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Efficacy of the Botanical Extracts, *Azadirachta indica* (Sapindales: Meliaceae) and *Tagetes minuta* (Asterales: Asteraceae) in the Control of Cabbage Insect Pests in Iringa District, Tanzania

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Abstract

Although botanical extracts have been widely studied globally, the efficacy of neem and Mexican marigold against cabbage insect pests is scanty. Field experiments were conducted at Kalenga and Mgera in 2022 using a randomized complete block design. Four treatments (neem, Mexican marigold, a mixture of the two extracts and untreated) were replicated three times. In Kalenga, damage levels for treated plots varied significantly from 3.33 to 9.20% and 5.0 to 18.33%, while for untreated plots varied from 37.70 to 45.85% during the rainy and dry seasons, respectively ($F_{(3, 499)} = 111.71$, $p < 0.05$). A similar trend was recorded in Mgera, the damage levels varied significantly between treated (4.44–15.83%) and untreated plots (34.40–46.60%) ($F_{(3, 449)} = 94.23$, $p < 0.05$). Treated plots had higher marketable cabbage yields (30.6–43.10 t/ha) than untreated plots (4.78–11.20 t/ha), which differed significantly in Kalenga ($F_{(3, 67)} = 141.79$, $p < 0.05$) and Mgera ($F_{(3, 67)} = 53.36$, $p < 0.05$). These extracts have shown insecticidal properties, can serve as promising candidates for further studies aimed at isolating active compounds for scaling up ecologically friendly strategies of controlling pests and improve the quality of cabbage products.

Keywords: Cabbage, Mexican marigold, Neem, Kalenga, Mgera.

Introduction

Cabbage (*Brassica oleracea* var. capitata) is a vital vegetable crop with overlying leaves forming a compact head (ball like structure) grown as an annual crop (Singh et al. 2021). It is considered as a good source of nutritional value, mainly vitamins, proteins, carbohydrates, and essential minerals such as calcium, iron, and sodium, as well as dietary fibres (Balliu et al. 2014). The crop is widely grown worldwide, with an average production of 70,644,191 tons per year (Kidane 2016). China is the largest producer, and the country accounts for about 47% of the total cabbage production, while Africa accounts only for 4% of the total cabbage production in the world (Asomah et al. 2021). Regionally, East Africa produces about 14.8 million tons, and Tanzania contributes 4%, which is equivalent to 592,000 tons of the total cabbage production in the region (United Republic of Tanzania 2021). Of these, Iringa region produced 2,542 tons whereby the Iringa District produced 407 tons, which accounted for 16% of the total cabbage production in the region (United Republic of Tanzania 2021).

Cabbage is the third most important vegetable crop in Tanzania after tomatoes and onions (Massomo 2005). Low production of cabbage is attributed to biotic and abiotic factors, the former factors are mainly due to insect pests and disease infestations (Kiptoo et al. 2015). The latter include sub-optimal applications of fertilizers (Terefe et al. 2018), lack of knowledge on the use of appropriate agronomic practices (Ünlü et al. 2010), the use of local varieties, and weather condition variability (Labou et al. 2017). However, the magnitude of problems caused by insect pests varies significantly from planting to postharvest (Oerke 2006). Insect infestations can affect both cabbage production and its quality (Krishnamoorthy 2004), specifically a single insect larva can consume between 74 and 80 cm^2 of the total leaf area (Younas et al. 2004). As a result of feeding, the cabbage either fails to form compact heads or produce deformed heads (Uddin et al. 2007).

Also, several interventions have been used for the management of cabbage pest infestations. In Tanzania, cultural controls such as crop rotation, push-pull techniques, weeding (Mayanglambam et al. 2021) and good farming practices are widely used by smallholder farmers (Kidane 2016, Karthikeyan et al. 2020). The use of synthetic insecticides such as abamectin, fipronil, deltamethrin, and chlorpyrifos has been considered as the main control strategy against the cabbage insect pests (Mazlan and Mumford 2005). Despite the efficacy of these synthetic insecticides in the management of cabbage insect pests, prolonged and excessive use tends to have adverse effects on beneficial organisms and the environment (Mayanglambam et al. 2021). It was also attributed to the development of insect pest resistance, which threatens sustainability of ecosystems (Aktar et al. 2009). Therefore, the use of alternative control measures is crucial to reduce the adverse effects of synthetic insecticides (Mayanglambam et al. 2021). One of the promising control methods is to integrate the use of biological agents such as microbial products and botanical extracts once scaled up into pest management systems (Lengai et al. 2020). Botanical extracts are readily available, safe for non-target organisms and nearby ecosystems (Lengai et al. 2020, Kanwal et al. 2020), and have different roles, including insecticidal and fungicidal activities (Campos et al. 2019). Also, botanical extracts can degrade more rapidly than most synthetic insecticides and are considered as environmentally viable and friendly to beneficial organisms (Kanwal et al. 2020). Botanical extracts can also contribute to plant vigour by working as either a green fertilizer or provision of additional nutrition and inducing systemic plant responses (Mkindi et al. 2020). Neem leaves (*Azadirachta indica)* and Mexican marigold (*Tagetes minuta*) have been used against various grain pests such as pulse beetle (*Callosobruchus chinensis*) (Ahmad et al. 2015) and lesser grain borer (*Rhyzopertha dominica*) (Bakshi and Ghosh 2022). However, there was a dearth of information related to the efficacy of the two botanical extracts, namely neem and Mexican marigold for the management of cabbage insect pests. A need, therefore, exists to establish a comprehensive rationale for ecological and applied control assessments to improve cabbage productivity. The present study aimed to assess the efficacy of the two extracts in controlling insect pests as alternative strategies to increase cabbage production and improve the nutritional status of agro-produces in Tanzania.

Materials and Methods

Study sites

Field experiments were conducted during the rainy (February to April) and dry (July to September) seasons in 2022 at Kalenga and Mgera villages in Iringa District, which is one of the districts of Iringa region in Southern, Tanzania. The experimental sites were located between latitudes and longitudes S 7°47′ E 35°36′, 1457 m above sea level in Kalenga and S 7°43′13, E 35°31′, 1450 m above sea level in Mgera (Figure 1). The average temperature ranges from 20 to 25 °C between September and April and from 14 to 20 °C between May and August. It also exhibits uni-modal rainfall ranging from 600 to 1000 mm per annum (Osiemo and Kweka

2019). The economic activities mainly practiced in the area include farming especially horticultural crops such as cabbage, tomatoes, onions and sweet peppers. The production per unit area is very low due to poor good agronomic practices and high cost of production.

The experimental sites were selected due to the existence of Ruaha-basin irrigation schemes. The irrigation schemes provided conducive environment for sufficient water supply to ensure cabbage production throughout the year. In this study, the Copenhagen market seed variety was used due to its earliest maturing and open-pollinated variety (OPV) of between 65 and 70 days after transplanting (Adeniji et al. 2010). This variety was also reported to survive in different climatic conditions and its sizes range from small to medium (Ministry of Agriculture, Livestock and Fisheries 2019).

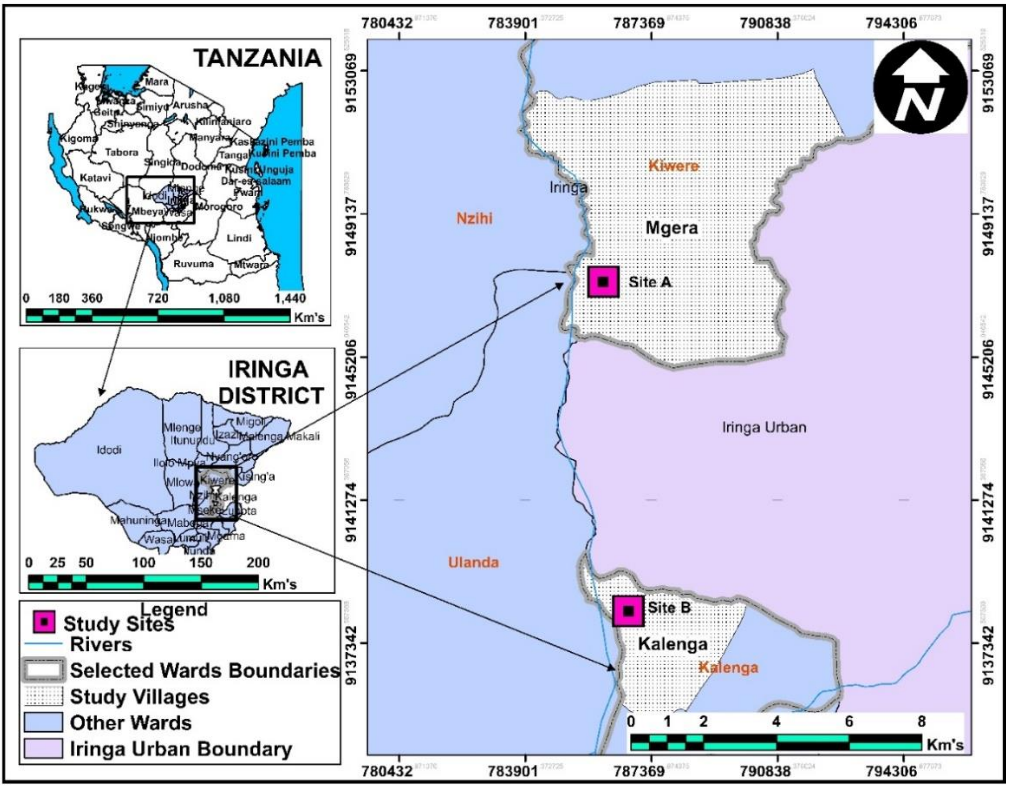

Figure1: A map showing location of the study sites in Iringa District (Source: Google map using Maptive software).

Preparation and nursery management

Seedling trays consisted of 120 cells which were filled in with fertile soil and watered using a 2 L hand sprayer. Two seeds per cell were sown at a depth of 0.5–1.0 cm. Seeds under trays were then transferred into a shade house, which served as a germination chamber for three days and five days during the rainy and dry seasons, respectively. The thinning was done on the fifth and eighth days during the rainy and dry seasons, respectively, leaving one seedling per cell. NPK (19% N: 19% P_2O_5: 10% K_2O + 1% Mg, 2.8% S, 0.25% B), formulated as foliar fertilizer was sprayed at intervals of 5, 10, and 20 days during the rainy season and at 8, 13, and 23 days during the dry season. Foliar fertilizer was used to allow direct absorption of nutrients by the leaves through stomata and epidermis which in turn stimulates the root development by demanding more water. Regular watering started immediately and lasted in a period of one month, and seedlings were allowed to acclimatise to field conditions for five days before transplanting.

Preparation of botanical extracts and their usage

The preparation of the neem extract comprised of leaves collected from areas in the vicinity of the experimental sites. Leaves were used due to its ability to enhance the shelf life of target plant as suggested by Ahmad et al. (2015). The sampled leaves were washed with distilled water and air-dried for two weeks. The dried leaves were pulverized to powder using a mortar and pestle as suggested by Phoofolo et al. (2013). A 100 g of the powdered neem leaves were dissolved in 500 ml of distilled water, giving a concentration of 20% (w/v) in the solution. Soap (20 g) was added to the solution and kept for 3 days for full extraction of compounds as suggested by Mondédji et al. (2021). The solution was then sieved to get a clear extract. A similar procedure was used to prepare an extract derived from Mexican marigold (Figure 2). During the field applications, 100 mL of each extract, namely neem leaf and Mexican marigold leaf, were dissolved in 2 L of water. The formulation of extracts was prepared on the day of the application.

Land preparation, transplanting, and management

Land preparation was done using a hand hoe two weeks before transplanting cabbage seedlings. Each experimental site had 3 blocks, each block comprised of 12 plots and each plot had an area of 4 m^2, making a total of 144 m^2 area per site. The plots were separated from each other by a 2 m distance to reduce drifting effects. Each plot accommodated 12 cabbage plants at the recommended spacing of 60 cm by 45 cm. Plots were irrigated a day before the transplanting of cabbage seedlings. After a month, cabbage seedlings had 4–6 true leaves per plant; this was considered as ideal size for transplanting. Seedlings were transplanted on raised beds of 12 cm high during the rainy season and on sunk beds during the dry season.

Figure 2: A schematic representation for preparation of botanical extracts (i.e., Mexican marigold and neem).

Transplanting was done late in the evening to help the seedlings adjust themselves during the night because the amount of water absorbed exceeded the amount lost through transpiration. After transplanting, NPK (15% N:9% P: 20% K: 1.8% MgO: 9.5%SO_3:0.015% B: 0.02% Mn:0.02% Zn), formulated as granular fertilizers were added at a rate of 10 g/plant. A similar fertilizer was added as the second top-dressing and during the onset of head formation at 20 g/plant, respectively at the onset of head formation. Furthermore, poorly established seedlings were replaced by new ones during the first week of experimentation to ensure balancing of the experiments. All plots were irrigated every 10 to 15 days, depending on soil conditions to ensure uniformity of head formation, splitting, and enlargement.

An assessment of insect pest infestations was done before spraying. First application of the botanical extracts was done one week after transplanting, and the subsequent application was done at an interval of seven days in both seasons. Treatments were sprayed on top and under the leaves of the cabbage during the evening to avoid direct sunlight, which might cause the decomposition of bioactive compounds in botanical extracts (Mpumi et al. 2020). Weeding was done once weeds appeared in the field.

Experimental design

The field experiment was laid out using a randomized complete block design (RCBD) as the most reliable method for creating homogenous groups. Four treatments were used to determine the efficacy of botanical extracts against cabbage insect pest infestations under the following protocol: untreated treatment (T1), neem treatment (T2), Mexican marigold treatment (T3), and a mixture of neem and Mexican marigold treatment (T4). These treatments were replicated three times in each block, and there were three blocks per experimental site in both the rainy and dry seasons.

Data collection

Evaluation of insect pest damage

Leaf damage caused by the diamondback moths, cabbage webworms, cabbage aphids, and cabbage loopers was examined before the application of the botanical extracts at an interval of seven days. Leaf damage scores on each third leaf of a plant from six plants in each plot were randomly selected based on a scale of 0–5 as recommended by Begna and Damtew (2015). The assessments were as follows: (0 = no leaf damage; 1 = up to 20% of the total leaf area damaged; 2 = 21–40% of the total leaf area damaged; 3 = 41–60% of the total leaf area damaged; 4 = 61–80% of the total leaf area damaged, and 5 = more than 80% of the total leaf area damaged). Total leaf area was calculated by using the general formula: $LA = 5.5981 + 0.8961\ W$ (Olfati et al. 2010), where LA means the total leaf area, and W means the width of the cabbage leaf. Additionally, the leaf damage levels were estimated using a squared paper grid of the damaged area.

Determination of cabbage yields

Cabbage was considered mature when it showed signs of maturation, such as being firm and solid to the touch, the head colour changing to a lighter shade of green, and some cabbage displaying signs of bursting or loosened leaves. Six cabbages per plot were harvested by cutting the stalk just below the bottom leaves with a knife and weighed at analytical balance. Marketable yields expressed as a ton per hectare were considered as insect-and disease-free if were mechanically undamaged cabbage heads and weighed 0.5 kg and above per plot. This was done between the 10th and 12th weeks after transplanting during the rainy and dry seasons, respectively. Secondly, unmarketable yield (tons/ha) was considered diseased, mechanically damaged, or injured heads, as well as heads that weighed less than 0.5 kg. This was done between the 10th and 12th weeks after transplanting during the rainy and dry seasons, respectively.

Data analysis

Data were analysed using R Software version 4.1.3 by R Core Team (2021). A generalised linear model procedure (GLM) was used for the analysis. An analysis of variance (ANOVA) was used to compare the mean difference between treatments, seasons, and their interactions in terms of damage levels and yields of cabbage. Similarly, the Least Significant Difference (LSD) test was used to separate means at a significance level of 5%.

Results

Efficacy of botanical extracts in controlling cabbage damage

The results revealed that damage levels varied significantly from 3.33 to 9.20% and 5.0 to 18.33% in the treated plots, while the untreated plots recorded the highest damage of 33.70 and 45.85% during the rainy and dry seasons, respectively, at Kalenga ($F_{(3,\ 499)}$ = 111.71, $p < 0.05$). A similar trend was also observed in Mgera where damage levels varied significantly from 4.44 to 8.80% and 7.50 to 15.83% were recorded in the treated plots, while the untreated plots recorded the highest damage of 34.40 and 46.66% during rainy and dry seasons ($F_{(3,\ 449)}$ = 94.23, $p < 0.05$). It was observed that the high damage levels were recorded during the dry season than rainy season at both experimental sites (Table 1). This indicates that the botanical extracts; Mexican marigold, neem, a mixture of neem and Mexican marigold recorded the lowest damage levels of infestations in both seasons and at both sites.

Table 1: Damage levels at Kalenga and Mgera sites in both the dry and rainy seasons

	Kalenga		Mgera	
	Rainy season (%)	Dry season (%)	Rainy season (%)	Dry season (%)
Control	33.70 ± 35	44.83 ± 3.5	34.40 ± 3.6	46.66 ± 3.7
Neem	6.29 ± 1.2	10.00 ± 1.1	7.70 ± 1.6	11.66 ± 1.5
Mexican marigold	9.20 ± 1.7	18.33 ± 1.9	8.80 ± 1.8	15.83 ± 2.0
Neem + Mexican marigold	3.33 ± 10	5.00 ± 1.0	4.44 ± 1.1	7.50 ± 1.1

Marketable and unmarketable cabbage yields

It was also observed that significantly higher marketable cabbage yields were recorded in the treated plots than in the untreated plots during both seasons at Kalenga ($F_{(3,\ 67)}$ = 141.79, $p < 0.05$) and Mgera sites ($F_{(3,67)}$ = 53.36, $p < 0.05$). The treated plots had marketable yields ranging 30.60–34.73 tons/ha and 37.20–43.10 tons/ha, while the untreated plots had the lowest marketable yields of cabbage of 11.20 and 4.78 tons/ha during the rainy and dry seasons, respectively, at the Kalenga site. Similarly, at Mgera site, the marketable yields of cabbage varied from 28.70 to 5.86 tons/ha and 24.30 to 36.31 tons/ha in the treated plots, while the untreated plots recorded the lowest marketable yields of 10.28 and 5.09 tons/ha during the rainy and dry seasons, respectively (Table 2).

Table 2: Marketable yield at Kalenga and Mgera sites in dry and rainy seasons

	Kalenga		Mgera	
	Rainy season (tons/ha)	Dry season (tons/ha)	Rainy season (tons/ha)	Dry season (tons/ha)
Control	11.20 ± 2.2	4.78 ± 1.2	10.28 ± 2.0	5.09 ± 1.2
Neem	32.95 ± 0.6	40.10 ± 0.9	32.3 ± 0.5	32.98 ± 3.2
Mexican marigold	30.60 ± 1.5	37.2 ± 1.4	28.70 ± 0.4	24.30 ± 4.5
Neem + Mexican marigold	34.73 ± 1.2	43.1 ± 1.1	35.86 ± 0.9	36.31 ± 1.2

On the other hand, the present study revealed that the overall highest unmarketable yields were recorded in untreated plots, which varied between 5.87 and 8.59 tons/ha during the rainy and dry seasons, respectively. The variation was statistically significant between the treated plots and untreated plots at Kalenga site ($F_{(3, 67)} = 85.03$, $p < 0.05$). A similar trend was also observed in Mgera (Table 3), untreated plots recorded the highest unmarketable yields, which varied between 7.32 and 8.06 tons/ha compared to the treated plots, which ranged 4.39–6.61 and 1.82–5.08 tons/ha during the rainy and dry seasons ($F_{(3, 67)} = 4$ 3.77, $p < 0.05$).

Table 3: Unmarketable yields at Kalenga and Mgera sites in dry and rainy seasons

Treatment	Sites			
	Kalenga		Mgera	
	Rainy season(tons/ha)	Dry season (tons/ha)	Rainy season(tons/ha)	Dry season (tons/ha)
Control	5.87 ± 1.4	8.59 ± 0.5	7.32 ± 0.3	8.06 ± 0.3
Neem	0	0	5.28 ± 0.2	1.82 ± 0.4
Mexican marigold	0	0	6.61 ± 0.5	5.08 ± 0.7
Neem + Mexican marigold	0	0	4.39 ± 0.2	0

Discussion

Efficacy of botanical extracts in controlling cabbage damage

The overall aim of this study was to assess the efficacy of neem and Mexican marigold extract in controlling cabbage damage that results from insect pests' infestations. This study shows that botanical extracts from the named plants could be promising candidates for fighting against various insect pests. However, the significant differences in damage levels between treated and untreated plots imply possible decrease in leaf photosynthetic area. Similarly, the impact of folivory on photosynthesis was found to be greater than the sum of its leaf holes (Zangerl et al. 2002). It was also found that the leaf growth continued to decline after defoliation, and this might be due to the normal partitioning of photosynthates between foliage, stem, and roots being altered or curtailed. This was supported by Costa et al. (2017), who observed significant reduction in the rate of photosynthesis and transpiration as leaf miners' larvae per leaf increased. Likewise, studies conducted by Eyles et al. (2013a and b) demonstrated the poor performances of plants after some leaves were infested by insect pests.

The overall cabbage damage levels were significantly different between the two seasons probably due to the drying up of nearby vegetation observed during the dry season. This means, insect pests would have been forced to migrate to more suitable locations for their survival. The findings of the present study are consistent with those of Westbrook et al. (2016), who reported that fall armyworms tend to migrate from food scarcity areas to sufficient and suitable food sources. However, the variability of insect pests between the two seasons might be due to environmental conditions mainly rainfall, light intensity, and daily temperature ranges though they were not covered under this study. According to Kobori and Amano (2003) and Zayan et al. (2019) the effects of rainfall on diamondback moth eggs and warm temperatures could lead to an increase in insect populations.

The low infestations recorded in the treated plots at both experimental sites probably could be attributed to the efficacy of the botanical extract formulations in controlling the targeted insect pests. Previous studies showed that Mexican marigold composed of z-ocimene, caryophyllene and myrcene as active ingredients, and neem composed of azadirachtin and salannin were effective against a number of insect pests (Onyambu et al. 2015, Chaudhary et al. 2017). Also, the lowest damage levels under the mixture of neem and Mexican marigold treatment implies how strong it was compared with when these botanical extracts were applied separately. Our findings are in agreement with the findings of Wini et al. (2018) as well as Khan and Dewanda (2019), who reported synergistic effects of different botanical extracts blended together. Specifically, the mixture of neem and Mexican marigold were reported to offer multiple actions, such as feeding inhibition and insecticidal activity against insect pests (Dadang and Ohsawa 2007).

Marketable and unmarketable cabbage yields

The differences in marketable and unmarketable cabbage yields recorded in both experimental sites could be attributed to high insect pest infestations especially in untreated plots reported during dry and rainy seasons. Similar findings were reported by Kiptoo et al. (2015) and Jat et al. (2017), who observed serious yield losses of up to 52% in cabbage crops due to insect pest infestations. Our findings are also in agreement with those Stephenson et al. (2020), who showed that insect pests have significant effects on both crop yields and quality. The control treatment had the lowest marketable and highest unmarketable cabbage yields suggesting the direct relationship between pest infestations and yield losses as also reported by Tolman et al. (2004) and Dadang et al. (2009).

It was also observed that apart from managing insect pests in cabbage, the botanical extract formulations might be contributing to releasing extra nutrients to the soil. Similarly, studies by Ibrahim et al. (2018) and Tembo et al. (2018) reported that apart from controlling crop pests, botanical extracts also play crucial roles in releasing soil nutrients and therefore serve as fertilizers. Some of the nutrients found in Mexican marigolds (Navarro-González et al. 2014) and in neem (Garba and Mungadi 2019) include potassium, phosphorus, sulfur, iron, zinc, and magnesium.

Conclusions and recommendation

The use of botanical extract formulations can effectively control cabbage insect pests. The tested botanical extract formulations have shown insecticidal activities towards the targeted cabbage pests that could be used to contribute in improving cabbage growth. As these botanical extracts have yielded promising results, they hold a potential for future studies aiming at validating and scaling up these results to increase cabbage production and improve the quality of cabbage products. Furthermore, there is a need to investigate more and develop formulations with longevity while retaining the desired efficacy.

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Conflict of interest

The authors declare that there is no conflict of interest regarding this work.

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