Development of Neutrosophic Cognitive Maps (NCM) for the Evaluation and Ranking of the Main Causes of the Appearance of Fruit Fly Pests

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Abstract

The development of Neutrosophic Cognitive Maps (NCM) for the evaluation and ranking of the main causes of the appearance of fruit fly pests represents a significant advance in the field of agriculture and entomology. This innovative approach allows for a holistic and integrated view of the complex and often interdependent factors that contribute to the proliferation of these destructive pests. Using neutrosophic theory, which incorporates degrees of truth, falsehood, and indeterminacy, NCMs offer a powerful tool for identifying and prioritizing critical variables. In this way, a more nuanced and precise understanding of the phenomenon is facilitated, enabling the design of more effective and sustainable management strategies. The methodology applied in the construction of the NCM is characterized by its ability to manage the uncertainty and ambiguity inherent to ecological and agricultural systems. Through the participation of experts and the analysis of empirical data, maps can be outlined that reflect the real complexity of the problem. These maps not only highlight direct causes, such as weather conditions and poor agricultural practices, but also address underlying and systemic factors. Thus, the use of NCM provides a robust conceptual framework for informed decision making, improving the efficiency of interventions and contributing significantly to crop protection and global food security.

Keywords: Teaching Methods; Fruit Fly, Neutrosophic Cognitive Maps (NCM); NCM

1. Introduction

The emergence of agricultural pests, specifically the fruit fly, has been a persistent concern in the global agricultural industry. The economic losses and environmental damage these pests cause are significant and far-reaching. The search for efficient and accurate methods to evaluate and prioritize the underlying causes of these infestations is therefore crucial for agricultural sustainability and productivity [1]. In this context, the development of Neutrosophic Cognitive Maps (NCM) is presented as a promising methodology. NCMs allow a detailed and nuanced representation of information, integrating uncertainty, indeterminacy and vagueness, aspects inherently present in biological and ecological systems. This innovative approach allows for a more holistic and accurate assessment of the various variables that contribute to pest emergence. Traditionally, methodologies for studying pests have been limited by their ability to handle complexity and uncertainty [2]. Conventional statistical techniques and deterministic models, although useful, do not adequately capture the inherently uncertain and dynamic nature of agricultural ecosystems. In contrast, NCMs offer superior flexibility, allowing the incorporation of diverse types of knowledge, from empirical data to expert judgments.

The fruit fly, a formidable enemy to crops such as citrus, apples and grapes, presents a particular challenge due to its rapid reproduction and adaptability Identifying and prioritizing the main causes of its appearance is essential

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for the development of effective and sustainable control strategies [3]. NCMs, with their ability to handle uncertain data and interdependent variables, become an invaluable tool in this process.
A crucial aspect of NCMs is their ability to integrate different sources of information and perspectives. This multidimensional approach is essential in the fight against fruit flies, since it allows considering agronomic, climatic, biological and socioeconomic factors [4]. Integrating these various dimensions provides a more complete and nuanced view of the underlying causes of infestations.
Furthermore, the application of NCM facilitates the identification of key interactions and causal relationships between variables. This approach not only allows for a better understanding of the factors that contribute to pest emergence, but also helps to identify critical intervention points [5]. The ability to prioritize these causes allows farmers and policy makers to prioritize the most effective actions to mitigate pest impacts.
The use of NCM in pest assessment also stands out for its adaptability to different contexts and scales. Whether at the level of an individual farm or across a broader agricultural region, NCMs can be adjusted to reflect local particularities and provide specific recommendations. This adaptability is essential to address the diversity of conditions that can influence the emergence of the fruit fly [6].
The development of Neutrosophic Cognitive Maps represents a significant advance in the evaluation and ranking of the main causes of the appearance of the fruit fly. This innovative approach offers a powerful tool to manage the complexity and uncertainty inherent in agricultural systems. By integrating multiple sources of information and perspectives, NCMs provide a more complete and accurate view of underlying factors, facilitating the development of more effective and sustainable control strategies.
This methodology not only promises to improve pest management in agriculture, but can also be applied in other fields where uncertainty and complexity play a crucial role. Continued research and development in the use of NCM will open new opportunities to address complex challenges more holistically and effectively.

2. Related work

2.1. The Fruit Fly

The fruit fly, an insidious and persistent pest, represents a constant challenge to farmers around the world. Its ability to adapt and proliferate in various climatic and geographical conditions makes it a formidable enemy. It is not just a matter of direct damage to crops; The fruit fly also imposes a considerable economic burden due to the need to implement control measures and the loss of international markets for infested products [7].

From a biological point of view, the fruit fly is equal parts fascinating and alarming. These tiny creatures, often just a few millimeters in length, possess an extraordinary reproductive capacity [8]. A single female can lay hundreds of eggs in her lifetime, each of which has the potential to become a new source of infestation. This rapid and efficient life cycle facilitates the rapid expansion of fruit fly populations, making their control and eradication difficult [9-10].
Fruit fly control has evolved significantly over the years. Initially, there was a heavy reliance on chemical pesticides, a solution that, while effective in the short term, has proven unsustainable. Heavy use of pesticides not only has serious environmental implications, but can also lead to the development of resistance in fly populations. Furthermore, pesticide residue in agricultural products can negatively affect human health and limit access to markets demanding in terms of food safety.
In response to these challenges, research and development of biological control methods and integrated agricultural practices have gained importance. The use of natural enemies, such as parasitoids and predators, has shown promising results. However, these methods are not a panacea and require a deep understanding of local ecological dynamics and careful implementation to be effective. The fight against fruit flies, therefore, is a game of chess, where each move must be carefully considered and strategically executed [11].
Another innovative approach has been the use of mass trapping and sexual confusion techniques. These strategies seek to interfere with the flies' ability to find mates and reproduce, thus significantly reducing their populations. Implementing these techniques, however, requires initial investments and constant monitoring, which can be a challenge for farmers with limited resources[10].

2.2. Neutrosophic Cognitive Maps.

In the vast field of social and behavioral sciences, the need for analytical tools that capture the complexity and uncertainty of human interactions is increasingly evident – Neutrosophic Cognitive Maps (NCM), an innovative methodology that integrates the principles of neutrosophic logic, have emerged as a promising solution to address this need. NCMs allow modeling situations that include degrees of truth, falsity and indeterminacy, offering a

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more faithful and nuanced representation of reality [12]. The concept of NCM is based in neutrosophic set theory, developed by Florentin Smarandache, which extends classical logic to handle uncertainty, ambiguity and paradox. This theory introduces a third neutral value (N), in addition to the traditional values of truth (T) and falsity (F), allowing a more flexible and adaptive representation of information. NCMs apply these principles to the field of cognitive maps, allowing a graphical and analytical representation of the causal relationships and dynamics of complex systems [13- 14].

In the context of parenting competencies and family and social issues, NCMs offer a powerful tool for assessment and intervention – Family interactions are often marked by ambivalence and contradiction, and traditional approaches may be insufficient to capture this complexity. NCMs, by incorporating neutrosophic elements, allow a richer and more detailed representation of these dynamics, facilitating a deeper and more precise understanding [13]

The implementation of NCM in the analysis of parenting competencies involves the identification and modeling of causal relationships between different factors and behaviors. For example, an NCM can represent how effective communication between parents and children influences the emotional development of the child, or how economic stress can affect parents' ability to set clear boundaries. By capturing these nuances, NCMs provide a solid foundation for the development of more effective and personalized intervention strategies. One of the main advantages of NCMs is their ability to manage indeterminacy and uncertainty, aspects that are inherent to human interactions. In familiar situations, there are often unknown factors or variables that cannot be clearly defined. NCMs allow these elements to be incorporated explicitly into the model, offering a more complete and realistic representation of the situation [13]. This is particularly useful in the assessment of parenting competencies, where perception and subjectivity play a crucial role.

Furthermore, NCMs facilitate the identification of patterns and dynamics that may not be evident through traditional analysis methods - By graphically representing causal relationships and interactions between different factors, NCMs allow the underlying structure of the system to be visualized and detect areas of conflict or dysfunction. This capacity for in-depth analysis is essential for the design of more precise and effective interventions. The use of NCM in the evaluation of parenting skills and the resolution of family and social problems not only offers benefits at the individual level, but also to community and societal level. By providing a more accurate and detailed understanding of family dynamics, NCMs can inform the development of more effective and adaptive policies and support programs. This, in turn, can contribute to improving the overall well-being of families and strengthen the social fabric.

Neutrosophic Cognitive Maps represent an innovative and powerful tool for evaluation and intervention in the field of parenting skills and family and social problems - By allowing a richer and more nuanced representation of reality, capturing indeterminacy and uncertainty, NCM offer a renewed and profound perspective to address the complex challenges of human interactions – The adoption and development of this methodology promises to significantly transform professional practice in the social and behavioral sciences, providing new avenues for understanding and supporting families in diverse and changing contexts [14]

In this study, neutrosophic cognitive maps will be used, so we explain them below -

Definition 1[15]: Let X be a universe of discourse - A Neutrosophic Set (NS) is characterized by three membership functions, $u_A(x)$, $r_A(x)$, $v_A(x)$: [, which satisfy the condition $-0 \leq \inf u_A(x) + \inf r_A(x) + \inf v_A(x) \leq \sup u_A(x) + \sup r_A(x) + \sup v_A(x) \leq 3+$ $\in$ for $_{all}$ x standard]-0 ,1 +[. [15]

Definition 2: Let X be a universe of discourse - A single-valued neutrosophic set (SVNS) A in X is a set of the form [16] :

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

Where $u_A, r_A, v_A : \in_A(x)$ are the true, indeterminate, and falsity 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 $\in$[0,1] and satisfies $0 \leq a + b + c \leq 3$.

Other important definitions are related to graphs. [16, 17, 18]

Definition 3 : A *neutrosophic graph* contains at least one indeterminate edge , represented by dotted lines [17]

Definition 4: A *neutrosophic directed graph* is a directed graph that contains at least one indeterminate edge, which is represented by dotted lines

Definition 5: A *neutrosophic cognitive map (NCM) is a* neutrosophic directed graph, whose nodes represent concepts and whose edges represent causal relationships between the edge [15]

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If there are k vertices $C_1, C_2, \ldots, C_k$, each can be represented by a vector $(x_1, x_2, \ldots, x_k)$ where $xi \in \{0,1, I\}$ depending on the state of the vertex C_i at a specific time or situation:

- $x_i = 0$: Vertex C_i is in an activated state.
- $x_i = 1$: Vertex C_i is in deactivated state.
- $x_i = I$: The state of vertex C_i is indeterminate.

Definition 6 [19, 10]: An NCM that has edges with weights in $\{-1, 0, 1, I\}$ is called *a simple neutrosophic cognitive map*

Connections between vertices: a directed edge from C_m to C_n is called a connection and represents causality from C_m to C_n

Associate weights to each vertex: Each vertex in the NCM is associated with a weight within the set { 0 , 1, -1, I}. The weight of the edge $C_m C_n$, denoted as α_{mn}, indicates the influence of C_m on C_n and can be:

-$\alpha_{mn} = 0$: Cm does not affect C_n

-$\alpha_{mn} = 1$: An increase (decrease) of C_m increases (decrease) of C_n

-$\alpha_{mn} = -1$: An increase (decrease) of C_m results in a decrease (increase) of C_n

-$\alpha_{mn} = I$: The effect of C_m on C_n is indeterminate.

Definition 7: If $C_1, C_2, \ldots, C_k$ are the vertices of an NCM. The neutrosophic matrix N(E) is defined as N(E) = α_{mn}), where α_{mn} denotes the weight of the directed edge $C_m C_n$, with $\alpha_{mn} \in$ [-1,0,1, I]. N (E) is called *the neutrosophic adjacency matrix* of the NCM.

Definition 8: Let $C_1, C_2, \ldots, C_k$ be the vertices of an NCM. Let A = $(a_1, a_2, \ldots, a_k)$, where am $\in$ {-1, 0, 1, I}. A is called *the neutrosophic instantaneous state vector* and means an on-off-indeterminate state position of the vertex at a given instant.

- $a_m = 0$ if C_m is disabled (has no effect),

- $a_m = 1$ if C_m is activated (takes effect),

- $a_m = I$ if C_m is indeterminate (its effect cannot be determined).

Definition 9: Let $C_1, C_2, \ldots, C_k$ be the vertices of an NCM. Let $\overrightarrow{C_1C_2}, \overrightarrow{C_2C_3}, \overrightarrow{C_3C_4}, \ldots, \overrightarrow{C_mC_n}$ the edges of the NCM be, then the edges constitute a *directed cycle*.

- The NCM is said to be *cyclic* if it has a directed cycle. It is said to be *acyclic* if it does not have any directed cycle.

Definition 10: An NCM containing cycles is said to have *feedback*. When there is feedback in the NCM it is said to be a *dynamic system*.

Definition 11: Let $\overrightarrow{C_1C_2}, \overrightarrow{C_2C_3}, \overrightarrow{C_3C_4}, \ldots, \overrightarrow{C_{k-1}C_k}$ be a cycle. when Cm is activated and its causality flows along the edges of the cycle and then is the cause of C_m itself, then the dynamical system is circulating. This is valid for each vertex C_m with m = 1, 2,… , k. The equilibrium state of this dynamic system is called the *hidden pattern*.

Definition 12: If the equilibrium state of a dynamical system is a single state, then it is called a *fixed point*. An example of a fixed point is when a dynamical system starts being activated by C_1. If the NCM is assumed to be set at C_1 and C_k, which means the state remains as (1, 0,…, 0, 1), then this neutrosophic state vector is called fixed point.

Definition 13: If the NCM establishes a repeating neutrosophic state vector of the form:

$A_1 \to A_2 \to \cdots \to A_m \to A_1$LCM *limit cycle*.

3. Results and discussion

To successfully implement a strategy that allows the eradication and prevents the appearance of the fruit fly pest, it is necessary to carry out a study of all the causes that generate this disease, which is why it is necessary, due to the large number of causes, make a study of the main ones to focus the work and resources in this battle. Several

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surveys were applied which revealed 8 other fundamental causes which we will expose in this study to focus on the three most recurrent ones. In the study carried out, the most frequent causes were:

Table 1: Fundamental causes of the appearance of the fruit fly pest.

CAUSE 1: Lack of Hygienic Practices in Production and Storage: Poor hygiene during fruit production and storage can allow fruit flies to find suitable places for oviposition and larval development.
CAUSE 2: Improper Management of Crop Residues: The accumulation of crop residues not properly disposed of can provide shelter and food for fruit flies, thus increasing pest populations in subsequent seasons.
CAUSE 3: Lack of Control of Transit and Trade of Infested Products: The lack of adequate measures to control the transport and trade of infested fruits allows the spread of the pest to new geographic areas.
CAUSE 4: Poor Agricultural Education and Training: Lack of knowledge among farmers about proper integrated pest management practices can result in ineffective or inadequate control strategies.
CAUSE 5: Absence of Constant Monitoring and Surveillance: The lack of regular monitoring and surveillance programs makes early detection of fruit fly outbreaks difficult, allowing pest populations to grow uncontrolled.
CAUSE 6: Lack of knowledge of the biology and life cycle of the pest: Lack of understanding of the biology and life cycle of the fruit fly can lead to erroneous decisions regarding the timing and method of applying control measures. .
CAUSE 7: Shortage of Investment in Research and Development: The lack of investment in research and development of innovative control methods limits the options available to effectively combat the fruit fly pest in the long term.
CAUSE 8: Improper Use of Pesticides: The indiscriminate or incorrect use of pesticides can cause resistance of fruit flies to these chemicals, making their effective control difficult and increasing the infestation.

Knowing and elucidating these causes contributes to better dealing with the pest and its devastating effects on crops, as well as enhancing and redirecting all efforts and resources on the appropriate front.

The process began by developing an NCM to represent the causal connections between the eight fundamental causes, according to Table 1. this stage involved defining the interactions between the various causes and visualizing them in a neutrosophic cognitive map, detailed in Figure 1.

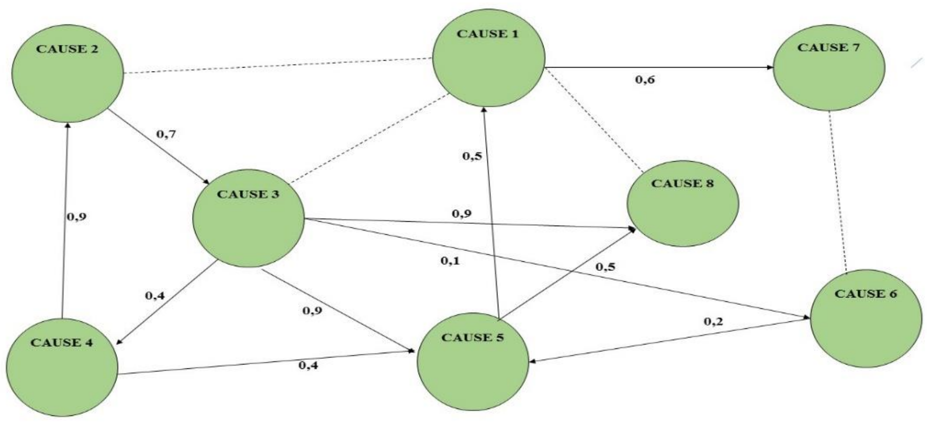

Figure 1. Neutrosophic cognitive map between fundamental causes of the appearance of the fruit fly. Source: self made

The NCM is developed through the collection and representation of relevant knowledge – The adjacency matrix obtained, which is based on the neutrosophic values provided by specialists, is detailed in Table *2* as an essential tool to analyze and interpret causal connections within the framework of the study.

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Table 2: Adjacency matrix. Source: own elaboration.

	CAUSE1	CAUSE2	CAUSE3	CAUSE4	CAUSE5	CAUSE6	CAUSE7	CAUSE8
CAUSE1	0	Yo	Yo	0	0	0	0.6	Yo
CAUSE 2	Yo	0	0.7	0	0	0	0	0
CAUSE3	0	0	0	0.4	0.9	0.1	Yo	0.9
CAUSE4	0	0.9	0	0	0.4	0	0	0
CAUSE5	0.5	0	0	0	0	0	0	0.5
CAUSE6	0	Yo	0	Yo	0.2	0	0	0
CAUSE7	0	0	0	0	0	0	Yo	0
CAUSE8	0	0	Yo	0	0	Yo	0	0

Following this perspective, the calculated centrality measures are presented below (Table 3). these metrics provide a quantitative analysis of the relative relevance of nodes within the network framework, which is crucial for understanding the dynamics and impact of the various components in the analyzed system.

Table 3: Centrality analysis. Source: Own elaboration.

Node	*od(vi)*	*id (vi)*	*td(vi)*
CAUSE1	0.6+3I	0.5+I	1.1+4I
CAUSE2	0.7+I	0.9+2I	1.6+3I
CAUSE3	2,3+I	0.7+2I	3+3I
CAUSE4	1.3	0.4+I	1.7+I
CAUSE5	1	1.5	2.5
CAUSE6	0.2+2I	0.1+I	0.3+3I
CAUSE7	0+I	0.6+2I	0.6+3I
CAUSE8	0+2I	1.4+I	1.4+3I

In the context of static analysis in the NCM, initial results are obtained that incorporate the element of indeterminacy "I" within their neutrosophic values. To refine these results it is essential to carry out a process known as deneutrosopification, recommended by [20]. This process consists of replacing the indeterminacy parameter I, which ranges between 0 and 1, considering in this case "I" as 0.5. The importance of this method lies in its ability to produce more defined and precise results, which significantly simplifies the understanding of the interconnections present in the analysis in question (Table 4).

Table 4: Deneutrosified centrality. Source: own elaboration.

nod	*td(vi)*
CAUSE1	3.1
CAUSE2	3.1
CAUSE3	4.5
CAUSE4	2.2
CAUSE5	2.5
CAUSE6	1.8
CAUSE7	twenty-one
CAUSE8	2.9

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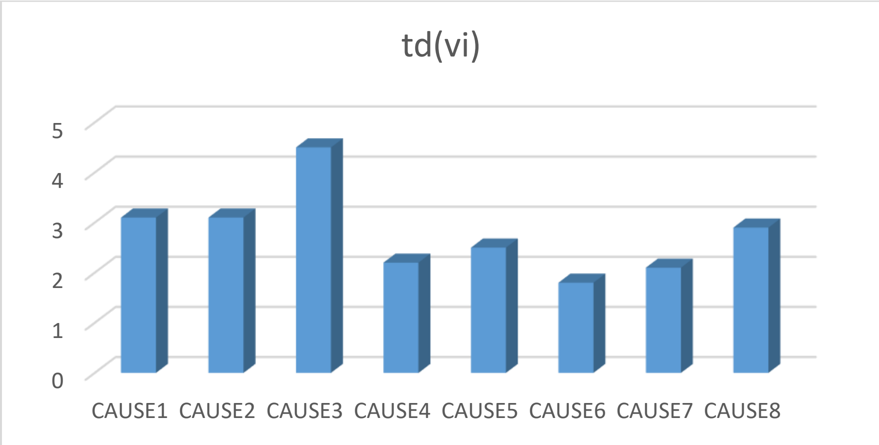

Figure 2. Deneutrosified centrality Source: own elaboration.

Table 5: Deneutrosified centrality ordered from highest to lowest. Source: own elaboration.

CAUSES OF APPEARANCE OF THE FRUIT FLY **(in order of relevance)**	**Deseutrosophized Centrality**
Lack of Control of Traffic and Trade of Infested Products: The lack of adequate measures to control the transport and trade of infested fruits allows the spread of the pest to new geographical areas.	4.5
Lack of Hygienic Practices in Production and Storage: Poor hygiene during fruit production and storage can allow fruit flies to find suitable sites for oviposition and larval development.	3.1
Improper Management of Crop Residues: The accumulation of crop residues not properly disposed of can provide shelter and food for fruit flies, thus increasing pest populations in subsequent seasons.	3.1
Improper Use of Pesticides: The indiscriminate or incorrect use of pesticides can cause resistance of fruit flies to these chemicals, making it difficult to effectively control them and increasing the infestation.	2.9
Lack of Constant Monitoring and Surveillance: The lack of regular monitoring and surveillance programs makes early detection of fruit fly outbreaks difficult, allowing pest populations to grow uncontrolled.	2.5
Poor Agricultural Education and Training: Lack of knowledge among farmers about proper integrated pest management practices can result in ineffective or inappropriate control strategies	2.2
Lack of Investment in Research and Development: Lack of investment in research and development of innovative control methods limits the options available to effectively combat the fruit fly pest in the long term.	2.1
Lack of knowledge of the biology and life cycle of the pest: Lack of understanding of the biology and life cycle of the fruit fly can lead to erroneous decisions regarding the timing and method of applying control measures.	1.8

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In summary, the most relevant causes of the appearance of the fruit fly infestation are:

1. **Lack of Control of Traffic and Trade of Infested Products:** The lack of adequate measures to control the transport and trade of infested fruits allows the spread of the pest to new geographical areas.

2. **Lack of Hygienic Practices in Production and Storage:** Poor hygiene during fruit production and storage can allow fruit flies to find suitable sites for oviposition and larval development.

3. **Improper Management of Crop Residues:** The accumulation of crop residues not properly disposed of can provide shelter and food for fruit flies, thus increasing pest populations in subsequent seasons.

The emergence of the fruit fly, a devastating agricultural pest, is influenced by a series of human factors that exacerbate its impact and spread. Among the main causes is the lack of effective control of the transit and trade of infested products. This deficiency allows the pest to spread rapidly to new geographic areas, where it can establish and multiply without restrictions, severely affecting local crops and the agricultural economy. Another crucial factor is the lack of proper hygiene practices in fruit production and storage. Poor hygiene provides favorable environments for fruit flies to lay their eggs and develop larvae, thus perpetuating cycles of infestation that could be avoided with appropriate and rigorous preventive measures. Improper management of crop residues also plays a significant role. The accumulation of not properly disposed of agricultural debris provides shelter and food for fruit flies, facilitating the survival of their populations between growing seasons and providing a basis for future pest outbreaks that could have been mitigated with more careful management practices. Additionally, the indiscriminate or incorrect use of pesticides contributes to the resistance of fruit flies to these chemicals. This resistance greatly hinders effective pest control efforts, allowing infested populations to grow uncontrolled and cause considerable damage to crops. The absence of regular monitoring and surveillance programs is also a critical factor. Without constant monitoring, early fruit fly outbreaks can go unnoticed, allowing pest populations to expand without timely intervention to contain them, further compounding problems for farmers and farming communities. Furthermore, lack of adequate agricultural education and training among farmers contributes to ineffective or inappropriate control strategies. Lack of knowledge of integrated pest management practices limits farmers' ability to make informed and effective decisions, leaving them vulnerable to the consequences of fruit fly infestations. Another critical aspect is the lack of investments in research and development of innovative control methods. The lack of resources dedicated to finding new solutions limits the options available to effectively combat the pest in the long term, leaving agricultural systems exposed to repeated cycles of infestation and economic losses. Finally, lack of knowledge of the specific biology and life cycle of the fruit fly can lead to erroneous decisions regarding the timing and method of applying control measures. This lack of understanding can result in ineffective interventions that do not address the specific management needs of the pest, thus perpetuating ongoing problems for farmers and the agricultural sector as a whole.

Effectively addressing the underlying human causes of fruit fly emergence and spread requires an integrated and multifaceted approach. From improving hygiene and waste management practices to strengthening agricultural education and encouraging research into innovative control methods, every measure must be carefully considered and implemented to mitigate the devastating impacts of this pest on global agricultural systems.

4. Conclusion

Understanding and addressing the human causes behind the emergence and spread of the fruit fly are essential to developing effective and sustainable strategies to protect global agricultural systems. This insect, recognized for its destructive capacity on various crops, finds in the transit and trade of infested products a quick way to spread to new regions. The lack of adequate controls in these activities facilitates their geographical dispersion, expanding their presence and generating severe impacts on local production and the agricultural economy. Poor hygiene during fruit production and storage emerges as another critical factor. Neglect in sanitary practices creates environments conducive to the oviposition of fruit flies and the development of larvae, perpetuating cycles of infestation that are avoidable with more rigorous and systematic preventive measures. Likewise, inadequate management of agricultural waste provides an ideal habitat for these insects, increasing pest populations and predisposing to future outbreaks that could be controlled with more efficient and conscious practices. The indiscriminate or incorrect use of pesticides represents an additional challenge. The resistance developed by fruit flies against these chemicals makes control tasks extremely difficult, allowing infested populations to grow unchecked and cause significant damage to crops. This situation highlights the urgent need to adopt integrated pest management strategies that minimize the use of pesticides and promote more sustainable and effective alternative

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methods. The lack of regular monitoring and surveillance programs constitutes another critical point. The lack of constant monitoring prevents early detection of fruit fly outbreaks, allowing pest populations to expand without timely intervention to contain them. This shortcoming further compounds the challenges faced by farmers and farming communities, who rely on active surveillance to prevent and effectively manage infestations. Furthermore, insufficient education and training in integrated pest management practices among farmers contribute significantly to ineffective or inappropriate control strategies. Lack of adequate knowledge limits the ability of producers to implement informed and effective measures, leaving them vulnerable to the devastating consequences of fruit fly infestations on their crops and livelihoods. Underinvestment in research and development of innovative control methods constitutes another significant challenge. The lack of resources dedicated to exploring new solutions limits the options available to effectively combat the pest in the long term, exposing agricultural systems to repeated cycles of infestation and economic losses. This aspect underlines the urgent need to increase financial and technical support for research into more advanced and sustainable control methods.

Finally, ignorance of the specific biology and life cycle of the fruit fly leads to erroneous decisions regarding the timing and method of applying control measures. This lack of understanding compromises the effectiveness of the interventions adopted, perpetuating ongoing challenges for farmers and the agricultural sector as a whole. Effectively addressing these underlying human causes requires a comprehensive, multifaceted approach that promotes responsible agricultural practices, improves education and training, and encourages innovation in integrated pest management. Only through coordinated and proactive actions, can we mitigate the devastating impacts of the fruit fly and protect food and economic security in agricultural communities globally.

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