A Novel Way of Addressing Eminent Food Insecurity Challenges Caused by American Fall Army Worms (*Spodoptera Frugiperda*)

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Abstract—American Fall Army Worms *Spodoptera frugiperda* (J.E. Smith) has been a great nuisance to farmers in West, South, East Africa and Asia imparting significant losses ranging from 80 to 100% to maize crops while in the fields. This paper presents and describes the results of an investigative study carried out to examine the efficacy of a simple detergent water mixture as an effective remedy for controlling American Fall Army Worms. This should be good news and great relief to governments and farmers at large with regards to time and financial resources that have been used to control these worms. The experiments were carried out at a laboratory in Kilimanjaro street, Kihonda ward, Morogoro region, Tanzania. Various concentrations of 0.1 graduation (0.1% - 1.5%) of detergents (Trade names: KLEESOFT, OMO, FOMA, ARIEL and FAMILY) water mixtures were prepared. These were applied to the worms to detect; which concentration was effective in killing them in the shortest time possible. Five worms were subjected to each concentration of detergent:water mixture and the time was recorded to detect the duration it took to kill the worms. Simple detergent:water mixtures have shown to be very effective in controlling the American Fall Army Worms. For each concentration prepared from 0.1% to 1.5% we observed a 100% mortality of the worms, with only difference being the time to kill. On average at 0.1%, the worms were killed in 689 seconds (≈ 12 minutes), while at 1.5%, the worms were killed in 32 seconds (≈ 0.5 minutes). The duration decreased with level of concentration of the detergent. As the detergent concentration increased less and less time was required to kill the worms completely. From the lowest concentration 0.1% to the highest 1.5%, there was a 100% mortality of the worms, with the only difference being time to kill. A 0.5% detergent:water mixture has been shown to be very effective in killing the fall army worms within 60 seconds as the difference in time to kill was negligible after this concentration. The findings of this study call for urgent need to introduce this remedy to all farmers in order to protect maize and other crops in the fields during production season and to reduce financial burden incurred by farmers in purchasing costly pesticides.

Further research is needed to explore the specific content of the detergents that causes abrupt death and the mechanism in which the worms are killed.

Keywords— American Fall Army Worms, Cost-effective, Detergents, Farmers, Maize, Pesticides

I. INTRODUCTION

American Fall armyworm (FAFW), *Spodoptera frugiperda* (J.E. Smith) is a polyphagous destructive pest that attacks economically important crops such as maize, wheat, millet, sorghum, sugarcane and rice at all stages, in which the damage can lead to 100 percent crop loss [22, 5]. The FAW develop through six developmental instars, with the last instar causing over 70% of the overall damage [1]. The larval stage is about 14 days [14]. A single larva can consume about 140cm² of maize leaf area to complete the larval development period [1]. FAW is capable of feeding on over 80 different crop species, making it one of the most damaging crop pests [37]. The pest belongs to **Kingdom: Animalia, Order: Lepidoptera, Family: Noctuidae, Genus: Spodoptera and Species: Spodoptera frugiperda** [12]. The larval stages 1st to 5th instars are considered the stages that cause heavy crop losses. Among the crops mentioned above, maize is the most important staple cereal crop grown by smallholder farmers in Sub-Saharan Africa and is one of the dominant cereals grown in most other African countries [12, 36]. The larvae feed voraciously on the maize plant leaves by staying in between the nodal and pedicel region of the leaves [3]. They feed by scraping the leaf surface as they loosen causing defoliation [7].

FAFW, is native to tropical and sub-tropical region of America that has spread worldwide uncontrollably to Africa and Asia [6]. FAW appeared for the first time in 2016 on maize crops in Central and West Africa, Nigeria in particular [23, 9, 34].

By 2017 the pest spread very quickly, as it was found in most of sub-Saharan Africa [12], threatening food security in individual countries [15]. Due to its rapid spread and distinctive ability to inflict widespread damage across multiple crops, AFAW poses a serious threat to the food and nutrition security and livelihoods of hundreds of millions of farming households in Sub Saharan Africa [37]. According to Huesing [33], some of the factors that helped AFAW to spread quickly over the continent were their propensity to attack a wide range of crops and their ability to migrate over long distances [39]. Equally, adult AFAW moths are strong flyers [38], which have enabled the pests to spread very fast in Africa in 2016, India 2018 [35], Myanmar [20], and China [19]. This pest has caused unsurmountable financial losses in African countries with respect to loss in planted and harvested maize crop [12, 40].

Several approaches that have been reported to control AFAW include; cultural, biological and chemical control [24, 18, 12]. Of all the mentioned approaches the control of AFAW has usually been achieved through the application of synthetic insecticides [4]. However, it has been reported that these methods were costly, causes environmental pollution, at most times the worms developed resistance to chemicals and often pest resurgence [10, 11]. Some pesticides that are currently applied to control AFAW include pyrethroids, carbamates and organophosphates [1]. The aim of this paper is to inform the General Public that a simple and effective remedy of the devastating AFAW pest has been found. Secondly, the remedy is very affordable to poor farmers

II. MATERIALS AND METHODS

A. Materials

Table 1 shows the materials that were used in the experiments. The experiments were carried out at a laboratory in Kilimanjaro street, Kihonda ward, Morogoro region, Tanzania.

TABLE 1
MATERIAL REQUIREMENT

S/No.	Materials	Amount
1.	Laboratory weighing scale (ACPro-200 200g x 0.01g Lot No03-20588)	1
2.	Detergents (KLEESOFT, OMO, FOMA, ARIEL, FAMILY): Each 50 grams pack	4
3.	Beakers 100 mL capacity	75
4.	Worms: 5 th or 6 th Instars growth stage	375
5.	Petri dishes: with a capacity of 100 mL	75
6.	Measuring cylinder: 100 mL	1
7.	Stop watch	1
8.	Distilled water (Litres)	5

B. Methods

1. Collection of American Fall Army Worms:

A total of 375 live worms that were approximately in their 5th to 6th instars growth stage, were collected from maize fields in Kilimanjaro street, Kihonda ward, Morogoro, Tanzania. These worms were put in a well-ventilated plastic container, ready for the experiment. An instar refers to the developmental stage of an arthropod between moults [1]. For instance, after hatching from the egg the larvae or worm is referred to the first instar. When the larvae/worm moults again become a second instar and so on. The AFAW larvae/worm develop through six developmental instars and the sixth is the complete mature worm [14].

2. Preparation of Detergent:Water Mixtures:

The following concentrations of Detergent/Distilled water mixtures were prepared: 0.1%, 0.2%, 0.3%, 0.4%, 0.5%, 0.6%, 0.7%, 0.8%, 0.9%, 1.0%, 1.1%, 1.2%, 1.3%, 1.4% and 1.5% as shown in Table 2. The Table indicates the amount of detergent measured in grams for each concentration. A laboratory weighing scale (ACPro-200 200gx0.01g Lot No03-20588) was used to weigh the detergent for each mixture. The weighed detergents were put in a total of 15 beakers. A measuring cylinder was used to measure and dispense 50 mL of distilled water for each concentration into the beakers containing the detergents and mixed well until the detergents were clearly mixed.

TABLE 2:
CONCENTRATION OF DETERGENT: DISTILLED WATER MIXTURE

Sample No.	Detergent (grams)	Distilled Water (mL)	Detergent Concentration (g/mL)	Detergent Concentration (%)
1	0.05	50	0.001	0.1
2	0.10	50	0.002	0.2
3	0.15	50	0.003	0.3
4	0.20	50	0.004	0.4
5	0.25	50	0.005	0.5
6	0.30	50	0.006	0.6
7	0.35	50	0.007	0.7
8	0.40	50	0.008	0.8
9	0.45	50	0.009	0.9
10	0.50	50	0.010	1.0
11	0.55	50	0.011	1.1
12	0.60	50	0.012	1.2
13	0.65	50	0.013	1.3
14	0.70	50	0.014	1.4
15	0.75	50	0.015	1.5

3. Mode of Exposing the Worms to the Detergents:

For each detergent, 15 petri-dishes were arranged in a single row and labelled in order of increasing concentration (0.1% to 1.5%). About 30 mL of each concentration was poured into the petri-dishes from the beakers. Five (5) AFAW in their 5th or 6th in-stars growth stage were put on each petri-dish at a time and a stopwatch was started. The stopwatch was stopped when the fifth worm was killed. The time was recorded in seconds.

C. Response of the Efficacy of the Detergent:Water Mixtures from the General Public:

When we discovered this mixture to be effective against AFAW, in March, 2020 during maize production season in Tanzania, we sent a video clip in the internet in order to inform various stakeholders including the farmers on this discovery so that they could use in their farms to save their maize crop. After one week, we started to get feedback from users of the detergent:water mixtures on how effective the detergent mixture was in controlling AFAW. We then called by phone 10 participants (6 males, 4 females) who used the detergent:water mixtures and asked them structured questions, which compared the experience of using the chemical pesticides and detergent:water mixtures. The respondents retorted by comparing the detergents and the chemical pesticides they have been applying on several aspects such as, cost/litre or kilogram, cost of spraying per acre, odour/smell, effect to the environment, efficacy, spray concentration and time the worms were killed after application.

D. Data Analysis

Data analysis was performed using Statistical Product and Service Solutions (SPSS) version 25. Descriptive statistics was used to explore distribution of the time to kill the AFAW and concentration of the detergents. The results were presented both in a tabular format and the scatter diagram. The tabular format was used in presenting the various concentrations employed and the time taken for the worms to be killed by the detergents. The scatter diagrams were used to show the time trend on how AFAW were killed with detergents concentrations.

III. RESULTS

E. Time Taken to Kill the Worms: Lethal Dose Determination

Based on the concentrations prepared, the time in seconds the last worm of the five worms was killed for each concentration was recorded as indicated in Table 3. The time the worms were killed was inversely proportional to the concentration of the detergents; that is; as the concentration of the detergents increased, the time taken to kill the worms decreased. However, for each detergent concentration prepared from 0.1% to 1.5%, we observed a 100% mortality of the worms, with only difference being the time they were killed. On average at 0.1%, the worms were killed in 689 seconds ($\approx$ 12 minutes), while at 1.5%, the worms were killed in 32 seconds ($\approx$ 0.5 minutes).

TABLE 3:
CONCENTRATION OF DETERGENT/DISTILLED WATER MIXTURES PREPARED AND TIME TO KILL

S/No.	Detergent Concentration (%)	Number of Worms' at 5 th or 6 th Instars Growth Stage	Time the worms were killed (seconds)					
			Detergents					Mean of all Detergents
			KLEESOFT	OMO	ARIEL	FOMA	FAMILY	
(1)	0.1	5	676	702	653	723	692	689.2
(2)	0.2	5	410	398	450	463	557	455.6
(3)	0.3	5	228	193	202	232	194	209.8
(4)	0.4	5	120	97	92	139	91	107.8
(5)	0.5	5	58	48	61	56	54	55.4
(6)	0.6	5	57	46	55	53	51	52.4
(7)	0.7	5	53	43	53	51	47	49.4
(8)	0.8	5	51	41	49	48	45	46.8
(9)	0.9	5	50	38	45	44	43	44.0
(10)	1.0	5	48	34	43	40	40	41.0
(11)	1.1	5	47	32	41	37	38	39.0
(12)	1.2	5	45	30	39	36	35	37.0
(13)	1.3	5	43	29	35	33	33	34.6
(14)	1.4	5	43	27	32	31	30	32.6
(15)	1.5	5	43	26	30	31	29	31.8

Figure 1, 2, 3, 4 and 5 displays the linear, quadratic and cubic trends of time taken to kill the worms by concentration of KLEESOFT, OMO, FOMA, ARIEL and FAMILY detergents, respectively. Figure 6 shows the average trend of all detergents. All the detergents showed a similar pattern in killing the worms with increase in concentration. The results showed that the cubic trend lines were a better fit for the data than the linear and quadratic trend lines.

With cubic trend lines, it was noted that the time to kill decreased with increasing concentration of the detergents:water mixtures. However, after the detergents' reached a concentration of 0.5 g/100 mL (0.5%), the difference in time to kill was negligible. This indicated that the optimal value of detergent concentration to be used was 0.5 gm/100 mL (0.5%). Otherwise by increasing the concentration of detergent:water mixtures, the time to kill was negligible and hence there is no need of adding more detergent as it will increase cost with no tangible savings of the detergents.

KLEESOFT DETERGENT

Figure 1: The distribution of observed and predicted values of time to kill in seconds by concentration of the KLEESOFT detergent for three different models

OMO DETERGENT

Figure 2: The distribution of observed and predicted values of time to kill in seconds by concentration of the OMO detergent for three different models.

FOMA DETERGENT

Figure 3: The distribution of observed and predicted values of time to kill in seconds by concentration of the FOMA detergent for three different models.

ARIEL DETERGENT

Figure 4: The distribution of observed and predicted values of time to kill in seconds by concentration of the ARIEL detergent for three different models.

FAMILY DETERGENT

Figure 5: The distribution of observed and predicted values of time to kill in seconds by concentration of the FAMILY detergent for three different models.

MEAN OF ALL DETERGENTS

Figure 6: The distribution of observed and predicted values of time to kill in seconds by concentration of the Mean of all detergents for three different models

F. Feedback of the Efficacy of the Detergent:Water Mixtures from the General Public

The responses to the questions of those who sprayed the detergent:water mixtures to control AFAW are summarized in Table 4. The respondents retorted by personal evaluation of using the detergent:water mixtures with the experience they had, in using the chemical pesticides. The price per litre for the chemical pesticides ranged from US\$ 10 to US\$ 21, Tanzanian Shillings Equivalent, while the detergents were purchased on average of US\$ 3 per kilogram. The cost for spraying an acre for the chemical pesticides ranged from US\$ 5 to US\$10.5, while for the detergents costed US\$ 0.9 only.

All respondents generally agreed that the cost of using the detergents was very low and could be afforded by most farmers. Responding to the efficacy of the detergent:water mixtures in controlling the AFAW, they reported as; very effective and death was certain, and within a very short time of less than 3 minutes on average. Reporting on the smell of detergents while spraying, all the respondents said they enjoyed as the smell was good and perfumed contrary to the choking chemical pesticides. They all agreed that as a result of using the detergent:water mixtures, pollution to the environment might be very minimal as the concentration of the detergents used was relatively low (0.5%).

TABLE 4:
COMPARISON OF THE DETERGENT MIXTURE AND THE CHEMICAL PESTICIDES

S/No.	Criterion	Chemical pesticide	Detergents water mixtures
(1)	Cost: Price per Litre/kilogram	Vitashield 48 EC (48% chlorpyrifos ethyl): Equivalent to US\$ 16 per litre	Detergents: KLEESOFT, OMO, ARIEL, FOMA AND FAMILY. Equivalent to US\$ 3 per kilogram
(2)		Select-Plus 315 EC (Profenofos+lambdacyhalothrin) Equivalent US\$ 10 per litre	
(3)		Bamethrin 5EC (Deltamethrin 5g/L) Equivalent US\$ 21 per litre	
(4)		Kung-Fu 5 EC (Lambda-cyhalothrin) Equivalent to US\$ 18 per litre	
(5)		Duduba 450 EC (Cypermethrin 10%+chlorpyrifos 35%) Equivalent to US\$ 18 per litre	
(6)	Efficacy	Not very effective and at times does not kill. Sometimes advised to use mixture of two or three insecticides at one time	Very effective, kills 100%
(7)	Liters enough to spray an acre	80 litres: Chemical:Water mixture	80 litres: Detergent:Water mixture
(8)	Cost of spraying an acre	Vitashield 40 EC (40% chlorpyrifos ethyl): 500 mL per acre; Equivalent US\$ 8 per ½ litre	Detergent:water mixture: Equivalent to US\$ 0.9 per acre
(9)		Select-Plus 315 EC, 500 mL per acre; Equivalent to US\$ 5 per ½ litre	
(10)		Bamethrin 2.5 EC, 500 mL per acre; Equivalent to US\$ 10.5 per ½ litre	
(11)		Kung-Fu (Lambda-cyhalothrin), 300 mL per acre; Equivalent US\$ 9 per 300mL	
(12)		Duduba 450 EC (Cypermethrin 10%+chlorpyrifos 35%) US\$ 9 per ½ litre	
(13)	Overall cost	Relatively high	Relatively very low
(14)	Smell while spraying	Choking after mixing with water	Good and perfumed
(15)	Environmental pollution	Relatively bad and high	Relatively very little
(16)	Spraying on plant	Spray economically due to high cost of the chemical	Spray to the whole plant since its affordable
(17)	Duration of worm death	1-2 days on average, sometimes do not kill	Less than 3 minutes on average

III. DISCUSSION

AFAW has been a great nuisance to farmers in West, South and East Africa imparting 80 to 100% loss to maize crops while in the fields [21, 37, 22]. However, the results of these detergent:water mixtures show that the AFAW are very susceptible to even very low concentration of 0.001g/mL (0.1%) of detergents. According to GAIN [22], AFAW were detected for the first time in Ruvuma and Mbeya regions located in southern Tanzania in February 2017. Interventions to control AFAW by the Government of Tanzania (GoT) were initiated by the Permanent Secretary in the Ministry of Agriculture, Livestock and Fisheries, in April 2017. The GoT embarked on various initiatives to control the situation in Katavi, Mbeya and Songwe regions. The GoT deployed agricultural experts, bought and distributed pesticides worth \$132,439, and trained farmers on how to fight the worms. With this intervention by the government it was possible to control the invasion by 70 percent. During this period nearly 30 percent of the country was already affected and most farmers complained of incurring huge costs to contain the worms. The Food and Agriculture Organization of the United Nations (FAO) and the Ministry of Agriculture signed a cooperation agreement on 31/01/2018, that aimed to support Tanzania in building its surveillance and management capacity to respond efficiently to AFAW invasion in the country [17].

An informative video on the control of AFAW in maize provided information about the initial attack of AFAW in Africa, and subsequent attacks in various regions of Tanzania (<https://www.sua.ac.tz/news/fall-armyworm-farmers-nightmare> [27]). Another video showed the spread and initial attacks of AFAW in Africa, and subsequent in various states of India. (<https://video.search.yahoo.com/search/video?p=fall+army+worm+control+in+india+youtube#id=1&vid=db22db61e8ba3eba912a46e486262567&action=click> [26]). The video informed that AFAW had become a major threat and, hence its timely control was imperative. Another video prepared by FAO, explained the 'Best Practices for AFAW Management' in Africa (<https://www.youtube.com/watch?v=JIFOZAj3iT8>). [29]

In Uganda scientist have been trying hard to control AFAW (<https://www.youtube.com/watch?v=p05C1q2HRrg> [31]), however advices by agricultural experts have been on the use of insecticides. In the same country, AFAW outbreaks continued spreading and reached 78 districts by May 2017 and later to other districts in North Eastern part of the country [22].

The Government of Uganda (GoU) distributed pesticides to affected farmers. The pest was reported causing a total crop loss in some places where replanting was necessitated. The GoU developed an action plan with a budget of USD 1 million but they had estimated a potential annual loss of some 450,000 MT of maize to established and unabated AFAW outbreaks. Malawi farmers went an extra mile to try other materials like detergents and salt mixture (<https://www.youtube.com/watch?v=9tOLYD7eJEA> [28]). However, the detergent mixed with salt was just applied in solid form without a known concentration. In this study known concentrations have been tested and optimal concentration have been determined.

Zambia had its own efforts to control the pest by using FORTENZA™ Duo (Cyantraniliprole+Thiamethoxam) insecticide seed treatment to control the pest (<https://www.youtube.com/watch?v=ZCFu12ja8Oo> [32]). Maize growers informed that it was quite effective although no mention was given on the cost of the insecticide. A video clip titled 'Fall armyworm wreaks havoc in southern Africa' (https://www.youtube.com/watch?v=jR4p_AWuFZc [30]) is another evidence how this worm has been a threat to countries in the southern block of Africa. Up to early June 2017, in Kenya, the pest had been reported in 27 of the 47 counties threatening more than 200,000 hectares of maize crop. Ground control operations continued in all affected areas by farmers with assistance and coordination from the Ministry of Agriculture [22]. However, in a survey conducted by De-Groote et al. [13] in Kenya, on pesticides control of AFAW, about 60% of the farmers interviewed perceived pesticides as not effective in controlling AFAW.

Scientists in India came up with simple organic methods for controlling the worms like applying individually soil, rock dust, charcoal powder, or wood-ash into the maize whorls with some success. The most effective method was application of soil/soil slurry in the maize whorls in which the worms were killed after three to four days (<https://video.search.yahoo.com/search/video?p=fall+army+worm+control+in+india+you+tube+using+sand+and+ash#id=1&vid=6518d41210a41875581260134cec60e1&action=click> [25]). According to Fotso et al. [21], other efforts for the control of AFAW have focused on identifying potential indigenous natural enemies and screening soft insecticides and biopesticide as part of an integrated control of the pest.

On the 7th January 2019, The Citizen Newspaper carried a title 'The Tropical Pesticides Research Institute (TPRI) issues new guidelines to control fall armyworms- Arusha'. The story narrated that, TPRI has released a new system of controlling AFAW.

The move came after seven pesticides, developed by TPRI in 2017, proved to be ineffective against the type of worms, scientifically known as *Spodoptera frugiperda*. The pesticides included Belt 480 SC, Duduba 450 EC, and Emamectin Benzoate, Mupacron 50EC, Abamectin 5% and Lambda Cyhalothrin 'karate' [8].

Several approaches by FAO and individual countries have been made to eradicate the AFAW but it has all been in vain. Huge resources have been used in form (i) Purchasing and applying pesticides of different kinds (ii) Holding conferences, webinar and seminars and workshops for exchanging experiences on the control of AFAW and (iii) Publications that came from international organizations working in the field, including the Food and Agriculture Organization [16, 18] and the International Maize and Wheat Improvement Centre (CIMMYT) [37].

IV. CONCLUSIONS

For each concentration we observed a 100% mortality of the AFAW regardless of time. However, the detergent:water mixture of a concentration of 0.5% seems to be very effective in destroying the worms in about 60 seconds as the difference in time to kill was negligible after this concentration. The mixture is cost effective as most farmers could purchase these detergents and apply to their maize in the fields. Governments will do away with expensive chemical controls that cost governments huge financial resources that can be allocated to other important requirements.

V. RECOMMENDATIONS

The findings of this study call for urgent need to introduce this remedy to all farmers in order to protect maize and other crops in the fields during production season as the worms are extremely susceptible to the detergent:water mixtures and hence reduce financial burdens incurred by farmers in purchasing costly pesticides. The authors would like to urge Ministries of Agriculture in all countries facing AFAW problem to use this protocol in order to improve food and nutrition security by ensuring bumper harvests in their respective countries. Nevertheless, further research is needed to: (i) explore the specific content of the detergents that causes sudden or abrupt death of the worms and (ii) determine the mechanism in which the detergents kill the worms.

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VI. DECLARATION OF CONFLICT OF INTERESTS

The authors declare that, they do not have conflicts of interest with respect to the research, authorship, and/or publication of this article. In addition, the authors do not have any commercial or other association that might pose a conflict of interest.

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