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Design, Sizing and Performance Evaluation of Biopesticide Production Plant

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Abstract— The toxicity, persistence, and non-biodegradability of chemical pesticides have increased calls for the adoption of sustainable and cost-effective pest control measures. Bio-pesticides present a sustainable alternative to synthetic pesticides but it is still underutilization in agrarian countries like Nigeria because of low production capacity. The feasibility of economically mass production of a stable product is a key factor to a successful microbial pest control product. In the production of bio-pesticide economically, two phases are involve namely, development of the production process and the development of the product. In this research, the development of the product was duly, carried out by identifying the unit operations involved, evaluating the material and energy balance necessary for product processing. Each unit operation was properly sized and a centrifuge designed. Product development involves product formulation, packaging of formulated products and application of the formulated product to evaluate its efficacy. Therefore, the key elements to successful bio-pesticides are both production efficiency and product efficacy. The efficacy of the formulated product was tested on its ability to repel and control insect pests on leaves of five different crop plants for six days. The mortality rate of the individual pest was 90%, 90%, 93.3%, 93.3% and 96.7% for *Myzus persicae, Chilo partellus, Aphis craccivora, Spodoptera frugiperda* and *Popillia japonica* Newman, respectively.

Keywords— Design, Material balance, Energy balance,Bio-pesticide, Neem seed, Decanter Centrifuge

I. INTRODUCTION

Evidences in economic history have shown that the upheaval of agricultural sector is a fundamental pre-condition for economic growth, especially in developing countries like Nigeria [1, 2]. However, with the increase in human population [3, 4] and unavailability of land, crop production will have to significantly increase in order to meet the food need of the human population [3, 5].

It is estimated that approximately 40% of the yearly crop production is destroyed by pests worldwide prior to harvest [6, 7, 8, 9, 10] observed that nearly 20-30% Nigerian agricultural produce are damaged during post-harvest. Therefore, there is an urgent need for advanced food production, pest eradication, and disease management prior to harvest and post-harvest through the adoption of innovative, cost-effective agricultural practices [4]

Biopesticide is the control of pest through the use of bioactive compounds of microbes gotten from plant and animal sources. Biopesticides are utilized for pre- and post-harvest control of crop pests and diseases. Unlike the chemical or synthetic insecticides, biopesticides are biodegradable [11, 12]

Bio-pesticide can be obtained from Neem tree [13, 14]. The up to 150 compounds isolated from different parts of neem tree are used mainly as insecticide, fertilizer, manure and soil conditioner in an era where the major challenge is on how to increase the food security without harming the environment [15, 16]. This implies that Neem seed is a broad spectrum botanical insecticide, miticide and fungicide agent. Neem oil contains 40% bitter tasting non edible oil that is powerful and safe pest fighter [17].

The major challenges facing the use of bio-pesticides in an agrarian country like Nigeria are high cost of bio-pesticide resulting from import duties, poor efficacy, and inconsistent field performance associated with bio-pesticide utilization as well as lack of basic processing knowledge and cohesive advocacy [4]. In essence if the percentage of bio-pesticides that is imported is reduces, its usability would increase as the cost would be avoidable. To reduce importation, production must be localized. Therefore, this paper seeks to examine the engineering knowledge of bio-pesticide production from neem seed by providing the necessary material balance, sizing of the necessary machines as well as designing the appropriate decanter centrifuge.

II. RELATED WORK

[18] observed that the a stable and cost-efficient product and production is key in developing Microbial Pest Control products such as neem based extract, that is capable in delivering effective pest control. Large-scale production, entails making a decision on the choice of production system, equipment required for product formulation, and often times building a production plant with the entire infrastructure. [19, 20, 21] also developed details on large-scale production systems, production manuals, formulation methods and formulation recipes of Microbial Pest Control Products.

[15] observed that Neem oil is recognized as a powerful bio-pesticide and may offer a solution to global agricultural, environmental, and public health problems. The neem seed oil allelochemicals are reported to have feeding and oviposition deterrence, repellency, growth disruption, reduced fitness, and sterility activities, and hence have been widely used in agricultural pest control. [22] reported that the extract of neem seed, garlic and a combination of both is capable in repelling and controlling insect pests on stored grain. The work further proved that the extract has no effect on the progeny of crop seed and is safe for human consumption. [23] reported that neem-based biopesticide gotten from neem leave gave a 100% efficiency in stopping mosquito bite in households. [24] after investigating the effect of three commercial neem-based bio-pesticide, concluded that neem-based pesticides were capable of controlling Aphids without any environmental hazards. [23] investigated the effect of bio-pesticides produced from neem leave oil on mosquitos. From the result obtained, it was observed that bites were recorded half an hour after application of the insecticide. Yet, an hour later, no mosquito bites were recorded leading to an efficiency of 100%. An hour and half and even two hours later, only a few bites were recorded leading to an efficiency of 84.5%-85%.

III. METHODOLOGY

Material and Energy balance

Material Balance on Depulping

Weight of the flesh on the fresh neem fruit=5% of the total seed mass

Amount of moisture content on the fresh neem fruit=5% of the seed; water

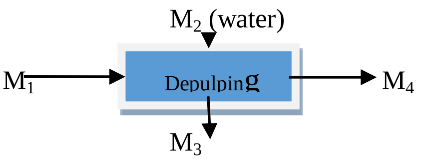
Amount of water for depulping=50% of fresh Neem fruit.

Basis: 1000kg/hr of fresh fruit

Total Material Balance

Accumulation=Output + Consumption – Input – Generation

Input = Output (Steady state process)

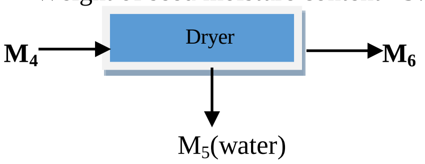


M_1(fresh fruit +5%M_2); M_3 (95%water+ 5% flesh of seed); M_4(Seed 95%M1)

Material Balance around the Dryer

Assume that all water contents are removed from the seed by drying using sun light for 24hours

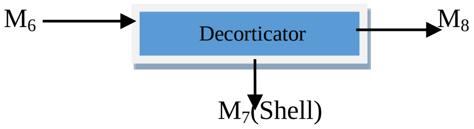
Weight of seed moisture content= 5% of wt. wet seed



M_4 (Seed +shell); M_6 (dried seed)

Material Balance on Decortictor

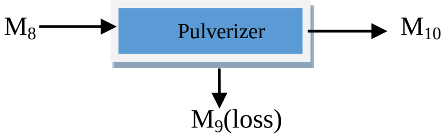
Weight of Neem kernel= 60% of M_6



Where M_6(neem seed); M_8=Neem kernel

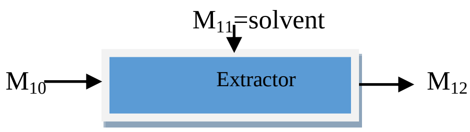
Material Balance on Size Reduction Machine

Assuming a 1% of Neem kernel loss,



M_{10}(crushed kernel)

Material Balance on Extraction machine

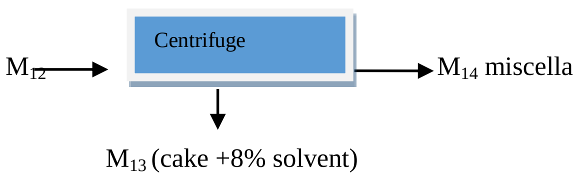


Where M_{12}=Cake+Solvent+oil

The extraction of the oil using the solvent extraction method was done on a scale of 1:2 for crushed neem seed kernel to hexane used.

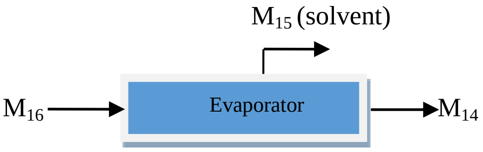
Material Balance on Centrifuge

From the experimental data, 1kg of Neem kernel produces 0.64kg of cake in the extractor; 8% loss of solvent. Thus, to process 26.804kg of Neem kernel there is 17.154kg of cake as by product.



M_{14} is separated by evaporation and the solvent will recycled by using the condenser.

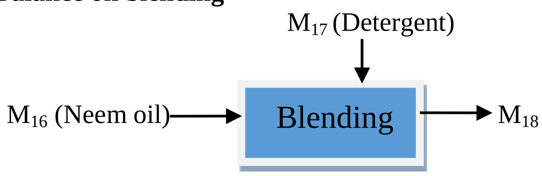
Material Balance on the Evaporator



Where M_{16} (Neem oil); M_{14} (miscella)

From the experimental work, cake from the centrifuge contains 6.1% solvent. For processing 45gm Neem kernel, there is 2.745gm of the solvent loss. Thus, to process 2556.1kg there is a loss of 155.9kg of solvent.

Balance on blending

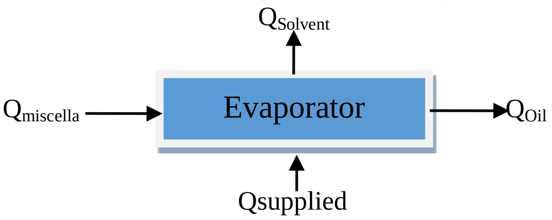


Where M_{18} is Biopesticide

From the experimental work 5gm of detergent was mixed with 10gm of neem oil .Thus to processes 350.55kg it requires 175.275kg/hr of detergent.

Energy Balance

Energy balance on evaporator



Cpoil=2.053J/g.^{o}c; Cps =2.195J/g.^{o}c; Cpmiscella = 0.86*2.1956+0.14*2.053= 2.18j/g.^{o}c

Qsupplied + $Q_{Miscella}$ = $Q_{Solvent}$ + Q_{Oil}

Qsupplied = $M_SCp_S(T_2\text{-}T_1)+M_OCp_O(T_2\text{-}T_1)\text{-}M_MCpmix(T_2\text{-}T_1)$ = 138.44j/s energy supply is required.

Design of Decanter centrifuge

A decanter is a centrifuge that separates solids from liquids. There are different kinds of decanter centrifuges, 2-phased and 3-phased. The 2-phased separates solids from liquid and the 3-phased can separate solids, and two liquids with different densities. It is based on the simple theory of a clarifier or a settling tank in which the sediment, particles and the solids fall to the bottom due to the force of gravity. For the purpose of this research, a 2-phase decanter centrifuge is designed.

The design of the Decanter Centrifuges was done taking into consideration the following: material of use (stainless steel (316), geometric shape (conical and cylindrical bowels), centrifugal force, suspension volume, retention time, beach angle, clarifying area and equivalent clarifying area by evaluating: D_B = Inner bowl diameter (m), D_W = Weir diameter (m), L_{cyl} = Cylindrical length (m), n = bowl speed (rpm). α = cone angle (^{o})

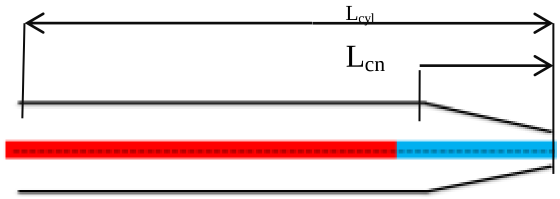


Fig 6.2.Dimension specification of solid bowel decanter centrifuge

Design Calculations

Clarifying Area

The clarifying area of the decanter centrifuge was calculated using the equation for conical-cylindrical SBD centrifuge was used to calculate the clarifying area on a ratio of 4:1 bowel length to bowel diameter. The equation is given as:

$$A_c = \pi \times D_b \times L_{cyl}$$

Where, Ac, D_b, L_{cyl} are Clarifying area (m^2), inner bowel diameter and Cylinder length respectively. Using Sokolov as the standard ( ), Ac = 5.50 m^2 and D_b=0.73m; L_{cyl} = 2.39m

Centrifugal Force

The centrifugal or G-force which is defined as the ratio between the centrifugal acceleration created inside the bowl and the earth gravity acceleration was calculated using the equation for calculating the bowl periphery:

$$G = \frac{n^2 \times D_b}{1800}$$

Where, G = G-force; n =bowel speed (rpm); D_b = inner bowel diameter (m). n is 2500.

G-force=2,535G

Beach Angle

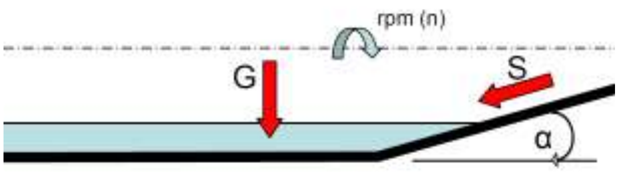


Fig 6.3 Slippage force on the beach of SBDC

For a given set of feed densities the slippage force can be calculated as follows:

S = G * sin α ……………………….. (4)

Where; G = Gravitational force generated by the centrifuge

α = the cone angle of the centrifuge and for the purpose of this design, the cone angle of 10^{0} was selected.

S is 440.2G.

Suspension Volume

The suspension volume (V_s) consists of two components: the volume contained in the cylindrical section (V_{cyl}) and the volume contained in the conical section (V_{cn}).It can be calculated as follows:

$$V_{cyl} = \frac{\pi \times (D_B^2 - D_W^2) \times L_{cyl}}{4}$$

$$V_{cn} = \frac{\pi}{8} \times \frac{D_B - D_W}{\tan\alpha} \times \left(\frac{(D_B^2 + D_B \times D_W + D_W^2)}{3 - D_W^2}\right)$$

$V_s = V_{cyl} + V_{cn}$

Where; α = angle of inclination or cone angle (^{o})

At D_w=0.269m, α=10^0; Vcyl = 0.864 m^3 and Vcn =0.2820m^3. Therefore, Vs =1.146m^3

Retention Time

The retention time of the centrifuge was calculated using the equation:

$$T_R = 3600 \times \frac{V_s}{Q}$$

Where, T_R = Retention time (sec), Vs= Suspension volume (m^3), Q = Volumetric feed rate (m^3/h). At Q equal to 3.38m^3/hr, Retention time (T_R) is calculated to be 1214.2sec.

Equivalent Clarifying Area

In order to gets an idea of the relative settling capacity of a centrifuge; one can calculate the Equivalent Clarifying Area or Sigma value (Σ)

$$\sum = A_c \times G$$

Σ = sigma value (m^2)

A_C = Clarifying area (m^2)

G = G-force (m)

Or

$$\Sigma = \left(\pi \times n^2 \times D_B^2 \times L_{cyl}\right) / 1800$$

When the values of Ac and G are substituted in equation (10). Thus Σ becomes 13,886 m^2

Terminal Falling Velocity of Particles

This terminal falling velocity of particles is calculated as follow:

$$U_0 = Q / \sum$$

Thus, Uo = 0.00024m/hr

Fluid (Centrifugal) Pressure

If the machine is separating solid liquid particles, the fluid pressure is given by:

$$P_f = \frac{\rho_l \times \omega^2 (r_1^2 - r_2^2)}{2}$$

Where, Pf = pressure of fluid, ρl = density of liquid, ω = angular velocity, r_1 and r_2= radius of bowel and liquid surface respectively.

For design case, the maximum fluid pressure will occur when the bowel is full, (r_2= 0).

Again angular velocity; ω = (2πn)/60 (13). Therefore, P_f = 2004.7N/m when the density of the miscella ρ= 756.37Kg/m^3 ω =262 rad/s, bowel radius r_1=0.37m and radius of liquid surface r_2=0m.

Wall Thickness

The maximum allowable wall thickness required can be estimated using the equation

$$E_t = (P_t \times r_1) / F_m \times 10^3 \qquad (7)$$

Where, E_t = wall thickness, P_t = Total Pressure, Fm = design stress

But from table Fm=120N/mm@200℃, thus

Et = 0.0062m =6.2mm and with a corrosion allowance of 2mm ≈ say 8mm, which is perfectly meet the selected design thickness given in table (3). **(8)**

Table 1. Material properties for 316 stainless steal

Density	7870-8070 kg/m3	Endurance limit	256-307MPa
Young's modules	190-205 GPa	Fracture toughness	112-278MPa.$m^{1/2}$
Tensile strength	480-620 MPa	Hardness-Vickers	170-220 HV
Compressive strength	170-310 MPa	Modulus of rupture	170-310MPa
Bulk modules	134-152 GPa	Poisson's ratio (9)	0.265-0.275
Elongation	30-51%	Shape factor	63
Elastic limit	170-310 MPa	Shear modulus	74-82GPa
Design stress at 200^oC = 120N/mm2			
Minimum wall thickness without corrosion allowance, Et = 4mm to 12mm (10)			

Description of the Decanter centrifuge

Solids discharge: Solids/cakes which are sediment inside the bowel discharged due to high rotational speed of the bowel and G-force.

Solids deposited: These are the settled solids forming an annular of 360 degree, shape around the bowel, and being conveyed forward by the scroll at the rate relative to the differential speed. (11)

Liquid discharge: is the liquid discharge end of SBDC, this liquid is sent to the processing plant for further clarifications and treatments.

(12)

Cylindrical section: Dewatering is occurred in this section if necessary.

Beach (conical section): This section is designed to exert additional force on the solids squeezing out the last drops of liquid as we are not only applying centrifugal G-force but also pushing the solids. It is designed to elevate the solids above the waterline into the discharge chamber.

Gearbox: Decanter Centrifuge is equipped with a drive system composed of different motors. The electric motor provides the power required to turn the complete rotating assembly driving the bowel directly and the scroll through the hydraulics.

Formulation of Product

50kg of matured neem seeds were sourced from Unwana in Afikpo North Local Government Area of Ebonyi State, Nigeria and processed in the Department of Food Technology Akanu Ibiam Federal Polytechnic Unwana Afikpo North Local Government Area of Ebonyi State, Nigeria. Sourced Neem seeds were cleaned, dried in the sun and sorted to remove any unwanted material. The dried seeds were shelled and winnowing to obtain clean kernels. The dried sample was then milled by an attrition miller to make it ready for oil extraction. Oil was extracted from the crushed neem kernels by soxhlet extraction method using hexane as the solvent. An organic pesticide was formulated by diluting 0.25ml of neem oil by 20litres of water which can be applied directly on crops by spraying.

Experimental Analysis

The repellency effects of the neem-based bio-pesticide on pests were tested under laboratory conditions. Young uninfected leaves of Pumpkin vegetable, maize, beans, groundnut and Okra were dipped for one minute in solution of each neem-based bio-pesticide and then left to dry at room temperature for 15 minutes. Uninfected leaves of the plants were collected and dipped in tap water to serve as control and used for comparison. The collected leaves were excised and maintained with their abaxial surface facing up in a double glass jar container with a connecting tube and lined on the bottom with moist tissue and covered with a tight lid to avoid early drying of the leaves [22, 24]. 80 adult insects of *Myzus persicae*, *Chilo partellus, Aphis craccivora, Spodoptera frugiperda* and *Popillia japonica* Newman were randomly collected and placed in the jar containing leaves of Pumpkin vegetable, Maize, Beans, groundnut and Okra respectively. The treated and untreated uninfected leaves were place on one side of the air-tight jar while the pests were place on the other side and monitored for six (6). After a 6 day exposure period, the number of insects on dead or alive for both treated and untreated leaves was recorded.

Test for Control of the Pests by the Extracts

The treated leaves and each corresponding pest were placed together in a single transparent plastic container and the death rate daily was observed and recorded for 6 days.

IV. RESULTS AND DISCUSSION

Table 2: Summary of Material Balance

Equipment	Input type	Flow rate (kg/hr)	Output	Flow rate (kg/hr)	Capacity
Pulping	Fresh fruit	1000	Water +flesh	525	1500
	Water	500	Water +seed	975	
Drying	Seed and water	975	Water	25	975
			Seed	950	
Decorticator	Seed	950	Kernel	546.25	950
			Shell	403.75	
Pulverizer	Kernel	546.25	Loss	5.4625	546.25
			Crushed kernel	540.79	
Extractor	Kernel	546.5	Oil	2902.24	2902.24
	Solvent	2361.45	cake		
Centrifuge	Oil and cake	2902.24	Miscella	2556.1	2902.24
			Cake	346.1	
Evaporator	Miscella	2556.1	Oil	350.55	2556.1
			Solvent	2205.55	
Blending	Detergent	175.27	Biopesticide	525.82	525.82
	Oil	350.55			

Table 3: Summary of Sizing of Equipment for the Production of Neem Seed-based Bio-pesticide

Machines	Materials to handle	Density (kg/m^3)	Flow rate (kg/hr)	Temperature (℃)	Volumetric flow rate (m^3/hr)	Operation time (hr)	Volume (m3)	Material of construction
Depulping	Fresh fruit and water	1200	**1500**	25	1.406	8	11.25	Carbon steel
Dryer	Neem seed	1200	975	25	0.8125	8	6.5	Carbon steel
decorticator	Neem seed	1200	950	25	0.779	8	6.33	Carbon steel
Pulverizer	Crushed neem seed	1200	546.25	25	0.46	8	3.64	Carbon steel
Extractor	Slurry (crushed neem seed +solvent)	756.37	2902.24	65	3.84	8	30.7	Stainless steel
Centrifuge	Cak+oil+solvent	756.37	2902.24	65	3.84	8	30.7	Stainless steel
Evaporator	Miscella	890.94	2556.1	65	2.87	8	28.95	Stainless steel
Mixer	Detergent+Oil	846.53	525.35	65	0.62	8	4.96	Carbon steel

Table 4: Insect Pest Repellence of Neem-based bio-pesticide Treated Crop Leaves

Pests	Leaves	Day 1		Day 2		Day 3		Day 4		Day 5		Day 6	
		T	E	T	E	T	E	T	E	T	E	T	E
Myzus persicae	Pumpkin Vegetable	20	5	16	9	18	7	10	15	8	17	5	20
Chilo partellus	Maize	19	6	17	8	15	10	10	15	7	18	4	21
Aphis craccivora	Beans	21	4	18	7	16	9	12	13	9	16	6	19
Spodoptera frugiperda	Groundnut	20	5	14	11	11	14	9	16	7	18	5	20
Popillia japonica Newman	Okra	22	3	19	6	17	8	14	11	10	15	6	19

Table 5: %Migration of Pests from Neem seed-based Bio-pesticidesTreated crop leaves

Insect/Pests	Leaves	Percentage of Insect Pests Migration (%)					
		Day 1	Day 2	Day 3	Day 4	Day 5	Day 6
Myzus persicae	Pumpkin Vegetable	20	36	28	60	68	80
Chilo partellus	Maize	24	32	40	60	72	84
Aphis craccivora	Beans	16	28	36	52	64	76
Spodoptera frugiperda	Groundnut	20	44	56	64	72	80
Popillia japonica Newman	Okra	12	24	32	44	60	76

Table 6: Insect Pest Repellence of Non-Treated Neem-based bio-pesticide Crop Leaves (control)

Pests	Leaves	Day 1		Day 2		Day 3		Day 4		Day 5		Day 6	
		UT	E	UT	E	UT	E	UT	E	UT	E	UT	E
Myzus persicae	Pumpkin Vegetable	25	0	24	1	25	0	23	2	24	1	25	0
Chilo partellus	Maize	24	1	23	2	25	0	21	4	25	0	24	1
Aphis craccivora	Beans	22	3	24	1	24	1	25	0	24	1	23	2
Spodoptera frugiperda	Groundnut	24	1	25	0	25	0	24	1	24	1	23	2
Popillia japonica Newman	Okra	25	0	23	2	21	4	25	0	24	1	25	0

Key: T= treated crop leave; E= without leave; UT = untreated leave (control)

Table 7: Mortality rate of adult insects in Neem-based bio-pesticide Treated Crop Leaves

Insect/Pests	Leaves	Mortality rate in Hours						Total Mortality	Percentage mortality rate (%)
		Day 1	Day 2	Day 3	Day 4	Day 5	Day 6		
Myzus persicae	Pumpkin Vegetable	1	2	3	5	6	5	27	90
Chilo partellus	Maize	0	4	5	6	5	7	27	90
Aphis craccivora	Beans	1	3	4	6	7	7	28	93.3
Spodoptera frugiperda	Groundnut	3	2	4	6	7	6	28	93.3
Popillia japonica Newman	Okra	1	2	6	6	8	7	29	96.7

Discussion

Test of Repellence

The effect of neem seed-based bio-pesticides have many pest control properties such as repelling, mortality, affecting insect growth, fertility, and metamorphosis in addition to direct toxicity and antifeedant and oviposition-deterrent effects [24]. In addition, neem products reduce the fecundity and fertility of adults, and molting of nymphs [25, 26], along with increasing development time of nymphs surviving to adulthood [27]. The present research showed that locally produced neem seed- based bio-pesticide is potentially very effective in the control of *Myzus persicae, Chilo partellus, Aphis craccivora, Spodoptera frugiperda* and *Popillia japonica* Newman being some of the common pests that attack our crops. Table 1 showed that regardless of the treatment given to the individual leaves, the migration of the insects towards the food source (crop leaves) or ovipositing source was highest on day 1 and gradually reduces over time. This migration of the pests can be attributed to natural drive for feeding or depositing of the fertilized eggs on the crops [14]. From day 1, the number of insect pests that found their way back to the untreated part of the double jar glass increased for each of the insect pest and crop leave. For *Myzus persicae* the percentage migration from pumpkin vegetable were 20%, 36%, 28%, 60%, 68%, and 80% for day through 6 respectively*; Chilo partellus* migrated from maize leave in 6 days according in the following order 24%, 32%, 40%, 60%, 72%, and 84% respectively; *Aphis craccivora* percentage migration was 16%, 28%, 36%, 52%, 64%, 76% day 1, day 2, day 3 day 4 day 5 and day 6 respectively, *Spodoptera frugiperda* the percentage migration from pumpkin vegetable were 20%, 44%, 56%, 64%, 72% and 80% for day through 6 respectively and *Popillia japonica* Newman the percentage migration from pumpkin vegetable were 12%, 24%, 32%, 44%, 60% and 76% for day through 6 respectively. The observation is similar to the result reported by [22, 23, 24, 28]. This was different from what was observed from the control as almost all the insect pests migrated to the oviposition and stayed there for the whole period of investigation. In other words the neem oil-based bio-pesticide actively repelled the pests from the crops.

Test of Pest Control

The findings of the study revealed that plant extracts of neem and garlic are effective in controlling insects of crop plants. As reported by [29], the extracts contain *limnoids* such as *azadirachtin*, *salaninmeliantriol* and *nimbin* which are useful bioactive component for insect control. The presence of *Azadirachtin* has a profound effect on insects: at the physiological level, it inhibits the synthesis and release of molting hormones (ecdysteroids) from the prothoracic gland, leading to incomplete ecdysiast in the insects [22]. In adult female insects, *Azadirachtin* causes sterility thus preventing reproduction and multiplication. *Azadirachtin* is also an anti-feedant to many insects while *salannun*and *sodium nimbinate* are repellent and spermicide respectively [29]. From the finding of this research, the produced bio-pesticide was very effective in controlling the pest as the mortality rate of the individual pest was very high after six days of experiment. The neem-based pesticide produced 90%, 90%, 93.3%, 93.3% and 96.7% for *Myzus persicae, Chilo partellus, Aphis craccivora, Spodoptera frugiperda* and *Popillia japonica* Newman, respectively after six days. This effective control of pest by neem-based extract has been reported by [22, 23, 24, 28]. [30, 31, 32, 33, 34, 35, 36] reported the effectiveness of plant extracts in pest control. The use of plants in this way as insecticides not only ensures safety of the environment and consumption of the treated produces, it is reliable, readily available for production by the farmer and economical, especially for the small scaled indigent farmers. All in all, plants of insecticidal potentials are compelling alternative to synthetic pesticides [33, 35, 37]

V. CONCLUSION AND FUTURE SCOPE

Production considerations and recommendations

The difficulty in process development is the translation of laboratory scale techniques to commercial and large scale technology. It is often times assumed that the laboratory production parameters are valid when put on a large scale production. Scaling-up always presents new problems and unforeseen deviations that need to be tackled. In this research, these challenges are seen in performing the necessary mathematical manipulation involved in material handling, choice of equipment and specification of these machines, hence it was tackled. However, this work did not cover all the areas necessary for large scale product like production cost, process quality control and product packaging.

Product Development and Performance Evaluation

The neem seed-based biopesticide was successfully formulated and applied to crop plants. The evaluation repots effectiveness of neem seed oil-based bio-pesticide on different pests attacking our crops in the field. The study reveals that prolong exposure of the insect pests to the formulated pesticide increases efficiency in both repelling and controlling of the pests without any adverse effect on the environment. On the issue of repelling, the study reports about 80% repellence ability of the formulated product on each of the pests tested. While for controlling, the mortality rate of the individual pest was 90%, 90%, 93.3%, 93.3% and 96.7% for *Myzus persicae*, *Chilo partellus*, *Aphis craccivora*, *Spodoptera frugiperda* and *Popillia japonica* Newman, respectively after six days of exposure to neem seed oil-based pesticide treated crop plants.

Thus, this study recommends that:

1. Having shown to be a crop protectant without adverse effect on the ecosystem, farmers should be sensitize on the need to use bio pesticide of plant extracts such as those of neem-based extract for safe and economic preservation of crop and environment.
2. These plant based-insecticides should be made available to farmers so as to avoid the harmful side effect of using synthetic pesticides on both human and the environment.
3. The local mass production of plant based insecticide such as that of neem plant origin should be encouraged to avoid the cost implication of an imported goods since the neem available to us is of high quality.

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