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Full Length Research Paper

Management of Bean bruchids (*Accanthoscelides obtectus* Say.) (Coleoptera: Bruchidae) using botanical oils in Western Amhara, Ethiopia

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Faba bean, *Vicia faba* L. is an important legume crop that substitute animal proteins especially in developing countries. Bean bruchids or bean weevil, *Accanthoscelides obtectus* Say is a major insect pest of the faba bean grains mainly in the store. An experiment was conducted in Debre Markose University to screen effective botanical oils for the management of bean bruchids on faba bean grains. The tested oils were from seeds of Noug (*Guizotia abyssinica* L. f.), Rapeseed (*Brassica napus* L.), Lantana (*Lantana camara* L.), Pepper (*Capsicum annum* L.), Tephrosia (*Tephrosia vogelii* Hook), Groundnut (*Arachis hypogaea* L.) and Castor (*Ricinus communis* L.). The untreated check, Acetone (solvent used to extract oils from the botanicals) and Ethiothion 5% dust (a standard check) were used for comparison. One day after treatment application, the dead bruchid in Ethiothion 5% dust, noug oil and rapeseed oil treated grains were 100, 90.85±0.63 and 78.35±0.78%, respectively indicating the fast knock down effect of the treatments. Four days after treatment, 100% of the parent bruchids were killed in all oil treated grains. The mortality of the parent bruchids four days after treatment application was 10.85±0.6% in acetone treated grains and 11.65±0.5% in untreated grains. Statistically lower number of eggs and progeny (adults) were recorded from Ethiothion 5% dust and oil treated grains than the acetone treated and untreated grains. Bean grain losses due to bruchids were 18.3±0.4% in acetone treated grains and 18.4±0.44% in the untreated check, while 0 to 5.2±0.27% losses were recorded in other treatments. Ethiothion 5% dust and the oils inhibited emergence of bruchids from 71.7±2.56 to 100±0.53%. Lower germination percentages were recorded from acetone (67.3±4.23%) treated grains and the untreated grains (66.7±3.02%). From the results of this experiment, it can be concluded that the Ethiothion 5% dust and all the tested oils can effectively control bean bruchid and recommended for the management of the same.

Key words: Bean bruchid/weevil, botanical oil, faba bean grain (*Vicia faba* L.), mortality, survival, progeny.

INTRODUCTION

The faba bean, *Vicia faba* L. is one of the earliest domesticated legumes after chickpea and field pea which

was vastly distributed throughout the world (Kanaji, 2007). It is an important crop used as a source of organic protein

for peoples who cannot afford feeding expensive animal protein on regular basis (El-Tokhy and Kasem, 2012). However, bean storage at small scale subsistence farming level is limited due to bruchid infestations that result in heavy losses (Mushobozy et al., 2009). The common bean weevil, *Acanthoscelides obtectus* (Say) and the Mexican bean weevil, *Zabrotes subfasciatus* (Boheman) are the common insect pests in a wider area where faba bean is growing (Mushobozy et al., 2009; Taponjou et al., 2002). Their attack results in yield reduction, poor grain quality, loss of seed viability and unsuitable taste for human consumption (Prakash et al., 2008).

Farmers are using synthetic insecticides to keep faba bean grains free of insect infestation and to reduce damage during storage (Taponjou et al., 2002). They use insecticides without having appropriate knowledge on its application and drawbacks like development of resistance, environmental pollution and poisoning of fauna and flora (Prakash et al., 2008; Taponjou et al., 2002). To date, attentions were diverted to look for effective, biodegradable, simple to apply and homemade control options such as oil extracts of botanical origin for the management of bruchids (Olotuah, 2013). Oils of many plant species are known to have one or more insecticidal properties in terms of pest control such as fumigants, repellents, toxicant and oviposition deterrent among others (Mushobozy et al., 2009; Olotuah, 2013).

In Ethiopia, specifically in Amhara region small scale farmers are facing problems of storing their bean grains due to damage by *A. obtectus*. The faba bean grains are prone to damage by *A. obtectus* starting from field at the maturity of the crop and extended to storage where heavy infestation occurs. In the region, the availability of plants with insecticidal value is tremendous. Hence, the objective of this study was to screen effective botanical oils for the management of *A. obtectus* on the faba bean grains.

MATERIALS AND METHODS

Description of the study area

The study was conducted in Eastern Gojjam zone, Debre Markose University located 300 and 265 km away from Addis Ababa and Bahir Dar, respectively. The average elevation of the study area was 2400 masl. The rainfall pattern was uni-modal with a mean annual rainfall of 1500 mm. Daily average temperature was 24°C. The major crops grown are Teff, wheat, maize, faba bean, chickpea and rough pea.

Rearing of *A. obtectus*

Cultures of *A. obtectus* were established at Debremarkose

University to obtain the same age group and required numbers of adult bruchids for the experiment. The bruchids used for rearing were collected from local farmer faba bean stores and reared in three plastic pots having 5 L capacity each. Each pot was half filled with 3 kg grains to serve as food for the bruchids. Newly harvested faba bean grains with no bruchid eggs were collected from local market. The grains were carefully examined by hand lens for the presence of bruchid eggs. The selected grains were washed with potable water to avoid any obscure sources of infestation and frozen at a temperature of $-4\pm 1^\circ\text{C}$ for three weeks to protect fungal development and to ensure uniform moisture content of the grains (Ileke and Olotuah, 2012). Grains having 14% moisture contents were used as a substrate for *A. obtectus* rearing (Kanaji, 2007).

About 100 unsexed adults of *A. obtectus* were added to each jar assuming that 50% of the adults are females and the rest are males as the sex ratio for the series of sex ratio experiments was 1:1 (Ileke and Olotuah, 2012). The jars were covered with muslin cloths held in place by rubber bands. Rearing was conducted at $28\pm 1.5^\circ\text{C}$ and $65\pm 5\%$ RH (Ileke and Olotuah, 2012; Kanaji, 2007). The temperature used for rearing was adjusted by electric power, while the follow up record was taken by Thermo hygro and a thermometer. Frequent inspection of the culture for emergence of the progeny was carried out daily starting from twenty two days after parent bruchids introduction (Bhardwaj and Verma, 2012). The newly emerged one day old adult F_1 progenies were used for the experiment (Bhardwaj and Verma, 2012).

Treatment preparation

The botanical seeds were collected from the localities nearby Debre Markos University. Oils were extracted from various plant species using acetone. The plant species used for the experiment were seed of Noug (*Guizotia abyssinica* L.f.), rapeseed (*Brassica napus* L.), Lantana (*Lantana camara* L. (Sensu lato)), pepper (*Capsicum annum* L.), Tephrosia (*Tephrosia vogelii* Hook.), Groundnut (*Arachis hypogaea* L.) and Castor oil (*Ricinus communis* L.) (Table 1). Untreated check, Ethiothion 5% dust (standard check) and Acetone (a solvent to extract the oils) were used in the experiment for comparison.

The seeds were dried under shade and grinded with pestle and mortar to obtain fine dusts. The dusts were further grinded until it passed through 0.5 mm perforated sieves (Ileke and Olotuah, 2012). The dusts were dissolved in acetone in a two liters plastic pot to separate oils from fine dusts. Each mixture was stayed for one month and shaken daily for 15 min (Bhardwaj and Verma, 2012). The liquid that contains oil and acetone was float on the upper surface of the containers. Each container was pierced with scissor at the site of layer formation between dust residues and the floated liquids. The liquids that float on the surface of the containers were come out through the hole prepared between the layers. Each liquid was collected and filtered again using muslin cloths. The oils and solvents were exposed to air for two days to evaporate the solvent (Acetone). Subsequently, the oils collected from each botanical were stored separately in clean vials at a temperature of 4°C in a refrigerator until use (Ileke and Olotuah, 2012).

A concentration of 3 to 4 ml/kg oils were added in one litter plastic pots containing 500 g of the faba bean grains. The pots containing faba bean grains, the botanical oils, Ethiothion 5% dust and acetone were vigorously shaken and rolled for one minute to coat the treated grains uniformly (Ileke and Olotuah, 2012).

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Table 1. Botanical oils evaluated for their efficacy against *A. obtectus* on faba bean grains.

Common name	Scientific name	Plant parts used	Dosage
Noug oil	<i>Guizotia abyssinica</i>	Seed	4 ml/kg
Castor oil	<i>Ricinus communis</i>	Seed	4 ml/kg
Groundnut	<i>Arachis hypogaea</i>	Seed	3 ml/kg
Pepper	<i>Capsicum annum</i>	Seed	3 ml/kg
Tephrosia	<i>Tephrosia vogelii</i>	Seed	3 ml/kg
Lantana	<i>Lantana camara</i>	Seed	4 ml/kg
Rapeseed	<i>Brassica napus</i>	Seed	4 ml/kg
Ethiothion 5% dust	-	-	50 g/Qt
Acetone	Dimethyl ketone	-	4 ml/kg
Untreated check	-	-	-

Effects of botanical oils on parent adult bruchid fertility and mortality

The treated bean grains in each pot were infested with 24 hour old 20 unsexed adult of *A. obtectus* (Ileke and Olotuah, 2012). The pots were covered with muslin cloth to allow sufficient aeration, to protect escape of *A. obtectus* and entrance of other pests. The experimental design was a Completely Randomized Design (CRD) in three replications. Parent adult *A. obtectus* mortality and the number of eggs laid per 20 grains were recorded from each pot 1, 2, 4, 8 and 10 days after treatment application. In each subsequent count, dead bruchids were counted and removed from each pot. Ten days after treatment application all dead and alive bruchids were counted and removed from the pots.

Emergence of adult progeny of *A. obtectus*

Bruchid progenies inspection and continuous follow up started from 22 days after treatment application. Subsequent counts of dead and alive adult bruchids were done. The bruchids were separated from bean grains with the help of three mm sieve made from wire mesh (Swella and Mushobozy, 2007). Data on grains with and without eggs per 20 randomly selected grains were taken for three months with ten days interval.

Percentage protection

Protective efficacy of the botanical oils was calculated based on the emerged progenies using Taponjou et al. (2002) and El-Ghar et al. (1987) procedures. Percentage reduction to adult emergence or inhibition rate (% IR) was calculated as:

$$\% IR = \frac{(C_n - T_n)}{C_n} \times 100$$

Where: C_n = the number of newly emerged insects in the untreated pot, and T_n = the number of newly emerged insects in the treated pot.

Seed weight loss determination

On the 90th day of treatment application, 1000 grains were randomly taken from each treatment. The selected grains were separated and categorized into damaged grains with exit holes and undamaged grains. Grains with and without exit holes were counted and weighed separately and the obtained data were used to calculate the percentage weight loss. Percentage weight losses

were determined by the count and weigh method applied by Gwinner et al. (1996):

$$\text{Percent weight loss} = \frac{(W\mu \times Nd) - (Wd \times N\mu)}{W\mu \times (Nd + N\mu)} \times 100$$

Where: $W\mu$ = weight of undamaged grains; $N\mu$ = number of undamaged grains; Wd = weight of damaged grains; Nd = number of damaged grains.

Germination test

The effect of botanical oils on faba bean grain germination was done three months after treatment application. Faba bean grains from the untreated check, acetone and the standard check were used for comparison. Fifty grains were randomly selected from each treatment. Grains from each treatment were treated separately with sodium hypochlorite (Clorox 10%) for one minute to eliminate fungal contamination. Grains treated with sodium hypochlorite were washed by water for one minute to avoid physical damage. The seeds were placed on moist filter paper in petri dish for seven days. The number of sprouted seeds was counted seven days after incubation. Subsequently, germination percentage was determined using the following formula (Gwinner et al., 1996):

$$\text{Germination}(\%) = \frac{\text{Total No. of bean grains sprouted}}{\text{Total No. of bean grains added to the petridish}} \times 100$$

Statistical analysis

Analysis of variance (ANOVA) was done according to Gomez and Gomez (1984) procedures. All obtained data were transformed using square-root, logarithmic and arc sign transformations before the analysis. Tukey's studentized range test (HSD) at $p=0.05$ was used to separate significant means. SAS (SAS 9.2) and MS Excel 07 soft wares were used for these analyses. Results were reported using back transformed values.

RESULTS AND DISCUSSION

Number of eggs laid by adult parent female bruchid on treated and untreated faba bean grains

The number of eggs laid by parent bruchids on treated

Table 2. *Mean(\pm se) number of eggs laid by adult parent bruchids during the first ten days of treatment application.

Year	Treatment	Dose	**Parent bruchid eggs after treatment application				
			1 st day	2 nd day	4 th day	8 th day	10 th day
2013- 2014	Noug	4 ml/kg	0.33 \pm 0.33 ^c	0.67 \pm 0.33 ^{de}	0 \pm 0 ^d	0 \pm 0 ^b	0 \pm 0 ^b
	Rapeseed	3 ml/kg	0.50 \pm 0.35 ^c	1.33 \pm 0.33 ^{de}	0 \pm 0 ^d	0 \pm 0 ^b	0 \pm 0 ^b
	Groundnut	3 ml/kg	0.50 \pm 0.35 ^c	2.00 \pm 0.58 ^d	0 \pm 0 ^d	0 \pm 0 ^b	0 \pm 0 ^b
	Castor	4 ml/kg	2.17 \pm 0.75 ^b	4.33 \pm 0.78 ^c	4.83 \pm 0.95 ^c	0 \pm 0 ^b	0 \pm 0 ^b
	Lantana	4 ml/kg	2.83 \pm 0.63 ^b	5.17 \pm 0.63 ^{bc}	6.67 \pm 2.67 ^{bc}	0 \pm 0 ^b	0 \pm 0 ^b
	Tephrosia	3 ml/kg	2.67 \pm 0.33 ^b	6.17 \pm 0.75 ^b	7.17 \pm 0.75 ^{bc}	0 \pm 0 ^b	0 \pm 0 ^b
	pepper	3 ml/kg	3.17 \pm 0.48 ^b	5.13 \pm 0.26 ^{bc}	10.67 \pm 0.91 ^b	0 \pm 0 ^b	0 \pm 0 ^b
	Ethiothion 5% dust	50 g/Qt	0 \pm 0 ^c	0 \pm 0 ^e	0 \pm 0 ^d	0 \pm 0 ^b	0 \pm 0 ^b
	Acetone	4 ml/kg	7.50 \pm 0.68 ^a	11.67 \pm 0.67 ^a	16.33 \pm 0.89 ^a	19.33 \pm 0.67 ^a	20.67 \pm 1.05 ^a
Untreated check		7.33 \pm 0.53 ^a	11.83 \pm 0.79 ^a	16.67 \pm 1.13 ^a	18.33 \pm 1.2 ^a	20.83 \pm 1.27 ^a	

Means followed by the same letter (s) within a column are not significantly different at 5%, Tukey's studentized range test HSD.

*Data from both years pooled together; **Means presented in the table are square root back transformed values.

(the oils, the Ethiothion 5% dust and the Acetone) and untreated grains are shown in Table 2. Parent bruchids were started mating with in the first days of an experiment due to their eggs were recorded on day one after treatment application. Significantly ($p < 0.05$) higher number of bruchid eggs were laid on untreated check (7.33 \pm 0.53) and acetone (7.5 \pm 0.68) treated faba bean grains compared to the botanical oils (0.33 \pm 0.33 to 3.17 \pm 0.48) and Ethiothion 5% dust treated grains which did not yield any bruchid egg one day after treatment. The current result was similar to that of Ibrahim (2012) who reported sesame, olive and sunflower oils effectively decreased the egg laying capacity of *C. maculatus* on chickpea grain starting from treatment application up to the end of the experiment. Similar results were reported by Abdulahi (2011) who tested four levels of *Balantia aegyptiaca* leaf extract and found that the botanical treatments were an efficient ovipositional deterrent compared to the untreated check. Tabu et al. (2012) conducted similar experiment that bruchids inhibited oviposition on chickpea grains treated by seed powders of *Azadiracta indica* at 2% (w/w) and *Chenopodium ambrosioides* at 4% (w/w) starting from day one of treatment application up to three months.

Two days after treatment the number of eggs laid by bruchids on noug oil and rapeseed oil treated the faba bean grains were 0.67 \pm 0.3 and 1.33 \pm 0.33, respectively. Significantly ($p < 0.05$) higher number of bruchid eggs were laid on pepper (5.13 \pm 0.26), lantana (5.17 \pm 0.63) and tephrosia (6.17 \pm 0.75) than the rest of the oil treatments. The highest number of bruchid eggs were recorded on untreated grains (11.83 \pm 0.79) and acetone (11.67 \pm 0.67) treated faba bean grains. Similar results were reported by Uddinll and Sanusi (2013) such that no bruchid eggs were recorded on cowpea grains treated with groundnut and palm kernel oils starting from two days after treatment application. Yahaya et al. (2013) reported similar result on chickpea grains treated with groundnut

or palm oil at the rate of 2.5 to 3 ml/kg which significantly reduced *C. maculatus* oviposition.

There were no extra bruchid eggs after four days of treatment application than the two days of experiment on Ethiothion 5% dust, noug oil, rapeseed oil and groundnut oil treated grains. Based on Okonkwo and Okoye (2008) finding, essential oils of *D. tripetela* and *P. guineense* achieved 100% mortality of *C. maculatus* and *S. zeamais* in 24 h after treatment application as a result no extra eggs were recorded till death of the parent insects. Statistically higher numbers of bruchid eggs were recorded on oils of castor (4.83 \pm 0.95), lantana (6.67 \pm 2.6), tephrosia (7.17 \pm 0.75) and pepper (10.67 \pm 0.91) treated faba bean grains four days after treatment. The numbers of bruchid eggs were significantly higher than the rest of the treatments in untreated (16.67 \pm 1.13) and acetone (16.33 \pm 0.89) treated grains four days after treatment (Table 2). Yahaya et al. (2013) indicated that, significantly lower number of *C. maculatus* eggs were recorded on cowpea grains treated with botanical oils (0-4.5 \pm 1) compared to 62.87 \pm 0.2 eggs laid in the control plot.

Eight days after treatment, no extra eggs of bruchids were recorded in Ethiothion 5% dust, and oil treated faba bean grains. However, the numbers of bruchid eggs laid in acetone treated and untreated grains were recorded to 19.33 \pm 0.67 and 18.33 \pm 1.2 eggs, respectively. The number of *A. obtectus* eggs laid in acetone (20.67 \pm 1.05) treated and the untreated (20.83 \pm 1.27) faba bean grains were slightly increased ten days after treatment (Table 2). Ibrahim (2012) remarked that sesame (98.49%), olive (96.54%) and sunflower (95.37%) oils at the rate of 7.5 ml/kg (v/w) were effectively deterring bruchids oviposition on chickpea grain. Comparable result was reported by Shukla et al. (2007) that *Murraya koenigii* L. and *Eupatorium cannabinum* L. dusts deter bruchid oviposition by 90.62 and 86.46%, respectively. Sangeeta and Apte (2015) reported that green gram grains treated with botanical oils were 100% free from parent

Table 3. *Dead adult parent Bruchids in the first ten days of treatment application.

Year	Treatment	Rate	**Mortality of bruchids (%) after treatment application					Live bruchids after 10 days
			1 st day	2 nd day	4 th day	8 th day	10 th day	
2013-2014	Noug	4 ml/kg	90.85±0.63 ^{ab}	100±0 ^a	0±0 ^c	0±0 ^b	0±0 ^b	0±0 ^b
	Rapeseed	3 ml/kg	78.35±0.78 ^{bc}	100±0 ^a	0±0 ^c	0±0 ^b	0±0 ^b	0±0 ^b
	Groundnut	3 ml/kg	70.85±0.85 ^c	98.35±1.27 ^a	100±0 ^a	0±0 ^b	0±0 ^b	0±0 ^b
	Castor	4 ml/kg	52.5±1.0 ^d	90±0.98 ^b	100±0 ^a	0±0 ^b	0±0 ^b	0±0 ^b
	Lantana	4 ml/kg	37.5±0.97 ^e	75±1.06 ^c	100±0 ^a	0±0 ^b	0±0 ^b	0±0 ^b
	Tephrosia	3 ml/kg	28.35±0.52 ^e	70±0.67 ^c	100±0 ^a	0±0 ^b	0±0 ^b	0±0 ^b
	pepper	3 ml/kg	30±0.81 ^e	73.35±0.88 ^c	100±0 ^a	0±0 ^b	0±0 ^b	0±0 ^b
	Ethiothion 5% dust	50 g/Qt	100±0 ^a	0±0 ^e	0±0 ^c	0±0 ^b	0±0 ^b	0±0 ^b
	Acetone	4 ml/kg	0±0 ^f	3.35±0.53 ^d	10.85±0.6 ^b	50±0.53 ^a	86.65±0.41 ^a	13.35±0.63 ^a
	Untreated check		0±0 ^f	3.35±0.56 ^d	11.65±0.5 ^b	55±1.49 ^a	85.85±0.35 ^a	14.15±0.26 ^a

Means followed by the same letter (s) within a column are not significantly different at 5%, Tukey's studentized range test HSD); *Data from both years pooled together; **Means presented in the table are square root back transformed values.

Callosobruchus maculatus infestation.

Effects of botanical oils on the survival of adult parent bruchids

The oils killed parent bruchids started from day one after treatment application. Parent bruchids died in Ethiothion 5% dust, noug oil and rapeseed oil were 100, 90.85±0.63 and 78.4±0.78%, respectively within the first day of experiment. 28±0.52 to 70.85±0.85% the parent bruchids were died in groundnut, lantana, tephrosia and pepper oil treated grains. On the contrary, 100% of the parent bruchids were survived in acetone and untreated check treated grains day one after treatment application (Table 3). Olotuah (2013) conducted similar experiment to control *C. maculatus* (F.) that the oils were killed 100% of the parent bruchids with in six minutes while 100% of the parents survived in the untreated check. Chickpea grains treated with dusts of *A. indica* at 2% (w/w) were killed parent bruchids 80, 91.67 and 93.67% after one, two and four days respectively (Taba et al., 2012). Tadele et al. (2014) also confirmed that botanical dusts were completely eradicated soldiers and worker termites a day after treatment. Okonkwo and Okoye (2008) evaluated the efficacy of *D. tripetela* dusts at 1.5 to 2.5 g/kg to manage *S. zeamais* on maize grains that 100% of the parent weevils were died at ($P < 0.05$) within 24 h of treatment.

Treatments like Ethiothion 5% dust, noug, rapeseed and groundnut oils were statistically shown similar results that 98.35±1.27% to 100% of the parent bruchids were died after two days of treatment application. The rest of the botanical oils were shown superior efficacy (70±0.67 to 90±0.98%) to kill parent bruchids than acetone treated and untreated check faba bean grains that 96.65% of the parents were continued to exist. Four days after treatment 100% of the parent bruchids were died in Ethiothion 5% dust and oil treated faba bean grains. In

acetone and the untreated check 88.65 and 88.35% of the parent bruchids respectively were alive to lay their eggs (Table 3). Similar result was reported by Bhardwaj and Verma (2012) and Tabu et al. (2012) management of beetles by botanical dusts, edible oils and inert materials were appeared to be more effective compared with control after four days of treatment. According to Yohannes et al. (2013) 85 to 100% parent bruchids were eradicated by botanical dusts within seven days after treatment application. *C. ambrosiodes* leaf dusts at 4% (w/w) killed the parent bruchids 88.34 and 91.67% after two and four days of treatment application (Taba et al., 2012).

The dead bruchids in acetone and the untreated check after eight days of experiment were 50±0.53 and 55±1.49, respectively. The numbers of dead parent bruchids were increased in acetone and the untreated check with time due to natural death was expected. As a result, the dead parent bruchids were 85.85±0.35% in untreated check and 86.65±0.41% in acetone ten days after treatment application. 14.15±0.26 and 13.35±0.63% of the parent bruchids in the untreated check and acetone treated grains respectively were continued and alive after ten days of the experiment (Table 3). Waktole (2014) was reported similar finding that a dust prepared from *Chenopodium* spp. was achieved 66.67% mortality of *S. zeamais* parents at par with Acetic 2% dust (70.39%). Sangeeta and Apte (2015) report was also confirmed that *C. maculatus* were not survived in any of the green gram grains treated with botanical oils. Shukla et al. (2007) report indicated that parent bruchids were effectively controlled by *M. koenigii* and *E. cannabinum* dusts of leaves.

Effects of botanical oils on adult progeny emergence and the capacity of adult progeny in egg laying

Eggs laid by bruchids on bean grains were vary due to

Table 4. Eggs laid, Bruchids emerged and death due to the effects of botanical oils on bean grains.

Year	Treatment	Dose	Numbers of bruchids and their eggs**		
			Bruchid eggs	Emerged progenies	Live bruchids
2013-2014	Noug	4 ml/kg	0±0 ^f	0±0 ^f	0±0 ^d
	Rapeseed	3 ml/kg	0±0 ^f	0±0 ^f	0±0 ^d
	Groundnut	3 ml/kg	0±0 ^f	0.67±0 ^f	0±0 ^d
	Castor	4 ml/kg	37.67±3.16 ^e	22.7±2.69 ^e	4.3±0.49 ^{cd}
	Lantana	4 ml/kg	61.67±5.15 ^d	41.7±4.91 ^d	11.7±1.36 ^{bc}
	Tephrosia	3 ml/kg	72.67±6.05 ^c	58±6.86 ^c	14.7±1.75 ^b
	pepper	3 ml/kg	98.00±8.19 ^b	77.7±9.19 ^b	21.7±2.56 ^b
	Ethiothion 5% dust	50 g/Qt	0±0 ^f	0±0 ^f	0±0 ^d
	Acetone	4 ml/kg	493.3±41.1 ^a	465.3±54.83 ^a	350.7±41.31 ^a
	Untreated check	-	498.3±41.5 ^a	462.3±54.48 ^a	360.3±42.45 ^a
	Noug	4 ml/kg	0±0 ^f	0±0 ^f	0±0 ^d
	Rapeseed	3 ml/kg	0±0 ^f	0±0 ^f	0±0 ^d
	Groundnut	3 ml/kg	0±0 ^f	0±0 ^f	0±0 ^d
	Castor	4 ml/kg	39.3±4.62 ^e	28.7±3.38 ^d	9.3±1.11 ^c
	Lantana	4 ml/kg	63.7±7.49 ^d	52.3±6.24 ^c	15.3±1.82 ^{bc}
	Tephrosia	3 ml/kg	73.7±8.67 ^c	62±7.29 ^{bc}	15.3±1.79 ^{bc}
	pepper	3 ml/kg	95.3±11.22 ^b	71.7±8.43 ^b	17.7±2.07 ^b
	Ethiothion 5% dust	50 g/Qt	0±0 ^f	0±0 ^f	0±0 ^d
Acetone	4 ml/kg	486.3±57.3 ^a	449.7±54.2 ^a	363.3±42.84 ^a	
Untreated check	-	496±57.3 ^a	448±52.4 ^a	353.3±42.23 ^a	

Means followed by the same letter (s) within the column are not significantly different at 5%, Tukey's studentized range test (HSD)
 Means presented in the table are logarithmic (**) back transformed values.

various efficacy of treatments. Numbers of eggs laid in noug, rapeseed and groundnut oils were statistically lower (0±0) at par with Ethiothion 5% dust treated grains. Yahaya et al. (2013) reported that palm, groundnut and coconut oils treated chickpea grains at the rate of 4 ml/kg completely inhibited *C. chinensis* infestation for three months of storage periods. Sangeeta and Apte (2015) indicated that green gram grains treated with botanical oils were free from bruchid eggs one year after treatment application while 100% of the grains were infested with the insect eggs within the same period at the same conditions of experiment.

Significantly lower numbers of bruchid eggs were laid on castor, lantana, tephrosia and pepper oil (37.67±3.16 to 98±8.19 eggs) treated grains compared to 498.3±41.5 eggs in untreated check and 493.3±41.1 eggs in acetone treated grains. The numbers of eggs laid in acetone and untreated check were fivefold that of pepper oil shows better numbers of eggs laid than other oil treatments (Table 4). A comparable result was reported by Abdulahi (2011) that the eggs laid by bruchids on cowpea grains treated with actellic 2% and botanical dusts were statistically lower (88.6±4.6 to 203.6± 5.9) than acetone (798.6±27.4) and untreated check (794.3±15). Shukla et al. (2007) report was in line with the current finding that bruchids were laid lower numbers of eggs on 2% (w/w)

leaves dusts of *M. koenigii* (17.67±5.5) and *E. canabinum* (22.34±4.5) treated chickpea grains compared to control (127.67±8.05).

There was no bruchid progeny emerged in oil treatments like noug, Rapeseed, Groundnut and Ethiothion 5% dust treated grains (Table 4). Okonkwo and Okoye (2008) were reported the same result that there was no F₁ *S. zeamais* progeny emerged on maize grains treated with leaves dusts of *D. tripetela* and *Piper guineense* till three months of experiment. According to Okonkwo and Okoye (2008) seed oils of *D. tripetela* and *P. guineense* treated maize and Cowpea grains were completely suppressed the emergence of F₁ progenies and given protection up to 4 months of storage.

The maximum numbers of bruchid progenies emerged from castor, lantana, tephrosia and pepper oils were 28.8±2.69, 52.3±4.91, 62±6.86 and 77.7±9.19, respectively. Statistically higher numbers of bruchid progenies were recorded in acetone (465.3±54.83) and the untreated check (462.3±54.48) (Table 4). Abdulahi (2011) was reported related result on numbers of bruchids emerged from actellic 2% dust and botanical dust treated cowpea grains were ranged from 9.3±1.2 to 40.3±7.9 compared to acetone (698±24.46) and control (672.3±19.6). The similar result was reported by Regmil and Dhoj (2011) that numbers of bruchids emerged in oil

Table 5. Weight loss and germination percentage of bean grains and inhibition rates of botanical oils on Bruchids, 2013-2014.

Treatment	Rate	Weight loss	Germination percentage	IR
Noug	4 ml/kg	0±0 ^c	98.6±1.33 ^a	100±0 ^a
Rapeseed	3 ml/kg	0±0 ^c	97±1.73 ^{ab}	99.3±0.51 ^a
Groundnut	3 ml/kg	0±0.1 ^c	96.2±2.13 ^{ab}	97.3±1.35 ^a
Castor	4 ml/kg	0.4±0.39 ^c	93.8±1.65 ^{bc}	92.2±1.55 ^{ab}
Lantana	4 ml/kg	2.9±0.43 ^c	84.3±1.81 ^d	78.9±3.64 ^{bc}
Tephrosia	3 ml/kg	3.2±0.51 ^{bc}	87.2±1.84 ^{dc}	81.4±2.47 ^{bc}
pepper	3 ml/kg	5.2±0.27 ^b	79.3±1.75 ^d	71.7±2.56 ^c
Ethiothion 5% dust	50 g/Qt	0.71±0 ^c	98.7±1.05 ^a	100±0.0 ^a
Acetone	4 ml/kg	18.3±0.4 ^a	67.3±4.23 ^e	0±0 ^d
Untreated check	-	18.4±0.44 ^a	66.7±3.02 ^e	0±0 ^d

Means followed by the same letter (s) within the column are not significantly different at 5% Tukey's studentized range test HSD. Data from both years are pooled together; Means presented in the table are square root back transformed values.

and dust treated chickpea grain were significantly lower (0 to 2292±204.6) compared to control (4713±204.6). Tabu et al. (2012) reported similar results on the numbers of progenies emerged from *A. indica* at 2% (w/w) and *C. ambrosiodes* at 4% (w/w) were 42 and 24.33 respectively compared to 320 bruchids were recorded from untreated check.

A comparable result was reported by Waktole (2014) that *S. zeamais* progenies emerged from maize grains treated with *Chenopodium* leaves dusts at 10% (w/w) and control were 20 and 80% of the recorded eggs respectively. Based on Ibrahim (2012) experiment sesame seed oils treated chickpea grain at 5 and 7.5 ml/kg were decreased adult emergence by 96.03 and 96.22% respectively compared to the untreated check. A similar result was reported by Yahaya et al. (2013), e.g., applications of groundnut or palm oil at the rate of 2.5 to 3 ml/kg on cowpea grains were significantly suppressed *C. maculatus* progeny emergence.

Effect of botanical oils, Ethiothion 5% dust and acetone treatments on the germination and grain weight loss by bean bruchid

The oil treatments and Ethiothion 5% dust were statistically shown lower percentage weight loss than untreated check and acetone treated bean grains. There was no weight loss recorded in Ethiothion 5% dust, noug, rapeseed and groundnut oil treated grains. Higher weight losses were recorded from tephrosia oil (3.2±0.51%) and pepper oil (5.2±0.27%) treated bean grains than the rest of the oil treatments, however, the loss recorded from untreated check was 3.5 to 18.4 folds exceeded than the oil treatments and the standard check (Table 5). Regmil and Dhoj (2011) reported comparable results on chickpea grains treated with oils and botanical dusts were no loss compared to 38.44%±9.43 chickpea grain weight loss was recorded in the control treatments. Loth et al. (2007)

were recorded significantly lower bean seed weight loss (0 to 8.54%) in Ngongwe, pyrethrum flower and garlic powder treated grains than 14.64% in the untreated check after three months of experiment.

Higher bean grain germination was recorded from Ethiothion 5% dust (98.7±1.05%), noug (98.7±1.33%), rapeseed (97±1.73%) and groundnut oil (96±2.13%) treated grains. All the treatments were statistically shown better bean grains germination than acetone and untreated check after three months of the experiment (Table 5). Treatments like oils and Ethiothion 5% dust inhibited emergence of bruchids from 71.7±2.56 to 100% compared to 0±0% in acetone and untreated check. Mushobozy et al. (2009) were conducted similar research on common bean to manage *Zabrotes subfasciatus* that the oils treatments were shown superior efficacy to inhibit emergence of bruchids and better germination (87.5 to 95%) ability of grains. As Tabu et al. (2012) reported that on *A. indica* at 2% (w/w) and *C. ambrosiodes* at 4% (w/w) seed dust treated chickpea grains were effectively germinated to 100 and 98.33% respectively. Ibrahim (2012) was added that 80 to 93% of the chickpea grains treated with botanical oils were effectively germinated after the 90 days of experiment.

Higher bean grain germinations were achieved from treatments of better inhibition rate on bruchids emergence and their correlation was strongly positive (Figure 1). Okonkwo and Okoye (2008) conducted similar experiment on essential oils of *D. tripetela* and *P. guineense* to control *C. maculatus* and *S. zeamais* and their finding was indicated that 100% of the parent insects mortality were observed within the first 24 h as well as the insects were inhibited to lay their eggs and emerge to adult stages. Tabu et al. (2012) also indicated that *A. indica* at 2% (w/w) and *C. ambrosiodes* at 4% (w/w) seed dust treated chickpea grains were inhibited emergence of bruchids 86.85 and 92.36% respectively. In general oils and Ethiothion 5% dust were shown lower faba bean grain weight loss, better

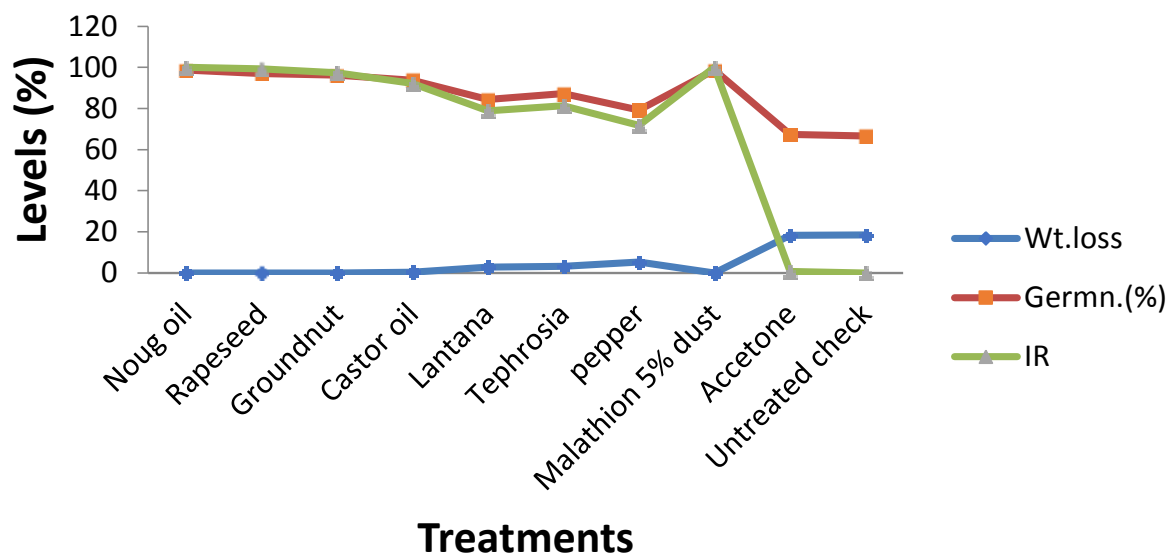


Figure 1. Effectiveness of botanical oils on faba bean grain weight loss and germination due to bruchids.

germination percentage and better seedling performance even after germination than acetone treated and untreated faba bean grains.

Conclusion

Ethiothion 5% dust and oils were eradicated 30 ± 0.81 to 100% parent bruchids day one after treatment application while 100% of adult bruchids were survived in acetone and untreated check treated grains. The parent bruchids were totally eradicated in Ethiothion 5% dust and oil treated faba bean grains four days after treatment application. The numbers of dead bruchids in acetone and the untreated check treated grains were only 10.85 ± 0.6 and $11.65 \pm 0.5\%$, respectively after four days of experiment. Ten days after treatment application in acetone ($13.35 \pm 0.63\%$) treated grains and untreated check ($14.15 \pm 0.26\%$) of the parent bruchids were survived. The numbers of eggs laid by parent bruchids during the first ten days of experiment were significantly lower in Ethiothion 5% dust (0 ± 0) and oil (0.67 to 10.67 ± 0.91) treated bean grains. However, very significantly higher numbers of bruchid eggs were laid in acetone (20.67 ± 1.05) and the untreated check (20.83 ± 1.27) and the eggs were continued to lay till ten days of experiment.

Bean grains treated with Ethiothion 5% dust and oils were shown lower numbers of eggs laid by bruchids and lower numbers of progeny emerged adults than acetone and untreated check (Table 4). Statistically lower percentage of bean grain weight loss, no adult bruchids emergence and better germination percentage of faba bean grains were recorded from Ethiothion 5% dust, noug, rapeseed and groundnut oil treated grains. Higher

weight losses of faba bean due to bruchids and lower germination percentages of the grains as well as freely emergence of bruchids were recorded from acetone treated and the untreated check grains.

Based on the results recorded, the botanical oils tested were effective to control bruchids from day one to 90 days of experiment. The botanical oils were effectively controlled parent bruchids and their progenies. The numbers of eggs laid by parent bruchids and their progenies were effectively inhibited by the oils evaluated up to the whole durations of the experiment. As a result bean grains treated with the oils were effectively sprouted (79.3 ± 1.75 to $98.7 \pm 1.05\%$).

It is needed to assess efficacy, biodegradability, chemistry of the evaluated botanical oils and their effect on bruchids biology on faba bean and other pulse grains at different agro-ecological zones started from field to storage conditions to be used as one component of Integrated Pest Management (IPM) to manage bruchids and other storage insect pests. The farmers can be used to manage bruchids of based on the evaluated botanical oils due to their availability and ease of extraction without adversely affecting the health of farmers, other consumers and the environment.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Full Length Research Paper

Comparative studies of fish smoking and solar drying in the Sierra Leone artisanal fishing industry

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“Energy efficient rural food processing utilizing renewable energy to improve rural Livelihoods” known as the “RE4Food” project is a three year effort by researchers in Sierra Leone, Ghana, Kenya, South Africa, Germany and the UK, funded by the Engineering and Physical Sciences Research Council (EPSRC). It takes its objectives from the observation by the World Health Organization (WHO) that nearly 60% of the world population is malnourished. Developing countries have high population growth and are increasingly using fossil fuels within their food production systems and it is estimated that 7 to 10 calories of energy are required in the production of 1 calorie of food. The artisanal fishing industry in Sierra Leone is faced with challenges in fish processing due to lack of modern facilities. Fish landings typically exceed local demand and the surplus is smoked; the inefficiency of traditional methods threatens terrestrial and mangrove forests. Our research focused on collecting indigenous technical knowledge, economic and efficiency measurements of energy utilized along the value chain. We report initial findings on use of a passive solar drier which shows that they are unlikely to make a substantial contribution to fish processing in Sierra Leone in the immediate future.

Key words: Fish processing, smoking, renewable energy, solar dryer, fishing.

INTRODUCTION

Fish is nutritious food and it constitutes a reasonable percentage of protein to human diets when processed (Adair, 1976). The principal nutritional constituents of fish are: proteins, lipids, minerals and vitamins such as B2. The importance of fish production in the tropics cannot be over emphasized; it is a source of food and raw materials for our growing factories (Alamu, 1990). Fish production from tropical waters accounts for about 17% of the

world's total catch (Eyo, 1999). In Sierra Leone the FAO (2014) estimates a total marine catch of about 206,477 tons from 900 powered and 8,526 unpowered fishing vessels employing just over 70 thousand people directly. Ignoring exports and losses, this equates to about 80 grams/person/day of fresh fish or about 20 grams/day of dried smoked fish, and this 20 grams/day is somewhere between 65% and 90% of the animal protein consumed

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(the reported figures are rather variable). Studies carried out in 2011 by the Swedish Institute for Food and Biotechnology (SIK) for the Food and Agriculture Organization of the United Nations (FAO) revealed that, roughly one-third of food produced for human consumption is lost or wasted globally, which amounts to about 1.3 billion tons per year (FAOSTAT, 2010a). A significant percentage of these losses are related to improper and/or untimely drying of foodstuffs (Bassey, 1989; Togrul and Pehlivan, 2004). Losses in the food value chain are approximately 1/3 of the total world yield and are estimated to range from about 15% for cereals up to 50% for fresh fruit and vegetables in some developing countries (Hodges et al., 2010). These losses occur during harvest, processing, storage, transportation and retail and apply to almost all food stuffs. Significant losses are a result of a number of factors which include insufficient drying, inadequate storage, insufficient cooling and poor transport – all of which rely on high levels of energy input. In sub-Saharan Africa, losses are predominantly at the producer end of the food chain and reducing these losses is often beyond the means of individual producers, who are predominantly small scale producers (Anon., 2013). Minimization of losses in the food chain will not only increase the quantity and quality of produce but also reduce energy, water and land use (FAOSTAT, 2010b).

The food and nutritional situation in Sierra Leone is poor but not unique. One of the major causes of wastes is the unavailability of energy in poor rural communities for efficient food processing (freezing, canning, drying etc.). In response to this situation the EPSRC (Engineering and Physical Sciences Research Council) of UK funded the “Energy Efficient Rural Food Processing utilizing renewable Energy to improve Rural Livelihoods” known as RE4Food for three years. The project is coordinated by Newcastle University with partners in South Africa, Sierra Leone, Kenya, Ghana and Germany. Three food-chains are being studied; the processing, preservation and use of maize (Ghana), leafy vegetables (Kenya) and fish (Sierra Leone). In each case the critical link between the use of (renewable) energy and food losses are looked at. In Sierra Leone, the project focuses on the use of renewable energy in the artisanal fishing industry for fish processing. Fish was selected after a multi-criteria assessment using 18 factors including items such as the existing and potential market for the product, current energy efficiency and potential for improvement, impact on women’s workload, etc. From a research perspective fish are particularly interesting because:

(1) There is lack of knowledge and actual data on fishermen’s, fishmongers’ and fish processors’ activities,
 (2) Widespread, but unsubstantiated beliefs that fish smoking utilizing wood is a major cause of deforestation, and

(3) Fish forms the major component of high grade protein consumed within Sierra Leone, with an estimated average consumption of smoked marine fish in the order of 18kg/person/year, which compares to a consumption figure for “meat” (beef, mutton, goat, bush meats, chicken, etc.) of less than 2 kg/person/year.

The artisanal fishing industry in Sierra Leone provides not only the cheapest source of protein but also employment for a large number of under-educated young people and substantial revenue for government. As the industry attracts more people, more complex fishing techniques were adopted leading to an increase in the catch rate especially for pelagic species. Our research findings have shown that a typical artisanal fishing boat sets off with only 200 to 300 kilograms of ice and those returning late often have a high proportion of fish in bad condition. Due to the lack of refrigerators and other processing facilities, the preferred preservation is by hot smoking. This mode of fish preservation has been practiced for many years. As the industry became more attractive to investors, the number of boats, total catch rate and demand for fire wood also increased. The need for fire wood for smoking fish is believed to have put pressure on the terrestrial and mangrove forests near fishing communities, increasing both the cost of firewood and accelerating the degradation of remaining forested areas. In the capital city of Freetown, smokers said they can no longer afford to purchase mangrove wood which was traditionally held as the best wood for fish smoking. This has caused some individuals to change from farmers to full-time firewood collectors with attendant impact on the terrestrial environment. Sierra Leone is still predominantly a rural country and agriculture accounts for almost half of the GDP, which in 2008 was approximately 46% (Sannoh, 2010). The country was ranked as “needs improvement” with the score of 34.1 out of 100, marking it as food insecure. The global food security index was produced by the economic intelligence unit (EIU, 2016) and according to this report, Sierra Leone scored the following:

80% of population under global poverty line,
 65.4 in nutritional standards,
 43.6 in food safety,
 36 in sufficiency of food supply,
 34.1% Food loss,
 30.4 in diet diversification,
 29.1 micro nutrient availability,
 26.7% had access to portable water,
 18.1 in protein quality,
 10.2 in agricultural infrastructure.

In the context of our research, the low score for “protein quality” (EIU, 2016), is significant given the high dependence of a large majority of the Sierra Leone population on fish protein. In Sierra Leone, marine fish



Figure 1. Consultative meeting with stakeholders.

forms the main source of high quality protein consumed by the people, making it essential to the food security needs of the population. In addressing some of the underlying problems associated with protein quality in the artisanal fishing industry, we have attempted to compare fish processed through the use of traditional fish smoking using wood and those dried using renewable energy (solar dryer) in terms of taste, texture, color, flavor and hardness. In addition, we measured the amount of energy utilized to produce a given quantity of dried fish, and finally conducted an economic valuation of resources used in fish processing.

MATERIALS AND METHODS

Description of study area

According to the Fisheries Division of Sierra Leone, there are 58 official fish landing sites along the coast of Sierra Leone, with 19 in Port Loko District, 9 in Kambia, 3 in Western Area, 8 in Moyamba District, and the remaining 19 in both Bonthe and Pujehun districts. Our research activities concentrated on two major fishing communities, Goderich and Tombo in the western area. Goderich is located in the western area rural district of Sierra Leone approximately 8 kilometers to the city center Freetown. It is a coastal community bordered by a number of smaller communities and stretches from the coast to the peninsular mountains, with key livelihood activities including fishing and petty trading. According to results from the national population and housing census of 2004, the community has a population of slightly over 4,221 people and the fishing industry is the main employer. Tombo is also in the western area peninsular and is the largest fish market in the country where fish traders from the provinces come to buy and process fish. It is also as a trans-shipment site for remote fishing communities like Shenge, Plantain islands, etc., as they cannot access large markets centers by road due to poor road networks. Tombo is about twenty-four kilometers from Freetown, and the major

livelihood activities are fishing, fish processing and marketing, and petty trading.

Indigenous technical knowledge gathering events

This work focused on fish processing by smoking using potentially renewable energy in the form of firewood as utilized in the artisanal fishing industry. To better understand this, we considered stakeholder's involvement as a necessity. In this regard, we identified all key stakeholders in the artisanal fishing industry including fishermen, fish processors, fish and wood traders. In a consultative meeting organized with major fishing communities, firsthand information such as, type and sources of energy used in fish processing, causes of fish postharvest losses, and major problems encountered in fish smoking and drying, and possible solutions or alternatives were discussed (Figure 1). Feedbacks from the consultative meeting provided us with a clear picture of challenges encountered by all stakeholders in fish processing (smoking and drying). Apart from stakeholder involvement, experimentation was also adopted in our field research activities. Experimental work involved measurements of fresh and dry weights of fish (Figure 2), quantity of wood used in the smoking for both traditional and improved smokers (Figure 3), and the results obtained were analyzed and subjected to statistical treatment, primarily single factor ANOVA (analysis of variance).

Experiment with solar dryers

In many parts of the world, there is a growing awareness that renewable energy has an important role to play in extending technology to the farmer in developing countries to increase their productivity (Waewsak et al., 2006). In an attempt to find possible alternatives to the traditional methods of fish drying by smoking, three local solar dryers were constructed. The solar dryers were constructed with plywood of five-ply thickness for the base, and three-ply thickness for the sides and the frames reinforced with 1" x 1" square sections of timber for strength and holding sections of the plywood together. Halfway between the top and the floor of the



Figure 2. Fresh fish being weighed before smoking.



Figure 3. Weighing wood before using to smoke fish.

solar dryer, pieces of 1" x 1" square sections of timber were fitted on the walls of the plywood and across the inside to support a wire mesh to serve as platform for drying the fish (Figures 4 and 5).

In order to determine variations in effectiveness, two of the dryers were covered with transparent plastic sheet and the one with plain glass. On one side of the dryer, an opening was created making it easy for materials to be placed into the box. To enhance emission of moisture from products in the dryer, holes covered with plastic mosquito nets were made into the side of the plywood to prevent flies from entering the dryer. Three such dryers were made and the drying areas (shelf areas) were as follows, 3' x 2' (glass top), 4' x 2' (plastic top) and 6.5' x 2' (plastic top). The front edge of each drier is 6" and the back 18", so that the 6.5' x 2' drier is the largest that can be made from a single sheet of plywood (a standard sized sheet of plywood is 8' x 4'). We also determined the economic value of the solar dryer by calculating the total cost of materials used in construction over the useful days of the dryer per year and the expected life of the device. The weight of the fully constructed

solar dryer can be approximated to about 4 kg, making it easy to move it around (Figure 6).

Problems associated with fish smoking and drying in the fishing industry of Sierra Leone

Food drying is a method of food preservation in which food is dried (dehydrated or desiccated). Drying inhibits the growth of bacteria, yeast, and mold through the removal of water. Fresh fish is a highly perishable food product that requires proper handling and distribution to ensure that it can be utilized in a cost effective and efficient manner. Global demand for fish is growing, and understanding existing handling and marketing channels is essential to maintain reliable supply chains and profitable fisheries sector (Delgado et al., 2003; Williams, 1996). Research shows that the supply of fresh fish at each fishing harbor is erratic with shortages linked to inability to transport fresh fish; freezer trucks are



Figure 4. *Ethmalosa fimbriata* on a wire mesh in a solar drier.



Figure 5. *Sardinella maderensis* on a wire mesh in a solar drier.



Figure 6. Cabinet style dryer with glass top.

rare and most harbors lack facilities to make ice. Due to the limited market for fresh fish, much of the catch is preserved by smoking and to a lesser extent sun drying, steaming and frying, the latter two methods are mostly for local consumption, as cooked fish is rarely traded. Fish smoking requires a large quantity of wood, either from terrestrial sources (forests and farm bush) or coastal environments (mangroves). However, a number of challenges are encountered with fish smoking including the scarcity of wood, type of smoking stacks used, and seasonal variations in climatic conditions. Wood used for smoking of fish are harvested from forests, farm bushes and mangrove swamps several miles from Tombo and Goderich, where most of the fishing and fish smoking are done.

Poor road networks and lack of maintenance of vehicles involved in the transportation of firewood from the interior often lead to scarcity of wood when it is needed. When such scarcity coincides with a large catch, high losses are not uncommon, with economic consequences for the industry. For the smoking of fish, the most common type of smoking stacks used are made locally and often referred to as traditional smoking stacks or 'banda'. Such stacks are made with metal drums on the sides and iron poles to support the platform structure, with the surface made out of wire mesh for spreading of fish during smoking. Heat retention capacity of such stacks is very low, often requiring large quantities of wood to process the fish. Our observations of commercial smokers show that up to 130kg of wood is burnt to produce 170 kg of smoked "herring" (*Clupea harengus*). Despite the ease of use and low costs associated with the traditional smoke stacks, they are not energy efficient. The continued use increases the demand for already scarce firewood.

Sierra Leone has a monsoon type climate with a rainy season from May to November and a dry season from December to April, and this has a profound effect on the usefulness of solar dryers. Along the coast, night-time temperatures can be as low as 16°C (60.8°F), and the average daytime temperature is 26°C (78.8°F), sometimes moderated by the harmattan when dry winds blow in from the Sahara Desert. While the use of passive solar dryers for fish drying can be seen as a clean source of energy, they are useful for only about 150 days per year, mostly between the months of December to April and less useful for the rest of the year. Another major challenge associated with fish drying using solar dryers is the length of time it takes to complete a drying cycle; it took approximately five days operating at 7 hours per day to dry 15kg of herring in one of our solar driers. This time duration renders solar dryers less useful in the artisanal fishing industry as most fish processors prefer faster methods that allow them to process fish for the Freetown market in only 2 to 3 h.

Mode of fish smoking and drying

Processing can be defined as a method applied to the product from the time of harvest to the consumption period. Processing of fish into forms for human consumption or suitable to be used as a supplement in animal food has been neglected in fish culture practices. This may be due to the high technology required in some of the processes and the fact that those involved in actual fish production are ignorant of the different processing methods. In order to prevent fish deterioration, every fish processor must strive to employ the best method possible in handling fish to maximize returns on processing investment (Davies, 2005). Fish processing by smoking in Sierra Leone is done in traditional smoking sheds called "banda" and consists of simple construction with a frame about a meter high on which the fish are placed and burning wood placed below the frame. In an "emergency" any type of wood can be used, but under normal condition the preferred species characteristically burn slowly, produce high heat energy, and "sweet" smelling odor from the smoke.

Mangrove wood (*Rhizophora mangle* and *Rhizophora harrisonii*) is



Figure 7. A traditional "banda" in operation.

the most desired, but declining supplies near the capital and increased price have resulted in most processors switching to species such as, *Dialium guineense* and *Sterculia tragacantha* from forests and farms. Using a banda, small fish such as herring are placed in rows with stomach facing downwards to ensure the entrails receive enough heat (Figure 7). Species such as "Spanish" are smoked with the aid of a thin stick inserted through the mouth to the tail to enhance easy handling during smoking. Larger species such as barracuda (*Sphyraena afra*) and sharks (*Carcharodon carcharias*) are gutted and cut into chunks to enhance heat penetration during smoking. Fish position is often changed during smoking to ensure an effective and even drying process. There are variations on how long the fish is smoked, depending on whether the fish is to be sold locally or transported to distant provincial markets. Fish processors operate independent businesses from fishermen, but some fish processors are also traders/transporters.

Quantitative data collection

We could find little data on fish smoking in the artisanal fishing industry in Sierra Leone, although there are some refereed journal articles from the sub-region e.g. Essumang et al. (2012) on the possible negative effects of PAH contamination with fish smoking; Nti et al. (2002) examined improved fish smoking in Ghana, while Feka and Manzano (2008) discussed the impact of fish smoking on mangrove forests in Cameroon. In Ghana, Lokko and Anson (2002) focused their socio-economic assessment of fishing in coastal communities but noted a paucity of relevant papers on the artisanal fishing industry regionally. Through several consultative meetings, we managed to gain the trust of the fish processors before data collection began. We were partially interested in confirming (or refuting) the ITK (indigenous technical knowledge) supplied by participants at the series of workshops held with them. In the first round of data collection, we concentrated on the process of fish smoking, energy use and food losses in the value chain. For each smoking event, we recorded the species of fish, fresh weight, finished weight, amount and type of wood burnt during smoking and type of banda used. Three types of banda are in use, but our data collection concentrated on the traditional and improved Altona type which were commonly used in the study area (the mud brick type was too rare for statistical comparisons to be made).

Table 1. Operations of a traditional banda

Fresh fish weight (kg)	Dry weight (kg)	% weight dry fish (%)	Weight loss (kg)	Weight of wood	Water loss per kg of wood used
300	170	57	130	130	1.00
153	80	52	73	75	0.97
77	40	52	37	38	0.97
32	13	41	17	20	0.85
63	27	42	36	43	0.84
231	135	58	96	114	0.84
126	57	45	69	86	0.80
51	28	55	23	30	0.77
252	108	43	114	170	0.67
250	159	64	91	160	0.57

Seasonal variability

RESULTS AND DISCUSSION

Fish smoking

Data was used to confirm and quantify some of the ITK held by the fishing community but we were unable to confirm other aspects. With the data available we were able to test:

- (1) Seasonal variability,
- (2) Species variability,
- (3) Type of "banda" (traditional versus Altona), and
- (4) Size of catch (load in the banda).

We were unable to investigate:

- (1) The impact of fishing gear (especially use of mono-filament nets as these are illegal),
- (2) Quality of fish - we lacked the skill to make an expert judgment, and
- (3) Use of mangrove wood versus "forest" wood, as so few people were using mangrove in these communities.

We measured "efficiency" in two ways:

- (1) Loss of weight in catch per unit of wood used - mostly this is water driven off, but could include some wastage such as fish falling into the fire, and
- (2) Weight of dried product per unit of wood used (Table 1).

Observations were carried out in May/June (early wet season) and January/February (late dry season). Mean weight loss per kg of wood burnt was:

- (3) Dry season = 1.28 kg (n=21)
- (4) Wet season = 1.43 kg (n=22)

One-way ANOVA shows these differences are not significantly different ($p > 0.05$, $F = 0.87$, total $df = 42$), nor are the results in accordance with ITK which suggests higher energy use in the wet season. It is possible that our "wet season" observations were too early and in

consequence we intend to take more measurements in October at the tail end of the rainy season (when the rainfall in the preceding six months should have totaled about 3 meters).

Species type

We had sufficient observations to assess three species. Mean weight loss per kilogram of wood burnt was:

- (1) Herring (*Clupea harengus*) = 1.00 kg (n=17)
- (2) Spanish (*Gadus morhua*) = 1.35 kg (n=9)
- (3) Bonga (*Ethmalosa fimbriata*) = 1.74 kg (n=14)

One-way ANOVA shows these differences are significantly different $p < 0.001$, ($F = 7.81$, $df = 39$). Herring is an oily fish, and smoked whole, while Spanish is a large fish that is usually cut into pieces before smoking. Bonga is a small thin fish and the most common species found in the markets.

Types of Banda

Traditional and Altona were compared; we had too few observations to include the mud brick banda in the analysis. Mean weight loss per kg of wood burnt was:

- (1) Traditional banda = 1.10 kg (n=31)
- (2) Improved banda = 2.17 kg (n=9)

One-way ANOVA shows these differences are statistically significantly different at $p < 0.001$, ($F = 45.7$, total $df = 39$). Despite its obvious technical efficiency, the improved banda is not widely used. Further discussion with fish processors revealed that the improved banda required more labor to smoke a load of fish, and this increased cost was greater than the value of the wood saved (at current market prices). The main preference for use made of the improved banda is by traders from

Table 2. Operation of the solar dryer

Fish species	Fresh weight (g)	Dry weight (g)	Dry weight (%)	Final colour	Duration in the dryer (days)
Herring	3,875.2	1,083.9	28	Silver	5
Herring	1,900.8	888.3	47	Silver	4
Shine nose	840.0	392.0	47	Light brown	4

the provinces who buy fresh fish and then smoke them to their own specifications, rather than buying already processed fish. Correlation between the size of the load in the banda and the efficiency of the drying process is very low ($r=-0.049$) and not statistically significant ($p>0.05$, $n=43$). Our working assumption is that what is important is whether the banda is filled to some optimal design capacity; too much or too little makes the process much less efficient. Partial confirmation of this is from a comment at the workshop when stakeholders discussed integration of fishing and fish processing businesses. It was perceived as being too difficult, as either the banda was too full or not full enough (so less efficient), or the fisherman stayed out too long trying to get a full banda load and so arrived on shore with lower quality fish.

Solar dryer

Due to the seasonality of usefulness of the solar dryer, only herring and other small pelagic fish were tested in the solar dryer. It took between 24 and 30 h (at 6 h per day) to dry herring so that no more weight loss was possible. Smaller fish (Figure 4) could be dried only slightly faster (Table 2). Result acquired from solar dryer experiment clearly shows the potentials in solar dryer for food processing as an alternative to firewood. Despite a few disadvantages, our observations show that, fish dried in solar dryer have a longer shelf life than smoked fish. Consumer perception on taste of fish dried in the solar dryer during our second round of consultative stakeholder knowledge sharing event showed that, there was only slight difference in taste between fish dried in solar dryer and those dried through wood smoking. Unfortunately, fish dried by smoking is considered to be a bit tastier with pleasant smell due to the presence of smoke aroma.

Economics of solar dryers

The approximate cost of building our solar cabinet dryers was Le 150,000 (US \$90); this is considerably more than the 1,700 Rupees (US \$36) reported by Sengar et al. (2009) for a plastic covered dryer for prawns. The low capital cost comes at the downside of being a fairly fragile construction. For the glass topped drier, there is a risk of breakage and while the plastic top can be mended

with tape the UV light and dust spoilt the surface rapidly. The cheapest and thinnest grade plywood was used and this adds to the fragility. Despite the low capital cost of the solar dryers, our findings reveal that, the use of solar dryers still have economic implication when the following factors such as, cost of dryer, useful days of dryer and duration of drying are considered.

The data in Table 3 was used to determine the cost of the dryer per day and as well as the cost of drying.

Cost of drying one dozen herring =

$$\frac{\text{cost of solar dryer} \times \text{drying time}}{\text{useful days per year} \times \text{capacity of dryer}}$$

$$= \frac{150,000 \times 5}{140 \times 6} = \text{Le } 893 / \text{dozen (US } \$0.154)$$

The above analysis excludes labor costs which are modest compared to hot smoking where a fire has to be tended and fish moved about. The cost of smoking herring was observed to be between Le 1,000 to Le 1,500 (\$0.259) per dozen for the Freetown market and Le 2,000 to Le 2,500 (\$0.431) for the provincial market where fish need to be drier for a longer "shelf-life". Theoretically the "pay-back" period on saved wood would be between 77 days and 8 years; even in the most optimistic scenario this is longer than Songar et al. (2009) who estimated a pay-back period of about one month when the dryer is used for salted dried prawns. As well as the lower capital costs, the device benefited from being able to dry the prawns in one day rather than the 4 or 5 days we required to dry fin fish. Results from current work on energy used in fish processing shows that, about a quarter of the expenditure goes on firewood. Fish processors are changing their habitats more rapidly than expected, for example it is always said that they prefer mangrove wood, but we found very few people using it. It would seem rational to assume that they will switch to other forms of processing fish as soon as it becomes economically sensible to do so and that they are not hide bound by tradition. However, new technologies need to fit into the available labor supply and be affordable. This is in line with work done by Waewsak, et al. 2006 on mathematical modeling study of hot air drying for some agricultural products in which he stated that, in many parts of the world there is a growing awareness that renewable energy have an important role to play in extending technology to the farmer in developing countries to increase their productivity.

Table 3. Characteristics of the cabinet solar dryer

Cost of materials and construction	Le 150,000 (US \$90)
Working days per year	140
Life span of the dryer (estimated)	1 year
Maximum capacity	6 dozen herring (or 25 kg)
Drying time	4 to 5 days at 6 hours per day

The data in Table 3 was used to determine the cost of the dryer per day and as well as the cost of drying.

Conclusion

Sierra Leone is not very food secure and access to high quality protein is limited, with most being supplied by the artisanal fishing industry. The challenges of inadequate energy for fish processing faced by the industry has limited the quality and to a lesser extent quantity of fish protein for some parts of the year. In such a situation, measures to increase protein accessibility by using more energy efficient technology need to be encouraged, by taking into account the socio-economic constraints faced by producers and processors. While technically efficient technologies exist to reduce waste, they often require excessive capital or running costs. Our assessment is that simple passive cabinet solar driers are unlikely to make a substantial contribution to fish processing in Sierra Leone in the immediate future because they take too long to dry the fish to an acceptable moisture content and they can only be used for less than half the year.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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