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Neutrosophic Analysis in the Evaluation of the Use of Beauveria Bassiana against the Potato White Grub

Edwin M. Chancusig-Espin[1], Paulina Imbaquingo Cachipuendo[2], and Doris Guilcamaigua[3]

[1] Technical University of Cotopaxi, Cotopaxi. Ecuador. E-mail: edwin.chancusig@utc.edu.ec
[2] Technical University of Cotopaxi, Cotopaxi. Ecuador. E-mail: paulina.imbaquingo@utc.edu.ec
[3] Simon Bolivar Andean University, Quito. Ecuador. E-mail: doris.guilcamaigua@uasb.edu.ec

Abstract. Beauveria bassiana is an entomopathogenic fungus that has been shown to have the potential to control the potato white grub (Premnotrypes vorax), a pest that significantly affects potato production, especially in Ecuador. Therefore, the present study has focused on evaluating the effectiveness of Beauveria bassiana in the control of the potato white grub under laboratory conditions. To this end, neutrosophic statistics have been used to analyze larval mortality, by applying concentrations of $\mathbf{10^4}$, $\mathbf{10^6}$ and $\mathbf{10^8}$ conidia of Beauveria bassiana by spraying and immersion. Among the results, it was determined that treatment at a concentration of 10^8 conidia per spray has proven to be the best option, with a neutrosophic coding from very effective to extremely effective in mortality in larvae. In conclusion, neutrosophic analysis has shown that Beauveria bassiana is effective in controlling white grub, especially with high concentrations and spraying.

Keywords: Sustainable agriculture, treatment efficacy, entomopathogen, neutrosophic statistics.

1 Introduction

In this study, the effectiveness of *Beauveria bassiana*, an entomopathogenic fungus isolated from rabbit manure, was evaluated for the control of the white potato grub (*Premnotrypes vorax*) under laboratory conditions [1]. *Beauveria bassiana* is known for its ability to act as a natural biological insecticide in soils, controlling a wide variety of pests. This fungus thrives in cool, moist environments with little sun exposure. It infects pests with muscardine disease, characterized by a whitish-yellowish cotton-like covering [2].

The use of *Beauveria bassiana* is especially relevant since it does not harm crops, soil, and is harmless to humans and animals [3]. This represents a sustainable alternative to the use of agrochemicals for pest control [4], helping to avoid environmental pollution and reduce the economic costs associated with purchasing pesticides.

Therefore, it constitutes a solution for the protection of potato crops, considered among the most important globally, with an estimated production of 341 million tons on an area of 20 million hectares. The main producing countries include China, with a production of between 66 and 71 million tons, followed by Russia, India, Poland, the United States, Ukraine, and Germany.

Among the most impactful afflictions that affect this crop is the white potato grub (Premnotrypes vorax), which is a pest that significantly affects the quality of the tubers. Therefore, the use of entomopathogenic fungi such as Beauveria bassiana has gained popularity as an efficient alternative to chemical insecticides [5] [6], which are harmful to human health and ecosystems [7] [8] [9].

Recent studies indicate that farmers report the white grub as the main pest of potato cultivation [10], affecting it consistently every year. They point out that the price of potatoes can decrease by up to 50% if the damage ranges between 10% and 30%. Whereas, higher damage even prevents the marketing of the product. As a control measure, farmers often defoliate the crop before it reaches its normal maturity, which can reduce yield between 10% and 40%.

Therefore, this study has focused on evaluating the efficacy of *Beauveria bassiana* in controlling the white potato grub under laboratory conditions. For this purpose, neutrosophic statistics were used to analyze larval mortality, applying concentrations of 10^4, 10^6, and 10^8 conidia of Beauveria bassiana by spraying and immersion in a sample of 35 experimental units.

For the development of this research, it is necessary to apply a neutrosophic analysis due to the level of indeterminacy in the study. Thus, indeterminacies are included as part of the statistical processing in evaluating larval mortality in controlling the white grub.

2 Materials and methods

2.1 Neutrosophic Statistics

Before analyzing the neutrosophic statistics of the method, it is necessary to define the neutrosophic set being analyzed [11]. The neutrosophic set is defined by the following elements: true ϑ, indeterminate η, and false δ of x in Q, respectively, and their images constitute standard or non-standard subsets within the range (0,1). For X from the universe of discourse, the single-valued neutrosophic set Q over X is defined as an object in the representation $l = \{\langle x, \vartheta_A(x), \eta_A(x), \delta_A(x)\rangle : x \epsilon X\}$.

Neutrosophic probabilities and statistics are a generalization of classical and imprecise probabilities and statistics [12]. The neutrosophic probability of an event E is the probability that the event E occurs, the probability that the event E does not occur, and the probability of indeterminacy (not knowing whether the event E occurs or not). In classical probability, the highest value (nsup) is less than or equal to 1, while in neutrosophic probability, nsup is less than or equal to 3. The function that models the neutrosophic probability of a random variable X is called the neutrosophic distribution:

Where $\vartheta_A(x), \eta_A(x), \delta_A(x)$ meet the following condition: $0 \leq \vartheta_A(x), \eta_A(x), \delta_A(x) \leq 3$ for all $x \in X$. Thus, to define each neutrosophic number, it is expressed in the form h, i, j for the modeling of the neutrosophic methodology to be used. Therefore, the following functions are defined:

$h = \vartheta_A(x)$ for true membership functions, where $\in \{0,1\}$.

$i = \eta_A(x)$ for indeterminate membership functions, where $\in \{0,1\}$.

$j = \delta_A(x)$ for false membership functions, where $\in \{0,1\}$.

Therefore, the neutrosophic number defined for the study is determined as $L = (h, i, j)$, where h, i, j $\in$ $\{0,1\}$ and satisfies the following condition $0 \leq h + i + j \leq 3$. So, it is defined as a B-score function of a neutrosophic number according to the proposal of Smarandache or Basset.

In the given text, where h represents the probability that the value x occurs, j(x) represents the probability that the value x does not occur, and I(x) represents the indeterminate or unknown probability of x. Neutrosophic statistics is the analysis of neutrosophic events and deals with neutrosophic numbers, neutrosophic probability distribution, neutrosophic estimation, neutrosophic regression, etc.

Single-Valued Neutrosophic Sets (SVNS) emerged with the idea of applying neutrosophic sets for practical purposes [13]. Some operations among Single-Valued Neutrosophic Numbers (SVNN) are expressed below:

Given $L_1 = (h_1, i_1, j_1)$ and $L_2 = (h_2, i_2, j_2)$, two Single-Valued Neutrosophic Numbers (SVNN), the sum of L_1 and L_2 is defined as follows:

$$L_1 + L_2 = (h_1 + h_2 - h_1 h_2, i_1 i_2, j_1 j_2) \quad (1)$$

Given $L_1 = (h_1, i_1, j_1)$ and $L_2 = (h_2, i_2, j_2)$, two Single-Valued Neutrosophic Numbers (SVNN), the multiplication of L_1 and L_2 is defined as follows:

$$L_1 \cdot L_2 = (h_1 h_2, i_1 + i_2 - i_1 i_2, j_1 + j_2 - j_1 j_2) \quad (2)$$

The product of a positive scalar with an SVNN, $L = (h, i, j)$c) is defined by:

$$\mathrm{L} = (1 - (1 - h), \mathrm{i}, \mathrm{j}) \quad (3)$$

It refers to a dataset, which is wholly or partly composed of data with some degree of indeterminacy and the methods for analyzing them. Neutrosophic statistical methods allow for the interpretation and organization of neutrosophic data (data that can be ambiguous, vague, imprecise, incomplete, or even unknown) to reveal underlying patterns.

In conclusion, neutrosophic logic [14], neutrosophic sets, and neutrosophic probabilities and statistics have broad applications in various research fields and constitute a novel reference for study in full development. Neutrosophic descriptive statistics encompass all the techniques for summarizing and describing the characteristics of neutrosophic numerical data.

The study of neutrosophic statistics refers to a neutrosophic random variable, where L represents the corresponding lower and upper levels that the variable under study can reach within an indeterminate interval. Thus, it follows the neutrosophic mean of the variable ($\bar{\mathrm{L}}$) when formulating:

$$\bar{\mathrm{L}} = \frac{1}{n_N} \sum_{i=1}^{n_N} L_i \quad (4)$$

Where n_N is a neutrosophic random sample from the studied population. Once the neutrosophic mean is defined, the next step is the calculation of the variance of the neutrosophic sample. For this, the following equation is defined:

$$S_N^2 = \frac{\sum_{i=1}^{n_N}(L_i - \bar{L}_i)^2}{n_N} \tag{5}$$

Subsequently, the calculation of the Neutrosophic Coefficient of Variation (NCV)[15] is carried out, which measures the consistency of the variable. The smaller the value of the NCV, the more consistent the performance of the factor compared to other factors. For this purpose, the following equation is proposed:

$$CV_N = \sqrt{S_N^2} \times 100 \tag{6}$$

To measure the variable, the Neutrosophic Argumentation Coefficient is used. This evaluates the criteria through Linguistic Terms with Single-Valued Neutrosophic Numbers (SVNN) of consensus of justification of the expert opinion (see Table 1).

Table 1: Linguistic terms that represent the weight of larval mortality.

Coding	Linguistic Term	SVNN (T, I, F)	Description
EE	Extremely Effective	(1,0,0)	Indicates 100% efficacy in daily larval mortality, without indeterminacies or uncertainty.
VE	Very Effective	(0.9,0.05,0.1)	Almost complete efficacy with slight indeterminacies about daily consistency.
E	Effective	(0.8,0.15,0.2)	High efficacy with some uncertainties about mortality results.
ME	Moderately Effective	(0.7,0.25,0.3)	Good overall efficacy but with notable daily fluctuations.
SE	Somewhat Effective	(0.6,0.35,0.4)	Medium efficacy with considerable daily uncertainty.
N	Neutral	(0.5,0.45,0.5)	Balance between efficacy and inefficacy with high indeterminacy.
SHI	Somewhat High Ineffective	(0.4,0.55,0.65)	Somewhat low efficiency with significant indeterminacy and a tendency towards inefficacy.
SI	Somewhat Ineffective	(0.3,0.65,0.7)	Low efficacy with a predominance of negative results.
I	Ineffective	(0.2,0.75,0.8)	Mostly ineffective with few incidents of effective mortality.
VI	Very Ineffective	(0.1,0.85,0.9)	Almost completely ineffective with sporadic larval deaths.
EI	Extremely Ineffective	(0,0.95,1)	Total inefficacy in inducing mortality, without indeterminacies.

2.2 Sample Selection.

For the study, the sample size of respondents is determined using Equation 7, which takes the probabilities as 50% or 0.05, according to the following results:

- Maximum allowable error margin = 10.0%
- Population size = 55 experimental units.
- Size for a confidence level of 95%: 35
- Size for a confidence level of 97%: 38
- Size for a confidence level of 99%: 42

Additionally, the following formula was used for statistical processing to calculate the sample size.

$$n = \frac{ZNpq}{E^2(N-1) + Z^2pq} \tag{7}$$

Where:

- n: Sample size
- Z: Value from the normal distribution corresponding to the assigned confidence level

- E: Desired sampling error
- N: Population size

3 Results

3.1 Data collection

In this research, a Randomized Complete Block Design (RCBD) was used with 6 treatments and 1 control, covering a total of 35 experimental units. This design allowed for the evaluation of the efficacy of Beauveria bassiana, isolated from rabbit manure, for controlling the white grub of the potato (Premnotrypes vorax), by measuring variables such as the number of live and dead larvae, and the condition of the tubers (healthy and infected).

Study factors:

- Factor A (Dose concentration): A1 (10^4), A2 (10^6), and A3 (10^8).
- Factor B (Types of application): B1 (immersion) and B2 (aspersion).

Operationalization of variables: The study variables are defined where the independent variable is the dosage and type of application of Beauveria bassiana, and the dependent variables are effectiveness (% of pest invasion) and yield (percentage of healthy and infected tubers).

Specific management of the experiment: The study was conducted on the Salache campus of the Technical University of Cotopaxi, in the Agronomy laboratory. Meanwhile, the collection of rabbit manure was carried out in the American neighborhood, Cayambe, Pichincha.

Method of application of treatments (see Table 2):

- Aspersion: 10 ml of the Beauveria bassiana bioformulate was used per treatment using a small pump.
- Immersion: 15 worms were submerged in 10 ml of the bioformulate per treatment.

Variables evaluated:

- Mortality: the initial number of worms was counted, with daily readings, to obtain the percentage of mortality. To determine the levels of inconsistencies and indeterminacies in the study, work is carried out with 95% confidence in the analyzed variable (see Table 3).

Table 2: Treatment applied. Source: own elaboration.

Treatment	Conidia Concentration (per ml)	Application Method	Treatment description
T1	10^4	Aspersion	Use of low concentration applied through aspersion, aiming to cover wider areas in a less concentrated manner.
T2	10^4	Immersion	Application by immersion with low concentration to allow more prolonged and direct contact.
T3	10^6	Aspersion	Increase of concentration to evaluate a more potent effect through aspersion.
T4	10^6	Immersion	Medium concentration applied by immersion, seeking efficiency in use and balance in effectiveness.
T5	10^8	Immersion	Use of the highest concentration in immersion to maximize direct efficacy against larvae.
T6	10^8	Aspersion	Application of the maximum concentration through aspersion to test effectiveness under conditions of wide dispersion.

Table 3: Variable characteristics. Source: own elaboration.

Variable	Coding	Sample	Scale $[0\ ;\ 1], \forall\ F_n$
Larval mortality in the control of the white grub	MLCGB	[25;35]	Complete efficacy: There is no indeterminacy; the treatment with the highest concentration has proven to be completely effective in larval mortality, achieving the highest levels of mortality observed **(1,0,0)**. Mostly effective: The treatment is generally effective with some minor indeterminacies, suggesting that although it is effective, there might be minor variations in efficacy among replicates or similar conditions **(0.75,0.20,0.05)**. Moderately effective: There is considerable indeterminacy. The treatment is partially effective, showing inconsistent efficacy that might require adjustments or combination with other methods **(0.50,0.50,0)**.

Variable	Coding	Sample	Scale $[0\ ;\ 1], \forall F_n$
			Mostly ineffective: Most of the time, the treatment fails to effectively control larval mortality, indicating the need for review or substantial improvement of the treatment approach **(0.30,0.65,0.05)**. Completely ineffective: The treatment has no impact on larval mortality, indicating a total lack of effectiveness and the urgent need for a complete review or change of strategy **(0,0,1)**.

Development of the method: For the neutrosophic statistical modeling, observations and evaluations were carried out on each of the experimental units to define the level of MLCGB. Statistical analysis would determine the best treatment to apply based on the impact on the mortality of live larvae and the condition of healthy tubers. For the evaluation of the sample, linguistic terms are applied to each experimental unit according to the treatment applied over 25 days (the scale used according to the linguistic term from Table 1). For modeling, neutrosophic statistics are used to include various complex criteria at the time of evaluation (see Table 4).

Table 4: Neutrosophic frequency of daily evaluations in the monitoring of MLCGB. Source: own elaboration.

Day	Treatment 1 (T1)	Treatment 2 (T2)	Treatment 3 (T3)	Treatment 4 (T4)	Treatment 5 (T5)	Treatment 6 (T6)
1	(0.2,0.75,0.8)	(0.3,0.65,0.7)	(0.6,0.35,0.4)	(0.7,0.25,0.3)	(0.8,0.15,0.2)	(0.9,0.05,0.1)
2	(0.3,0.65,0.7)	(0.4,0.55,0.65)	(0.7,0.25,0.3)	(0.6,0.35,0.4)	(0.7,0.25,0.3)	(0.8,0.15,0.2)
3	(0.1,0.85,0.9)	(0.3,0.65,0.7)	(0.8,0.15,0.2)	(0.7,0.25,0.3)	(0.9,0.05,0.1)	(1,0,0)
4	(0.3,0.65,0.7)	(0.5,0.45,0.5)	(0.6,0.35,0.4)	(0.8,0.15,0.2)	(0.8,0.15,0.2)	(0.9,0.05,0.1)
5	(0.5,0.45,0.5)	(0.4,0.55,0.65)	(0.7,0.25,0.3)	(0.6,0.35,0.4)	(0.9,0.05,0.1)	(0.8,0.15,0.2)
6	(0.4,0.55,0.65)	(0.3,0.65,0.7)	(0.8,0.15,0.2)	(0.7,0.25,0.3)	(1,0,0)	(0.9,0.05,0.1)
7	(0.5,0.45,0.5)	(0.3,0.65,0.7)	(0.6,0.35,0.4)	(0.7,0.25,0.3)	(0.8,0.15,0.2)	(0.9,0.05,0.1)
8	(0.3,0.65,0.7)	(0.4,0.55,0.65)	(0.7,0.25,0.3)	(0.6,0.35,0.4)	(0.7,0.25,0.3)	(1,0,0)
9	(0.1,0.85,0.9)	(0.3,0.65,0.7)	(0.8,0.15,0.2)	(0.7,0.25,0.3)	(0.8,0.15,0.2)	(0.9,0.05,0.1)
10	(0.3,0.65,0.7)	(0.5,0.45,0.5)	(0.6,0.35,0.4)	(0.8,0.15,0.2)	(0.7,0.25,0.3)	(0.9,0.05,0.1)
11	(0.4,0.55,0.65)	(0.3,0.65,0.7)	(0.2,0.75,0.8)	(0.6,0.35,0.4)	(0.8,0.15,0.2)	(0.9,0.05,0.1)
12	(0.2,0.75,0.8)	(0.4,0.55,0.65)	(0.8,0.15,0.2)	(0.7,0.25,0.3)	(0.9,0.05,0.1)	(0.9,0.05,0.1)
13	(0.3,0.65,0.7)	(0.5,0.45,0.5)	(0.6,0.35,0.4)	(0.8,0.15,0.2)	(0.9,0.05,0.1)	(0.9,0.05,0.1)
14	(0.4,0.55,0.65)	(0.3,0.65,0.7)	(0.7,0.25,0.3)	(0.6,0.35,0.4)	(0.8,0.15,0.2)	(0.9,0.05,0.1)
15	(0.3,0.65,0.7)	(0.4,0.55,0.65)	(0.6,0.35,0.4)	(0.7,0.25,0.3)	(0.9,0.05,0.1)	(0.9,0.05,0.1)
16	(0.2,0.75,0.8)	(0.3,0.65,0.7)	(0.2,0.75,0.8)	(0.6,0.35,0.4)	(0.7,0.25,0.3)	(0.9,0.05,0.1)
17	(0.4,0.55,0.65)	(0.5,0.45,0.5)	(0.6,0.35,0.4)	(0.8,0.15,0.2)	(0.9,0.05,0.1)	(0.9,0.05,0.1)
18	(0.3,0.65,0.7)	(0.4,0.55,0.65)	(0.7,0.25,0.3)	(0.6,0.35,0.4)	(0.8,0.15,0.2)	(1,0,0)
19	(0.1,0.85,0.9)	(0.3,0.65,0.7)	(0.8,0.15,0.2)	(0.7,0.25,0.3)	(0.9,0.05,0.1)	(0.9,0.05,0.1)
20	(0.3,0.65,0.7)	(0.5,0.45,0.5)	(0.6,0.35,0.4)	(0.8,0.15,0.2)	(0.9,0.05,0.1)	(0.9,0.05,0.1)
21	(0.4,0.55,0.65)	(0.3,0.65,0.7)	(0.7,0.25,0.3)	(0.6,0.35,0.4)	(0.8,0.15,0.2)	(0.9,0.05,0.1)
22	(0.5,0.45,0.5)	(0.4,0.55,0.65)	(0.2,0.75,0.8)	(0.7,0.25,0.3)	(0.9,0.05,0.1)	(0.9,0.05,0.1)
23	(0.3,0.65,0.7)	(0.5,0.45,0.5)	(0.6,0.35,0.4)	(0.8,0.15,0.2)	(0.9,0.05,0.1)	(0.9,0.05,0.1)
24	(0.4,0.55,0.65)	(0.3,0.65,0.7)	(0.7,0.25,0.3)	(0.6,0.35,0.4)	(0.8,0.15,0.2)	(0.9,0.05,0.1)
25	(0.3,0.65,0.7)	(0.4,0.55,0.65)	(0.6,0.35,0.4)	(0.7,0.25,0.3)	(0.9,0.05,0.1)	(1,0,0)
$\bar{x}$	**[(0.3,0.65,0.7); (0.4,0.55,0.65)]**	**[(0.3,0.65,0.7); (0.4,0.55,0.65)]**	**[(0.6,0.35,0.4); (0.7,0.25,0.3)]**	**[(0.6,0.35,0.4); (0.7,0.25,0.3)]**	**[(0.8,0.15,0.2); (0.9,0.05,0.1)]**	**[(0.9,0.05,0.1); (1,0,0)]**

Neutrosophic statistical analysis: The preliminary results of the treatments applied to the experimental units define varied and complex evaluations within the neutrosophic linguistic scales on average. The average analysis of evaluations regarding the effectiveness of the treatments in the experimental units shows that:

- For *treatment T1 and T2*: The average evaluations are between SI and SHI, indicating that the efficacy of this treatment with the assigned concentration tends towards ineffectiveness. The same applies to these two treatments that use the same concentration of 10^4, but with the difference that one applies the method of aspersion and the other of immersion.
- For *treatment T3 and T4*: The evaluations of these two alternatives on average cover a state of effectiveness from ME to SE. Thus, these alternatives represent a tendency to be effective but with notable daily fluctuations, where it does not completely eliminate the pest from the tubers. Therefore, the variation for both methods of application of the treatments T3 and T4 is found in the same neutrosophic area and at the

same concentration of 10^6.

- For *treatment T5*: This treatment performed by immersion at a concentration of 10^8 is observed that the average evaluations are between E and VE. Therefore, this treatment indicates that it is an effective neutrosophic area to combat the pest with positive results and with slight indeterminacies about daily consistency.
- For *treatment T6*: It is considered according to the neutrosophic average as the alternative with the best results for combating the pest at a concentration of 10^8. By applying this treatment through the aspersion method, effectiveness from VE to EE was achieved. This indicates that, although it does not achieve 100% mortality of the pest, it is positioned close to this neutrosophic point of greater impact. Nevertheless, the application of T6 achieves higher tuber yields.

Once the results are analyzed, it is observed that the treatments are located in four neutrosophic areas, two of which are accepted and positive impact on the control of the white grub. For this, the following areas where the daily results obtained converge the most are defined:

- Neutrosophic Area AN1: With the classification [SI; SHI] and a tendency towards ineffectiveness. It also has a high probability of negative results and significant indeterminacy. In this area, treatments T1 and T2 are found and it is located in a neutral zone in the analyzed neutrosophic set.

- Neutrosophic Area AN2: With classification [ME; SE], with a tendency towards the limit of effectiveness. With low daily fluctuations in the results of the mortality of the pest. In this area, treatments T3 and T4 are located at the extreme of the neutral zone in the analyzed neutrosophic set.

- Neutrosophic Area AN3: With classification [E; VE]. It is characterized by being an area of high effectiveness and slight uncertainties about daily consistency. In it, treatment T5 is located, being part of the neutrosophic acceptance zone.

- Neutrosophic Area AN4: With classification [VE; EE]. It is characterized by being an almost completely effective area, where the desired alternatives to the identified problem are found. In it, treatment T6 is located and forms part of the neutrosophic acceptance zone.

Comparative analysis: To determine the best treatment that complies in terms of consistency and reliability, the variance and standard deviation are calculated. The results are shown in Figure 1, where it can be observed that treatments T1, T2, and T3 have the least effectiveness and high variability. While treatments T4 significantly improve in effectiveness and consistency. Furthermore, treatment T5 has high effectiveness and good consistency, but treatment T6 stands out more, possessing the highest effectiveness and the best consistency (with a lower variance of 0.0012 and standard deviation of 0.0346).

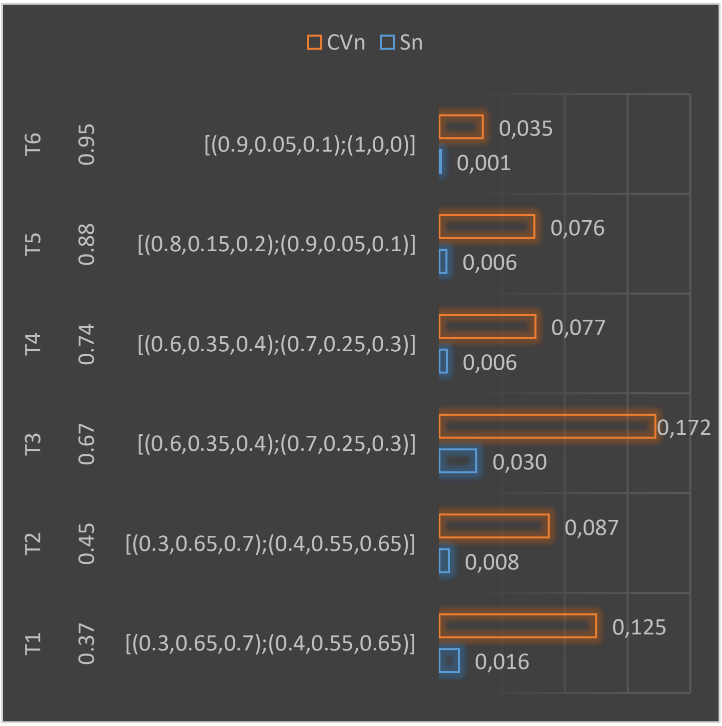

Figure 1: Calculation of the $\bar{L}, S_N$ and CV_N of the MLCGB variable. Source: own elaboration.

The concentration of 10^8 conidia of Beauveria bassiana (T6), especially through aspersion, is highly effective in controlling the white grub, especially with high concentrations and aspersion. The application of neutrosophic statistics allowed for precisely identifying the optimal conditions for its use. This emphasizes the need to adjust application practices to maximize efficacy and promote sustainable agriculture less dependent on chemical insecticides. Integrating these findings with agronomic practices could significantly improve integrated pest management. This treatment should be considered the preferred option for practical application, subject to additional considerations such as cost, applicability in the field, and environmental sustainability. Therefore, solutions should be proposed to enhance the application in other regions of Ecuador, such as promoting acceptance by potato growers.

3.2 Solutions to enhance the effectiveness of T6 Treatment.

To enhance the T6 treatment of Beauveria bassiana for the control of the white grub of the potato (Premnotrypes vorax) in Ecuador, two research projects are proposed as follows:

Project 1: Optimization of Beauveria bassiana Application by Aspersion for White Grub Control in Potato Crops

Scope: Develop improved aspersion application methodologies of Beauveria bassiana that increase the effectiveness in controlling the white grub in potato crops in Ecuador.

Estimated duration of the project: 2 years.

General objective: Increase the effectiveness of the T6 treatment through the optimization of aspersion techniques and dosing of Beauveria bassiana.

Specific objectives:

- Determine the optimal dosage of conidia for aspersion application.
- Evaluate the effectiveness of different types of aspersion equipment under field conditions.
- Develop application protocols that minimize the degradation of the biological agent by environmental factors.

Stages:

- Experimental design and preliminary data collection.
- Field trials under different climatic conditions and soil types.
- Data analysis and formulation of recommendations.

Resources:

- Biotechnology and agronomy laboratories.
- Experimental fields.
- Aspersion equipment.
- Funding by governmental and academic entities.

Expected impact: Reduction in the use of chemical pesticides and an increase in pest-free potato production.

Qualified personnel: Researchers in biotechnology, agronomy, and entomology.

Approval levels: Requires ethical and environmental approval.

Funding: Seeking funding through governmental research funds and international collaborations.

Results: Development of a best practices manual for the application of Beauveria bassiana in agriculture.

Benefits: Improvement of sustainability in agriculture and cost reduction for farmers.

Project 2: Long-term Environmental and Agronomic Impact Assessment of Beauveria bassiana on Potato Crops

Scope: Study the long-term effects of the continued use of Beauveria bassiana on local biodiversity and soil health in potato-growing areas.

Estimated duration of the project: 3 years.

General objective: Evaluate the environmental and agronomic impacts of prolonged use of Beauveria bassiana to ensure its viability as a sustainable solution.

Specific objectives:

- Monitor the biodiversity of insects and soil microorganisms in areas treated with Beauveria bassiana.
- Analyze the impact on soil health and the quality of potato crops.
- Develop strategies to mitigate any observed negative impacts.

Stages:

- Selection of study sites and methodological design.
- Implementation of treatments and continuous monitoring.
- Analysis of results and development of management guidelines.

Resources:

- Environmental monitoring equipment.
- Laboratories for soil and biodiversity analysis.
- Technical and scientific staff.

Expected impact: Validation of Beauveria bassiana as an ecologically efficient and long-term treatment.
Qualified personnel: Specialists in ecology, microbiology, and crop protection.
Approval levels: Regulatory approvals for long-term field studies.
Funding: Sustainability research funds and academic grants.
Results: Publication of studies in scientific journals and presentations at international conferences.
Benefits: Promote integrated pest management that is effective and ecological, thereby reducing dependence on synthetic pesticides and improving ecosystem health.

These projects involve active collaboration from Ecuadorian universities, providing academic and scientific resources. Additionally, they offer opportunities for students to conduct applied research and theses related to sustainable agriculture and biological pest control.

4 Conclusion

The use of neutrosophic statistics in this study has enabled a richer and more nuanced interpretation of the results. The research demonstrated that Beauveria bassiana, isolated from rabbit manure, is highly effective in controlling the white grub of the potato, especially when applied in concentrations of 10^8 conidia and by aspersion. This form of treatment showed significant efficacy, with very effective mortality of the white grub for an evaluation between (0.9,0.05,0.1) and (1,0,0) compared to the control group, where no significant mortality was observed. This result underscores the potential of Beauveria bassiana as a viable and effective biocontrol agent that can be integrated into pest management programs to reduce the use of chemical insecticides and promote more sustainable agriculture.

To maximize the efficacy of Beauveria bassiana and its sustainable use in agriculture, it is essential to adopt a comprehensive approach. This includes adjusting the conidial concentration and preferring aspersion for effective coverage, to actively control environmental conditions such as humidity and temperature to maintain the effectiveness of the biocontrol agent. Additionally, combining Beauveria bassiana with other pest management methods and agronomic practices strengthens the control of threats and minimizes dependence on single methods. Training farmers and technicians in best practices and the interpretation of results through neutrosophic statistics is crucial for improving decision-making and fostering resilient and productive agriculture. This deepened understanding helps to formulate more precise and adaptive strategies for the use of Beauveria bassiana, ensuring a more effective and efficient application.

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