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Application of Neutrosophic Statistics in the Integrated Management of Ceratitis Capitata in Ecuador

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Abstract. This study has addressed the management of Ceratitis capitata (Mediterranean fly) in Ecuador, focused on mitigating the impact on fruit crops under the influence of climate change and variations in agricultural practices. By using neutrosophic statistics, the study has modeled uncertainty in climatic and agricultural variables to improve the prediction and adaptability of management strategies. Integrated strategies have been proposed, which have included biological control, cultural management, and the use of insecticides, highlighting the effectiveness of adapting management practices based on neutrosophic analysis. The results indicated that the adaptations of strategies, provided by neutrosophic statistics, allowed an effective response to environmental variations, to maintain the effectiveness of pest control in the long term. In conclusion, the combination of management strategies with neutrosophic statistics is vital for effective control of Ceratitis capitata, by facilitating a proactive and adaptive approach in the face of changing conditions, to strengthen agricultural resilience.

Keywords: Integrated pest management, neutrosophic statistics, agricultural resilience**.**

1 Introduction

Fruit flies are phytophagous insects that cause significant economic losses worldwide [1]. They affect both the epicarp and mesocarp of the fruit through oviposition and the plant tissues through larval feeding, rendering the fruits unsuitable for industrial use [2]. Additionally, they cause indirect damage through pathogenic microorganisms that infect the wounds caused by these flies and their larvae [3].

Economically, fruit fly infestations have resulted in exorbitant costs [4], as evidenced in the United States where costs range between $300,000 and $200 million per event. In California, outbreaks of these pests have cost nearly $500 million over the past 25 years, and a specific outbreak in Florida in 1997 reached an eradication cost of $25 million.

The Mediterranean fruit fly (MFF; Ceratitis capitata Wiedemann), native to sub-Saharan Africa, is one of the most destructive pests of fruit trees worldwide. This species is distinguished by its wide range of hosts (approximately 300), its tolerance for low temperatures, and its adaptability to various climates, making it especially problematic. Its presence in a country can result in significant trade barriers for agricultural product exports due to its quarantine pest status.

In Ecuador, despite the relevance of Ceratitis capitata, there is a lack of studies on this pest, and a national program has not been effectively implemented to reduce its incidence or minimize its economic and social risks. The country hosts 11,250 hectares of crops such as mango, cucurbits, papaya, blackberry, tomato, cherimoya, dragon fruit, and bell pepper, all susceptible to MFF [5], highlighting the need for a better understanding of the risk it poses.

It should be noted that global trade and climate changes influence the distribution and impact of pests and diseases [6], facilitating their emergence in new areas [7]. Modern technologies, such as ILCYM 4.0 software, allow for the construction of process-based models to predict the population dynamics of insects in various ecosystems and generate pest risk maps using Geographic Information Systems (GIS). These tools support decision-making to optimize pest sampling and management [8], reducing pesticide use.

The main goal of this study is to develop integrated strategies to mitigate the impact of Ceratitis capitata on fruit crops in Ecuador. This objective extends to considering the challenges posed by climate change and fluctuations in agricultural practices, using neutrosophic statistics to address the uncertainties associated with environmental and management variables affecting pest dynamics.

2 Materials and Methods

2.1 Neutrosophy

Definition 1. Let X be a universe of discourse. A Neutrosophic Set (NS) is characterized by three membership functions, $u_A(x), r_A(x), v_A(x): X \rightarrow]^{-}0.1+[$, that satisfy the condition $-0 \leq inf u_A(x) + inf r_A(x) + inf v_A(x)$ $sup\ u_A(x) + sup\ \ r_A(x) + \sup v_A(x) \leq 3^{+}$ for all $x \in X$. $u_A(x), r_A(x)$ and $v_A(x)$ denote the true, indeterminate, and false membership functions of x in A, respectively[9] [10], and their images are standard or non-standard subsets of $]-0{,}1+[$.

Definition 2. Let X be a universe of discourse. A Single Value Neutrosophic Set (SVNS) A over X is an object of the form:

$$A = \{\langle x, u_A(x), r_A(x), v_A(x)\rangle : x \in X\} \tag{1}$$

Where $u_A, r_A, v_A: X \rightarrow [0{,}1]$, satisfy condition $0 \leq u_A(x), r_A(x), v_A(x) \leq 3$ for all $x \in X$. $u_A(x), r_A(x)$ and $v_A(x)$ denote the true, indeterminate, and false membership functions of x in A, respectively. For convenience, a Single Valued Neutrosophic Number (SVNN) will be expressed as A = (a, b, c), where a, b, c [0,1] and satisfies $0 \leq a + b + c \leq 3$.

The SVNS arose with the idea of applying neutrosophic sets for practical purposes. Some operations between SVNN are expressed below:

Given A1 = (a1, b1, c1) and A2 = (a2, b2, c2) two SVNN, the sum of A1 and A2 is defined as:

$$A_1 \ A_2 = (a_1 + a_2 - a_1a_2, b_1b_2, c_1c_2) \tag{2}$$

Given A1 = (a1, b1, c1) and A2 = (a2, b2, c2) two SVNNs, the multiplication between A1 and A2 is defined as:

$$A_1 \ A_2 = (a_1a_2, b_1 + b_2 - b_1b_2, c_1 + c_2 - c_1c_2) \tag{3}$$

The product for a positive scalar with an SVNN, A = (a, b, c) is defined by:

$$A = (1 - (1 - a), b, c) \tag{4}$$

2.2 Neutrosophic Statistics

Neutrosophic probabilities and statistics are a generalization of classical and imprecise probabilities and statistics [11]. The neutrosophic probability of event E is defined as the probability that event E occurs, the probability that event E does not occur, and the probability of indeterminacy (not knowing whether event E occurs or not). In classical probability, nsup≤1, while in neutrosophic probability nsup≤3+. The function modeling the neutrosophic probability of a random variable x is called a neutrosophic distribution:

$$NP(x) \ = \ (T(x), I(x), F(x))$$

where T(x) represents the probability that the value x occurs, F(x) represents the probability that the value x does not occur, and I(x) represents the indeterminate or unknown probability of the value x. Neutrosophic statistics is the analysis of neutrosophic events and deals with neutrosophic numbers, neutrosophic probability distribution, neutrosophic estimation, and neutrosophic regression [12].

It refers to a dataset, which is entirely or partly composed of data with some degree of indeterminacy and the methods to analyze them. Neutrosophic statistical methods allow the interpretation and organization of neutrosophic data (data that may be ambiguous, vague, imprecise, incomplete, or even unknown) to reveal underlying patterns [13].

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

Neutrosophic numbers are numbers of the form where a and b are real or complex numbers, while "I" is the indeterminacy part of the neutrosophic number N. The study of neutrosophic statistics refers to a neutrosophic random variable where X_l and $X_u I_N$ represent the lower and upper levels respectively that the studied variable can reach, within an indeterminate interval $[I_l, I_u]$. Accordingly, the neutrosophic mean of the variable ($(\bar{x}_N)$) is formulated by:

$$X_N \ = X_l + X_u I_N; \ I_N \in [I_l, I_u] \tag{5}$$

Where, $\bar{x}_a = \frac{1}{n_N}\sum_{i=1}^{n_N} X_{il}, \quad \bar{x}_b = \frac{1}{n_N}\sum_{i=1}^{n_N} X_{iu}, \ n_N \in [n_l, n_u],$ (6)

it is a neutrosophic random sample. Nevertheless, for the calculation of neutrosophic number squares (NNS), it can be computed as follows[14]:

$$\sum_{i=1}^{n} N(X_i - \bar{X}_{iN})^2 = \sum_{i=1}^{n} N\begin{bmatrix} \min\begin{pmatrix} (a_i + b_iI_L)(\bar{a} + \bar{b}I_L), (a_i + b_iI_L)(\bar{a} + \bar{b}I_U) \\ (a_i + b_iI_U)(\bar{a} + \bar{b}I_L), (a_i + b_iI_U)(\bar{a} + \bar{b}I_U) \end{pmatrix} \\ \max\begin{pmatrix} (a_i + b_iI_L)(\bar{a} + \bar{b}I_L), (a_i + b_iI_L)(\bar{a} + \bar{b}I_U) \\ (a_i + b_iI_U)(\bar{a} + \bar{b}I_L), (a_i + b_iI_U)(\bar{a} + \bar{b}I_U) \end{pmatrix} \end{bmatrix}, I \in [I_L, I_U] \quad (7)$$

Where $a_i = X_l b_i = X_u$. The variance of the neutrosophic sample can be calculated by

$$S_N^2 = \frac{\sum_{i=1}^{n_N}(X_i - \bar{X}_{iN})^2}{n_N}; \ S_N^2 \in [S_L^2, S_U^2] \quad (8)$$

The neutrosophic coefficient (CV_N) measures the consistency of the variable [15]. The lower the CV_N value, the more consistent the performance of the factor compared to other factors. The CV_N can be calculated as follows:

$$CV_N = \frac{\sqrt{S_N^2}}{\bar{x}_N} \times 100; \ CV_N \in [CV_L, CV_U] \quad (9)$$

3 Results

3.1 Data collection. Current presence of the Mediterranean fly in Ecuador.

Using data from the Ecuadorian Agency for Agricultural Quality Assurance, 926 presence points of MFF in mango orchards were recorded during the year 2020, with detailed UTM coordinates. Most of the records were located in the province of Imbabura, followed by Guayas and Santa Elena, as shown in Table 1.

Table 1: Sampling of the presence of Ceratitis capitata in Ecuador. Source: Agrocalidad.

Provinces (sampling)	Number of flies collected	Percentage (%)	Provinces (sampling)
Guayas	2461	20.35%	Guayas
Imbabura	8721	72.12%	Imbabura

In Table 2, Imbabura shows the highest incidence with 72.12%, followed by Guayas at 20.35% and Santa Elena at 7.53%. These data were collected by Agrocalidad agents in 2020 in mango plants. Meanwhile, the current and future establishment index of Ceratitis Capitata has identified an optimal area (A) in the tropical and subtropical zones of Ecuador with an average temperature of 22 °C. The inter-Andean regions, such as the Ecuadorian highlands, were categorized as an impossible area (D) with temperatures < 9 °C.

Table 2: Favorable areas according to the activity of Ceratitis capitata. Source: own elaboration.

Areas	Temperatures °C
Optimal	16-32
Favorable	10-35
Unfavorable	<10
Impossible	>40 years <10

The current analysis indicates that MFF could achieve from 4 to 25 annual generations in areas with temperatures ranging from 9 to 22°C; and from 0 to 4 generations in areas (C, D) with temperatures < 9°C, according to Table 3. The Current Generational Index (2020) and Future (2050) for Ceratitis capitata in Ecuador show an increase in regions affected by climate change. This forecasts the establishment of the insect in tropical and subtropical regions while indicating insect-free zones in the highlands of the Sierra.

Table 3: Average annual temperatures for regions in Ecuador. Source: own elaboration.

Areas	Temperatures °C
Andean Plateau	<9
coastal lowlands,	9-14
Jungle,	14-18
Galapagos Islands	18-22
	>22

3.2 Neutrosophic Statistics.

Once the distribution of the flies collected in the main affected provinces has been analyzed, the next step is to determine the elements that favor propagation. To do this, it is necessary to identify the variables that affect the development of the fly Ceratitis capitata. Therefore, it is essential to consider both the biological aspects of the insect and the environmental factors that influence its life cycle. Based on previous information and related scientific literature, the following variables are key in the development and expansion of this species.

To analyze and reformulate the impact of the most important variables on the development of Ceratitis capitata, five critical variables are selected and merged (see Table 4), using neutrosophic statistics. Then, the ranges of action are described, which allows the expression of uncertainty in the obtained information.

Table 4: Critical variables that affect the development of Ceratitis capitata. Source: own elaboration.

Cod.	Variable	Neutrosophic scale	Intervals	Description
H	Humidity and precipitation	The analysis covers from optimal humidity (65-80% RH) to non-suitable conditions (too low <65% RH or too high >80% RH).	Covers from optimal humidity (65-80% RH) to unsuitable conditions (too low <65% RH or too high >80% RH).	Humidity primarily affects the larval development and survival of pupae. Adequate moisture is crucial for pupation and the emergence of adults, while extremes can cause desiccation or diseases.
DH	Availability and diversity of hosts	From high diversity and availability of hosts (optimal) to low diversity (inadequate).	From high diversity and host availability (optimal) to low diversity (inappropriate).	The availability of a wide range of fruits and vegetables provides continuous opportunities for oviposition and feeding, essential for maintaining high annual generations.
PS	Agricultural practices and pest control	It evaluates from integrated and sustainable management practices (good) to inappropriate practices that increase the pest (bad).	Evaluates from integrated and sustainable management practices (good) to inadequate practices that increase the pest (bad).	Sustainable practices and integrated pest management help control populations without creating resistance or damaging the ecosystem, while inappropriate practices can increase the fly population.
CCA	Climate change and altitude	From moderate changes that can be manageable (moderately good) to extremes that displace the fly from optimal areas (moderately bad).	From moderate changes that can be manageable (fairly good) to extremes that displace the fly from optimal areas (fairly bad).	Climate change can alter the optimal geographic zones for Ceratitis capitata by modifying temperature and humidity conditions, while altitude locally affects these conditions.
T	Temperature	It evaluates from optimal conditions (16-32°C) to non-suitable conditions (<16°C or >32°C) for the development of the fly.	Evaluates from optimal conditions (16-32°C) to unsuitable conditions (<16°C or >32°C) for fly development.	Temperature is crucial for all development phases of Ceratitis capitata, from the rate of development to reproduction. An optimal range allows for up to 25-26 generations per year, while temperatures outside this range can inhibit development and reduce survival.

Observations:

- Variable: Elements that influence the life and proliferation of Ceratitis capitata.
- Neutrosophic Scale: Adapts from an evaluation of "Extremely Good" to "Extremely Bad," using a scale of truth, indeterminacy, and falsehood according to the provided neutrosophic coefficients.

Once the variables and their ranges of action have been defined, the process moves to the projected estimation of the variables over 20 years. This forecast projection includes indeterminacies and the ranges where the analyzed variable would impact various regions (see Tables 5 and 6).

Table 5: Estimated projection of variability intervals of H, DH, and PS in the coming years. Source: own elaboration.

Year	H		DH		PS	
A1	(0.3,0.75,0.80)	(0.50,0.55,0.5)	(0.10,0.90,0.95)	(0.3,0.75,0.80)	(0.10,0.90,0.95)	(0.3,0.75,0.80)
A2	(0.10,0.90,0.95)	(0.3,0.75,0.80)	(0.3,0.75,0.80)	(0.50,0.55,0.5)	(0.10,0.90,0.95)	(0.3,0.75,0.80)
A3	(0.3,0.75,0.80)	(0.3,0.75,0.80)	(0.10,0.90,0.95)	(0.10,0.90,0.95)	(0.3,0.75,0.80)	(0.50,0.55,0.5)
A4	(0.10,0.90,0.95)	(0.10,0.90,0.95)	(0.3,0.75,0.80)	(0.7,0.2,0.25)	(0.10,0.90,0.95)	(0.50,0.55,0.5)
A5	(0.50,0.55,0.5)	(0.50,0.55,0.5)	(0.50,0.55,0.5)	(0.50,0.55,0.5)	(0.10,0.90,0.95)	(0.3,0.75,0.80)
A6	(0.10,0.90,0.95)	(0.50,0.55,0.5)	(0.3,0.75,0.80)	(0.50,0.55,0.5)	(0.3,0.75,0.80)	(0.7,0.2,0.25)
A7	(0.3,0.75,0.80)	(0.50,0.55,0.5)	(0.10,0.90,0.95)	(0.3,0.75,0.80)	(0.10,0.90,0.95)	(0.50,0.55,0.5)
A8	(0.10,0.90,0.95)	(0.50,0.55,0.5)	(0.50,0.55,0.5)	(0.7,0.2,0.25)	(0.10,0.90,0.95)	(0.50,0.55,0.5)
A9	(0.3,0.75,0.80)	(0.50,0.55,0.5)	(0.10,0.90,0.95)	(0.50,0.55,0.5)	(0.10,0.90,0.95)	(0.50,0.55,0.5)
A10	(0.50,0.55,0.5)	(0.92,0.1,0.12)	(0.50,0.55,0.5)	(0.92,0.1,0.12)	(0.10,0.90,0.95)	(0.50,0.55,0.5)
A11	(0.50,0.55,0.5)	(0.92,0.1,0.12)	(0.50,0.55,0.5)	(0.92,0.1,0.12)	(0.3,0.75,0.80)	(0.50,0.55,0.5)
A12	(0.50,0.55,0.5)	(0.92,0.1,0.12)	(0.50,0.55,0.5)	(0.7,0.2,0.25)	(0.3,0.75,0.80)	(0.50,0.55,0.5)
A13	(0.3,0.75,0.80)	(0.7,0.2,0.25)	(0.3,0.75,0.80)	(0.92,0.1,0.12)	(0.3,0.75,0.80)	(0.7,0.2,0.25)
A14	(0.3,0.75,0.80)	(0.7,0.2,0.25)	(0.50,0.55,0.5)	(0.92,0.1,0.12)	(0.50,0.55,0.5)	(0.92,0.1,0.12)
A15	(0.3,0.75,0.80)	(0.7,0.2,0.25)	(0.3,0.75,0.80)	(0.50,0.55,0.5)	(0.50,0.55,0.5)	(0.92,0.1,0.12)
A16	(0.50,0.55,0.5)	(0.92,0.1,0.12)	(0.50,0.55,0.5)	(0.92,0.1,0.12)	(0.3,0.75,0.80)	(0.7,0.2,0.25)
A17	(0.3,0.75,0.80)	(0.92,0.1,0.12)	(0.50,0.55,0.5)	(0.92,0.1,0.12)	(0.3,0.75,0.80)	(0.7,0.2,0.25)
A18	(0.3,0.75,0.80)	(0.7,0.2,0.25)	(0.50,0.55,0.5)	(0.92,0.1,0.12)	(0.50,0.55,0.5)	(0.92,0.1,0.12)
A19	(0.50,0.55,0.5)	(0.92,0.1,0.12)	(0.50,0.55,0.5)	(0.92,0.1,0.12)	(0.3,0.75,0.80)	(0.7,0.2,0.25)
A20	(0.3,0.75,0.80)	(0.92,0.1,0.12)	(0.3,0.75,0.80)	(0.92,0.1,0.12)	(0.3,0.75,0.80)	(0.92,0.1,0.12)

Table 6: Estimated projection of CCA and T variability intervals in the coming years. Source: own elaboration.

Year	CCA		T	
A1	(0.10,0.90,0.95)	(0.3,0.75,0.80)	(0.10,0.90,0.95)	(0.50,0.55,0.5)
A2	(0.50,0.55,0.5)	(0.7,0.2,0.25)	(0.10,0.90,0.95)	(0.50,0.55,0.5)
A3	(0.50,0.55,0.5)	(0.92,0.1,0.12)	(0.3,0.75,0.80)	(0.92,0.1,0.12)
A4	(0.10,0.90,0.95)	(0.3,0.75,0.80)	(0.3,0.75,0.80)	(0.50,0.55,0.5)
A5	(0.3,0.75,0.80)	(0.50,0.55,0.5)	(0.3,0.75,0.80)	(0.50,0.55,0.5)
A6	(0.3,0.75,0.80)	(0.7,0.2,0.25)	(0.3,0.75,0.80)	(0.50,0.55,0.5)
A7	(0.50,0.55,0.5)	(0.92,0.1,0.12)	(0.3,0.75,0.80)	(0.7,0.2,0.25)
A8	(0.3,0.75,0.80)	(0.50,0.55,0.5)	(0.3,0.75,0.80)	(0.7,0.2,0.25)
A9	(0.3,0.75,0.80)	(0.50,0.55,0.5)	(0.3,0.75,0.80)	(0.7,0.2,0.25)
A10	(0.3,0.75,0.80)	(0.7,0.2,0.25)	(0.50,0.55,0.5)	(0.92,0.1,0.12)
A11	(0.3,0.75,0.80)	(0.7,0.2,0.25)	(0.3,0.75,0.80)	(0.50,0.55,0.5)
A12	(0.3,0.75,0.80)	(0.50,0.55,0.5)	(0.3,0.75,0.80)	(0.50,0.55,0.5)
A13	(0.50,0.55,0.5)	(0.7,0.2,0.25)	(0.3,0.75,0.80)	(0.7,0.2,0.25)
A14	(0.3,0.75,0.80)	(0.50,0.55,0.5)	(0.50,0.55,0.5)	(0.92,0.1,0.12)
A15	(0.3,0.75,0.80)	(0.50,0.55,0.5)	(0.50,0.55,0.5)	(0.92,0.1,0.12)
A16	(0.50,0.55,0.5)	(0.92,0.1,0.12)	(0.50,0.55,0.5)	(0.92,0.1,0.12)
A17	(0.3,0.75,0.80)	(0.7,0.2,0.25)	(0.50,0.55,0.5)	(0.92,0.1,0.12)
A18	(0.50,0.55,0.5)	(0.92,0.1,0.12)	(0.3,0.75,0.80)	(0.7,0.2,0.25)
A19	(0.50,0.55,0.5)	(0.92,0.1,0.12)	(0.50,0.55,0.5)	(0.92,0.1,0.12)
A20	(0.3,0.75,0.80)	(0.92,0.1,0.12)	(0.3,0.75,0.80)	(0.92,0.1,0.12)

Neutrosophic Statistical Analysis of the Sample: Temperature emerges as the primary variable influencing the biological development of Ceratitis capitata, with direct effects on the rate of development, survival, and reproduction. However, the interaction of temperature with other factors such as humidity, availability of hosts, and agricultural practices is also fundamental. These combined factors determine the fly's ability to establish, survive, and expand, particularly under the climate change scenarios projected for the future. Therefore, calculations of the neutrosophic mean ($\bar{x}_N$,), neutrosophic standard deviation (S_N), and neutrosophic coefficient of variation (CV_N) are conducted to understand the relationship between the presence of this pest and the significance of the variables, and how Ceratitis capitata would impact Ecuador in the coming years (see Table 7).

Table 7: Estimated projection of $\bar{x}_N$, S_N, and CV_N in the next years. Source: own elaboration.

Items	$\bar{x}_N$		S_N		CV_N	
H	[(0.3,0.65,0.7);(0.4,0.55,0.65)]	0.37	4,511 + 7,163 I	0.016	1,271 + 1,038 I	0.125
DH	[(0.3,0.65,0.7);(0.4,0.55,0.65)]	0.45	5,305 + 7,528 I	0.008	1,378 + 1,046 I	0.087
PS	[(0.6,0.35,0.4);(0.7,0.25,0.3)]	0.67	3,448 + 6,825 I	0.030	1,112 + 1,019 I	0.172
CCA	[(0.6,0.35,0.4);(0.7,0.25,0.3)]	0.74	5,019 + 7,861 I	0.006	1,338 + 1,028 I	0.077
T	[(0.8,0.15,0.2);(0.9,0.05,0.1)]	0.88	5.113 + 8 I	0.006	1,346 + 1,026 I	0.076

The impact of Ceratitis capitata (Mediterranean fruit fly) in Ecuador is favored by temperature variations and how these affect the development and expansion of the annual generations of this pest in agriculture, especially in mango crops. The increase in temperatures may allow Ceratitis capitata to increase the number of generations per year under climate change scenarios projected for the year 2050, compared with current data. This underscores the importance of temperature as a determining factor in population dynamics and the potential for infestation of this species. The results for each variable in Table 7 showed that:

i. Temperature (Average: 0.88, Standard Deviation: 0.076)
   - ❖ Stability: The low standard deviation indicates that the temperature remains relatively constant over the years, varying slightly around the average of 0.76 on the de-neutrosophied scale. This suggests that thermal conditions for Ceratitis capitata are stable and predictable, which is crucial for planning phenological and biological controls.
   - ❖ Favorable Conditions: An average close to 0.8 implies that temperatures are often within optimal ranges for the insect's development, potentially increasing the frequency of its annual generations.

ii. Humidity (Average: 0.37, Standard Deviation: 0.125)
   - ❖ Moderate Variability: Humidity shows little variation from year to year, suggesting that moisture conditions do not fluctuate drastically and are predictably adequate for the fly.
   - ❖ Sufficiency: An average close to 0.37 on the de-neutrosophied scale suggests that humidity conditions are generally adequate for the survival and reproduction of Ceratitis capitata.

iii. Hosts (Average: 0.45, Standard Deviation: 0.087)
   - ❖ Optimal and Stable: The high average indicates a constant and sufficient abundance of hosts available for Ceratitis capitata, which is critical for its feeding and reproduction.
   - ❖ Impact on Management: The stability in host availability requires that management strategies continuously focus on crop rotation and other techniques to minimize infestation risks.

iv. Agricultural Practices (Average: 0.67, Standard Deviation: 0.172)
   - ❖ Management Efficacy: A high average and low variability in this variable suggest that agricultural management and pest control practices are effective and consistently applied, contributing to the effective management of the Ceratitis capitata population. However, the standard deviation indicates that effective methods to combat this pest have an impact on increasing costs.

v. Climate Change (Average: 0.74, Standard Deviation: 0.077)
   - ❖ Uncertainty and Risk: Although the average is moderately high, the relevance of climate change on this scale suggests that there is a significant potential impact on local conditions that could influence the population dynamics of Ceratitis capitata. Fluctuations, although small, could mean years with more extreme conditions in the future.

The consistency in the variables of temperature, humidity, and host availability suggests that the environment in Ecuador is generally favorable for Ceratitis capitata, which could complicate its management if adequate and effective agricultural practices are not applied. Management strategies must, therefore, be dynamic and adapt to the small annual changes in these conditions, especially considering the influence of climate change. Anticipation and adaptation to these conditions through the use of predictive models and sustainable agricultural practices are key to controlling the population of this pest and minimizing the economic impact on agriculture.

In summary, the analyses show a moderate increase in the number of generations of Ceratitis capitata due to the projected temperature rise for 2050. This trend suggests that climate change could exacerbate the impact of this pest in Ecuador, affecting agriculture and requiring attention to management and control strategies.

4 Long-term stock projection

The following table (Table 8) provides a comprehensive framework of actions and strategies to effectively address the issue of Ceratitis capitata. By integrating these measures, farmers and resource managers can enhance the resilience of agricultural systems against this pest and thus ensure the sustainability of agricultural production in the region. These strategies should be reviewed and adapted regularly to reflect changing conditions and advancements in agricultural science and technology. Additionally, it helps to visualize and understand how each environmental and management factor affects the biology of Ceratitis capitata, especially regarding temperature variability due to climate change.

Table 8: Strategies to mitigate the impact of Ceratitis capitata in the coming years. Source: own elaboration.

No.	Strategy type	Action/alternative	Description	Scope	Objective	Measurement Metrics
S1	Monitoring and Surveillance.	Implementation of traps.	Use traps with specific attractants to monitor and reduce adult populations.	Local to National.	Adult population reduction.	Number of flies captured.
		Early warning systems.	Apply predictive models and alert systems based on meteorological and phenological data.	Regional to National.	Outbreak forecasting.	Alerts issued / Responses.
S2	Integrated Pest Management.	Biological control.	Encourage the use of natural enemies such as parasitoids and predators of the fly.	Local to Regional	Effective biological control.	Rate of parasitism / Predation.
		Microbial control.	Use entomopathogens such as fungi (Beauveria bassiana) and bacteria (Bacillus thuringiensis).	Local to Regional	Reduction of larvae and adults.	Reduction in larval population.
S3	Sterile Insect Techniques.	Release of sterile insects.	Release sterile males to interrupt reproduction and reduce the fly population.	Regional to National	Interruption of reproduction.	Number of sterile males released.
S4	Cultural and Agronomic Management.	Crop rotation.	Rotate crops that are not hosts to break the pest's life cycle.	Local to Regional	Host reduction.	Area of non-host crops.
		Removal of crop residues.	Clean fields to eliminate potential pest hosts.	Local	Minimizing resources for the pest.	Tons of waste removed.
		Physical barriers.	Use nets and covers to protect crops and prevent infestation.	Local	Prevention of infestation.	Hectares protected.
S5	Responsible Use of Insecticides.	Targeted application.	Employ specific insecticides in high-risk areas in a targeted manner.	Local to Regional	Efficient pest control.	Treated area vs. infested area.
		Biorational insecticides.	Promote less toxic and specific products such as insect growth regulators.	Local to National	Sustainability in control.	Reduction in chemical use.
S6	Adaptation to Climate Change.	Adjustment of practices based on climate predictions.	Modify management practices based on climate predictions to anticipate changes in pest activity.	National	Adaptation to climate change.	Changes implemented / Effectiveness.
		Research and development.	Promote research on climate models and their impact on pest dynamics.	National	Improvement in knowledge and action.	Publications / New strategies adopted.
S7	Education and Cooperation.	Farmer training.	Provide training on effective and sustainable pest management.	Local to National	Education and awareness.	Number of farmers trained.
		International collaboration.	Participate in international programs to share knowledge and strategies.	International	Global cooperation.	Joint programs and projects.
S8	Development of Resistant Varieties.	Genetic improvement.	Develop crop varieties that are resistant or less attractive to the fly.	National	Genetic resistance in crops.	Number of varieties developed.

5 Conclusion

Climate change is a critical factor influencing the distribution, phenology, and population dynamics of Ceratitis capitata. The analysis of future scenarios using neutrosophic statistics shows how the uncertainty and variability inherent in climate projections can be managed to anticipate changes in pest activity. Adapting management strategies to the context of climate change, by adjusting practices according to climate predictions, is essential for maintaining the effectiveness of fly control in the future.

Neutrosophic statistics prove to be a valuable tool in analyzing fluctuations and uncertainties in variables affecting Ceratitis capitata. By providing a framework to incorporate truth, indeterminacy, and falsehood into the assessment of environmental and management conditions, it allows for a deeper understanding and a richer description of the complex dynamics at play. Using neutrosophic statistics helps to better model and understand how variations in factors such as temperature, humidity, and host availability can influence fly populations.

The proposed strategies, including monitoring and surveillance, integrated pest management, the use of sterile insect techniques, and agronomic and cultural practices, prove to be essential for effectively controlling the population of Ceratitis capitata. The coordinated implementation of these strategies addresses various cycles and aspects of the pest's biology, thereby reducing the impact on crops and minimizing economic losses. Moreover, the combination of biological, physical, chemical, and educational approaches ensures a sustainable solution that is adaptable to local and changing conditions.

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