FEDERAL UNIVERSITY OF SÃO CARLOS
CENTER FOR SCIENCE AND TECHNOLOGY FOR SUSTAINABILITY SOROCABA CAMPUS
GRADUATE PROGRAM IN PLANNING AND USE OF RENEWABLE RESOURCES

Marcia Magalhães Arruda

HOPS: AGROCLIMATIC ZONING AND FAVORABILITY FOR THE OCCURRENCE OF DOWNY MILDEW FOR THE STATE OF SANTA CATARINA, BRAZIL

Sorocaba - SP
2024

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Thesis submitted to the Graduate Program in Planning and Use of Renewable Resources to obtain the title of Doctor in Planning and Use of Renewable Resources.

PhD Supervisor: Prof. Dr. Waldir Cintra de Jesus Junior
Co-supervisor: Alexandre Rosa dos Santos

Sorocaba – SP

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I dedicate this work to my husband and my parents, who have never stopped believing in me, who have lived through every phase of this process with me, and for always giving me roots and wings

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“He who has a ‘why’ to live can bear almost any ‘how’”

Nietzsche, Friedrich

ABSTRACT

ARRUDA, Márcia Magalhães de. **Hops: Agroclimatic zoning and favorability for the occurrence of Downy Mildew for the state of Santa Catarina, Brazil.** 2024. Doctoral Thesis, Federal University of São Carlos, Sorocaba, SP. Advisor: Dr. Waldir Cintra de Jesus Junior. Co-advisor: Dr. Alexandre Rosa dos Santos.

Hops (*Humulus lupulus*) is a herbaceous species with significant economic value, primarily used as a fundamental ingredient in the brewing industry, providing bitterness, aroma, and stability to beer. However, its cultivation faces significant challenges, among them downy mildew, a disease caused by the pathogen *Pseudoperonospora humuli*. To gain a better understanding of this pathogen, we conducted a systematic literature review, employing bibliometric techniques to analyze existing knowledge on the subject. We identified 54 publications focusing on the efficacy and resistance of downy mildew management in hops, as well as the genetic and pathogenic relationships. The analysis also highlighted themes such as disease management, cultivar susceptibility, and the influence of climate on the development of downy mildew. Regarding hop cultivation in Santa Catarina, Brazil, an agroclimatic zoning was carried out using conventional approaches and Fuzzy logic. Based on the results, it was found that the mountainous and southern regions of the state are more favorable for hop cultivation, while areas such as the extreme north and coastal regions present restrictions due to unfavorable climatic conditions. The zoning through the reclassification of variables for downy mildew incidence identified 63.13% of the area of Santa Catarina as favorable for the disease, while the *Pseudoperonospora humuli* approach indicated a proportion of 92.80%. It was concluded that the combination of these techniques provides a comprehensive view of the favorable climatic conditions for hop cultivation and downy mildew occurrence, highlighting the importance of management and the development of resistant varieties for hop cultivation in Santa Catarina.

Keywords: Spatialization, Review, Climate, Disease.

RESUMO

ARRUDA, Marcia Magalhães de. **Lúpulo: Zoneamento agroclimático e favorabilidade à ocorrência de míldio para o estado de Santa Catarina, Brasil** 2024. Tese (Doutorado em Planejamento e Uso de Recursos Renováveis) – Universidade Federal da São Carlos, Sorocaba, SP. Orientador: Dr. Waldir Cintra de Jesus Junior. Coorientador: Dr. Alexandre Rosa dos Santos.

O lúpulo (*Humulus lupulus*) é uma espécie herbácea com grande valor econômico, sendo usada sobretudo como ingrediente fundamental na indústria cervejeira, proporcionando amargor, aroma e estabilidade à cerveja. Entretanto, seu cultivo enfrenta desafios significativos, entre eles o míldio, uma doença causada pelo patógeno *Pseudoperonospora humuli*. Buscando uma maior compreensão a respeito deste patógeno, realizamos uma revisão sistemática da literatura, empregando técnicas bibliométricas para analisar o conhecimento existente sobre o tema. Foram identificadas 54 publicações, com foco na eficácia e resistência do manejo do míldio no lúpulo, bem como na relação genética e patogênica. A análise também destacou temas como manejo de doenças, suscetibilidade de cultivares e a influência do clima no desenvolvimento do míldio. Em relação ao cultivo do lúpulo em Santa Catarina, Brasil, foi realizado um zoneamento agroclimático empregando abordagens convencionais e lógica Fuzzy. Com base nos resultados verificou-se que as regiões serranas e do sul do estado são mais favoráveis para o cultivo do lúpulo, enquanto áreas como o extremo norte e as regiões costeiras apresentam restrições devido a condições climáticas desfavoráveis. O zoneamento através da reclassificação das variáveis para incidência do míldio identificou 63,13% da área do estado de Santa Catarina como favorável à doença, enquanto pela abordagem Fuzzy a proporção foi 92,80%. Concluiu-se que a combinação dessas técnicas fornece uma visão abrangente das condições climáticas favoráveis ao cultivo do lúpulo e ocorrência do míldio, destacando a importância do manejo e desenvolvimento de variedades resistentes para o cultivo do lúpulo em Santa Catarina.

Palavras-chave: Espacialização, Revisão, Clima, Doença.

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LIST OF ACRONYMS

A	Area in Km^2
AI	Improper Area
ARET	Apt with thermal excess restriction
AREPT	Apt with rain excess restriction
HRTH	High risk for temperature and humidity
HRTMH	High risk for temperature and moderate humidity
I	Inapt
IEPAT	Inapt due to rain excess and suitable due to temperature
IEPRET	Inapt due to rain excess and restriction due to thermal excess
LR	Low Risk
MR	Moderate Risk
TA	Total area

SUMMARY

1 INTRODUCTION

Hops (*Humulus lupulus* L.) are plants with an annual inflorescence that is cultivated in temperate climate countries, especially between latitudes 35º and 55º in both the Northern and Southern Hemispheres (Bocquet *et al.*, 2018). Native to Europe, Western Asia, and North America, it is a perennial plant that produces annual bines, meaning new shoots from rhizomes emerge each growing season (Fagherazzi *et al.*, 2018; Mpanga; Schalau, 2020). Methods of hop propagation include cuttings, rhizomes, micropropagation, and seeds. Seed propagation is primarily used in genetic improvement projects for the development of new cultivars (Fagherazzi *et al.*, 2018; Mpanga; Schalau, 2020).

Hops are primarily grown for beer production (Fagherazzi; Rufato, 2018). It is the least used component in terms of quantity but also the most expensive, responsible for bitterness, microbiological stability, and physicochemical properties of beer (Gonçalves *et al.*, 2014; Kramer *et al.*, 2015; Rosa; Afonso, 2015). In Brazil, the largest hop cultivation area is in the Southern region, particularly in the state of Santa Catarina (Aprolúpulo, 2023). According to data from the Ministry of Agriculture (MAPA, 2022), 25 tons of hops were produced in 2021. By 2023, production had increased to 88 tons, according to the Brazilian Hop Growers Association (Aprolúpulo, 2023), with the state of Santa Catarina contributing 21.8 tons to this total.

In Brazil, hop cultivation faces significant challenges crucial for industry development and cultivar adaptation (Bizzoto, 2019). Climate is one of the main factors affecting cultivation success, with air temperature, photoperiod, solar radiation, and water availability playing important roles (Jastrombek *et al.*, 2022). Other limiting factors include pests and diseases, impacting hop productivity, with downy mildew (Pseudoperonospora humuli) being a notable threat (Choi; Hong; Shin, 2005; Thines; Choi, 2016). Downy mildew is the primary threat to hop production in humid regions (Gent; Nelson; Grove, 2008). In addition to drastically reducing yields, it can compromise grain quality (O'Neal *et al.*, 2015; Thines; Choi, 2016). Its symptoms include localized lesions on leaves, flowers, and cones, stunted shoots, as well as chlorotic and curled leaves (Coley-Smith, 1962; Purayannur *et al.*, 2020; Royle; Kremheller, 1981), requiring integrated management for disease control (O'Neal *et al.*, 2015).

The use of geotechnologies, artificial intelligence, and big data has become indispensable for agroclimatic zoning, proving to be a crucial tool for planning and controlling various land uses and occupation activities (Santos *et al.*, 2016). These technologies also enable the identification of prospective and favorable areas for production, as well as disease incidence in agricultural zones (Yates; Schoeman; Klein, 2015). Zoning studies for crop production are essential for adapting to different climatic and geographic conditions, as seen in coffee cultivation across different states in Brazil (Filete *et al.*, 2022), eucalyptus (Eugenio; Pedra; Martins, 2020; Tsoraeva *et al.*, 2020), and assessing disease occurrence favorability (Moreira *et al.*, 2020).

2 OBJECTIVES

2.1 General Objective

To analyze the spatiotemporal landscape of scientific production on hop downy mildew worldwide and to develop an agroclimatic zoning for hop cultivation, as well as assess the favorability of downy mildew occurrence in the state of Santa Catarina, Brazil.

2.2 Specific Objectives

- Conduct a systematic bibliometric and spatiotemporal analysis of scientific production on hop downy mildew.
- Development of temperature and precipitation maps, and definition of climatic suitability classes for hop cultivation in Santa Catarina.
- Generation of a climatic suitability map for hop cultivation in the state of Santa Catarina.
- Preparation of temperature and humidity maps, and definition of favorability classes for the occurrence of downy mildew in hops in the state of Santa Catarina.
- Generation of a favorability map for the occurrence of downy mildew in the state of Santa Catarina.

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CHAPTER 1

1. Spatiotemporal evolution of scientific production on downy mildew (*Pseudoperonospora humuli*) in hops (*Humulus lupulus* L.)

ABSTRACT

Hop cultivation has been growing, as has its economic importance, and with it the need to understand its diseases and pests. To this end, a systematic literature review was conducted using bibliometric techniques to explore the current knowledge on downy mildew (*Pseudoperonospora humuli*) in hops (*Humulus lupulus* L.). For this purpose, databases such as Scopus, Web of Science, and Science Direct were used to collect data from 1928 to 2023. The analysis identified 54 publications, with the most cited studies mainly focusing on the efficacy and resistance of downy mildew management in hops. Additionally, these studies explored the genetic and pathogenic relationship between *P. cubensis* and *P. humuli*. A word co-occurrence map revealed that the main topics covered in the publications included “hops”, “disease”, “downy”, “humuli”, “mildew”, and “Pseudoperonospora”. Notably, there was a particular emphasis on subtopics such as disease management, susceptibility of hop cultivars, and the influence of climate on hop mildew. It is essential to note that, in tropical climate regions, knowledge about diseases affecting hop cultivation is limited. This study contributes to filling this gap by providing detailed information on downy mildew development and its influence on hop cultivation in tropical climates, offering valuable insights that can support and guide future research efforts on mildew in hop cultivation.

Keywords: Disease Management; Fungal Disease; Overview; Review.

1 INTRODUCTION

The hop (*Humulus lupulus* L.) is primarily cultivated as a component in beer production. Global hop production is concentrated in the northern and southern hemispheres, between latitudes 35º and 55º, with the United States and Germany being the largest producers. However, hop cultivation productivity is closely linked to plant health conditions, and one of the major challenges affecting productivity is pests and diseases (Jastrombek *et al.,* 2022; Mpanga; Schalau, 2020).

Downy mildew, one of the most devastating diseases for hop cultivation, is caused by *Pseudoperonospora humuli*, an obligate biotrophic oomycete that can lead to losses of up to 100% in susceptible cultivars. Hop downy mildew is favored by moderate temperatures (15 to 20°C), high humidity (above 90% relative humidity), and prolonged periods of moisture (Purayannur *et al.,* 2020; Royle, 1970).

Disease control is achieved through the use of fungicides, cultivars with specific disease resistance levels, and appropriate cultural practices (Wyenandt *et al.,* 2015). It is crucial to understand the pathogen biology and disease ecology to identify and utilize new sources of resistance, as well as to develop more sustainable approaches for disease management (Purayannur *et al.,* 2021; Woods; Gent, 2016).

As a result, questions arise that encourage researchers to plan and structure their studies more effectively to meet the scientific demands associated with the subject, creating networks that complement knowledge production (Oh; Lee, 2020). Textual data analyses suggest breaking a known dichotomy between quantitative and qualitative data, allowing textual data to be analyzed similarly to numerical data. This enables answering qualitative questions with the support of quantitative elements (Lahlou, 1994).

Therefore, the following guiding question was defined: “What studies have been developed on the topic of hop downy mildew?” Based on this premise, the aim of this study was to conduct a systematic bibliometric review of the literature by aggregating produced content and performing textual statistical analyses.

2 MATERIAL AND METHODS

A bibliometric review of the literature was conducted using a quantitative approach to identify the main themes addressed in existing studies on hop downy mildew. The analysis was conducted using the keywords “downy mildew,” “*Pseudoperonospora humuli*,” and “hop.” These keywords were combined using the boolean operator “AND” in a search string, as shown in Table 1. The studies were extracted from the scientific publication databases Scopus (Elsevier), Web of Science (Clarivate), and Science Direct (Elsevier), considering works published from 1928 to 2023.

Table 1 – Parameters of the query performed in the Scopus, Web of Science, and Science Direct databases

Scopus	(TITLE-ABS-KEY (hop) AND TITLE-ABS-KEY (downy AND mildew) AND TITLE-ABS-KEY (*pseudoperonospora* AND *humuli*) AND PUBYEAR <2023 AND PUBYEAR <2023)
Web of Science	hop (Topic) and downy mildew (Topic) and *Pseudoperonospora humuli* (Topic)
ScienceDirect	hop AND downy AND mildew AND *Pseudoperonospora humuli*

Based on the research questions, inclusion and exclusion criteria were established, as well as methods for data extraction and analysis. Initially, no filters such as language, year, document type, and knowledge area were applied to encompass the earliest studies on the subject. Duplicate articles were eliminated before classifying and organizing them according to the year of publication and topic. Full articles were analyzed in the review; however, journals that did not address downy mildew in hop cultivation or focused on diseases other than downy mildew in hops were excluded. The selected publication had their geographical coordinates (latitude and longitude) extracted in CSV format. These coordinates were obtained from the study sites mentioned in the articles or from the institutions that conducted the research. In a Geographic Information Systems (GIS) environment, the distribution of these locations was visualized on a map format.

The obtained data were subjected to analysis of the most frequent topics using two open-source software programs: VOSviewer (version 1.6.17) and IRAMUTEQ (version 0.7, alpha 2). While VOSviewer is standalone software, IRAMUTEQ is anchored in the statistical environment of *R* software and uses the Python language. These software tools were employed to perform the topic analysis based on the collected data (R Core Team, 2018).

Using IRAMUTEQ, a textual analysis of the data was conducted to explore the correlation between the keywords found in the researched articles, represented by the distance between them. This analysis involved a similarity analysis based on graph theory, which helped to identify co-occurrences between words and provided insights into their connections. Furthermore, a lexical analysis was conducted through a word cloud, which visually grouped and organized the keywords based on their frequency. The main and most frequent topics are represented by different sizes and frequency through clusters (Camargo; Justo, 2013).

Another software used was VOSviewer, which is widely employed in bibliometric analysis. By employing graph theory, VOSviewer facilitates the extraction of information from scientific collaborative networks and presents graphical representations of bibliometric maps in an intuitive manner (Eck; Van; Waltman, 2010). One of the main features of VOSviewer is its ability to identify co-occurrences between words, which provides insights into the connections between them. This analysis helps to identify the main structures within a textual corpus, distinguishing similarities and specificities based on the descriptive variables identified in the analysis (Marchand; Ratinaud, 2012).

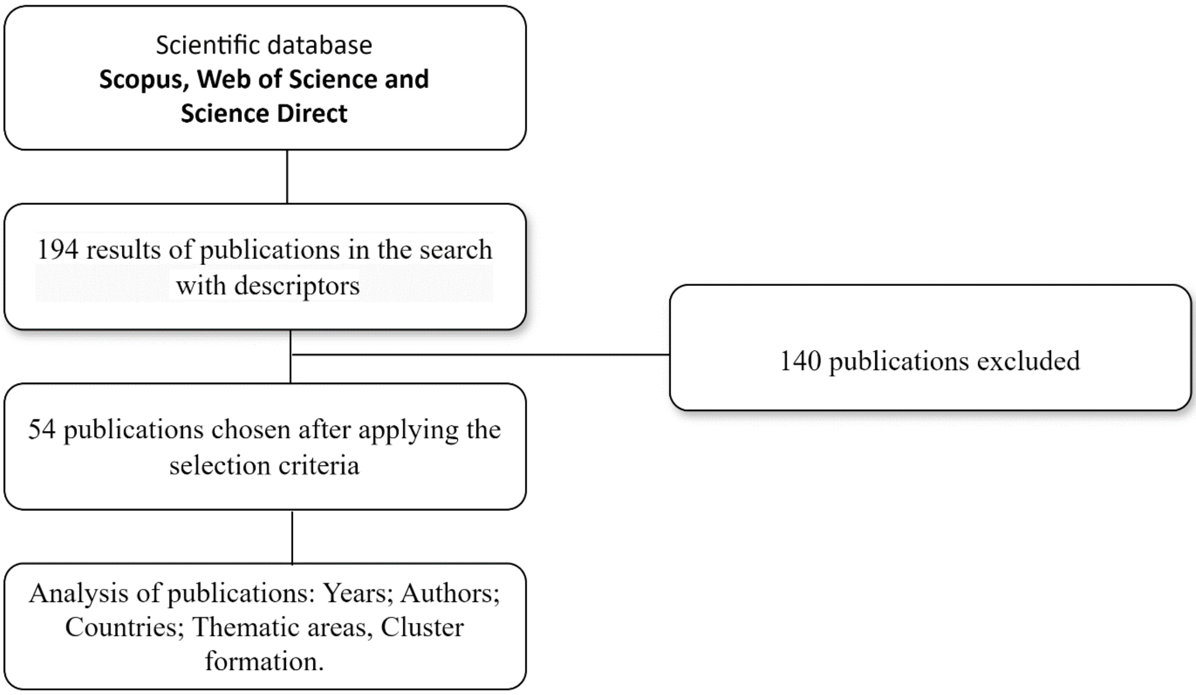
In VOSviewer, a bibliometric map of keyword co-occurrences was generated. This map illustrates the frequency of each keyword used by the authors, as well as the intensity of the connections, indicating the relationship of each term with other words. Additionally, VOSviewer allows for the visualization of clusters, which are groups of items (nodes) with greater affinity on the map. These clusters represent topics or concepts that are closely related. (Eck; Van; Waltman, 2010).

3 RESULTS AND DISCUSSION

In the initial search, through scientific databases such as Scopus, Web of Science, and ScienceDirect, it was possible to observe extensive collections of abstracts and citations, making them valuable sources of literature on the subject. These databases also provided bibliometric data tools for tracking, analyzing, and visualizing research.

In this way, using the keywords and the databases mentioned above, a total of 194 publications were identified (Figure 1). However, to compose the bibliographic portfolio, the journals were filtered based on their titles and abstracts. Using the exclusion criteria, 140 journals were excluded, resulting in a final selection of 54 articles for this review. The exclusion criteria ensured that only relevant articles addressing the topic of downy mildew were included in the analysis.

Figure 1 - Process of selection and analysis of scientific literature publications on hop mildew.



After applying the exclusion criteria, only complete and unique publications were selected for further analysis. The Scopus database resulted in 50 articles that met the criteria, while the Web of Science database provided 3 publications, and ScienceDirect contributed 1 publication (Table 2), totaling 54 complete articles. The analysis of the selected publications indicates that there are still a limited number of studies focusing on downy mildew in hops, both in Brazil and worldwide. This suggests that more research in this area is needed to expand the current knowledge base.

Table 2 - Publications on hop mildew found in the Scopus, Web of Science, and ScienceDirect

	Authors	Article Title	Journals
		Web of Science	
1	(Runge, Thines e Wolfgang, 2012)	*Reevaluation of Host Specificity of the Closely Related Species Pseudoperonospora humuli and P.cubensis*	*Plant disease*
2	(Crandall *et al.*, 2021)	*A Multiplex TaqMan qPCR Assay for Detection and Quantification of Clade 1 and Clade 2 Isolates of Pseudoperonospora cubensis and Pseudoperonospora humuli*	*Plant disease*
3	(Bello *et al.*, 2021)	*Detection of Airborne Sporangia of Pseudoperonospora cubensis and P. humuli in Michigan Using Burkard Spore Traps Coupled to Quantitative PCR*	*Plant disease*
		ScienceDirect	
1	(Cohen; Eyal, 1980)	*Effects of light during infection on the incidence of downy mildew (Pseudoperonospora cubensis) on cucumbers*	*Physiological Plant Pathology*
		Scopus	
1	(Salmon; Ware, 1928)	*Inoculation experiments with the downy mildews of the Hop and Nettle (Pseudoperonospora humuli (Miy. et Taka.) Wils. and P. Urticare (Lib.) Salmon et Ware)*	*Annals of Botany*
2	(Ware, 1929)	*Experiments on the Production of Diseased Shoots by the Hop Downy Mildew, Pseudoperonospora humuli (Miy. et Takah.), Wils.*	*Annals of Botany*
3	(Salmon; Ware, 1931)	*The downy mildew of the hop in 1930.*	*Annals of Botany*
4	(Coley-Smith, 1962)	*Overwintering of hop downy mildew Pseudoperonospora humuli (Miy. and Tak.) Wilson*	*Annals of Applied Biology*
5	(Coley-Smith, 1964)	*Persistence and identification of downy mildew Pseudoperonospora humuli (Miy. and Tak.) Wilson in hop rootstocks*	*Annals of Applied Biology*
6	(Coley-Smith, 1965)	*Infection of hop rootstocks by downy mildew Pseudoperonospora humuli (Miy. & Tak.) Wilson and its control by early-season dusts*	*Annals of Applied Biology*
7	(Coley-Smith, 1966)	*Early -season control of hop downy mildew, Pseudoperonospora humuli (Miy. and Tak.) Wilson, with streptomycin and protectant fungicides in severely infected plantings*	*Annals of Applied Biology*
8	(Royle, 1970b)	*Infection periods in relation to the natural development of hop downy mildew (Pseudoperonospora humuli)*	*Annals of Applied Biology*
9	(Royle; Thomas, 1971)	*The influence of stomatal opening on the infection of hop leaves by Pseudoperonospora humuli*	*Hysiological Plant Pathology*
10	(Royle, 1973)	*Quantitative relationships between infection by the hop downy mildew pathogen, Pseudoperonospora humuli, and weather and inoculum factors*	*Annals of Applied Biology*
11	(Royle; Thomas, 1973)	*Factors affecting zoospore responses towards stomata in hop downy mildew (Pseudoperonospora humuli) including some comparisons with grapevine downy mildew (Plasmopara viticola)*	*Physiological Plant Pathology*
12	(Dolinar; Zolnir (1994)	*Epidemic related decision model for control of downy mildew in hop (Pseudoperonospora humuli Miy. et Tak.), based on critical amont of spores.*	*Invasive Species Compendium*
13	(Pares; Greenwood,	*Ultrastructure of the Host-Parasite Relationships*	*Australian*

	1977)	*of Pseudoperonospora humuli on Hops*	*journal of botany*
14	(Kralj *et al.*, 1998)	*Marker-assisted hop (Humulus lupulus L.) breeding*	*Monatsschrift fur Brauwissenschaft*
15	(Pethybridge; Nelson; Wilson, 2003)	*Forecasting climate suitability of Australian hop-growing regions for establishment of hop powdery and downy mildews*	*Australasian Plant Pathology*
16	(Choi; Hong; Shin, 2005)	*A re-consideration of Pseudoperonospora cubensis and P.humuli based on molecular and morphological data*	*The British Mycological Society*
17	(Schwekendie *et al.*, 2005)	*Hop (Humulus lupulus L.) Transformation with Stilbene Synthase for Increasing Resistance against Fungal Pathogens*	*Acta horticulturae*
18	(Chee *et al.*, 2006)	*Population Biology of Pseudoperonospora humuli in Oregon and Washington*	*The American Phytopathological Society*
19	(Gent; Nelson; Grove, 2008)	*Persistence of Phenylamide Insensitivity in Pseudoperonospora humuli*	*Plant Disease*
20	(Gent; Ocamb, 2009)	*Predicting Infection Risk of Hop by Pseudoperonspora humuli*	*The American Phytopathological Society*
21	(Gent *et al.*, 2009)	*PCR detection of Pseudoperonospora humuli in air samples from hop yards*	*Plant Pathology*
22	(Gent; Ocamb; Farnsworth, 2010)	*Forecasting and Management of Hop Downy Mildew*	*Plant Disease*
23	(Mitchell *et al.*, 2011)	*Genetic and Pathogenic Relatedness of Pseudoperonospora cubensis and P.humuli*	*The American Phytopathological Society*
24	(Čerenak *et al.*, 2012)	*Registration of 'Dana'—A Bittering Hop Cultivar with a Pleasant Hoppy Aroma*	*Journal of Plant Registrations*
25	(Gent; Farnsworth; Johnson, 2012)	*Spatial analysis and incidence–density relationships for downy mildew on hop*	*Plant Pathology*
26	(Gent *et al.*, 2012)	*Association of Spring Pruning Practices with Severity of Powdery Mildew and Downy Mildew on Hop*	*The American Phytopathological Society*
27	(Gent *et al.*, 2015)	*Pre-and postinfection activity of fungicides in control of hop downy mildew*	*Plant Disease*
28	(Henning *et al.*, 2015)	*Precision QTL mapping of downy mildew resistance in hop (Humulus lupulus L.)*	*Euphytica*
29	(Summers *et al.*, 2015)	*Pseudoperonospora cubensis and P.humuli detection using species-specific probes and high-definition melt curve analysis*	*Canadian Journal of Plant Pathology*
30	(Henning *et al.*, 2016)	*Genotyping-by-sequencing of a bi-parental mapping population segregating for downy mildew resistance in hop (Humulus lupulus L.)*	*Euphytica*
31	(Woods; Gent, 2016)	*Susceptibility of Hop Cultivars to Downy Mildew: Associations with Chemical Characteristics and Region of Origin*	*Plant Health Progress*
32	(Gent; Cohen;	*Homothallism in Pseudoperonospora humuli*	*Plant Pathology*

	Runge, 2017)		
33	(Gent *et al.*, 2019)	*Genotyping-by-Sequencing Reveals Fine-Scale Differentiation in Populations of Pseudoperonospora humuli*	*Phytopathology*
34	(Marks; Gevens, 2019)	*Investigating Phenylamide Insensitivity in Wisconsin Populations of Pseudoperonospora humuli*	*Plant Health Progress*
35	(Rahman *et al.*, 2019)	*Genome sequencing and transcriptome analysis of the hop downy mildew pathogen Pseudoperonospora humuli reveal species-specific genes for molecular detection*	*Phytopathology*
36	(Dušek *et al.*, 2020a)	*Post-harvest recognition of various fungicide treatments for downy mildew of hops using comprehensive pesticide residue monitoring*	*International Journal of Pest Management*
37	(Gent; Block; Claassen, 2020)	*High Levels of Insensitivity to Phosphonate Fungicides in Pseudoperonospora humuli*	*Plant Disease*
38	(Purayannur *et al.*, 2020)	*The Effector Repertoire of the Hop Downy Mildew Pathogen Pseudoperonospora humuli*	*Frontiers Genetic*
39	(Purayannur *et al.*, 2020a)	*Hop Downy Mildew Caused by Pseudoperonospora humuli: A Diagnostic Guide*	*Plant Health Progress*
40	(Feiner *et al.*, 2021)	*Downy mildew resistance is genetically mediated by prophylactic production of phenylpropanoids in hop*	*Plant, Cell & Environment*
41	(Higgins; Douglas; Hausbeck, 2021)	*Susceptibility of Hop Cultivars and Rootstock to Downy Mildew Caused by Pseudoperonospora humuli*	*Hortscience*
42	(Kitner *et al.*, 2021)	*Pseudoperonospora humuli might be an introduced species in Central Europe with low genetic diversity but high distribution potential*	*Jornal Plant Pathology*
43	(Nowicki *et al.*, 2021)	*"Jumping Jack": Genomic Microsatellites Underscore the Distinctiveness of Closely Related Pseudoperonospora cubensis and Pseudoperonospora humuli and provide new insights into their evolutionary past*	*Frontiers Microbiology*
44	(Purayannur *et al.*, 2021)	*The hop downy mildew pathogen Pseudoperonospora humuli*	*Wiley Molecular Plant Pathology*
45	(Rutto *et al.*, 2021)	*Results from Hop Cultivar Trials in Mid-Atlantic United States*	*HortTechnology*
46	(Higgins; Miles; Hausbeck, 2021)	*Fungicide efficacy against Pseudoperonospora humuli and point-mutations linked to carboxylic acid amide (CAA) resistance in Michigan*	*Plant Disease*
47	(Higgins *et al.*, 2022)	*Optimizing Molecular Detection for the Hop Downy Mildew Pathogen Pseudoperonospora humuli in Plant Tissue*	*Phytopathology*
48	(Procházka *et al.*, 2022)	*Use of botanicals to protect early stage growth of hop plants against Pseudoperonospora humuli*	*Crop Protection*
49	(Olatoye *et al.*, 2023)	*Genetic characterization of downy mildew resistance from the hop (Humulus lupulus L.) line USDA 64035M*	*Crop Science*
50	(Zaidi *et al.*, 2023)	*Diversity in genetic and downy mildew resistance among wild and mutagenized hops as revealed by single nucleotide polymorphisms and disease rating*	*Canadian Journal of Plant Science*

Based on the research results, it is evident that the number of published articles on downy mildew across all databases has shown a slow evolution. From 1928 to 2006, over a period of 78 years, only 19 articles were published, resulting in an average of one publication every 4.1 years. However, from 2007 onwards, there has been a notable increase in the number of published articles. From 2007 to 2023, spanning 16 years, 35 publications were made available, averaging 2.1 publications per year. This indicates that in recent years, scientific production on hops has been more actively explored (Figure 2).

Figure 2 - Comparison of the number of articles published on downy mildew in the Scopus, Web of Science, and ScienceDirect databases from 1928 to 2023.

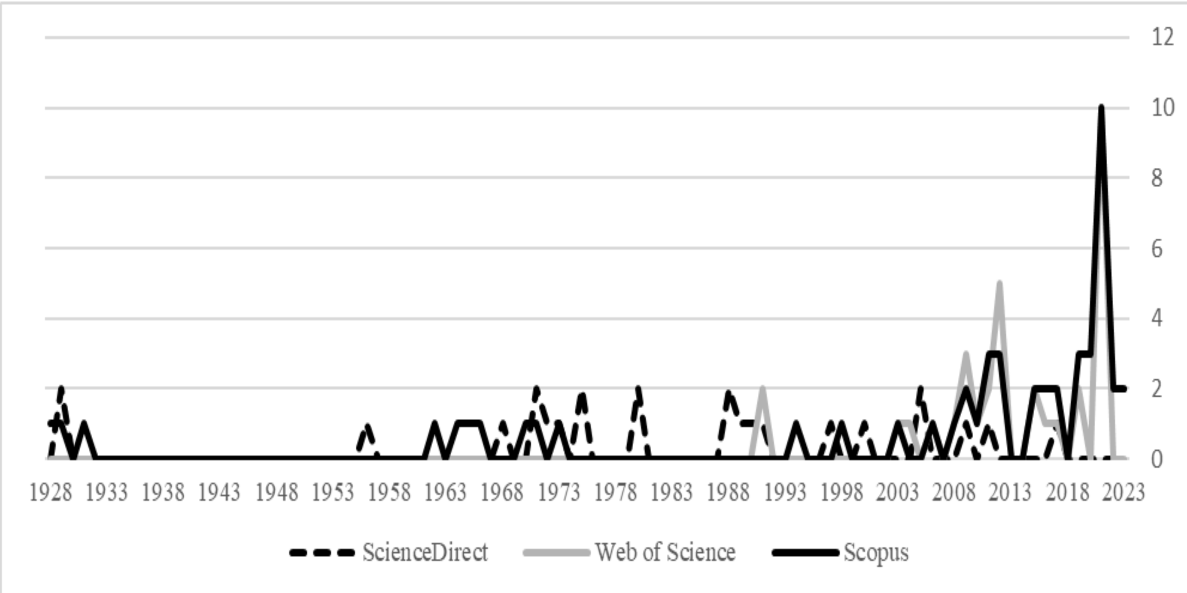
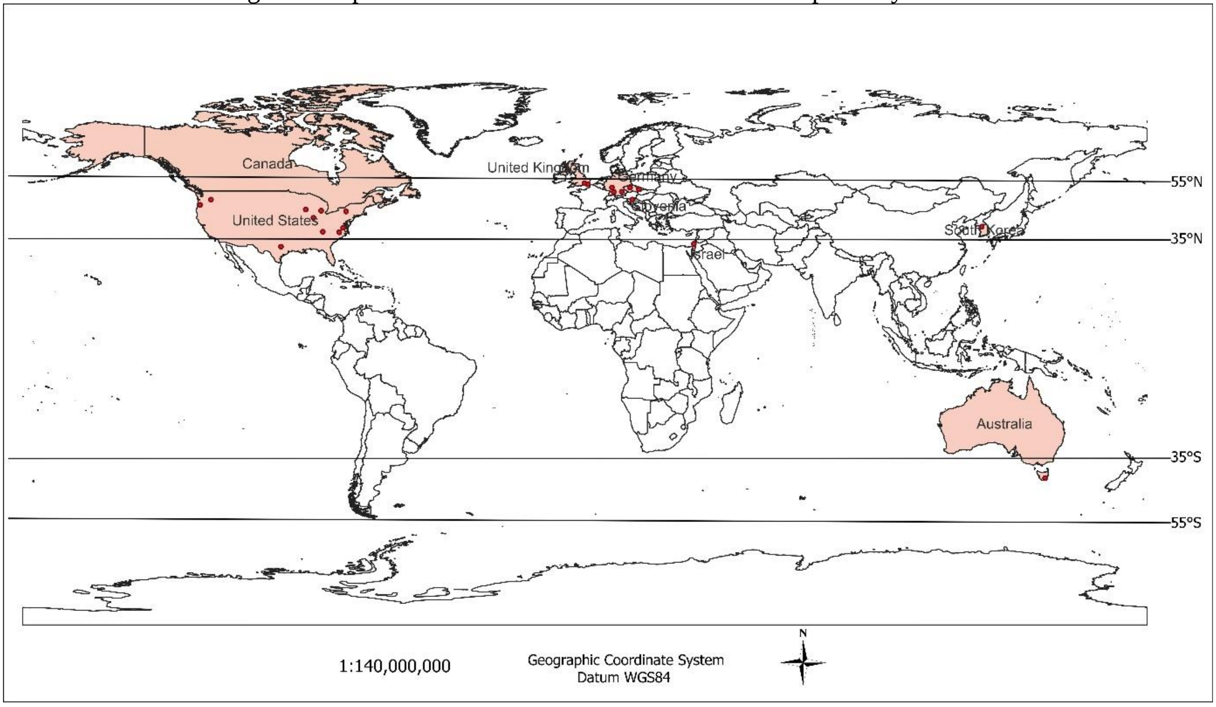


Figure 3 illustrates the distribution of publications on downy mildew among different countries, with the United States leading with 29 articles, followed by the United Kingdom with 12 articles. Together, these two countries contribute approximately 76% of the total publications. This concentration of scientific production aligns with the fact that the United States is one of the largest producers of hops, along with Germany, the United Kingdom, Slovenia, and the Czech Republic, as noted by Jastrombek *et al.* (2022). The geographical location of these countries within the latitudinal range of 35° to 55°, where hops are traditionally cultivated, may also contribute to their significant scientific contributions in this area (Jastrombek *et al.,* 2022). It's worth noting that no studies have been conducted on downy mildew in South America. However, issues related to hop adaptability have been gaining prominence in Brazil, as highlighted by Fagherazzi and Rufato (2018) and Guimarães *et al.* (2021). Although research on hop cultivation is growing in Brazil, there is still a lack of knowledge specifically about downy mildew. The absence of studies on the subject in tropical climate regions reinforces the need for more research and understanding in these areas.

The limited knowledge of downy mildew in hop cultivation in tropical climate regions represents challenges for hop producers and researchers in these areas. Future research efforts should aim to address this knowledge gap and explore hop adaptability to tropical conditions, as well as develop effective management strategies for downy mildew.

Figure 3 - Spatial distribution of selected articles on hop downy mildew



Among the published articles, the study by Choi, Hong and Shin (2005) leads in citations with 62 citations, followed by the works of D H Gent, Nelson, Farnsworth, and Grove (2009) and Mitchell *et al.* (2011) with 33 and 32 citations, respectively. These studies address the phylogenetic analysis of *Pseudoperonospora cubensis* and *P. humuli,* molecular studies indicating the efficiency and effectiveness of hop downy mildew management, and the genetic and pathogenic relationship of *P. cubensis* and *P. humuli*. It is worth noting that Gent, D. H. is the author or co-author of 10 studies, demonstrating his significant contribution to publications on the topic of this review. Several studies address infection, resistance, management, and control of downy mildew in hop cultivation. These studies provide essential information on disease dissemination pathways and pave the way for effective prevention and control strategies. The early studies focused on downy mildew infection in hop rootstocks, investigating the mechanisms through which infection occurs, evaluating management methods to reduce secondary infections (Čerenak *et al.* 2012; Coley-Smith, 1964, 1965, 1966; Cohen; Eyal, 1980), and identifying the initial outbreaks of mildew in Europe (Salmon *et al.,* 2021; Salmon; Ware, 1928; Ware, 1929).

Gent *et al.* (2019) and Gent *et al.* (2017) address issues regarding reproduction such as oospore viability and homothallism in downy mildew, aiming to understand population behavior. In this vein, Gent *et al.* (2012) analyze the spatial pattern of mildew on shoots and relate pruning to the development of downy mildew and powdery mildew in hops (Crandall *et al.,* 2021; Mitchell *et al.,* 2011; Nowicki *et al.,* 2021; Summers *et al.*, 2015).

Some authors have investigated the relationship between different species of Pseudoperonospora, aspects such as morphological comparison (Runge; Thines, 2012) and environmental conditions necessary for infection and their effects on disease development (Royle, 1970). Stomatal opening is highlighted as a factor significantly affecting the epidemic development of hop downy mildew (Royle, 1970, 1973; Royle; Thomas, 1971, 1973).

Gent and Ocamb (2009), Rutto *et al.* (2021) and Henning *et al.* (2016) highlighted in their research agronomic factors such as pest and disease interactions, climate influence, and hop genetics. These studies help understand the factors that can affect productivity and disease resistance in hop. Although each author has a unique approach, their studies complement each other and provide valuable insights into various aspects related to infection, resistance, management, and control of the disease.

Furthermore, Dušek *et al.* (2020), Feiner *et al.* (2021), Gent, Nelson and Grove (2008), Higgins and Hausbeck (2021) stand out by exploring the hop's response to the pathogen at the biochemical, molecular, and genetic levels. They identify markers and metabolites associated with resistance and provide valuable information for the development of more resistant hop varieties and integrated pest management strategies. On the other hand, the study by (Pares; Greenwood, 1981) focuses on analyzing the structure of hyphae during infection, exploring the cellular components involved in the process.

In further molecular research, Crandall *et al.* (2021), Mitchell *et al.* (2011), Nowicki *et al.* (2021) developed methods for detection, quantification of sporangia, and genetic diversity of Pseudoperonospora species such as *P. humuli* and *P. cubensis*. Chee *et al.* (2006) analyzed the genes of different populations of *P. humuli*. Choi *et al.* (2005) also highlighted the relationship between *P. cubensis* and *P. humuli* in terms of morphological and molecular characteristics. Both studies rely on molecular techniques such as polymorphisms in mitochondrial genomes and real-time PCR assays (qPCR) to identify and distinguish between different species of Pseudoperonospora. These advanced molecular approaches are crucial for the effective management and control of these pathogens, enabling early detection of sporangia presence and abundance, host variety issues (Mitchell *et al.,* 2011), and assisting in decision-making related to crop protection against downy mildew.

Bello *et al.* (2021), Gent *et al.* (2009), Henning *et al.* (2016), Purayannur and Cano *et al.* (2020), Purayannur and Miles *et al.* (2020) highlight recent advances in genomics and the discovery of important factors for management, timing of fungicide application, and primarily issues related to mildew resistance. In addition to the relationship between climate and these factors over a 30-year period as described by (Pethybridge; Nelson; Wilson, 2003).

It is worth highlighting the work of (Rutto *et al.*, 2021) who evaluated hop cultivars, stating that meteorological data interfere with hop downy mildew development, as well as the publication by (Purayannur *et al.*, 2021), which conducted a review on the current knowledge of disease symptoms, life cycle, virulence factors, and management of hop downy mildew, including various forecasting systems available worldwide.

These studies collectively contribute to a better understanding of hop downy mildew, including its molecular characteristics, epidemiology, management strategies, and factors influencing disease development. They play a crucial role in guiding disease control practices, improving crop resilience, and optimizing hop production.

3.1 Graphical analysis of keywords using VOSviewer software

The analysis of keyword co-occurrence revealed three distinct clusters on the map. The first cluster, represented in red, is centered around keywords such as "*Pseudoperonospora humuli,*" "Peronosporaceae," and "*Humulus*", which are related to the biological classification of downy mildew and hops. This cluster likely includes studies that specifically focus on the taxonomy, classification, and characteristics of *Pseudoperonospora humuli* and its relationship with the Peronosporaceae family and the genus *Humulus* (Figure 4).

The second cluster, represented in green, encompasses keywords such as "Peronospora," "microbiology," "genetics," "Plant Disease," and "oomycetes". These terms indicate a focus on studies related to the genus Peronospora, including aspects of microbiology and genetics. The inclusion of "Plant Disease" suggests that these studies may be published in the journal Plant Disease, which is a prominent journal in the field of plant pathology. This cluster likely represents research exploring microbiological and genetic aspects of Peronospora species, including their interactions with host plants and the broader field of oomycete research.

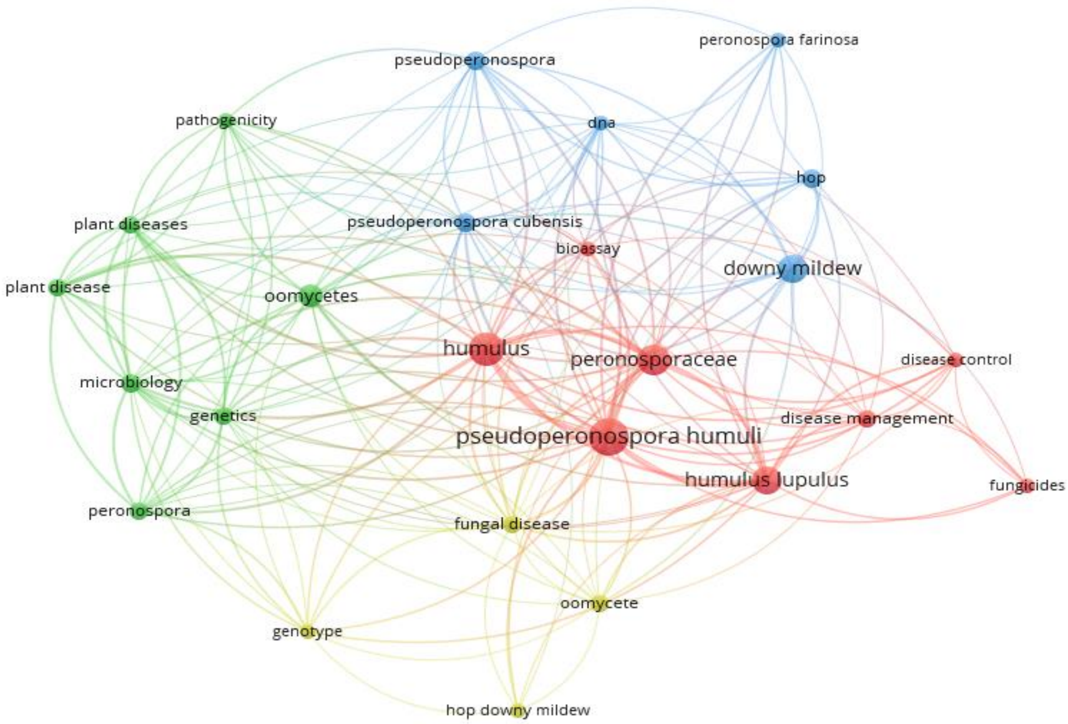
The third cluster, represented in blue, includes keywords such as "hops," "*Pseudoperonospora cubensis*," and "mildew."

These terms are closely associated with the genus of hop downy mildew and suggest studies focused on various aspects of this pathogen. The presence of "*Pseudoperonospora* *cubensis*” indicates research investigating genetic and pathogenic similarities between *P. cubensis* and *P. humuli*, two species of *Pseudoperonospora* associated with downy mildew in hop.

This cluster likely encompasses studies that explore genetic diversity, pathogenicity, and management of mildew specifically in hop. Overall, the co-occurrence analysis highlights the main thematic clusters and research areas within the broader topic of downy mildew in hop.

It provides insights into the interconnection of keywords and concepts, helping to identify key directions and research themes within the literature on this subject.

Figure 4 – Bibliometric map of keyword co-occurrence networks used in this review.



3.2 Keyword Graphical Analysis using IRAMUTEQ software

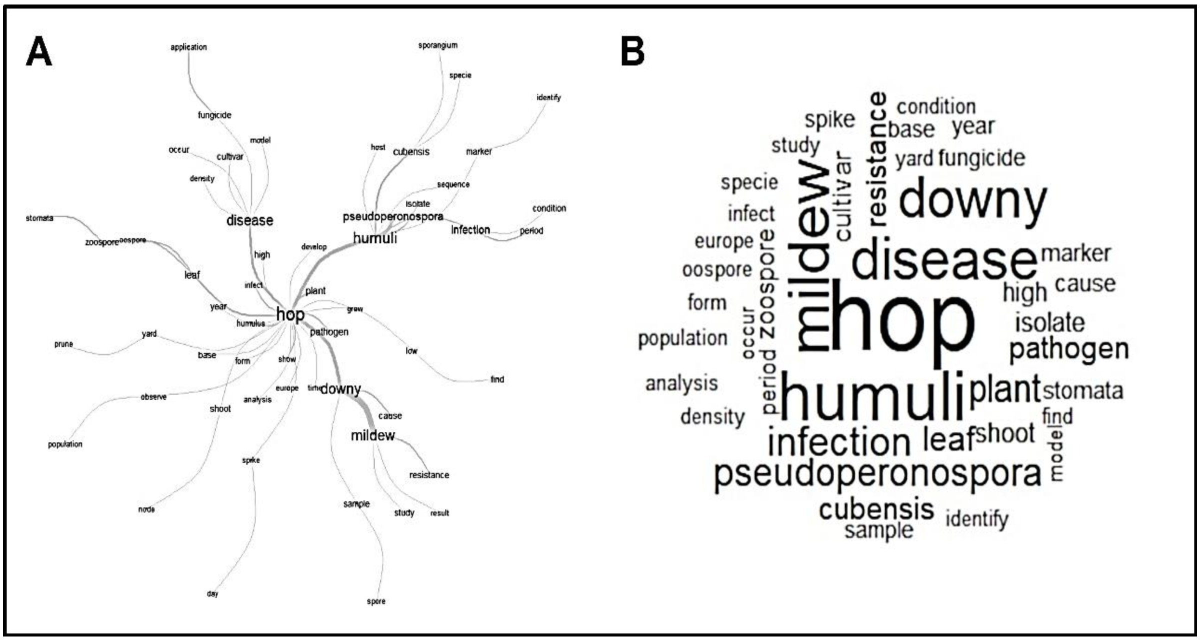
The graphical representation of keywords with more co-occurrences in IRAMUTEQ allows for a more simplified visualization of the relationships between subjects and their depths compared to VOSviewer. The similarity graph generated by IRAMUTEQ highlights the main topics covered in the 54 studies, namely: “hop”, “disease”, “downy”, “humuli”, “mildew” and “Pseudoperonospora” (Figure 5A). This indicates that these keywords were frequently mentioned together in the analyzed publications.

The prominence of these keywords can be attributed to the increasing demand for hop-derived products and the consequent emphasis on improving productivity and efficiency in hop cultivation. Scientific production on the subject has evolved in parallel with the agricultural industry's need for effective disease management strategies and a deeper understanding of the biology and control of hop downy mildew.

By identifying the most recurrent keywords, IRAMUTEQ provides a concise view of the main themes and topics covered in the analyzed literature.

This visualization allows researchers and readers to quickly understand the main areas of focus in the studies and gain insights into the central aspects explored in the field of mildew research.

Figure 5 – Similarity graph (A) and point cloud (B) of the 50 articles published on hop downy mildew.



The word cloud (Figure 5B) highlights the most frequent keywords present in the studies, including terms such as “hop,” “disease,” “humuli,” “mold,” “downy,” “infection,” “resistance” and “Pseudoperonospora”. When analyzing these keywords together, it becomes evident that a significant focus of the studies is on the species *P. humuli* and its potential socio-economic consequences in hop cultivation.

According to the study, downy mildew caused by *P. humuli* (Choi; Hong; Shin, 2005) results in substantial economic losses in hop plantations. Therefore, managing this mildew species is a major challenge in hop cultivation, particularly in regions with high humidity, as emphasized by Gent *et al.* (2015) and Feiner *et al.* (2021).

Although the term “cultivar” is less represented among the total of 54 publications, it deserves special attention for appearing more frequently in recent article keywords. This can be attributed to the growing global market demand for hops and its byproducts, as observed by Rutto *et al.* (2021).

Concerns regarding diseases and pests, including mildew, are a central theme in current studies, reflecting the need to develop effective strategies for maintaining the health and productivity of hop crops.

4 FINAL CONSIDERATIONS

The analysis of scientific research on hop downy mildew demonstrates significant advances in recent decades, reflected in the notable increase in the number of published articles. The main topics covered in these 54 articles focus on “hop,” “humuli,” “disease,” and “mildew,” highlighting the relevance of mildew in hop production. Regarding mildew, studies focus on disease management, susceptibility of hop varieties to mildew, the influence of climate on disease development, and detection methods and control strategies. Even older articles maintain their relevance as they discuss challenges in disease management, forecasts based on infection periods and weather factors, and the potential use of geotechnologies to address these challenges.

The expansion of hop cultivation to new regions, including Brazil, demonstrates the interest in exploring the adaptability of this crop to different climates. However, it is crucial to emphasize that Brazil lacks more in-depth research on downy mildew, highlighting the need to encourage studies and publications in this area, especially in tropical climate regions.

Ultimately, encouraging further research and interdisciplinary collaborations could lead to significant advancements in understanding, managing, and controlling hop downy mildew, benefiting both the hop industry and global beer production, supporting sustainable hop farming practices.

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CHAPTER 2

2. Agroclimatic zoning for the cultivation of hops (*Humulus lupulus* L.), with a conventional approach and Fuzzy logic for the state of Santa Catarina, Brazil

ABSTRACT

Hop is a perennial herbaceous plant traditionally grown in temperate regions, with significant economic importance in the brewing industry. Interest in its cultivation in Brazil has increased due to technological adaptations and genetic improvement, although persist challenges such as the genetic determination of cultivars and environmental conditions. Agroclimatic zoning was performed using meteorological data obtained from various sources and techniques, such as the reclassification of variables and Fuzzy logic. In the conventional method, the combination of temperature and precipitation resulted in different suitability classes for hop cultivation, with apt, restrict, and inapt areas identified in the state of Santa Catarina. In the Fuzzy method, membership functions were used to classify the meteorological variables into degrees of suitability, resulting in fuzzified temperature and rainfall maps. The overlay of these maps with different values of the Fuzzy *Gamma* operator allowed for the final agroclimatic zoning, divided into suitability classes for hop cultivation. Based on the results, it is concluded that the mountainous regions and the southern part of Santa Catarina are more favorable for hop cultivation, while areas such as the far north of the state and coastal regions present restrictions due to unfavorable climatic conditions Overall, approximately 61% of the state's area was considered favorable for hop cultivation, while about 32% presented less conducive climatic conditions.

Keywords: Climate, Spatial reclassification, *Gamma* operator.

1 INTRODUCTION

The hop (*Humulus lupulus* L.) is a plant belonging to the order Rosales and the family Cannabaceae (Spósito *et al.*, 2019). It is a perennial herbaceous species that produces annual inflorescences (Fagherazzi; Rufato, 2018; Mpanga; Schalau, 2020) and is traditionally cultivated in temperate regions (Acosta-Rangel *et al.*, 2021), between latitudes 35° and 55° North and 35° and 55° South (Jastrombek *et al.*, 2022). Hops and their derivatives are used in a variety of products, ranging from the pharmaceutical to the food industry. However, their production is notably prominent in serving the brewing sector (Fagherazzi, 2020). The main beer-producing regions in Brazil are the South and Southeast. The state of Santa Catarina is the largest producer of hops in the country, and its production is concentrated in the region of Lages (latitude 28° S). This state has a considerable production of beer, especially the so-called “craft beers”, and is the third state with the highest number of breweries (Jastrombek *et al.*, 2022).

Despite its significant economic importance, there are still factors that hinder the further growth of this crop. These factors include the genetic determination of cultivars, soil capacity and local nutrition, agronomic and phytosanitary operations, as well as environmental conditions (Donner *et al.*, 2020).

Therefore, the interest in hop cultivation in Brazil has increased with the influence of adapted technologies, species manipulation through crossbreeding for genetic improvement, and the possibility of adaptation to local conditions (Guimarães; Evaristo; Ghesti, 2021). Although still in development, cultivation experiments with the aid of adapted technologies have shown good yields of hop cultivars in the southern region of the country (Jastrombek *et al.*, 2022).

Hop is a plant sensitive to photoperiod, typically requiring 15 to 16 hours (Jastrombek *et al.*, 2022; Krebs, 2019). It demonstrates higher productivity when the day length ensures good vegetation, growth, and overall plant development (MAPA, 2022). The average required rainfall is 500-600 mm during the vegetative growth period, with uniform distribution throughout this period, in order to achieve higher cone yields (Jastrombek *et al.*, 2022). Furthermore, the optimal temperature range for photosynthesis is between 10 and 35 °C (Yamori; Hikosaka; Way, 2014).

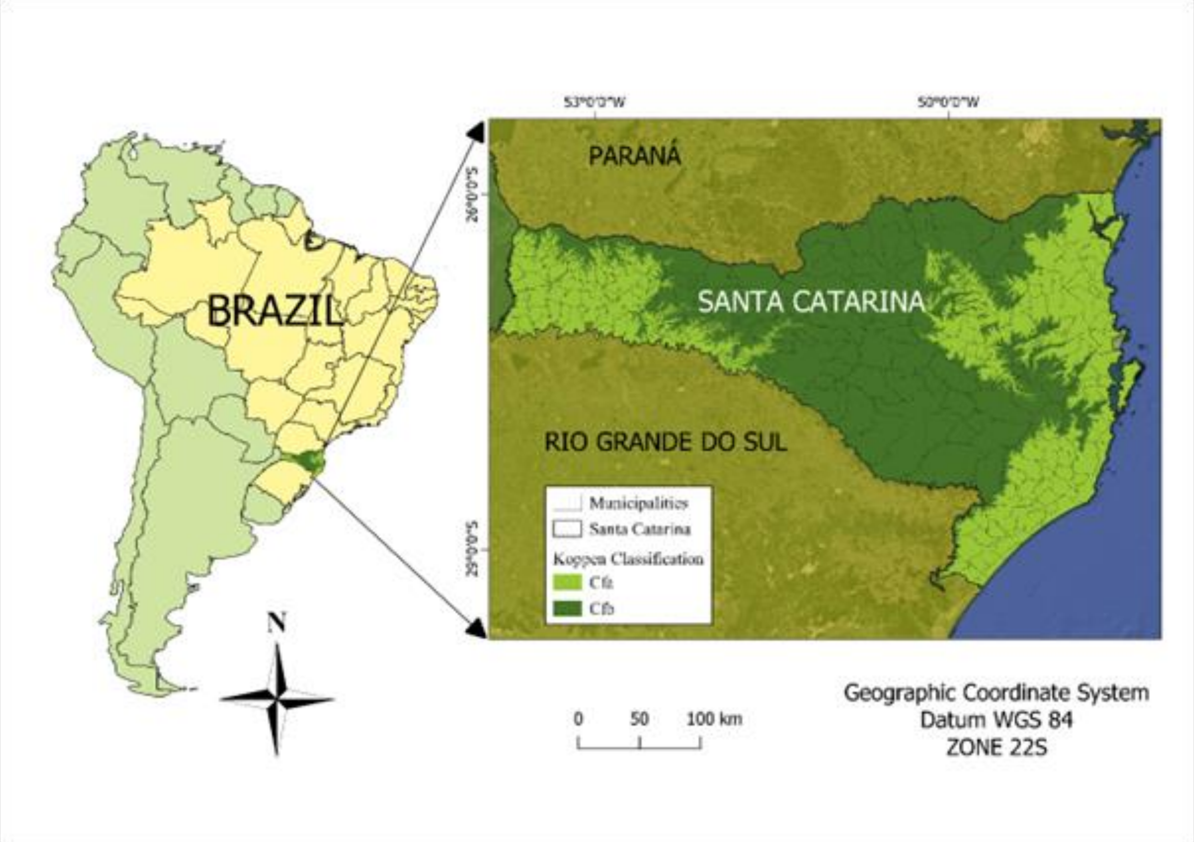
In this regard, with the need to improve productivity while maintaining crop quality, agroclimatic zoning has proven to be an essential tool for planning and managing various activities related to land use, terrain, fertility, climate, and rainfall (Santos *et al.*, 2016). Zoning allows for the identification of potentialities and promotes production in agricultural areas, as well as predicts the incidence of diseases (Yates; Schoeman; Klein, 2015). This tool facilitates the execution of complex analyses through the overlay of various precise climatic data (Luppi *et al.*, 2015; Sentelhas *et al.*, 2016), making it possible to identify apt and restrict regions to guide territorial planning according to climate and soil properties aptitude for the crop.

2 MATERIAL AND METHODS

2.1 Study area

The study area is represented by the state of Santa Catarina, which has a territorial area of 95,346 km². The territory of Santa Catarina is located between parallels 25°57'41” and 29°23'55” South latitude and between meridians 48°19'37” and 53°50'00” West longitude, in the Southern Region of Brazil (Figure 1). According to Köppen (1936), the state has two climatic types: humid subtropical with hot summers (Cfa) and humid subtropical with mild summers (Cfb), which is predominant. Temperatures range from 13 to 25°C, and rainfall is distributed throughout the year.

Figure 1 - Geographic location of the study area, Santa Catarina State, Brazil.

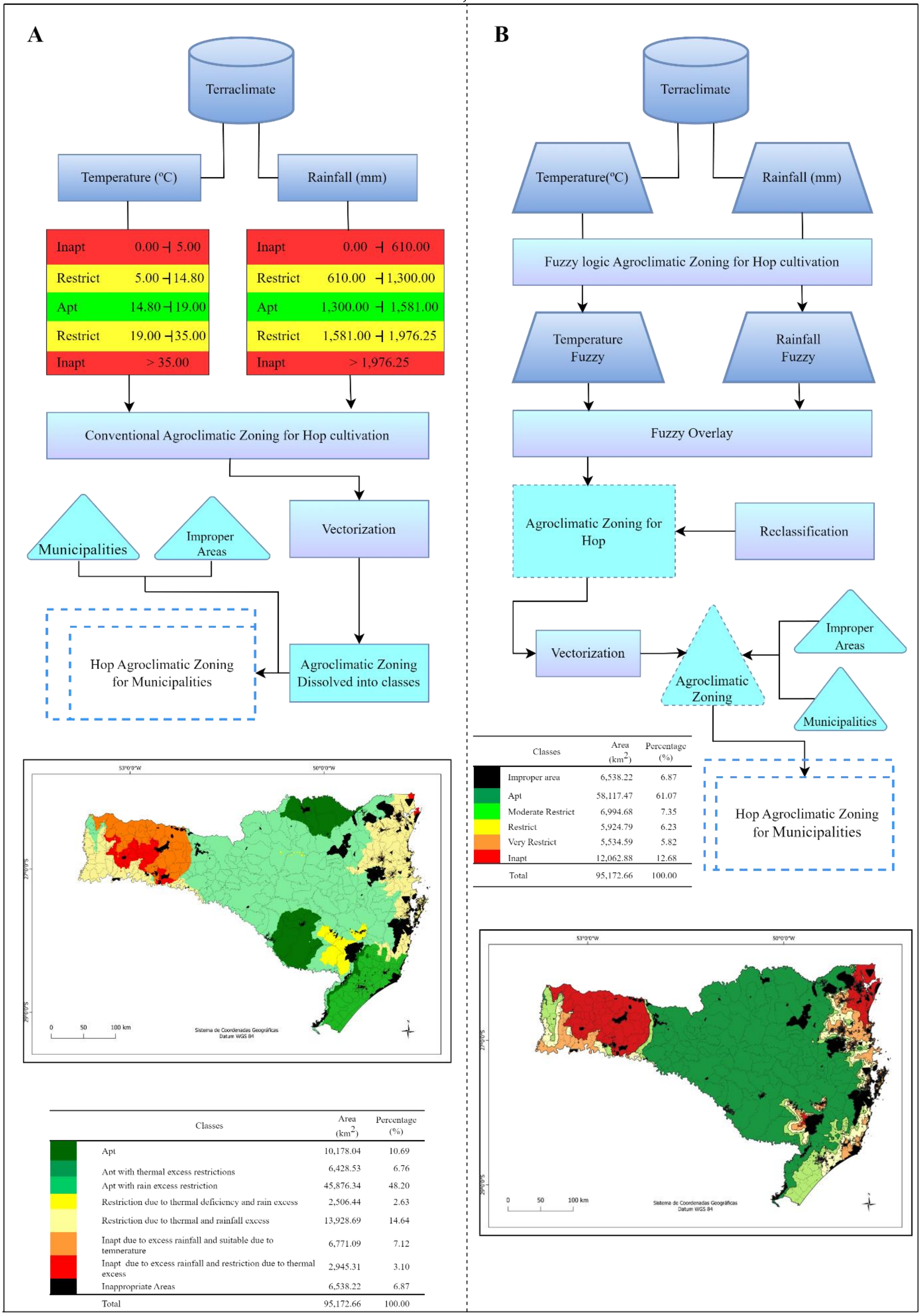


Source: Author's work.

2.2 Agroclimatic Zoning for hops cultivation in the state of Santa Catarina, Brazil

The methodological steps necessary for the development of agroclimatic zoning for hop cultivation in the state of Santa Catarina, Brazil, are presented in Figure 2. Climatic data are classified according to a range of suitability for cultivation, based on temperature and precipitation conditions. The suitability categories are then vectorized and overlaid to delineate the appropriate and inappropriate zones for hop cultivation, considering both reclassification based on suitability intervals and overlay of the analyzed variables (conventional approach), as well as overlay of fuzzified maps of the analyzed variables and reclassification (Fuzzy approach).

Figure 2 - Methodological steps required for the agroclimatic zoning for hop cultivation in the state of Santa Catarina, Brazil.



Classes	Area (km^2)	Percentage (%)
Apt	10,178.04	10.69
Apt with thermal excess restrictions	6,428.53	6.76
Apt with rain excess restriction	45,876.34	48.20
Restriction due to thermal deficiency and rain excess	2,506.44	2.63
Restriction due to thermal and rainfall excess	13,928.69	14.64
Inapt due to excess rainfall and suitable due to temperature	6,771.09	7.12
Inapt due to excess rainfall and restriction due to thermal excess	2,945.31	3.10
Inappropriate Areas	6,538.22	6.87
Total	95,172.66	100.00

Classes	Area (km^2)	Percentage (%)
Improper area	6,538.22	6.87
Apt	58,117.47	61.07
Moderate Restrict	6,994.68	7.35
Restrict	5,924.79	6.23
Very Restrict	5,534.59	5.82
Inapt	12,062.88	12.68
Total	95,172.66	100.00

Source: Author's work.

2.2.1 Database

The meteorological database used for the agroclimatic zoning of hops was obtained from the TerraClimate platform (https://www.climatologylab.org/terraclimate.html), which provides meteorological variables in a time series from 1958 to the present (Abatzoglou *et al.*, 2018) in compressed NetCDF format with monthly values and a spatial resolution of 4 km. For this study, we extracted data for 30 years (1991 to 2021), using the meteorological variables minimum temperature, maximum temperature, and average rainfall to create the final variables: average temperature and rainfall.

As a preprocessing step, the gridded layers representing the available meteorological variables from the TerraClimate server were imported, clipped, and reprojected (Sirgas 2000 UTM 22S) to the state of Santa Catarina, Brazil, using QGIS software version 3.28.1.

After preprocessing, the raster images were vectorized into point format and interpolated using the IDW (Inverse Distance Weighting) method with a resolution of 1 km².

To develop the climatic suitability classes, climatic data from locations where hop production is already established in Brazil were used for agroclimatic zoning.

The hop cultivation areas identified are located in the following Brazilian cities: São Bento do Sapucaí and São Paulo (state of São Paulo); São José dos Pinhais (state of Paraná); and Lages, São Bento, and São Joaquim (state of Santa Catarina). To support this study with relevant climatic information, a search was conducted on the Climate-data.org portal, which provides access to monthly records of air temperature and rainfall, crucial data for understanding the local climate of these producing regions.

Table 1 - Climatic data from hop producing regions in Brazil.

Municipalities	State	Latitude	Longitude	Temperature (°C)	Rainfall (mm)
São Bento do Sapucaí	São Paulo	22° 41' 20"	43° 43' 51"	18.70	1,581.00
São Paulo	São Paulo	23° 32' 52"	46° 38' 09”	18.50	1,340.00
São Bento do Sul	Santa Catarina	26° 15' 4"	49° 22' 49"	19.00	1,400.00
São José dos Pinhais	Paraná	25° 26' 41"	49° 11' 33”	16.90	1,281.00
Lages	Santa	27° 48' 58"	50°19' 34”	16.29	1,562.90

	Catarina				
São Joaquim	Santa Catarina	28° 18' 38"	49° 56"54”	14.80	1,388.00

Source: Adapted from Carvalho (2021).

To define the rainfall ranges, the upper limit of the optimal annual rainfall range (1,581.00 mm), which corresponds to 80% of the irrigation water depth, is inferred as the upper limit of the membership function by proportionality. Thus, the maximum value obtained was 1,976.25 mm, above which hop cultivation will be considered inapt due to excessive rainfall. Locations with values between 1,581.00 and 1,976.25 mm are classified into intermediate risk classes where hop cultivation can be carried out, but production may be affected by excess moisture.

With the projected raster images at a resolution of 1 km², the “Reclassify” function was applied based on the values of each variable, generating reclassified raster images with suitability, restriction, and unsuitability classes for hop cultivation in Brazil (Tables 2 and 3).

Table 2 - Climate suitability classes of average air temperature for hop development in the state of Santa Catarina, Brazil.

Class	**Temperature (°C)** **Literature**
Inapt	0.00 ⊣ 5.00
Restrict	5.00 ⊣ 14.80
Apt	14.80 ⊣ 19.00
Restrict	19.00 ⊣ 35.00
Inapt	>35.00

Source: Adapted from Fagherazzi (2020a), Fagherazzi and Rufato (2018), Jastrombek *et al.* (2022), Rybáček (1991), Burgues (1964), Darby *et al.* (2017), and Linke (1958).

Table 3 - Climatic suitability classes of average air precipitation for hop development in the state of Santa Catarina, Brazil.

Class	**Rainfall (mm)** **Literature**
Inapt	0.00 ⊣ 610.00
Restrict	610.00 ⊣ 1300.00
Apt	1,300.00 ⊣ 1,581.00

Restrict	1,581.00 ⊣ 1,976.25
Inapt	> 1,976.25

Source: Adapted from Fagherazzi (2020a), Fagherazzi and Rufato (2018), Jastrombek *et al.* (2022), Rybáček (1991), Burgues (1964), Darby *et al.* (2017), and Linke (1958).

2.2.3. Conventional agroclimatic zoning for hop cultivation in the state of Santa Catarina, Brazil

At this stage, cross-classification of average air temperature and average precipitation was performed using the 'r.cross' tool. The report for this classification was generated using the 'r.report' command, which allowed the creation of new categories through the combination of these climate variables, generating the agroclimatic zoning for hops in the state of Santa Catarina, Brazil.

2.2.4. Agroclimatic zoning through Fuzzy logic for hops cultivation in the state of Santa Catarina, Brazil

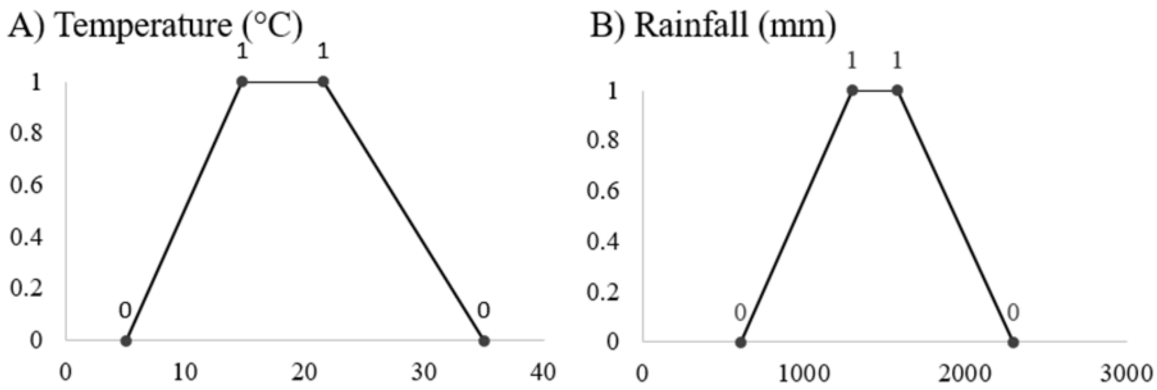
In this stage, continuous raster images of average air temperature and average rainfall were reclassified according to Fuzzy logic principles, where the classes (Tables 2 and 3) of a particular region were classified based on their degree of suitability with values ranging from 0 to 1, with 0 representing locations inapt for hop cultivation, and 1 representing locations apt for hop cultivation (Figure 3).

In this context, within the QGIS software environment, the “trapezoidal membership function” was applied to continuous raster images representing average air temperature and relative humidity. Since this specific function is not present in QGIS, its application was carried out through the “Raster Calculator”.

Figure 3 - Trapezoidal membership functions for meteorological variables for hop cultivation in the state of Santa Catarina, Brazil. A) Average air Temperature and B) Rainfall

Trapezoidal function: parameters (a, m, n, b), with $a \leq m$, $n \leq b$ and $m < n$.

$$\mu_A(x) = \begin{cases} 0, x \leq a \\ \dfrac{x-a}{m-a}, a < x \leq m \\ 1, m < x \leq n \\ \dfrac{b-x}{b-n}, n < x \leq b \\ 0, x > b \end{cases}$$



Source: Author's work.

To discretize the fuzzified variables and understand the frequency distribution of average air temperature and rainfall, we used intervals categorized as inapt (0 to 0.2), very restrict (0.2 to 0.4), restrict (0.4 to 0.6), moderate restrict (0.6 to 0.8), and apt (0.8 to 1), respectively ranging from inapt (0) to apt (1). In other words, inapt conditions of temperature and precipitation are limiting factors for hop development, whereas the opposite applies to the apt end, where variables pose little or no resistance to crop development.

After this analysis, the Fuzzy *Gamma* operator was applied to the fuzzified images of average temperature and average precipitation for hop cultivation in the state of Santa Catarina, Brazil (Câmara *et al.*, 2004; Meirelles, 1997). The Fuzzy *Gamma* operator is the product of the Fuzzy algebraic sum and the Fuzzy product (Equation 1). In the equation, it is observed that the sum is raised to a weighting factor γ and the product is raised to a complementary factor $1 - \gamma$. Favorability and downy mildew incidence maps were generated using different *Gamma* values: 0.10; 0.20; 0.30; 0.40; 0.50; 0.60; 0.70; 0.80, and 0.90.

$$\mu(x) = \{1 - \prod_{i=1}^{n}(1-\mu_i)\}^{\gamma} * \{\prod_{i=1}^{n}\mu_i\}^{1-\gamma} \quad \text{(Equation 1)}$$

Here, μ_i are the Fuzzy membership values for i = 1, 2, 3, ..., 5; n corresponds to the raster layer of data, i.e., the number of variables in the study; and γ is the coefficient with values between 0 and 1.

Fuzzy *Gamma* allows for combining the increasing effect of Fuzzy Sum and the decreasing effect of Fuzzy Product, rather than simply returning the value of a single Fuzzy set (Meirelles, 1997).

2.2.5 Agroclimatic zoning for hop cultivation conventional approach and Fuzzy logic for the state of Santa Catarina, Brazil

After obtaining the representative raster images of agroclimatic zoning, they were converted to polygonal vector format using the “raster to polygon” function. Subsequently, the “polygon dissolve” function was applied due to the high number of polygons obtained during the conversion process.

Thus, a new vector image was obtained with an attribute table containing suitability classes named apt, restrict, and inapt. In the attribute table of the dissolved polygonal vector image, two new fields were created with real data types: 'area' to record the spatial dimensions of each polygon, and 'percentage' to indicate the proportion each one represents relative to the total. In the editing state, the “geometric calculation” function was used to compute the areas (km^2) and perimeters (km) of the aforementioned suitability classes. Finally, using the “field calculator” function, the percentage of suitability classes for hop cultivation was calculated.

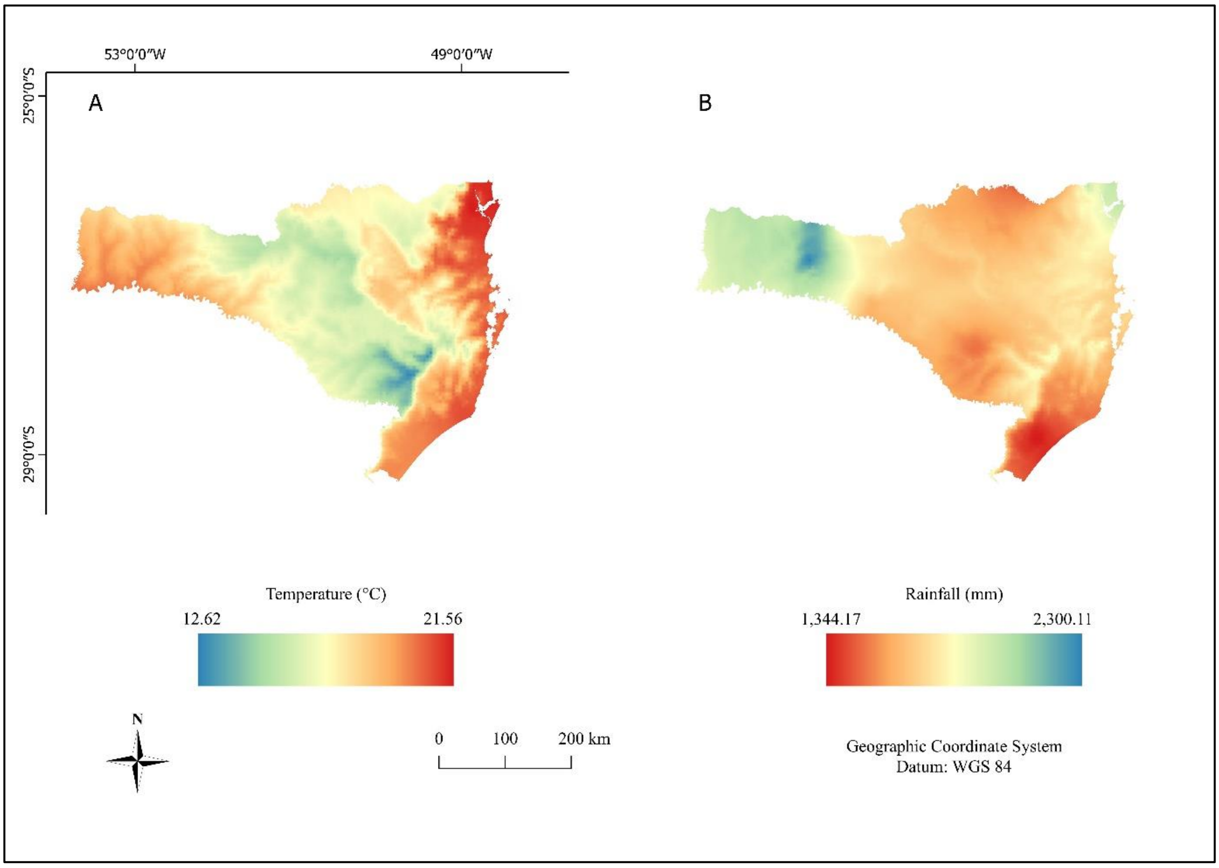
To refine the agroclimatic zoning for the state of Santa Catarina, the “intersection” function was applied to the polygonal vector images of municipalities and the agroclimatic zoning, resulting in two new polygonal vector images representing the agroclimatic zoning for hop cultivation across the municipalities of Santa Catarina, Brazil.

3 RESULTS

The state of Santa Catarina has average annual minimum and maximum temperatures ranging between 12.62°C and 21.56°C. This temperature variation spans from the coldest regions, typically found in the mountainous areas and the Itajaí Valley, to the warmer areas located to the north and along the coast of Santa Catarina (Figure 4A). A correlation has been identified between the occurrence of cold weather and areas of elevated topography. The geographic characteristics inherent to such regions are conducive to a relatively temperate climate.

Figure 4B shows the map of rainfall precipitation, with annual indices ranging from a minimum average of 1,344.17 mm to a maximum of 2,300.11 mm. This map highlights the concentration of rainfall in the western part of the state, reflecting a favorable environment for agriculture.

Figure 4 - Spatial distribution of annual average air temperature and rainfall precipitation in the state of Santa Catarina.



Source: Author's work.

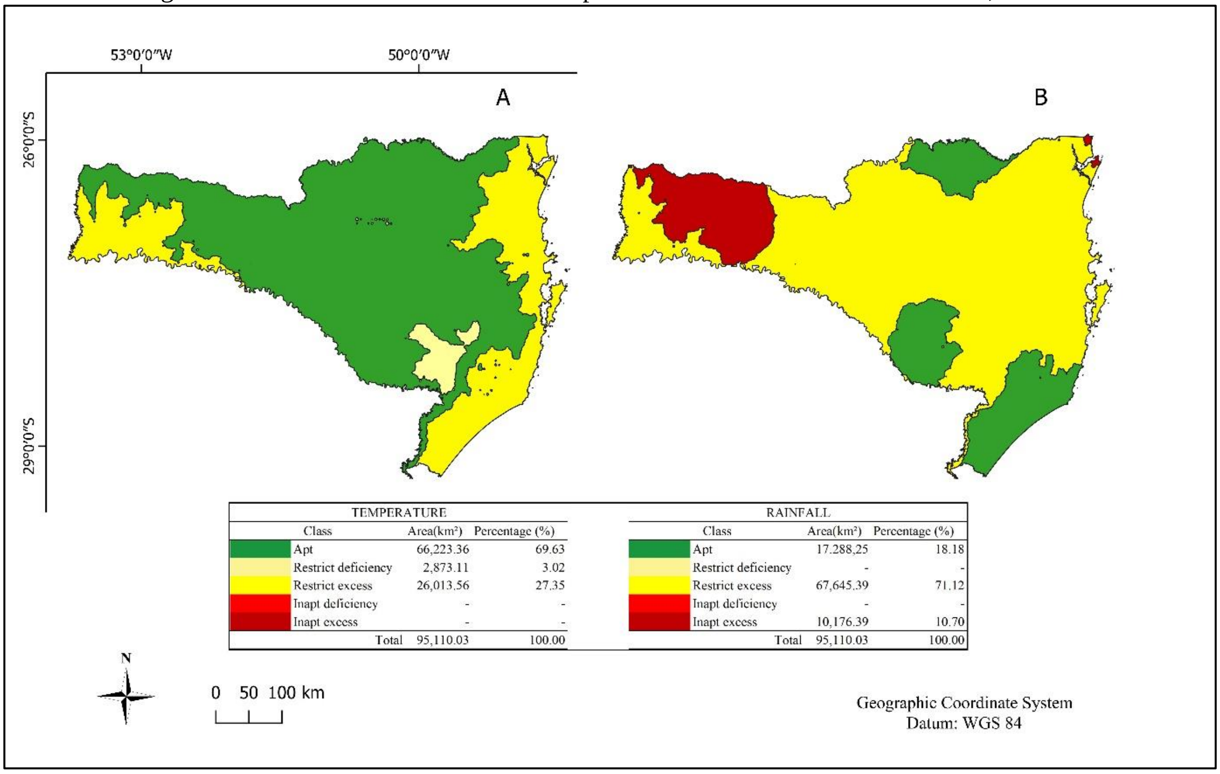
3.1 Conventional agroclimatic zoning for hops cultivation in the state of Santa Catarina, Brazil

The classes of conventional agroclimatic zoning for air temperature and precipitation variables for hop cultivation in the state of Santa Catarina are presented in Figure 5. In Figure 5A, concerning temperature, it is observed that areas considered apt for cultivation cover most of the territory, representing 66.33% of the total area. However, there are regions where restrictions due to thermal deficiency or excess are observed, indicating the presence of microclimates with less favorable conditions.

In Figure 5B, which analyzes precipitation, it is observed that only 18.18% of the territory of Santa Catarina is classified as apt due to ideal rainfall levels for hop cultivation. In contrast, most of the state, representing 71.12%, faces restrictions due to excessive rainfall. Areas considered inapt for the same reason of excessive rainfall correspond to a smaller fraction, occupying 10.70% of the state.

Notably, no values were identified for the restriction or unsuitability classes due to lack of precipitation.

Figure 5 - Reclassified Variables for Temperature and rainfall in Santa Catarina, Brazil.

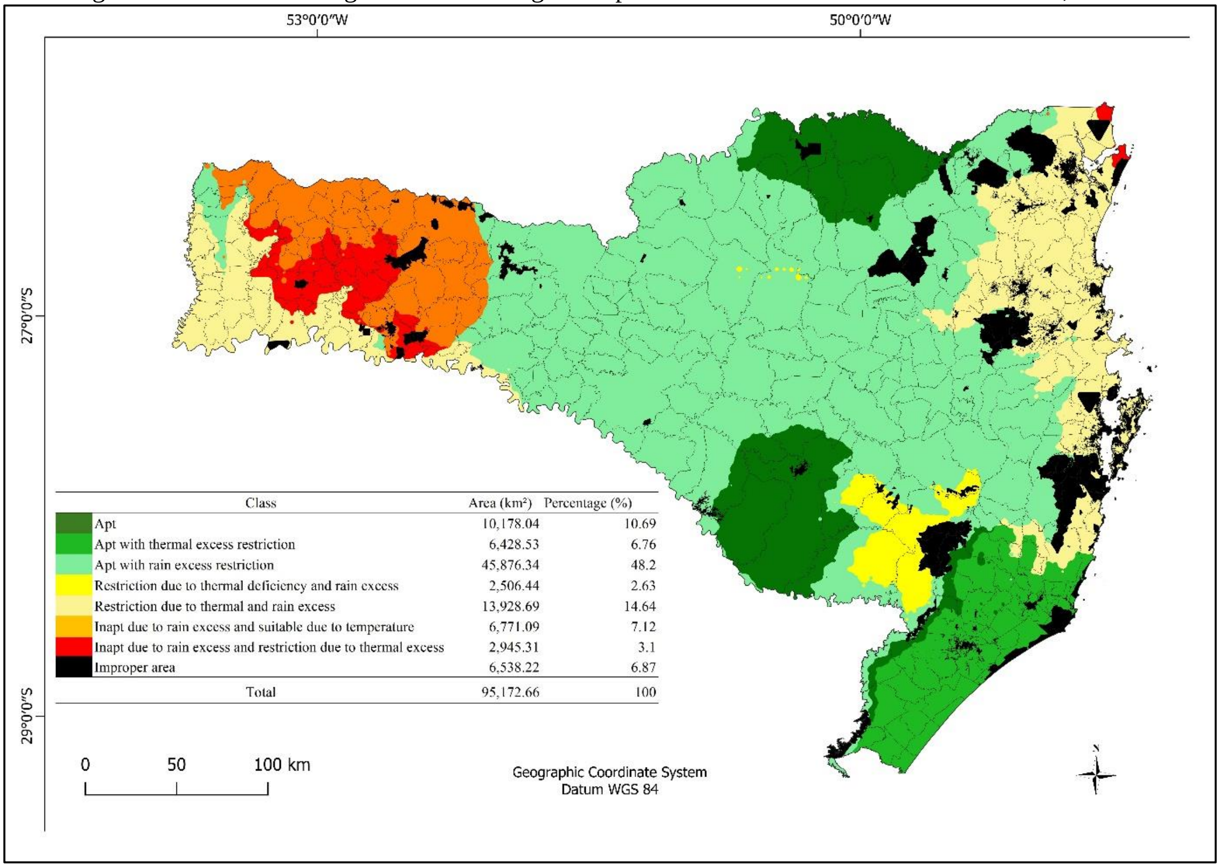


Source: Author's work.

According to the results, the regions categorized as apt for cultivation cover 10.69% of the total area of the state (Figure 6). Additionally, locations considered apt but with restrictions due to thermal excess represent 6.76%, while areas apt but restricted due to excessive rainfall cover 48.20%, totaling an area of 62,482.91 km².

The classes with restrictions due to thermal excess and rainfall excess correspond to 14.62% of the state, and the classes with restrictions due to thermal deficiency and rainfall excess represent 2.63%, totaling 16,928.13 km². The regions inapt due to excessive rainfall but apt for temperature correspond to 7.12% of the state's territory, while the areas inapt due to excessive rainfall and restricted by thermal excess amount to 3.10%. These, along with areas considered inapt for cultivation, including units of strict conservation and urban areas, total 16,254.62 km².

Figure 6 - Conventional agroclimatic zoning for hop cultivation in the state of Santa Catarina, Brazil



Source: Author's work.

Through conventional agroclimatic zoning for hop cultivation in the state of Santa Catarina, it is evident that overall, all 295 municipalities face some degree of restriction for hop cultivation. The municipality of Três Barras stands out (Table 4), with an area of 353.143 km2, corresponding to 81% of the total area classified as suitable; the remaining 19% is in inappropriate areas (conservation units, urban areas, and others).

Furthermore, 38 municipalities were identified with apt areas ranging from 97.81% to 0.09% of their total area. In Table 4, 10 of these municipalities are highlighted. We identified municipalities where 100% of their areas fall into a single class: 13 municipalities classified as apt with thermal restriction, 68 municipalities classified as apt with precipitation restriction, 14 municipalities classified as restricted due to excess thermal and precipitation, 10 municipalities classified as inapt due to excess precipitation, and 2 municipalities classified as inapt due to excess precipitation and thermal restriction.

For a detailed breakdown of all evaluated municipalities, the information can be accessed in the Appendix (Supplementary Table 1).

Table 4 – The 10 municipalities with the highest percentages of areas within the Suitable class of agroclimatic zoning with a conventional approach, for the state of Santa Catarina, Brazil.

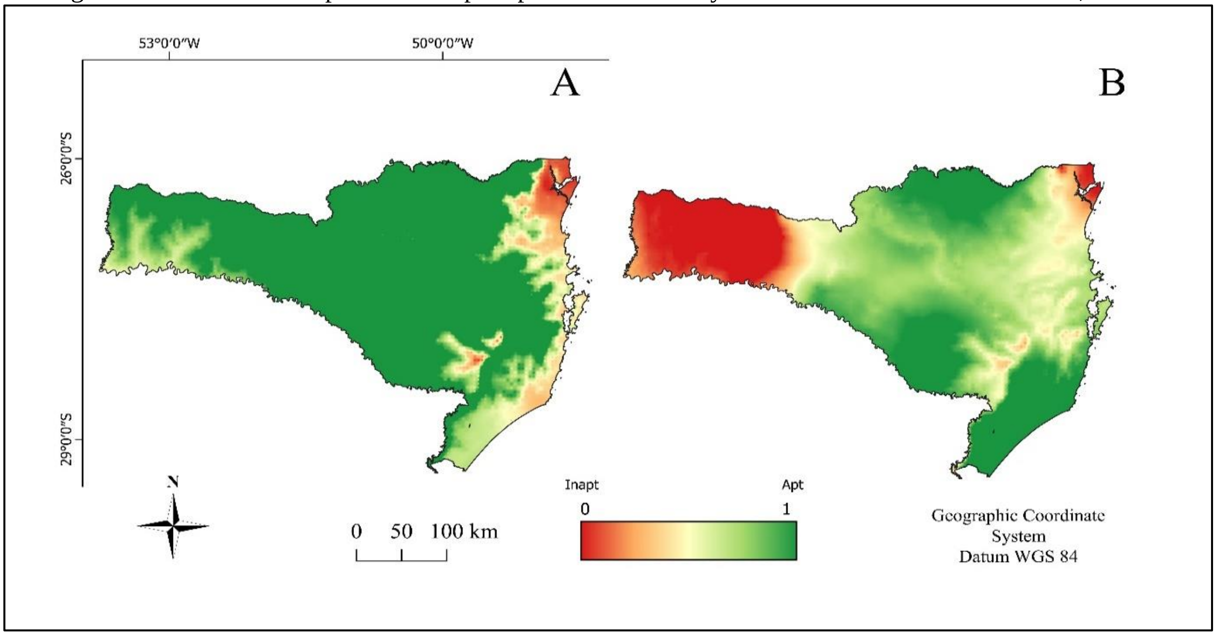
	Classes	Municipalities									
		Mafra	Lages	Capão Alto	Três Barras	Papanduva	Itaiópolis	Canoinhas	Treviso	Correia Pinto	Painel
Area km^2	A	1,372.02	2,426.42	12,20.30	353.14	493.69	813.21	643.24	78.15	266.31	276.55
	ARET	-	-	-	-	-	-	-	51.32	-	-
	AREP	30.72	164.18	99.93	-	270.12	440.60	499.72	14.88	383.19	222.95
	RCTEP	-	-	-	-	-	-	-	-	-	236.28
	RETP	-	-	-	-	-	-	-	-	-	-
	IEPAT	-	-	-	-	-	-	-	-	-	-
	AI	0.06	41.25	13.79	84.81		40.13	0.14	12.06		5.93
	Total	1,402.80	2,631.85	1,334.02	437.95	763.80	1,293.95	1,143.09	156.41	649.50	741.71
Percentage %	A	97.81	92.19	91.48	80.63	64.64	62.85	56.27	49.97	41.00	37.29
	ARET	-	-	-	-	-	-	-	32.81	-	-
	AREP	2.19	6.24	7.49	0.00	35.36	34.05	43.72	9.51	59.00	30.06
	RCTEP	-	-	-	-	-	-	-	-	-	31.86
	RETP	-	-	-	-	-	-	-	-	-	-
	IEPAT	-	-	-	-	-	-	-	-	-	-
	AI	0.00	1.57	1.03	19.37	0.00	3.10	0.01	7.71		0.80
	Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Source: Author's work. A=Apt, ARET= Apt with thermal excess restriction, AREP= Apt with rain excess restriction, RCTEP= Restriction due to thermal deficiency and rain excess, RETP= Restriction due to thermal and rain excess, IEPAT= Inapt due to rain excess and suitable due to temperature, IEPRET= Inapt due to rain excess and restriction due to thermal excess, I= Inapt, AI= Improper Area.

3.2 Agroclimatic zoning for hops cultivation using Fuzzy logic for the state of Santa Catarina, Brazil

The matrix images of the reclassified temperature and precipitation variables can be observed in Figure 7, referring to air temperature, where the regions identified as apt (value 1) for hop cultivation include the Serrana region, the Vale do Itajaí, and the Southern and Northern regions of Santa Catarina. However, the coastal portion and the extreme south of western Santa Catarina are restricted to hop cultivation.

Figure 7 – Annual air temperature and precipitation A-B Fuzzyfied in the state of Santa Catarina, Brazil.



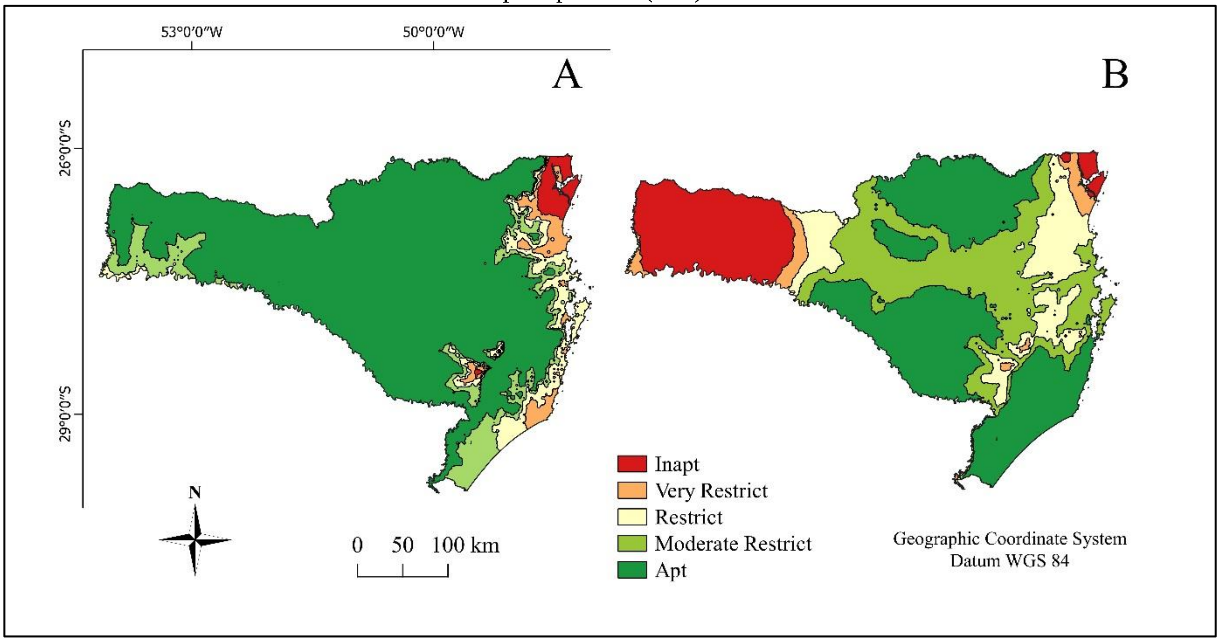
Source: Author's work.

In Figure 7, the areas classified as apt for hop cultivation are highlighted with a value of 1 (dark green), covering the Serrana region, Southern Santa Catarina, and the North. The regions facing restrictions for cultivation, indicated by values between 0 and 1 (light green, yellow, orange and red), include the Midwest and the Vale do Itajaí. On the other hand, the areas considered inapt for cultivation, with values equal to 0 (in red), correspond to Western Santa Catarina and the extreme North of the coastal region of Santa Catarina.

Thus, Figure 8 represents the spatial distribution of Fuzzy frequencies of meteorological variables related to hop cultivation in the state of Santa Catarina, Brazil, categorized into five distinct categories – Inapt (extremely unfavorable condition for hop development), Very Restrict, Restrict, Moderate restrict, and Apt (conditions without impediments, i.e., favorable for the crop) – with intervals of 0.2.

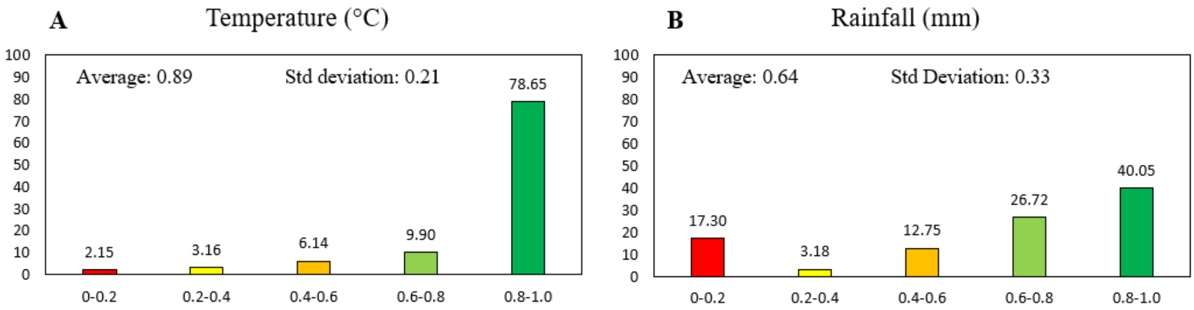
In Figure 9, we observe this distribution of Fuzzy frequencies of the variables; temperature is illustrated in Figure 9A, revealing an average of 0.89 and a standard deviation of 0.21, with the Apt category being the most significant, representing 78.65% of the state territory. Meanwhile, the precipitation analysis, as shown in Figure 9B, records an average of 0.64 and a standard deviation of 0.33. For this variable, the Apt category also emerges as the most representative, covering 40.05% of Santa Catarina.

Figure 8 – Categorization of Fuzzy meteorological variables between the years 1991 and 2021 (30-year series) for hop cultivation in the state of Santa Catarina, Brazil. A) Average air temperature (ºC), B) Rainfall precipitation (mm).



Source: Author's work

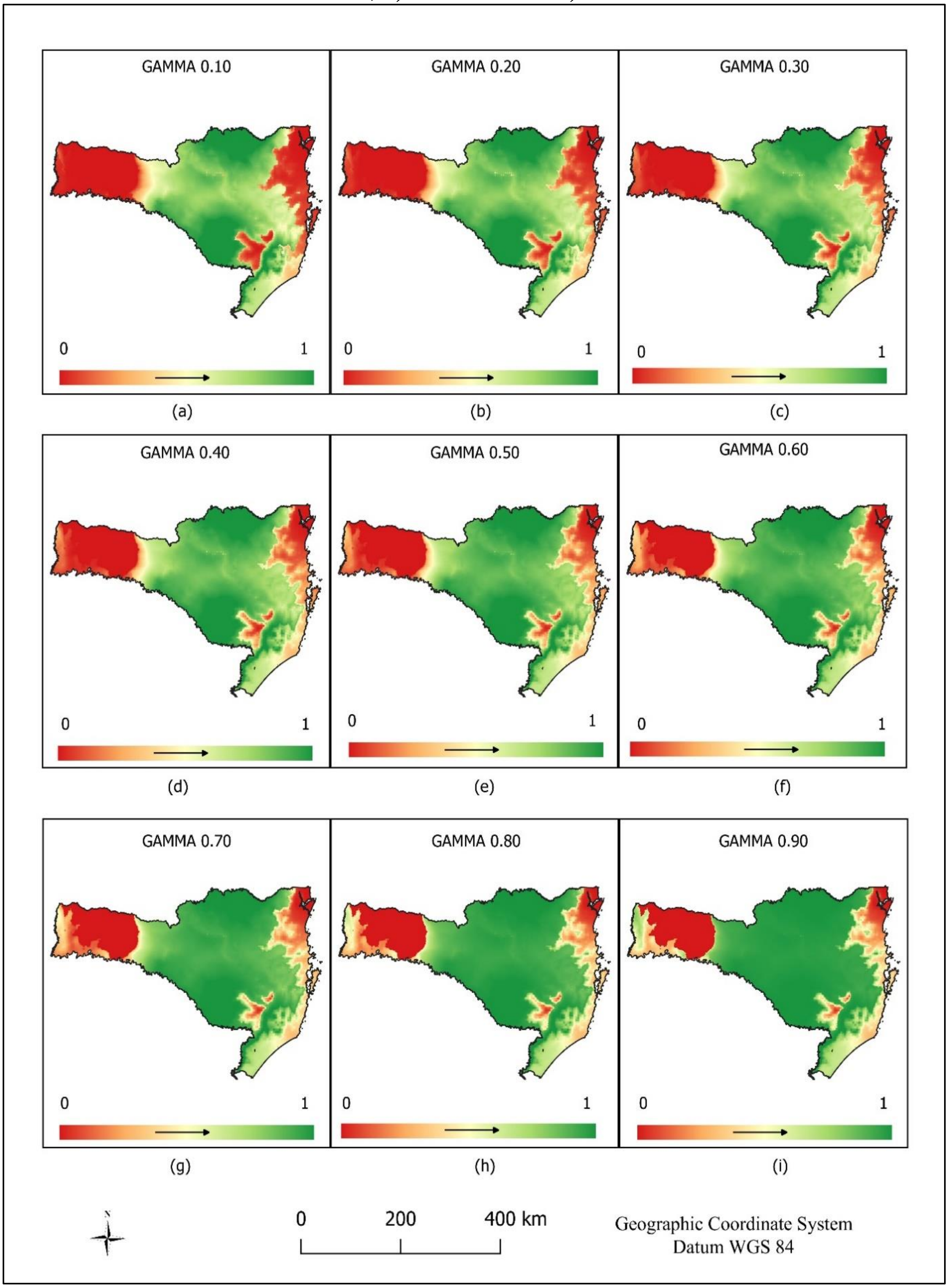
Figure 9 – Distribution of Fuzzy frequencies of meteorological variables for hop cultivation in the state of Santa Catarina, Brazil. A) Average air temperature (ºC), B) Rainfall precipitation (mm).



Source: Author's work

In pursuit of the best results for Agroclimatic Zoning for hop cultivation, values ranging from 0.1 to 0.9 were tested in the Fuzzy *Gamma* operator (Figure 10). Among these, the *Gamma* operator at 0.9 proved to be the most effective, resulting in sharper and more realistic transitions of areas, translating into a more favorable scenario for hop cultivation in the state. Conversely, the *Gamma* operator at 0.1 presented a more restrictive scenario, with a larger number of areas considered inapt for hop cultivation.

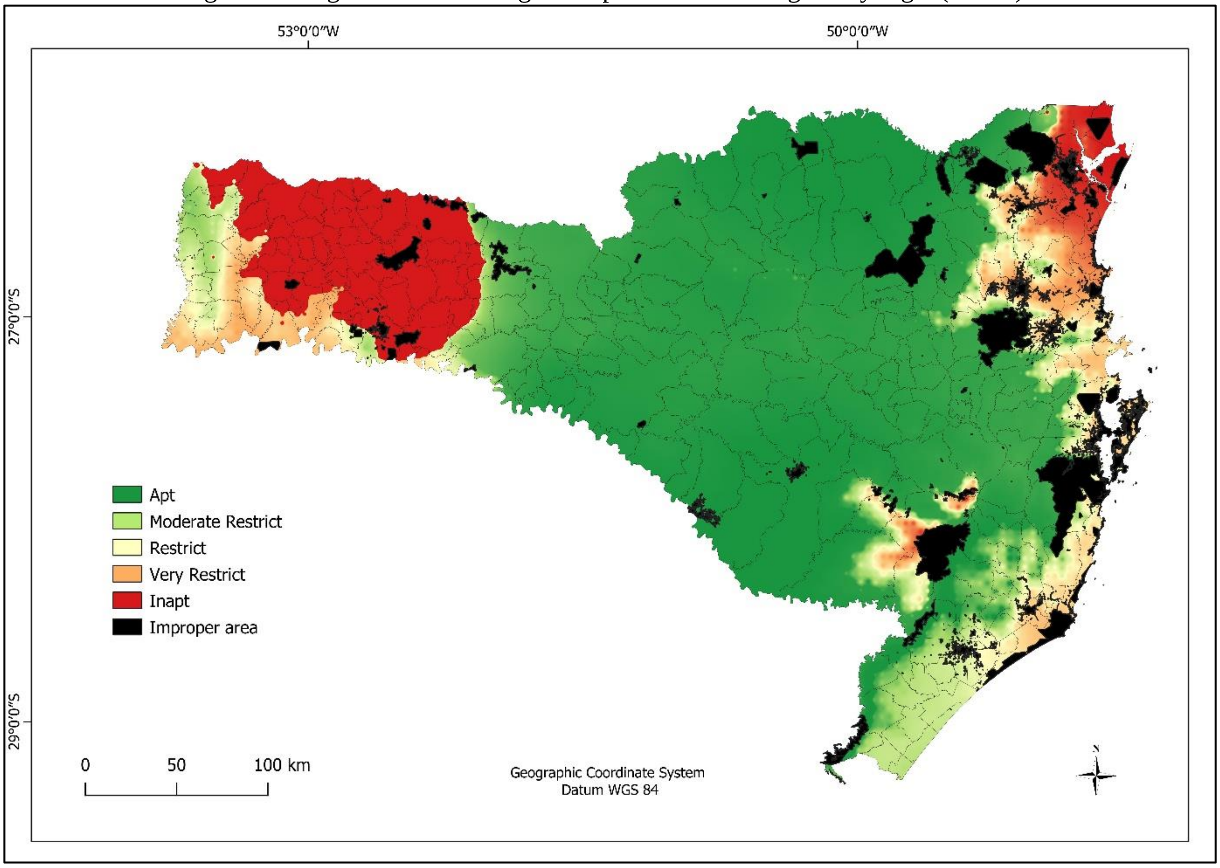
Figure 10 - Fuzzy overlay of meteorological variables for hop cultivation in the state of Santa Catarina, Brazil. A) *Gamma* = 0.1, B) *Gamma* = 0.2 C) *Gamma* = 0.3) D) *Gamma* = 0.4, E) *Gamma* = 0.5 F) *Gamma* = 0.6, G) *Gamma* = 0 .7, H) *Gamma* = 0.8 and I) *Gamma* = 0.9



Source: Author's work

With the selected *Gamma* operator, the Agroclimatic Zoning was generated using Fuzzy Logic (Figure 11). Following the nomenclature used for temperature and rainfall variables, this zoning classifies areas into five categories – Apt, Moderate restrict, Restrict, Very Restrict, and Inapt – regarding their suitability for hop production in Santa Catarina. In other words, the more inapt the values of the variables (closer to zero), the less favorable the development of the crop. The areas classified as Apt, representing 61.07% of the territory or 58,117.47 km², are considered the most suitable for hop cultivation, indicating that a vast portion of the state has ideal climatic conditions of temperature and precipitation for the crop. The remaining categories are distributed as follows: Moderate restrict (7.35%), Restrict (5.82%), Very Restrict (12.68%), and Inapt (12.68%), totaling 30,516.94 km² of areas with less favorable or restrictive climatic conditions for hop cultivation. In addition to these, areas classified as unsuitable, totaling 6,538.22 km², are excluded from the analysis of productive potential.

Figure 11 - Agroclimatic Zoning for hop cultivation using Fuzzy logic (ZALF).



Source: Author's work

The use of Fuzzy logic in agroclimatic zoning for hop cultivation in Santa Catarina resulted in 94 municipalities being classified 100% in the Apt class, with 10 municipalities highlighted in Table 5. In the other classes, there are 8 municipalities fully classified in the

Moderate restrict class and 28 in the Inapt class, highlighting areas with greater challenges for hop cultivation. Detailed information about all evaluated municipalities can be found in the Appendix (Supplementary Table 2).

Table 5 - Areas and Percentage of agroclimatic zoning classes using Fuzzy logic for municipalities in the state of Santa Catarina, Brazil.

	Classes	Municipalities									
		Abdon Batista	Agrolândia	Agronômica	Água Doce	Angelina	Anita Garibaldi	Arroio Trinta	Atalanta	Aurora	Braço do Trombudo
Area (km²)	Apt	237.47	207.23	129.60	1,309.61	501.71	587.45	94.25	94.19	206.59	89.60
	Moderate Restrict	-	-	-	-	-	-	-	-	-	-
	Restrict	-	-	-	-	-	-	-	-	-	-
	Very Restrict	-	-	-	-	-	-	-	-	-	-
	Inapt	-									
	Improper Area	-	-	-	-	-	-	-	-	-	-
	TOTAL	237.47	207.23	129.60	1,309.61	501.71	587.45	94.25	94.19	206.59	89.60
Percentage (%)	Apt	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
	Moderate Restrict	-	-	-	-	-	-	-	-	-	-
	Restrict	-	-	-	-	-	-	-	-	-	-
	Very Restrict	-	-	-	-	-	-	-	-	-	-
	Inapt	-	-	-	-	-	-	-	-	-	-
	Improper Area	-	-	-	-	-	-	-	-	-	-
	TOTAL	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Source: Author's work

4 DISCUSSION

Hops plants are native to temperate zones, and their adaptability has been studied for different climates (Gonsaga, 2021; Jastrombek *et al.*, 2022b; Marceddu; Carrubba; Sarno, 2020; Rossini *et al.*, 2021; Simieli *et al.*, 2021). Temperature and precipitation are decisive factors for hop production (Burgues, 1964).

However, for the state of Santa Catarina, the average, minimum, and maximum annual temperatures range between 12.62°C and 21.56°C (Figure 3). In the mountainous region (Serrana) of the state, temperatures are lower due to the high altitude of these areas, while the eastern region including the Vale do Itajaí, northern Santa Catarina, and the northern coast, experience higher average temperatures. The western part of Santa Catarina has milder temperatures (Ferreira, 2017), all within the ideal range for hop development, which is inhibited below 5°C or above 35°C (Rybáček, 1991).

As the season progresses, a gradual increase in average temperature is expected, coinciding with the beginning of hop vegetative activity. During the months of July and August, the average maximum temperatures are expected to range between 15.5°C and 18.3°C, followed by a slight reduction in September, which coincides with the final maturation of hop cones in the northern hemisphere (Burgues, 1964). Sharp variations in temperature can significantly impact both the production and quality of hops, affecting crucial elements such as alpha acids (Thomas, 1980) and the flowering phase (Pavlovic *et al.,* 2012; Thomas; Schwabe, 1969).

The average annual rainfall in the state ranges from 1,344.17mm to 2,300.11mm, with higher rainfall volumes in the western and northeastern regions, and lower in the central, eastern, and southeastern areas (Figure 3). Gotado (2018) observed these patterns in his study and predicted precipitation over the years for the state. Although the amount of rainfall during the growing cycle is not decisive for good productivity, its distribution is crucial. For successful cultivation without irrigation, rainfall should not be less than 300 mm during the growth period and should be well distributed (Burgues, 1964; Gonsaga, 2021). An important factor is soils with good drainage capacity, which is the solution for rainy winters (Burgues, 1964).

Regarding the results of climate suitability zones for hop cultivation, the conventional zoning showed that suitable and restricted areas together comprise 82.92% (78,981.04 km²) of the territory of Santa Catarina, while the Fuzzy approach – apt and moderate restrict areas – indicated that 68.42% (65,112.15 km²) are favorable for cultivation, due to the more gradual transition between classes, contrasting with the more abrupt delineations of the conventional approach. The region of Lages, in the state of Santa Catarina, is highlighted as one of the three most promising regions for hop cultivation in Brazil (Jastrombek *et al.,* 2022), but it is also important to consider the cultivar, soil conditions, and sunlight for the success of the crop. Other zoning studies for hops in Brazil, such as those conducted in Rio de Janeiro using Fuzzy and agroecological approaches, include additional variables such as water deficiency and altitude (Carvalho *et al.,* 2018; Silva *et al.,* 2022).

After analyzing and comparing the results related to the different *Gamma* operators used, it was found to be consistent with existing literature that highlights the effectiveness of this operator. Santos and Lobão (2017), in their research on environmental vulnerability modeling, and Silva Jr *et al.* (2016), in their studies on susceptibility in Maranhão, reported positive results when applying *Gamma* operators at 0.9.

Comparing with the agroecological and socioeconomic zoning of the state of Santa Catarina, developed by EPAGRI, which adopted the sum of water excess and temperature to delimit cultivation areas, there was a predominance of areas classified as suitable and preferred for cultivation, with no areas classified as not recommended for cultivation (Thomé, 2022). This finding reinforces the results obtained from both the conventional and Fuzzy approaches, adding, however, an important nuance by detailing the specific restrictions of each area. This detailed information provides valuable insights to producers to anticipate challenges and strategically adapt their agricultural practices, aiming to optimize production.

In the analyses conducted both by conventional zoning, considering areas within the classes inadequate due to excessive rainfall and suitable due to temperature, inadequate due to excessive rainfall and restriction due to thermal excess, and by Fuzzy in the inapt, very restrict, and restrict classes identified as areas considered unsuitable for hop cultivation are primarily located in the coastal strip and the far west of Santa Catarina. These regions are characterized, respectively, by higher temperatures and the rainfall index of the state. Additionally, the Serrano Plateau of São Joaquim stands out, characterized by a consistently humid temperate climate with no dry periods and mild summers (Thomé, 2022).

5 CONCLUSION

Hops cultivation is increasing in Brazil, with the state of Santa Catarina being one of the regions with important climatic characteristics for the adaptability of this crop. Temperature and rainfall are the most discussed variables in the literature; however, photoperiod should be included in new studies. The state of Santa Catarina presented a large area suitable for hop cultivation (approximately 61% of the state's area), while 32% exhibited restricted or unfavorable climatic conditions.

The use of agroclimatic zoning as a guide for selecting the best locations for hop planting requires further investigation, especially on-site assessments. Regarding the methodology used, both the conventional approach and the Fuzzy approach have their peculiarities, with the conventional approach being more precise and the Fuzzy approach more gradual in terms of class change but offering the possibility to create hierarchies and more detailed scenarios.

Additionally, the results of this study reinforce the importance of a detailed evaluation of agroclimatic and geographic conditions in promoting hop cultivation in Santa Catarina. Considering the complexity of the variables involved and regional specificities, continuous collaboration between farmers, researchers, and agricultural institutions is essential for the sustainable expansion of hop cultivation.

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CHAPTER 3

3. Climatic favorability of the occurrence of downy mildew (*Pseudoperospora humuli*) on hops (*Humulus lupulus* L.) using conventional approach and Fuzzy logic for the state of Santa Catarina, Brazil

ABSTRACT

Brazil is a major importer of hops for the brewing industry, and its adaptability is currently being extensively studied. However, hop cultivation is subject to various diseases, with downy mildew being one of the most harmful. In this context, the objective was to spatialize the climatic favorability for the occurrence of downy mildew in the state of Santa Catarina, Brazil, using conventional approaches and Fuzzy Logic. Based on the results, it was found that the state has favorable climatic conditions for the occurrence of downy mildew due to the presence of areas with mild temperatures and high humidity. In the conventional approach, 63.13% of the state's area was identified as favorable to the disease, while in the Fuzzy approach, this proportion was 92.80%. The combination of these techniques provides a comprehensive view of the climatic conditions favorable to downy mildew, which can aid in decision-making regarding disease management. These results provide support for the adoption of appropriate agricultural practices and the development of cultivars better adapted to the specific climatic conditions of Santa Catarina.

Keywords: Spatialization, climatic variables, *Pseudoperonospora humuli*.

1 INTRODUCTION

Hops production and its economic value are tied to the quality of the product. In other words, a healthy and well-cared-for plant has a better chance of reaching a higher quality level, thereby adding value to the product. One of the major obstacles is diseases and pests.

Regarding diseases, notable ones include powdery mildew (*Sphaerotheca humuli*), downy mildew (*Pseudoperonospora humuli*), Verticillium wilt (*Verticillium alboatrum*), fusarium wilt (*Fusarium culmorum*), and viral infections (Lizotte *et al.,* 2022; Mpanga; Schalau, 2020; O'Neal *et al.,* 2015). Among these diseases, downy mildew is one of the most important because it causes significant reductions in both the quantity and quality of production, representing a major challenge for hop cultivation (Thines; Choi, 2016).

Downy mildew has caused significant economic losses in various crops and ornamental plants (Belbahri *et al.,* 2005; Larran *et al.,* 2006; Hukkanen *et al.,* 2006). Downy mildew of hops, caused by the obligate oomycete pathogen Pseudoperonospora humuli, is the most serious disease affecting hops in cultivation regions worldwide (Royle; Kremheller, 1981). This biotrophic oomycete can systemically infect hop crowns, allowing it to overwinter as mycelium and resulting in infected shoots the following spring, known as basal spikes (Coley-Smith, 1962). The pathogen can be spread through planting material, infecting both rhizomes and plants propagated from softwood cuttings (Royle; Kremheller, 1981). The disease can affect the entire above-ground part of the plant, as well as underground organs such as roots and the crown (Marcos *et al.,* 2011).

In the field, downy mildew is typically diagnosed through visual observations of leaf tissue, which exhibit typical disease lesions and, in many cases, pathogen sporulation (Holmes *et al.,* 2015). Secondary inoculum from sporulating foliage is critical for downy mildew epidemics, and much diagnostic effort has focused on detecting sporangia in the air using spore traps (Gent *et al.,* 2009; Klosterman *et al.,* 2014; Kong *et al.,* 2016; Kunjeti *et al.,* 2016). The disease is favored by moderate temperatures (15 to 20 °C) and prolonged periods of high humidity (> 90%) (Royle; Kremheller, 1981).

In colder and wetter regions, there is often a need for fungicide application to manage the disease. In some cases, susceptible cultivars cannot be economically produced due to the costs associated with spraying (Johnson *et al.,* 1985).

In this sense, Santos *et al.* (2016) present edaphoclimatic zoning as an essential tool for spatializing areas of climatic suitability (meteorological variables) and soil suitability (soil types) aimed at promoting agricultural production and productivity. Moreira *et al.* (2020)

present an adaptation of the edaphoclimatic zoning methodology aimed at spatializing the favorability of agricultural diseases in a conventional manner through the reclassification of favorability classes.

With the advancement of geotechnologies and artificial intelligence, there is a growing need for the application of modern methodological combinations, particularly highlighting the use of Fuzzy logic to spatialize the favorability of agricultural diseases.

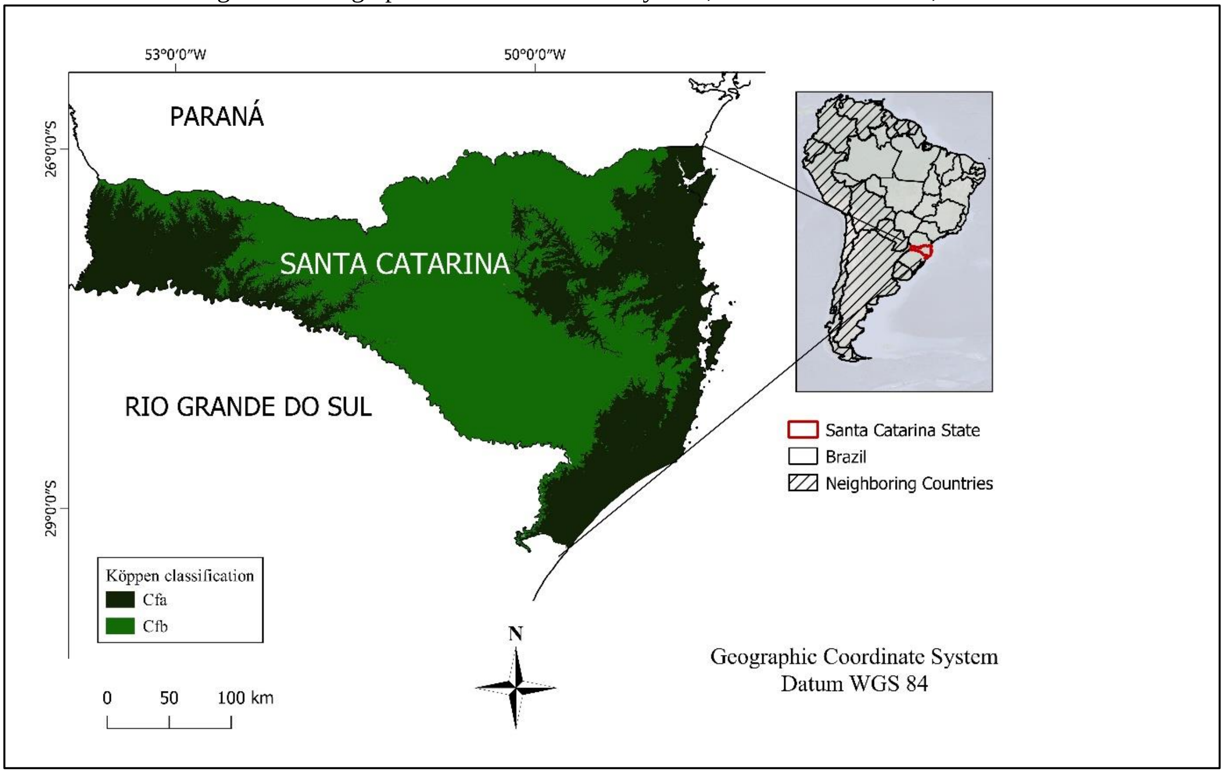
Given the above, this study aims to spatialize the climatic favorability for the occurrence of downy mildew (*Pseudoperonospora humuli*) in hop cultivation (*Humulus lupulus* L.) in the state of Santa Catarina, Brazil.

2 MATERIAL AND METHODS

2.1 Study area

The study area is represented by the state of Santa Catarina, located in the southern region of Brazil, with a territorial area of 95,346 km². The territory of Santa Catarina is located between parallels 25°57'41” and 29°23'55” South latitude and meridians 48°19'37” and 53°50'00” West longitude, Figure 1. According to Köppen (1936), the state has two climate types: humid subtropical with hot summers (Cfa) and humid subtropical with mild summers (Cfb), which is predominant. Temperatures range from 13 to 25°C, and rainfall is distributed throughout the year.

Figure 1 - Geographic location of the study area, Santa Catarina state, Brazil.

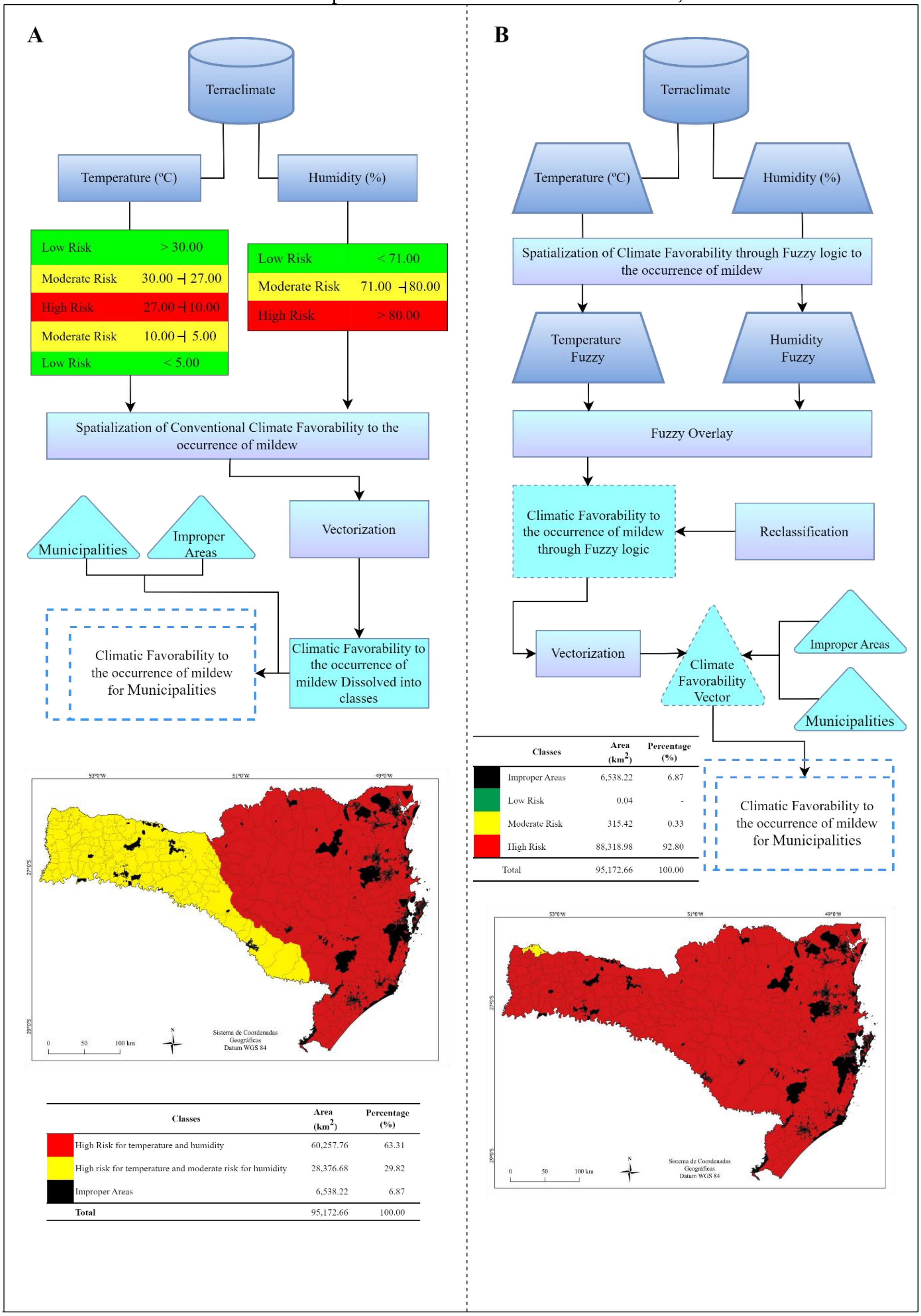


Source: Author's work

2.2 Spatialization of climatic favorability for downy mildew incidence in hops cultivation in the state of Santa Catarina, Brazil

The methodological steps required for spatializing the climatic favorability for downy mildew incidence in hop cultivation in the state of Santa Catarina, Brazil, are presented in Figure 2. The climatic variables are classified on a risk spectrum ranging from low to high, based on specific thresholds of temperature and humidity. The classified areas are vectorized and overlaid to define the spatialization of climatic favorability, which is dissolved into classes highlighting areas with different levels of risk for downy mildew incidence. This considers both reclassification based on disease risk intervals and overlay of analyzed variables (conventional approach), as well as overlay of fuzzified maps of analyzed variables and reclassification (Fuzzy approach), combining conventional and Fuzzy logic techniques.

Figure 2 - Methodological steps required for the spatialization of climatic favorability for downy mildew occurrence in hop cultivation in the state of Santa Catarina, Brazil.



Classes	Area (km^2)	Percentage (%)
High Risk for temperature and humidity	60,257.76	63.31
High risk for temperature and moderate risk for humidity	28,376.68	29.82
Improper Areas	6,538.22	6.87
Total	95,172.66	100.00

Classes	Area (km^2)	Percentage (%)
Improper Areas	6,538.22	6.87
Low Risk	0.04	-
Moderate Risk	315.42	0.33
High Risk	88,318.98	92.80
Total	95,172.66	100.00

Source: Author's work

2.2.1 Database

The meteorological database used for spatializing the climatic favorability for downy mildew incidence in hop cultivation was obtained from the TerraClimate platform (https://www.climatologylab.org/terraclimate.html), which provides meteorological variables in a time series from 1958 to the present (Abatzoglou *et al.*, 2018) in compressed NetCDF format with a spatial resolution of 4 km. In this study, initially, the meteorological variables minimum temperature, maximum temperature, and water vapor pressure were used for the period from 1991 to 2021 (30 years).

As preprocessing, the gridded layers representing the available meteorological variables from the TerraClimate server were imported, clipped, and reprojected (Sirgas 2000 UTM 23S) to the state of Santa Catarina, Brazil, using QGIS software version 3.28.1.

After preprocessing, the raster images were vectorized into point format and interpolated using the "Inverse Distance Squared (IQD)" method with a resolution of 1 km².

Subsequently, the raster calculator function was applied with the aim of generating raster images of average air temperature (Equation 1), vapor saturation pressure proposed by Otto Tetens (1930) (Equation 2), and relative air humidity (Equation 3).

$$T_{ar} = \frac{T_{min}+T_{max}}{2} \qquad \text{(Equation 1)}$$

Where T_{ar} is the average air temperature (°C), T_{min} is the minimum air temperature (°C), and T_{max} is the maximum air temperature (°C).

$$e_s = 0{,}6108 * 10^{[(7{,}5*T_{ar})/(237{,}3+T_{ar})]} \qquad \text{(Equation 2)}$$

Where e_s is the vapor saturation pressure (kPa) and T_{ar} is the average air temperature (°C).

$$UR = \frac{e}{e_s} \qquad \text{(Equation 3)}$$

Where UR is the relative air humidity (%), e is the actual vapor pressure (kPa), and e_s is the vapor saturation pressure (kPa).

Thus, the raster images of average air temperature and relative air humidity were reclassified using the "reclassify by table" function into favorability classes adapted for the study area, based on the intervals presented in Tables 1 and 2.

Table 1 - Favorability classes of average air temperature for downy mildew occurrence in hop cultivation adapted for the state of Santa Catarina, Brazil.

Classes	**Temperature (°C)**
	Literature
Low Risk	≥30.00
Moderate Risk	30.00 ⊣27.00
High Risk	27.00 ⊣10.00
Moderate Risk	10.00 ⊣5.00
Low Risk	<5.00

Source: Adapted from Gent, Nelson, and Grove (2008) and Purayannur *et al.*, 2020.

Table 2 - Favorability classes of relative air humidity for downy mildew occurrence in hop cultivation adapted for the state of Santa Catarina, Brazil

Classes	**Relative humidity (%)**
	Literature
Low Risk	<71.00
Moderate Risk	71.00 ⊢80.00
High Risk	≥80.00
Moderate Risk	-
Low Risk	-

Source: Adapted from Dodds (2017) and Royle, 1970a; b, 1973

2.2.2 Spatialization of climatic favorability using the Conventional approach for downy mildew incidence in hops cultivation in the state of Santa Catarina, Brazil.

In this stage, a tabular cross-referencing was performed between the reclassified raster images of average air temperature and relative humidity using the “r.cross” function, followed by applying the “r.report” functions to identify and adjust the conventional climatic favorability classes for downy mildew incidence in hop cultivation in the state of Santa Catarina, Brazil.

2.2.3. Spatialization of climatic favorability using Fuzzy Logic for downy mildew incidence in hop cultivation in the state of Santa Catarina, Brazil.

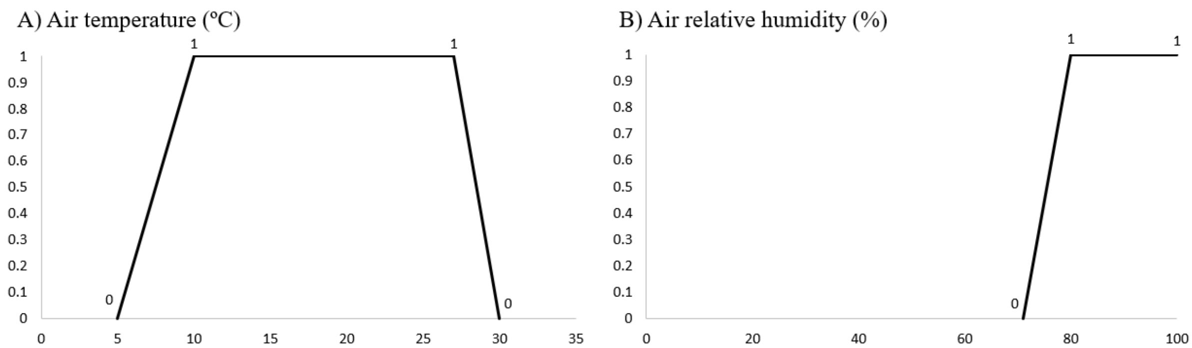
In this stage, the continuous raster images of average air temperature and relative humidity were reclassified according to the favorability classes presented in Tables 1 and 2 following the principles of Fuzzy Logic, with intervals ranging from 0 to 1. In this scale, the value 0 represents a location unfavorable for downy mildew incidence, while the value 1 represents a favorable location.

In this context, within the QGIS software, the “trapezoidal membership” function was applied to the continuous raster images of average air temperature and relative humidity (Figure 3). Since this function is not directly available in QGIS, it was processed using its “map calculator”.

Figure 3 - Trapezoidal membership functions for meteorological variables favorable to downy mildew occurrence in hop cultivation in the state of Santa Catarina, Brazil. A) average air temperature and B) relative humidity.

Trapezoidal function: parameters (a, m, n, b), with $a \leq m$, $n \leq b$ and $m < n$.

$$\mu_A(x) = \begin{cases} 0, x \leq a \\ \dfrac{x-a}{m-a}, a < x \leq m \\ 1, m < x \leq n \\ \dfrac{b-x}{b-n}, n < x \leq b \\ 0, x > b \end{cases}$$



Source: Author's work.

To discretize the fuzzified variables and understand the distribution of frequencies of average air temperature and relative air humidity, we used 5 intervals: 0-0.2, 0.2-0.4, 0.4-0.6, 0.6-0.8, and 0.8-1.0, respectively ranging from unfit (0) to fit (1).

The Fuzzy *Gamma* operator was applied using the fuzzified images of average air temperature and relative humidity favorable to downy mildew incidence in hop cultivation in the state of Santa Catarina, Brazil (Câmara *et al.*, 2004; Meirelles, 1997).

The Fuzzy *Gamma* operator includes the product between the Fuzzy algebraic sum and Fuzzy product (Equation 4). In the equation, it is observed that the summation is raised to a weighting factor γ, and the product is raised to a complementary factor $1 - \gamma$. Downy mildew incidence favorability maps were generated with different *Gamma* values: 0.10; 0.20; 0.30; 0.40; 0.50; 0.60; 0.70; 0.80, and 0.90.

$$\mu(x) = \{1 - \prod_{i=1}^{n}(1 - \mu_i)\}^{\gamma} * \{\prod_{i=1}^{n}\mu_i\}^{1-\gamma} \quad \text{(Equation 4)}$$

Where μ_i are the Fuzzy association values for i= 1,2, 3,...,5; n corresponds to the layer of matrix data, i.e., the number of variables in the study; γ is the coefficient with values between 0 and 1.

The Fuzzy *Gamma* allows combining the increasing effect of the Fuzzy Sum and the decreasing effect of the Fuzzy Product, and it does not simply return the value of a single Fuzzy set (Meirelles, 1997).

2.2.4 Climate favorability for downy mildew (*Pseudoperonospora humuli*) occurrence in hops (*Humulus lupulus* L.) using conventional and Fuzzy logic approaches for the state of Santa Catarina, Brazil.

After obtaining the raster images representing climate favorability for downy mildew incidence, these were converted to polygonal vector format, followed by applying the "polygonal dissolution" function due to the high number of polygons obtained after the conversion process. Thus, a new vector image with attribute table containing the incidence classes named low risk, moderate, and high risk was obtained. In the attribute table of the dissolved polygonal vector image, two fields were created, with real data types, named area and percentage. In the editing state, the "geometric calculation" function was used to compute the areas (km²) and perimeters (km) of the favorability classes. Finally, using the "field calculator" function, the percentage of favorability classes for downy mildew incidence in hop cultivation was calculated.

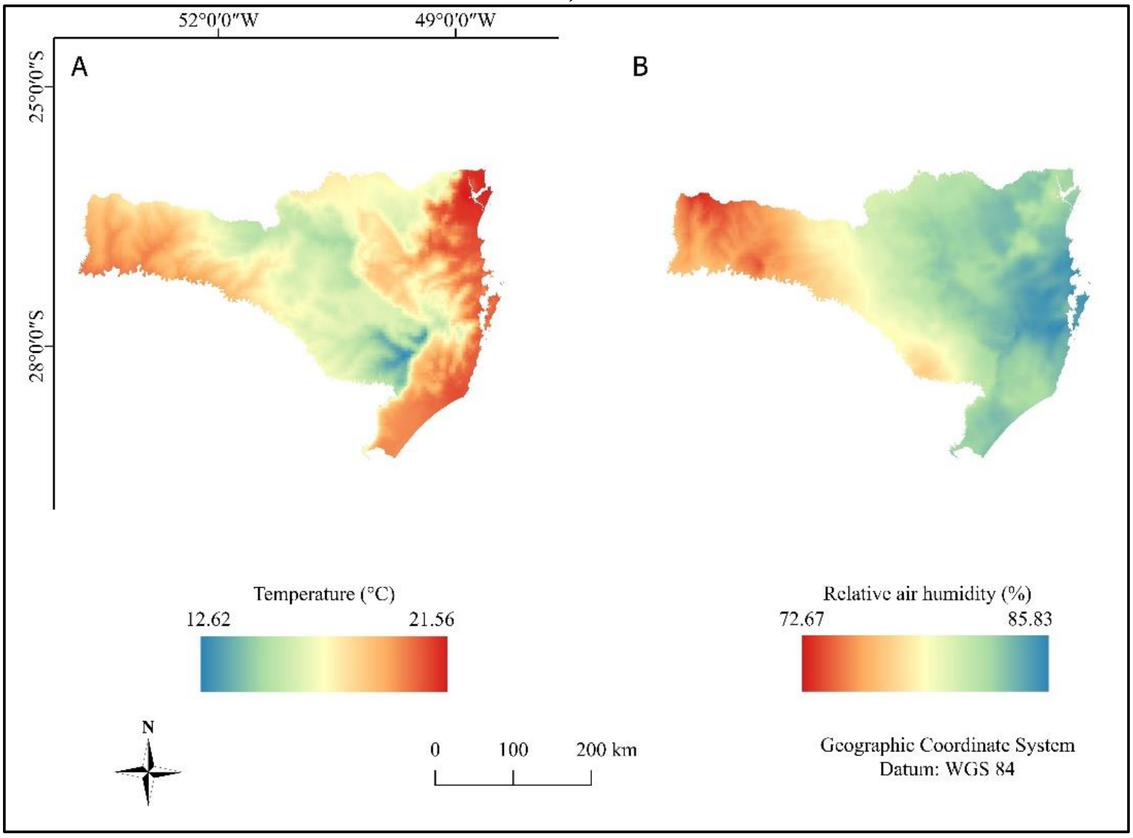
Finally, the "intersection" function was applied to the polygon vector images of the municipalities and the favorability for downy mildew incidence in hop cultivation, generating a single polygon vector image representative of the climatic favorability through Fuzzy logic for downy mildew incidence in hop cultivation for the municipalities of the state of Santa Catarina, Brazil.

3 RESULTS

The state of Santa Catarina has annual average minimum and maximum temperatures ranging from 12.62°C to 21.56°C. This thermal variation extends from the colder regions, typically located in the mountainous areas and in the Itajaí Valley, to the warmer areas situated in the north and along the coast of Santa Catarina (Figure 4A). In this figure, it can be observed that the colder zones are associated with areas of higher topographic elevation, which provide a milder climate and can affect the distribution of diseases related to humidity and temperature.

In Figure 4b, the humidity map shows that most of the state has a high level of relative air humidity, ranging between 72.67% and 85.83%. This map highlights the coastal regions and areas adjacent to the east as the most humid, reflecting an environment that, while beneficial for agriculture, also favors the occurrence of pathogens such as mildew.

Figure 4 - Spatial distribution of average air temperature and average relative air humidity for the state of Santa Catarina, Brazil.



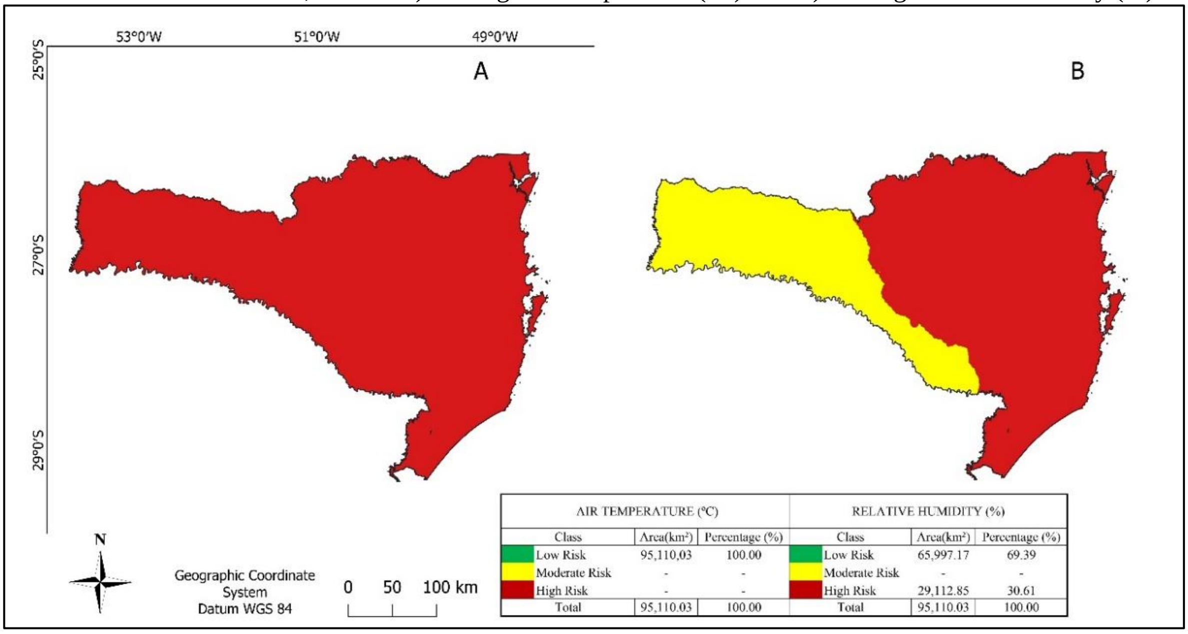
Source: Author's work

3.1. Spatial distribution of conventional climatic favorability for the occurrence of downy mildew in hops cultivation in the state of Santa Catarina, Brazil.

The conventional climatic favorability classes for the variables of temperature and relative humidity regarding the incidence of downy mildew in hop cultivation in the state of Santa Catarina are presented in Figure 5. In Figure 5A, related to temperature, a high-risk condition for the incidence of downy mildew is observed throughout the entire state. This homogeneous representation suggests that the climate across the mapped area provides ideal conditions for the development of the disease, which may require rigorous control and prevention measures by farmers and authorities.

A more detailed differentiation of risk concerning relative humidity is presented in Figure 5B. While the majority of the state is still categorized as high risk (69.39%), there is a significant band in the center, cutting across the territory from east to west, indicating a zone of moderate risk (30.61%). This area may reflect a slightly less favorable climate for downy mildew, which could be due to factors such as lower humidity or slightly higher temperatures that do not favor the pathogen as much.

Figure 5 - Conventional climatic favorability classes for the occurrence of downy mildew in hop cultivation in the state of Santa Catarina, Brazil. A) Average air temperature (°C) and B) Average relative humidity (%).



Source: Author's work

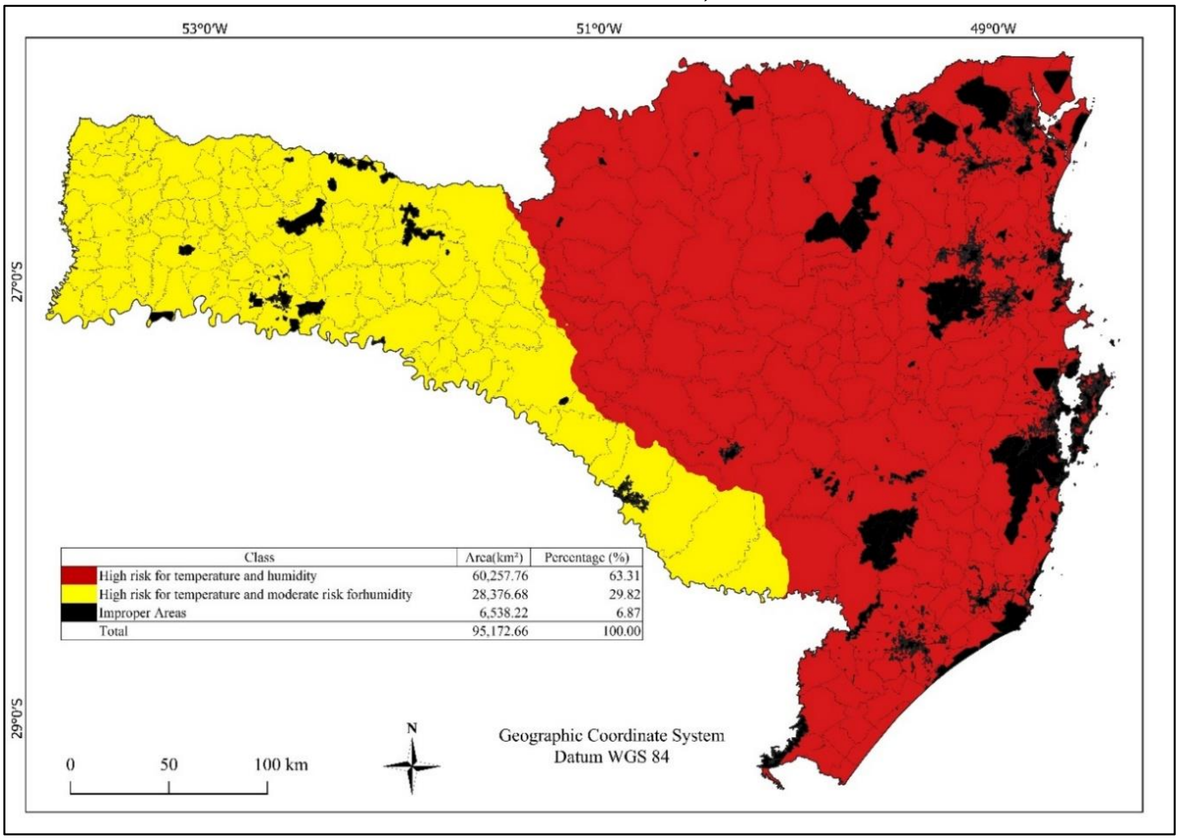
The spatial distribution of conventional climatic favorability for the incidence of downy mildew in hop cultivation in the state of Santa Catarina is presented in Figure 6. According to the results, 63.31% of the state's area (60,257.76 km²) shows high-risk favorability for temperature and humidity, while 29.82% (28,376.68 km²) shows high-risk favorability for temperature and moderate risk for humidity.

The high-risk favorability class for temperature and humidity (Figure 6) is predominantly spatialized in the eastern portion of the state of Santa Catarina, covering extensive areas from the coast to the interior.

This vast geographic expanse indicates that the climatic conditions are highly conducive to downy mildew development in hop cultivation.

On the other hand, the class representing high risk for temperature and moderate risk for humidity is centrally located, forming a corridor that extends from the western border to the central region of the state. This area can be interpreted as a transition zone, where the reclassification of variables indicates an environment less favorable to mildew, although the risk remains significant. The reclassification of meteorological variables represented by average air temperature and average relative humidity highlights a significant climatic differentiation between regions, emphasizing the need for differentiated agricultural management strategies for each identified risk zone.

Figure 6 - Spatialization of conventional climatic favorability for downy mildew occurrence in hop cultivation in the state of Santa Catarina, Brazil.



Source: Author's work

Through spatialization of conventional climatic favorability for downy mildew incidence in hop cultivation in the state of Santa Catarina, it was identified that 79 municipalities are classified as high-risk for temperature and humidity. Furthermore, 82 municipalities were classified as high-risk for temperature and moderate risk for humidity.

In Table 4, 10 municipalities stand out with high risk for temperature and humidity. For a detailed breakdown of all evaluated municipalities, the information can be accessed in the Appendix (Supplementary Table 3).

Table 3 – Area and Percentage of favorability classes for downy mildew occurrence in hop cultivation for municipalities in the state of Santa Catarina, Brazil using a conventional approach.

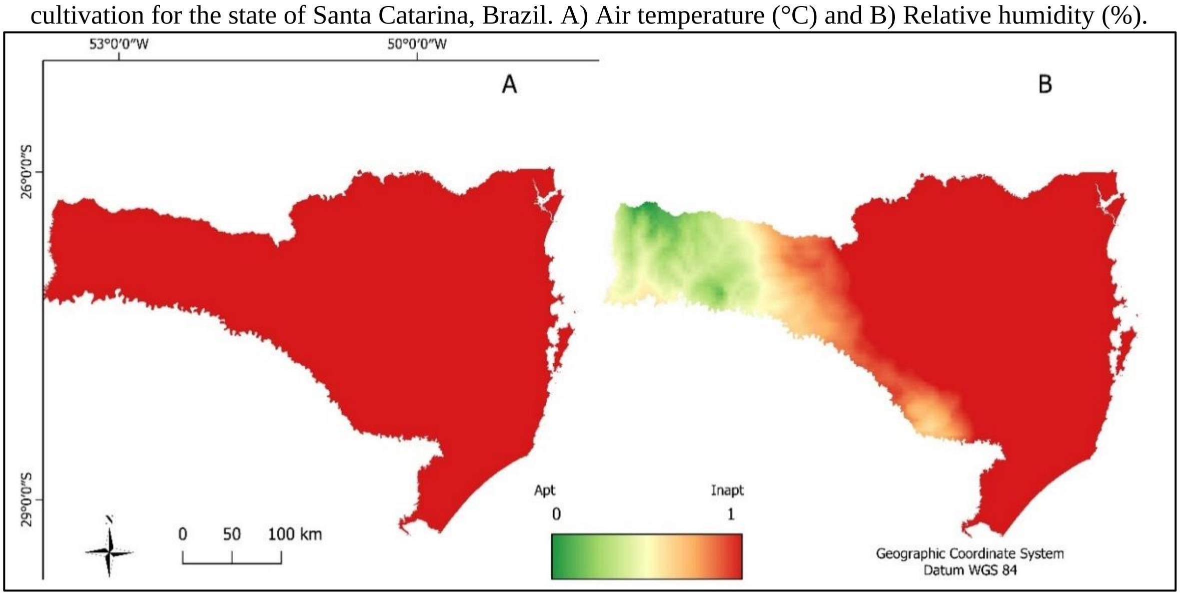
	Classes	Municipalities									
		Santa Cecília	Curitibanos	São José do Cerrido	Lebon Régis	Otacílio Costa	Papanduva	Taió	Correia Pinto	Calmon	Timbó Grande
Area km²	High risk for temperature and humidity	1,151.14	952.83	946.65	936.15	845.09	763.81	692.36	649.50	637.30	595.31
	High risk for temperature and moderate risk for humidity	-	-	-	-	-	-	-	-	-	-
	Improper areas	-	-	-	-	-	-	-	-	-	-
	Total	1,151.14	952.83	946.65	936.15	845.09	763.81	692.36	649.50	637.30	595.31
Percentage %	High risk for temperature and humidity	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
	High risk for temperature and moderate risk for humidity	-	-	-	-	-	-	-	-	-	-
	Improper areas	-	-	-	-	-	-	-	-	-	-
	Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Source: Author's work.

3.2 Spatialization of climatic favorability using Fuzzy logic for downy mildew occurrence in hops cultivation for municipalities in Santa Catarina, Brazil.

The raster images of temperature and humidity variables were reclassified using Fuzzy membership functions (Figure 7). As seen in Figure 7A, regarding air temperature, the entire state shows high risk for downy mildew incidence. Regarding humidity (Figure 7B), the figure shows a differentiation between high and moderate risk classes. The fuzzification of these meteorological variables provides a more detailed view of the potential risk of mildew across the entire territory of Santa Catarina.

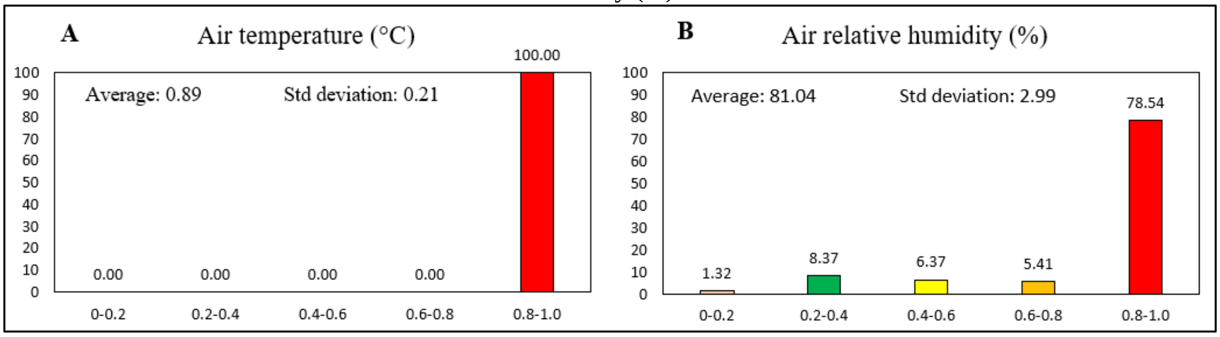
Figure 7 - Fuzzification of meteorological variables using Fuzzy logic for downy mildew occurrence in hop cultivation for the state of Santa Catarina, Brazil. A) Air temperature (°C) and B) Relative humidity (%).



Source: Author's work

The Fuzzy frequency distribution of meteorological variables related to downy mildew incidence in hop cultivation for the state of Santa Catarina, Brazil, is presented in Figure 8. Due to the climatic conditions in the state of Santa Catarina, there is a single frequency distribution class of 0.89 to 1.0 (high risk), represented by 100% of the pixel distribution with a mean and standard deviation of 0.89 and 0.21, respectively (Figure 8A). As for the average relative air humidity (Figure 8B), it is represented across all classes, with 78.54% of the pixel distribution relating to the high-risk class ranging from 0.8 to 1.0.

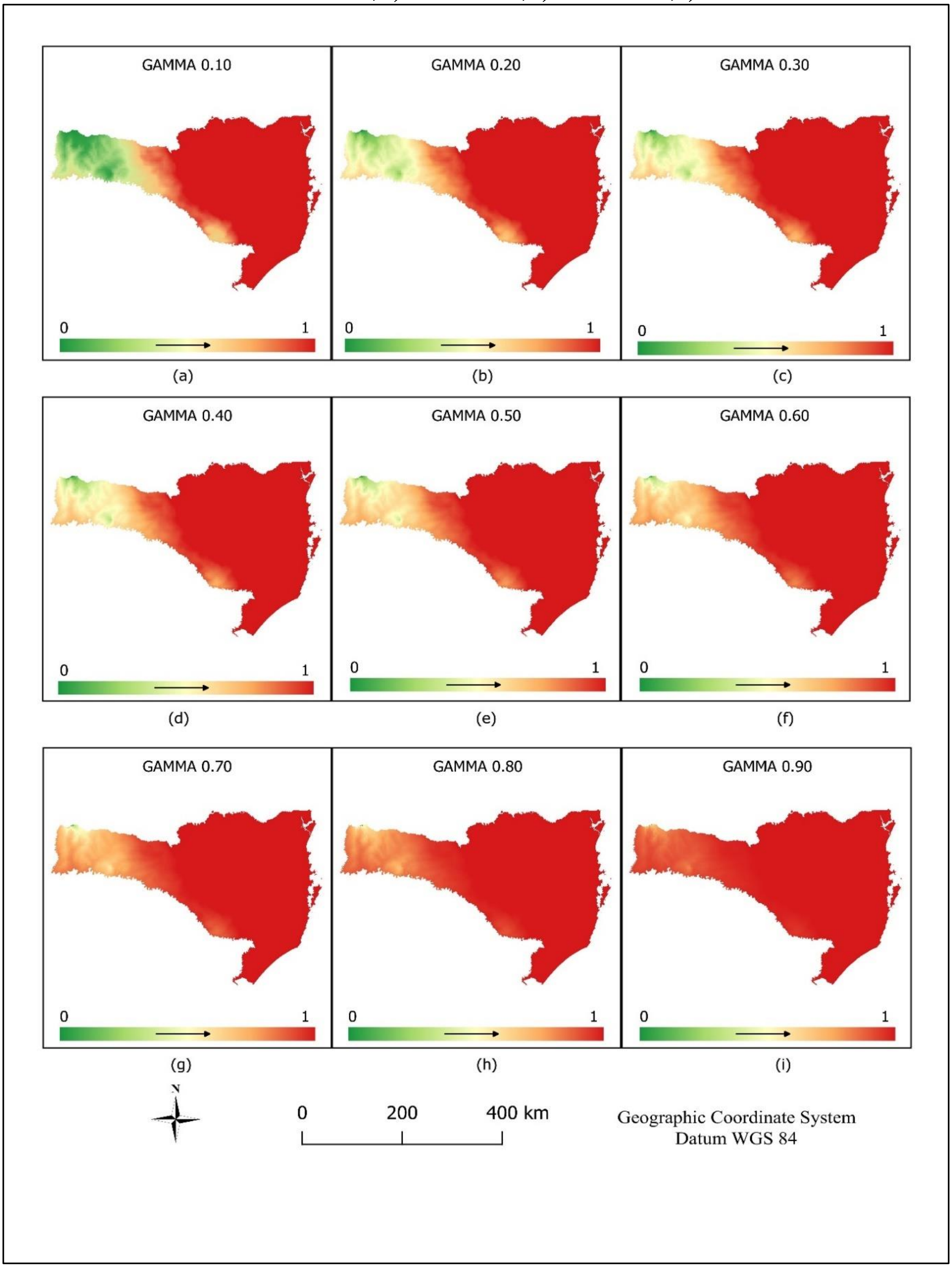
Figure 8 - Fuzzy frequency distribution of meteorological variables related to downy mildew occurrence in hop cultivation for the state of Santa Catarina, Brazil. A) Average air temperature (°C) and B) Average relative humidity (%).



Source: Author's work

The downy mildew incidence favorability maps were generated with different *Gamma* values: 0.10; 0.20; 0.30; 0.40; 0.50; 0.60; 0.70; 0.80, and 0.90. In pursuit of better results, *Gamma* values ranging from 0.1 to 0.9 were tested, with the *Gamma* operator of 0.9 proving to be the most effective. It resulted in clearer and more realistic transitions between areas, translating into a more preventive scenario for *Pseudoperonospora humuli* incidence in hops in the state of Santa Catarina. Conversely, *Gamma* 0.1 portrays an optimistic scenario for mildew incidence (Figure 9).

Figure 9 - Fuzzy overlay of meteorological variables for downy mildew occurrence in hop cultivation for the state of Santa Catarina, Brazil, considering different *Gamma* operators. a) *Gamma* = 0.1; b) *Gamma* = 0.2; c) *Gamma* = 0.3; d) *Gamma* = 0.4; e) *Gamma* = 0.5; f)

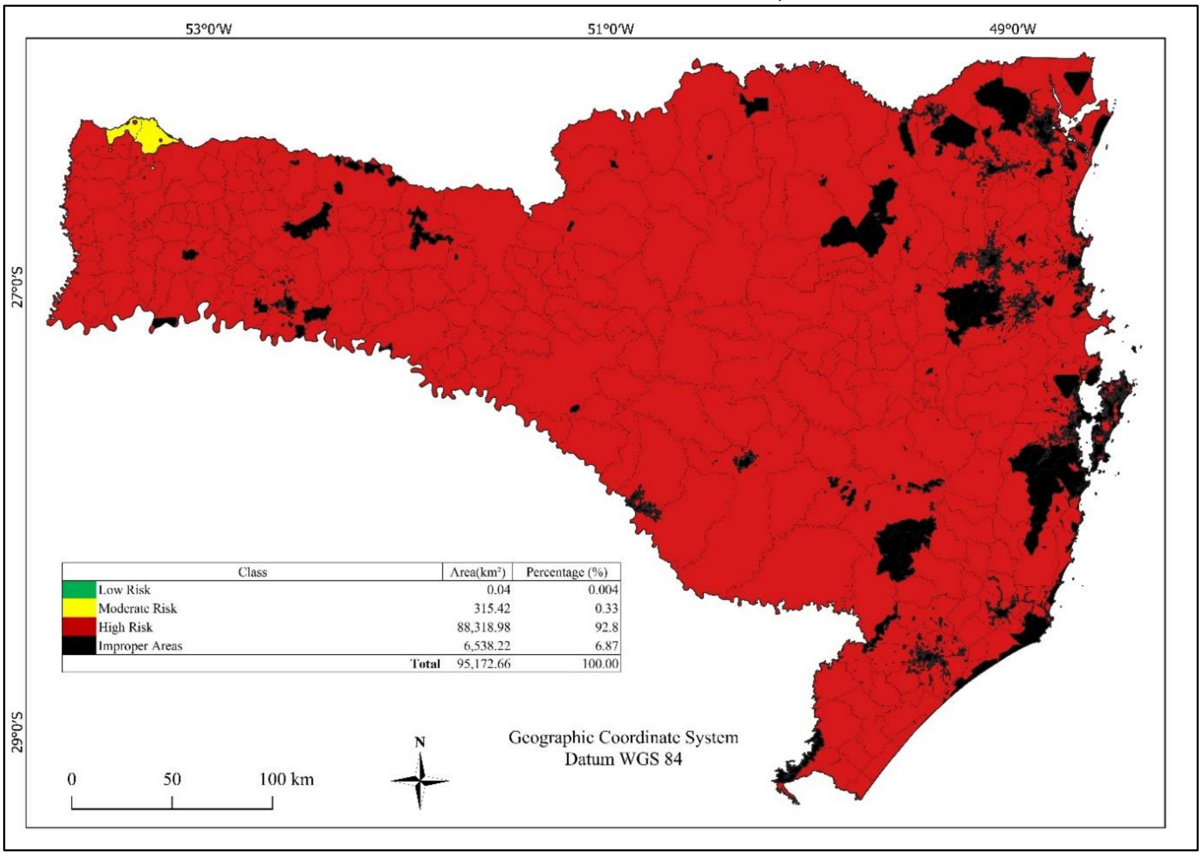


Source: Author's work

After analyzing and comparing the results obtained with the different *Gamma* operators used, it was found to be consistent with existing literature that highlights the effectiveness of this operator. Santos and Lobão (2017), in their research on environmental vulnerability modeling, and Silva Jr *et al.* (2016), in their studies on susceptibility in Maranhão, reported positive results when applying *Gamma* operators of 0.9. The *Gamma* operator 0.9 was also chosen in this study aiming at the spatialization of climatic favorability using Fuzzy logic for downy mildew incidence in hop cultivation in the state of Santa Catarina, Brazil. The spatialization of climatic favorability using Fuzzy logic for downy mildew incidence in hop cultivation in the state of Santa Catarina, Brazil, is presented in Figure 10. According to the results, 0.001% (0.04 km²), 0.33% (315.42 km²), 92.8% (88,318.98 km²), and 6.87% (6,538.22 km²) are represented by the classes low risk, moderate risk, high risk, and unsuitable areas, respectively.

The spatialized data highlight the predominance of the high-risk class for downy mildew incidence in hop cultivation in Santa Catarina, covering most of the state. The impact of this risk class is significant, as it signals potential negative economic impacts on hop productivity and quality.

Figure 10 - Spatialization of climatic favorability using Fuzzy logic for downy mildew occurrence in hop cultivation for the state of Santa Catarina, Brazil.



Source: Author's work

Through the spatialization of climatic favorability using Fuzzy logic for downy mildew incidence in hop cultivation in the state of Santa Catarina, all 295 municipalities have areas classified as high risk, ranging from 100% to 24.4%. In Table 4, 10 municipalities with high risk were selected. Detailed information about all evaluated municipalities can be found in the Appendix (Supplementary Table 4).

Table 4 – Area and Percentage of favorability classes for downy mildew occurrence in hop cultivation for municipalities in the state of Santa Catarina, Brazil using Fuzzy logic.

	Classes	Municipalities									
		São Joaquim	Água Doce	Santa Cecília	Curitibanos	São José do Cerrido	Lebon Régis	Otacílio Costa	Papanduva	Taió	Correia Pinto
Area km^2	High risk	1,881,76	1.309.62	1.151.14	952.83	946.65	936.15	845.09	763.80	692.36	649.50
	Moderate risk	-	-	-	-	-	-	-	-	-	-
	Low risk	-	-	-	-	-	-	-	-	-	-
	Improper areas	-	-	-	-	-	-	-	-	-	-
	Total	1,881,76	1.309.62	1.151.14	952.83	946.65	936.15	845.09	763.80	692.36	649.50
Percentage %	High risk	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
	Moderate risk	-	-	-	-	-	-	-	-	-	-
	Low risk	-	-	-	-	-	-	-	-	-	-
	Improper areas	-	-	-	-	-	-	-	-	-	-
	Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Source: Author's work

4 DISCUSSION

Downy mildew is the most important disease of hops, causing production losses and quality issues, depending on the hop variety (O'Neal *et al.*, 2015; Purayannur *et al.*, 2020). The favorable conditions described in the literature highlight moderate temperatures and high relative humidity (Purayannur *et al.*, 2021; Royle, 1970b, 1973).

Regarding relative air humidity, it was possible to observe that in places close to the Atlantic Ocean, the values are very high compared to other inland locations, which highlights the strong influence of continentality in the studied region (Thomé, 2022). Similarly, Gent and Ocamb (2009) noted that in the coastal region of western Oregon, the infection risk is strongly related to temperature and relative humidity conditions.

The favorable conditions for mildew pose considerable challenges to cultural management in hop cultivation, including techniques such as pruning, which is directly related to disease severity (Gent *et al.*, 2012). The use of fungicides in combination has been a recommended practice (Dušek *et al.*, 2020b; Gent *et al.*, 2015). However, in Brazil, the absence of pesticides registered specifically for hop cultivation (MAPA, 2024) complicates decision-making for rural producers. In addition to this issue, there is the resistance of *P. humuli* to certain fungicides, as indicated by studies conducted in regions of the United States by Gent, Block, and Claassen (2020) and Gent, Nelson, and Grove (2008), as well as research in Wisconsin by Marks and Gevens (2019), and in Michigan by Higgins, Miles, and Hausbeck

(2021). These findings underscore the need for integrated and innovative approaches for effective disease control in hop cultivation.

Thus, the search for hop varieties resistant to mildew becomes crucial (Higgins, Douglas; Hausbeck, 2021; Rutto *et al.*, 2021; Woods; Gent, 2016). Currently, Brazil has 17 nurseries certified by the Ministry of Agriculture, Livestock and Supply, with Cascade, Chinook, and Columbus varieties being the most cultivated (Gomes *et al.*, 2022). However, these varieties are susceptible to mildew, and the Brazilian market offers few options of resistant varieties. Resistant or moderately resistant varieties, such as *Hallertauer Magnum* and Fuggle (Dodds, 2017), represent important alternatives for diversifying and strengthening hop cultivation in the country.

In this context, the spatialization of climatic favorability for downy mildew occurrence, using the conventional approach, indicated that 63.13% of Santa Catarina's territory has favorable conditions for the disease, whereas the Fuzzy approach identified that areas with high risk represent 92.80% of the state, demonstrating a widespread vulnerability to mildew development. The conventional methodology provides specific information on which variable has the greatest influence, while the Fuzzy approach allows for a more integrated understanding of risk conditions through a continuous transition between favorability classes.

5 CONCLUSION

Downy mildew is the most destructive disease in hop cultivation, with mild temperatures and high humidity favoring its occurrence. The spatial analysis of climatic favorability, conducted using both conventional approaches and Fuzzy logic, highlighted the extent of the favorable area for disease occurrence, with the Fuzzy approach further emphasizing the prevalence of these conditions. This highlights the importance of effective management strategies, such as pruning and fungicide application, as well as the ongoing development of mildew-resistant cultivars.

Additionally, it was found that approximately 63.31% of Santa Catarina's territory is categorized as high risk for the thermal and humidity conditions that favor downy mildew occurrence. Furthermore, 29.82% of the area exhibits high thermal risk combined with moderate humidity, constituting an intermediate alert zone.

The dominant presence of high-risk zones, especially in the eastern region, directs attention to the need for an agricultural management regime that addresses local climatic specificities. Adapting mildew management approaches according to regionalized risk classification can optimize the effectiveness of interventions, minimizing the impacts of this disease and ensuring the viability of hop production in the state.

Furthermore, the research highlights the need for an integrated approach that takes into account not only local climatic conditions but also plant genetic resistance and sustainable agricultural practices. These conclusions provide valuable insights for hop producers in Santa Catarina, helping to guide their cultivation and management decisions to mitigate the impacts of mildew and ensure sustainable production in the state.

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APPENDICES

Complementary Table 1 - Percentage of classes in the Agroclimatic Zoning for hop using the Conventional approach for municipalities in the state of Santa Catarina, Brazil.

(continued)

Municipalities	Percentage %								
	A	ARET	AREP	RCTEP	RETP	IEPAT	IEPRET	AI	Total
Abdon Batista	-	-	1.00	-	-	-	-	-	100.00
Abelardo Luz	-	-	0.13	-	-	0.76		0.11	100.00
Agrolândia	-	-	1.00	-	-	-	-	-	100.00
Agronômica	-	-	1.00	-	-	-	-	-	100.00
Água Doce	-	-	1.00	-	-	-	-	-	100.00
Águas de Chapecó	-	-	-	-	1.00	-	-	-	100.00
Águas Frias	-	-	-	-	0.04	-	0.96	-	100.00
Águas Mornas	-	-	0.70	-	0.08	-	-	0.23	100.00
Alfredo Wagner	-	-	0.98	0.02	-	-	-	-	100.00
Alto Bela Vista	-	-	0.46	-	0.54	-	-	-	100.00
Anchieta	-	-	-	-	0.11	0.74	0.14	-	100.00
Angelina	-	-	1.00	-	-	-	-	-	100.00
Anita Garibaldi	-	-	1.00	-	-	-	-	-	100.00
Anitápolis	-	-	1.00	-	-	-	-	-	100.00
Antônio Carlos	-	-	0.38	-	0.61	-	-	0.01	100.00
Apiúna	-	-	0.53		0.26			0.21	100.00
Arabutã	-	-	0.67		0.13	0.20	-	-	100.00
Araquari	-	-	-	-	0.81	-	-	0.19	100.00
Araranguá	-	1.00	-	-	-	-	-	-	100.00
Armazém	-	0.71	-	-	0.29	-	-	-	100.00
Arroio Trinta	-	-	1.00	-	-	-	-	-	100.00
Arvoredo	-	-	-	-	-	0.73	0.19	0.08	100.00
Ascurra	-	-	0.10	-	0.90	-	-	-	100.00
Atalanta	-	-	1.00	-	-	-	-	-	100.00
Aurora	-	-	1.00	-	-	-	-	-	100.00
Balneário Arroio do Silva	-	1.00	-	-	-	-	-	-	100.00

Where A=Apt, ARET= Apt with thermal excess restriction, AREP= Apt with rain excess restriction, RCTEP= Restriction due to thermal deficiency and rain excess, RETP= Restriction due to thermal and rain excess, IEPAT= Inapt due to rain excess and suitable due to temperature, IEPRET= Inapt due to rain excess and restriction due to thermal excess, I= Inapt, AI= Improper Area.

Complementary Table 1 - Percentage of classes in the Agroclimatic Zoning for hop using the Conventional approach for municipalities in the state of Santa Catarina, Brazil.

(continuation)

Municipalities	Percentage%								
	A	ARET	AREP	RCTEP	RETP	IEPAT	IEPRET	AI	Total
Balneário Barra do Sul	-	-	-	-	0.77	-	-	0.23	100.00
Balneário Cambouriú	-	-	-	-	0.69	-	-	0.31	100.00
Balneário Gaivota	-	1.00	-	-	-	-	-	-	100.00
Balneário Piçaras	-	-	-	-	0.92	-	-	0.08	100.00
Balneário Rincão	-	0.63	-	-	-	-	-	0.37	100.00
Bandeirante	-	-	-	-	1.00	-	-	-	100.00
Barra Bonita	-	-	-	-	1.00	-	-	-	100.00
Barra Velha	-	-	-	-	0.91	-	-	0.09	100.00
Bela Vista do Toldo	0.33	-	0.67	-	-	-	-	0.01	100.00
Belmonte	-	-	-	-	1.00	-	-	-	100.00
Benedito Novo	-	-	0.83	-	0.14	-	-	0.03	100.00
Biguaçu	-	-	0.07	-	0.57	-	-	0.36	100.00
Blumenau	-	-	0.01	-	0.64	-	-	0.35	100.00
Bocaina do Sul	-	-	0.95	0.04	-	-	-	0.01	100.00
Bom Jardim da Serra	-	-	0.21	0.55	-	-	-	0.24	100.00
Bom Jesus	-	-	-	-	-	0.99	-	0.01	100.00
Bom Jesus do Oeste	-	-	-	-	-	1.00	-	-	100.00
Bom Retiro	-	-	0.84	0.12	-	-	-	0.04	100.00
Bombinhas	-	-	-	-	1.00	-	-	-	100.00
Botuverá	-	-	0.56	-	0.23	-	-	0.21	100.00
Braço do Norte	-	0.79	0.03	-	0.18	-	-	-	100.00
Braço do Trombudo	-	-	1.00	-	-	-	-	-	100.00
Brunópolis	-	-	1.00	-	-	-	-	-	100.00
Brusque	-	-	0.05	-	0.76	-	-	0.19	100.00
Caçador	-	-	0.99	-	-	-	-	0.01	100.00
Caibi	-	-	-	-	0.85	-	0.15	-	100.00
Calmon	-	-	1.00	-	-	-	-	-	100.00
Camboriú	-	-	0.03	-	0.91	-	-	0.06	100.00
Campo Alegre	0.02	-	0.98	-	-	-	-	-	100.00

Where A=Apt, ARET= Apt with thermal excess restriction, AREP= Apt with rain excess restriction, RCTEP= Restriction due to thermal deficiency and rain excess, RETP= Restriction due to thermal and rain excess, IEPAT= Inapt due to rain excess and suitable due to temperature, IEPRET= Inapt due to rain excess and restriction due to thermal excess, I= Inapt, AI= Improper Area.

Complementary Table 1 - Percentage of classes in the Agroclimatic Zoning for hop using the Conventional approach for municipalities in the state of Santa Catarina, Brazil.

(continuation)

Municipalities	Percentage%								
	A	ARET	AREP	RCTEP	RETP	IEPAT	IEPRET	AI	Total
Campo Belo do Sul	0.33	-	0.62	-	-	-	-	0.05	100.00
Campo Erê	-	-	-	-	-	1.00	-		100.00
Campos Novos	-	-	0.99	-	-	-	-	0.01	100.00
Canelinha	-	-	0.05	-	0.95	-	-	-	100.00
Canoinhas	0.56	-	0.44	-	-	-	-	-	100.00
Capão Alto	0.91	-	0.07	-	-	-	-	0.01	100.00
Capinzal	-	-	1.00	-	-	-	-	-	100.00
Capivari de Baixo	-	0.85	-	-	-	-	-	0.15	100.00
Catanduvas	-	-	1.00	-	-	-	-	-	100.00
Caxambu do Sul	-	-	-	-	1.00	-	-	-	100.00
Celso Ramos	-	-	1.00	-	-	-	-	-	100.00
Cerro Negro	-	-	1.00	-	-	-	-	-	100.00
Chapadão do Lageado	-	-	1.00	-	-	-	-	-	100.00
Chapecó	-	-	0.06	-	0.20	0.34	0.26	0.15	100.00
Cocal do Sul	-	0.93	-	-	-	-	-	0.07	100.00
Concórdia	-	-	0.78	-	0.21	-	-	0.01	100.00
Cordilheira Alta	-	-	-	-	-	0.84	0.14	0.02	100.00
Coronel Freitas	-	-	-	-	0.03	0.04	0.93	-	100.00
Coronel Martins	-	-	-	-	-	0.99	0.01	-	100.00
Correia Pinto	0.41	-	0.59	-	-	-	-	-	100.00
Corupá	-	-	0.51	-	0.45	-	-	0.04	100.00
Criciúma	-	0.78	-	-	-	-	-	0.22	100.00
Cunha Porã	-	-	-	-	0.04	0.05	0.87	0.05	100.00
Cunhataí	-	-	-	-	0.11	-	0.89	-	100.00
Curitibanos	-	-	1.00	-	-	-	-	-	100.00
Descanso	-	-	0.01	-	0.99	-	-	-	100.00
Dionísio Cerqueira	-	-	0.40	-	-	0.60	-	-	100.00
Dona Emma	-	-	1.00	-	-	-	-	-	100.00
Doutor Pedrinho	-	-	0.87	-	-	-	-	0.13	100.00

Where A=Apt, ARET= Apt with thermal excess restriction, AREP= Apt with rain excess restriction, RCTEP= Restriction due to thermal deficiency and rain excess, RETP= Restriction due to thermal and rain excess, IEPAT= Inapt due to rain excess and suitable due to temperature, IEPRET= Inapt due to rain excess and restriction due to thermal excess, I= Inapt, AI= Improper Area.

Complementary Table 1 - Percentage of classes in the Agroclimatic Zoning for hop using the Conventional approach for municipalities in the state of Santa Catarina, Brazil.

(continuation)

Municipalities	Percentage%								
	A	ARET	AREP	RCTEP	RETP	IEPAT	IEPRET	AI	Total
Entre Rios	-	-	-	-	-	0.18	0.26	0.56	100.00
Ermo	-	1.00	-	-	-	-	-	-	100.00
Erval Velho	-	-	1.00	-	-	-	-	-	100.00
Faxinal dos Guedes	-	-	-	-	-	1.00	-	-	100.00
Flor do Sertão	-	-	-	-	0.31	-	0.69	-	100.00
Florianópolis	-	-	-	-	0.41	-	-	0.59	100.00
Formosa do Sul	-	-	-	-	-	0.90	0.10	-	100.00
Forquilhinha	-	0.96	-	-	-	-	-	0.04	100.00
Fraiburgo	-	-	1.00	-	-	-	-	-	100.00
Frei Rogério	-	-	1.00	-	-	-	-	-	100.00
Galvão	-	-	-	-	-	0.99	-	0.01	100.00
Garopaba	-	-	-	-	0.83	-	-	0.17	100.00
Garuva	-	-	0.29	-	0.67	-	-	0.04	100.00
Gaspar	-	-	-	-	0.93	-	-	0.07	100.00
Governador Celso Ramos	-	-	-	-	0.73	-	-	0.27	100.00
Grão Pará	0.22	0.45	0.18	-	-	-	-	0.16	100.00
Gravatal	-	0.92	-	-	0.06	-	-	0.02	100.00
Guabiruba	-	-	-	-	0.63	-	-	0.37	100.00
Guaraciaba	-	-	0.38	-	0.62	-	-	-	100.00
Guaramirim	-	-	-	-	0.96	-	-	0.04	100.00
Guarujá do Sul	-	-	0.38	-	0.04	0.58	-	-	100.00
Guatambu	-	-	-	-	0.66	0.13	0.08	0.13	100.00
Herval d'Oeste	-	-	1.00	-	-	-	-	-	100.00
Ibiam	-	-	1.00	-	-	-	-	-	100.00
Ibicaré	-	-	1.00	-	-	-	-	-	100.00
Ibirama	-	-	0.56	-	0.44	-	-	0.00	100.00
Içara	-	0.94	-	-	-	-	-	0.06	100.00
Ilhota	-	-	-	-	0.93	-	-	0.07	100.00
Imaruí	-	0.38	0.02	-	0.46	-	-	0.14	100.00

Where A=Apt, ARET= Apt with thermal excess restriction, AREP= Apt with rain excess restriction, RCTEP= Restriction due to thermal deficiency and rain excess, RETP= Restriction due to thermal and rain excess, IEPAT= Inapt due to rain excess and suitable due to temperature, IEPRET= Inapt due to rain excess and restriction due to thermal excess, I= Inapt, AI= Improper Area.

Complementary Table 1 - Percentage of classes in the Agroclimatic Zoning for hop using the Conventional approach for municipalities in the state of Santa Catarina, Brazil.

(continuation)

Municipalities	Percentage%								
	A	ARET	AREP	RCTEP	RETP	IEPAT	IEPRET	AI	Total
Imbituba	-	0.31	-	-	0.56	-	-	0.12	100.00
Imbuia	-	-	1.00	-	-	-	-	-	100.00
Indaial	-	-	0.04	-	0.50	-	-	0.47	100.00
Iomerê	-	-	1.00	-	-	-	-	-	100.00
Ipira	-	-	1.00	-	-	-	-	-	100.00
Iporã do Oeste	-	-	-	-	1.00	-	-	-	100.00
Ipuaçu	-	-	-	-	-	0.60	-	0.40	100.00
Ipumirim	-	-	0.31	-	-	0.69	-	-	100.00
Iraceminha	-	-	-	-	0.59	-	0.41	-	100.00
Irani	-	-	1.00	-	-	-	-	-	100.00
Irati	-	-	-	-	-	0.75	0.25	-	100.00
Irineópolis	0.01		0.99	-	-	-	-	-	100.00
Itá	-	-	-	-	0.81		0.19		100.00
Itaiópolis	0.63		0.34	-	-	-	-	0.03	100.00
Itajaí	-	-	-	-	0.80	-	-	0.20	100.00
Itapema	-	-	-	-	0.58	-	-	0.42	100.00
Itapiranga	-	-	-	-	1.00	-	-	-	100.00
Itapoá	-	-	-	-	0.41	-	0.27	0.32	100.00
Ituporanga	-	-	1.00	-	-	-	-	-	100.00
Jaborá	-	-	1.00	-	-	-	-	-	100.00
Jacinto Machado	0.15	0.69	0.09	-	-	-	-	0.07	100.00
Jaguaruna	-	0.67	-	-	-	-	-	0.33	100.00
Jaraguá do Sul	-	-	0.16	-	0.75	-	-	0.09	100.00
Jardinópolis	-	-	-	-	-	0.17	0.83	-	100.00
Joaçaba	-	-	1.00	-	-	-	-	-	100.00
Joinville	-	-	0.12	-	0.40	-	-	0.49	100.00
José Boiteux	-	-	0.64	-	0.00	-	-	0.36	100.00
Jupiá	-	-	-	-	-	1.00	-	-	100.00
Lacerdópolis	-	-	1.00	-	-	-	-	-	100.00

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Complementary Table 1 - Percentage of classes in the Agroclimatic Zoning for hop using the Conventional approach for municipalities in the state of Santa Catarina, Brazil.

(continuation)

Municipalities	Percentage%								
	A	ARET	AREP	RCTEP	RETP	IEPAT	IEPRET	AI	Total
Lageado Grande	-	-	-	-	-	0.80	0.20	-	100.00
Lages	0.92	-	0.06	-	-	-	-	0.02	100.00
Laguna	-	0.44	-	-	-	-	-	0.56	100.00
Laurentino	-	-	1.00	-	-	-	-	-	100.00
Lauro Müller	0.34	0.42	0.18	-	-	-	-	0.06	100.00
Lebon Régis	-	-	0.99	0.01	-	-	-	-	100.00
Leoberto Leal	-	-	1.00	-	-	-	-	-	100.00
Lindóia do Sul	-	-	0.83	-	-	0.17	-	-	100.00
Lontras	-	-	0.97	-	0.03	-	-	-	100.00
Luiz Alves	-	-	-	-	1.00	-	-	-	100.00
Luzerna	-	-	1.00	-	-	-	-	-	100.00
Macieira	-	-	1.00	-	-	-	-	-	100.00
Mafra	0.98	-	0.02	-	-	-	-	-	100.00
Major Gercino	-	-	0.79	-	0.21	-	-	-	100.00
Major Vieira	0.20	-	0.80	-	-	-	-	-	100.00
Maracajá	-	1.00	-	-	-	-	-	-	100.00
Maravilha	-	-	-	-	-	0.51	0.49	-	100.00
Marema	-	-	-	-	-	0.03	0.96	-	100.00
Massaranduba	-	-	-	-	1.00	-	-	-	100.00
Matos Costa	-	-	1.00	-	-	-	-	-	100.00
Meleiro	-	1.00	-	-	-	-	-	-	100.00
Mirim Doce	-	-	1.00	-	-	-	-	-	100.00
Modelo	-	-	-	-	-	0.05	0.95	-	100.00
Mondaí	-	-	-	-	1.00	-	-	-	100.00
Monte Carlo	-	-	1.00	-	-	-	-	-	100.00
Monte Castelo	0.07	-	0.93	-	-	-	-	-	100.00
Morro da Fumaça	-	0.94	-	-	-	-	-	0.06	100.00
Morro Grande	0.28	0.45	0.26	-	-	-	-	0.01	100.00
Navegantes	-	-	-	-	0.83	-	-	0.17	100.00

Where A=Apt, ARET= Apt with thermal excess restriction, AREP= Apt with rain excess restriction, RCTEP= Restriction due to thermal deficiency and rain excess, RETP= Restriction due to thermal and rain excess, IEPAT= Inapt due to rain excess and suitable due to temperature, IEPRET= Inapt due to rain excess and restriction due to thermal excess, I= Inapt, AI= Improper Area.

Complementary Table 1 - Percentage of classes in the Agroclimatic Zoning for hop using the Conventional approach for municipalities in the state of Santa Catarina, Brazil.

(continuation)

Municipalities	Percentage%								
	A	ARET	AREP	RCTEP	RETP	IEPAT	IEPRET	AI	Total
Nova Erechim	-	-	-	-	0.52	-	0.48	-	100.00
Nova Itaberaba	-	-	-	-	0.19	-	0.81	-	100.00
Nova Trento	-	-	0.55	-	0.44	-	-	-	100.00
Nova Veneza	0.12	0.79	0.01	-	-	-	-	0.07	100.00
Novo Horizonte	-	-	-	-	-	1.00	-	-	100.00
Orleans	0.19	0.53	0.02	-	-	-	-	0.26	100.00
Otacílio Costa	-	-	1.00	-	-	-	-	-	100.00
Ouro	-	-	1.00	-	-	-	-	-	100.00
Ouro Verde	-	-	-	-	-	1.00	-	-	100.00
Paial	-	-	-	-	0.11	-	0.86	0.04	100.00
Painel	0.37	-	0.30	0.32	-	-	-	0.01	100.00
Palhoça	-	-	-	-	0.24	-	-	0.76	100.00
Palma Sola	-	-	0.02	-	0.03	0.94	-	-	100.00
Palmeira	0.07	-	0.93	-	-	-	-	-	100.00
Palmitos	-	-	-	-	0.75	-	0.14	0.12	100.00
Papanduva	0.65	-	0.35	-	-	-	-	-	100.00
Paraíso	-	-	-	-	1.00	-	-	-	100.00
Passo de Torres	-	1.00	-	-	-	-	-	-	100.00
Passos Maia	-	-	0.81	-	-	0.10	-	0.09	100.00
Paulo Lopes	-	-	0.01	-	0.37	-	-	0.62	100.00
Pedras Grandes	0.05	0.95	-	-	-	-	-	-	100.00
Penha	-	-	-	-	0.84	-	-	0.16	100.00
Peritiba	-	-	1.00	-	-	-	-	-	100.00
Pescaria Brava	-	0.97	-	-	-	-	-	0.03	100.00
Petrolândia	-	-	1.00	-	-	-	-	-	100.00
Pinhalzinho	-	-	-	-	-	-	1.00	-	100.00
Pinheiro Preto	-	-	1.00	-	-	-	-	-	100.00
Piratuba	-	-	1.00	-	-	-	-	-	100.00
Planalto Alegre	-	-	-	-	0.74	-	0.26	-	100.00

Where A=Apt, ARET= Apt with thermal excess restriction, AREP= Apt with rain excess restriction, RCTEP= Restriction due to thermal deficiency and rain excess, RETP= Restriction due to thermal and rain excess, IEPAT= Inapt due to rain excess and suitable due to temperature, IEPRET= Inapt due to rain excess and restriction due to thermal excess, I= Inapt, AI= Improper Area.

Complementary Table 1 - Percentage of classes in the Agroclimatic Zoning for hop using the Conventional approach for municipalities in the state of Santa Catarina, Brazil.

(continuation)

Municipalities	Percentage%								
	A	ARET	AREP	RCTEP	RETP	IEPAT	IEPRET	AI	Total
Pomerode	-	-	-	-	1.00	-	-	-	100.00
Ponte Alta	-	-	1.00	-	-	-	-	-	100.00
Ponte Alta do Norte	-	-	1.00	-	-	-	-	-	100.00
Ponte Serrada	-	-	0.74	-	-	0.13	-	0.13	100.00
Porto Belo	-	-	-	-	1.00	-	-	-	100.00
Porto União	-	-	0.99	-	-	-	-	0.01	100.00
Pouso Redondo	-	-	1.00	-	-	-	-	-	100.00
Praia Grande	0.01	0.42	0.20	-	-	-	-	0.37	100.00
Presidente Castelo Branco	-	-	1.00	-	-	-	-	-	100.00
Presidente Getúlio	-	-	0.93	-	0.07	-	-	-	100.00
Presidente Nereu	-	-	0.78	-	-	-	-	0.22	100.00
Princesa	-	-	0.98			0.02			100.00
Quilombo	-	-	-	-	-	0.07	0.93	-	100.00
Rancho Queimado	-	-	1.00	-	-	-	-	-	100.00
Rio das Antas	-	-	1.00	-	-	-	-	-	100.00
Rio do Campo	-	-	1.00	-	-	-	-	-	100.00
Rio do Oeste	-	-	1.00	-	-	-	-	-	100.00
Rio do Sul	-	-	1.00	-	-	-	-	-	100.00
Rio dos Cedros	-	-	0.79	-	0.21	-	-	-	100.00
Rio Fortuna	0.04	0.36	0.42	-	0.18	-	-	-	100.00
Rio Negrinho	0.12	-	0.62	-	-	-	-	0.26	100.00
Rio Rufino	-	-	0.70	0.19	-	-	-	0.11	100.00
Riqueza	-	-	-	-	1.00	-	-	-	100.00
Rodeio	-	-	0.09		0.91	-	-	-	100.00
Romelândia	-	-	-	-	0.57	0.01	0.42	-	100.00
Salete	-	-	1.00	-	-	-	-	-	100.00
Saltinho	-	-	-	-	-	0.94	0.06	-	100.00
Salto Veloso	-	-	1.00	-	-	-	-	-	100.00
Sangão	-	1.00	-	-	-	-	-	-	100.00

Where A=Apt, ARET= Apt with thermal excess restriction, AREP= Apt with rain excess restriction, RCTEP= Restriction due to thermal deficiency and rain excess, RETP= Restriction due to thermal and rain excess, IEPAT= Inapt due to rain excess and suitable due to temperature, IEPRET= Inapt due to rain excess and restriction due to thermal excess, I= Inapt, AI= Improper Area.

Complementary Table 1 - Percentage of classes in the Agroclimatic Zoning for hop using the Conventional approach for municipalities in the state of Santa Catarina, Brazil.

(continuation)

Municipalities	Percentage%								
	A	ARET	AREP	RCTEP	RETP	IEPAT	IEPRET	AI	Total
Santa Cecília	-	-	0.98	0.02	-	-	-	-	100.00
Santa Helena	-	-	-	-	1.00	-	-	-	100.00
Santa Rosa de Lima	-	0.00	0.93	-	0.07	-	-	-	100.00
Santa Rosa do Sul	-	1.00	-	-	-	-	-	-	100.00
Santa Terezinha	0.16	-	0.84	-	-	-	-	-	100.00
Santa Terezinha do Progres	-	-	-	-	-	0.63	0.37	-	100.00
Santiago do Sul	-	-	-	-	-	0.49	0.51	-	100.00
Santo Amaro da Imperatriz	-	-	0.04	-	0.34	-	-	0.62	100.00
São Bento do Sul	0.06		0.40	-	-	-	-	0.53	100.00
São Bernardino	-	-	-	-	-	1.00	-	-	100.00
São Bonifácio	-	-	0.79	-	0.03	-	-	0.19	100.00
São Carlos	-	-	-	-	0.82	-	0.18	-	100.00
São Cristóvão do Sul	-	-	1.00	-	-	-	-	-	100.00
São Domingos	-	-	-	-	-	0.91	0.08	0.01	100.00
São Francisco do Sul	-	-	-	-	0.66	-	0.14	0.20	100.00
São João Batista	-	-	0.34	-	0.66	-	-	-	100.00
São João do Itaperiú	-	-	-	-	1.00	-	-	-	100.00
São João do Oeste	-	-	-	-	1.00	-	-	-	100.00
São João do Sul	-	1.00	-	-	-	-	-	-	100.00
São Joaquim	0.21	-	0.44	0.35	-	-	-	-	100.00
São José	-	-	-	-	0.66	-	-	0.34	100.00
São José do Cedro	-	-	0.46	-	0.42	0.12	-	-	100.00
São José do Cerrito	0.27	-	0.73	-	-	-	-	-	100.00
São Lourenço do Oeste	-	-	-	-	-	1.00	-	-	100.00
São Ludgero	-	0.98	0.01	-	-	-	-	-	100.00
São Martinho	-	0.10	0.33	-	0.55	-	-	0.02	100.00
São Miguel da Boa Vista	-	-	-	-	-	0.22	0.64	-	100.00
São Miguel do Oeste	-	-	0.29	-	0.70	0.01	-	-	100.00
São Pedro de Alcântara	-	-	0.43	-	0.56	-	-	0.01	100.00

Where A=Apt, ARET= Apt with thermal excess restriction, AREP= Apt with rain excess restriction, RCTEP= Restriction due to thermal deficiency and rain excess, RETP= Restriction due to thermal and rain excess, IEPAT= Inapt due to rain excess and suitable due to temperature, IEPRET= Inapt due to rain excess and restriction due to thermal excess, I= Inapt, AI= Improper Area.

Complementary Table 1 - Percentage of classes in the Agroclimatic Zoning for hop using the Conventional approach for municipalities in the state of Santa Catarina, Brazil.

(continuation)

Municipalities	Percentage%								
	A	ARET	AREP	RCTEP	RETP	IEPAT	IEPRET	AI	Total
Saudades	-	-	-	-	0.19	-	0.73	0.08	100.00
Schroeder	-	-	0.11	-	0.77	-	-	0.13	100.00
Seara	-	-	0.02	-	0.14	0.58	0.13	0.13	100.00
Serra Alta	-	-	-	-	-	0.34	0.66	-	100.00
Siderópolis	0.16	0.62	0.03	-	-	-	-	0.19	100.00
Sombrio	-	1.00	-	-	-	-	-	-	100.00
Sul Brasil	-	-	-	-	-	0.02	0.98	-	100.00
Taió	-	-	1.00	-	-	-	-	-	100.00
Tangará	-	-	1.00	-	-	-	-	-	100.00
Tigrinhos	-	-	-	-	-	0.79	0.21	-	100.00
Tijucas	-	-	0.01	-	0.99	-	-	-	100.00
Timbé do Sul	0.30	0.35	0.35	-	-	-	-	-	100.00
Timbó	-	-	-	-	1.00	-	-	-	100.00
Timbó Grande	-	-	1.00	-	-	-	-	-	100.00
Três Barras	0.81	-	-	-	-	-	-	0.19	100.00
Treviso	0.50	0.33	0.10	-	-	-	-	0.08	100.00
Treze de Maio	-	1.00	-	-	-	-	-	-	100.00
Treze Tilhas	-	-	1.00	-	-	-	-	-	100.00
Trombudo Central	-	-	1.00	-	-	-	-	-	100.00
Tubarão		0.88	-	-	-	-	-	0.12	100.00
Tunápolis		-	-	-	1.00	-	-	-	100.00
Turvo		1.00	-	-	-	-	-	-	100.00
União do Oeste		-	-	-	-	-	1.00	-	100.00
Urubici		-	0.28	0.57	-	-	-	0.15	100.00
Urupema	0.04	-	0.23	0.70	-	-	-	0.03	100.00
Urussanga	0.09	0.89	-	-	-	-	-	0.02	100.00
Vargeão	-	-	0.06	-	-	0.94	-	-	100.00
Vargem	-	-	1.00	-	-	-	-	-	100.00
Vargem Bonita	-	-	0.99	-	-	-	-	0.01	100.00

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Complementary Table 1 - Percentage of classes in the Agroclimatic Zoning for hop using the Conventional approach for municipalities in the state of Santa Catarina, Brazil.

(Conclusion)

Municipalities	Percentage%								
	A	ARET	AREP	RCTEP	RETP	IEPAT	IEPRET	AI	Total
Vidal Ramos	-	-	0.95	-	-	-	-	0.05	100.00
Videira	-	-	1.00	-	-	-	-	-	100.00
Vitor Meireles	-	-	0.47	-	-	-	-	0.53	100.00
Witmarsum	-	-	1.00	-	-	-	-	-	100.00
Xanxerê	-	-	-	-	-	1.00	-	-	100.00
Xavantina	-	-	-	-	-	1.00	-	-	100.00
Xaxim	-	-	-	-	-	0.79	0.21	-	100.00
Zortéa	-	-	1.00	-	-	-	-	-	100.00

Where A=Apt, ARET= Apt with thermal excess restriction, AREP= Apt with rain excess restriction, RCTEP= Restriction due to thermal deficiency and rain excess, RETP= Restriction due to thermal and rain excess, IEPAT= Inapt due to rain excess and suitable due to temperature, IEPRET= Inapt due to rain excess and restriction due to thermal excess, I= Inapt, AI= Improper Area.

Complementary Table 2 – Percentage (%) of classes in the Agroclimatic Zoning for hop using Fuzzy logic for municipalities in the state of Santa Catarina, Brazil.

(continued)

Municipalities	Percentage%					
	Improper Area	Apt	Moderate restrict	Restrict	Very Restrict	Inapt
Abdon Batista	0.11	1.00	-	-	-	-
Abelardo Luz	-	0.06	0.06	0.00	0.00	0.76
Agrolândia	-	1.00	-	-	-	-
Agronômica	-	1.00	-	-	-	-
Água Doce	-	1.00	-	-	-	-
Águas de Chapecó	-	-	-	0.07	0.93	-
Águas Frias	-	-	-	-	0.03	0.97
Águas Mornas	0.23	0.75	0.02	0.00	-	-
Alfredo Wagner	0.00	0.99	0.01	0.00	-	-
Alto Bela Vista	-	0.97	0.03	-	-	-
Anchieta	-	-	-	0.11	0.00	0.89
Angelina	-	1.00	-	-	-	-
Anita Garibaldi	-	1.00	-	-	-	-
Anitápolis	0.00	1.00	-	-	-	-
Antônio Carlos	0.01	0.50	0.20	0.29	0.01	-
Apiúna	0.21	0.62	0.14	0.03	-	-
Arabutã	-	0.27	0.50	0.02	0.00	0.20
Araquari	0.19	-	-	-	-	0.81
Araranguá	0.00	0.00	0.86	0.14	-	-
Armazém	-	0.24	0.65	0.11	-	-
Arroio Trinta	-	1.00	-	-	-	-
Arvoredo	0.08	-	-	-	-	0.92
Ascurra	0.00	0.22	0.21	0.57	-	-
Atalanta	-	1.00	-	-	-	-
Aurora	-	1.00	-	-	-	-
Balneário Arroio do Silva	0.00		0.00	-	-	-
Balneário Barra do Sul	0.23	-	-	-	-	0.77
Balneário Cambouriú	0.31	-	-	0.10	0.58	-
Balneário Gaivota	-	-	1.00	-	-	-
Balneário Piçaras	0.08	-	-	-	0.07	0.85

Complementary Table 2 – Percentage (%) of classes in the Agroclimatic Zoning for hop using Fuzzy logic for municipalities in the state of Santa Catarina, Brazil.

(continued)

Municipalities	Percentage%					
	Improper Area	Apt	Moderate restrict	Restrict	Very Restrict	Inapt
Balneário Rincão	0.37	-	-	0.63	-	-
Bandeirante	0.00	-	0.44	0.56	-	-
Barra Bonita	-	-	-	0.38	0.62	0.00
Barra Velha	0.09	-	-	-	-	0.91
Bela Vista do Toldo	0.01	0.99	-	-	-	-
Belmonte	-	-	0.54	0.46	-	-
Benedito Novo	0.03	0.90	0.06	0.01	-	-
Biguaçu	0.36	0.09	0.08	0.40	0.07	-
Blumenau	0.35	0.02	0.05	0.28	0.27	0.03
Bocaina do Sul	0.01	0.98	0.01	0.00	-	-
Bom Jardim da Serra	0.24	0.30	0.17	0.21	0.07	0.02
Bom Jesus	0.01	-	-	-	-	0.99
Bom Jesus do Oeste	-	-	-	-	-	1.00
Bom Retiro	0.04	0.87	0.03	0.03	0.03	0.01
Bombinhas	-	-	-	0.19	0.81	-
Botuverá	0.21	0.66	0.08	0.05	-	-
Braço do Norte	-	0.44	0.54	0.02	-	-
Braço do Trombudo	-	1.00	-	-	-	-
Brunópolis	-	1.00	-	-	-	-
Brusque	0.19	0.11	0.26	0.21	0.23	
Caçador	0.01	0.99	-	-	-	-
Caibi	-	-	-	0.08	0.77	0.15
Calmon	-	1.00	-	-	-	-
Camboriú	0.06	0.05	0.18	0.50	0.22	
Campo Alegre	0.00	0.98	0.01	0.00	-	0.00
Campo Belo do Sul	0.05	0.95	-	-	-	-
Campo Erê	-	-	-	-	-	1.00
Campos Novos	0.01	0.99	-	-	-	-
Canelinha	-	0.12	0.14	0.41	0.33	-
Canoinhas	0.00	1.00	-	-	-	-

Complementary Table 2 – Percentage (%) of classes in the Agroclimatic Zoning for hop using Fuzzy logic for municipalities in the state of Santa Catarina, Brazil. (continued)

Municipalities	Percentage%					
	Improper Area	Apt	Moderate restrict	Restrict	Very Restrict	Inapt
Capinzal	-	1.00	-	-	-	-
Capivari de Baixo	0.15	-	-	0.25	0.59	-
Catanduvas	-	1.00	-	-	-	-
Caxambu do Sul	-	-	-	0.25	0.75	-
Celso Ramos	-	1.00	-	-	-	-
Cerro Negro	-	1.00	-	-	-	-
Chapadão do Lageado	-	1.00	-	-	-	-
Chapecó	0.15	-	0.16	0.09	-	0.59
Cocal do Sul	0.07	-	0.54	0.39	-	-
Concórdia	0.01	0.84	0.10	0.05		
Cordilheira Alta	0.02	-	-	-	-	0.98
Coronel Freitas	-	-	-	-	0.03	0.97
Coronel Martins	-	-	-	-	-	1.00
Correia Pinto	-	1.00	-	-	-	-
Corupá	0.04	0.61	0.12	0.17	0.05	-
Criciúma	0.22	-	0.37	0.42	-	-
Cunha Porã	0.05			0.03	0.01	0.91
Cunhataí	-	-	-	-	0.11	0.89
Curitibanos	-	1.00	-	-	-	-
Descanso	-		0.20	0.32	0.48	-
Dionísio Cerqueira	-	0.04	0.30	0.06	-	0.60
Dona Emma	-	1.00	-	-	-	-
Doutor Pedrinho	0.13	0.87	-	-	-	-
Entre Rios	0.56	-	-	-	-	0.44
Ermo	-	-	1.00	-	-	-
Erval Velho	-	1.00	-	-	-	-
Faxinal dos Guedes	-	-	-	-	-	1.00
Flor do Sertão	-	-	-	-	0.31	0.69
Florianópolis	0.59	-	-	0.10	0.31	-
Formosa do Sul	-	-	-	-	-	1.00
Forquilhinha	0.04		0.94	0.02		

Complementary Table 2 – Percentage (%) of classes in the Agroclimatic Zoning for hop using Fuzzy logic for municipalities in the state of Santa Catarina, Brazil.

(continuation)

Municipalities	Percentage%					
	Improper Area	Apt	Moderate restrict	Restrict	Very Restrict	Inapt
Fraiburgo	-	1.00	-	-	-	-
Frei Rogério	-	1.00	-	-	-	-
Galvão	0.01	-	-	-	-	0.99
Garopaba	0.17	-	0.02	0.67	0.14	-
Garuva	0.04	0.26	0.07	0.03	0.05	0.55
Gaspar	0.07	0.01	0.09	0.23	0.60	0.01
Governador Celso Ramos	0.27	-	0.01	0.54	0.17	-
Grão Pará	0.16	0.72	0.13	0.00	-	-
Gravatal	0.02	0.05	0.36	0.51	0.05	-
Guabiruba	0.37	0.01	0.03	0.34	0.25	-
Guaraciaba	-	0.00	0.77	0.22	0.00	-
Guaramirim	0.04	-	-	-	0.08	0.88
Guarujá do Sul	-	-	0.27	0.15	0.00	0.58
Guatambu	0.13		0.13	0.53	0.00	0.21
Herval d'Oeste	-	1.00	-	-	-	-
Ibiam	-	1.00	-	-	-	-
Ibicaré	-	1.00	-	-	-	-
Ibirama	0.00	0.94	0.06	-	-	-
Içara	0.06	-	-	0.94	-	-
Ilhota	0.07	-	0.04	0.07	0.79	0.03
Imaruí	0.14	0.06	0.18	0.58	0.04	-
Imbituba	0.12	-	-	0.45	0.43	-
Imbuia	-	1.00	-	-	-	-
Indaial	0.47	0.09	0.11	0.17	0.17	-
Iomerê	-	1.00	-	-	-	-
Fraiburgo	-	1.00	-	-	-	-
Frei Rogério	-	1.00	-	-	-	-
Galvão	0.01	-	-	-	-	0.99
Garopaba	0.17	-	0.02	0.67	0.14	-
Garuva	0.04	0.26	0.07	0.03	0.05	0.55
Gaspar	0.07	0.01	0.09	0.23	0.60	0.01

Complementary Table 2 – Percentage (%) of classes in the Agroclimatic Zoning for hop using Fuzzy logic for municipalities in the state of Santa Catarina, Brazil.

(continuation)

Municipalities	Percentage%					
	Improper Area	Apt	Moderate restrict	Restrict	Very Restrict	Inapt
Governador Celso Ramos	0.27	-	0.01	0.54	0.17	-
Grão Pará	0.16	0.72	0.13	-	-	-
Gravatal	0.02	0.05	0.36	0.51	0.05	-
Guabiruba	0.37	0.01	0.03	0.34	0.25	-
Guaraciaba	-	-	0.77	0.22	-	-
Guaramirim	0.04	-	-	-	0.08	0.88
Guarujá do Sul	-	-	0.27	0.15	-	0.58
Guatambu	0.13	-	0.13	0.53	-	0.21
Herval d'Oeste	-	1.00	-	-	-	-
Ibiam	-	1.00	-	-	-	-
Ibicaré	-	1.00	-	-	-	-
Ibirama	0.00	0.94	0.06	-	-	-
Içara	0.06	-	-	0.94	-	-
Ilhota	0.07	-	0.04	0.07	0.79	0.03
Imaruí	0.14	0.06	0.18	0.58	0.04	-
Imbituba	0.12	-	-	0.45	0.43	-
Imbuia	-	1.00	-	-		
Indaial	0.47	0.09	0.11	0.17	0.17	
Iomerê	-	1.00	-	-	-	-
Ipira	-	1.00	-	-	-	-
Iporã do Oeste	-	-	0.17	0.45	0.38	-
Ipuaçu	0.40	-	-	-	-	0.60
Ipumirim	-	0.15	0.14	0.02	-	0.69
Iraceminha	-	-	-	0.30	0.28	0.42
Irani	-	1.00	-	-	-	-
Irati	-	-	-	-	-	1.00
Irineópolis	-	1.00	-	-	-	-
Itá	-	-	0.14	0.57	0.10	0.19
Itaiópolis	0.03	0.97	-	-	-	-
Itajaí	0.20	-	-	0.11	0.65	0.04
Itapema	0.42	-	0.02	0.19	0.37	-

Complementary Table 2 – Percentage (%) of classes in the Agroclimatic Zoning for hop using Fuzzy logic for municipalities in the state of Santa Catarina, Brazil.

(continuation)

Municipalities	Percentage%					
	Improper Area	Apt	Moderate restrict	Restrict	Very Restrict	Inapt
Itapiranga	-	-	-	0.13	0.87	-
Itapoá	0.32	-	-	-	-	0.68
Ituporanga	-	1.00	-	-	-	-
Jaborá	-	1,00	-	-	-	-
Jacinto Machado	0.07	0.64	0.29	-	-	-
Jaguaruna	0.33	-	-	0.24	0.43	-
Jaraguá do Sul	0.09	0.19	0.08	0.31	0.32	0.02
Jardinópolis	-	-	-	-	-	1,00
Joaçaba	-	1.00	-	-	-	-
Joinville	0.49	0.12	-	-	0.02	0.38
José Boiteux	0.36	0.64	-	-	-	-
Jupiá	-	-	-	-	-	1.00
Lacerdópolis	-	1.00	-	-	-	-
Lageado Grande	-	-	-	-	-	1,00
Lages	0.02	0.98	-	-	-	-
Laguna	0.56	-	-	0.06	0.39	
Laurentino	-	1.00	-	-	-	-
Lauro Müller	0.06	0.94	-	-	-	-
Lebon Régis	-	1,00	-	-	-	-
Leoberto Leal	-	1.00	-	-	-	-
Lindóia do Sul	-	0.38	0.43	0.02	-	0.17
Lontras	-	1.00				
Luiz Alves	-	-	0.16	0.13	0.63	0.08
Luzerna	-	1.00	-	-	-	-
Macieira	-	1.00	-	-	-	-
Mafra	-	1.00	-	-	-	-
Major Gercino	-	0.88	0.12	-	-	-
Major Vieira	-	1,00	-	-	-	-
Maracajá	-	-	1.00			
Maravilha	-	-	-	-	-	1.00
Marema	-	-	-	-	-	1.00

Complementary Table 2 – Percentage (%) of classes in the Agroclimatic Zoning for hop using Fuzzy logic for municipalities in the state of Santa Catarina, Brazil. (continuation)

Municipalities	Percentage%					
	Improper Area	Apt	Moderate restrict	Restrict	Very Restrict	Inapt
Massaranduba	-	-	0.02	0.35	0.43	0.20
Matos Costa	-	1.00	-	-	-	-
Meleiro	-	-	1.00	-	-	-
Mirim Doce	-	1.00	-	-	-	-
Modelo	-	-	-	-	-	1.00
Mondaí	-	-	-	0.01	0.99	-
Monte Carlo	-	1.00	-	-	-	-
Monte Castelo	-	1.00	-	-	-	-
Morro da Fumaça	0.06	-	-	0.93	-	-
Morro Grande	0.01	0.80	0.19	-	-	-
Navegantes	0.17	-	-	-	0.54	0.30
Nova Erechim	-	-	-	-	0.51	0.49
Nova Itaberaba	-	-	-	-	0.19	0.81
Nova Trento	-	0.63	0.21	0.16	-	-
Nova Veneza	0.07	0.30	0.63	-	-	-
Novo Horizonte	-	-	-	-	-	1.00
Orleans	0.26	0.60	0.14	-	-	-
Otacílio Costa	-	1.00	-	-	-	-
Ouro	-	1.00	-	-	-	-
Ouro Verde	-	-	-	-	-	1.00
Paial	0.04	-	-	-	0.11	0.86
Painel	0.01	0.81	0.11	0.06	0.01	-
Palhoça	0.76	-	0.02	0.13	0.09	-
Palma Sola	-	-	0.01	0.04	-	0.94
Palmeira	-	1.00	-	-	-	-
Palmitos	0.12	-	-	-	0.75	0.14
Papanduva	-	1.00	-	-	-	-
Paraíso	-	-	0.93	0.07	-	-
Passo de Torres	-		1.00	-	-	-
Passos Maia	0.09	0.66	0.14	0.01	-	0.10
Paulo Lopes	0.62	0.01	0.15	0.21	0.01	-

Complementary Table 2 – Percentage (%) of classes in the Agroclimatic Zoning for hop using Fuzzy logic for municipalities in the state of Santa Catarina, Brazil. (continuation)

Municipalities	Percentage%					
	Improper Area	Apt	Moderate restrict	Restrict	Very Restrict	Inapt
Pedras Grandes	-	0.68	0.32	-	-	-
Penha	0.16	-	-	-	0.56	0.29
Peritiba	-	1.00	-	-	-	-
Pescaria Brava	0.03	-	-	0.71	0.25	-
Petrolândia	-	1.00	-	-	-	-
Pinhalzinho	-	-	-	-	-	1.00
Pinheiro Preto	-	1.00	-	-	-	-
Piratuba	-	1.00	-	-	-	-
Planalto Alegre	-	-	-	0.58	0.16	0.26
Pomerode	-	-	0.15	0.58	0.27	-
Ponte Alta	-	1.00	-	-	-	-
Ponte Alta do Norte	-	1.00	-	-	-	-
Ponte Serrada	0.13	0.63	0.11	0.01	-	0.13
Porto Belo	-	-	-	0.28	0.72	-
Porto União	0.01	0.99	-	-	-	-
Pouso Redondo	-	1.00	-	-	-	-
Praia Grande	0.37	0.34	0.29	-	-	-
Presidente Castelo Branco	-	1.00	-	-	-	-
Presidente Getúlio	-	1.00	-	-	-	-
Presidente Nereu	0.22	0.78	-	-	-	-
Princesa	-	0.04	0.93	0.01	-	0.02
Quilombo	-	-	-	-	-	1.00
Rancho Queimado	-	1.00	-	-	-	-
Rio das Antas	-	1.00	-	-	-	-
Rio do Campo	-	1.00	-	-	-	-
Rio do Oeste	-	1.00	-	-	-	-
Rio do Sul	-	1.00	-	-	-	-
Rio dos Cedros	-	0.83	0.07	0.09	0.01	-
Rio Fortuna	-	0.92	0.08	-	-	-
Rio Negrinho	0.26	0.74	-	-	-	-
Rio Rufino	0.11	0.75	0.07	0.05	0.02	-

Complementary Table 2 – Percentage (%) of classes in the Agroclimatic Zoning for hop using Fuzzy logic for municipalities in the state of Santa Catarina, Brazil. (continuation)

Municipalities	Percentage%					
	Improper Area	Apt	Moderat e restrict	Restrict	Very Restrict	Inapt
Riqueza	-	-	-	0.17	0.83	-
Rodeio	-	0.19	0.34	0.45	0.01	-
Romelândia	-	-	-	0.09	0.48	0.43
Salete	-	1.00	-	-	-	-
Saltinho	-	-	-	-	-	1.00
Salto Veloso	-	1,00	-	-	-	-
Sangão	-	-	-	0.98	0.02	-
Santa Cecília	-	1.00	-	-	-	-
Santa Helena	-	-	0.15	0.85		
Santa Rosa de Lima	-	1.00	-	-	-	-
Santa Rosa do Sul	-	0.03	0.97	-	-	-
Santa Terezinha	-	1.00	-	-	-	-
Santa Terezinha do Progresso	-	-	-	-	-	1.00
Santiago do Sul	-	-	-	-	-	1.00
Santo Amaro da Imperatriz	0.62	0.08	0.13	0.17	-	-
São Bento do Sul	0.53	0.46	-	-	-	-
São Bernardino	-	-	-	-	-	1.00
São Bonifácio	0.19	0.81	-	-	-	-
São Carlos	-	-	-	-	0.82	0.18
São Cristóvão do Sul	-	1.00	-	-	-	-
São Domingos	0.01	-	-	-	-	0.99
São Francisco do Sul	0.20	-	-	-	-	0.80
São João Batista	-	0.42	0.11	0.34	0.13	-
São João do Itaperiú	-	-	-	-	0.03	0.97
São João do Oeste	-	-	0.04	0.61	0.35	-
São João do Sul	-	-	1.00	-	-	-
São Joaquim	-	0.76	0.11	0.08	0.05	0.01
São José	0.34	-	0.02	0.32	0.32	-
São José do Cedro	-	0.05	0.62	0.20	-	0.12
São José do Cerrito	-	1.00	-	-	-	-
São Lourenço do Oeste	-	-	-	-	-	1.00

Complementary Table 2 – Percentage (%) of classes in the Agroclimatic Zoning for hop using Fuzzy logic for municipalities in the state of Santa Catarina, Brazil. (continuation)

Municipalities	Percentage%					
	Improper Area	Apt	Moderate restrict	Restrict	Very Restrict	Inapt
São Pedro de Alcântara	0.01	0.67	0.31	0.01	-	-
Saudades	0.08	-	-	-	0.19	0.73
Schroeder	0.13	0.14	0.11	0.21	0.39	0.03
Seara	0.13	-	0.07	0.09	-	0.71
Serra Alta	-	-	-	-	-	1.00
Siderópolis	0.19	0.48	0.33	-	-	-
Sombrio	-	-	1.00	-	-	-
Sul Brasil	-	-	-	-	-	1.00
Taió	-	1.00	-	-	-	-
Tangará	-	1.00	-	-	-	-
Tigrinhos	-	-	-	-	-	1.00
Tijucas	-	0.02	0.09	0.32	0.57	-
Timbé do Sul	-	0.98	0.02	-	-	-
Timbó	-	-	0.05	0.41	0.54	-
Timbó Grande	-	1.00	-	-	-	-
Três Barras	0.19	0.81	-	-	-	-
Treviso	0.08	0.91	0.02	-	-	-
Treze de Maio	-	0.20	0.40	0.38	0.03	
Treze Tilhas	-	1.00	-	-	-	-
Trombudo Central	-	1.00	-	-	-	-
Tubarão	0.12	0.06	0.16	0.26	0.40	-
Tunápolis	-	-	0.13	0.86	0.01	-
Turvo		0.07	0.93			-
União do Oeste	-	-	-	-	-	1.00
Urubici	0.15	0.35	0.11	0.13	0.16	0.09
Urupema	0.03	0.48	0.19	0.23	0.07	-
Urussanga	0.02	0.65	0.30	0.03	-	-
Vargeão	-	-	0.05	0.01	-	0.94
Vargem	-	1.00	-	-	-	-
Vargem Bonita	0.01	0.99	-	-	-	-
Vidal Ramos	0.05	0.95	-	-	-	-

Complementary Table 2 – Percentage (%) of classes in the Agroclimatic Zoning for hop using Fuzzy logic for municipalities in the state of Santa Catarina, Brazil.

(Conclusion)

Mnicipalities	Percentage%					
	Improper Area	Apt	Moderate restrict	Restrict	Very Restrict	Inapt
Videira	-	1.00	-	-	-	-
Vitor Meireles	0.53	0.47	-	-	-	-
Witmarsum	-	1.00	-	-	-	-
Xanxerê	-	-	-	-	-	1.00
Xavantina	-	-	-	-	-	1.00
Xaxim	-	-	-	-	-	1.00
Zortéa	-	1.00	-	-	-	-

Complementary Table 3 - Percentage (%) of classes of the spatialization of conventional climatic favorability for downy mildew occurrence in hop, for the municipalities of the state of Santa Catarina, Brazil.

(continued**)**

Municipalities	**Area total**	**HRTH**	**HRTMH**	**AI**	**HRTH (%)**	**HRTMH (%)**	**Area (%)**
Abdon Batista	237.47	106.95	130.52	-	45.00	55.00	-
Abelardo Luz	955.34	-	845.98	109.36	-	88.60	11.40
Agrolândia	207.23	207.23	-	-	100.00	-	-
Agronômica	129.60	129.60	-	-	100.00	-	-
Água Doce	1309.61	35.45	1274.16	-	2.70	97.30	-
Aguas de Chapecó	138.70	-	138.7	-	-	100.00	-
Águas Frias	75.86	-	75.86	-	-	100.00	-
Águas Mornas	325.66	251.61	-	74.05	77.30	-	22.70
Alfredo Wagner	731.16	730.19	-	0.97	99.90	-	0.10
Alto Bela Vista	102.25	-	102.25	-	-	100.00	-
Anchieta	232.26	-	232.26	-	-	100.00	-
Angelita	501.70	501.70	-	-	100.00	-	-
Anita Garibaldi	587.45	3.35	584.10	-	0.60	99.40	-
Anitápolis	544.23	544.08	-	0.15	100.00	-	
Antônio Carlos	233.09	230.94	-	2.15	99.10	-	0.90
Apiúna	493.44	389.3	-	104.14	78.90	-	21.10
Arabutã	132.66	-	132.66	-	-	100	
Araquari	365.01	294.75	-	70.26	80.80	-	19.20
Araranguá	304.92	304.68	-	0.24	99.90	-	0.10
Armazém	173.28	173.28	-	-	100.00	-	-
Arroio Trinta	94.26	23.14	71.12	-	24.50	75.50	-
Alvoredo	89.83	-	82.20	7.63	-	91.50	8.50
Ascurra	111.14	110.99	-	0.15	99.90	-	0.10
Atalanta	94.19	94.19	-	-	100.00	-	
Aurora	206.59	206.59	-	-	100.00	-	--
Balneário Arroio do Silva	94.00	93.86	-	0.14	99.90	-	0.10
Balneário Barra do Sul	102.95	78.91	-	24.04	76.60	-	23.40
Balneário Cambouriú	46.58	31.93	-	14.65	68.50	-	31.50
Balneário Gaivota	147.82	147.82	-	-	100.00	-	-

Where A = Area in Km², and percentage, HRTH = High risk for temperature and humidity, HRTMH = High risk for temperature and moderate humidity, and AI = Improper Area.

Complementary Table 3 - Percentage (%) of classes of the spatialization of conventional climatic favorability for downy mildew occurrence in hop, for the municipalities of the state of Santa Catarina, Brazil.

(continued**)**

Municipalities	**Area total**	**HRTH**	**HRTMH**	**AI**	**HRTH (%)**	**HRTMH (%)**	**Area (%)**
Balneário Piçaras	98.95	90.99	-	7.96	92.00	-	8.00
Balneário Rincão	63.17	39.62	-	23.55	62.70	-	37.30
Bandeirante	145.60	-	145.42	0.18	-	99.90	0.10
Barra Bonita	93.4	-	93.4	-	-	100.00	-
Barra Velha	139.73	126.48	-	13.25	90.50	-	9.50
Bela Vista do Toldo	538.93	535.76		3.17	99.40	-	0.60
Belmonte	93.4	-	93.4	-	-	100.00	-
Benedito Novo	388.6	376.21	-	12.39	96.80	-	3.20
Biguaçu	317.75	203.35	-	114.4	64.00	-	36.00
Blumenau	519.86	336.94	-	182.92	64.80	-	35.20
Bocaina do Sul	511.77	509.02	-	2.75	99.50	-	0.50
Bom Jardim da Serra	937.71	716.58	-	221.13	76.40	-	23.60
Bom Jesus	63.48	-	62.81	0.67	-	98.90	1.10
Bom Jesus do Oeste	67.68	-	67.68	-	-	100.00	-
Bom Retiro	1,055.88	1,013.29	-	42.59	96.00	-	4.00
Bombinhas	34.64	34.64	-		100.00	-	-
Botuverá	295.66	233.19	-	62.47	78.90	-	21.10
Braço do Norte	211.5	211.5	-		100.00	-	-
Braço do Trombudo	89.6	89.6	-		100.00	-	-
Brunópolis	336.4	336.4	-		100.00	-	-
Brusque	282.89	229.22	-	53.67	81.00	-	19.00
Caçador	985.53	978.4	-	7.13	99.30	-	0.70
Caibi	171.92	-	171.92	-	-	100.00	-
Calmon	637.3	637.3	-	-	100.00	-	-
Camboriú	212.68	200.69	-	11.99	94.40	-	5.60
Campo Alegre	497.44	495.55	-	1.89	99.60	-	0.40
Campo Belo do Sul	1,024.55	300.44	674.77	49.34	29.30	65.90	4.80
Campo Erê	479.77	-	479.77	-	-	100.00	-
Campos Novos	1,716,13	439,6	1,265.19	11.34	25.60	73.70	0.70
Canelinha	152.7	152.7	-	-	100.00	-	-

Where A = Area in Km², and percentage, HRTH = High risk for temperature and humidity, HRTMH = High risk for temperature and moderate humidity, and AI = Improper Area.

Complementary Table 3 - Percentage (%) of classes of the spatialization of conventional climatic favorability for downy mildew occurrence in hop, for the municipalities of the state of Santa Catarina, Brazil.

(continuation)

Municipalities	Area total	HRTH	HRTMH	AI	HRTH (%)	HRTMH (%)	Area (%)
Canoinhas	1,143.09	1,142.90	-	0.14	100.00	-	-
Capão Alto	1,334.02	136.12	1,184.11	13.79	10.20	88.80	1.00
Capinzal	244.27	-	244.27	-	-	100.00	-
Capivari de Baixo	52.98	44.84	-	8.14	84.60	-	15.40
Catanduvas	198.17	-	198.17	-	-	100.00	-
Caxambu do Sul	141.2	-	141.2	-	-	100.00	-
Celso Ramos	207.67	-	207.67	-	-	100.00	-
Cerro Negro	416.4	108.06	308.34	-	26.00	74.00	-
Chapadão do Lageado	125.37	125.37	-	-	100.00	-	-
Chapecó	623.45	-	528.07	95.38	-	84.70	15.30
Cocal do Sul	71.05	65.77	-	5.28	92.60	-	7.40
Concórdia	795.7	-	788.45	7.25	-	99.10	0.90
Cordilheira Alta	84.01	-	82.19	1.82	-	97.80	2.20
Coronel Freitas	233.94	-	233.94	-	-	100.00	-
Coronel Martins	107.28	-	107.28	-	-	100.00	-
Correia Pinto	649.5	649.5	-	-	100.00	-	-
Corupá	406.74	388.85	-	17.89	95.60	-	4.40
Criciúma	236.16	185.08	-	51.08	78.40	-	21.60
Cunha Porã	219.43	-	208.82	10.61	-	95.20	4.80
Cunhataí	54.83	-	54.83	-	-	100.00	-
Curitibanos	952.83	952.83	-	-	100.00	-	-
Descanso	286.91	-	286.91	-	-	100.00	-
Dionísio Cerqueira	377.58	-	377.58	-	-	100.00	-
Dona Emma	180.98	180.98	-	-	100.00	-	-
Doutor Pedrinho	375.96	326.97	-	48.99	87.00	-	13.00
Entre Rios	105.36	-	46.71	58.65	0.00	44.30	55.70
Ermo	63.65	63.65	-	-	100.00	-	-
Erval Velho	208.37	-	208.37	-	-	100.00	-
Faxinal dos Guedes	339.8	-	339.8	-	-	100.00	-
Flor do Sertão	58.39	-	58.39	-	-	100.00	-

Where A = Area in Km², and percentage, HRTH = High risk for temperature and humidity, HRTMH = High risk for temperature and moderate humidity, and AI = Improper Area.

Complementary Table 3 - Percentage (%) of classes of the spatialization of conventional climatic favorability for downy mildew occurrence in hop, for the municipalities of the state of Santa Catarina, Brazil.

(continuation)

Municipalities	**Area total**	**HRTH**	**HRTMH**	**AI**	**HRTH (%)**	**HRTMH (%)**	**Area (%)**
Florianópolis	435.75	180.69	-	255.06	41.50	-	58.50
Formosa do Sul	99.66	-	99.66	-	-	100.00	-
Forquilhinha	182.42	175.91	-	6.51	96.40	-	3.60
Fraiburgo	547.01	547.01	-	-	100.00	-	-
Frei Rogério	158.28	158.28	-	-	100.00	-	-
Galvão	139.16	-	1,38.37	0.79	-	99.40	0.60
Garopaba	114.47	94.9	-	19.57	82.90	-	17.10
Garuva	497.04	478.22	-	18.82	96.20	-	3.80
Gaspar	386.54	360.74	-	25.80	93.30	-	6.70
Governador Celso Ramos	93.95	68.23	-	25.72	72.60	-	27.40
Grão Pará	337.18	284.58	-	52.6	84.40	-	15.60
Gravatal	165.23	161.24	-	3.99	97.60	-	2.40
Guabiruba	173.65	110.09	-	63.56	63.40	-	36.60
Guaraciaba	330.36	-	330.36	-	-	100.00	-
Guaramirim	269.29	258.71	-	10.58	96.10	-	3.90
Guarujá do Sul	100.6	-	100.6	-	-	100.00	-
Guatambu	205.18	-	178.14	27.04	-	86.80	13,20
Herval d'Oeste	215.51	-	215.51	-	-	100.00	-
Ibiam	146.89	89.3	57.59	-	60.80	39.20	-
Ibicaré	155.72	0.23	155.49	-	0.10	99.90	-
Ibirama	246.27	246.07	-	0.20	99.90	-	0.10
Içara	228.96	214.52	-	14.44	93.70	-	6.30
Ilhota	253.36	236.33	-	17.03	93.30	-	6.70
Imaruí	542.54	465.93	-	76.61	85.90	-	14.10
Imbituba	181.19	158.9	-	22.29	87.70	-	12.30
Imbuia	122.69	122,69	-	-	100,00	-	0,00
Indaial	432.47	231.35	-	201.12	53.50	-	46.50
Iomerê	115.32	67.28	48.04	-	58.30	41.70	-
Ipira	155.22	-	155.22	-	-	100.00	-
Iporã do Oeste	201.66	-	201.66	-	-	100.00	-

Where A = Area in Km², and percentage, HRTH = High risk for temperature and humidity, HRTMH = High risk for temperature and moderate humidity, and AI = Improper Area.

Complementary Table 3 - Percentage (%) of classes of the spatialization of conventional climatic favorability for downy mildew occurrence in hop, for the municipalities of the state of Santa Catarina, Brazil (continuation)

Municipalities	**Area total**	**HRTH**	**HRTMH**	**AI**	**HRTH (%)**	**HRTMH (%)**	**Area (%)**
Ipuaçu	261.73	-	158.33	103.4	-	60.50	39.50
Ipumirim	247.11	-	247.11	-	-	100.00	-
Iraceminha	165.01	-	165.01	-	-	100.00	-
Irani	329.51	-	329.51	-	-	100.00	-
Irati	77.49	-	77.49	-	-	100.00	-
Irineópolis	589.51	589.5	-	0.01	100.00	-	-
Itá	165.44	-	165.44	-	-	100.00	-
Itaiópolis	1,293.95	1,253.81	-	40.14	96.90	-	3.10
Itajaí	288.45	230.87		57.58	80.00	-	20.00
Itapema	58.7	34.12		24.58	58.10	-	41.90
Itapiranga	278.55	-	278.55	-	-	100.00	-
Itapoá	239.07	163.03	-	76.04	68.20	-	31.80
Ituporanga	336.98	336.98	-	-	100.00	-	-
Jaborá	180.91	-	180.91	-	-	100.00	-
Jacinto Machado	438.02	407.53	-	30.49	93.00	-	7.00
Jaguaruna	326.92	220.33	-	106.59	67.40	-	32.60
Jaraguá do Sul	530.02	483.97	-	46.05	91.30	-	8.70
Jardinópolis	68.25	-	68.25	-	-	100.00	-
Joaçaba	242,93	-	242,93	-	-	100,00	-
Joinville	1,102.37	565.01	-	537.36	51.30	-	48.70
José Boiteux	405.39	260.95	-	144.44	64.40	-	35.60
Jupiá	92.44	-	92.44	-	-	100.00	-
Lacerdópolis	68.75	-	68.75	-	-	100.00	-
Lageado Grande	65.60	-	65.60	-	-	100.00	-
Lages	2,631.85	1,180.32	1,410.28	41.25	44.80	53.60	1.60
Laguna	330.25	146.7	-	183.55	44.40	-	55.60
Laurentino	79.58	79.56	-	0.02	100.00	-	-
Lauro Müller	269.92	252.78	-	17.14	93.60	-	-
Lebon Régis	936.15	936.15	-	-	100.00	-	-
Leoberto Leal	292.28	292.2	-	0.08	100.00	-	-

Where A = Area in Km², and percentage, HRTH = High risk for temperature and humidity, HRTMH = High risk for temperature and moderate humidity, and AI = Improper Area.

Complementary Table 3 - Percentage (%) of classes of the spatialization of conventional climatic favorability for downy mildew occurrence in hop, for the municipalities of the state of Santa Catarina, Brazil.

(continuation)

Municipalities	Area total	HRTH	HRTMH	AI	HRTH (%)	HRTMH (%)	Area (%)
Lindóia do Sul	188.91	-	188.91	-	-	100.00	-
Lontras	197.6	197.6	-	-	100.00	-	-
Luiz Alves	260.77	260.71	-	0.06	100.00	-	-
Luzerna	116.55	-	116.55	-	-	100.00	-
Macieira	259.15	168.46	90.69	-	65.00	35.00	-
Mafra	1402.8	1402.74	-	0.06	100.00	-	-
Major Gercino	304,36	304,36	-	-	100,00	-	-
Major Vieira	524.21	524.21	-	-	100.00	-	-
Maracajá	62.79	62.79	-	-	100.00	-	-
Maravilha	169.7	-	169.7	-	-	100.00	-
Marema	103.13	-	102.98	0.15	-	99.90	0.10
Massaranduba	374.14	374.14	-	-	100.00	-	-
Matos Costa	434.26	434.09	-	0.17	100.00	-	-
Meleiro	186,1	186,1	-	-	100,00	-	-
Mirim Doce	339.25	339.25	-	-	100.00	-	-
Modelo	92.63	-	92.63	-	-	100.00	-
Mondaí	200.85	-	200.85	-	-	100.00	-
Monte Carlo	192.15	192.15	-	-	100.00	-	-
Monte Castelo	557.29	557.29	-	-	100.00	-	-
Morro da Fumaça	82.98	77.69	-	5.29	93.60	-	6.40
Morro Grande	259.31	257.39	-	1.92	99.30	-	0.70
Navegantes	111.44	92.87	-	18.57	83.30	-	16.70
Nova Erechim	64.72	-	64.72	-	-	100.00	-
Nova Itaberaba	136.75	-	136.75	-	-	100.00	-
Nova Trento	402.66	401.58	-	1.08	99.70	-	0.30
Nova Veneza	294.03	272.49	-	21.54	92.70	-	7.30
Novo Horizonte	151.45	-	151.45	-	0.00	100.00	0.00
Orleans	549.4	405.49	-	143.91	73.80	-	26.20
Otacílio Costa	845.09	845.09	-		100.00	-	-
Ouro	213.45	-	213.45	-	-	100.00	-

Where A = Area in Km², and percentage, HRTH = High risk for temperature and humidity, HRTMH = High risk for temperature and moderate humidity, and AI = Improper Area.

Complementary Table 3 - Percentage (%) of classes of the spatialization of conventional climatic favorability for downy mildew occurrence in hop, for the municipalities of the state of Santa Catarina, Brazil.

(continuation)

Municipalities	**Area total**	**HRTH**	**HRTMH**	**AI**	**HRTH (%)**	**HRTMH (%)**	**Area (%)**
Ouro Verde	189.03	-	189.03	-	-	100.00	-
Paial	85.11	-	82.08	3.03	-	96.40	3.60
Painel	741.72	655.49	80.3	5.93	88.40	10.80	0.80
Palhoça	326.25	79.75	-	246.5	24.40	-	75.60
Palma Sola	330.45	-	330.45	-	-	100.00	-
Palmeira	290.48	290.48	-	--	100.00	-	-
Palmitos	352.07	-	311.13	40.94	-	88.40	11.60
Papanduva	763.81	763.81	-	-	100.00	-	-
Paraíso	178.56	-	178.56	-	-	100.00	-
Passo de Torres	96.04	96.04	-	-	100.00	-	-
Passos Maia	612.69	-	555.83	56.86	-	90.70	9.30
Paulo Lopes	449.04	171.23	-	277.81	38.10	-	61.90
Pedras Grandes	159.1	159.1	-	-	100.00	-	-
Penha	58.45	49.35	-	9.10	84.40	-	15.60
Peritiba	96.43	-	96.43	-	-	100.00	-
Pescaria Brava	111.38	107.57	-	3.81	96.60	-	3.40
Petrolândia	305.97	305.97	-	-	100.00	-	-
Pinhalzinho	128.41	-	128.41	-	-	100.00	-
Pinheiro Preto	61.99	52.14	9.85	-	84.10	15.90	-
Piratuba	144.61	-	144.61	-	-	100.00	-
Planalto Alegre	62.71	-	62.71	-	-	100.00	-
Pomerode	215.19	215.17	-	0.02	100.00	-	-
Ponte Alta	572.47	572.47	-	-	100.00	-	-
Ponte Alta do Norte	400.03	400.03	-	-	100.00	-	-
Ponte Serrada	563.39	-	492.16	71.23	-	87.40	12.60
Porto Belo	93.84	93.70	-	0.14	99.90	-	0.10
Porto União	848.57	840.62	-	7.95	99.10	-	0.90
Pouso Redondo	362	362	-	-	100.00	-	-
Praia Grande	285.45	180.53	-	104.92	63.20	-	36.80
Presidente Castelo Branco	65.4	-	65.4	-	-	100.00	-

Where A = Area in Km², and percentage, HRTH = High risk for temperature and humidity, HRTMH = High risk for temperature and moderate humidity, and AI = Improper Area.

Complementary Table 3 - Percentage (%) of classes of the spatialization of conventional climatic favorability for downy mildew occurrence in hop, for the municipalities of the state of Santa Catarina, Brazil.

(continuation)

Municipalities	Area total	HRTH	HRTMH	AI	HRTH (%)	HRTMH (%)	Area (%)
Presidente Getúlio	295.11	295.11	-	-	100.00	-	-
Presidente Nereu	224.62	175.77	-	48,85	78.30	-	21.70
Princesa	85.43	-	85.43	-	-	100.00	-
Quilombo	279.87	-	279.65	0.22	-	99.90	0.10
Rancho Queimado	288.26	288.21	-	0.05	100.00	-	-
Rio das Antas	318.62	318.62	-	-	100.00	-	-
Rio do Campo	503.09	503.09	-	-	100.00	-	-
Rio do Oeste	246.32	246.32	-	-	100.00	-	-
Rio do Sul	260.89	260.74	-	0.15	99.90	-	0.10
Rio dos Cedros	554.49	554.07	-	0.42	99.90	-	0.10
Rio Fortuna	301.74	301.74	-	-	100.00	-	-
Rio Negrinho	907.13	668.69	-	238.44	73.70	-	26.30
Rio Rufino	282.49	252.68	-	29.81	89.40	-	10.60
Riqueza	190.11	-	190.11	-	-	100.00	-
Rodeio	128.01	128.01	-	-	100.00	-	-
Romelândia	221.56	-	221.56	-	-	100.00	-
Salete	180.49	180.49	-	-	100.00	-	-
Saltinho	156.38	-	156.38	-	-	100.00	-
Salto Veloso	105.66	-	105.66	-	-	100.00	-
Sangão	82.69	82.69	-	-	100.00	-	-
Santa Cecília	1,151.10	1,151.10	-	-	100.00	-	-
Santa Helena	80.81	-	80.81	-	-	100.00	-
Santa Rosa de Lima	202.58	202.58	-	-	100.00	-	-
Santa Rosa do Sul	151.61	151.61	-	-	100.00	-	-
Santa Terezinha	718.66	717.77	-	0.89	99.90	-	0.10
Santa Terezinha do Progresso	119	-	119	-	-	100.00	-
Santiago do Sul	72.97	-	72.97	-	-	100.00	-
Santo Amaro da Imperatriz	345.09	132.21	-	212.88	38.30	-	61.70
São Bento do Sul	495.57	230.90	-	264.67	46.60	-	53.40

Where A = Area in Km², and percentage, HRTH = High risk for temperature and humidity, HRTMH = High risk for temperature and moderate humidity, and AI = Improper Area.

Complementary Table 3 - Percentage (%) of classes of the spatialization of conventional climatic favorability for downy mildew occurrence in hop, for the municipalities of the state of Santa Catarina, Brazil.

(continuation)

Municipalities	**Area total**	**HRTH**	**HRTMH**	**AI**	**HRTH (%)**	**HRTMH (%)**	**Area (%)**
São Bernardino	149.21	-	149.21	-	-	100.00	-
São Bonifácio	460.8	374.82	-	85.98	81.30	-	18.70
São Carlos	158.10	-	158.10	-	-	100.00	-
São Cristóvão do Sul	343.96	343.96	-	-	100.00	-	-
São Domingos	367.79	-	362.32	5.47	-	98.50	1.50
São Francisco do Sul	383.12	308.26	-	74.86	80.50	-	19.50
São João Batista	199.47	199.47	-	-	100.00	-	-
São João do Oeste	163.43	-	163.43	-	-	100.00	-
São João do Sul	180.19	180.19	-	-	100.00	-	-
São Joaquim	1881.76	1126.73	755.03	-	59.90	40.10	-
São José	113.3	74.67	-	38.63	65.90	-	34.10
São José do Cedro	280.24	-	280.24	-	-	100.00	-
São José do Cerrito	946.65	946.65	-	-	100.00	0.00	-
São Lourenço do Oeste	356.29	-	356.29	-	-	100.00	-
São Ludgero	107.55	107.55	-	-	100.00	-	-
São Martinho	224.41	220.39	-	4.02	98.20	-	1.80
São Miguel da Boa Vista	71.53	-	71.53	-	-	100.00	-
São Miguel do Oeste	233.46	-	233.46	-	-	100.00	-
São Pedro de Alcântara	139.72	138.61	-	1.11	99.20	-	0.80
Saudades	205.42	-	188.01	17.41	-	91.50	8.50
Schroeder	164.1	142.96	-	21.14	87.10	-	12.90
Seara	311.65	-	271.43	40.22	-	87,10	12,90
Serra Alta	90.59	-	90.59	-	-	100.00	-
Siderópolis	261.6	210.6	-	51.00	80.50	-	19.50
Sombrio	142.54	142.54	-	-	100.00	-	-
Sul Brasil	113.06	-	113.06	-	-	100.00	-
Taió	692.36	692.36	-	-	100.00	-	-
Tangará	386.41	351.12	35.29	-	90.90	9.10	-
Tigrinhos	57.41	-	57.41	-	-	100.00	-
Tijucas	279.48	279.48	-	-	100.00	-	-

Where A = Area in Km², and percentage, HRTH = High risk for temperature and humidity, HRTMH = High risk for temperature and moderate humidity, and AI = Improper Area.

Complementary Table 3 - Percentage (%) of classes of the spatialization of conventional climatic favorability for downy mildew occurrence in hop, for the municipalities of the state of Santa Catarina, Brazil.

(Conclusion)

Municipalities	**Area total**	**HRTH**	**HRTMH**	**AI**	**HRTH (%)**	**HRTMH (%)**	**Area (%)**
Timbé do Sul	325.68	325.68	-	-	100.00	-	-
Timbó	127.36	127.02	-	0.34	99.70	-	0.30
Timbó Grande	595.31	595.31	-	-	100.00	-	-
Três Barras	437.95	353.14	-	84.81	80.60	-	19.40
Treviso	156.41	144.35	-	12.06	92.30	-	7.70
Treze de Maio	162.06	162.06	-	-	100.00	-	-
Treze Tilhas	183.99	-	183.99	-	-	100.00	-
Trombudo Central	108.77	108.77	-	-	100.00	-	-
Tubarão	300.50	264.49	-	36.01	88.00	-	12.00
Tunápolis	132.6	-	132.6	-	-	100.00	-
Turvo	233.96	233.96	-	-	100.00	-	-
União do Oeste	93.21	-	93.21	-	-	100.00	-
Urubici	1,016.07	863.03	-	153.04	84.90	-	15.10
Urupema	351.11	342.03	-	9.08	97.40	-	2.60
Urussanga	254.14	249.01	-	5.13	98.00	-	2.00
Vargeão	166.62	-	166.62	-	-	100.00	-
Vargem	351.21	351.21	-	-	100.00	-	-
Vargem Bonita	299.12	-	296.27	2.85	-	99.00	1.00
Vidal Ramos	344.01	326.23	-	17.78	94.80	-	5.20
Videira	383.23	383.06	-	0.17	100.00	-	-
Vitor Meireles	371.24	173.77	-	197.47	46.80	-	53.20
Witmarsum	151.32	151.32	-		100.00	-	-
Xanxerê	377.46	-	376.83	0.63	-	99.80	0.20
Xavantina	216.68	-	216.68	-	-	100.00	-
Xaxim	294.07	-	294.07	-	-	100.00	-
Zortéa	189.15	-	189.15	-	-	100.00	-

Where A = Area in Km², and percentage, HRTH = High risk for temperature and humidity, HRTMH = High risk for temperature and moderate humidity, and AI = Improper Area.

Complementary Table 4 - Percentage (%) of classes of climatic favorability for downy mildew occurrence in hop using Fuzzy logic, for the municipalities of the state of Santa Catarina, Brazil. (continued**)**

Municipalities	**Area Km²**					**Percentage%**			
	HR	**AI**	**MR**	**LR**	**TA**	**HR**	**AI**	**MR**	**LR**
Abdon Batista	237.473	-	-	-	237.473	100.00	-	-	-
Abelardo Luz	845.976	109.36	-	-	955.336	88.60	11.40	-	-
Agrolândia	207.227	-	-	-	207.227	100.00	-	-	-
Agronômica	129.6	-	-	-	129.6	100.00	-	-	-
Água Doce	1,309.615	-	-	-	1,309.615	100.00	-	-	-
Águas de Chapecó	138.7	-	-	-	138.7	100.00	-	-	-
Águas Frias	75.858	-	-	-	75.858	100.00	-	-	-
Águas Mornas	251.605	74.054	-	-	325.659	77.30	22.70	-	-
Alfredo Wagner	730.191	0.968	-	-	731.159	99.90	0.10	-	-
Alto Bela Vista	102.251	-	-	-	102.251	100.00	-	-	-
Anchieta	229.362	-	2.898		232.26	98.80	-	1.20	0.00
Angelina	501.707	-	-	-	501.707	100.00	-	-	-
Anita Garibaldi	587.446	-	-	-	587.446	100.00	-	-	-
Anitápolis	544.085	0.15	-	-	544.235	100.00	-	-	-
Antônio Carlos	230.942	2.152	-	-	233.094	99.10	0.90	-	-
Apiúna	389.3	104.14	-	-	493.44	78.90	21.10	-	-
Arabutã	132.656	-	-	-	132.656	100.00	-	-	-
Araquari	294.752	70.263	-	-	365.015	80.80	19.20	-	-
Araranguá	304.679	0.242	-	-	304.921	99.90	0.10	-	-
Armazém	173.275	-	-	-	173.275	100.00	-	-	-
Arroio Trinta	94.254	-	-	-	94.254	100.00	-	-	-
Arvoredo	82.202	7.625	-	-	89.827	91.50	8.50	-	-
Ascurra	110.993	0.154	-	-	111.147	99.90	0.10	-	-
Atalanta	94.19	-	-	-	94.19	100.00	-	-	-
Aurora	206.59	-	-	-	206.59	100.00	-	-	-
Balneário Arroio do Silva	93.862	0.14	-	-	94.002	99.90	0.10	-	-
Balneário Barra do Sul	78.913	24.039	-	-	102.952	76.70	23.30	-	-
Balneário Cambouriú	31.934	14.647	-	-	46.581	68.60	31.40	-	-
Balneário Gaivota	147.82	-	-	-	147.82	100.00	-	-	-

Where HR = High Risk, AI = Improper areas, MR = Moderate Risk, LR = Low Risk, and TA = Total Area.

Complementary Table 4 - Percentage (%) of classes of climatic favorability for downy mildew occurrence in hop using Fuzzy logic, for the municipalities of the state of Santa Catarina, Brazil.

(continuation)

Municipalities	Area Km²					Percentage%			
	HR	**AI**	**MR**	**LR**	**TA**	**HR**	**AI**	**MR**	**LR**
Balneário Piçaras	90.98	7.95	-	-	98.94	92.00	8.00	-	-
Balneário Rincão	39.61	23.55	-	-	63.17	62.70	37.30	-	-
Bandeirante	145.42	0.17	-	-	145.59	99.90	0.10	-	-
Barra Bonita	93.40	-	-	-	93.40	100.00	-	-	-
Barra Velha	126.47	13.25	-	-	139.72	90.50	9.50	-	-
Bela Vista do Toldo	535.75	3.17	-	-	538.93	99.40	0.60	-	-
Belmonte	93.40	-	-	-	93.40	100.00	-	-	-
Benedito Novo	376.21	12.38	-	-	388.59	96.80	3.20	-	-
Biguaçu	203.35	114.39	-	-	317.75	64.00	36.00	-	-
Blumenau	336.94	182.91	-	-	519.86	64.80	35.20	-	-
Bocaina do Sul	509.02	2.75	-	-	511.77	99.50	0.50	-	-
Bom Jardim da Serra	716.58	221.12	-	-	937.71	76.40	23.60	-	-
Bom Jesus	62.80	0.66	-	-	63.47	98.90	1.10	-	-
Bom Jesus do Oeste	67.68	-	-	-	67.68	100.00	-	-	-
Bom Retiro	1,013.29	42.59	-	-	1,055.88	96.00	4.00	-	-
Bombinhas	34.64	-	-	-	34.63	100.00	-	-	-
Botuverá	233.19	62.47	-	-	295.66	78.90	21.10	-	-
Braço do Norte	211.50	-	-	-	211.50	100,00	-	-	-
Braço do Trombudo	89.60	-	-	-	89.60	100.00	-	-	-
Brunópolis	336.398	-	-	-	336.398	100.00	-	-	-
Brusque	229.22	53.66	-	-	282.89	81.00	19.00	-	-
Caçador	978.40	7.13	-	-	985.53	99.30	0.70	-	-
Caibi	171.91	-	-	-	171.91	100.00	-	-	-
Calmon	637,3	-	-	-	637,3	100,00	-	-	-
Camboriú	200.69	11.99	-	-	212.68	94.40	5.60	-	-
Campo Alegre	495.55	1.89	-	-	497.44	99.60	0.40	-	-
Campo Belo do Sul	975.20	49.33	-	-	1,024.54	95.20	4.80	-	-
Campo Erê	476.18	-	3.59	-	479.77	99.30	-	0.70	-
Campos Novos	1,704.793	11.34	-	-	1,716.13	99.30	0.70	-	-
Canelinha	152.698	-	-	-	152.698	100.00	-	-	-

Where HR = High Risk, AI = Improper areas, MR = Moderate Risk, LR = Low Risk, and TA = Total Area.

Complementary Table 4 - Percentage (%) of classes of climatic favorability for downy mildew occurrence in hop using Fuzzy logic, for the municipalities of the state of Santa Catarina, Brazil.

(continuation)

Municipalities	Area Km^2					Percentage%			
	HR	**AI**	**MR**	**LR**	**TA**	**HR**	**AI**	**MR**	**LR**
Canoinhas	1,142.95	0.13	-	-	1,143.08	100.00	-	-	-
Capão Alto	1,320.22	13.79	-	-	1,334.019	99.00	1.00	-	-
Capinzal	244.27	-	-	-	244.27	100.00	-	-	-
Capivari de Baixo	44.837	8.141	-	-	52.978	84.60	15.40	-	-
Catanduvas	198.16	-	-	-	198.16	100.00	-	-	-
Caxambu do Sul	141.20	-	-	-	141.20	100.00	-	-	-
Celso Ramos	207.66	-	-	-	207.66	100.00	-	-	-
Cerro Negro	416.39	-	-	-	416.39	100.00	-	-	-
Chapadão do Lageado	125.36	-	-	-	125.36	100.00	-	-	-
Chapecó	528.06	95.38	-	-	623.45	84.70	15.30	-	-
Cocal do Sul	65.77	5.28	-	-	71.06	92.60	7.40	-	-
Concórdia	788.45	7.25	-	-	795.70	99.10	0.90	-	-
Cordilheira Alta	82.19	1.82	-	-	84.01	97.80	2.20	-	-
Coronel Freitas	233.93	-	-	-	233.93	100.00	-	-	-
Coronel Martins	107.27	-	-	-	107.27	100.00	-	-	-
Correia Pinto	649.49	-	-	-	649.49	100.00	-	-	-
Corupá	388.85	17.89	-	-	406.74	95.60	4.40	-	-
Criciúma	185.08	51.08	-	-	236.16	78.40	21.60	-	-
Cunha Porã	208.81	10.60	-	-	219.42	95.20	4.80	-	-
Cunhataí	54.82	-	-	-	54.82	100.00	-	-	-
Curitibanos	952.83	-	-	-	952.83	100.00	-	-	-

Where HR = High Risk, AI = Improper areas, MR = Moderate Risk, LR = Low Risk, and TA = Total Area.

Complementary Table 4 - Percentage (%) of classes of climatic favorability for downy mildew occurrence in hop using Fuzzy logic, for the municipalities of the state of Santa Catarina, Brazil.

(continuation)

Municipalities	Area Km^2					Percentage%			
	HR	**AI**	**MR**	**LR**	**TA**	**HR**	**AI**	**MR**	**LR**
Descanso	286.90	-	-	-	286.90	100.00	-	-	-
Dionísio Cerqueira	270.52	-	107.01	0.04	377.58	71.60	-	28.30	-
Dona Emma	180.97	-	-	-	180.97	100.00	-	-	-
Doutor Pedrinho	326.96	48.98	-	-	375.95	87.00	13.00	-	-
Entre Rios	46.70	58.64	-	-	105.35	44.30	55.70	-	-
Ermo	63.64	-	-	-	63.64	100.00	-	-	-
Erval Velho	208.37	-	-	-	208.37	100.00	-	-	-
Faxinal dos Guedes	339.79	-	-	-	339.79	100.00	-	-	-
Flor do Sertão	58.38	-	-	-	58.38	100.00	-	-	-
Florianópolis	180.69	255.06	-	-	435.75	41.50	58.50	-	-
Formosa do Sul	99.66	-	-	-	99.66	100.00	-	-	-
Forquilhinha	175.90	6.513	-	-	182.419	96.40	3.60	-	-
Fraiburgo	547.01	-	-	-	547.01	100.00	-	-	-
Frei Rogério	158.28	-	-	-	158.28	100.00	-	-	-
Galvão	138.36	0.78	-	-	139.15	99.40	0.60	-	-
Garopaba	94.89	19.57	-	-	114.47	82.90	17.10	-	-
Garuva	478.21	18.82	-	-	497.03	96.20	3.80	-	-
Gaspar	360.74	25.80	-	-	386.54	93.30	6.70	-	-
Governador Celso Ramos	68.23	25.72	-	-	93.95	72.60	27.40	-	-
Grão Pará	284.58	52.60	-	-	337.18	84.40	15.60	-	-
Gravatal	161.24	3.99	-	-	165.23	97.60	2.40	-	-
Guabiruba	110.09	63.56	-	-	173.65	63.40	36.60	-	-
Guaraciaba	330.35	-	-	-	330.35	100.00	-	-	-
Guaramirim	258.71	10.57	-	-	269.29	96.10	3.90	-	-
Guarujá do Sul	99.14	-	1.44	-	100.59	98.60	-	-	-
Guatambu	178.13	27.04	-	-	205.17	86.80	13.20	-	-
Herval d'Oeste	215.50	-	-	-	215.50	100.00	-	-	-
Ibiam	146.88	-	-	-	146.88	100.00	-	-	-
Ibicaré	155.72	-	-	-	155.72	100.00	-	-	-

Where HR = High Risk, AI = Improper areas, MR = Moderate Risk, LR = Low Risk, and TA = Total Area.

Complementary Table 4 - Percentage (%) of classes of climatic favorability for downy mildew occurrence in hop using Fuzzy logic, for the municipalities of the state of Santa Catarina, Brazil.

(continuation)

Municipalities	Area Km^2					Percentage%			
	HR	**UI**	**MR**	**LR**	**TA**	**HR**	**UI**	**MR**	**LR**
Ibirama	246.07	0.20	-	-	246.27	99.90	0.10	-	-
Içara	214.51	14.43	-	-	228.95	93.70	6.30	-	-
Ilhota	236.33	17.03	-	-	253.36	93.30	6.70	-	-
Imaruí	465.92	76.61	-	-	542.54	85.90	14.10	-	-
Imbituba	158.90	22.28	-	-	181.18	87.70	12.30	-	-
Imbuia	122.69	-	-	-	122.69	100.00	-	-	-
Indaial	231.35	201.12	-	-	432.47	53.50	46.50	-	-
Iomerê	115.31	-	-	-	115.31	100.00	-	-	-
Ipira	155.21	-	-	-	155.21	100.00	-	-	-
Iporã do Oeste	201.65	-	-	-	201.65	100.00	-	-	-
Ipuaçu	158.32	103.40	-	-	261.72	60.50	39.50	-	-
Ipumirim	247.10	-	-	-	247.10	100.00	-	-	-
Iraceminha	165.00	-	-	-	165.00	100.00	-	-	-
Irani	329.50	-	-	-	329.50	100.00	-	-	-
Irati	77.49	-	-	-	77.49	100.00	-	-	-
Irineópolis	589.50	0.013	-	-	589.51	100.00	-	-	-
Itá	165.44	-	-	-	165.44	100.00	-	-	-
Itaiópolis	1,253.81	40.13	-	-	1,293.94	96.90	3.10	-	-
Itajaí	230.86	57.58	-	-	288.44	80.00	20.00	-	-
Itapema	34.11	24.57	-	-	58.69	58.10	41.90	-	-
Itapiranga	278.55	-	-	-	278.55	100.00	-	-	-
Itapoá	163.03	76.04	-	-	239.07	68.20	31.80	-	-
Ituporanga	336.98	-	-	-	336.98	100.00	-	-	-
Jaborá	180.915	-	-	-	180.91	100.00	-	-	-
Jacinto Machado	407.52	30.48	-	-	438.01	93.00	7,00	-	-
Jaguaruna	220.33	106.58	-	-	326.92	67.40	32.60	-	-
Jaraguá do Sul	483.97	46.04	-	-	530.01	91.30	8.70	-	-
Jardinópolis	68.25	-	-	-	68.25	100.00	-	-	-
Joaçaba	242.92	-	-	-	242.92	100.00	-	-	-
Joinville	565.01	537.35	-	-	1,102.36	51.30	48.70	-	-

Where HR = High Risk, AI = Improper areas, MR = Moderate Risk, LR = Low Risk, and TA = Total Area.

Complementary Table 4 - Percentage (%) of classes of climatic favorability for downy mildew occurrence in hop using Fuzzy logic, for the municipalities of the state of Santa Catarina, Brazil.

(continuation)

Municipalities	Area Km²					Percentage%			
	HR	AI	MR	LR	TA	HR	AI	MR	LR
José Boiteux	260.94	144.44	-	-	405.39	64.40	35.60	-	-
Jupiá	92.43	-	-	-	92.43	100.00	-	-	-
Lacerdópolis	68.75	-	-	-	68.75	100.00	-	-	-
Lageado Grande	65.60	-	-	-	65.60	100.00	-	-	-
Lages	2,590.60	41.24	-	-	2,631.85	98.40	1.60	-	-
Laguna	146.69	183.54	-	-	330.24	44.40	55.60	-	-
Laurentino	79.56	0.02	-	-	79.58	100.00	-	-	-
Lauro Müller	252.78	17.14	-	-	269.92	93.60	6.40	-	-
Lebon Régis	936.14	-	-	-	936.14	100.00	-	-	-
Leoberto Leal	292.20	0.07	-	-	292.27	100.00	-	-	-
Lindóia do Sul	188.91	-	-	-	188.91	100.00	-	-	-
Lontras	197.60	-	-	-	197.60	100.00	-	-	-
Luiz Alves	260.70	0.06	-	-	260.76	100.00	-	-	-
Luzerna	116.55	-	-	-	116.55	100.00	-	-	-
Macieira	259.15	-	-	-	259.15	100.00	-	-	-
Mafra	1,402.73	0.05	-	-	1,402.79	100.00	-	-	-
Major Gercino	304.35	-	-	-	304.35	100.00	-	-	-
Major Vieira	524.21	-	-	-	524.21	100.00	-	-	-
Maracajá	62.79	-	-	-	62.79	100.00	-	-	-
Maravilha	169.70	-	-	-	169.70	100.00	-	-	-
Marema	102.97	0.14	-	-	103.12	99.90	0.10	-	-
Massaranduba	374.14	-	-	-	374.14	100.00	-	-	-
Matos Costa	434.09	0.16	-	-	434.25	100.00	-	-	-
Meleiro	186.10	-	-	-	186.10	100.00	-	-	-
Mirim Doce	339.24	-	-	-	339.24	100.00	-	-	-
Modelo	92.62	-	-	-	92.62	100.00	-	-	-
Mondaí	200.84	-	-	-	200.84	100.00	-	-	-
Monte Carlo	192.15	-	-	-	192.15	100.00	-	-	-
Monte Castelo	557.29	-	-	-	557.29	100.00	-	-	-
Morro da Fumaça	77.69	5.28	-	-	82.98	93.60	6.40	-	-

Where HR = High Risk, AI = Improper areas, MR = Moderate Risk, LR = Low Risk, and TA = Total Area.

Complementary Table 4 - Percentage (%) of classes of climatic favorability for downy mildew occurrence in hop using Fuzzy logic, for the municipalities of the state of Santa Catarina, Brazil.

(continuation)

Municipalities	Area Km^2					Percentage%			
	HR	AI	MR	LR	TA	HR	AI	MR	LR
Morro Grande	257.39	1.92	-	-	259.31	99.30	0.70	-	-
Navegantes	92.86	18.57	-	-	111.43	83.30	16.70	-	-
Nova Erechim	64.71	-	-	-	64.71	100.00	-	-	-
Nova Itaberaba	136.75	-	-	-	136.75	100.00	-	-	-
Nova Trento	401.58	1.08	-	-	402.66	99.70	0.30	-	-
Nova Veneza	272.48	21.54	-	-	294.02	92.70	7.30	-	-
Novo Horizonte	151.45	-	-	-	151.45	100.00	0.00	-	-
Orleans	405.49	143.91	-	-	549.401	73.80	26.20	-	-
Otacílio Costa	845.09	-	-	-	845.09	100.00	-	-	-
Ouro	213.45	-	-	-	213.45	100.00	-	-	-
Ouro Verde	189.02	-	-	-	189.02	100.00	-	-	-
Paial	82.07	3.03	-	-	85.11	96.40	3.60	-	-
Painel	735.78	5.92	-	-	741.71	99.20	0.80	-	-
Palhoça	79.74	246.50	-	-	326.24	24.40	75.60	-	-
Palma Sola	130.49	-	199.95		330.44	39.50	-	60.50	0.00
Palmeira	290.47	-	-	-	290.47	100.00	-	-	-
Palmitos	311.13	40.93	-	-	352.06	88.40	11.60	-	-
Papanduva	763.80	-	-	-	763.80	100.00	-	-	-
Paraíso	178.55	-	-	-	178.55	100.00	-	-	-
Passo de Torres	96.04	-	-	-	96.04	100.00	-	-	-
Passos Maia	555.82	56.86	-	-	612.69	90.70	9.30	-	-
Paulo Lopes	171.22	277.81	-	-	449.04	38.10	61.90	-	-
Pedras Grandes	159.09	-	-	-	159,099	100,00	-	-	-
Penha	49.34	9.10	-	-	58.45	84.40	15.60	-	-
Peritiba	96.43	-	-	-	96.43	100.00	-	-	-
Pescaria Brava	107.57	3.81	-	-	111.38	96.60	3.40	-	-
Petrolândia	305.96	-	-	-	305.96	100.00	-	-	-
Pinhalzinho	128.40	-	-	-	128.40	100.00	-	-	-
Pinheiro Preto	61.99	-	-	-	61.99	100.00	-	-	-
Piratuba	144.60	-	-	-	144.60	100.00	-	-	-

Where HR = High Risk, AI = Improper areas, MR = Moderate Risk, LR = Low Risk, and TA = Total Area.

Complementary Table 4 - Percentage (%) of classes of climatic favorability for downy mildew occurrence in hop using Fuzzy logic, for the municipalities of the state of Santa Catarina, Brazil.

(continuation)

Municipalities	Area Km²					Percentage%			
	HR	AI	MR	LR	TA	HR	AI	MR	LR
Planalto Alegre	62.71	-	-	-	62.71	100.00	-	-	-
Pomerode	215.17	0.02	-	-	215.19	100.00	-	-	-
Ponte Alta	572.46	-	-	-	572.46	100.00	-	-	-
Ponte Alta do Norte	400.02	-	-	-	400.02	100.00	-	-	-
Ponte Serrada	492.16	71.23	-	-	563.39	87.40	12.60	-	-
Porto Belo	93.70	0.14	-	-	93.84	99.80	0.20	-	-
Porto União	840.62	7.94	-	-	848.57	99.10	0.90	-	-
Pouso Redondo	361.99	-	-	-	361.99	100.00	-	-	-
Praia Grande	180.52	104.91	-	-	285.44	63.20	36.80	-	-
Presidente Castelo Branco	65.40	-	-	-	65.40	100.00	-	-	-
Presidente Getúlio	295.10	-	-	-	295.10	100.00	-	-	-
Presidente Nereu	175.77	48.84	-	-	224.62	78.30	21.70	-	-
Princesa	85.42	-	-	-	85.42	100.00	-	-	-
Quilombo	279.64	0.22	-	-	279.86	99.90	0.10	-	-
Rancho Queimado	288.21	0.05	-	-	288.26	100.00	-	-	-
Rio das Antas	318.62	-	-	-	318.62	100.00	-	-	-
Rio do Campo	503.09	-	-	-	503.09	100.00	-	-	-
Rio do Oeste	246.31	-	-	-	246.31	100.00	-	-	-
Rio do Sul	260.74	0.15	-	-	260.89	99.90	0.10	-	-
Rio dos Cedros	554.06	0.41	-	-	554.48	99.90	0.10	-	-
Rio Fortuna	301.74	-	-	-	301.74	100.00	-	-	-
Rio Negrinho	668.69	238.44	-	-	907.13	73.70	26.30	-	-
Rio Rufino	252.68	29.81	-	-	282.49	89.40	10.60	-	-
Riqueza	190.11	-	-	-	190.11	100.00	-	-	-
Rodeio	128.01	-	-	-	128.01	100.00	-	-	-
Romelândia	221.56	-	-	-	221.56	100.00	-	-	-
Salete	180.49	-	-	-	180.492	100.00	-	-	-
Saltinho	156.38	-	-	-	156.383	100.00	-	-	-
Salto Veloso	105.66	-	-	-	105.66	100.00	-	-	-

Where HR = High Risk, AI = Improper areas, MR = Moderate Risk, LR = Low Risk, and TA = Total Area.

Complementary Table 4 - Percentage (%) of classes of climatic favorability for downy mildew occurrence in hop using Fuzzy logic, for the municipalities of the state of Santa Catarina, Brazil.

(continuation)

Municipalities	Area Km^2					Percentage%			
	HR	AI	MR	LR	TA	HR	AI	MR	LR
Sangão	82.68	-	-	-	82.68	100.00	-	-	-
Santa Cecília	1,151.14	-	-	-	1,151.14	100.00	-	-	-
Santa Helena	80.80	-	-	-	80.80	100.00	-	-	-
Santa Rosa de Lima	202.57	-	-	-	202.57	100.00	-	-	-
Santa Rosa do Sul	151.61	-	-	-	151.61	100.00	-	-	-
Santa Terezinha	717.76	0.89	-	-	718.65	99.90	-	-	-
Santa Terezinha do Progresso	119.00	-	-	-	119.00	100.00	-	-	-
Santiago do Sul	72.96	-	-	-	72.96	100.00	-	-	-
Santo Amaro da Imperatriz	132.20	212.88	-	-	345.09	38.30	61.70	-	-
São Bento do Sul	230.89	264.66	-	-	495.56	46.60	53.40	-	-
São Bernardino	149.21	-	-	-	149.21	100.00	-	-	-
São Bonifácio	374.81	85.98	-	-	460.80	81.30	18.70	-	-
São Carlos	158.09	-	-	-	158.09	100.00	-	-	-
São Cristóvão do Sul	343.96	-	-	-	343.96	100.00	-	-	-
São Domingos	362.32	5.47	-	-	367.79	98.50	1.50	-	-
São Francisco do Sul	308.25	74.85	-	-	383.11	80.50	19.50	-	-
São João Batista	199.47	-	-	-	199.47	100.00	-	-	-
São João do Itaperiú	151.703	-	-	-	151.70	100.00	-	-	-
São João do Oeste	163.42	-	-	-	163.42	100.00	-	-	-
São João do Sul	180.18	-	-	-	180.18	100.00	-	-	-
São Joaquim	1,881.76	-	-	-	1,881.76	100.00	-	-	-
São José	74.67	38.62	-	-	113.30	65.90	34.10	-	-
São José do Cedro	280.24	-	-	-	280.24	100.00	-	-	-
São José do Cerrito	946.64	-	-	-	946.64	100.00	-	-	-
São Lourenço do Oeste	356.29	-	-	-	356.29	100.00	-	-	-
São Ludgero	107.55	-	-	-	107.55	100.00	-	-	-
São Martinho	220.39	4.01	-	-	224.40	98.20	1.80	-	-
São Miguel da Boa Vista	71.53	-	-	-	71.53	100.00	-	-	-
São Miguel do Oeste	233.45	-	-	-	233.45	100.00	-	-	-

Where HR = High Risk, AI = Improper areas, MR = Moderate Risk, LR = Low Risk, and TA = Total Area.

Complementary Table 4 - Percentage (%) of classes of climatic favorability for downy mildew occurrence in hop using Fuzzy logic, for the municipalities of the state of Santa Catarina, Brazil.

(continuation)

Municipalities	Area Km^2					Percentage%			
	HR	AI	MR	LR	TA	HR	AI	MR	LR
São Pedro de Alcântara	138.61	1.10	-	-	139.72	99.20	0.80	-	-
Saudades	188.00	17.40	-	-	205.41	91.50	8.50	-	-
Schroeder	142.96	21.13	-	-	164.09	87.10	12.90	-	-
Seara	271.42	40.21	-	-	311.64	87.10	12.90	-	-
Serra Alta	90.58	-	-	-	90.58	100.00	-	-	-
Siderópolis	210.61	50.99	-	-	261.61	80.50	19.50	-	-
Sombrio	142.53	-	-	-	142.53	100.00	-	-	-
Sul Brasil	113.06	-	-	-	113.06	100.00	-	-	-
Taió	692.35	-	-	-	692.35	100.00	-	-	-
Tangará	386.40	-	-	-	386.40	100.00	-	-	-
Tigrinhos	57.41	-	-	-	57.41	100.00	-	-	-
Tijucas	279.47	-	-	-	279.47	100.00	-	-	-
Timbé do Sul	325.67	-	-	-	325.67	100.00	-	-	-
Timbó	127.01	0.34	-	-	127.36	99.70	0.30	-	-
Timbó Grande	595.30	-	-	-	595.30	100.00	-	-	-
Três Barras	353.14	84.81	-	-	437.95	80.60	19.40	-	-
Treviso	144.35	12.05	-	-	156.40	92.30	7.70	-	-
Treze de Maio	162.06	-	-	-	162.06	100.00	-	-	-
Treze Tilhas	183.99	-	-	-	183.99	100.00	-	-	-
Trombudo Central	108.76	-	-	-	108.76	100.00	-	-	-
Tubarão	264.49	36.01	-	-	300.50	88.00	12.00	-	-
Tunápolis	132.59	-	-	-	132.59	100.00	0.00	-	-
Turvo	233.96	-	-	-	233.96	100.00	-	-	-
União do Oeste	93.21	-	-	-	93.21	100.00	-	-	-
Urubici	863.03	153.04	-	-	1016.07	84.90	15.10	-	-
Urupema	342.03	9.07	-	-	351.10	97.40	2.60	-	-
Urussanga	249.00	5.12	-	-	254.13	98.00	2.00	-	-
Vargeão	166.61	-	-	-	166.61	100.00	-	-	-
Vargem	351.21	-	-	-	351.21	100.00	-	-	-
Vargem Bonita	296.26	2.85	-	-	299.12	99.00	1.00	-	-

Where HR = High Risk, AI = Improper areas, MR = Moderate Risk, LR = Low Risk, and TA = Total Area.

Complementary Table 4 - Percentage (%) of classes of climatic favorability for downy mildew occurrence in hop using Fuzzy logic, for the municipalities of the state of Santa Catarina, Brazil.

(Conclusion)

Municipalities	Area Km²					Percentage%			
	HR	AI	MR	LR	TA	HR	AI	MR	LR
Vidal Ramos	326.23	17.78	-	-	344.01	94.80	5.20	-	-
Videira	383.05	0.16	-	-	383.22	100.00	0.00	-	-
Vitor Meireles	173.77	197.46	-	-	371.24	46.80	53.20	-	-
Witmarsum	151.32	-	-	-	151.32	100.00	-	-	-
Xanxerê	376.83	0.62	-	-	377.45	99.80	0.20	-	-
Xavantina	216.68	-	-	-	216.68	100.00	-	-	-
Xaxim	294.06	-	-	-	294.06	100.00	-	-	-
Zortéa	189.154	-	-	-	189.15	100.00	-	-	-

Where HR = High Risk, AI = Improper areas, MR = Moderate Risk, LR = Low Risk, and TA = Total Area.