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## Bioefficacy of crude polyherbal formulations against hoppers (Insecta: Hemiptera) of rice

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### Abstract

Bio-efficacy of two crude polyherbal formulations against *Nephotettix virescens*- the Green Leafhopper (GLH) and *Sogatella furcifera*, the White-backed plant hopper (WBPH), major sucking insect pests of paddy was carried out at farmer's field of North Gujarat Zone (GJ-4), Gandhinagar, Gujarat during Kharif 2018. The aqueous and oil-based crude formulations were tested at two different concentrations each, in comparison with chemical, botanical and untreated control. Both the crude formulations were effective in the management of green leafhopper and white backed plant hopper in a dose-dependent manner, however, the aqueous formulation was more efficacious as compared to the oil-based formulation. These herbal formulations are an eco-friendly, cost-effective and safe alternative to chemical control measures for the management of paddy pests and can easily be incorporated in the integrated pest management (IPM) programs for the control of sucking pests in Paddy.

**Keywords:** Rice, *Sogatella furcifera*, *Nephotettix virescens*, herbal formulation, pest control, IPM

### Introduction

Rice (*Oryza sativa* L. Family: Poaceae) – the staple food of over half the worlds' is the most prominent crop of India ranking first in total harvested area and second in production (INDIASTAT, 2018) [18]. It is the staple diet of two-third Indian population fulfilling 21% of energy, 15% of protein and other nutritional requirements like zinc and niacin (Tripathi *et al.*, 2011; Gnanamanickam, 2009) [46, 11]. Rice is the primary source of income for majority of rural households (Mahajan *et al.*, 2017) [22] and its by-products are used in snacks, brewed beverages, oil production, and have medicinal value too. Several abiotic and biotic factors including pests and diseases cause significant loss of rice production (Zibae, 2013) [52]. In India, insect borne damages account to about twenty–five per cent loss of yield (Dhaliwal *et al.*, 2010; Prakash *et al.*, 2014) [8, 33].

*Sogatella furcifera* (Horvath) (White backed plant hopper – WBPH) and *Nephotettix virescens* (Distant) (Green paddy leafhopper, GLH) are the most prevalent and severe rice pests in the tropics and subtropics in Asia (Heinrichs, 1994) [13]. WBPH causes yield losses by decrease in leaf area, plant height, dry weight, leaf and stem nitrogen concentration, chlorophyll contents and photosynthetic rate (Rubia-Sanchez *et al.* 1999, Watanabe and Kitagawa 2000) [41, 50]. "Hopperburn" a typical leaf-drying symptom is caused due to toxic saliva of injected into leaves by adults and nymphs while sucking the sap. Apart from causing significant reduction in 1000 seed weight and increase in the percentage of unfilled grains per panicle (Li *et al.*, 1999) [21], WBPH is also vector of the rice black-streaked dwarf virus (Li *et al.*, 2010) [20] whereas GLH is the vector of tungro, yellow dwarf, yellow-orange leaf, transitory yellowing (CABI, 2020) [17].

Chemical control has been the most preferred insect management strategy owing to its quick knock down effects. Indiscriminate use of chemicals has caused resistance, pest resurgence, biomagnification along with toxicity to non-target organisms, humans and environment (Lengai *et al.* 2020) [19]. Indigenous traditional knowledge (ITK) based pest management is a safe alternative to chemical pesticides (Narayanasamy, 2002) [30]. Plants elicit several defensive responses due to selection pressure from various pests and diseases, producing over 10,000 secondary metabolites and comprise one of the largest pools of naturally available biogenic substances (Arnason *et al.*, 2012) [3]. More than 2,000 plant species have been reported to contain toxins effective against insects (Purkayastha *et al.*, 2016) [35] and are used in botanical control by farmers of the developing countries.

Though several reports of bioefficacy of individual herbal extracts against different insects is available, but, to the best of our knowledge the bioefficacy evaluation of ITK based Polyherbal formulations against rice pests is lacking. The present study was undertaken to fill this lacuna and provide effective, low cost and sustainable solution to the farmers for the management of hoppers in rice.

### Materials and Methods:

The present experiment was conducted at farmer's field in village Alua (23.3482° N and 72.7038° E) Gandhinagar, Gujarat during *khari* 2018. The experiment was conducted in Randomized Complete Block Design, having seven treatments with three replications each.

The soil of this area is well-drained, fertile and sandy clay loam type. Rice variety *GAR-13* was planted with all the recommended agronomic practices of paddy except plant protection for good plant stand. Crude formulations were prepared as per methodologies of Sashidharan *et al.*, (2011)<sup>[43]</sup>, Hossain *et al.*, (2014)<sup>[16]</sup> and Harborne, (1998)<sup>[12]</sup>.

Briefly, for preparation of aqueous formulation, maceration and infusion method was used. 10 per cent fresh leaves each of *Vitex negundo*, *Azadirachta indica*, *Lantana camara*, *Calotropis procera*, *Pongamia pinnata* were macerated and infused overnight in sterile distilled water in 1:10 ratio followed by filtration. To the filtrate, 1% each of Neem oil, Vitex essential oil was added; aqueous fruit extracts of *Sapindus mukorossi* were used as botanical emulsifier and stirred continuously to form a homogeneous aqueous formulation.

The oil-based formulation was prepared using decoction method with Sesame oil as the carrier. Ten per cent fresh macerated leaves each plant were added in sesame oil and the mixture was heated on low flame to infuse the extracts in the oil.

The oil was filtered and 1% each of Neem oil, Vitex essential oil along with aqueous fruit extracts of *Sapindus mukorossi* were added and stirred continuously to form a homogeneous oil formulation. Both the formulations were tested at two doses (10 ml/ L and 20 ml/L) in comparison with standard chemical, botanical and untreated controls.

A total of 3 sprays at 10 days' interval were applied at economic threshold level (ETL) using battery operated Knapsack sprayer. Insect population per hill was recorded from 5 tagged hills per replication per treatment before spray, 5 and 10 days after each spray. All the insect data collected was pooled, subjected to square root transformation and analysis of variance (ANOVA) was done using MS excel ver.2010 (Microsoft, USA) to find significant difference between the means at  $p \leq 0.05$ . The per cent reduction in insect population between the treatments and control was calculated using the Henderson-Tilton's formula (1955)<sup>[14]</sup> as follows:

$$\text{Corrected \%} = \left( 1 - \frac{n \text{ in Co before treatment} * n \text{ in T after treatment}}{n \text{ in Co after treatment} * n \text{ in T before treatment}} \right) * 100$$

Where, n = no of insects; Co = control and T = treatments.

All the data presented in tables and figures as means and SEM

unless otherwise stated. The figures were drawn in MS excel ver.2010 (Microsoft, USA).

**Results:** The crude Polyherbal formulations were found to be effective in the management of both *Sogatella furcifera* (WBPH) and *Nephotettix virescens* (GLH) infesting rice crop when compared with the untreated control in a dose dependent manner.

**Bio-efficacy of against *Sogatella furcifera* (WBPH):** The differences in population of White backed plant hopper recorded before spraying during the first spray was found to be non-significant among various treatments ranging between 20.27 to 29.07 WBPH/hill (SEM  $\pm$  0.27), which indicated that the initial infestation of WBPH across the experiment was homogenous (Table 1).

Both the aqueous and oil-based Polyherbal formulations controlled the WBPH in all the three sprays causing a significant reduction in populations at 5 and 10 days after treatments (Table 1).

The aqueous formulation at 20 ml/L (T4) was found significantly superior in all the three sprays with 63.8, 83.8 and 96.5 per cent reduction of WBPH population during first, second and third sprays respectively; with an overall cumulative reduction of 81.4 per cent when compared with untreated control (Table 1; Fig 1).

The aqueous formulation at dose 10 ml/L (T3) recorded an overall pooled control of 61.1% with 36.3%, 59.5% and 87.1 per cent reduction in WBPH populations over untreated control during first, second and third sprays respectively (Table 1, Fig. 1)

The oil-based formulation (T2) at 20ml/L resulted in 57.5%, 73.3% and 93.8 per cent control of WBPH populations during first, second and third sprays with 74.9 per cent overall reduction as compared to control in all the three sprays (Table1, Fig.1) whereas in treatment T1 at 10 ml/L doses, there was 38.9, 60.9 and 90.0 per cent reduction in WBPH populations during first, second and third sprays respectively with 63.3 per cent cumulative reduction in population as compared to untreated control (Table 1, Fig 1).

A significant reduction of WBPH population was recorded in Chemical control (T6) with the per cent reduction of WBPH population over untreated control was 73.4%, 94.3% and 98.9% during first, second and third spray respectively and the cumulative per cent reduction over control of 88.9 per cent; whereas the overall pooled efficacy of botanical control (T5) was 55.6 per cent as compared to untreated control with 20.2%, 56.7% and 89.8 per cent reduction of WBPH population during the first, second and third sprays respectively (Table 1, fig. 1).

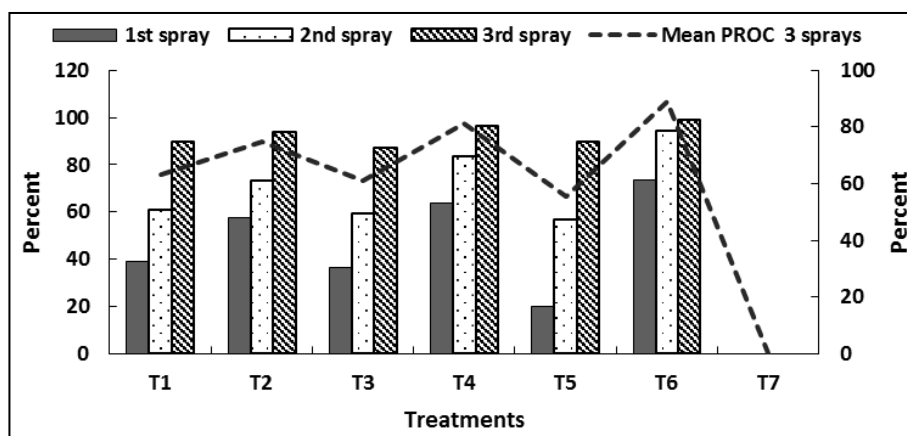
Also, both the formulations were found to be more effective than the botanical control (T5) at all the doses tested. There was a gradual decline in WBPH population after 5<sup>th</sup> and 10<sup>th</sup> days, showing a persistent efficacy across the test period. The overall pooled bioefficacy of against WBPH recorded is as follows: Chemical control (T6) > Aqueous formulation @20ml/L (T4) > Oil-based formulation @20ml/L (T2) > Oil-based formulation @10ml/L (T1) > Aqueous formulation @10ml/L (T3) > Botanical control (T5) > Untreated control.

**Table 1:** Bioefficacy of crude Polyherbal formulation against White backed plant hopper (WBPH) of rice under field conditions.

Tr. No.	First spray				Proc	Second spray				Proc	Third spray				PROC	#Overall Pooled WBPH/ hill	Cumulative PROC of 3 sprays (%)
	Mean WBPH population/hill*					Mean WBPH population/hill*					Mean WBPH population/hill*						
	1 DBS	5 DAS	10 DAS	Pooled		1 DBS	5 DAS	10 DAS	Pooled		1 DBS	5 DAS	10 DAS	Pooled			
T <sub>1</sub>	4.93 (24.3)**	4.40 (18.9)	3.01 (8.7)	3.70 (13.8)	38.9	3.01 (8.7)	2.66 (6.7)	2.17 (4.3)	2.41 (5.5)	60.9	2.17 (4.3)	1.47 (1.7)	1.44 (1.6)	1.46 (1.6)	90.0	2.52 (6.9)	63.3
T <sub>2</sub>	4.86 (23.2)	3.65 (12.9)	2.58 (6.3)	3.12 (9.6)	57.5	2.58 (6.3)	2.35 (5.1)	1.68 (2.3)	2.01 (3.7)	73.3	1.68 (2.3)	1.25 (1.1)	1.19 (0.9)	1.22 (1.0)	93.8	2.12 (4.8)	74.9
T <sub>3</sub>	4.94 (24.2)	4.44 (19.5)	3.02 (9.1)	3.73 (14.3)	36.6	3.02 (9.1)	2.55 (6.5)	2.25 (4.9)	2.40 (5.7)	59.5	2.25 (4.9)	1.61 (2.20)	1.58 (2.0)	1.59 (2.1)	87.1	2.57 (7.4)	61.1
T <sub>4</sub>	4.56 (20.3)	3.45 (11.7)	2.22 (4.7)	2.84 (8.2)	63.8	2.22 (4.7)	1.89 (3.1)	1.37 (1.4)	1.63 (2.3)	83.8	1.37 (1.4)	1.11 (0.7)	0.94 (0.4)	1.03 (0.6)	96.5	1.83 (3.7)	81.4
T <sub>5</sub>	5.43 (29.1)	5.10 (27.9)	2.87 (8.1)	3.98 (18.0)	20.2	2.87 (8.1)	2.74 (7.2)	2.32 (4.9)	2.53 (6.1)	56.7	2.32 (4.9)	1.54 (1.9)	1.40 (1.5)	1.47 (1.7)	89.8	2.66 (8.6)	55.6
T <sub>6</sub>	4.83 (23.4)	3.07 (9.1)	1.77 (2.9)	2.42 (6.0)	73.4	1.77 (2.9)	1.21 (1.0)	1.05 (0.6)	1.13 (0.8)	94.3	1.05 (0.6)	0.84 (0.2)	0.79 (0.1)	0.82 (0.7)	98.9	1.45 (2.3)	88.9
T <sub>7</sub>	4.97 (24.8)	5.11 (25.9)	4.37 (19.3)	4.74 (22.6)	-	4.37 (19.3)	4.08 (16.6)	3.34 (11.4)	3.71 (14.0)	-	3.34 (11.4)	4.00 (15.6)	4.19 (17.1)	4.09 (16.3)	-	4.18 (17.6)	-
S.Em ±	0.27	0.38	0.13	0.22	-	0.13	0.20	0.24	0.15	-	0.24	0.13	0.08	0.08	-	0.12	
CD (0.05)	NS	1.17	0.39	0.64	-	0.39	0.60	0.74	0.44	-	0.74	0.40	0.25	0.22	-	0.33	
S.Em (P X T)	-	-	-	0.31	-	-	-	-	0.21	-	-	-	-	0.11	-	0.16	
CD (P X T)	-	-	-	NS	-	-	-	-	NS	-	-	-	-	NS	-	NS	
S.Em (S X P X T)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.29	
CD (S X P X T)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	NS	
CV %	9.58	15.74	7.65	15.49	-	7.65	13.55	20.47	16.4	-	20.47	13.17	8.49	11.06	-	19.97	

T<sub>1</sub>- Oil based extracts (X dose) 10 ml/L, T<sub>2</sub>- Oil based extracts (2X dose) 20 ml/L, T<sub>3</sub>- Aqueous extracts (X dose) 10 ml/L, T<sub>4</sub>- Aqueous extracts (2X dose) 20 ml/L, T<sub>5</sub>- Botanical control (Neem oil 3 ml/L), T<sub>6</sub>- Chemical control (Imidacloprid 17.8% SL) @ 0.3 ml/L, T<sub>7</sub>- Control Check (Water spray)

DBS: Day before spray; DAS: Days after spray PROC: percent reduction over control; \*Mean of three replications, \*\*Figure in parentheses are retransformed values, those outside parentheses are  $\sqrt{\quad}$  (Square root) Transformed values; #Pooled of all three sprays,

**Fig 1:** Bioefficacy of crude polyherbal formulations on population of Whitebacked plant hopper (WBPH) under field conditions

**Bio-efficacy against *Nephotettix virescens* (GLH):** The differences in population of GLH recorded before spray was during first, second and third spray was also found to be non-significant among different treatments reflecting uniform infestation of GLH during the experiment. In case of Polyherbal formulations, T<sub>4</sub>, the aqueous formulation at dose of 20ml/L was found to be significantly superior in reducing GLH population during all the three sprays at both fifth and tenth days after spray recording 55.6%, 77.2% and 86.5 per cent population reduction during first, second and third spray respectively with an overall pooled per cent reduction of 73.1% when compared with untreated control. (Table 2, Fig. 2). At the lower dose of 10 ml/L (T<sub>3</sub>), the per cent reduction

in GLH population as compared to control was 27.1%, 60.6% and 65.8 per cent respectively during first, second and third sprays respectively. The overall cumulative per cent reduction in GLH population as compared to untreated control was 73.1 per cent (Table 2; Fig 2).

The oil-based formulation at dose 10ml/L (T<sub>1</sub>) reported a significant 27.9%, 58.3% and 72.3 per cent population reduction as compared to untreated control during first, second and third sprays respectively with 52.8 per cent overall reduction as compared to untreated control (Table 2, Fig 2) whereas at the dose 20 ml/L (T<sub>2</sub>) the per cent reduction in GLH population increased with the increase in dose recording 47.6%, 70.1% and 78.1 per cent reduction during first, second

and third sprays respectively with 65.2% overall cumulative reduction over control (Table 2, Fig. 2).

The chemical control (T6) caused a significant reduction in GLH populations with 72.9%, 96.6% and 93.6 per cent during first, second and third sprays respectively with an overall reduction of 87.8 per cent as compared to untreated control. The botanical control (T5) recorded 38.6%, 48.8% and 50.3 per cent GLH reduction in first second and third sprays producing a cumulative reduction of 45.9 per cent as compared to untreated control (Table 2, Fig. 2). All the

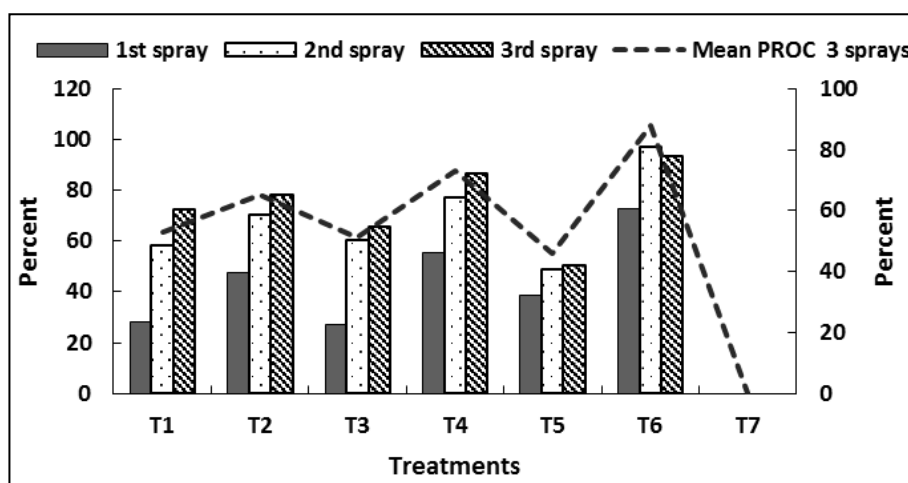
treatments were found effective in reduce the population of GLH as compared to untreated control. Similar to the efficacy against WBPH, the formulations were more effective against the botanical control against GLH also showing persistent efficacy under field conditions. The comparative efficacy of all the treatments against GLH follows the same trend as in WBPH as - Chemical control (T6) > Aqueous formulation @20ml/L (T4) > Oil-based formulation @20ml/L (T2) > Oil-based formulation @10ml/L (T1) > Aqueous formulation @10ml/L (T3) > Botanical control (T5) > Untreated control.

**Table 2:** Bioefficacy of crude Polyherbal formulations against Green leaf hopper (GLH) in rice under field conditions.

Tr. no.	First spray					Second spray					Third spray					#Overall Pooled WBPH/ hill	Cumulative PROC of 3 sprays (%)
	Mean GLH population/hill*				Proc	Mean GLH population/hill*				Proc	Mean GLH population/hill*				Proc		
	1 DBS	5 DAS	10 DAS	Pooled		1 DBS	5 DAS	10 DAS	Pooled		1 DBS	5 DAS	10 DAS	Pooled			
T <sub>1</sub>	3.03 (8.7)**	3.23 (9.9)	2.32 (5.0)	2.77 (7.5)	27.9	2.32 (5.0)	2.16 (4.2)	1.82 (2.9)	1.99 (3.5)	58.3	1.82 (2.9)	1.45 (1.6)	1.33 (1.3)	1.39 (1.4)	72.3	2.05 (4.1)	52.8
T <sub>2</sub>	3.40 (11.1)	2.76 (7.1)	2.06 (3.7)	2.41 (5.4)	47.6	2.06 (3.7)	2.00 (3.5)	1.42 (1.5)	1.71 (2.5)	70.1	1.42 (1.5)	1.32 (1.3)	1.19 (0.9)	1.25 (1.1)	78.1	1.79 (3.0)	65.2
T <sub>3</sub>	2.98 (8.5)	3.10 (9.3)	2.50 (5.8)	2.80 (7.6)	27.0	2.50 (5.8)	2.02 (3.7)	1.85 (3.0)	1.93 (3.3)	60.6	1.85 (3.0)	1.60 (2.1)	1.40 (1.5)	1.50 (1.8)	65.8	2.08 (4.2)	51.1
T <sub>4</sub>	3.29 (10.4)	2.67 (6.9)	1.65 (2.3)	2.16 (4.6)	55.6	1.65 (2.3)	1.78 (2.7)	1.27 (1.1)	1.52 (1.9)	77.2	1.27 (1.1)	1.14 (0.8)	1.05 (0.6)	1.09 (0.7)	86.5	1.59 (2.4)	73.1
T <sub>5</sub>	3.05 (8.9)	2.89 (7.9)	2.29 (4.8)	2.59 (6.4)	38.6	2.29 (4.8)	2.41 (5.4)	1.93 (3.3)	2.17 (4.3)	48.8	1.93 (3.3)	2.00 (3.8)	1.33 (1.3)	1.66 (2.6)	50.3	2.14 (4.4)	45.9
T <sub>6</sub>	2.94 (8.2)	2.25 (4.7)	1.16 (0.9)	1.71 (2.8)	72.9	1.16 (0.9)	0.91 (0.3)	0.83 (0.2)	0.87 (0.3)	96.9	0.83 (0.2)	0.83 (0.2)	0.98 (0.5)	0.91 (0.3)	93.6	1.16 (1.1)	87.9
T <sub>7</sub>	3.26 (10.1)	3.34 (10.7)	3.25 (10.1)	3.29 (10.4)	-	3.25 (10.1)	3.16 (9.6)	2.79 (7.3)	2.97 (8.5)	-	2.79 (7.3)	2.43 (5.5)	2.32 (4.9)	2.37 (5.2)	-	2.88 (8.0)	-
SEm ±	0.12	0.12	0.10	0.12	-	0.10	0.11	0.12	0.09	-	0.12	0.18	0.10	0.10	-	0.07	
CD (0.05)	NS	0.38	0.30	0.35	-	0.30	0.34	0.37	0.27	-	0.37	0.55	0.30	0.30	-	0.19	
SEm (P X T)	-	-	-	0.17	-	-	-	-	0.13	-	-	-	-	0.15	-	0.10	
CD (P X T)	-	-	-	NS	-	-	-	-	NS	-	-	-	-	NS	-	NS	
S. Em (S X P X T)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.17	
CD (S X P X T)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	NS	
CV %	6.53	7.41	7.75	11.66	-	7.75	9.30	12.06	12.09	-	12.06	20.23	12.45	17.27	-	14.68	

T<sub>1</sub>- Oil based extracts (X dose) 10 ml/L, T<sub>2</sub>- Oil based extracts (2X dose) 20 ml/L, T<sub>3</sub>- Aqueous extracts (X dose) 10 ml/L, T<sub>4</sub>- Aqueous extracts (2X dose) 20 ml/L, T<sub>5</sub>- Botanical control (Neem oil 3 ml/L), T<sub>6</sub>- Chemical control (Imidacloprid 17.8% SL) @ 0.3 ml/L, T<sub>7</sub>- Control Check (Water spray)

DBS: Day before spray; DAS: Days after spray PROC: percent reduction over control; \*Mean of three replications, \*\*Figure in parentheses are retransformed values, those outside parentheses are  $\sqrt{\quad}$  (Square root) Transformed values; #Pooled of all three spray



**Fig 2:** Bioefficacy of crude polyherbal formulations on population of Green paddy leafhopper (GLH) under field conditions

**Discussion**

All the treatments effectively reduced both WBPH and GLH incidence as compared to untreated control. Among the two Polyherbal formulations tested, the aqueous formulation was more efficacious than the oil-based formulation, both exerting

effects in a dose-dependent manner. It was also observed that the both the Polyherbal formulations were superior to neem-based commercial botanical control throughout the trial. In the present study, the Polyherbal aqueous formulations were found to be effective against both the major sucking



pests of rice, the efficacy comparable to the standard chemical control. Only a few reports of Polyherbal formulations have been reported for the control of rice pests under field conditions. Some reports of mosquito repellent and medico-veterinary pest control formulations are available; however, none of the reports was congruent with plant combination used in the present study. Ravichandra *et al.*, (2014) [39] reported the efficacy of aqueous extracts of *Pongamia pinnata*, *Acorus calamus*, Garlic and Chilli extract in comparison with commercial neem products and Buprofezin against the WBPH and BPH while Rajappan *et al.*, (2000) [36] reported the efficacy of leaf extracts of *Vitex negundo*, *Synadenium grandii*, *Prosopis juliflora* and neem cake extracts against the GLH. Sankari and Narayanasamy (2007) [42], studied the bioefficacy of flyash (FA)-based herbal pesticides of *Curcuma longa*, Neem seed kernel, *Vitex negundo* and *Ocimum* sp. against various rice and vegetable pests and reported the successful control at 10% composition. Prabhakaran *et al.*, (2017) [32] demonstrated the synergistic molluscicidal effect of crude extracts of *Nerium indicum*, *Nicotiana tabacum*, *Piper nigrum*, and *Azadirachta indica* and the combinations of extracts in binary and tri-herbal combinations against the invasive rice pest (*Pomacea maculata*). Arivudainambi *et al.*, (2010) [2] evaluated the bioefficacy of extracts of *Cleistanthus collinus*, *Cleome viscosa*, *Gynandropsis pentaphylla*, and *Andrographis paniculata* in comparison with a commercial formulation of neem and the insecticide Endosulfan under field conditions against amaranth leaf caterpillar (*Hymenia recurvalis*) and reported that the extracts at 7-day application interval, successfully reduced populations of *H. recurvalis* in Amaranth.

Uppala *et al.*, (2017) [47] had reported that the results of Polyherbal formulation based ointment made from extracts of *Annona squamosa*, *Azadirachta indica*, *Eucalyptus alba*, *Citrus aurantium* and *Rosa indica* were at par with the standard commercially available Odomos® against mosquitoes. Similar polyherbal liquid formulation using essential oils of *Curcuma longa*, *Zanthoxylum limonella* and *Pogostemon heyneanus* were evaluated for the repellent activity against medically important blackflies- *Simulium* sp. under field conditions by Dhiman *et al.*, (2012) [9] while Nayak (2015) [31] reported the effects of polyherbal formulation made from extracts of *Sphaeranthus indicus*, *Piper betel*, *Trachyspermum ammi*, *Cymbopogon citratus* and tested against *Anopheles stephensi* and *Culex quinquefasciatus*. The superior efficacy of aqueous formulation over the oil formulation in the present study may be because there might be a loss of some heat-labile active ingredients during the formulation preparation using the decoction method (Mohan *et al.*, 2008) [29] as thermal treatments and increasing extraction temperatures are the main cause of reduction or decomposition of natural antioxidants and active ingredients of the plants (Hossain *et al.*, 2013) [15].

Several plants and/or plant extracts have been reported for their insecticidal activities against the WBPH and GLH. Sujeetha (2008) [45] evaluated the effects of several plant extracts including the neem seed kernel extract (NSKE) (5%), neem oil (3%), neem leaf extract (3%) along with *Vitex negundo* leaf extract (3%), *Catharanthus roseus* (3%), *Cymbopogon maurtini* oil, *Jatropha carcus* oil with recommended chemical controls against White Backed planthopper (WBPH) and reported the detrimental effects of

NSKE and plant extracts on survival, development time and growth index of WBPH. Similar effects of Neem-based products and extracts have also been reported in the studies of David, 1986; Rajasekaran *et al.*, 1987; Mohan and Gopalan, 1990 [7, 37, 28]. Owing to their combined antifeedant, IGR and toxic effects, Neem oil, neem based products (Mariappan *et al.*, 1982; Mariappan and Saxena, 1983; Mariappan *et al.*, 1988) [26, 27, 25] and extracts of *Vitex negundo* (Rajappan *et al.*, 2000; Mahapatra *et al.*, 2009) [36, 23], *Pongamia pinnata* & *Calotropis* sp. (Prakash *et al.*, 2008) [34] were also found to be effective in the management of GLH in rice. Xianying *et al* (2014) [51] reported the repellent action of volatiles from twenty non-host plants including *Lantana camara* against the Brown plant hopper-*Nilaparvata lugens* an important sucking pest of rice. Insect protectant activities of Lantana extracts have also been reported by Rajashekar *et al.* (2012) [38], Baidoo and Adam (2012) [5] and Ayalew (2020) [4]. The prolonged effects of Polyherbal formulations against WBPH and GLH reported in the present study are in line with Reddy *et al.*, (2012) [40] who reported the aqueous extracts of leaves of *Vitex negundo*, *Pongamia pinnata*, *Annona squamosa* and *Calotropis procera* reduced plant hoppers infesting paddy 7 days' post-treatment.

The use of plant-based natural emulsifiers, surfactants and carriers, owing to their multiple actions, result either in potentiating, additive, agonistic or synergistic action when combined with plant extracts. *Sapindus mukorossi* (Reetha) has adsorption kinetics and wetting behaviour and works as a plant-based natural surfactant (Walia *et al.*, 2017) [49] apart from being reported for its insecticidal properties alone against *Sitophilus oryzae* and *Pediculus humanus* (Suhagia *et al.*, 2011) [44] or in combination with other plant extracts (Dubey *et al.*, 1991) [10]. Sesame oil extracted from seeds of *Sesamum indicum* is rich in lignans - Sesamin and Sesamol and is reported for its synergistic and insecticidal action (Baker and Grant, 2018) [6]. The biological and physiological effects of sesame oil against *Spodoptera littoralis* was reported by Marei *et al.*, 2009 [24] while Visetson *et al.*, (2003) [48] reported the good synergism of sesame oil with Cypermethrin against larval population in Chinese kale in both field and laboratory conditions. The oviposition deterrent and larvicidal properties of Sesame and Neem oil against the stored insect pest of beans - *Callosobruchus chinensis* were reported by Ahmed *et al.*, (1999) [1]. The synergistic and/or agonist effects of different plant extracts together with the surfactants and carriers are responsible for the superior effects of both Polyherbal formulations over the standard neem oil product used as botanical control in the present study.

## Conclusions

The present study reports the effective control of *Sogatella furcifera* (WBPH) and *Nephotettix virescens* (GLH) by the crude Polyherbal formulations in a dose-dependent manner. Among the two, the aqueous extract was superior in control of both WBPH and GLH as compared to the oil-based formulation. A gradual increase in their efficacy spread across each consecutive spray and results comparable to chemical control were observed. It was also interesting that both the formulations were superior to the neem-based botanical owing to their cumulative effects. Plant-based Polyherbal formulations, due to the presence of a concoction of active ingredients, exert their potentiating effect on multiple metabolic pathways resulting in an array of detrimental effects on survival, growth and reproduction of insect pests

without causing resistance and resurgence. The widespread use of these formulations through social dissemination channels will not only reduce the total cost of cultivation but will also provide a low-cost, easily available and eco-friendly product to the farmers. Being safe and eco-friendly, with minimal impact on the ecosystem and human health, mass adoption of such technologies in IPM programs is strongly warranted.

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