sustainable and environmentally friendly solutions for stored grain protection.

Keywords*: Seaweed extract;Sitophilus zeamais; bio-control; maize storage;Azadirachta indica.*

1.0 INTRODUCTION

Maize (*Zea mays L.,* also commonly known as corn) is a common food crop cultivated and consumed globally [17]. It originated in Mexico from a wild grass domesticated by Native Americans and spread fairly quickly throughout the Americas, Europe, Asia, and Africa, where it is also extensively planted and used [24]. In sub-Saharan Africa (SSA), it is the most important cereal crop, and over 300 million Africans depend on it as the main staple food crop [4]. In Tanzania, maize is one of the most important food crops and it comprises about 45% of the total cultivated area, generating close to 50% of rural cash income at an average of 100 USD per maize producing household in 2018 [5]. Maize contributes to the diversity and dynamic of global agri-food systems as well as the security of food and nutrition [21].

Storage is a crucial link in the food supply chain. Maize storage involves not only placing grain in a suitably sized vessel until it is needed but also preserving it against pests and diseases. Proper storage may therefore lead to quantity equalization and market stabilization [20]. Furthermore, good storage of seeds is critical to smallholder maize farmers as it determines the quality and quantity of maize to be produced in the following seasons. Post-harvest losses in maize involve degradation in both quantity and quality from harvest to consumption[3]. Poor post-harvest handling, infrastructure, weather variability, bacteria, viruses, fungi, and biotic factors such as insects and pests, often worsen such losses [39]. It has been observed that, insect infestation is the greatest cause of losses of stored grains globally. Insects impair the quality of grain directly through their feeding and development, and indirectly through the generation of heat and moisture, which favor the development of insects and molds. Maize is susceptible to many insect pests at all stages of growth, from seedling to post-harvest or storage [37]. According to Zorya *et al.,*[44] maize grains are stored between one harvesting season and another, ranging between 3 and 12 months, a period in which high post-harvest losses (30-50%) arise, especially those caused by insects. In developing countries like Tanzania, a significant amount of produce is lost in post-harvest operations due to a lack of knowledge, inadequate technology, and/or poor storage facilities [41].

Maize weevil (*Sitophilus zeamais*Motsch.) is one of the most destructive pests in stored grain, especially maize in tropical regions [33]. Chemical control using synthetic chemical insecticides has been observed to be mostly used but its application by small-scale farmers is limited due to the high cost of these chemicals, infrequent supply, poor information, and lack of knowledge on handling and proper application [22] [19] [29]. These synthetic insecticides have been linked to negative health effects in humans who consume them, including dermatological, gastrointestinal, neurological, carcinogenic, respiratory, endocrine, and reproductive effects, as well as the development of insect resistant strains, toxic residues, and worker safety issues [30] [9]. For these reasons, the development of alternative means of insect pest control that remain sustainable for the environment is inevitable.

According to Ileke&Oni [23], the use of plant products is a cheaper, renewable, and ecologically safer means of controlling insect pest infestations of stored cereal and grains, especially in the tropics, where poor farmers are found. Such plant materials include terrestrial plants like tephrosia (*Tephrosia vogelii),*moringa (*Moringa oleifera*), neem (*Azadirachta indica)*, tobacco (*Nicotiana tabacum*), chili pepper (*Capsicum* spp.) and the bitter leaf(*Vernonia amygdalina*) [14]. Marine plants (seaweed) have also found uses in agriculture due to their antibacterial, antifungal, anti-microalgae, and antioxidant properties [43]. Many studies have found that, seaweeds can be used to prevent different fungal diseases and infestations of pests in horticultural crops, cotton, beans, and sugar beets and as organic fertilizers [40] [7] [2]. They are considered to be an excellent natural bio-source in agricultural fields, and they are characterized by producing a large range of biologically active biocidal substances against plant-infecting pathogens. Moreover, the neem tree (*Azadirachta indica A.* Juss) has been used in the field of agricultureas a natural fertilizer with pesticidal properties. It is considered an easily accessible, eco-friendly, biodegradable, cheap, and non-toxic bio-pesticide that control the target pests [1].
This study explores the utilization of seaweed *Eucheuma denticulatum* extract and *Azadirachta indica* powder as eco-friendly alternatives to control the influx of *Sitophilus zeamais* in stored maize, aiming to provide effective control while mitigating adverse effects associated with synthetic pesticides.

2.0 MATERIALS AND METHODS

2.1 Maintenance of Pure Culture of Maize Weevil

The pure culture of *S. zeamais* for the experiment was prepared at the Food Science Laboratory, Department of Food Science and Agro-processing of Sokoine University of Agriculture in Morogoro. Maize grains (250g) were kept in 500g capacity plastic jars (experimental jars) and 50 pairs of S*. zeamais* were introduced and left for oviposition for one week. The mouths of the experimental jars were covered with screens on top to allow airflow. The samples were observed daily until the emergence of F1 progenies. The average temperature of the laboratory was around 26.9 ± 1.76 ºC. The culture was used for the experiment.

2.2 Collection, Preparation and Details of Botanicals

Two botanicals, *Eucheuma denticulatum (red seaweed)* and *Azadirachta indica* (neem) were used for this study. Seaweeds (*E. denticulatum)* were collected along the shores of the Indian Ocean, Lindi District and brought to the laboratory. The collected seaweeds were sorted to remove dirt, washed to remove sea salt and other epiphytes and then air dried (with the assistance of a fan) for 24 hours from moisture content of 33.75% to 5.25%. They were then milled using a high speed multi-functional crusher MODEL-750A into powder. The powder was macerated in ethanol (99%) and placed in a dark environment for 72 hours with occasional shaking. This mixture was separated by decantation before being placed on a rotary evaporator to remove excess alcohol, and then dried into powder form. The powder was sieved with a testing sieve 500µm aperture

Leaves and seeds of neem plant (*A. indica)* were collected from neem trees around Morogoro. They were properly washed to remove dirt. Thereafter, neem leaves were dried in shade for 5 days, whereas; neem seeds were solar dried at 49 – 50^{0}C for 3 days*.* The dried plant materials were turned into powder form by a high speed multi-functional crusher MODEL-750A. Both powders were sieved separately using a 500µm mesh to get a fine powder and kept separately in airtight plastic bags in the laboratory.

2.3 Experimental Procedure

A sample of freshly harvested maize grains from Ilonga Research Institute Kilosa-Morogoro, Tanzania was cleaned of all foreign materials and sun-dried to eliminate insect pests and to minimize excess moisture to a recommended storage moisture content of 14%. Clean and dry maize was packed in a polythene bag and kept in the laboratory under room conditions (26.9 ± 1.76 ºC) before the experiment.

Two hundred and fifty (250) grams of maize grains were measured, and separately, treated with the powder form of botanicals at three rates (0.0, 1.6 and 4.8% w/w) of seaweed extract, a combination of seaweed extract and neem leaf powder, and a combination of seaweed extract and neem seed powder respectively. They were kept in the experimental jars and each jar was infested with 15 freshly emerged *Sitophilus zeamais*. The experiment was laid out in CRD, replicated three times. The lid of the experimental jars was covered with screens to allow airflow but prevent the escape of *Sitophilus zeamais*. The untreated maize grains served as a control in the experiment. Treatments used for are shown in Table 1 below.

Table 1: **Treatments used for the grain quality evaluation**

Treatments	Description	Dosages(% w/w)

Control	Untreated (C)	0.0
T4	Seaweed extract (SE)	1.6%
T1	Seaweed extract (SE)	4.8%.
T5	Seaweed extract and Neem Leaf powder (SE+NL)	1.6%
T2	Seaweed extract and Neem Leaf powder (SE+NL)	4.8%
T6	Seaweed extract and neem seed powder (SE+NS)	1.6%
T3	Seaweed extract and neem seed powder (SE+NS)	4.8%

The stored maize samples were assessed after 30, 60, and 90 days. At the end of these three periods, all *S. zeamais* were separated and removed by handand the maize weevil's mortality was recorded. By visual inspection, the number and weight of damaged kernels were recorded. Damaged kernels were those with visible physical damage (a hole) caused by the maize weevils. The organoleptic properties of stored maize, together with the seed viability index, were also evaluated at the end of the storage period.

2.4 Effect of Bio-pesticides on Organoleptic Properties of Stored Maize

Sensory evaluation was conducted by a quantitative descriptive test (QDA) by ten trained sensory panelists, comprising 5 males and 5 females with ages ranging from 21 to 28 years, according to the method described by Lawless [25]. The change in grain color and odor of both treated and untreated maize samples was assessed at the end of the storage period (90 days). The sub-samples were drawn from the treated grain and cleaned by blowing off the residual particles. Samples were assessed for change in odor and color by using a scoring scale of 1 to 5 that was defined separately for each of the two parameters [31]. In order to ensure that panelists were not influenced in any way, no information with regard to the nature of the samples was provided, and panelists were reminded not to use perfumed cosmetics and to avoid exposure to food stuffs at least 30 minutes before evaluation sessions.

Table 2: Scoring for change in grain odor scale 1 to 5

Score	Description
1	Grain is odourless
2	Grain has little offensive odour
3	Grain has moderately offensive odour
4	Grain has offensive odour
5	Grain has very offensive odour making it unacceptable for human consumption

Table 3: Scoring for change in grain color scale 1 to 5

Score	Description
1	No detectable change in colour
2	Slight change in colour
3	Moderate change in colour
4	Great change in colour
5	Highly significant change making grain unacceptable for human consumption

To obtain unbiased scores, each sample was coded with 3-digit random numbers. The coded samples were presented in a well-lit and ventilated room for assessment. Panelists were allowed into the assessment room and samples were given in a randomized order and instructed to rate the sample in terms of odour and colour attributes.

2.5 Germination Assays

The effect of treatments on seed viability, expressed as germination percentage, was evaluated at the end of the three month storage period. The germination test was carried out in a completely randomized design, and data on seed viability were collected 7 days after setting up the experiment. Twenty (20) undamaged maize grains were selected randomly from each sample of treatments, and they were then germinated in a petri dish lined with cotton. The Petri dishes were covered to prevent loss of moisture and contamination and placed in a room environment. After one week, the number of seeds that germinated was counted and recorded. The germination percentage was calculated using the formula given by Muzemu*et al.,*[28].

Germination percentage %= $\frac{G1}{G2} \times 100$……………………………….. *(1)*

Where *G1* = total germinated grain, *G2* = total grain in Petri dish

2.6 Data Analysis

Data for the effect of bio-pesticides on maize weevils, germination of maize seeds and sensory attributes of maize grains were analyzed using IBM SPSS statistics version 25 using the one-way analysis of variance (one way ANOVA) and post hoc Turkey's Honestly Significant Difference (HSD) test at a significance level $p< 0.05$. A p-value <0.05 was considered statistically significant. All the data were reported using mean values of determinations ± standard deviation. Principle component analysis (PCA) was done by R software (R Core Team) to assess the association between samples and attributes.

3.0 Results and discussion

3.1 Effects of botanicals on weevil mortality

The protection of stored grains through the use of plant materials is a common practice among smallholder farmers in Africa. The efficacy of*E. denticulatum*extract and *A. indica*powder in controlling *Sitophilus zeamais* is presented in Table 4. Both botanicals acted as grain protectants against *Sitophilus* *zeamais*, especially when applied at higher dosages. According to Deyab*et al.,*[13], bioactive secondary metabolites found in seaweed, such as alkaloids, flavonoids, phenols, saponins, tannins, steroids, terpenoids and glycosides can be used as antimicrobial and insecticidal substances. Seaweed extract application to crops is known to reduce the numbers of detrimental nematodes and insects in different crops, although the mechanism behind the pesticidal functioning of the extracts is unknown [10].

Maximum mortality of *S. zeamais* was caused by the combination of seaweed extract and neem seed powder at 4.8%w/w, followed by a 4.8%w/w combination of seaweed extract and neem leaf powder and seaweed extract at 4.8%w/w, both inducing 80% mortality. Neem is well known for its insecticidal properties, and it is very effective against a wide range of insect pests. The most active insecticidal ingredients are said to be present mostly in the seeds, leaves and other parts of the neem plant [36] [38]. The lowest dosages of seaweed extract and neem powder (1.6%w/w of grain) respectively, resulted in the minimum mortality. The killing efficacy of the botanicals increased with increasing dosages.

Table 4: Effects of seaweed extract and neem powderas bio-pesticides on *Sitophilus zeamais* and maize grains

		Time (days)		
Characteristics	**Treatments**	**30 days**	**60 days**	**90 days**
No. of damaged maize grains	4.8%w/wSE+NS	2.33 ±0.58^{c}	7.67 ±1.53c	8.33 ±1.53c
	4.8%w/wSE+NL	3.33 ±0.58^{c}	8.33 ±1.53c	9.0 ± 1.73c
	4.8%w/wSE	3.67 ±1.15^{c}	8.67 ± 1.15c	11.0 ± 1.00c
	1.6%w/wSE+NS	10.67±0.58^{b}	16.0 ±2.00^{b}	16.67 ± 1.53^{b}
	1.6%w/wSE+NL	10.67±0.58^{b}	16.0 ±2.00^{b}	17.33 ± 1.15^{b}
	1.6%w/wSE	11.67 ±0.58^{b}	17.67±2.58^{b}	19.33 ± 2.08^{b}
	Control	20.67 ±3.05^{a}	31.33±4.16a	34.67 ± 1.53a
Dead *Sitophilus zeamais*	4.8%w/wSE+NS	12.67 ±0.58^{a}	11.67 ±1.52^{a}	7.67 ±1.15^{a}
	4.8%w/wSE+NL	11.0 ±1.73^{a}	11.0 ±1.73^{a}	7.67 ±0.58^{a}
	4.8&w/wSE	8.0 ±1.00^{b}	7.0 ±1.00^{b}	6.33 ±0.58^{ab}
	1.6%w/wSE+NS	6.33±0.58^{bc}	6.62 ±3.73^{b}	4.67 ±1.15^{bc}
	1.6%w/wSE+NL	5.0 ±1.00c	5.33±1.15^{b}	3.67 ±2.08^{c}
	1.6%w/wSE	5.0 ±1.00^{c}	5.0±1.00^{b}	3.33 ±0.58^{cd}
	Control	0.33 ±0.58d	0.67 ±0.58^{c}	0.67 ±0.58^{d}

Means ± SD, values within the same column with different superscript letters are significantly different from each other (p<0.05)

The mortality rates of *Sitophilus zeamais* were higher in the treatment groups compared to the control group. The analysis of variance for the seaweed extract (SE), combination of seaweed extract, and neem powder concentration also showed a statistical difference in the mortality of adult weevils. After 30 days of treatment application, the extract, leaf powder, and seed powder concentrations at rates of 0.0, 1.6, and 4.8% w/w were statistically different from each other, while after 60 days of treatment application, they were statistically similar to each other and statistically different from the control. Maize samples treated with the combination of seaweed extract and neem seed powder (SE+NS) showed higher mortality than other groups. Comparing the results of seaweed extract combined with neem seed powder treatment and neem leaf powder treatment, the highest mortality rate was recorded in the combination of the extract with neem seed powder. These results are in line with the findings of Erenso& Berhe [16]. In their study on the effect of neem leaf and neem seed powders on adult maize weevil (*Sitophilus zeamais*Motschulsky) mortality on stored maize grains, Erenso& Berhe [16] found that the highest mortality rate was recorded in maize grains treated with neem seed powder.

3.2 Grain Weight Loss

The weight loss of maize grains treated with seaweed extract and neem seed powder followed a similar trend as the weevils' mortality. The number of damaged seeds was lower in treated maize samples than in the control groups. Treated grains experienced very low weight loss compared to the control (untreated grains). The weight loss of the untreated grains (control group) continued to increase throughout the storage period up, to 7%, while in those grains that received the highest treatment dosage, the weight loss was only about 1%. In all treatments, weight loss decreased with an increase in the concentration of the bio-pesticides. The weight loss of the control group was significantly higher than that of grains treated with the botanicals (< 0.05).

Table 5: Weight loss (g) by *S. zeamais* during storage

		Time (days)		
Characteristics	**Treatments**	**30 days**	**60 days**	**90 days**
Weight of undamaged grains (g)	4.8%w/wSE+NS	248.95 ±0.06^{a}	247.96±0.29^{a}	246.83 ±0.68^{a}
	4.8%w/wSE+NL	248.71 ±0.03^{a}	247.88±2.67^{a}	246.34 ±0.42^{a}
	4.8%w/wSE	248.10 ±0.05^{d}	247.22±0.45^{a}	246.47 ±0.50^{a}
	1.6%w/wSE+NS	245.79 ±0.07^{bc}	244.54±0.73^{b}	243.29 ±0.06^{b}
	1.6%w/wSE+NL	245.92 ±0.06^{b}	243.88±0.50^{b}	243.21 ±0.14^{b}
	1.6%w/wSE	245.56 ±0.10^{c}	242.99±1.76^{b}	243.11 ±0.17^{b}
	Control	242.97 ±0.26^{e}	238.29±1.50c	236.06 ±0.59c

Means ± SD, values within the same column with different superscript letters are significantly different from each other (p<0.05)

Both seaweed extract and neem powder appeared to offer protection for stored maize, mostly during the early stages of storage (30 days). Over the 90 days storage period, while the number of dead weevils decreased in all samples, the treated samples exhibited a lower number of damaged seeds compared to the control group.Erenso& Berhe [16] reported that, the insecticidal effect of neem leaf and seed powder may increase or decrease with time, as the significant effect of the treatment is dependent on the active ingredient of each rate and the amount of powder that comes into contact with each individual weevil. The effectiveness of different non-synthetic chemical products on various storage insect pests of stored products has been reported by many researchers [18] [9] [42] [27] [15] [6]. These results suggest that, weevils would prefer to avoid maize grains treated with any plant powder.

3.3 Sensory Attributes

3.3.1 Quantitative Descriptive Analysis

The response of panelists to the effects of varying doses of seaweed extract, neem powders, and control on the color, odour, and overall acceptability of maize grains after 90 days of storage are summarized in Table 5. In this study, there was no significant difference in the intensity of color, odor and overall acceptability (p> 0.05) in most of the samples.

3.3.2 PCA Bi-plot

The PCA reduced the original three variables into two principal components, which accounted for 85.5% of the total variance. Table 6 below shows the variable loadings of the Principle Component Analysis

Table 6: Variables loading of PCA

Variable (attribute)	Principal component	
	1	**2**
Color	**0.6535**	0.4337
Odour	**-0.7273**	0.1329
Overall. Acceptability	0.2096	**-0.8912**

The variable loadings with an absolute value greater than 0.56 are shown in bold

According to Chapman *et al.,* [8], an absolute value greater than 0.56 represents a strong influence of sensory attributes on their respective components. The first component is strongly correlated with all color and odor attributes, except for “overall acceptability.” The second component does not correlate with color and odor where a negative correlation was observed with “overall acceptability.”

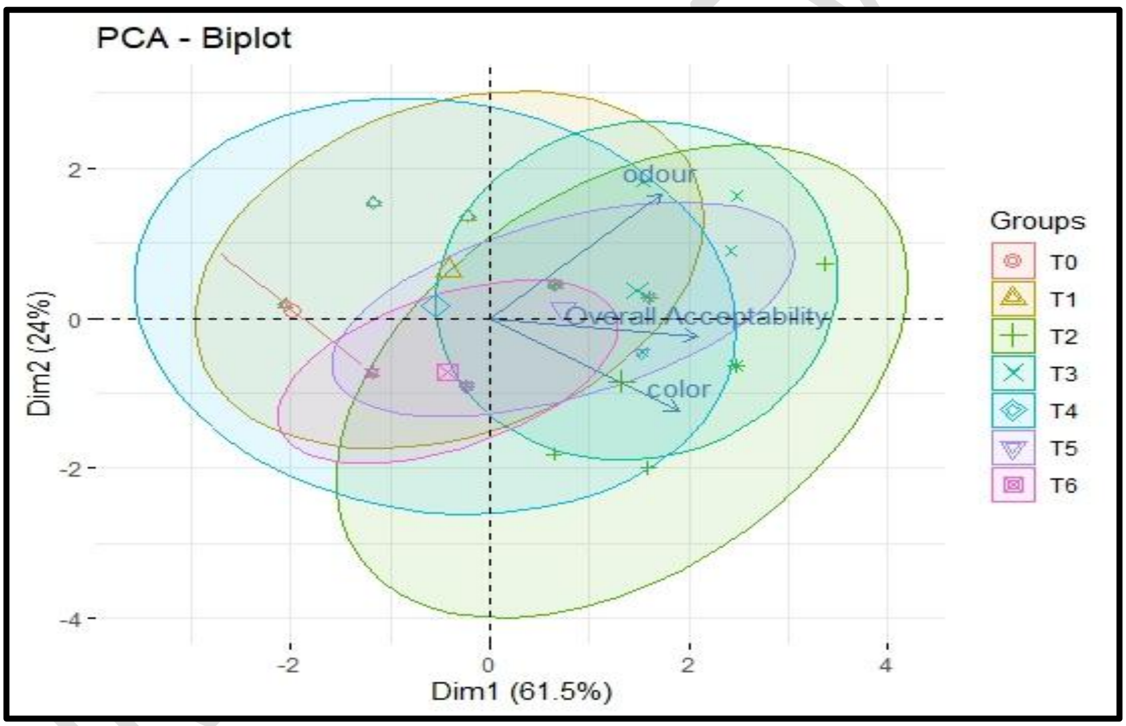

Fig. 1: Bi-plot of PCA showing an association between samples and attributes

From Figure 1, the bi-plot of the principal component analysis shows that, PC 1 accounts for 61.5% of the variation and PC 2 accounts for 24% of the variation. The bi-plot shows that the attributes of color and overall acceptability are closely associated as they are facing the same direction. This is unlike the attribute of odour, which shows no association with other attributes as it faces its own direction.

Table 7: Mean intensity scores of stored maize samples by the sensory panel

Samples	Color	Odor	Overall Acceptability
4.8%w/wSE+NS	1.67 ± 0.58^{a}	1.67 ± 0.58^{a}	1.67 ± 0.58^{ab}

4.8%w/wSE+NL	2.67 ± 0.58^{a}	1.67± 0.58^{a}	2.67±0.58^{a}
4.8%w/wSE	2.67± 0.58^{a}	2.33±0.58^{a}	2.33±0.58^{a}
1.6%w/wSE+NS	1.33± 0.58^{b}	1.33±0.58^{b}	2.0±0.00^{ab}
1.6%w/wSE+NL	2.00 ± 1.00^{a}	1.67 ± 0.58^{a}	2.0±0.00^{ab}
1.6%w/wSE	2.00 ± 1.00^{a}	1.33 ±0.58^{b}	1.67±0.58^{ab}
Control	1.33 ± 0.58^{b}	1.00± 0.00^{b}	1.0 ± 0.00^{b}

Means ± SD, values within the same column with different superscript letters are significantly different from each other (p<0.05)

3.3.3 Color

The scores of colors ranged from 1.33 to 2.67 on the 5-point scale. The control group received the highest rating (1.33), indicating that it was perceived as having the most favorable color. There was no significant difference in color in samples treated with higher concentrations and combinations of botanicals. The samples treated with seaweed extract at lower dosages (1.6%w/w) did not differ significantly in color from the control. The average value for colour change was below 2.7, indicating a slight change that is tolerable in the local market.

This is further supported by the PCA Bi-plot (Figure 1). The variable loading for color on the first principal component (PC1) is 0.6535, indicating a moderately strong positive relationship between color and PC1. This suggests that variations in color contribute significantly to the variance explained by PC1. Similarly, the variable loading for color on the second principal component (PC2) is 0.4337, indicating a weaker positive relationship between color and PC2.

3.3.4 Odor

There was no significant difference in odor between the values of the control, the lower dose (1.6%) of seaweed extract, and the combination of the extract and neem seed powder. Samples with a high concentration of botanicals (4.8%) and those with neem leaf powder did not differ significantly in odor.

The variable loading for odor on PC1 is -0.7273, indicating a strong negative relationship between odor and PC1. This suggests that variations in odor contribute significantly to the variance explained by PC1, but in the opposite direction. On the other hand, the variable loading for odor on PC2 is 0.1329, indicating a weak positive relationship between odor and PC2.

3.3.5 Overall Acceptability

Untreated samples received the highest score, followed by the lower dosages of botanicals and those treated with seaweed extract. The samples treated with seaweed extract alone were more acceptable, even when higher doses were used, compared to neem powder treated samples. As the concentration of the combination of seaweed extract and neem powder increased, the overall ratings tended to decrease, but still, these maize grains were acceptable to the panelists, as the highest value on the five point hedonic scale was 3. Response based on the 5-point hedonic scale pertaining to the effect of the seaweed extract and neem powders on the organoleptic properties of the treated maize grains after a three month period of storage confirmed that the grains treated with both botanicals could be accepted by the general public for consumption. This could indicate that the constituents from the botanicals were not absorbed by the grains [32].

The variable loading for overall acceptability on PC1 is 0.2096, indicating a relatively weak positive relationship between overall acceptability and PC1. This suggests that variations in overall acceptability contribute less to the variance explained by PC1 compared to color and odor. However, the variable loading for overall acceptability on PC2 is -0.8912, indicating a very strong negative relationship between overall acceptability and PC2. This suggests that variations in overall acceptability are strongly and inversely related to PC2.

Comparing the findings of the present study with other findings, the present study is in line with the findings of Qwarse*et al*[35] Musundire*et al* [27] Danjumma*et al* [12]. In their studies, they found that maize grains treated with the botanicals that effectively protected stored maize against *Sitophilus zeamais* did not affect grain organoleptic properties.

3.4 Effect of Insecticidal Plant Materials Concentration on Seed Viability index of Stored Maize

The germination test determines the percentage of seeds that are alive in any seed lot. The results of the effect of insecticidal plant material concentrations on the seed viability of stored maize during the storage period are presented in Table 8. Both seaweed extract and neem powder did not negatively affect seed germination.

Table 8: Effect of treatments on seed germination

Characteristics	Treatments	90 days
Percentage germination (% germination)	**1.6%w/wSE+NS**	76.67±5.78[b]
	1.6%w/wSE+NL	75.0 ± 5.0[b]
	1.6%w/wSE	86.67 ±5.77[ab]
	4.8%w/wSE+NS	80.0 ± 8.67[ab]
	4.8%w/wSE+NL	76.67 ±2.88[b]
	4.8%w/wSE	96.67 ± 2.88[a]
	Control	91.67 ± 2.88[a]

Means ± SD, values within the same column with different superscript letters are significantly different from each other (p<0.05)

The results from the study indicated that the seed viability of treated maize grains and the control group were all significant during the storage period. Both treated and untreated maize seed viability ranged between 97% - 75% germination during the storage period. The highest seed viability was observed on stored maize grains treated with 4.8%w/w of seaweed extract alone (96.67%), followed by the untreated sample (91.67%). These results are supported by the findings of Ali *et al*[2]Lee & Ryu [26]Parađiković*et al* [34] which stipulated that, compounds within seaweed extracts biochemically alter plants by playing vital roles in many biological activities such as improved seed germination, plant growth and protection against biotic and abiotic factors. These extracts have been shown to positively affect seed germination and plant growth at all stages, up to harvest and even post-harvest [2]. The least percentage of germination was recorded in the samples treated with the combination of seaweed extract and neem leaf powder. This could be explained by the fact that neem tree is well-known for its allelopathic properties, which means it can release bio-chemicals that affect the growth and development of other plants. The allelopathic effects of neem can inhibit the germination and growth of various plants and crops especially at higher concentration of *A. indica* [11].

4.0 CONCLUSION

The evidence gathered from the current study confirmed that seaweed extract and neem powder protected maize grains from the attack of *Sitophilus zeamais* and reduced grain damage during storage. The results demonstrated that, *Eucheuma denticulatum* extract and neem powder exhibit toxic activity to maize weevils especially at treatment rates of 4.8%w/w. Addition of more seaweed extract can result into more mortality rate of the weevils but addition of more neem powder may affect germination of seeds. The significance of these findings extends beyond the laboratory, offering tangible benefits to agricultural practices worldwide. With growing concerns over the environmental and health impacts of chemical pesticides, the identification of natural and sustainable alternatives becomes imperative. Seaweed extract and neem powder represent such alternatives, offering effective pest control while minimizing adverse effects on the environment, human health, and non-target organisms. By harnessing the power of nature's own defenses, farmers can not only protect their crops from maize weevil infestations but also contribute to the conservation of biodiversity and the preservation of ecosystem health. Yet, similar kinds of studies need to be conducted from time to time to ensure the sustainable and responsible use of these botanicals in agriculture and for further validation and acceptance.

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