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Insecticidal efficacy of neem (*Azadirachta indica* A. Juss.) products against the sweet potato (*Ipomea batatas* L.) weevil (*Cylas puncticollis* Boh.) in storage

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Abstract
The insecticidal efficacy of neem in storage at Dang (Ngaoundere) and Kismatari (Garoua) was investigated in the present study under controlled conditions for two consecutive years (2013, 2014). In each of the studied site and and during each year, a factorial fully randomized block design ((3x2) x 4) was adopted, with two varieties (local and TIB1) as the first factor, and treatments (Neem oil, Neam leaves Extract, Control) as the second factor, each of which was repeated four times. The rate and severity of attacks, as well as the population dynamic of *Cylas puncticollis* were assessed. Results indicate that, after 2 months of storage, neem oil has proven to be the best bi-oinsecticide to preserve the two varieties of sweet potato grown in storage, causing 100% mortality of the weevils, and 0% attack of tubers. The neem leaves extract also significantly ($p<0.001$) reduced the number of holes inflicted to tubers in storage by 2.46 and 2 folds in 2013, 1.64 and 1.7 folds in 2014 for the local variety, by 2.21 and 2.2 folds in 2013, 1.8 and 1.8 folds in 2014, respectively at Kismatari-Garoua and Dang-Ngaoundere compared to the controlled tubers. The improved sweet potato variety TIB1 was the most attacked by *C. puncticollis*, with average attack rates of 57% and 56% respectively at Kismatari-Garoua and Dang-Ngaoundere against 39% and 40% for the local variety. Refering to these results, neem oil could be applied by farmers as an alternative control measure to effectively control the sweet potato weevil (*C. puncticollis*) in storage.

Keywords: Sweet potato, Storage, *Cylas puncticollis*, Neem aqueous extracts, Neem oil, Damages

1. Introduction

There are many diseases and pests of sweet potatoes, of which the most severe are those affecting the tubers before and after harvest, and those that necrose the stems. In the field, various fungi such as *Pythium* and *Phytophtora* cause brown colored rots known as round spots disease. After harvest, fungi of the genus *Rhizopus* can cause soft tuber disease that rapidly develops as the temperature is constantly high [1]. The main enemies of sweet potato are nematodes, or the weevils (*Cylas puncticollis*) which form galleries in tubers (Denon and Mauleon, 2004, Varin *et al*., 2009, Rukarwa *et al*., 2010).

In Africa, the weevil is the main constraint of sweet potato production [2]. It is reponsible for significant damages (up to 97%) of crop losses, and is present in Cameroon [3, 6]. Larvae that emerge from eggs laid by adults also dig holes and live in tubers. Two types of post-harvest infestations exist that develop primary on attack tubers, and secondary on healthy ones [1]. Pest damage usually continues during storage, and thus, infested roots can not be stored for a long periods of time, and therefore, contaminate healthy tubers [1]. After severe or mild infestations, damaged tubers react to attacks by secreting a poison, making the crop unpleasant, thus inedible by humans due to terpenoids produced in response to weevil feeding [7]. This poison can affect the lungs or heart of humans and livestock [1]. Studies have been conducted to reduce *C. puncticollis* attacks and improve the conservation of sweet potato tubers [8, 9]. Neem is a very powerful insecticide and has been used as a natural insecticide for centuries to protect crops and foodstuffs stored in granaries. Neem extracts are used to control pests or to conserve food [10]. In Cameroon, all producers and distributors of agricultural products are familiar with neem extracts, which offer several services as far as storage of products is concerned [11]. In Ghana, leaves powder and neem seeds were reported to control mosquitoes [12].

In Sudan, the neem seed extract after spray was revealed to effectively control the pupal stage of *Tribulium castreneum* [13]. Neem seed extract has been tested on some sweet potato pests in storage (*Fusarium oxysporum*, *Macrophomina phaseolina*, *Ceratocytis fimbriata*, *Diplodia tubericola*, *Rhizopus oryzae*, *Rhizopus nigricans and Erwinia chrysanthemum*) [9], but the control of the weevil was not mentioned. The objective of the present research was to assess the efficacy of neem extracts (neem oil and leaves extract) against the weevil (*Cylas puncticollis*) in storage.

2. Material and methods

2.1 Plant material

The present study was conducted from October to December 2013 and 2014 at the Biology Laboratory of the University of Ngaoundere (Cameroon). Tubers for trials were harvested in the fields at Dang (Ngaoundere) and Garoua (Kismatari). Healthy tubers were selected and washed with tap water for the assay. Green neem leaves were harvested in each agro-ecological zone where experiments took place at Kismatari-Garoua (9° 18´ 5" N, 13° 23´ 51' E), and at Dang-Ngaoundere (7° 32' 380"N, 13° 51' 125"E). Neem seed oil was purchased from a phytosanitary store at Maroua (Far North region, Cameroon) in 1.5 L plastic bottles.

2.2 Preparation of bio-insecticides

The bio-insecticide from neem leaves extracts was obtained following the aqueous extraction method described [14]. Green neem leaves harvested were crushed in a traditional mortar to obtain a paste. This paste was then weighed and placed overnight (12 h) in a plastic sealed container with tap water at a dose of 200 g / L, that is 2 kg / 10 L. The mixture was filtered with a 0.5 mm mesh screen [15] to obtain a filtrate that was used to treat the tubers. The neem oil was diluted in a mixture of 0.5 L / 10 L (ethanol / tap water) solution.

2.3 Cultivation of *Cylas puncticollis*

At harvest, tubers with the galleries were collected and placed in 1.5 L plastic container (Tangui bottle), and then, each container was covered with a fine tissue which allows aeration and confines the insects (Figure 1). All containers were kept under laboratory conditions for one month, after which more than 2000 weevils emerged from sweet potato. These adult weevils were used to inoculate healthy sweet potato tubers during the experimentation.

2.4 Experimental design and treatments

The experimental set-up was a Split-plot (3 × 2) × 4, where the control liquid (NLE = neem leaves extract, NO = Neem oil, and Ctrl = control = tap water) was considered as the main factor or treatments, while the sweet potato variety (Local variety and improved variety or TIB1) served as the secondary factor. Each treatment was repeated four times. After harvest, 180 healthy tubers per sweet potato variety were selected for a total of 360 tubers used for the storage experiments. These tubers were equally distributed in 24 plastic containers, and inoculated with 20 adult weevils each. Before the distribution, they underwent different treatments as the control meaasure as follows: for the NO (Neem oil) treatment, tubers were immersed in the neem oil solution for 10 minutes, and then, dried for 30 minutes in the shade; for the NLE treatment (Neem leaves extract), tubers were immersed in a neem leaves extract solution for 10 minutes, and then, dried for 30 minutes in the shade; for treatment Ctrl (control), tubers were immersed in tap water for 10 minutes, and then, dried for 30 minutes in the shade.

(a)

(b)

Fig. 1: Cultivation of *C. puncticollis*: (a) Sweet potato tuber infested by *C. puncticollis*; (b) Sweet potato tubers enabling growth of *C. puncticollis* in Tangui plastic bottles

Plastic containers were stored under laboratory conditions at room temperature for 2 months [9], after which the following parameters were assessed:

The attack rate was estimated using expression formula:

Attack rate = % attacked tubers=(Number of tubers attacked × 100) / (Total number of tubers)

The attack severity was evaluated by counting the number of holes on attacked tubers.

To estimate the variation in the *C. puncticollis* population during the two months of storage, the number of insects in each plastic container was counted weekly, and the variation was calculated by the formula:

$DI = I_1 - I_0$

Where, I_0 = number of weevils introduced at the beginning of the experiments (n = 20 weevils), and I_1 = the number of insects counted after two months of storage.

Statistical analysis

All experimental data were subjected to the Analysis of Variance (ANOVA) procedure using the SPSS Statistical Analysis System Version 16.0. For the separation of means, the Tukey test (P = 0.05) was used. Correlation between the parameters considered was assessed using the Pearson correlation coefficient.

3. Results

3.1 Influence of treatments on attack rate of tubers by *C. puncticulis* in storage

The influence of treatments on neem products on the attack rate of sweet potato tubers between 2-8 weeks post-storage at Kismatari-Garoua and Dang-Ngaoundere during two consecutive years (2013 and 2014) is shown in Table 1 and 2. In general, neem products significantly reduced the attack rate of sweet potato tubers attributed to *C. puncticulis* compared to the control. Neem oil completely protected the tubers of both sweet potato varieties from attack by the weevil during the storage experiment, and the two studied years.

Table 1: Impact of treatments on attack rate of sweet potato tubers caused by *Cylas puncticollis* at Kismatari (Garoua) during the 2013 and 2014 cropping seasons.

Varieties	Treatments	Exposure time (Weeks)				F-value
		2	4	6	8	
		Agro-ecological Zone I (Kismatari, Garoua) 2013				
Local	Ctrl	13.00±0.70aD	16.00±0.70aC	21.00±1.29aB	41.50±1.44aA	139.00***
	NO	00±0.00cA	00±0.00cA	00±0.00cA	00±0.00cA	-
	NLE	6.25±0.47bC	7.25±0.47bC	8.50±0.64bAB	10.50±0.64bA	10.38**
	F-value	173.91***	264.08***	160.68***	558.70***	
TIB1	Ctrl	17.00±0.40aD	23.25±0.62aC	34.25±1.43aB	57.75±2.39aA	154.04***
	NO	00±0.00cA	00±0.00cA	00±0.00cA	00±0.00bA	-
	NLE	9.50±0.64bB	10.50±0.64bB	11.25±0.85bB	13.25±1.18bA	3.63*
	F-value	373.28***	500.53***	327.51***	385.32***	
		Agro-ecological Zone I (Kismatari, Garoua) 2014				
Local	Ctrl	10.00±0.70aD	17.50±1.04aC	27.75±1.25aB	38.50±2.66aA	60.12***
	NO	00±0.00cA	00±0.00cA	00±0.00cA	00±0.00cA	-
	NLE	6.75±0.47bC	10.75±0.47bB	12.50±0.64bB	16.00±0.70bA	34.63***
	F-value	107.05***	141.98***	292.76***	147.98***	
TIB1	Ctrl	13.00±0.70aD	18.50±2.25aC	29.50±1.35aB	57.00±3.62aA	74.76***
	NO	00±0.00cA	00±0.00bA	00±0.00cA	00±0.00bA	-
	NLE	8.50±0.64bD	13.75±1.65aC	18.50±2.53bB	24.25±2.17bA	12.65**
	F-value	142.63***	35.44***	81.64***	137.17***	

For a given variety, values affected by the same letter in a column are not significantly different between treatments according to Tukey test. For a given treatment, values affected by the same letter in a row are not significantly different between exposure times according to Tukey test. ^{S}p=0.05). ^{ns,}p>0.05 ; *p<0.05; **p<0.01; ***p<0.001; Ctrl: Control; NO: Neem Oil; NLE : Neem Leaves Extract.

When compared to the control, the aqueous neem leaves extract showed an insecticidal efficacy against sweet potato weevils, and this efficacy was reduced progressively with increased exposure time in the two agro-ecological zones. As a matter of fact, the attack rate of tubers treated with neem leaves extract at Kismatari-Garoua increased significantly (F (3.8) = 10.38, p<0.01) from 6.25% after 2 weeks to 10.50% in 8 weeks, and significantly (F (3.8) = 3.63; p<0.05) from 9.50% after 2 weeks to 13.25% in 8 weeks, respectively for the local and TIB1 varieties in 2013.

In 2014, the attack rate was significantly increased (F (3.8) = 34.63, p<0.001) from 6.75% after 2 weeks to 16% in 8 weeks for the local variety, and significantly (F (3.8) = 12.65; p<0.01) from 8.50% after 2 weeks to 24.25% in 8 weeks for the TIB1 variety.

Similarly, at Dang-Ngaoundere, the attack rate of tubers treated with neem leaves extract increased significantly (F (3.8) = 12.66, p<0.01) From 6% in 2 weeks to 11% in 8 weeks for the local variety, and significantly (F (3.8) = 14.58; p<0.001) from 8.75% after 2 weeks to 14.25% in 8 weeks for TIB1 variety in 2013. It was also increased significantly (F (3.8) = 8.03, p<0.001) from 5.50% after 2 weeks to 9.75% in 8 weeks for the local variety, and significantly (F (3.8) = 4.15; p<0.05) from 8.25% after 2 weeks to 12.50% in 8 weeks for the TIB1 variety in 2014.

Between the two varieties of the sweet potato tubers stored, the improved variety TIB1 was the most attacked by *C. puncticollis* compared to the local variety in the two study areas in 2013 and 2014. The average attack rates were 39% for the local variety against 57% for the improved TIB1 variety at Kismatari-Garoua, and approximately 56% for the improved variety TIB1 against only 40% for the local variety at Dang-Ngaoundere during the two consecutive years of study.

Table 2: Impact of treatments on attack rate of sweet potato tubers caused by *Cylas puncticollis* at Dang-Ngaoundere during the 2013 and 2014 cropping seasons.

Varieties	Treatments	Exposure time (Weeks)				F-value
		2	4	6	8	
		Agro-ecological Zone II (Dang, Ngaoundere) 2013				
Local	Ctrl	13.50±0.64aD	16.50±0.64aC	21.50±0.64aB	41.50±1.44aA	190.70***
	NO	00±0.00cA	00±0.00cA	00±0.00cA	00±0.00cA	-
	NLE	6.00±0.40bC	7.75±0.62bBC	9.50±0.86bAB	11.00±0.40bA	12.66**
	F-value	235.28***	251.61***	298.50***	616.33***	
TIB1	Ctrl	17.50±0.64aD	23.25±0.62aC	33.50±1.32aB	57.75±2.39aA	152.46***
	NO	00±0.00cA	00±0.00cA	00±0.00cA	00±0.00bA	-
	NLE	8.75±0.47bC	10.75±0.62bBC	11.25±1.47bB	14.25±0.75bA	14.58***
	F-value	355.64***	513.07***	440.55***	431.55***	
		Agro-ecological Zone II (Dang, Ngaoundere) 2014				
Local	Ctrl	12.50±1.04aD	15.25±1.03aC	20.25±0.85aB	40.00±1.95aA	92.00***
	NO	00±0.00cA	00±0.00cA	00±0.00cA	00±0.00cA	-

	NLE	5.50±0.64bB	6.75±0.47bB	7.75±0.85bAB	9.75±0.47bA	8.03***
	F-value	78.50***	135.62***	214.75***	321.24***	
TIB1	Ctrl	16.50±0.64aD	22.25±1.25aC	32.25±1.93aB	55.75±3.47aA	67.45***
	NO	00±0.00cA	00±0.00cA	00±0.00cA	00±0.00bA	-
	NLE	8.25±0.85bB	9.50±0.64bAB	10.00±0.91bAB	12.50±1.04bA	4.15*
	F-value	178.20***	188.93***	179.19***	195.30***	

For a given variety, values affected by the same letter in a column are not significantly different between treatments according to Tukey test. For a given treatment, values affected by the same letter in a row are not significantly different between exposure times according to Tukey test. ^{S}p=0.05). ^{ns,}*p*>0.05 ; **p*<0.05; ***p*<0.01; ****p*<0.001; Ctrl: Control; NO: Neem Oil; NLE: Neem Leaves Extract.

3.2 Influence of treatments on the attacks severity of sweet potato tubers in storage

Table 3 illustrates the responses of neem products (neem leaves extract and neem oil) application to the attacks severity of sweet potato by *C. puncticollis* in storage in 2013 and 2014 at Kismatari-Garoua and Dang-Ngaoundere. On the overall, neem products significantly reduced (*p*<0.05) the attack severity of tubers due to *C. puncticollis*.

Table 3: Impact of treatments on attack severity of sweet potato caused by *Cylas puncticollis* in stockage.

Varieties	**Treatments**			
	Control	**Neem Oil**	**Neem Leaves Extract**	**F-value**
Agro-ecological Zone I (Kismatari, Garoua) 2013				
Local	30.71±1.87a	00.00±0.00c	13.00±1.29b	71.03***
TIB1	32.00±2.05a	00.00±0.00c	14.25±0.85b	143.28***
t-value	5.94*	-	0.80ns	
Agro-ecological Zone I (Kismatari, Garoua) 2014				
Local	23.00±2.12a	00.00±0.00c	13.75±1.31b	64.50***
TIB1	27.00±2.79a	00.00±0.00c	14.75±0.47b	68.00***
t-value	1.13ns	-	0.71ns	
Agro-ecological Zone II (Dang, Ngaoundere) 2013				
Local	24.25±2.92a	00.00±0.00c	11.50±1.32b	42.80***
TIB1	33.50±4.55a	00.00±0.00c	14.75±3.30b	26.72***
t-value	1.70ns	-	0.91ns	
Agro-ecological Zone II (Dang, Ngaoundere) 2014				
Local	23.00±1.55a	00.00±0.00c	12.75±0.85b	131.98***
TIB1	27.75±1.03a	00.00±0.00c	14.75±1.10b	252.35***
t-value	2.27ns	-	1.42ns	

For a given variety, values affected by the same letter in a row are not significantly different between treatments according to Tukey test. For a given treatment, values affected by the same letter in a column are not significantly different between varieties according to Tukey test. ^{S}p=0.05). ^{ns,}*p*>0.05 ; **p*<0.05; ***p*<0.01; ****p*<0.001; Ctrl: Control; NO: Neem Oil; NLE : Neem Leaves Extract.

Neem oil completely protected the tubers from the weevil attacks, with no holes bore on tubers of the two cultivated sweet potato varieties in the two agro-ecological zones. However, the aqueous neem leaves extract significantly (*p*<0.05) decreased the number of holes inflicted to tubers in storage, although it was less efficient than neem oil. In 2013 at Kismatari-Garoua, neem extracts significantly (F (2.9) = 71.03; *p*<0.001) reduced holes from 32 in the control (Crtl) to 13 in NLE treated tubers, against 0 holes for the NO treatment for the local variety. Concerning the TIB1 variety, there was a significant reduction (F (2.9) = 143.28; *p*<0.001) from 31 holes in the control to 14 and 0 holes in, NLE and NO applied treatments respectively. Similarly, in 2014, NLE significantly (F (2.9) = 64.50; *p*<0.001) reduced holes on tubers from 23 (Ctrl) to 14 holes for the local variety, and significantly F (2.9) = 68.00, *p*<0.001) from 27 (Ctrl) to 15 holes for the TIB1 variety.

In the agro-ecological zone II (Dang-Ngaoundere) in 2013, neem leaves extract significantly (F (2.9) = 42.80, *p*<0.001) decreased the number of holes inflicted on tubers ranging from 24 (Ctrl) to 12 holes for the local variety, and significantly (F (2.9) = 26.72; *p*<0.001) from 33 (Ctrl) to 15 holes for the TIB1 variety. In 2014, the number of holes varied significantly (F (2.9) = 131.98; *p*<0.001) from 23 (Ctrl) to 13 holes for the local variety, and significantly (F (2.9) = 252 .35; *p*<0.001) from 28 (Ctrl) to 15 holes for the TIB1 variety. Between the two stored varieties, the improved variety TIB1 was the most severely attacked (t = 5.94, *p*<0.05), particularly in 2013 (Table 3).

3.3 Population dynamics of *C. puncticollis* as affected by neem products for two weeks of storage.

Fig. 2 and 3 show the influence of neem products on the weekly evolution of *C. puncticollis* population as affected by fluctuations due to treatments in the agro-ecological zone I (Kismatari-Garoua) and II (Dang-Ngaoundere) in 2013 and 2014. Neem products demonstrated their insecticidal efficacy against adults sweet potato weevils by significantly inhibiting their growth. In the two zones, neem oil in general completely inhibited the development of *C. puncticollis* population on the tubers of the two stored sweet potato varieties in 2013 and 2014. Compared to the control stored tubers, the aqueous neem leaves extract also significantly inhibited the development of *C. puncticollis* population in the studied zones. However, the insecticidal efficacy of theaqueous neem extract decreased as the exposure time increased. Within the tubers treated with aqueous neem leaves extract at Kismatari-Garoua in 2013, the weevil population significantly increased (F (4.10) = 43,45; *p*<0.001) from 5 weevils on average in 2 weeks to 18 after 8 weeks post-storage for the local variety, and significantly (F (4.10) = 18.68; *p*<0.001) from 4 weevils in 2 weeks to 16 weevils in 8 weeks for TIB1 variety. Similarly, in 2014 in tubers treated with neem leaves extract, the weevil population increased significantly (F (4.10) = 30.61; *p*<0.001) from 5 in two weeks to an average of 13 weevils in the local variety, and significantly (F (4.10) = 47.02; *p*<0.001) from 5 in 2 weeks to an averagely 16 weevils in 8 weeks in the improved TIB1variety.

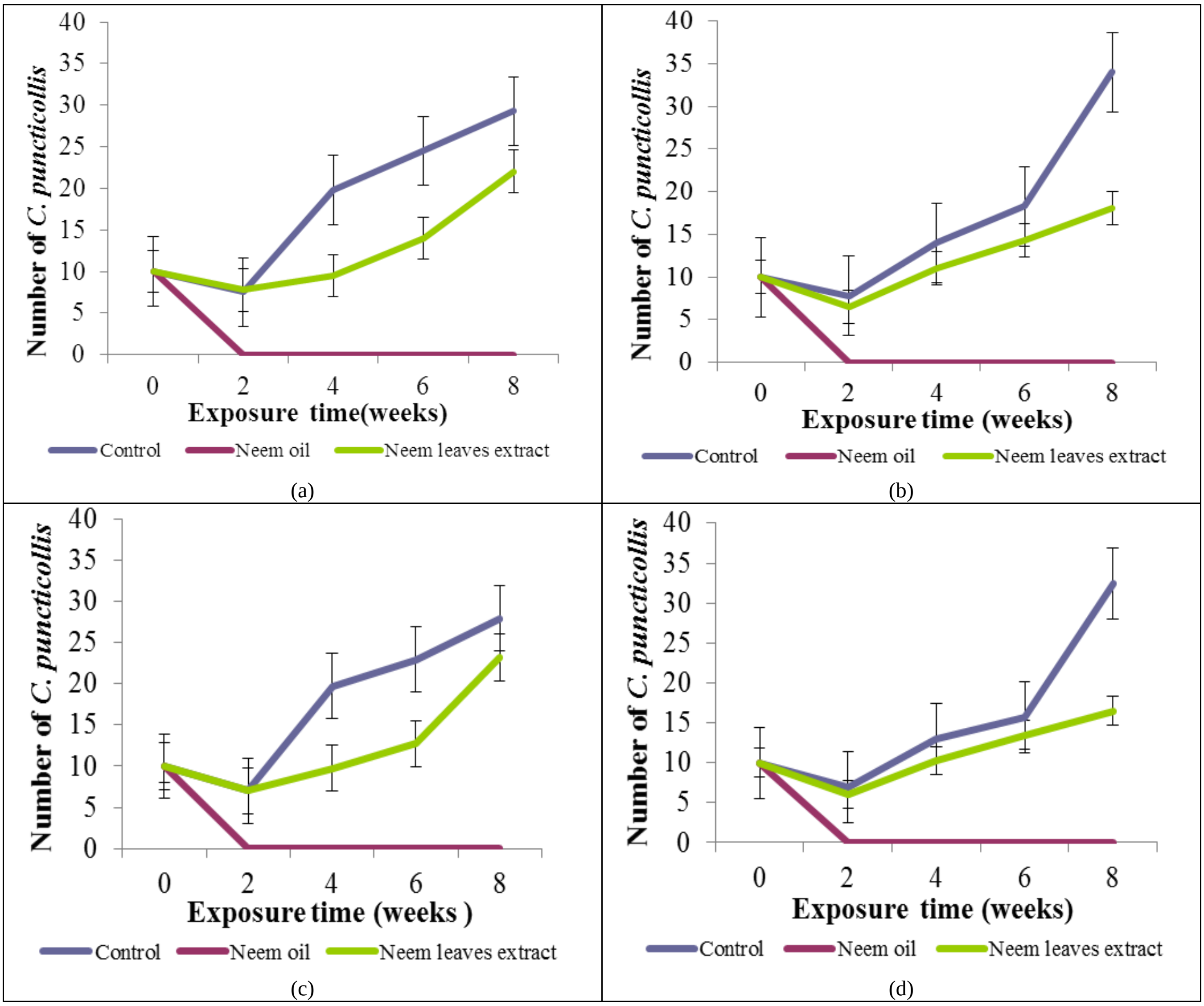
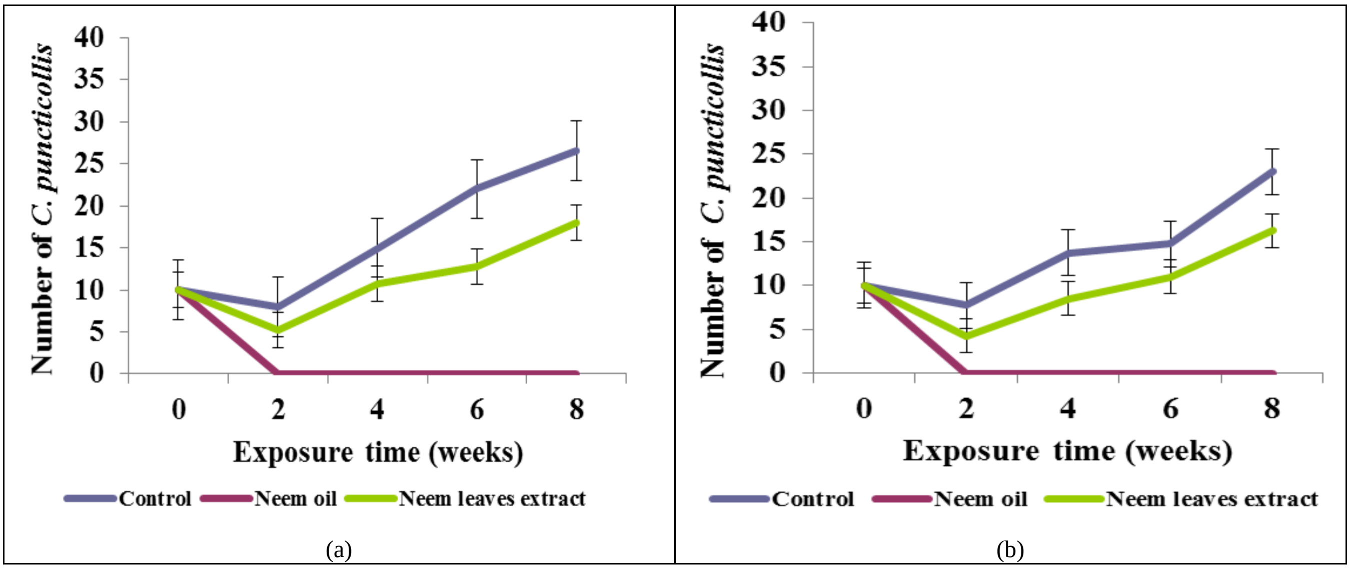


Fig 2: Weekly fluctuation of *Cylas puncticollis* population as affected by treatments in agro-ecological zone I (Kismatari-Garoua) during the 2013 (Local (a) and TIB1 (b) varieties), and 2014 (Local (c) and TIB1 (d) varieties) cropping seasons.



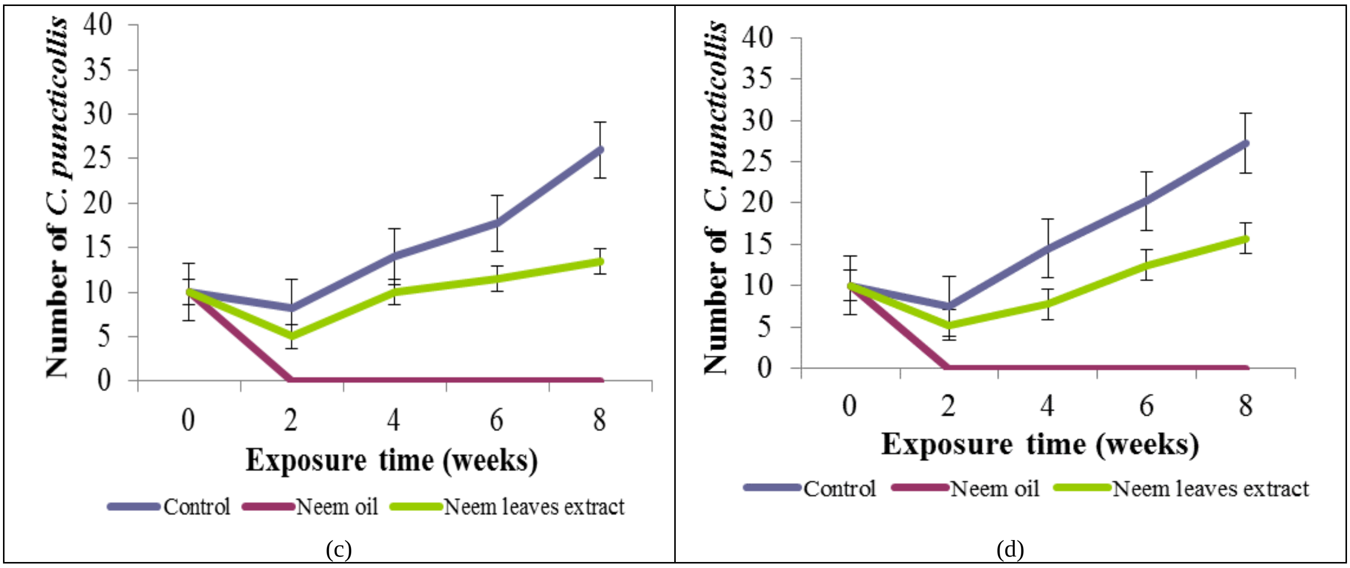


Fig. 3. Fig 3: Weekly fluctuation of *Cylas puncticollis* population as affected by treatments in agro-ecological zone II (Dang-Ngaoundere) during the 2013 (Local (a) and TIB1 (b) varieties) and 2014 (Local (c) and TIB1 (d) varieties) cropping seasons

At Dang-Ngaoundere in 2013, the *C. puncticollis* population increased significantly (F (4.10) = 124.00, p<0.001) from averagely 8 weevils in 2 weeks to 22 weevils after 8 weeks post-storage for the local variety, and significantly (F (4.10) = 94.40; p<0.001) from 7 weevils in 2 weeks to 18 weevils in 8 weeks for the TIB1 variety. In 2014, the weevil population was increased significantly (F (4.10) = 45,84; p<0.001) from 7 in two weeks to an average of 23 in the local variety, and significantly (4.10) = 63.81, p<0.001) from 6 in 2 weeks to an average of 17 weevils in 8 weeks in the improved TIB1variety. In both agro-ecological zones, the evolution of *C. puncticollis* population was almost similar for each treatment at each exposure time for the two sweet potato varieties stored at Dang in 2013 and 2014.

3.4 Correlation between severity rate, attack rate, and number of *Cylas puncticollis* on sweet potato tubers in storage

Table 4 indicates the correlations between severity, attack rates and the number of *C. puncticollis* on stored tubers at Kismatari-Garoua) and Dang-Ngaoundere during the two consecutive years 2013 and 2014. From this table, a strong positive bilateral correlations between the three parameters considered in the two agro-ecological zones in 2013 and 2014 were observed. In other words, the higher the *C. puncticollis* population, the greater the severity and attack rates inflicted to tubers by the weevils.

Table 4: Correlation between parameters in 2013 and 2014 at Kismatari (Garoua) and Dang (Ngaoundere).

Parameters	Attack rate	Attack severity	Evolution of population
Agro-ecological Zone I (Kismatari-Garoua) 2013			
Attack rate	1		
Attack severity	0.80**	1	
Evolution of population	0.84**	0.92**	1
Agro-ecological Zone I (Kismatari-Garoua) 2014			
Attack rate	1		
Attack severity	0.90**	1	
Evolution of population	0.94**	0.92**	1
Agro-ecological Zone II (Dang-Ngaoundere) 2013			
Attack rate	1		
Attack severity	0.88**	1	
Evolution of population	0.87**	0.89**	1
Agro-ecological Zone II (Dang-Ngaoundere) 2014			
Attack rate	1		
Attack severity	0.84**	1	
Evolution of population	0.93**	0.92**	1

5. Discussion

For all assessed parameters during this investigation in storage, the two neem products (leaves extract and oil) tested showed differential toxicity on adults *C. puncticollis*, thereby reducing the damages they caused to sweet potato tubers in storage. Neem oil was the most effective treatment, followed by neem leaves extract. Neem oil caused 100% mortality of cultivated *C. puncticollis* for two months period. In fact, neem has been reported to be more efficient in controlling stored food [16]. Neem has anti-appetant effects, and acts as a growth regulator that can affect moulting and larval development of certain arthropods. Moreover, it weakens insects and inhibits their resistance [17]. The contact of neem products with insect larvae reported to be lethal to their various developmental stages, as well as it contributes to their malformation [18], resulting in an insignificant number of tubers being attacked. Powder and aqueous neem leaves extract were revealed to prevent the perforation of young banana plants in Kenya by the insect borer of stems [19]. In the Logone Valley of Cameroon, 300µL oil powders and neem kernels in a 5% and

10% mass ratio were reported to protect 100 g of sorghum and maize seeds from insect pests attacks for 6 months [11]. In fact, all parts of neem have pesticidal properties [20]. Neem extracts are composed of a mixture of more than 100 compounds that are responsible for insect mortality, with the main documented component known as azadirachtin [21], although its concentration varies from one plant part to another. Several studies have shown elevated concentration of azadirachtin in neem leaves and seeds [22-25]. Other researchers have revealed that azadirachtin is instead more concentrated in seeds and oils [26, 27]. The significant efficacy of neem oil against the main sweet potato pest (*C. puncticollis*) could be attributed to the high concentration of insecticidal compounds, especially azadirachtin in neem oil [28].

Neem leaves extracts led to a significant protection of stored sweet potato tubers of the two varieties during the two consecutive years of experimentation. They have been extensively used for the conservation of foodstuffs [10]. In Cameroon, many growers and distributors of agricultural products are familiar with neem extracts due to its multiple therapeutic services. Neem is a very powerful insecticide and has been used for centuries as a natural insecticide to protect crops in granaries [11].

The induction of *C. puncticollis* mortality after neem extracts application appears to be further a proof of its insecticidal properties. They present 12 modes of action capable of killing 400 insect pests [16, 17]. An overall 100% of mosquito mortality was obtained during the first hour of experimentation following neem leaves powder and seeds oil application [12]. In a related research, 720 μL of neem oil of various concentrations was reported to induce 50-70% mortality of bees after 4 hours of exposure [29]. This is in agreement with other results in Sudan from which 62.83% mortality of pupal stage of *Tribulium castreneum* (flour beetle) was obtained after spray of neem seeds extract [13].

Reducing attacks on sweet potato due to weevils reduces the risk of health problems. For severe or mild infestations, damaged tubers react to attacks by secreting a poison which makes it unpleasant and therefore inedible by humans because of phyto-alexines produced in response to weevil feeding [5, 29]. Therefore, it is important to sustainably control the sweet potato pest to avoid this poison, that can affect the lungs and heart of humans and livestock [1].

6. Conclusion

After 2 months of storage, neem oil has proven to be the best insecticide to preserve two varieties of sweet potato grown in both agro-ecological zones, causing 100% mortality of *C. puncticollis*, with 0% tuber attack, while the neem leaves extract has induced averagely 86.25% mortality of this adult weevils. In the two agro-ecological zones and during the two consecutive years, the local variety, although less productive was more resistant to attacks by *C. puncticollis* in storage, compared to the TIB1 variety. From these results, it is suggested to apply neem seed oil as a sustainable alternative strategy to effectively control the sweet potato weevil in storage. Moreover, its biodegradable aspect makes it a serious rival to synthetic insecticides that are gradually prohibited because of their harmful effects on public health and the environment.

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8. References

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