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Presentation of Content

In the first article we present, *Equations to characterize diameter at breast height growth of Pinus montezumae based on increment cores* by Tamarit-Urias, Juan Carlos, with adscription in INIFAP, as the next article we present, *Market research on two natural predators of walnut pests: Trichogramma ssp and Chrysoperla carnea, in Delicias City, Chihuahua* by Ramírez-Moreno, Hilario, Aguirre-Orozco, Mario Abelardo, Delgado-Martínez, Martha Lilia and Contreras-Martínez, Jesús José, with adscription in Tecnológico Nacional De México Campus Delicias, as the next article we present, *Classical methods used for predicting temperature as a relevant variable of climate change* by Alarcón-Ruiz, Erika, González-Barbosa, Juan, Frausto-Solís, Juan and Rangel-González, Javier Alberto with adscription in Tecnológico Nacional de México - Instituto Tecnológico de Ciudad Madero, as the last article we present, *Design of the prototype of a system for the quantification of fungal cells* by Salazar-Casanova, Hermes, Meneses-Flores, Arturo Elfego, Mendoza-San Juan, Luis Alberto and Juárez-Castillo, Efrén, with adscription in Universidad Tecnológica de la Huasteca Hidalguense.

.

Content

Article	Page
	28-39

Article

Equations to characterize diameter at breast height growth of *Pinus montezumae* based on increment cores

Ecuaciones para caracterizar el crecimiento en diámetro normal de *Pinus montezumae* usando virutas de incremento

Tamarit-Urias, Juan Carlos *[a]

[a] ROR INIFAP • GOJ-7847-2022 • 0000-0003-3597-4510 • 86510

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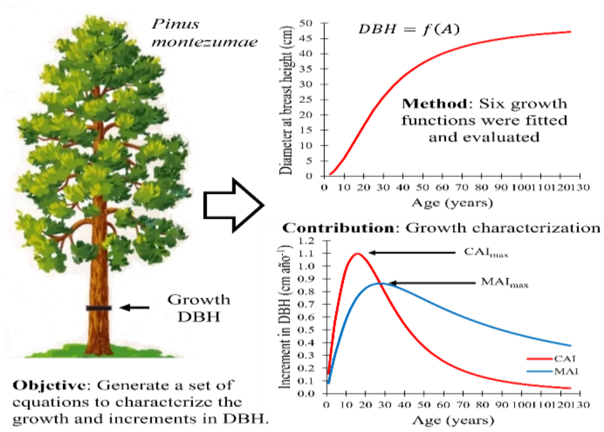
* ✉ [tamarit.juan@inifap.gob.mx]

Abstract

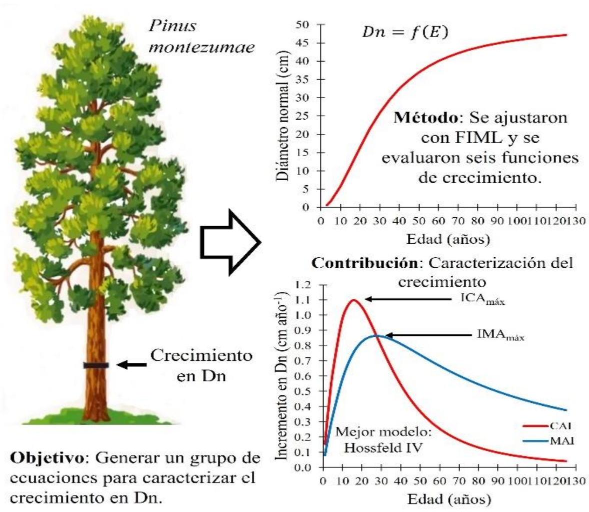
A set of equations to characterize the growth and increments in diameter at breast height (DBH) as a function of age (A) for *Pinus montezumae* in Puebla, Mexico was generated. From radial increment cores collected in the Forest Management Unit 2103 "Teziutlan" 294 pairs of DBH-A observations were processed. Six growth models were fitted. The Hossfeld IV model was selected (R_{2adj} of 0.8328, RMSE of 4.6649 cm and bias of 0.0525 cm). The technical turn was 27.5 years, which corresponds to a maximum mean annual increment of 0.86 cm year^{-1} and a DBH of 23.8 cm.



CAI-MAI, Hossfeld IV model, Technical turn

Resumen

Se generó un conjunto de ecuaciones para caracterizar el crecimiento e incrementos en diámetro normal (Dn) en función de la edad (E) para *Pinus montezumae* en Puebla, México. Se procesaron 294 pares de observaciones Dn-E provenientes de virutas de incremento radial colectadas en la Unidad de Manejo Forestal 2103 "Teziutlán". Se ajustaron seis modelos de crecimiento. Se seleccionó al modelo de Hossfeld IV (R_{2adj} de 0.8328, RCME de 4.6649 cm y sesgo de 0.0525 cm). El turno técnico fue de 27.5 años (IMAmáx de 0.86 cm año^{-1} y Dn de 23.8 cm).



ICA-IMA, Modelo de Hossfeld IV, Turno técnico

Citation: Tamarit-Urias, Juan Carlos. Equations to characterize diameter at breast height growth of *Pinus montezumae* based on increment cores**.** ECORFAN Journal-Ecuador. 2024. 11-21: 1-8.

Introduction

Biometric tools in form of mathematical models are necessary for determining the growth of commercially important tree species for timber (Pretzsch, 2009). The growth and increment rates of tree attributes are estimated using growth models, which are the scientific basis for planning silvicultural management regimes and for sustainable harvesting over time (Tamarit-Urias et al., 2021). Therefore, it is important for foresters to have quantitative biometric tools to generate accurate and updated dasometric information on the growth and increment of forest species with commercial interest.

Diameter at breast height (diameter at 1.3 m from the ground) is one of the most important attributes and dendrometric variables of trees, it should be measured to be certain about its size (García-Espinoza et al., 2023), its measurement is easy and direct to perform, and it has a high correlation with other tree and stand attributes (Umemi and Inoue, 2024). For these reasons, it is necessary to develop mathematical equations to adequately model growth and increment in order to make informed decisions for the optimal planning and execution of silvicultural practices.

Diameter at breast height growth models of a particular taxon can be basic components in timber growth and yield systems, contributing to simulate the development and timber production of stands under different silvicultural alternatives (Xu et al., 2014; Moreno et al., 2017; Briseño-Reyes et al., 2020). In addition, they allow predicting the time required for trees to reach a certain dimension in normal diameter and thus to predefine a commercial turn for final harvest (Sánchez-González et al., 2005; Quiñonez et al., 2015; Tamarit-Urias et al., 2021).

In Mexico, diameter at breast height growth models are useful for development and implementation of timber forest management programs because they allow the objective determination of growth rates, current and mean increments, average pass times by diameter category, technical turn or cutting cycle based on the diameters of interest to be harvested (Tamarit-Urias et al., 2021). To generate them it is common to use information on diameter at breast height (DBH) and age (A).

One way to obtain DBH-A data is through sampling sites for operational timber forest inventory. In this regard, Carrillo (2008) states that 3 to 4 dominant trees of the most frequent diameter class should be selected per site, from which the DBH is measured and then a radial increment cores is extracted. By counting the annual growth rings, the current age of the tree at the height of the DBH is determined. This technique is a non-destructive sampling because the trees are not felled, and for the purposes of DBH growth studies, it has a similar precision to the stem analysis technique.

Pinus montezumae Lamb. is a species of the conifer group, with a wide distribution and abundance in Puebla, Mexico; it is of high commercial importance for timber and is used industrially for various purposes. Specimens of this taxon reach heights of 25 to 30 m, with rapid to moderate growth at an average altitude of 2 500 m and an annual rainfall of 800 mm (Perry, 1991; CONAFOR, 2012a). Notwithstanding its importance, studies aimed at generating quantitative biometric tools to model and estimate with certainty the growth and increment in diameter at breast height of this taxon are limited. Therefore, the objective of the present study was to develop models to characterize the growth, current and mean annual increment, as well as the pass times of the diameter at breast height as a function of age for individual trees of *P. montezumae* using information from radial increment cores.

Methodology

The study was conducted in the Forest Management Unit (FMU) 2103 Teziutlan region, located northeast of Puebla, Mexico, at 20° 02' 34" - 19° 36' 34" N and 97° 43' 46" - 97° 22' 23" W. The average altitude is 2,220 m, average annual temperature is 12 to 22 °C, the soils are Luvisol type (CONAFOR, 2012b).

The arboreal stratum is composed mainly of taxa of the genus *Pinus*. *P. montezumae* prevails because of its abundance, in addition to *Quercus* sp. and *Liquidambar styraciflua* that form the type of vegetation called mountain cloud forest (Rodríguez-Acosta y Arteaga-Martínez, 2005).

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DBH and A information from 90 sampling sites was processed. The sites were circular of 1000 m^2, which were located in stands where *P. montezumae* was abundant with dominance ≥ 80 %. At each sampling site, 3 to 4 dominant trees of the most frequent diameter class were selected (Carrillo, 2008).

These specimens were healthy, free of defects and well conformed. The total sample of 294 trees included all categories of diameter at breast height and total height, as well as the different station quality conditions present in the FMU. Each selected tree had its DBH measured in cm with a Forestry Suppliers Inc. diameter tape, model 283D/5m-CSE, graduated in cm and accurate to the millimeter.

To determine the age in years of each specimen, we proceeded based on Hess et al. (2018) and Savidge et al. (2023). Using a Haglöf brand Presler increment borer, a radial increment core was extracted from each selected tree at the height of 1.3 m from ground level and at a depth equal to half of the DBH, so its length was variable and its diameter was 5 mm. Based on Iqbal et al. (2020) and Bakhtina et al. (2020) in each radial increment core the total number of annual growth rings from the center to the periphery was counted.

To the total number of rings counted, 8 were added, which corresponds to the average time in years that trees of this taxon in the study area need to reach the height of 1.3 m. A database was conformed with 294 pairs of DBH-A observations, which was curated to verify logical graphic behaviors and for the respective statistical processing. The descriptive statistics of the DBH-A variables are presented in Table 1.

Box 1

Table 1

Basic descriptive statistics of the variables diameter at breast height and age analyzed

Variable	Mean	Min	Max	SD	CV
DBH, cm	25.98	11.40	62.30	10.68	41.09
A, year	35.53	13.00	123.00	21.37	60.14

Min: Minimum, Max: Maximum, SD: Standard deviation, CV: Coefficient of variation.

Source: Own elaboration using sample data

A preliminary analysis consisting of fitting 16 growth models reported in Kiviste et al. (2002), Burkhart and Tomé (2012) and Panik (2013), showed based on goodness-of-fit criteria that six models (Schumacher, M1; Chapman-Richards, M2; Korf, M3; modified Hossfeld I, M4; Hossfeld IV, M5 and Weibull, M6) were plausible candidates for modeling diameter at breast height growth as a function of age (Table 2).

The general mathematical structure of these models is:

$$DBH_{ij} = f\left(A_{ij}, \alpha_i\right) + \varepsilon_{ij} \text{ con i=1, } \cdots \text{, n} \quad (1)$$

where DBH_{ij} is the j-th observation of the diameter at breast height in cm of tree i assumed as the response variable, A_{ij} is the j-th observation of the explanatory variable corresponding to the age in years of tree i, α_i is the vector of model parameters, ε_{ij} is the error of the j-th observation in tree i which is assumed independent and normally distributed with zero mean and constant variance.

Box 2

Table 2

Base growth models fitted and evaluated to estimate the diameter at breast height of *Pinus montezumae* in FMU 2103, Pue., México.

Mathematical expression of the model	Label
$DBH = \alpha_0\ exp(-\alpha_1\ /A)$	M1
$DBH = \alpha_0\ [1 - exp(-\alpha_1\ A)]^{\alpha_2}$	M2
$DBH = \alpha_0\ exp\left(\frac{-\alpha_1}{A^{\alpha_2}}\right)$	M3
$DBH = \frac{A^2}{(\alpha_0 + \alpha_1\ A)^2}$	M4
$DBH = \frac{\alpha_0}{1 + exp\ (\alpha_1)/A^{\alpha_2}}$	M5
$DBH = \alpha_0\ [1 - exp(-\alpha_1\ A^{\alpha_2})]$	M6

DBH: Diameter at breast height, E: Age, α_i parameters to estimate by regression; exp is the exponential function.

Source: Own elaboration using references Kiviste et al. (2002), Burkhart and Tomé (2012) and, Panik (2013)

The statistical analysis consisted of fitting the aforementioned models by regression. The full information máximum likelihood (FIML) method was applied using the Model procedure of the SAS/ETS v statistical program. 9.3 (SAS Institute Inc., 2011).

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To select the best model, the significance of the estimated parameters ($p<0.05$) and the goodness-of-fit statistics were considered: the highest value of the adjusted coefficient of determination (R^2_{adj}), the lowest values of the root mean square error (RMSE) and bias (B), the highest value of the likelihood (logLik) and the lowest value of the Akaike information criterion (AIC).

In the evaluation and identification of the best models a relative rating system was also implemented, on the statistics referred to based on Tewari and Singh (2018) each fit statistic of each model was ranked by assigning consecutive values from 1 to 6 (1 corresponded to the best value of the statistic and 6 to the worst value). A total rank (TR) was obtained for each model by adding the ranks assigned to each of the statistics. By comparing the TRs, the best models were identified, which were those with the lowest TR. In addition, a graphic analysis was made of the congruence and biological realism that each of the models reproduces, through the average curve that each model estimates superimposed on the trend of the observed growth data.

Based on Pretzsch (2009) and, Burkhart and Tomé (2012), for the best model, the respective expressions for: current annual increment (CAI), maximum CAI (CAI_{max}), mean annual increment (MAI) and, maximum MAI (MAI_{max}), which corresponds to the age of technical turn (CAI=MAI), were derived by differential calculus. With the selected model, average growth curve in DBH was constructed, and the CAI, MAI, CAI_{max} and MAI_{max} were calculated and plotted. Finally, the selected model was inverted to generate an expression that allows estimating the pass time (PT), which corresponds to average time in years that a tree requires to pass from a lower diameter category to the next higher one.

Results

All parameters of the fitted models were significant (Table 3). Based on the goodness-of-fit statistics of each model and the respective total ranks (Table 4), it is inferred that the M6, M2 and M5 models are comparatively superior for estimating diameter at breast height a function of age.

Notwithstanding the rating system suggests that M6 model is statistically better, the analysis of the graphical behavior about trend of average growth curve describing each model shows that the M6 model is biologically and comparatively more conservative.

Meanwhile, the same graphical analysis suggests that the M5 model performs better because its behavior is biologically more consistent, reasonable and realistic throughout the time interval analyzed (Figure 1), especially at the maximum ages where the DBH tends to stabilize with a higher asymptotic ceiling. In addition, the site quality in the study region is good, which is why model 5 is considered appropriate.

From the analysis referred to above, it can be deduced that the M5 model, which corresponds to the Hossfeld IV model, has the highest predictive capacity, so it was selected to model the growth of DBH as a function of age for *P. montezumae* trees in the study area.

Box 3

Table 3

Estimated values of the parameters of the evaluated growth models.

M	P	Estimates	SE	t	Pr>|t|*
M1	α_0	60.048650	1.0096	59.48	<0.0001
	α_1	25.348660	0.8792	28.83	<0.0001
M2	α_0	45.938840	0.8487	54.13	<0.0001
	α_1	0.046956	0.0052	8.96	<0.0001
	α_2	2.061518	0.3143	6.56	<0.0001
M3	α_0	59.029850	4.3656	13.52	<0.0001
	α_1	27.381130	11.1634	2.45	0.0147
	α_2	1.029353	0.1462	7.04	<0.0001
M4	α_0	2.330482	0.0873	26.69	<0.0001
	α_1	0.121340	0.0015	83.02	<0.0001
M5	α_0	50.073110	1.7591	28.46	<0.0001
	α_1	6.417781	0.5404	11.88	<0.0001
	α_2	1.905461	0.1786	10.67	<0.0001
M6	α_0	44.500930	0.6447	69.03	<0.0001
	α_1	0.004209	0.0014	3.11	0.0020
	α_2	1.565335	0.0978	16.01	<0.0001

M: Model, P: Parameter, SE: Standard error, t: t value, *Probability level 5% (α=0.05).

Source: Own elaboration with information obtained from the models fitted

Box 4

Table 4

Goodness-of-fit statistics of the growth models evaluated and total rank obtained for each model

M	R^2_{adj}	RMSE	B	logLik	AIC	TR
M1	0.8268	4.7477	0.0271	-900.91	945.94	18
M2	0.8361	4.6184	0.0378	-892.04	930.20	11
M3	0.8262	4.7551	0.0338	-900.87	947.87	21
M4	0.8219	4.8146	-0.0679	-905.14	954.41	30
M5	0.8328	4.6649	0.0525	-895.07	936.26	16
M6	0.8395	4.5707	0.0556	-888.89	923.91	9

M: Model, R^2_{adj}: adjusted coefficient of determination, RMSE: root mean square error, B: bias, logLik: log likelihood, AIC: Akaike information criterion, TR: total rank.

Source: Own elaboration with information obtained from the models fitted

Box 5

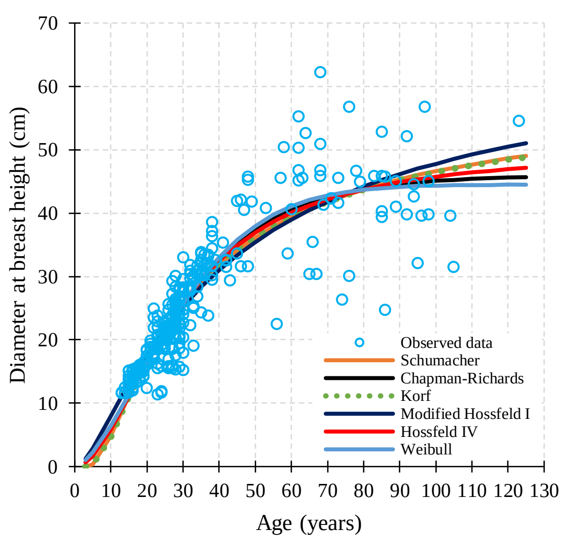

Figure 1

Trends of the average growth curves in diameter at breast height for *Pinus montezumae* estimated with the growth models evaluated against the observed values.

Source: Own elaboration using the data observed in the sample and estimated with the evaluated models

The M5 model had the third best value in the R^2_{adj}, RMSE, logLik and AIC statistics, explains 83.28% of the variability observed in DBH, the mean precision is 4.66 cm and offers a minimum deviation with respect to the observed values of 0.05 cm. In addition, all three parameters (α_i) were highly significant. These attributes ratify that the Hossfeld IV model is adequate to estimate the DBH of individual trees of *P. montezumae*, whose average growth trend and observed values are shown in Figure 2.

The expressions derived from the M5 model to calculate the different increments are presented below.

For the current annual increment (CAI):

$$CAI = \frac{\alpha_0 A^{\alpha_2 - 1} exp\,(\alpha_1)\alpha_2}{(A^{\alpha_2} + \exp(\alpha_1))^2} \quad (2)$$

For the maximum current annual increment (CAI_{max}):

$$CAI_{max} = exp\left(\frac{ln\left(\frac{\alpha_2 - 1}{\alpha_2 + 1}\right) + \alpha_1}{\alpha_2}\right) \quad (3)$$

For the mean annual increment (MAI):

$$MAI = \frac{\alpha_0 A^{\alpha_2 - 1}}{A^{\alpha_2} + \exp\,(\alpha_1)} \quad (4)$$

For the maximum mean annual increment (MAI_{max}):

$$IMA_{max} = exp\left(\frac{ln(\exp(\alpha_1)\alpha_2 - \exp(\alpha_1))}{\alpha_2}\right) \quad (5)$$

Where α_0=50.073110, α_1=6.417781 y α_2=1.905461, ln is the natural logarithm, the rest of the components were previously indicated.

Box 6

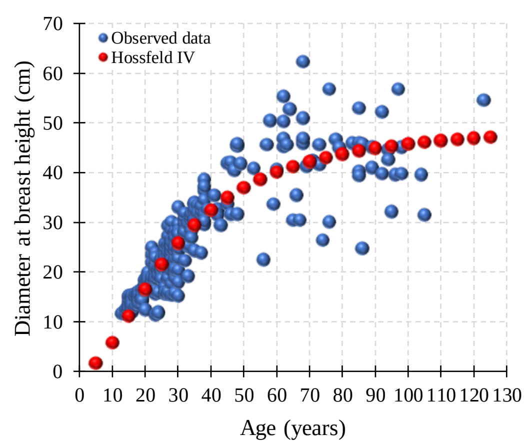

Figure 2

Trend of the growth curve in diameter at breast height estimated by the Hossfeld IV model and growth pattern observed in *Pinus montezumae*.

Source: Own elaboration using the data observed in the sample and those estimated by the selected model

With these expressions it was determined that the CAI_{max} occurs at 15.7 years, with a growth of 1.1 cm yr^{-1} and a DBH of 11.9 cm.

The technical turn, which corresponds to the MAI_{max} and is equivalent to the age at which the CAI and MAI curves cross, was estimated to occur at 27.5 years (age of greatest growth in DBH) with an increase of 0.86 cm yr^{-1} and a DBH of 23.8 cm (Figure 3). From the point of view of commercial use by the sawmill industry, it would imply letting the forest stands of this taxon grow up to the diameter category of 25 cm so that the volume increases and is profitable.

Hernández (2012) selected the Korf base growth model to estimate the DBH in *P. montezumae* trees in southeastern Hidalgo, Mexico; determined that the technical turn occurs at 41 years of age, at which time a Dn of 26.8 cm is reached, the ICA_{max} was 0.93 cm yr^{-1} at the age of 21 years and the MAI_{max} was 0.65 cm yr^{-1}. Meanwhile, Tamarit-Urias et al. (2021) with stem analysis data determined that growth in DBH in *P. montezumae* for FMU 2101 (Ixta-Popo) in Puebla, Mexico, should be modeled with a dynamic equation generated from applying the generalized algebraic difference approach to the Korf base growth model. For the average growth condition they estimated an CAI_{max} of 1 cm yr^{-1} corresponding to 9.33 cm and is reached at age 14.8 years; the MAI_{max} was 0.79 cm yr^{-1} corresponding to 25 cm of DBH and occurs at age 31.6 years. The differences in the growth parameters indicated can be explained by the fact that the conditions and productive capacity (quality site) are comparatively better in FMU 2103 than in the other two regions mentioned.

Box 7

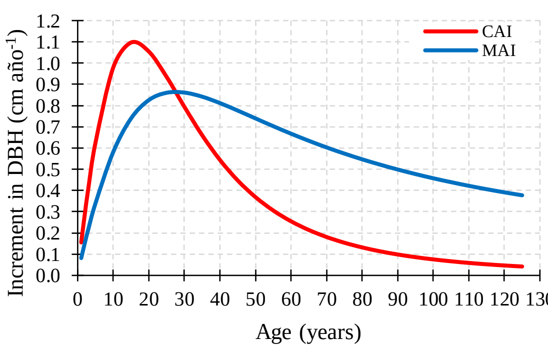

Figure 3

CAI and MAI curves in diameter at breast height for *Pinus montezumae* obtained with the Hossfeld IV growth model in FMU 2103 in Puebla, Mexico.

Source: Own elaboration with the CAI and MAI values generated with the respective expressions of selected Hosfeld IV model

In contrast, Pacheco et al. (2016) for the same taxon in the region of Sola de Vega, Oaxaca, Mexico, determined an CAI_{max} of 1.1 cm yr^{-1} at 13.5 years, while the MAI_{max} was 0.97 cm yr^{-1} at 25.31 years, suggesting that site conditions in that region are slightly better than those prevailing in FMU 2103.

The expression generated to estimate the average time (t) in years at which a commercial dimension of interest is reached in DBH and which is useful to calculate the technological turn, acquired the following mathematical structure:

$$t = exp\left(\frac{ln\left(\frac{DBH}{\alpha_0 - DBH}\right) + \alpha_1}{\alpha_2}\right) \quad (6)$$

Where ln is the natural logarithm, the remainder as defined above.

With this expression, in agreement with Ramírez et al. (2024), it is possible to calculate different commercial harvesting times depending on the industrial use of the raw material to be harvested, such as logs for the sawmill industry, where the minimum sawable diameter is relevant. In practice, it is common to calculate the pass time (PT) in years by diameter category, so that, for the average growth condition in DBH, in an ascending progression, the average PT calculated for this species in the diameter categories from 10 to 40 cm, with 5 cm classes and considering the center of each class, were 4.6, 4.7, 5.1, 6.1, 7.9, 11.4 and 20.3 years, respectively. These PT values show an exponential trend, which is contrary to the commonly assumed assumption that such progression is linear.

Conclusions

An equation based on the Hossfeld IV growth model was derived to model the diameter at breast height growth of individual *Pinus montezumae* trees in FMU 2103 (Teziutlan) in Puebla, Mexico.

Expressions were also derived to calculate the current annual increment, mean annual increment, maximum increments and pass times by diameter category.

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The generated quantitative biometric toolkit is fundamental to infer technological turns and cutting cycles, both basic parameters for technical management in the context of the development and implementation of forest management programs for sustainable timber harvesting of this taxon in the study area. It can also form part of timber growth and yield systems, as well as to make financial projections.

Annexes

Not applicable

Declarations

Conflict of interest

The author declare no interest conflict. He has no known competing financial interests or personal relationships that could have influenced the article reported in this paper.

Author contribution

Tamarit-Urias, Juan Carlos: Generated the research idea, coordinated the research and field work, conducted the documentary research of specialized literature, performed the statistical analysis, interpretation and discussion of results. He wrote, edited, revised and corrected the drafts and the final full version of this scientific article in the format and style of the Ecorfan Journal.

Availability of data and materials

The availability of data is in the possession of the author. They may be made available to the interested party upon request with a justified technical reason to the email: tamarit.juan@inifap.gob.mx

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Abbreviations

CAI	Current Annual Increment.
DBH	Diameter at Breast Height.
FMU	Forest Management Unit.
MAI	Mean Annual Increment.

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Article

Market research on two natural predators of walnut pests: Trichogramma ssp and Chrysoperla carnea, in Delicias City, Chihuahua

Investigación de mercado de dos depredadores naturales de plagas del nogal: trichogramma ssp y chrysoperla carnea, en ciudad Delicias, Chihuahua

Ramírez-Moreno, Hilario*[a], Aguirre-Orozco, Mario Abelardo [b], Delgado-Martínez, Martha Lilia [c] and Contreras-Martínez, Jesús José [d]

[a] Tecnológico Nacional De México Campus Delicias • LFS-6873-2024 • 0009-0000-3424-5215 • 263476
[b] Tecnológico Nacional De México Campus Delicias • KDO-9073-2024 • 0000-0002-6899-5230 • 813343
[c] Tecnológico Nacional De México Campus Delicias • LFS-4652-2024 • 0000-0002-5635-6853 • 813360
[d] Tecnológico Nacional De México Campus Delicias • LFS-7806-2024 • 0000-0002-9044-4216 • 991403

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* ✉ [hilario.rm@delicias.tecnm.mx]

Abstract

In Mexico, as in the world, the production of food of agricultural origin requires protection against pests and diseases that limit and/or destroy it, through the application of chemical pesticides (PQ) that, although they control them, also cause environmental pollution and in consequently deteriorating the quality of human life. Since plants began to be cultivated on a massive scale, pest problems began to arise, that is, where the population of very large insects that ate the crops and an alternative to controlling these insects is to occupy their natural predators or their natural pathogens for control. Since the 1940s, biological control has been applied in Mexico. The first pest that was fought with this method was the citrus black fly, where specialists imported a wasp from Australia. Since this time, in the 1940s, when these wasps were introduced, there has been no need for chemical control of this particular pest in Mexico. The use of biological control is regulated by Official Mexican Standards to avoid the potential risks it represents; once a species is released into the environment, it is no longer possible to remove it.

Título del resumen grafico en Ingles		
Objectives	**Metodology**	**Contribution**
To know the perception of walnut and pecan growers about biological control	**Malhotra (2004):**	**This market research evaluates the viability of a beneficial insect production laboratory in Delicias, Chihuahua. The region, a leader in walnut production, seeks to improve its agricultural practices with a focus on biological control to reduce agrochemical pollution.**

Research, Market, Pests, Walnut

Resumen

En México como en el mundo la producción de alimentos de origen agrícola requiere de protección contra plagas y enfermedades que la limitan y/o destruyen, mediante la aplicación de pesticidas químicos (PQ) que, si bien los controlan, también causan contaminación ambiental y en consecuencia deteriorando la calidad de vida humana. Desde que se comenzaron a cultivar las plantas de manera masiva, empezaron a surgir los problemas de las plagas, o sea donde la población de insectos muy grandes que se comían los cultivos y una alternativa al control de estos insectos es ocupar sus depredadores naturales o sus patógenos naturales para el control. Desde los años 40, el control biológico se aplica en México. La primera plaga que se combatió con este método fue la mosca prieta de los cítricos, donde los especialistas importaron una avispa de Australia. Desde esta época, en los años cuarenta que se introdujeron estas avispas no ha habido necesidad de hacer control químico sobre esta plaga en particular en México. El uso de control biológico está regulado por Normas Oficiales Mexicanas para evitar los riesgos potenciales que representa, una vez que se liberan alguna especie en el medio ambiente ya no es posible retirarla.

Título del resumen grafico en Español		
Objetivos	**Metodología**	**Contribución**
Conocer la percepción de los productos de nogal y nuez acerca del control biológico	**Malhotra (2004):**	**Este estudio de mercado evalúa la viabilidad de un laboratorio de producción de insectos benéficos en Delicias, Chihuahua. La región, líder en producción de nuez, busca mejorar sus prácticas agrícolas con un enfoque en el control biológico para reducir la contaminación por agroquímicos.**

Investigación, Mercado, Plagas, Nogal

Citation: Ramírez-Moreno, Hilario, Aguirre-Orozco, Mario Abelardo, Delgado-Martinez, Martha Lilia and Contreras-Martínez, Jesús José. Market research on two natural predators of walnut pests: Trichogramma ssp and Chrysoperla carnea, in Delicias City, Chihuahua**.** ECORFAN Journal-Ecuador. 2024. 11-21: 9-20.

Introduction

It is of utmost importance for any company to have information with which to identify and define the opportunities and problems that arise in the market, as this information is used to generate, refine and evaluate marketing activities. Market research can identify weaknesses and opportunities, the reasons for lack of demand or supply, or understand the degree of distortion in existing markets. This understanding can help to choose intervention strategies or to identify institutions and networks on which to build a baseline against which to measure progress in the development of the market in question.

This research was carried out at the request of the Junta Local de Sanidad Vegetal de Cd. Delicias, Chihuahua, in order to know the perception of walnut and walnut products about biological control; for this purpose, a survey was applied to the sector to be studied. Walnuts are an important crop for the economy of the south-central region of the state of Chihuahua. In the agricultural and livestock sector, the municipalities of Mequí, Delicias and Valle de Juárez account for 44 percent of the 40,000 hectares of walnut trees planted in the state of Chihuahua, of which the state is the leading national producer according to data from the State Plant Health Committee, an auxiliary body of the Ministry of Agriculture, Livestock and Fishery Resources (SAGARPA). Chihuahua is a national and international leader, as it produces 12 percent of the country's walnuts, and 90 percent of the total product is sold in the United States market, according to SAGARPA data. Annual production is around 70,000 tonnes; the main walnut production areas in the state are Jiménez, Camargo, Delicias, Saucillo, Julimes, Aldama, Ojinaga, Ricardo Flores Magón, Nuevo Casas Grandes and Valle de Juárez, according to the aforementioned agency. Walnut and non-walnut growers in Delicias and the region are looking for ways to improve their cultivation processes and techniques, which is being done in part with the support of the Junta Local de Sanidad Vegetal de Cd. Delicias, Chihuahua, (JLSVD) and the Instituto Nacional de Investigaciones Forestales Agrícolas y Pecuarias, (INIFAP) and through the Asociación Agrícola Local de Productores de Nogal y Nuez de Cd. Delicias, Chihuahua, through monthly conferences about the different cultivation processes such as pruning techniques, pest control, insecticide application technology, etc.

There is a need and an opportunity to set up a laboratory for the production of beneficial insects for the walnut sector, so market research was carried out to find out the market potential in the city of Delicias, Chihuahua and the region. In the state of Chihuahua, emphasis is being placed on biological control with the aim of reducing the contamination index due to the residues of agrochemicals used in crop pest control.

By virtue of the above, and through capital investment by La Asociación Civil de Delicias Hortícola and support managed by the Junta Local de Sanidad Vegetal Delicias, a beneficial insect production laboratory of La Junta Local de Sanidad Vegetal Delicias will be installed in coordination with the Comité Estatal de Sanidad Vegetal Chihuahua.

Methodology:

The project was implemented with the participation of the JLSVD, INIFAP and cooperating organisations including the Asociación Delicias Hortícola, which guarantees the socialisation of the experience. The methodology proposed by Malhotra (2004) was used for the development and implementation of this project: the purpose of the study and how it would be used by decision-makers was considered, an analysis was made with experts in the field of biological control from both the JLSVD and INIFAP, project leaders, the main researcher's advisor and a literature review, which was used to formulate a hypothesis and determine what information was needed.

In addition, the plan with which the market research was developed was elaborated, determining the research design technique that was used, this being the descriptive technique, which has the purpose of writing something, usually characteristics or functions of the market. The simple cross-sectional design was applied as information was collected from a given sample of population elements only once.

A frame of reference was developed to learn more about beneficial insects and pests of walnut by analysing the international context, the national context, the state context and the regional context. For this purpose, information from records in the irrigation modules of district 005, different web pages and bibliographic sources was analysed.

ISSN: 1390-9959.
RENIECYT-CONAHCYT: 1702902

The information collected included the number of hectares under walnut cultivation and the number of producers in order to determine the size of the sample and apply the number of questionnaires required according to the statistical formula that was used.

Within the descriptive research design, the aforementioned team and the researcher used the survey method, which was carried out by applying a questionnaire to obtain specific information. The questionnaires were applied through direct personal interviews, i.e. by interviewers. The survey collected data from the interviewees on serious aspects of the PBC market including:

- Extent of knowledge, understanding and use of CBP and chemical controls.
- Frequency of use, amount paid for both pest controls.
- Suppliers.
- Degree of effectiveness with the technologies used.
- Reasons for use and non-use of biological control.

The survey was carried out through structured questions, where the respondent had several answer options, from which he/she had to select one, and also dichotomous questions with only two answer options (affirming or denying), within the research a pilot test of 40 questionnaires was carried out to evaluate if the information obtained was going to be the required for the study, corrections were made in the structure of some questions to later apply the total questionnaire according to the calculated sample. A team consisting of a coordinator and two assistants was formed to carry out the pilot test.

Sample Size Determination

To define the target population, all walnut producers registered by irrigation module were taken into account. Currently there is a total walnut cultivation area of 17,598.56 hectares in irrigation district 005 according to data from

SAGARPA (2010), and a total of 1053 walnut producers according to records of irrigation modules 1, 2, 3, 4, 5, 7, 8, 9 and 12. The probability sampling technique was used, in which each sample has the same probability of being chosen. The calculation of the sample size was done with a formula for a finite population:

$$n = \frac{Z_\alpha^2 \, Npq}{E^2(N-1) + Z_\alpha^2 pq} \tag{1}$$

Where:

n Sample size.
N Population size.
Z Value corresponding to the Gaussian distribution 1.96 for α = 0,05.
p Expected prevalence of the parameter to be assessed.
q 1-p.
E Mistake to be made.

$$n = \frac{(1.96)^2(1053)(0.92)(0.08)}{(0.05)^2(1053-1) + (1.96)^2(0.92)(0.08)} = 102$$

The field work was carried out with a team of three people composed of a coordinator and two assistants, attending the producers' meeting places, mainly the Regional Association of Walnut Growers and in some cases the producers' orchards to collect the information through the questionnaires applied. The data analysis was carried out in parallel to the field work, checking that all the surveys were complete and checking the quality and legibility of the data collected.

Those questionnaires that successfully passed this check were passed on to the next stage and decisions were made about those that could be retrieved. For the data analysis, codes were assigned to all possible answers given by the respondents, which were numerical. Subsequently, all responses were entered into the computer so that the analysis of the responses could begin.

At this stage, checks were carried out in order to observe the consistency and handling of unanswered questions in the selected questionnaires.

Having finished preparing the data, statistical techniques were applied to obtain conclusions for the research, using tools such as frequency distributions, through which measures of central tendency and variations were found, as well as contingency tables comparing the following questions: Do you currently use the BC of pests?* Have you ever used the BC of pests? and If your answer is no, why didn't you use the BC?* Do you currently use the BC of pests?

ISSN: 1390-9959.
RENIECYT-CONAHCYT: 1702902

PASW Statistics software version 18 was used for this analysis, which allows for a quick and reliable analysis, thus minimising human error.

Analysis of results or Development

With the results obtained, it can be concluded that the use of biological pest control in Delicias City, Chihuahua and its region is part of the pest control agents since 91.2% of the respondents mentioned having used biological control at least once; of which 83.4% mentioned that they continue to use it, and we can see that it is a good market for the sale of PBC, since of the 102 respondents, 76.5% of them showed interest in having information about this technology for pest control. The results of the survey indicate that, in the short term, biological pest control has strong market potential.

What type of pest control do you currently use?

Box 1

Table 1

Type of control used

Valid	Frequency	Percentage	Percentage valid	Cumulative percentage
Agrochemicals	21	20.6	20.6	20.6
Biological Control	16	15.7	15.7	36.3
Biological and Chemical Control	65	63.7	63.7	100.0
Total	102	100.0	100.0	

When walnut growers were asked about the type of pest control they use, it can be seen in table 1 that 63.5% answered that they use both chemical and biological control, with only 15.7% using chemical control as the only control alternative. Which pests occur most frequently?

Box 2

Table 2

Most frequent pest

Valid	Frequency	Percentage	Percentage valid	Cumulative percentage
Gbn	40	39.2	39.2	39.2
Gbr	10	9.8	9.8	49.0
gbn y gbr	15	14.7	14.7	63.7
Pulgón	37	36.3	36.3	100.0
Total	102	100.0	100.0	

Table 2 shows that the most frequently occurring pest is the walnut borer followed by aphids in general. Which agrochemical do you use for pest control?

Box 3

Table 3

Agrochemical used

Valid	Frequency	Percentage	Percentage valid	Cumulative percentage
Intrepid	52	51.0	51.0	51.0
Aflix	14	13.7	13.7	64.7
Lorsban	15	14.7	14.7	79.4
Clorpirifos	1	1.0	1.0	80.4
Cipermeticina	1	1.0	1.0	81.4
Karate	3	2.9	2.9	84.3
No QC	16	15.7	15.7	100.0
Total	102	100.0	100.0	

Of the 102 farmers surveyed, 51% use Intrepid insecticide, followed by Lorsban with 14.6% and Aflix with 13.7% for pest control. How much agrochemical do you apply per hectare?

Box 4

Table 4

Dosage of agrochemicals used

Valid	Frequency	Percentage	Percentage valid	Cumulative percentage
0.25 L	23	22.5	22.5	22.5
0.5 L	47	46.1	46.1	68.6
0.75 L	9	8.8	8.8	77.5
1 L	5	4.9	4.9	82.4
2 L	2	2.0	2.0	84.3
No usa CQ	16	15.7	15.7	100.0
Total	102	100.0	100.0	

Of the 102 farmers surveyed 47 use a dose of up to 0.5 L per hectare and 23 use up to 0.25 L per hectare.

How many agrochemical applications do they make per year?

Box 5

Table 5

Number of applications of agrochemicals per year

Valid	Frequency	Percentage	Percentage valid	Cumulative percentage
1	16	15.7	15.7	15.7
2	42	41.2	41.2	56.9
3	16	15.7	15.7	72.5
4	12	11.8	11.8	84.3
No QC	16	15.7	15.7	100.0
Total	102	100.0	100.0	

The number of agrochemical applications per year most frequently mentioned was 41.2%, followed by 1 and 2 applications per year with 15.7% each.

ISSN: 1390-9959.
RENIECYT-CONAHCYT: 1702902

Ramirez-Moreno, Hilario, Aguirre-Orozco, Mario Abelardo, Delgado-Martinez, Martha Lilia and Contreras-Martínez, Jesús José. Market research on two natural predators of walnut pests: Trichogramma ssp and Chrysoperla carnea, in Delicias City, Chihuahua. ECORFAN Journal-Ecuador. 2024. 11-21: 9-20.
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In which months do you apply agrochemicals?

Box 6

Table 6

Months of application of agrochemicals

Valid	Frequency	Percentage	Percentage valid	Cumulative percentage
April – May	33	32.4	32.4	32.4
June – July	20	19.6	19.6	52.0
August – September	33	32.4	32.4	84.3
No QC	16	15.7	15.7	100.0
Total	102	100.0	100.0	

Table 6 shows that the periods of highest agrochemical application are April-May with a percentage of 32.4% and August-September with the same percentage. How much does the agrochemical you use cost you?

Box 7

Table 7

Cost of agrochemicals

Valid	Frequency	Percentage	Percentage valid	Cumulative percentage
De $250 a $500	15	14.7	14.7	14.7
De $501 a $1,000	16	15.7	15.7	30.4
De $1,001 a $1,500	55	53.9	53.9	84.63
No QC	16	15.7	15.7	100.0
Total	102	100.0	100.0	

Where do you buy the agrochemicals you use?

Box 8

Table 8

Agrochemical suppliers

Valid	Frequency	Percentage	Percentage valid	Cumulative percentage
Dansa	8	7.8	7.8	7.8
Miller	8	7.8	7.8	15.7
Tepeyac	14	13.7	13.7	29.4
Agronorte	10	9.8	9.8	39.2
Asoc. de nogaleros	12	11.8	11.8	51.0
Agricam	7	6.9	6.9	57.8
Bayer de México	8	7.8	7.8	65.7
Agrochemical Delights	10	9.8	9.8	75.5
Agricultural supplier	9	8.8	8.8	84.3
No QC	16	15.7	15.7	100.0
Total	102	100.0	100.0	

Table 8 shows that there is no preferred company for the purchase of agrochemicals as there is no marked difference in the frequencies.

Which biological control organism do you use for pest control?

Box 9

Table 9

B.C. bodies used

Valid	Frequency	Percentage	Percentage valid	Cumulative percentage
Chrysopa	29	28.4	28.4	28.4
Trichograma sp	31	30.4	30.4	58.8
Both	21	20.6	20.6	79.4
No CB use	21	20.6	20.6	100.0
Total	102	100.0	100.0	

Regarding the organisms used for biological control, table 9 shows that there is no considerable difference in the frequencies, as would be expected since one beneficial insect can help to combat several pests.

How many cm^3 of Chrysopa do you apply per hectare?

Box 10

Table 10

Dosage per hectare of Chrysopa

Valid	Frequency	Percentage	Percentage valid	Cumulative percentage
1 cm^3	26	25.5	25.5	25.5
2 cm^3	47	46.1	46.1	71.6
3 cm^3	8	7.8	7.8	79.4
No C.B.	21	20.6	20.6	100.0
Total	102	100.0	100.0	

Typically, walnut growers apply a dose of 2 cm3 per hectare of chrysopa, followed by a dose of 1 cm3, with percentages of 46.1% and 25.5% respectively. How many inches of trichogramma do you apply per hectare?

Box 11

Table 11

Doses per hectare of trichogramma

Valid	Frequency	Percentage	Percentage valid	Cumulative percentage
5 inches	14	13.7	13.7	13.7
10 inches	51	50.0	50.0	63.7
20 inches	16	15.7	15.7	79.4
No C.B.	21	20.6	20.6	100.0
Total	102	100.0	100.0	

Table 11 shows that in general a dose of 10 inches per hectare of trichogramma is applied.

How many Biological Control applications do you make per year?

ISSN: 1390-9959.
RENIECYT-CONAHCYT: 1702902

Box 12

Table 12

Applications per year of BC

Valid	Frequency	Percentage	Percentage valid	Cumulative percentage
1	27	26.5	26.5	26.5
2	41	40.2	40.2	66.7
3	10	9.8	9.8	76.5
4	3	2.9	2.9	79.4
No C.B.	21	20.6	20.6	100.0
Total	102	100.0	100.0	

40.2% of the farmers mentioned making two applications per cycle of biological control followed by one application representing 26.5% of the respondents.

In which month do you apply biological control?

Box 13

Table 13

Months of CB application

Valid	Frequency	Percentage	Percentage valid	Cumulative percentage
April - May	33	32.4	32.4	32.4
June - July	18	17.6	17.6	50.0
August - September	30	29.4	29.4	79.4
No QC	21	20.6	20.6	100.0
Total	102	100.0	100.0	

The results were similar to the periods of application of agrochemicals, with the periods of highest application of biological control being April-May with a percentage of 32.4% and August-September with 29.4%.

How much does a cm3 of chrysopa cost you?

Box 14

Table 14

Cost per cm^3 of chrysopa?

Valid	Frequency	Percentage	Percentage valid	Cumulative percentage
De $40 a $50	1	1.0	1.0	1.0
De $51 a $60	4	3.9	3.9	4.9
De $61 a $70	26	25.5	25.5	30.4
Más de $70	50	49.0	49.0	79.4
No usa CB	21	20.6	20.6	100.0
Total	102	100.0	100.0	

Table 14 shows a high percentage of producers spend more than $70 per cm3 of chrysopa.

How much does an inch of trichogramma cost you?

Box 15

Table 15

Costs of trichogramma

Valid	Frequency	Percentage	Percentage valid	Cumulative percentage
$2	18	17.6	17.6	17.6
$4	38	37.3	37.3	54.9
$6	24	23.5	23.5	78.4
$7	1	1.0	1.0	79.4
No usa C.B.	21	20.6	20.6	100.0
Total	102	100.0	100.0	

Table 15 shows the prices of trichogramma purchased by producers at a cost of $4.

Where do they buy the biological control they use?

Box 16

Table 16

C.B. Suppliers

Valid	Frequency	Percentage	Percentage valid	Cumulative percentage
UNIFRUT	50	49.0	49.0	49.0
CESAVESIN	6	5.9	5.9	54.9
JLSVD	21	20.6	20.6	75.5
OTROS	4	3.9	3.9	79.4
No usa C.B.	21	20.6	20.6	100.0
Total	102	100.0	100.0	

The place where biological control is most frequently purchased is the UNIFRUT laboratory with 49%.

What is the perception of biological pest control?

Box 17

Table 17

Perception of B.C

Valid	Frequency	Percentage	Percentage valid	Cumulative percentage
Very effective	10	9.8	9.8	9.8
Cash	57	55.9	55.9	65.7
Regularly Cash	35	34.3	34.3	100.0
Total	102	100.0	100.0	

The survey asked farmers to rate their perception of Biological Pest Control. The results are shown in figure 17, of the 102 farmers surveyed 57 consider biological pest control to be effective while 35 consider it to be regularly effective.

Have you ever used biological pest control?

Ramirez-Moreno, Hilario, Aguirre-Orozco, Mario Abelardo, Delgado-Martinez, Martha Lilia and Contreras-Martínez, Jesús José. Market research on two natural predators of walnut pests: Trichogramma ssp and Chrysoperla carnea, in Delicias City, Chihuahua. ECORFAN Journal-Ecuador. 2024. 11-21: 9-20.
https://doi.org/10.35429/EJE.2024.20.11.9.20

Box 18

Table 18

Use of the C.B. at least once

Valid	Frequency	Percentage	Percentage valid	Cumulative percentage
Si	93	91.2	91.2	91.2
No	9	8.8	8.8	100.0
Total	102	100.0	100.0	

A percentage of 91.2% have used biological control at least once, while 8.8% never use biological control.

Do you currently use biological pest control?

Box 19

Table 19

Current use of C.B

Valid	Frequency	Percentage	Percentage valid	Cumulative percentage
Yes	84	82.4	82.4	82.4
No	18	17.6	17.6	100.0
Total	102	100.0	100.0	

Currently 82.4% of respondents use biological pest control. If no, why do you use biological pest control?

Box 20

Table 20

Reasons for non-use of B.C

Valid	Frequency	Percentage	Percentage valid	Cumulative percentage
The following did not apply	15	14.7	14.7	14.7
Other	3	2.9	2.9	17.6
Yes he does	84	82.4	82.4	100.0
Total	102	100.0	100.0	

Of the respondents who do not use biological pest control, 14.7% do not know how to apply it. It is worth noting that none of the respondents mentioned that they do not use biological pest control because it is not effective or because it is expensive.

If Biological Pest Control were explained to you, would you be willing to use it?

Box 21

Table 21

Willingness to use the B.C

Valid	Frequency	Percentage	Percentage valid	Cumulative percentage
Si	79	77.5	77.5	77.5
No	23	22.5	22.5	100.0
Total	102	100.0	100.0	

77.5% of the respondents mentioned that they would be willing to use only biological control.

What factor would influence an increase in the use of biological control?

Box 22

Table 22

Change of agrochemicals to C.B

Valid	Frequency	Percentage	Percentage valid	Cumulative percentage
Price	41	40.2	40.2	40.2
Effectiveness	55	53.9	53.9	94.1
Other	6	5.9	5.9	100.0
Total	102	100.0	100.0	

The most influential factor for increasing the use of biological control is effectiveness. That is, farmers want to be sure that PBC works effectively in order to make a decision about increasing its use.

Would you like to get information about the use and application of biological control?

Box 23

Table 23

Willingness to obtain information on the use of the B.C

Valid	Frequency	Percentage	Percentage valid	Cumulative percentage
Yes	78	76.5	76.5	76.5
No	24	23.5	23.5	100.0
Total	102	100.0	100.0	

Two contingency tables were designed to analyse what percentage of farmers who mentioned having used PBC at some point in time still use it today and know the causes of non-use of PBC.

Box 24

Table 24

Contingency 1: Do you currently use pest C.B.? * Have you ever used the pest C.B.?

		Have you ever used C.B. Pest Control?		Total
		Yes	No	
Do you currently use the C.B. for pests?	Yes	78	6	84
	No	15	3	18
	Total	93	9	102

The table shows that out of the 93 farmers who mentioned having used biological control at least once, 78 continue to use it.

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Box 25

Table 25

Contingency 2: If no, why don't you use the B.C.? * Do you currently use C.B. for pests?

		Do you currently use the C.B. for pests?		Total
		Si	No	
If no, why don't you use the C.B.?	I don't know how to apply it	7	8	15
	Other	0	3	3
	Yes He uses it	77	7	84
Total		84	18	102

The table shows that of the 18 farmers who do not use biological control, 15 do not know how to apply it and three mentioned another cause.

The potential demand is the maximum possible demand for the products offered by the laboratory. This was determined by means of the buyer's intentions survey method: It consists of a survey of the opinion of desires or expectations about the purchase of a product. Its limitation is given because one thing is the intention to buy and the other the purchase itself (W.J. Stanton, 2004). The formula of the potential demand is:

$$Q = npq \quad (2)$$

Where:

Q: Potential demand.
n: Number of possible buyers for the same type of product on a given market.
p: Average market price of the product.
q: Average amount of consumption per capita on the market

Box 26

Table 26

Determination of potential demand

Product	n(ha)	p($)	q	Q
Chrysopa	13,638.884	60	1cm³/ha	$818,333.04
Trichogramma	13,638.884	2	10 inch/ha	$172,777.68
			Market size	$1,091,110.72

Box 27

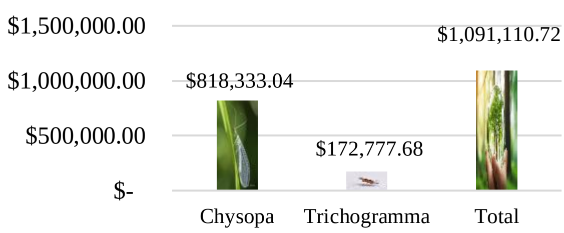

Figure 1

Potential demand for biological control

Economic and ecological impact of biological versus chemical control considering the total area of irrigation district 005.

Comparison of a traditional technology and two components of integrated pest management in the control of GBN per day.

Box 28

Table 27

Economic and ecological impact of IPM (Trichogramma) vs. chemical control

Control	Unit cost	Dosis ha	Cost ha	PPD	DP cost	Surface	Cost T. day	CPNPA	With regard to the NC
Trichogramma	$2.00	10 pulg	$20.00	45	$0.44	17,598.56	$7,743.37	0 L	Total
Lorsban	218.000	1.5 L	327.00	5	65.40	17,598.56	1,150,945.82	26,397.84	No
Intrepid	1,400.00	0.25 L	350.00	17	20.50	17,598.56	362,323.48	4,399.64	Total

Comparison of a traditional technology and an integrated pest management component in aphid control by day.

Box 29

Table 28

Economic and ecological impact of IPM (Chrysopa) vs. chemical control

Control	Unit cost	Dosis ha	Cost ha	PPD	DP cost	Surface	Cost T. day	CPNPA	With regard to the NC
Chrysopa	$60.00	10 cm³	$600.00	45	$13.33	17,598.56	$234,647.47	0 L	Total
Aflix	130.00	0.5 L	65.00	5	15.09	17,958.56	265,562.27	8,799.28	Moderado
D. Foca	20.9	0.5 K	10.45						
Lorsban	215.00	1.5 L	327	5	65.4	17,598.56	1,150,945.48	26,397.84	No

PPD. - Protection period in days.
PD. - Protected Day.
CPNPA. - Amount of pesticide needed per application.

The economic impact refers to the economic expenses avoided when comparing traditional chemical management with integrated pest management (IPM) supported by the use of beneficial insects Tarango Rivero (2007). This was estimated at 67.8% savings in daily expenditure comparing IPM (Trichogramma+intrepid) with traditional technology (Lorsban) for GBN control and 56.5% for aphid control using IPM (Crysopa+Aflix+D.Foca): in other words, savings of $1,431,614.62.

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Ramirez-Moreno, Hilario, Aguirre-Orozco, Mario Abelardo, Delgado-Martinez, Martha Lilia and Contreras-Martínez, Jesús José. Market research on two natural predators of walnut pests: Trichogramma ssp and Chrysoperla carnea, in Delicias City, Chihuahua. ECORFAN Journal-Ecuador. 2024. 11-21: 9-20.
https://doi.org/10.35429/EJE.2024.20.11.9.20

Box 30

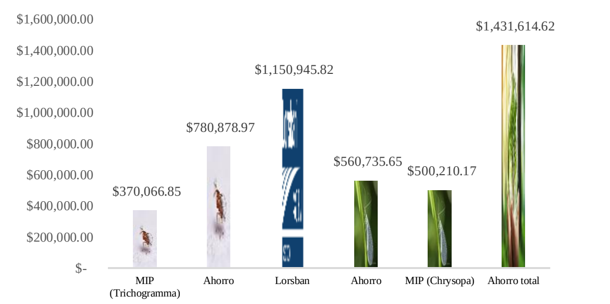

Figure 2
Economic impact of IPM

In the ecological impact, the volumes that are no longer discharged into the environment when spraying is reduced by the use of beneficial insects Tarango Rivero (Control de pulgones, 2005).

Comparing IPM (Trichogramma+intrepid) against a traditional management technology (Lorsban) in the control of GBN, a 83.33% reduction in the use of insecticides and a 66.66% reduction in the use of aphids using IPM (Chrysopa+Aflix+D. Foca) is obtained; in other words, 39,594.12 litres of some insecticide would no longer be discharged into the environment.

Box 31

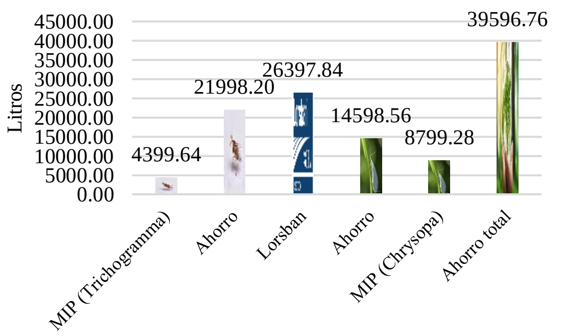

Figure 3
Ecological impact of IPM

Hypothesis Testing

Based on the proposed assertion 'more than half of the walnut and walnut growers are willing to use BC', the hypothesis test was conducted with the following steps:

Ho: Half of the walnut and walnut growers are willing to use biological control.

Ha: More than half of the walnut and walnut growers are willing to use biological control.
Ho: P = 0.50
Ha: P > 0.50

We selected a=0.05 for the significance level, obtaining a critical value of z=1.645, as this is a right-tailed hypothesis test.

The z-test statistic was calculated with the following formula:

$$z = \frac{p-P}{\sqrt{\frac{pq}{n}}} = \frac{0.775-0.50}{\sqrt{\frac{(0.50)(0.50)}{102}}} = 5.50 \quad (3)$$

Where:

z= Test statistic.
p= Sample proportion = 0.775
P= Proportion of the population = 0.50 (Ho)
q= 1 – p
n= Our size = 102

Box 32

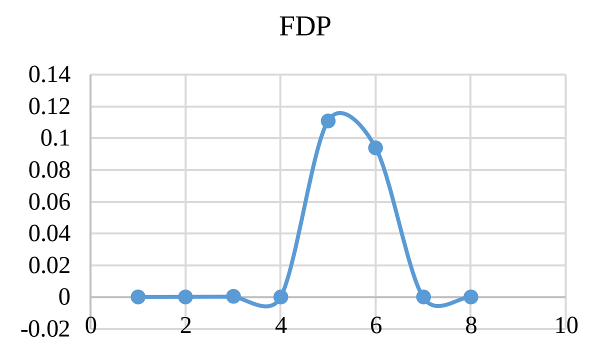

Figure 4
Critical región

Since the test statistic z=5.5 falls within the critical region, the null hypothesis is not accepted and we conclude that there is sufficient sample evidence to support the assertion that more than half of the walnut growers and not from the city of Delicias, Chihuahua are willing to use biological control.

Discussion of results

– As seen in the results of the questionnaires most of the producers use both biological control and chemical control a difference could be made with a good publicity campaign and information to producers on the use and benefits of biological pest control.

- Develop training courses on the use of biological pest control for all agricultural producers in Delicias and the region.

- Conduct a more detailed study on technical and financial feasibility.

- Ultimately, it is crucial to increase the quantity and quality of information flows about biological control. Increasing the availability of information to small and medium-sized producers can have a positive impact on product sales. The development of an appropriate information chain can be an action that can be undertaken from a public-private perspective.

- Sponsor advertising campaigns with generic programming, e.g. a campaign on the use of beneficial insects for pest control aimed at all agricultural producers to raise awareness among producers not only of walnuts, as beneficial insects can be used against pests of other agricultural products.

- Carry out field demonstrations of the application of biological control.

- Have sample orchards, where integrated pest management is carried out.

- The basic conditions necessary for small and medium walnut and walnut producers to demand biological pest control products are:

- That small and medium producers are aware of the technology.

- That small and medium producers have a basic understanding of its application.

- That small and medium producers have a correct understanding of the benefits that the use of biological versus chemical control can bring them.

- That small and medium producers see that these benefits are realistic and consider biological control as a priority in their agricultural activity.

- The need for eco-friendly inputs to increase participation in value markets. In addition, there are other conditions that facilitate the emergence of exchanges between suppliers and producers.
- That small and medium-sized producers can find a supplier who is in touch with their particular needs and wishes and who will satisfy them with the appropriate product.

- That small and medium-sized producers and suppliers are able to agree on the use of biological control as a win-win process

Conclusions

The results of the study indicate that, in the short term, biological pest control has strong market potential. The following conclusions were drawn from the research:

- April-May and August-September are the months with the highest incidence of walnut pests.

- The pests that occur most frequently in walnut trees are the walnut borer worm and the aphid.

- Walnut and pecan growers in Delicias and the region use both chemical pest control and PBC. When walnut growers were asked about the type of pest control they use, 63.7% answered that they use both controls, with only 20.6% using chemical control as the only control alternative.

- There is a very important market for producers of biological pest control in the region that is not being exploited, since 49% of those surveyed bring the product from the laboratory of beneficial insect production of UNIFRUT in Cuauhtémoc, Chihuahua. The project proposed by the Junta Local de Sanidad Vegetal would solve the shortage of biological control products in the region.

- The producers are paying a price of more than $70.00 per cm3 of chrysopa, having a cost of around $60.00.

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- Producers are paying a price of more than $4.00 per cm3 of chrysopa, at a cost of around $2.00.

- The factor that would influence increased use of biological control by growers is the effectiveness of biological control in pest control as growers like to see immediate results. If a technology does not show immediate results, it is difficult for farmers to adopt it.

- If it has a potential market of $1,091,110.72 per period considered to be done in a single application.

- The use of IPM supported with biological control would have an economic impact of $780,878.85 in the use of trichogramma and $650,735.65 in the use of chrysopa.

- IPM use supported with biological control would have an economic impact of $780,878.85 on trichogramma use and $650,735.35 on chrysopa sparing use.

- The use of IPM supported with biological control would have an ecological impact of 21,998.2 L in the use of trichogramma and 17,598.56 L in the use of chrysopa of fewer litres of insecticide discharged into the environment.

- The null hypothesis is not accepted and we conclude that there is sufficient sample evidence to support the assertion that more than half of the walnut and pecan producers in Delicias, Chihuahua are willing to use biological control.

- Based on the above, it can be concluded that from a market point of view it is feasible to set up a laboratory for the production of beneficial insects in the city of Delicias, Chihuahua.

Declarations

Conflict of interest

The authors declare that they have no conflict of interest. They have no known competing financial interests or personal relationships that could have influenced the publication of the article reported in this article.

Authors' contribution

Ramírez-Moreno, Hilario: Main idea of the article

Aguirre-Orozco, Mario Abelardo: I participate in the main idea. Author recognized before the SNI Level I CONAHCYT

Delgado-Martínez, Martha Lilia: Methodological design

Contreras-Martínez, Jesús José: Arrangement and design of tables

Availability of data and materials

The information was obtained from various sources and was the master's thesis of Hilario Ramírez Moreno from the Autonomous University of Chihuahua and is part of the library of master's thesis projects of the Faculty of Agronomy, Delicias campus, the links were reviewed to authenticate its validity on the web.

Financing

There was no budget that contributed to the production of this article, all expenses were incurred on behalf of the authors.

Abbreviations

CBP	Control Biológico de Plagas
CESAVESIN	Comité Estatal de Sanidad Vegetal del Estado de Sinaloa
CPNPA	Cantidad de Plaguicida Necesario por Aplicación.
CQ	Control Químico
DP	Día Protegido
gbn	Gusano Barrenador de la Nuez
gbr	Gusano Barrenador del Ruezno
INIFAP	Instituto Nacional de Investigaciones Forestales Agrícolas y Pecuarias
JLSVD	Junta Local de Sanidad Vegetal de Cd. Delicias
MIP	Manejo Integrado de Plagas
PPD	Periodo de Protección en Días
PQ	Pesticidas Químicos

SAGARPA	Secretaria de Agricultura Ganadería y Recursos Pesqueros
UNIFRUT	Unión de Fruticultores

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Article

Classical methods used for predicting temperature as a relevant variable of climate change

Métodos Clásicos utilizados para la predicción de la temperatura como variable relevante del cambio climático

Alarcón-Ruiz, Erika [a], González-Barbosa, Juan [b], Frausto-Solís, Juan [c] and Rangel-González, Javier Alberto [d]

[a] Tecnológico Nacional de México - Instituto Tecnológico de Ciudad Madero• LFS-8806-2024• 0000-0003-1375-3442 • 163514
[b] Tecnológico Nacional de México - Instituto Tecnológico de Ciudad Madero • T-2470-2018 • 0000-0002-3699-4436 • 202134
[c] Tecnológico Nacional de México - Instituto Tecnológico de Ciudad Madero • R-5308-2017 • 0000-0001-9307-0734 • 31308
[d] Tecnológico Nacional de México - Instituto Tecnológico de Ciudad Madero• LFT-0888-2024 • 0009-0007-3656-5459 • 551326

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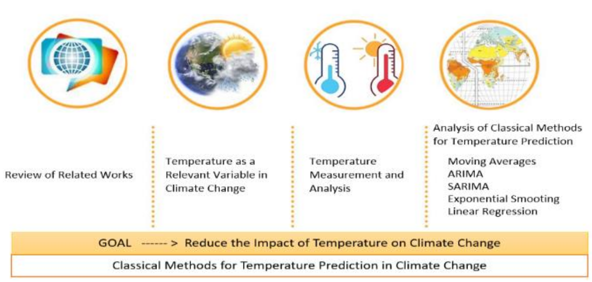
* ✉ [erika.ar@cdmadero.tecnm.mx]

Abstract

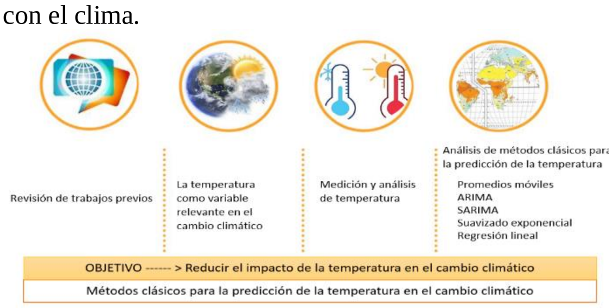
Temperature prediction has become a very important area of research in the context of climate change. Classical prediction methods have been highlighted as fundamental tools to address this problem. This work includes a state of the art on temperature prediction as an important variable of climate change, where we seek to identify the strengths and limitations of the methods used such as moving averages, ARIMA, SARIMA, exponential smoothing and linear regression. These methods continue to be valuable tools in temperature prediction, providing a solid basis for analysis and decision making in meteorology and other climate-related areas.



Climate change, Temperature analysis, Related works, Classical methods

Resumen

La predicción de la temperatura se ha convertido en un área de investigación muy importante en el contexto del cambio climático. Los métodos clásicos de predicción se han destacado como herramientas fundamentales para abordar esta problemática. En este trabajo se incluye un estado del arte sobre la predicción de la temperatura como variable importante del cambio climático, donde se busca identificar las fortalezas y limitaciones de los métodos usados como son los métodos de promedios móviles, ARIMA, SARIMA, suavizamiento exponencial y regresión lineal. Estos métodos continúan siendo herramientas valiosas en la predicción de la temperatura, proporcionando una base sólida para el análisis y la toma de decisiones en meteorología y otras áreas relacionadas con el clima.



Cambio climático, Análisis de temperatura, Trabajos relacionados, Metodos clásicos

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Introduction

The climate changes over the years, due to processes that occur within or outside the climate system, such as emissions of gases caused by human activities, which we call anthropogenic changes. The seriousness of the current climate change is that it is so fast (compared to historical changes) that natural ecosystems and we, humans, are not prepared to change at the same pace and be able to cope with it. This change is a variation of the average climate in the medium and long term, and can last for decades or longer periods.

In terms of prediction or forecasting, climate models try to simplify reality and use historical climate records (data from years ago) and global emissions trends (depending on how society evolves and how we behave) to project what may happen in the future. Therefore, the models can generate different results that must be interpreted with caution. Climate warming is unequivocal; unprecedented changes have been observed since the 1950s [1].

We can expect three types of fundamental climate changes: One is changes in the mean, meaning that the average value of a variable changes, causing the value to increase or decrease; another change is an increase in variability or amplitude, where the average value remains the same, but the range will be wider and more variable. The other is the one that involves both changes (mean + variability) [2].

The analysis of classical methods for temperature prediction involves evaluating and comparing statistical and time series techniques that have been widely used before the advent of machine and deep learning models. Below we describe some of the most commonly used classical methods and how they can be applied in temperature prediction.

Review of Related Works

Temperature prediction is one of the most studied areas in meteorology and time series analysis. Over the years, numerous studies have explored the use of classical methods for temperature prediction. This review summarizes some relevant works that have applied and evaluated classical methods such as moving averages, ARIMA, SARIMA, exponential smoothing, and linear regression.

Shahid et al. [3] conducted a study in which they propose to achieve traffic forecasting using air pollution data (carbon monoxide CO, carbon dioxide CO2, volatile organic compounds VOCs, hydrocarbons HCs, nitrogen oxides NOx, and particulate matter PM), since, as they mention, these have a great relationship, by the emissions of certain gases one can know the concentration of cars in a certain place. In this study they performed a comparative analysis of 7 different regression models to find which model gives better accuracy. Of these, the one that gave the best result was found to be the Multi-Layer Perceptron model. But in addition to this, the authors proposed a regression model that gives better results than the 7 previously used. This is an ensemble between MLP and SVR (Support Vector Regression). The experimental results show its effectiveness, indicating that the forecast error with this new model is reduced by 2.47%.

On the other hand, to compare forecast models, and in particular to evaluate these methods for climate change, several approaches are used, among the most common are the one known as AIC (Akaike Information Criterion) and BIC (Bayesian Information Criterion) which use measures of how likely it is that a method obtains better predictions than another with which it is compared; for this, metrics known as AUC (area under the curve) or MaxEnt (Max entropy) are used[4]. It is not yet known which of the numerous approaches is the best criterion for evaluating the combination of several forecast models, much less for climate change. However, a recent evaluation found that for the M4 competition the BIC approach is among the best approaches for such a comparison; in addition, the metrics of this approach can be used to obtain a combination of forecast methods and to select the combination of the highest quality [5].

Another research example is that of Ibarra and Huerta [6], whose objective was to build a spatial model to generate a fire prediction scenario for the year 2050 in the La Primavera Forest, taking as a reference the data of the climate projections for western Mexico and the historical occurrences of fires in recent years.

This model was taken from a subset of the best 10 models with less than 10% error by omission.

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The spatial model in this work had an AUC (area under the curve, which is the graphic output in which the ability to discriminate an occurrence "sensitivity" against the ability to discriminate an absence "specificity") of 0.81, indicating that the robustness to classify the presence of fires in the APFFLP was good. In conclusion, the spatial model developed with MaxEnt [7], under the climate change scenario, proved to be a reliable tool to predict the APFFLP for the year 2050. Also using MaxEnt, is the work of Qin, et al. in Truja, China [8]. the areas to be burned

On another occasion, K. Krishna Rani Samal, et al. [9], conducted a research study that explores a new pollutant forecasting model called Multi-output temporal convolutional network autoencoder (MO-TCNA). The MO-TCNA network serves both PM2.5 and PM10 pollutant forecasting for multiple locations, rather than performing single-output and site-specific pollutant forecasts. Consequently, the experimental results show that the MO-TCNA network saves time and performs better than traditional site-specific forecasting models. It has also shown its satisfactory long-term prediction results for PM2.5 and PM10 pollution at multiple sites. An absolute error (MAE) of 32 was obtained.

Temperature as a Relevant Variable in Climate Change

Temperature is one of the most important and sensitive variables in the study of climate change. Its variation affects various aspects of the climate and the environment, influencing ecosystems, the water cycle, and human activities. Below, we describe its relevance, how it is measured and analyzed in the context of climate change.

Main Indicator of Global Warming: The average global temperature has increased significantly since the beginning of the industrial era, mainly due to greenhouse gas (GHG) emissions such as carbon dioxide (CO_2). This increase in temperature is a direct indicator of global warming and its effects on the climate.

- Impact on Ecosystems: Changes in temperature affect the distribution and behavior of species, altering entire ecosystems. The melting of glaciers and rising sea levels are directly related to the increase in global temperature.
- Effects on Climate Phenomena: Increase in the frequency and intensity of extreme events such as heat waves, storms, and floods. Changes in precipitation patterns and the appearance of more severe droughts in some regions.
- Repercussions on Human Health: The increase in temperature can cause health problems such as heat stroke, respiratory and cardiovascular diseases. It also influences the spread of vector-borne infectious diseases, such as dengue and malaria.

Temperature Measurement and Analysis

Temperature measurement requires meteorological stations that collect temperature data at specific locations, providing detailed and accurate information. Satellites also measure the temperature of the land and ocean surface on a global scale, offering a broad and continuous view; while buoys and ocean soundings collect temperature data at different depths of the ocean.

Temperature analysis involves studying temperature trends over time, identifying patterns of increase or decrease.

This allows current temperatures to be compared with historical averages to identify anomalies that indicate unusual warming or cooling. Mathematical and simulation models are used with the collected data to predict future temperature variations and their possible impacts.

Regarding the prediction of temperature as a relevant variable in climate change, works such as that carried out by Lin et al. [20], which performs the forecast of the maximum temperature in the climate change area in the metropolitan region of the city of Tapei in Taiwan, using a hybrid method of a complementary multi-dimensional ensemble and a neural network, called in English as Multi-dimensional Complementary Ensemble Empirical Mode Decomposition and Radial Basis Function Neural Network (MCEEMD-RBFNN). With this, it is possible to forecast the maximum daily temperature for the next 7 days. In the results of this work, it was obtained that its average error according to MAPE tests was 2–4.5%. It should be noted that a low error is achieved because it is a very short-term prediction.

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On the other hand, Morid et al. [21], carried out a study where he makes an integrated framework for the prediction of the impact of climate change on a simulated river, taking into account the water temperature and other hydrological parameters.

The configuration of this model is based on a combination of two models called Soil and Water Assessment Tool (SWAT) and the international river interface cooperative (iRIC). The water temperature module in SWAT was modified to observe the effectiveness of the method. With this method, it was obtained that the prediction of this temperature obtained a mean square error RMSE of approximately 2 to 3 °C.

Continuing with the water temperature, Mercado-Bettín, Clayer et al. [21], made a forecast of the water temperature in lakes and dams taking into account the climatic seasons.

They used the seasonal climate forecast system (SEAS5) and reanalysis (ERA5) of the European Centre for Medium Range Weather Forecasts (ECMWF). According to the results, no significant progress was made in the forecast.

Al Sayah, et al.[22] , made a contribution to the evaluation of climate change in a hydrological basin in the Mediterranean by obtaining information from a distance and using an ARIMA forecast model for the average, minimum and maximum temperature in the area. For the average temperature forecast, it was found that the temperature trend will increase by more than 0.9 °C by 2030, with the adjusted SARIMA (2,0,0) (0,1,1)12 model. From this, an R2 in the model of 0.823 and a goodness of fit R2 of 0.825 were achieved.

Another study in which the SARIMA model was used is that of Farsi M, et al. [23] where a genetic algorithm was used to optimize it. This was used to predict as a test mean temperature data in India from 2000 to 2017 and an RMSE of 1.16 was obtained in the best case.

Within the prediction by classical methods, Su, Y, et al. [24] made a forecast of the urban ecological footprint of water with double exponential smoothing, where they used an adjustment of α=0.3 achieving a squared sum of residuals (SSE) of 0.005.

Indriani R., et al. [25] also performed a forecast with exponential smoothing, but they used the additive Holt-Winter method to predict the maximum and minimum air temperature. For the maximum temperature they used $\alpha = 0.4$, $\delta = 0.1$, and $\gamma = 0.1$, obtaining a MAPE = 1.62917%. On the other hand, to predict the minimum temperature they used $\alpha = 0.7$, $\delta = 0.1$, and $\gamma = 0.1$, obtaining a MAPE = 1.92473%.

To predict the monthly ambient temperature and precipitation, Papacharalampous, G, et al. [26] used several automatic prediction methods, including ARFIMA, Naive method, ARMA, BATS, and an exponential smoothing method, which had the lowest RMSE error globally of 1.68.

Another study that uses exponential smoothing is that of Mahajan, S., et al. [27] but in this model a drift (ESD) is added to predict PM 2.5 in the short term. They obtained a mean error of 0.16, the lowest compared to ARIMA which was 11.47 and NNAR of 1.19. ESD also gained in the shortest computing time.

In summary, there are many prediction methods and ensembles between these to reduce the error, and numerous studies, but none has been found for temperature as a relevant variable of climate change in the regions of Tampico, Tamaulipas and Xalapa, Veracruz in Mexico. The aim is to apply the classic methods proposed in this work such as SARIMA and exponential smoothing also used by Liu, et al. [28].

Analysis of Classical Methods for Temperature Prediction

Classical methods for temperature prediction are valuable tools that offer a balance between simplicity and effectiveness. Each method has its own advantages and limitations, and the choice of the appropriate method depends on the characteristics of the data and the specific objectives of the prediction. By understanding and applying these methods, valuable insights into temperature trends and patterns can be obtained, contributing to better planning and decision making in various areas. Classical prediction methods have been used for decades due to their simplicity and effectiveness. This section presents an analysis of the most common classical methods for temperature prediction, evaluating their characteristics, advantages and limitations.

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The Moving Averages method Smooths a time series to identify underlying trends and is based on calculating the average of subsets of data. Its advantages include being simple and easy to implement and reducing noise and highlighting general trends. On the other hand, it cannot capture complex seasonal patterns and it delays the response to rapid changes in the trend, so it is mainly used to identify short-term trends and for smoothing noisy data.

The ARIMA (AutoRegressive Integrated Moving Average) method combines autoregressive (AR), integrated difference (I) and moving average (MA) components and is suitable for stationary time series. It records temporal dependencies and autocorrelation patterns and is flexible and applicable to a wide range of time series. However, it requires the series to be stationary or to be adequately differenced and can be complex to fit. Widely used in economic and weather forecasts where the time series show autocorrelation.

The SARIMA (Seasonal ARIMA) method extends ARIMA to capture seasonal patterns by means of additional seasonal components with a given period. It captures both seasonality and temporal dependencies and is suitable for time series with strong seasonal patterns. It is more complex to fit than ARIMA due to the additional seasonal components and requires a sufficient series length to capture seasonality. It is used for time series with clear seasonality, such as annual weather data.

The Exponential Smoothing method predicts the time series by exponentially weighting past data and includes variants such as Single Exponential Smoothing, Double Exponential Smoothing and Triple Exponential Smoothing (Holt-Winters). It is simple to implement and tune and captures trends and seasonality effectively in more advanced variants (Holt-Winters). Its limitations include that the simple version does not record trends or seasonality and that more advanced versions require careful tuning of smoothing parameters. It is used for short and medium term predictions where trends and seasonality are evident.

The Linear Regression method models the linear relationship between temperature and one or more independent variables (predictors). It is divided into simple and multiple linear regression models that are easy to interpret and implement.

It is suitable for understanding the influence of multiple factors on temperature, although it assumes a linear relationship between variables, which may not be realistic for all time series and does not record complex non-linear or seasonal patterns, so it is used for predictions where a linear relationship between temperature and other variables is known or assumed.

Based on the review of previous work, Table 1 presents an analysis of the methods with an ensemble, whether machine learning, SES, ARIMA.

Box 1

Table 1

Comparison of forecasting methods

Method	1	2	3	4	5	6
SE double [24]	X	X	X	✓	X	X
SE triple additive [25].	X	X	✓	✓	X	X
SED [27].	✓	✓	X	✓	X	X
Ensemble-Neural Network. [20]	✓	✓	✓	X	X	X
Ensemble Wavelet transform [11]	✓	✓	X	✓	X	X
CMIP5 and GCM [10]	✓	X	✓	✓	X	X
MLP and SVR [3].	✓	✓	X	X	X	X
MaxEnt [8]	✓	✓	✓	X	X	✓
SES-Hurst [16]	✓	✓	X	✓	X	X
FCTA [17]	✓	✓	X	✓	X	X
ARIMA [23]	X	✓	✓	X	✓	X
SARIMA [26]	X	✓	✓	X	✓	X

Features:

1) Ensemble
2) Machine Learning
3) Predicts temperature
4) SES
5) ARIMA
6) Applies to regions of Mexico

Conclusions

Temperature is a crucial variable for the study of climate change due to its direct impact on the environment, ecosystems and human society.

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Measuring and analyzing temperature trends is essential to understand the extent of climate change and develop mitigation and adaptation strategies. Using data analysis tools and techniques, valuable scenarios can be obtained to help address this global challenge. Classical methods such as SMA, EMA, ARIMA and Holt-Winters are valuable tools for temperature prediction. Each method has its strengths and weaknesses, and the choice of the appropriate model depends on the nature of the data and the specific objectives of the analysis. These methods provide a solid basis for time series analysis and can be complemented with more advanced machine learning techniques to improve the accuracy of predictions. The methods described can be applied to other climate variables and results can be improved by using more advanced models and a more complete data set. Furthermore, the combination of machine learning techniques with spatial analysis can provide more accurate and useful predictions for the study of climate change.

Conflict of interest

The authors declare no interest conflict. They have no known competing financial interests or personal relationships that could have appeared to influence the article reported in this article.

Authors' Contribution

The contribution of each researcher in each of the points developed in this research, was defined based on:

Alarcón-Ruiz, Erika: contributed to the research design, the type of research, the approach, the method and the writing of the article.

González-Barbosa, Juan Javier: Carried out the systematisation of the background for the state of the art. He also contributed to the writing of the article.

Frausto-Solis, Juan: Contributed to the project idea, research method and technique. He supported the design of the field instrument.

Rángel-González, Javier Alberto: worked on the application of the field instrument, data collection and systematisation of the results. He also worked on the writing of the paper.

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Article

Design of the prototype of a system for the quantification of fungal cells

Diseño del prototipo de un sistema para la cuantificación de células fúngicas

Salazar-Casanova, Hermes*[a], Meneses-Flores, Arturo Elfego [b], Mendoza-San Juan, Luis Alberto [c] and Juárez-Castillo, Efrén [d]

[a] Universidad Tecnológica de la Huasteca Hidalguense • O-6647-2018 • 0000-0002-8444-6186 • 926456
[b] Universidad Tecnológica de la Huasteca Hidalguense • HHN-6951-2022 • 0000-0002-6629-0130 • 712025
[c] Universidad Tecnológica de la Huasteca Hidalguense • O-6650-2018 • 0000-0002-7186-0177 • 344988
[d] Universidad Tecnológica de la Huasteca Hidalguense • AAS-5698-2020 • 0000-0002-2136-2516 • 344990

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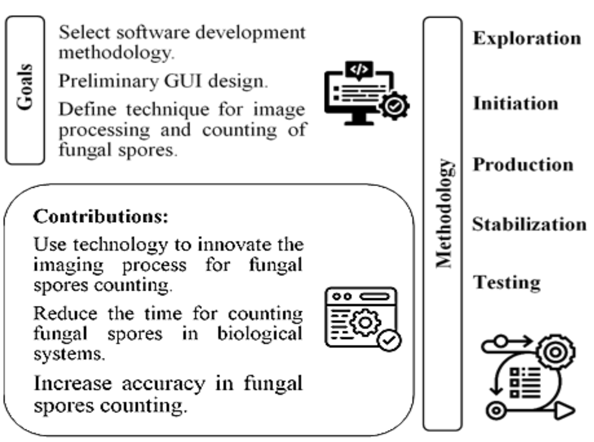
* ✉ [hermes.salazar@uthh.edu.mx]

Abstract

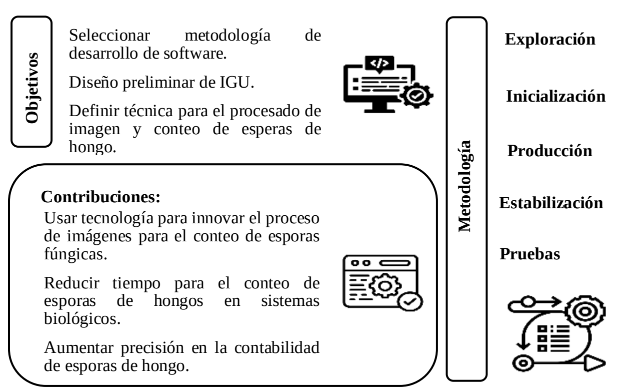
The initial purpose of this research is to design a mobile prototype that, through image processing, counts fungal spores in biological systems. With this, it is sought to make the execution of the process more efficient, as well as its accuracy, because the calculation carried out by the traditional method requires a lot of time and this continues to be not so precise. The Mobile-D methodology will be implemented, which consists of 5 phases: Exploration, Initiation, Production, Stabilization and Testing. This project has the scope of include the design of a prototype, derived from the fact that it is still in a preliminary development stage. In the future, it is intended to develop a mobile application that counts spores through the treatment of images located in a gallery within this tool, allowing you to select one to process it and perform the count that will show the results on the screen, indicating the number and highlighting with an indicative outline each element detected in the image.



Prototype, Spores, Mobile-D

Resumen

Esta investigación tiene como propósito inicial diseñar un prototipo móvil que, mediante el procesamiento de imagen, realice el conteo de esporas de hongos en sistemas biológicos. Con ello, se busca hacer más eficiente la ejecución del proceso, así como su exactitud, debido a que el cómputo realizado por el método tradicional requiere mucho tiempo y este continua sin ser tan preciso. Se implementará la metodología Mobile-D, que consta de 5 fases: Exploración, Iniciación, Producción, Estabilización y Pruebas. Este proyecto tiene como alcance incluir el diseño de un prototipo, derivado de que se encuentra aún en una etapa de desarrollo preliminar. Se pretende desarrollar a futuro una aplicación móvil que contabilice esporas a través del tratamiento de imágenes ubicadas en una galería dentro de esta herramienta, permitiendo seleccionar una para procesarla y realizar el conteo que mostrará los resultados en pantalla, indicando el número y remarcando con un contorno indicativo cada elemento detectado en la imagen.



Prototipo, Esporas, Mobile-D

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Introduction

Fungi were among the first organisms to appear on planet Earth, approximately 300 million years ago. They do not have the ability to form tissues, they are considered ubiquitous because they have the ability or versatility to live in different environments: they can colonise land, water or even air.

The conditions for their development in the environment are based on physico-chemical variables such as humidity, temperature, altitude, light, aeration, pH, nitrogen ions, carbohydrates, etc. Each species will have specific requirements, with independent ecological niches, but the climatic conditions of the tropics favour their development.

Their main function in nature is to degrade dead organisms, therefore they are considered saprophytes. But they can also be symbiotic organisms, living in intimate association with other living organisms for mutual benefit. They are also considered parasites, as they feed on substances produced by other living beings, such as humans, by living in their internal organs or on their surface, and cause damage or disease (Gómez Daza, 2024).

For this work, the first step is the design of a mobile application that allows the versatile and automated counting of fungal spores in the region of the Huasteca Hidalguense. For the moment, in this first step towards the creation of the prototype, only the elements and functions that will integrate the graphical user interface will be defined; in future advances, the operational modules that will allow the use of this tool for its use in the field of research will be developed.

Currently, the procedure for counting fungal spores is performed in the traditional way using a Neubauer chamber. This process has been employed over the years and has been found to require a significant amount of time and effort to perform due to the multiple counts that a laboratorian must perform (Márquez, et al., 2013).

Accuracy depends entirely on the experience of the person examining a sample, as the procedure is done manually, but this can be improved with the use of technology.

This article includes the following sections: Problem, where the situations to be solved with this research are indicated; the justification points out the main purpose of the research where the benefits and impact expected to be generated are indicated; then, the objective to be achieved in this work is included.

The theoretical foundations include the main concepts that relate to and contextualise the reader with the subject of the study; the methodology indicates in an orderly manner the stages in which the research will be carried out; the development shows the work and tasks carried out in each phase of the project's development. The final sections include the results and conclusions of the research, as well as acknowledgements and references.

Problem

Fungal spores are useful for improving various biological processes and systems, as well as preventing their negative effects. This is because some fungi offer great benefits, while others can be detrimental.

In the Huasteca Hidalguense there is a great variety of fungi, both edible and toxic. Some play an important role in the biological systems of the region, including plants, animals and humans, helping to keep them healthy, as long as they are not present in excess or harmful. A study revealed that there are five species of edible mushrooms in the region, identified by their white, purple and yellow colours. In contrast, toxic mushrooms, which are not suitable for consumption, are grey or red in colour (Cipriano, et al., 2019).

This fact is important, because the interaction with these organisms implies the need to know specifically how they expand their colonisation, in order to be used in different activities.

For this purpose, it is necessary to perform spore counting, a procedure that involves collecting a sample of a specific species of fungus. With the sample obtained, the total number of cells present is quantified. Once the number has been determined, their concentration can be assessed and a decision can be made as to whether or not it is beneficial to increase their population.

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This process requires the use of a haemocytometer (an instrument used in medicine and biology to count spores and cells). Once the sample is entered into the instrument, a section is selected for counting. An expert has to count the spores within that section one by one.

From the number obtained, an average of the estimated total of spores in the sample is obtained.

One of the main disadvantages is that counting requires a large amount of time and, by analysing only a part of the total sample, it may not give the most accurate result possible.

Justification

Having detected the need, the aim is to speed up the counting process, resulting as an initial proposal the design of a mobile application that will carry out this task, it will work by entering an image of the spores, so that, through the digital processing of the image, the computation is carried out.

With the help of this tool, the way in which spore counting is carried out would be innovated and speeded up, obtaining more accurate results and reducing the time required to carry out this process.

For the design of this prototype, various techniques will be used that allow for advanced and efficient image processing. Among the most prominent alternatives are **geometric transformations**, including scaling, rotation, transformation and perspective, allowing images to be adapted to different visual contexts. In addition, **image filtering**, particularly non-linear filtering, helps to remove noise without losing important details.

For deeper analysis, **feature detection and extraction** methods can be employed, such as contour detection, which highlights the boundaries of objects within the image. **Image segmentation**, on the other hand, allows the image to be divided into specific regions using models such as watershed, facilitating the identification of relevant areas.

Likewise, **object recognition** using deep learning offers a powerful tool to identify patterns and shapes within the prototype.

In terms of **image morphology**, skeletonisation is useful for simplifying complex shapes, and finally, **image enhancement** by adjusting contrast and brightness optimises the overall visualisation, providing sharper and more defined images. These combined techniques provide a holistic approach to improving the quality and functionality of the prototype. This project aims to generate a great impact by solving the problem detected through digital image analysis, thus giving the possibility to be implemented in other research fields where required, so it is feasible to invest time and/or resources in its development.

Objective

To develop a mobile application that implements artificial vision libraries, advanced image processing techniques and mobile application development environments to reduce the time and effort required to count fungal spores.

Theoretical background

Fungi: Characteristics and importance

Fungi are a group of living organisms devoid of chlorophyll. They resemble simple plants in that, with few exceptions, they have distinct cell walls, are usually non-motile, although they have motile reproductive cells, and reproduce by means of spores (García de la Rosa, 1990).

Like animals, fungi are heterotrophic organisms, which means that they must forage for food in order to survive. Faced with this pressure, throughout their evolution, fungi have developed effective and multiple survival and dispersal strategies, becoming a mega-diverse group whose distribution extends to practically all ecosystems on our planet (Heredia, 2020).

Throughout its history, man has always tried to know living beings in order to differentiate them by their usefulness, harm or to establish systems that allow him to identify them. The use of fungi has different applications, for example, in medicine, where Penicillium is used for the production of penicillin, which is an antibiotic used to fight infections; in the industrial sector, yeasts are used in the production of wine, beer and bread; as food, there are a large number of edible fungi, where mushrooms stand out, as well as other wild mushrooms such as huitlacoche.

The vast majority of fungi are not harmful to humans, but those capable of producing toxins in food are. The high pathogenicity of fungi is found in vegetables, which are more susceptible to them (Universidad Autónoma de Ciudad Juárez, 2012). In order to study the communities of organisms and ecosystems, several research studies have been carried out. For example, fungi are the most studied organisms due to their role as primary decomposers and their participation in biogeochemical cycles (Cuadros et al., 2011).

Fungi in Mexico

Mexico is a mega-diverse country in terms of groups of organisms, occupying fifth place in the world for its large number of species and endemisms, and has 10% of the planet's terrestrial diversity. As for the diversity of fungi, several investigations have been carried out in order to determine an approximate total of existing fungi. It is estimated that there are around 4,500 species of macro fungi and 2,000 micro fungi in the country, based on bibliographic reviews and specimens from collections. Based on estimation proposals made by different researchers, it is estimated that there are more than 200,000 species of fungi in Mexico, so that the amount currently recorded corresponds to 3.2% of the total number of fungi. (Aguirre, et al., 2014).

Box 1

Figure 1
Huitlacoche, Mexico's representative mushroom
Source: Gobierno de México, 2020

Mushrooms in Hidalgo

The state of Hidalgo has 1,138 species of fungi out of the 4,500 registered nationwide, according to the state diagnosis of biodiversity, prepared by the State Secretariat of Environment and Natural Resources (SEMARNATH), representing 25.3 per cent of Mexico's fungi varieties.

The study detailed that 15.9% of the mushroom species are used in local food, while 6% are used in local medicine, in addition to the fact that before the study began in 2017, there was no accurate data on the diversity of species that inhabit the state (García, 2019).

Mushroom spores

Spores play a crucial role in fungi, just as seeds do in plants. They can be of every conceivable shape: smooth, warty, round, cylindrical, ellipsoid, nabiform, etc. In addition to their shapes, some have other very peculiar characteristics, such as a germinating pore, which can be central, apical, or marginal, larger or smaller. On the other hand, their measurements are unalterable, so that when comparing them with those of the same species they provide us with very reliable data. (Carranza, 2006).

Box

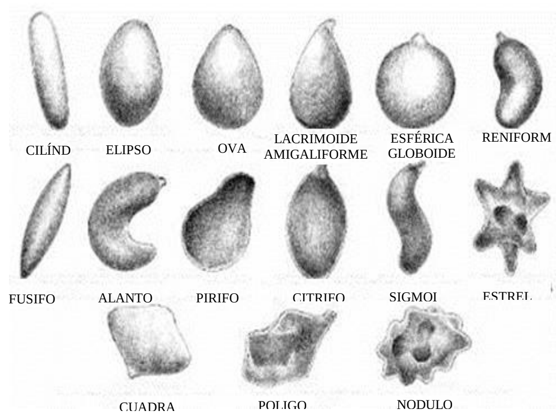

Figure 2
Different forms of spores
Source: Bruns et al., 2002

Spore counting techniques

The Neubauer chamber or haemocytometer, shown in figure 3, is an instrument used for counting fungal spores and biological cells in a liquid medium (distilled water).

Once homogenised, the suspension is filtered through a mesh or gauze to remove agar or mycelial debris that might obstruct the passage of the suspension through the sprayer during inoculation, and brought to a known volume.

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Subsequently, a drop is taken with a Pasteur pipette and placed in the centre of the Neubauer chamber; then the coverslip is placed, taking care that there are no bubbles and that the drop does not spill or fall out of the counting fields; this would give erroneous data, as the excess would drag the spores (Peña Sánchez, et al., 2018).

The chamber consists of two counting fields, each with nine squares, which in turn are divided into smaller squares. Both the large and small squares have known dimensions, so that the number of spores per ml can be obtained by means of formulas. The counting field to be used depends on the size of the conidia of the fungus you are working with. If they are large, it is best to count in the four corner squares (A, B, C, D) plus the centre square (E). In the case of small spore fungi, count the contents of 1, 2, 3, 4 and 5. The count is repeated at least six times and an average is taken (Gilchrist, et al., 2005).

Box

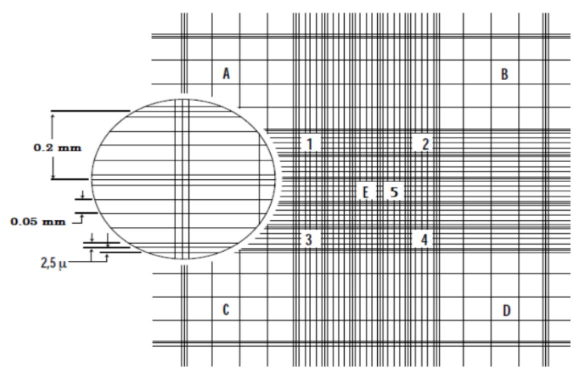

Figure 3

Internal conformation Neubauer chamber

With the data obtained, a mean value is calculated and multiplied by a constant which depends on the chamber used. From this product, the concentration in conidia/ml is obtained. The following formula 1 is used to calculate the counts:

$$Total\ number\ of\ spores = \frac{(NNo.of\ cells\ x\ dilution\ x\ 10^4)}{No.Areas\ mm^2\ counted} \quad (1)$$

This calculation estimates the number/millilitres of suspension. The result is then multiplied by the number of millilitres used in any test for quantification (Bustillo, 2010).

Digital image processing

Digital image processing is an open field of research.

The constant progress in this area is related in conjunction with mathematics, computing, and the increasing knowledge of certain organs of the human body involved in the perception and manipulation of images. The advancement of digital image processing is reflected in medicine, astronomy, geology, microscopy, etc. Meteorological information, transmission and streamlined display of images over the Internet are supported by these advances (Escalante, 2006).

Stages in image processing

The processing stages start from a sequence of image capture and image pre-processing. If the analysis is oriented towards continuous image learning processing (as in the case of a video), for artificial intelligence learning methods, the techniques of focusing and sharpening the capture become more relevant (Kaur, 2016).

In any case, pre-processing is required and the aim of this stage is to reduce ‘noise’ by scaling an image, and by limiting with upper or lower bounding values the intensity of each pixel in its respective region. Usually blurring and binarisation are applied, but in the case of the need to identify image features, preprocessing is required to find and extract lists of detectors or features, which are regions of pixels with values that fulfil a threshold function and are part of an algorithm that can vary whether high similarity (geometric homography) or close similarity is sought, such as detectors for robust matching. (Montoya, et al., 2014).

Geometric transformations

Geometric transformations are fundamental in image processing and computer graphics, as they allow objects and figures to be modified in various ways.

One of the most common transformations is scaling, which adjusts the size of an object without altering its original shape. This process can be uniform, when the dimensions change proportionally in all directions, or non-uniform, if they change only in some dimensions, such as width or height. In applications such as image resizing or graphic visualisation, scaling is essential to adapt objects to different resolutions and visual contexts (González and Woods, 2018).

ISSN: 1390-9959.
RENIECYT-CONAHCYT: 1702902

Mathematically, it is represented by scale matrices that multiply the object coordinates by a specific scale factor.

Rotation is another crucial transformation that rotates an object around a fixed point or axis, keeping its size and shape constant. This type of transformation is indispensable in graphics and geometric modelling, as it changes the orientation of objects without altering their internal properties.

In the 2D plane, rotation is performed with respect to a point, such as the origin of the coordinates, while in 3D space, rotation occurs around the X, Y or Z axis (Hartley and Zisserman, 2004).

Rotation is described by angles and is implemented using rotation matrices that adjust the positions of the object's points relative to its centre of rotation.

Geometric transformation, on the other hand, is a more general concept that encompasses several types of modifications that can be applied to an object, such as translation, scaling, rotation and reflection.

These transformations make it possible to change the position, size, orientation or shape of an object in space without changing its fundamental properties. In computer graphics, these transformations are essential to manipulate objects and scenes efficiently, facilitating their representation and analysis (Foley et al., 1995).

Linear transformations, which include combinations of the above, are represented by transformation matrices.

Finally, perspective is a geometric transformation that simulates the projection of a three-dimensional object onto a two-dimensional plane, similar to how human vision or a camera captures images of the real world.

This transformation is fundamental in the creation of realistic graphics and visualisations, as it introduces depth and distance into images.

Through perspective, parallel lines appear to converge at a vanishing point, allowing objects to be represented more accurately, especially in 3D graphics systems (Forsyth and Ponce, 2012).

This perspective projection is key to creating a sense of realism, making distant objects appear smaller and near objects appear larger, replicating the way light enters the human eye or a lens.

Non-linear image filtering

A technique used in image processing to reduce noise without significantly affecting important image features such as edges and fine textures.

Unlike linear filters, which apply a mathematical operation that combines pixel values in a neighbourhood uniformly, non-linear filters evaluate the local structure of the image and adjust pixel values based on specific criteria, such as the order of values in the neighbourhood or the morphology of the analysis area.

One of the best known methods in this field is the median filter, which replaces the value of a pixel by the median of its neighbouring pixel values, effectively removing impulsive noise without blurring the edges (Zhang and Karim, 2002).

Segmentation by regions

The watershed model is often used in images with fuzzy or high-noise edges, as it is able to detect boundaries based on topographic and intensity features, thus avoiding the common problems of gradient-based segmentation techniques. In medical applications, this technique is especially useful for image segmentation in radiology and tomography, allowing the accurate separation of complex anatomical structures, such as organs in MRI studies (Roerdink and Meijster, 2000).

In addition, the watershed algorithm can be combined with other image processing techniques, such as image pre-smoothing or edge detection, to improve results by avoiding over-segmentation, one of the main challenges of this technique when applied without pre-processing. This combined approach has been shown to be effective in areas such as computer vision, biomedical image analysis, and object detection in satellite images and microscopy (González Díaz, et al., 2017).

ISSN: 1390-9959.
RENIECYT-CONAHCYT: 1702902

Object recognition with deep learning

It is an advanced technique in the field of artificial intelligence and computer vision that allows systems to identify and classify objects within an image or video automatically. Deep learning is based on artificial neural networks that mimic the structure and functioning of the human brain, allowing the system to learn complex patterns and relevant features of images across large datasets (LeCun, et al., 2015).

One of the main advantages of deep learning-based object recognition is its ability to be **autonomous** in feature extraction, eliminating the need to manually design specific descriptors for each type of object, as was done in traditional methods. In addition, it has proven to be robust to noise, distortions and variations in images, making it very efficient in real-world situations where visual conditions are highly variable (He, et al., 2016).

Image morphology

In the field of image processing, the term skeletonisation refers to a morphological analysis technique used to reduce the shape of an object to its fundamental structure or ‘skeleton’.

This process is performed by iteratively removing pixels from the edges of a binary object until only the most essential structural components are retained, resulting in a more simplified but topologically equivalent representation of the original object (Kong and Rosenfeld, 1996).

Skeletonisation is especially useful in applications where it is necessary to preserve the structural and topological properties of the object, such as shape analysis, pattern recognition, computer vision and image compression. This technique facilitates the identification of key features of objects in an image, such as their connectivity, symmetry and branch points, which are essential for segmentation and analysis tasks (Lam, et al., 1992).

Image enhancement

Contrast and brightness adjustment is widely used in various fields, including medicine and satellite image processing.

In medical imaging, such as X-rays or MRIs, these adjustments can improve the visualization of internal structures, facilitating the detection of abnormalities or lesions (Khan et al., 2017).

In digital photography and object recognition, contrast adjustment allows for clearer identification of edges and fine details, which is crucial in object classification and segmentation (Pal and Pal, 2011).

Methodology

Mobile-D is a methodology proposed by Pekka Abrahamsson, which has as its main characteristic the rapid development of applications through cycles for small teams (Abrahamsson, 2004).

Box

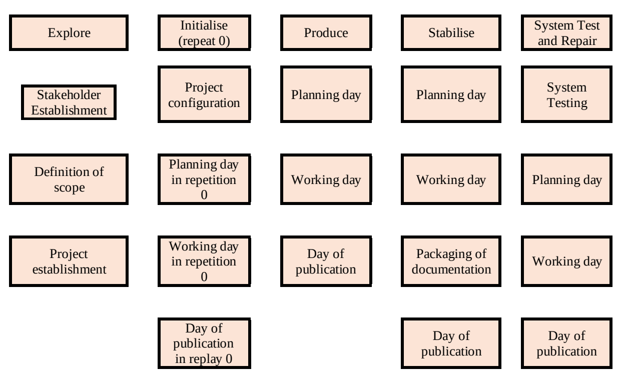

Figure 4
Mobile-D methodology

The exploration focuses on planning attention and basic concepts. The scope of the project and the establishment of functionalities are defined.

The purpose of the initiation phase is to ensure the success of the phases that continue the development of the mobile application by preparing the physical, technical and human resources. Therefore, all preparations are made to realise the project.

The production stage consists of prioritizing the implementation of the customer's requirements by focusing on the basic fundamental operation to allow for multiple improvement cycles. In this phase, the development of the different modules and functionalities of the project begins.

In stabilization, integration is applied to link the separately developed elements into a single application, whereby the various finished modules are implemented to verify that they work together.

Once the development is fully completed, the testing phase continues until a stable version is achieved according to the client's specifications.

If necessary, bugs are fixed, but nothing new is developed. Feedback on defects and bugs found in the software testing is provided to the development team to be corrected for delivery.

Development

It is important to mention in this section that the initial scope defined for this project will include in this first instance, only the first two stages of the Mobile-D methodology, taking into account that this research will continue with the development and completion of the prototype of a system for the quantification of fungal cells, so only the Exploration and Initialisation phases will be used.

In Exploration stage 1, the problem to be solved was clearly and precisely defined, the initial scope of the project was established, and the preliminary framework was established. This stage included several key activities to ensure that the project is well founded before moving on to more technical phases.

Within the Stakeholder Establishment phase, meetings were held with key stakeholders to address specific objectives such as the initial technical requirements, the potential use of the prototype and possible limitations identified, the people who will interact with the application (experts in the area of Agrobiotechnology), the current issues in fungal cell quantification to determine the functions of the tool and the decisions made regarding the initial scope of the project; all to gain a thorough understanding of the end-users' specifications, and to generate the user requirements document.

The scope of the project focused on defining the development of a prototype to quantify fungal cells using a mobile application. Here, it was specified that the prototype will perform the computation of fungal spores by using various elements that will help image processing such as geometric transformations (scaling, rotation, transformation and perspective), non-linear image filtering, contour detection, region segmentation using the watershed algorithm, object recognition through deep learning, cell skeletonisation, and brightness and contrast adjustments.

As part of this activity, stakeholder meetings were held to clarify the functional objectives and initial constraints of the project. Consequently, the testing and validation stages were clearly defined, ensuring that the results will be applicable in various research contexts once completed.

Within the project set-up, a detailed work plan was created, with an initial timeline specifying the team members responsible for each task, with a clear distribution of roles and responsibilities for carrying out the prototype design, and established deadlines and follow-up meetings. The tools and technologies to be used were also identified, such as the development environment for Android applications (Android Studio) and libraries for image processing. In addition, the decision to use this technology was derived from the development of a native Android application, because it offers the advantage of improving the performance of the final application, due to the fact that no adaptation process of the code contemplated in a third-party framework is carried out, as a consequence, the interaction of the tool with the hardware of the devices is carried out directly.

In stage 2, corresponding to Initialisation, the preliminary design of the project was launched, which involves the first sketches of the prototype. The aim of the Initialisation stage is to establish a basic outline of the prototype (version 0) in order to integrate activities that allow the creation of the interface and the functionality of the system. In the configuration phase of the project, the technical and design bases of the mobile prototype were established, because it is essential to define how the graphical user interface (GUI) and interaction flows will be from the beginning to ensure that the end-user experience is intuitive and functional. As a result, sketches were made to capture initial ideas for the user interface.

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https://doi.org/10.35429/EJE.2024.20.11.28.39

These sketches include the layout of key elements of the prototype from the moment the user uploads an image of a sample, until the application performs the quantification of fungal cells.

Box

Figure 5
Welcome screen sketch

In the Planning Day phase in Replay 0, essential tasks were prioritised to build the most basic and functional version of the mobile prototype, paying special attention to the user experience and critical functionalities. In addition, priority screens (such as the image loading screen) were defined.

Within the activities of the Replay 0 Work Day, progress was made in creating the interfaces and connecting the design with the key functionalities of the prototype. The design of the graphical user interface was essential to make the image processing functionalities accessible to the end user. The first screens of the system were implemented, such as the welcome screen, image upload and information screen related to the mobile application

Box

Figure 6
Welcome screen

Finally, a first sample design of the prototype was presented to stakeholders at the Replay Release Day 0 phase. Although this version is an early iteration of the project, it demonstrates the basic functionality of the system and how the interface will allow interaction with the sample images to be counted.

Similarly, feedback was conducted with stakeholders, who provided comments on the design and clarity of functionality.

Box

Figure 7
Prototype design sample

Results

This research has been an outstanding and ambitious initiative that has so far reached several key elements in its development, focusing on the early phases of the Mobile-D methodology, specifically the initialization phase.

During this phase, the team carried out a series of crucial activities that laid the foundations for the technical and methodological development of the prototype. First of all, a precise definition of the functional requirements was established based on the needs of the users.

In addition, a first draft of the graphical user interface design was made, with a focus on usability to facilitate interaction with users who are not specialised in the handling of technical or biological analysis software. The preliminary design of the mobile application included a basic model that will allow the capture and quantification of fungal cells.

In terms of technological resources, the team evaluated and selected the most appropriate hardware and software elements to ensure the optimal future development of this mobile tool.

During the initialization phase, frequent meetings were held with experts in the field of Agrobiotechnology to validate that the defined requirements met the technical requirements necessary for rigorous cell counting. These meetings allowed adjusting some of the functionalities of the prototype, mainly those related to cell detection and quantification, to align them with the expectations of the end users.

On the other hand, some key modules for image data processing are planned to be implemented in the future, although these modules are still in early stages as proposals and require further detailed specifications.

Although these results are preliminary, they indicate that the prototype has the potential to meet the established objectives, although it still needs to be optimized in several aspects, all this, to improve the traditional way of counting fungal spores or biological cells.

Conclusions

The development of this prototype has achieved important milestones in its initialisation phase, particularly in the indication and definition of key requirements and in the preliminary design of the mobile application.

The project has benefited from a collaborative approach, where continuous feedback from experts in the field has been fundamental to adjust and improve the system design, ensuring that it meets the requirements established for this type of application. However, despite this progress, the project is still at an early stage of development, which means that there are still critical areas that need to be addressed in the next phases of the Mobile-D cycle.

Initial feedback from users has shown promising results, but has also highlighted the need for improvements. The project has made significant progress in its initial phase, but there is still a long way to go to reach a fully optimized and highly accurate working prototype.

The development team plans to continue with the development of the remaining stages of the methodology.

It is expected that in the next stages of the Mobile-D cycle, the prototype will be refined and adapted to meet the specific needs of the end-users, allowing for a successful and effective implementation.

The development will continue with a focus on optimization of system performance, integration of new functionalities and thorough validation of the results in real usage contexts.

It can be established that the project has made significant progress in identifying system requirements and creating an initial prototype, although it is still in the early stages of development, with the intention to fully complete its development.

The results obtained so far indicate that the methodological and technical approach is adequate to achieve the proposed objectives.

Declarations

Conflict of interest

The authors declare that they have no conflict of interest. They have no known conflicting financial interests or personal relationships that could have influenced the article reported in this paper.

Authors' contribution

Salazar-Casanova, Hermes: Contributed to the selection of the development methodology to be implemented, design of sketches of the mobile application, research, organization of information, creation of the work plan and writing of this article.

Meneses-Flores, Arturo Elfego: Contributed with the research idea, conducting meetings with stakeholders and defining image processing techniques, meetings to indicate feedback and comments from users.

Mendoza-San Juan, Luis Alberto: Contributed with the specification of requirements, the identification of tools and technologies to be used for the development, as well as the basic construction of the prototype.

Juárez-Castillo, Efrén: Contributed with the identification of tools and technologies to be used for the development, the design of sketches of the mobile application, the basic construction of the prototype.

Availability of data and materials

The information used in this article is available in the publications of the different authors mentioned in the references.

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We are grateful, therefore, for the time, dedication and profound knowledge shared by the entire Agrobiotechnology team, whose efforts have helped to forge a prototype that promises to make a significant contribution to the scientific field and facilitate the work of researchers and technicians in the coming years. Undoubtedly, their participation has laid the foundations for this prototype to be successfully employed in the future, thus benefiting the Huasteca region of Hidalgo, society as a whole, and strengthening research capacities.

Abbreviations

IGU	Graphical User Interface
SEMARNATH	Secretaría de Medio Ambiente y Recursos Naturales de Hidalgo
UTHH	Universidad Tecnológica de la Huasteca Hidalguense (Hidalgo's Secretary of Environment and Natural Resources)

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Surname, Name 1st Author*[a], Surname, Name 1st Co-author[b], Surname, Name 2nd Co-author[c] and Surname, Name 3rd Co-author[d] [No.12 TNRoman]

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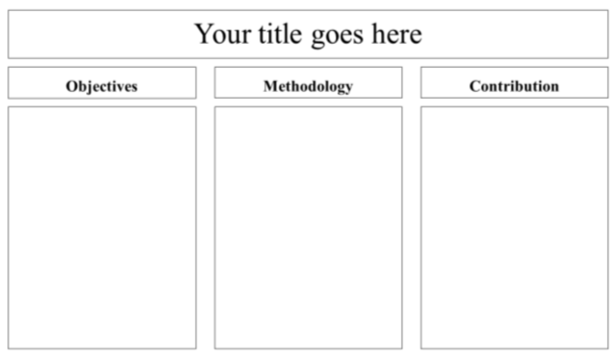

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Introduction

Text in TNRoman No.12, single space.

General explanation of the subject and explain why it is important.

What is your added value with respect to other techniques?

Clearly focus each of its features.

Clearly explain the problem to be solved and the central hypothesis.

Explanation of sections Article.

Development of headings and subheadings of the article with subsequent numbers

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Including figures and tables-Editable

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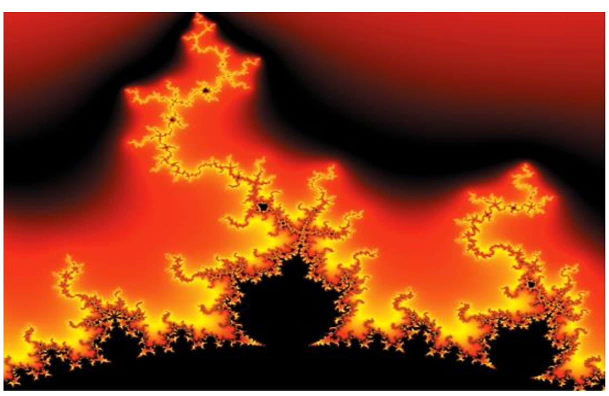

Figure 1
Title [Should not be images-everything must be editable]

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<u>The maximum number of Boxes is 10 items</u>

For the use of equations, noted as follows:

$$Y_{ij} = \alpha + \sum_{h=1}^{r} \beta_h X_{hij} + u_j + e_{ij} \qquad [1]$$

Must be editable and number aligned on the right side.

Methodology

Develop give the meaning of the variables in linear writing and important is the comparison of the used criteria.

Results

The results shall be by section of the article.

Conclusions

Clearly explain the results and possibilities of improvement.

Annexes

Tables and adequate sources.

<u>The international standard is 7 pages minimum and 14 pages maximum.</u>

Declarations

Conflict of interest

The authors declare no interest conflict. They have no known competing financial interests or personal relationships that could have appeared to influence the article reported in this article.

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Author contribution

Specify the contribution of each researcher in each of the points developed in this research.

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Benoit-Pauleter, Gerard: Contributed to the project idea, research method and technique.

Availability of data and materials

Indicate the availability of the data obtained in this research.

Funding

Indicate if the research received some financing.

Acknowledgements

Indicate if they were financed by any institution, University or company.

Abbreviations

List abbreviations in alphabetical order.

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ANN	Artificial Neural Network

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Use APA system. Should not be numbered, nor with bullets, however if necessary numbering will be because reference or mention is made somewhere in the Article.

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