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APPLICATION OF STATISTICAL MODEL TO DETERMINE THE EFFECTIVENESS OF PLANT EXTRACT ON THE MORTALITY OF TEA THRIPS

Abul Kalam Azad*, Iftekhar Ahmad, GM Rabiul Islam and A Mainuddin[1]

Department of Food Engineering and Tea Technology, Shahjalal University of Science and Technology, Sylhet-3114, Bangladesh

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Abstract

Bioactive chemicals found in medicinal plant extracts aid in the mitigation, eradication and cure of diseases of living animals and plants. In the quest for novel medicinally significant plants, the current article focuses on determining the most successful and promising plants for suppressing tea leaf thrips (*Scirtothrips bispinosus*) through applying statistical model. 22 medicinal plants extraction had been used to achieve the stated goals of the study. Plant extract solutions were dissolved in their respective solvents at varied concentrations for the assessment of entomopathogenic activity, namely 1, 5, 10 and 15%. According to the Translog stochastic frontier model, the level of solution concentration has had a substantial negative influence on the mortality of tea thrips, with thrips mortality increasing dramatically as the concentration level was decreased. The technical effectiveness of the mortality showed that plant extracts and their related features were over 98 percent effective in controlling tea thrips, as opposed to chemicals and pesticides.

Introduction

Tea, technically known as *Camellia sinensis L*., is the world's most popular and cost-effective beverage, manufactured in more than 40 countries. Tea plant young shoots are used to make this beverage. Tea plants, particularly young shoots, are attacked by a variety of insects, mites, nematodes, fungal diseases, and weeds, resulting in significant economic losses for tea-producing countries. *Scirtothrips bispinosus*, sometimes known as the tea thrips, is a prominent and dangerous tea pest in Southeast Asian and African countries. In Bangladesh, insect infestations in tea cause annual output losses of 10-15 percent (Mamun *et al.* 2016). Several micro-floras, such as *Colletotricum gloeosporioides, C. camelliae, Corticium theae, Fusarium oxysporum, Macrophoma theicola, Pestalotia theae, Ustulina zonata, Phomopsis theae,* and others, thrive in the tea ecosystem and infect plants when predisposing circumstances become suitable (Sana 1989, Alam 2003). Twenty-five bug species, 4 mite species, and 10 nematode species have been identified in Bangladesh tea (Ahmed 2005).

Since 1960, pesticides such as organochlorine, organophosphate, pyrethroids, carbamates, and certain unidentified groups have been employed in tea plantations to fight these problems. A long time used chemical pesticides have significant downsides because of the increasing awareness of adverse effects of synthetic pesticide on human and animal healt (Sharaby 1988, Hagstrum and Athanassiou 2019, and Zhou *et al.* 2019), including direct toxicity to beneficial insects, fish, and humans, pesticide-induced resistance, health hazards (Bhaduri *et al.* 1989), and increasing environmental and societal costs (Pimental *et al.* 1980). Because tea is a consumable product, pesticide residue in produced tea is detrimental to human health. Biopesticides are becoming more popular as an alternative to chemical pesticides (Paul *et al.* 2014). Plant extracts (botanicals) and

*Author for correspondence: <akazadt68@gmail.com>. [1]Bangladesh Tea Research Institute, Moulvibazar, Sylhet, Bangladesh.

nematopathogenic organisms (microbials) are the major sources of biopesticides. They are biodegradable, cost-effective, and may be prepared locally (Radhakrishna 2010, Akpheokhai *et al.* 2012, Taye *et al.* 2012). Botanicals such as Bonkalmi, Bazna, Bishkatali, Datura, Durba, Eucalyptus, Ghora-neem, Hijal, Karanja, Mahogoni, Marigold, Neem, Nishinda, Pithraj, and many more may be produced and extracted by farmers using traditional techniques (Mamun *et al.* 2009). These natural insecticides can be used instead of chemical pesticides.

Keeping in mind, the present study was aimed to determine the efficiency of various native medicinal plant extracts in controlling tea thrips based on thrips death rates as a function of time and concentration.

Materials and Methods

Tea leaves infested with thrips named *Scirtothrips bispinosus* functioned as the prime basis for this research. Afterwards, the thrips-infected tea leaves were subjected to the laboratory examination under the proper regulation of semi *in vitro* application which permitted the application of plant extracts to the damaged leaves without regard for temperature, weather, or air quality factors. Studies involving microbes, cells, or biological molecules are carried out *in vitro* (Latin for "in glass" or "in the glass"), away from their natural biological setting. These investigations in biology and related subfields are sometimes referred to as "test-tube experiments," and they are often carried out in labware such test tubes, flasks, Petri dishes, and microtiter plates. Studies that use isolated organismal parts from their natural biological environments provide a more thorough or practical investigation than is possible with complete organisms.

Tea leaves infected with thrips were collected from the different tea gardens in Sylhet division of Bangladesh, including Habibnagar Tea Estate, Khan Tea Estate, Baraoora Tea Estate, and Aminabad Tea Estate. To begin, thrips-affected tea clones (Fig.1) were discovered in distinct blocks of each tea garden and then collected individually. They were then placed in glass jars and capped with tissue paper to allow for appropriate air circulation before being transferred to the laboratory for the application of plant extract.

On the other hand, a total of 22 medicinal plants were collected from various regions of Sylhet and across the country (Table 1). However, the *in-vitro* laboratory application was conducted in the Food Engineering and Tea Technology department of Shahjalal University of Science and Technology, Sylhet, Bangladesh.

With the help of suitable attachments including washing, drying, blending, smashing, and finally preserving in airtight condition in plastic container as per Amadioha and Obi (1999), plant extracts were prepared for initial stage. Next 10g dust of the first extract was placed in a 250ml conical flux and mixed individually with 100 ml of solvents such as distilled water or 50% ethanol. A magnetic stirrer (at 6000 rpm) was used to agitate the mixture for 30 min and then allowed to stand for 48 hrs. The mixture was then filtered through Whatman No.1 filter paper, and the extracts were stored in tightly corked, labeled bottles, e.g., 50ml volumetric flux, and then refrigerated until used for entomopathogenic activity. For the investigation of entomopathogenic activity, the final stock solutions of plant extracts were dissolved in their respective solvents at different percentage of solution concentrations namely 1, 5, 10 and 15%.

The sampling procedure in the present study was involved a plethora of challenges depending on the assembling of numerous issues which were the number of affected leaves, number of species of medicinal plants, concentration level of plant extracts, and the time limit to death affect. Due to the uneven number of observations obtained from various tea clones and observable time limit to death effect, the exact number of samples cannot be estimated. However, 33 samples were created at each solution concentration level, and four distinct solution concentration levels (1, 5, 10, and 15%) were prepared for *in vitro* application, totaling 132 samples for analysis. Each technique was repeated or reproduced three times in order to determine the variability in the thrips control management. As a result, the total sample size in the semi *in vitro* approach was increased to 396.

Table 1. Description of collected medicinal plants in the study.

No.	Scientific name	Family	Common name	Local name
01	*Polygonum hydropiper*	Polygonaceae	Marsh pipper	Panimarich
02	*Persicaria flaccida*	Polygonaceae	Water pipper	Lal Biskatali
03	*Monochoria hastata*	Pontederiaceae	Arrow leaf pondweed	Pondweed
04	*Sepium indicum*	Euphorbiaceae	Kiri Makulu	Batul
05	*Anona reticulata*	Annonaceae	Custard Apple	Bullock's heart
06	*Ipomoea crassicaulis*	Convolvulaceae	Dud kolmi	Morning Glory
07	*Ipomoea hederaceaa*	Convolvulaceae	Nil kolmi	Morning glory
08	*Lantana camara*	Verbenaceae	Lantana weed	Gu Phul
09	*Glycosmis arborea*	Rutaceae	Orangeberry	Chagol ladi
10	*Justicia gendarussa*	Acanthaceae	Gardarusa	Jagat Modon
11	*Monochoria vaginalis*	Pontederiaceae	Pickerel weed	Pickerel weed
12	*Cassia alata*	Caesalpiniaceae	Candle bush	Dadmordon
13	*Nerium odoratum*	Apocynaceae	Oleander	Rakto korobi
14	*Annona squamosa*	Annonaceae	Sugar apple	Sharifa
15	*Mikania cordata*	Asteraceae	Refuji lota	Assam lota
16	*Linderina procumbens*	Lindernaceae	Malayasian pimpernel	Khet papra
17	*Cephalandra indica*	Cucurbitaceae	Lvy Gourd	Kovai
18	*Argemone mexicana*	Papaveraceae	Mexican coppy	Mexican coppy
19	*Lipia germinata*	Verbenaceae	Pitoniana	Motmotia ful
20	*Setaria viridis*	Poaceae	Green foxtail	Green bristlegrass
21	*Cassia tora*	Fabaceae	Soru-medelua	Chakunda
22	*Croton bonplandianum*	Euphorbiaceae	Ban Tulshi	Bon Tulshi

According to the research design, the response variable of interest is the number of tea thrips that died after exposing plant extracts in semi *in-vitro* application. The exposure variables employed in this study, on the other hand, are associated with the tea thrips infestation, plant extracts mechanism, and laboratory experiment that might have potential influence in the mortality of tea thrips. However, the exposure variables of interest include, according to the design, the species or variety of medicinal plants, the components used in extract preparation, the thrips infested tea clones, the level of solution concentration, and the time limit when death occurred. Additionally, because the laboratory experiment was conducted utilizing an *in vitro* approach and the samples were collected from various places within the Sylhet division. Therefore weather and climate related variables may have a nonnegligible effect on thrips control management. Thus, this study offers a framework for addressing weather and climate-related factors when estimating the effectiveness of plant extracts for thrips control management in tea utilizing inefficiency effects model (Battesi and Coelli 1995).

Data presented in Table 2 were analyzed using descriptive statistics to explore the study variables. Except for the technical inefficiency variables such as temperature, relative humidity, rainfall, and soil moisture, all of the study variables were required to be in natural logarithmic form because of the combination of the variables and the model. In addition to theoretical normality measurements such as skewness and kurtosis, the model variables have good measures of location (minimum, maximum, and mean) and dispersion (standard deviation). Because the variables are in natural logarithmic form, almost all of them are expected to have a normal distribution; however, asymmetry and kurtosis values between -2 and +2 are considered acceptable for the normal distribution (George and Mallery 2010, Khan 2015).

Table 2. Descriptive statistics variables based on the production frontier model.

Variables	Minimum	Maximum	Mean	SD	Skewness	Kurtosis
Dependent variable						
Mortality of thrips	0	2.079	0.568	0.570	0.414	-1.097
Independent variables						
Variety of plants	0	3.091	2.023	0.859	-0.778	-0.269
Parts of plants	0	1.609	0.565	0.609	0.302	-1.636
Tea clone	0	2.398	1.593	0.638	-0.936	-0.017
Concentration	0	2.708	1.655	1.034	-0.704	-1.043
Time to death affect	0	3.178	2.627	0.648	-1.453	2.001
Variety of plants squared	0	9.555	4.828	3.006	-0.078	-1.354
Parts of plants squared	0	2.590	0.690	0.824	0.817	-0.517
Tea clone squared	0	5.750	2.943	1.708	-0.314	-1.422
Concentration squared	0	7.334	3.806	2.771	-0.115	-1.419
Time to death affect squared	0	10.100	7.321	2.857	-0.782	-0.494
Variety of plants × Parts of plants	0	2.280	0.552	0.655	0.810	-0.425
Variety of plants × Tea clone	0	3.706	1.569	0.971	0.074	-0.916
Variety of plants × Concentration	0	4.185	1.674	1.340	0.078	-1.281
Variety of plants × Time to death affect	0	4.912	2.812	1.456	-0.506	-1.009
Parts of plants × Tea clone	0	1.768	0.471	0.551	0.622	-1.120
Parts of plants × Concentration	0	2.179	0.468	0.663	0.957	-0.603
Parts of plants × Time to death affect	0	2.557	0.723	0.830	0.543	-1.246
Tea clone × Concentration	0	3.247	1.318	1.033	0.005	-1.334
Tea clone × Time to death affect	0	3.810	2.066	0.993	-0.352	-0.763
Concentration × Time to death affect	0	4.303	2.045	1.392	-0.379	-1.240
Technical inefficiency variables						
Temperature	19.230	28.160	25.922	2.096	-1.827	3.739
Relative humidity	68.120	93.690	84.644	6.598	-0.965	0.135
Rainfall	0	85.200	28.264	25.755	0.613	-0.823
Soil wetness	0.590	1.000	0.852	0.125	-0.807	-0.467

While the literature reveals a variety of methods for measuring technical efficiency in this regard, Battese and Coelli's (1996) theory successfully satisfies the objective. As a result, this study used a stochastic frontier analysis model using the Frontier (version 4.1) computer program

(Coelli 1996) to measure the technical efficiency of thrips mortality caused by exposing plant extract in *in-vitro* application. Indirect goal of the present study was to maximize tea thrips mortality through administering plant extract, to focus on the production/performance frontier rather than the cost frontier. However, various assumptions must be reviewed prior to adopting the production model, including the model's functional form and the significance of inefficiency effects. Stochastic frontier production functions can be expressed in a variety of functional forms, the most prominent of which are Cobb-Douglas, constant return to scale, and Trans-log functions.

To begin, a statistical test using the generalized likelihood ratio was used to determine the production frontier's more specific functional shape. The Cobb-Douglas function implies that all the squared and interaction terms are zero, *i.e.*, $\beta_{ij} = 0$; i, j = 1, 2, …, n (when i = j, β_{ij}'s represent the effects of square terms and when $i \neq j$, β_{ij}'s represent the effects of interaction terms, whereas the Translog model implies for non-zero interaction terms. Besides, CRS implies that the squared element in the Translog model has no substantial impact and thus zero. All three of these tests employ generalized likelihood ratio tests to detect significant improvements in the model's likelihood and therefore to obtain the appropriate and desired model.

A generalized likelihood ratio test is an appropriate approach for determining whether the parameters of multiple models within the same class can indeed be improved based on their likelihood function. A similar class of model is required since the various classes used distinct likelihood approximation mechanisms for their respective probability distributions. Based on this, the likelihood ratio test statistic has the following functional structure:

$$\lambda = -2 \times [\ln(L_{H_0}) - \ln(L_{H_1})] \sim \chi^2_{\alpha,j} \quad (1)$$

where, $\ln(L_{H_0})$ stands for log-likelihood function under null hypothesis (initial model) and $\ln(L_{H_1})$ stands for log-likelihood function under alternative hypothesis (improved model). The likelihood ratio follows a generalized chi-square distribution where the degrees of freedom, denoted by "j", specifies the changes in the restriction (parameters) between the models.

Table 3 illustrates the results of the most critical tests that were performed in order to determining the final model of the study. Null hypothesis is disproved in first test (□=104.740 with 55 df) and shows improvement in Translog production frontier over Cobb-Douglas production frontier. The study is premised on a test for the feature of Translog production frontier in which a constant return to the production Frontier is found as ineffective (□=10.873 with 5 df). Additionally, a realistic and obligatory test was conducted to determine whether the inefficiency effects model is apparent. It is evident that the inefficiency effects reveal the characteristics liable for the inefficiency of thrips mortality. For optimum tea thrips mortality, the inefficiency effects model was determined to be unsuitable (□=0.002 with 7 df), and so the model of Battesi and Coelli (1992) is the most responsive in this context. That is, after dropping inefficiency effects coefficients, the values of variance parameter are to be estimated.

The performance efficiency of thrips mortality was examined using a stochastic production frontier model that encompasses the exposure of plant extract for the number of thrips death as the outcome variable in the semi *in-vitro* application. The model-building technique using generalized likelihood ratio test determined that the Translog production frontier with no inefficiency variables is the most appropriate model for this design. The explicit theoretical form of the Trans-log stochastic production frontier model is expressed in equation (2):

$$Y_i = f(X_i, \beta) \times e^{(v_i - u_i)}, \; i = 1, 2, \cdots, n \quad (2)$$

where Y_i represents the output of i-th firm; X_i is an input vector; β's are model parameters; v_i is independent of u_i and distributed as NID (0, σ_v^2); and the most prominent measure of the model is expressed by u_i which computes the technical inefficiencies of the output through exposing input and assumed to follow truncated (at zero) normal distribution as NID (μ, σ_u^2). Finally, the output oriented technical efficiency and the model's inefficiency estimates follows equation (3).

$$\text{Technical efficiency} = e^{-u_i} \qquad (3)$$

For a clear illustration of the stochastic production frontier model for the present study, the empirical production frontier was more obvious and the explicit Translog production frontier is expressed in equation (4).

$$\mathrm{Ln}(y_i) = \mathrm{Ln}(\beta_0) + \sum_{j=1}^{p} \beta_j \times \mathrm{Ln}(x_{ji}) + \frac{1}{2} \times \sum_{j=1}^{p}\sum_{k=1}^{p} \beta_{jk} \times \mathrm{Ln}(x_{ji}) \times \mathrm{Ln}(x_{ki}) + V_i - U_i \quad (4)$$

where i = 1, 2, . . ., n stands for the number of firm or cross-section (n=396) and j=k= 1, 2, . . ., p stands for the number of input variables (p which was 5) used in the study. The output variable y_i indicates the number of thrips mortality for exposing plant extract; the input variables x_1, x_2, . . ., x_5 indicate the variety of medicinal plants, parts used to prepare plant extract, tea clone, solution concentration level, time duration of observation respectively. The β's are unknown parameters to be estimated through maximum likelihood estimation method together with the variance parameter expressed in equation (5) and (6).

$$\sigma^2 = \sigma_u^2 + \sigma_v^2 \qquad (5)$$

$$\gamma = \frac{\sigma_u^2}{\sigma^2} \qquad (6)$$

where the value of the variance parameter γ lies between 0 and 1.

Table 3. Testing the functional form of the production frontier and test of hypothesis for the significance of the inefficiency effects model.

Null hypothesis	DF	Critical value	Log-likelihood		Statistic[1]	Comment
			Under H_0	Under H_1		
Test regarding functional form of the production frontier						
H_0: Exhibits Cobb-Douglas form	15	24.111	-275.2166	-222.8466	104.740	Reject H_0
H_0: Exhibits constant return to scale	5	10.371	-228.2833	-222.8466	10.873	Reject H_0
Test regarding inefficiency effects model						
$H_0: \gamma = \delta_0 = \delta_1 = \delta_2 = \delta_3 = \delta_4 = 0$	7	13.401	-222.8466	-222.8457	0.002	Fails to reject H_0

[1] Authors estimation based on equation (1).

Results and Discussion

The study counts the number of extracts applied in each clone for each replicate as a firm to calculate the time invariant technical efficiency of thrips mortality when medicinal plant extracts are used in place of chemicals and pesticides in thrips control management. Table 4 shows the parameter estimates of the Translog stochastic production frontier model.

The Translog stochastic frontier analysis model explores the main effects, squared effects and interaction effects of main study variables. The findings indicate that the level of solution concentration had significant negative impact on the mortality of tea thrips that is the mortality of thrips was increased significantly with the decrease of concentration level. However, there is no significant effect of plant and clone characteristics, time limit to death on the mortality of thrips. It is to be mentioned that a total of 24 hrs were observed for the possible number of deaths out of 12 thrips on the semi *in vitro* application and therefore a greater number of deaths could be observed for recurring experiment on a long duration. In addition, the squared effect of parts of medicinal plant and concentration level had significant effect on the mortality of thrips and indicates that the changing the parts of plants for extracts preparation and concentration level, significantly doubled thrips mortality.

Table 4. Maximum likelihood estimates of the parameters of the Trans-log stochastic production frontier model for the outcome variable mortality of tea thrips.

Variable	Parameter	Coefficient	SE	t-ratio[1]
Intercept	β_0	2.689	0.915	2.939***
Variety of plants	β_1	0.442	0.278	1.591
Parts of plants	β_2	0.136	0.396	0.344
Tea clone	β_3	-0.411	0.302	-1.361
Concentration	β_4	-0.648	0.232	-2.795***
Time to death affect	β_5	-0.702	0.466	-1.506
Variety of plants squared	β_6	-0.003	0.041	-0.084
Parts of plants squared	β_7	-0.343	0.147	-2.332**
Tea clone squared	β_8	0.006	0.059	0.109
Concentration squared	β_9	0.079	0.035	2.266**
Time to death affect squared	β_{10}	0.016	0.075	0.216
Variety of plants × Parts of plants	β_{11}	-0.240	0.085	-2.823***
Variety of plants × Tea clone	β_{12}	0.007	0.061	0.106
Variety of plants × Concentration	β_{13}	0.120	0.042	2.832***
Variety of plants × Time to death affect	β_{14}	-0.199	0.089	-2.243**
Parts of plants × Tea clone	β_{15}	-0.060	0.063	-0.958
Parts of plants × Concentration	β_{16}	0.066	0.043	1.527
Parts of plants × Time to death affect	β_{17}	0.296	0.106	2.788***
Tea clone × Concentration	β_{18}	0.066	0.038	1.744*
Tea clone × Time to death affect	β_{19}	0.100	0.088	1.160
Concentration × Time to death affect	β_{20}	0.060	0.071	0.852
Variance parameters	σ^2	0.182	0.023	7.778***
	γ	0.006	0.143	0.455
	μ	-0.069	0.389	-0.176
Log-likelihood value			-222.84663	
Mean efficiency			0.9873267	

[1]*** indicates significant at $p < 0.01$ level, ** indicates significant at $p < 0.05$ level, and finally * indicates significant at $p < 0.10$ level.

Besides, some interaction effects were found significant in this study. The study examined that the interaction between plants variety and parts used; plant variety and concentration level; plant variety and time limit; parts of plants and time limit; tea clone and concentration level had significant impact on the mortality of thrips. These findings indicate that the mortality of thrips is not linearly related with the individual effect of plant characteristics, clone characteristics, and time limit to death rather than concentration level. In addition, the study explores that all of the plant's characteristics, clone characteristics, concentration level, and time limit to death are significant predictor with the presence of one another and they all contributed substantial amount being together to measure the technical efficiency of thrips mortality in *in vitro* application.

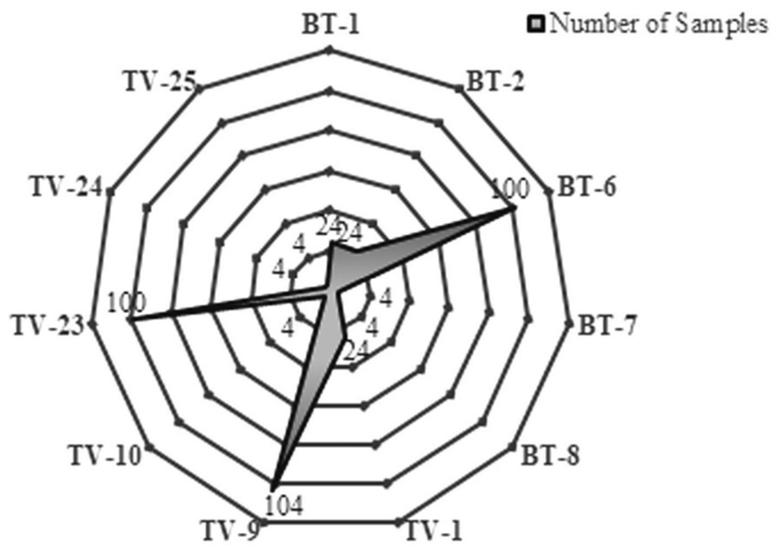

Fig. 1. Distribution and comparison of sampled tea clones.

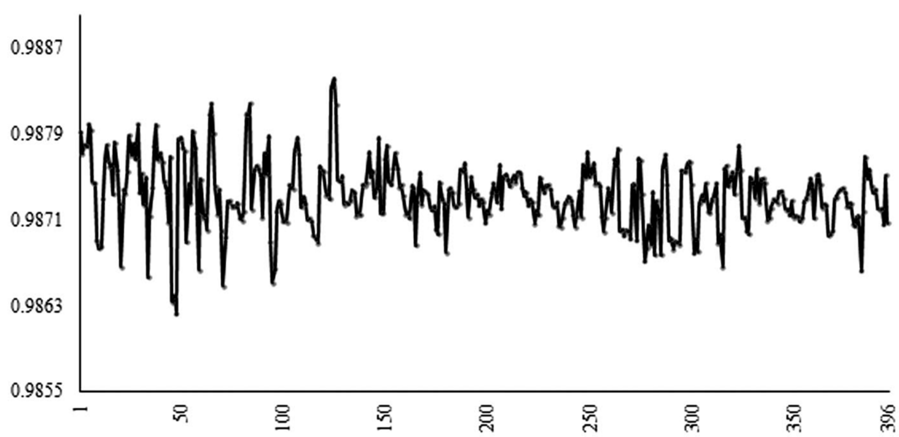

Fig 2. Exhibition of technical efficiency of the mortality of tea thrips.

The estimate for the variance parameter (γ) indicates that the inefficiency effects are likely to be insignificant in the analysis of the value of thrips mortality. The mean technical efficiency for the selected plant extraction characteristics on the thrips control management is estimated at 98.73% indicating that the plants extracts and associated characteristics are useful at a great extent rather than using pesticides and chemicals for controlling tea thrips.

Figure 2 exhibits the technical efficiency of the mortality of tea thrips with the execution of plant extract in semi *in-vitro* application. It was observed that the technical efficiency varied from 98.63 to 95.85% and indicates that the plant extracts and its associated characteristics are almost 98% efficient for controling tea thrips rather than chemicals and pesticides.

It may be concluded from the Stochastic Frontier Model that the thrips' mortality is not directly linked to the concentration level, but rather to the individual influence of plant features, clone characteristics, and the time limit to death. When analyzing the value of thrips mortality, the estimated variance parameter showed that inefficiency impacts are likely to be minor. The technical effectiveness ranged over 95 to 98 per cent, implying that plant extracts and their related features are about 98 per cent effective at controlling tea thrips instead of chemicals and pesticides.

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