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GEOGRAPHICAL REASONS FOR TRANSFORMATION IN CROP IMMUNE

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ABSTRACT:

Plant immunity, which is the collection of biochemical, physiological and genetic resistance of the crops against the pathogen attack, is not uniform. It undergoes a radical change in its geographical location throughout the earth. In this research paper, I present the multiple geographical factors that influence crop immune competence such as climatic zone, temperature regime, relative humidity, altitude gradient, soil type and soil pH, carbon dioxide concentration, and land use change. Based on peer-reviewed data from 2020–2025, the paper reveals that tropical humid crops uniformly have reduced levels of systemic acquired resistance (SAR) and increased disease incidence relative to crops grown at the temperate continental latitudes or highlands. Eight original data tables provide synthesized empirical evidence that addresses the interaction between climate and immunity, soil chemistry, pathogen pressure indices, and disease loss trends in regions. Each table is accompanied by interpretations to explain different causal mechanisms from heat-suppressed SAR to stomatal regulation under elevated CO_2. The paper concludes that geographic pathogen diversification – boosted by climate change – requires geographic diversification of breeding, agronomic and policy solutions to ensure global food security.

KEYWORDS:

CROP IMMUNE, GEOGRAPHICAL, GENETIC DEFENCES, CLIMATIC ZONE, AGRONOMIC.

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1. INTRODUCTION

Each year plant diseases in the world cause estimates of 20–40% of total agricultural production, equating to hundreds of billions of dollars of economic damage, and providing for food shortages for billions of people globally(Son, S., 2022). Most importantly is the uneven distribution of this destruction on the shelf of the Earth. The spectrum of diseases encountered by a rice grower in a humid lowland in Bangladesh is very different from that of a wheat farmer in a semi-arid plain in Kazakhstan or a potato farmer in the highlands of the Andes in Peru(Kumar, A., 2025). Instead of being a mere background to crop production, geography plays a major role as an agent shaping plant immunity(Tanaka, K., 2023). Crop immune transformation is the concept that a plant's ability to sense, signal and respond to pathogenic challenges will change over the life of a crop as it grows in different geographic locations(IPCC, 2023). The physiological regulatory components of plant immunity that drive pattern-triggered immunity (PTI), effector-triggered immunity (ETI), systemic acquired resistance (SAR), and induced systemic resistance (ISR) are extremely responsive to environmental factors, such as temperature, humidity, light quality, CO_2 concentration, soil chemistry, elevation, and biotic community composition(Pautasso, M., 2023). All of these variables exhibit a unique geographic traingle, varying with latitude as well as with elevation and geomorphic setting.

The geographical dimensions of crop immunity have been greatly magnified by climate change and split into several climate/disease categories. The Sixth Assessment Report (2021, updated in 2023) of the Intergovernmental Panel on Climate Change (IPCC) indicates that the global mean surface temperatures have been increased by about 1.1°C since the pre-industrial period, and are projected to rise by 1.5°C–4.0°C by the end of the century under different emission scenarios(Chaloner, T. M., 2021). Along with these temperature changes are shifts in the nature of precipitation, extreme weather events, ranges of crop pathogens and crop pests and increasing atmospheric CO_2 concentrations, all having direct implications for the immune response of crop plants(Shara, S., 2021).

2. CONCEPTUAL FRAMEWORK: CROP IMMUNITY AND ITS GEOGRAPHICAL SENSITIVITY

2.1 PLANT IMMUNE SYSTEM OVERVIEW

Plants have a complex two-pronged immunity system. The first layer of PTs are surface localized pattern recognition receptors (PRRs) that recognize conserved microbial molecules, leading to induction of basal defense mechanisms such as callose deposition, burst of Reactive Oxygen Species (ROS) and up-regulation of Patterns Responding (PR) genes. Second tier ETI occurs when intracellular NLR (nucleotide-binding leucine-rich repeat) proteins recognise pathogen effector proteins injected into the plant cell, but are associated with a hypersensitive response (HR) occurring where programmed cell death restricts the spread of the pathogen.

Plants can also be primed (pre-exposed) to pathogens, wounding or chemical signals, which can cause them to respond immune system quicker and more strongly if they are attacked; this is termed SAR or ISR. Salicylic acid (SA) usually mediated SAR and ET and Jasmonic acid (JA) mediated ISR that confer resistance against biotrophic and hemibiotrophic pathogens and herbivores respectively, whilst against necrotrophic pathogens. Generally these two signaling networks affect the immunity of a crop, and their effects are strongly influenced by environmental factors, which is why there is geographical variation in the crop immunity discussed in this paper.

2.2 GEOGRAPHY AS A DETERMINANT OF IMMUNE EXPRESSION

Geographers have been aware for a long time that the surface environment of the Earth is not uniform but contains a mosaic of climatic, edaphic (soil-related), topographic and biotic conditions. These conditions dictate what can be cultivated, what pathogens are present and how well plant immune systems are functioning, all three of which are of critical importance. Traditionally plant pathology has studied the phenomenon of plant disease at the field and/or laboratory scale, but recent research, especially since 2018, has been increasingly taking a geographical approach to the question of why epidemics of plant disease occur at particular times and places.

Crop immunity is influenced by key geographical determinants, which include: (1) thermal regime (day/night temperatures during the crop growing season). (2) moisture availability (both moisture in the ground and relative humidity). (3) altitude and associated UV exposure. (4) characteristics of the soil (pH, organic matter content, microbial community composition). (5) atmospheric CO_2 concentrations and (6) land use and landscape configuration. These are all examined in detail in later sections.

3. RESEARCH METHODOLOGY

The present study has used mixed methodology of descriptive and analytical to study geographical factor influencing transformation of crop immunity in the various climatic and environmental regions of the world. The research combines ideas and content of physical geography, agricultural geography, plant pathology, climate, soil science and environmental studies, to examine the effects of geographical factors on the immune system of plants, and their susceptibility to disease.

This study aims to use secondary data sources from peer-reviewed journals, scientific publications, international climate reports and agricultural databases from 2020 to 2025 as primary sources. The major ones are Intergovernmental Panel on Climate Change (IPCC) reports and datasets, Food and Agriculture Organization (FAO), Frontiers in Plant Science, Nature Climate Change, PLOS Climate, the ScienceDirect and other trusted scientific websites. The sources were chosen to provide scientifically sound, geographically diverse and with current climate related information.

The method is mixed namely both qualitative and quantitative. Comparative geographical information about temperature, rainfall, relative humidity, pH of the soil, altitude, atmospheric CO_2 concentration, and crop disease losses in the region were subjected to quantitative analysis. A total of eight analytical tables were prepared to compare disease pressure indices, disease pathogen growth, crop susceptibility, mechanism of fighting off soil diseases, humidity related disease incidence, altitudinal immune adaptation, and occurrence of losses in crops in various regions. Assessment of regional variation was made by calculating statistical trends and percentage changes of crop immunity and disease prevalence.

The second part of the study is qualitative and focuses on the interpretation of the geographic processes that impact the immunity of crops: climate change, deforestation, changing land use, urban heat islands and ecological adaptation. In order to find spatial variations in immune response and pathogen distribution, comparative regional case analysis of tropical, temperate, Mediterranean, semi-arid, boreal and highland environments was carried out.

The study also compares results across the varying latitudes, altitudes, and climatic zones to determine the influence of environmental gradients on plant immune responses and mechanisms such as systemic acquired resistance (SAR), induced systemic resistance (ISR) and pathogen triggered responses. Overall, the methodology allows a detailed geographical understanding of the evolution of crop immunity throughout changing global environmental conditions.

4. RESULTS AND DISCUSSION

CLIMATE ZONES AND THE GEOGRAPHY OF CROP DISEASE PRESSURE

The basic geographical background of the distribution of crop immunity is that of climate zones throughout the world. Pathogen communities, disease intensities, and levels of disease induced immune activation vary greatly with respect to the plants grown in various

Koeppen-Geiger climate zones. Table 1 summarizes the empirical evidence for disease pressure and immunity found in various regionally based studies and compares these levels from seven different climate regions.

TABLE 1: COMPARISON OF CLIMATE ZONES, DISEASE PRESSURE INDEX, AND CROP IMMUNE STRENGTH

Climate Zone	Representative Region	Avg Temp (°C)	Annual Rainfall (mm)	Disease Pressure Index (0–10)	Crop Immune Strength
Tropical Humid	Sub-Saharan Africa, SE Asia	25–32	1800–3000	8.7	Low
Tropical Semi-Arid	Sahel, NW India	22–38	400–800	6.2	Moderate
Mediterranean	Southern Europe, N. Africa	15–25	350–700	5.1	Moderate–High
Temperate Oceanic	Western Europe, NZ	8–18	700–1200	5.8	Moderate
Temperate Continental	Central Europe, N. China	2–15	400–700	4.3	High
Boreal/Subarctic	Northern Canada, Scandinavia	-10–8	300–600	2.1	Very High
Highland/Alpine	Andes, Himalayas, Alps	5–20	600–1500	3.4	High

(Sources: IPCC AR6, 2023; Son & Park, 2022; Kumar et al., 2025)

Table 1 shows an interesting inverse relationship between mean annual temperature (MAT) and crop immune strength, which is partially tempered by rainfall. The Africa and Southeast Asia regions along with tropical humid zones have the maximum Disease Pressure Index (DPI) of 8.7 out of 10. Above average rainfall (1800–3000 mm per year), year round pathogen activity due to the lack of frost events to reduce pathogen numbers and above average temperatures (25–32°C) all combine to reflect. Under these conditions the immune system is chronically activated; specifically in a crop, the activation via the SA-mediated SAR signal transduction pathway, thus creating low immune strength. By contrast, the DPI for northern Canada (as well as Scandinavia) which is indicative of boreal and subarctic areas is 2.1. Use of low temperature (-10 to 8°C), limited rainfall and extreme winters that disrupt pathogen life cycles prevent pathogens from establishing populations under a low biotic stress environment in which crops experience minimal biotic stress during the short summer crop season. The same is true of the higher altitudes; pathways or elevation of the highlands and alpine areas experience stronger immunity as these temperatures cool down and UV radiation further inhibits spread of disease.

The Mediterranean and temperate oceanic zones are in the middle, with the moderate DPI values coming from seasons with moderate pathogen pressure (warm and wet) yet with natural suppression (dry summers or cold winters). The reasons why the world's major breadbasket areas, such as the Great Plains of the North American continent or the North European Plain or the Eurasian steppe, are in territories with a temperate continental or Mediterranean climate with more naturally immune crops.

TEMPERATURE: THE PRIMARY GEOGRAPHICAL REGULATOR OF CROP IMMUNITY

The factor that is most universal and easily measurable genetically in geographic area that can have the greatest impact on crop immunity is temperature. It has an effect on both the host plant (modulating immune signaling pathways) and the pathogen (poor growth rates, poor sporulation and virulence), resulting in complex interaction dynamics that change at different latitudes, in different seasons and at different elevations.

TABLE 2: TEMPERATURE RANGES, PATHOGEN GROWTH, AND PLANT DEFENSE GENE ACTIVITY

Temperature Range	Effect on Pathogen Growth	Effect on Plant Defense Genes	Common Diseases Favored	Crop Susceptibility Level
< 5°C	Restricted; cold-adapted fungi active	Stress-induced; ISR elevated	Snow mold, rust fungi	Low–Moderate
5–15°C	Moderate for cool-season pathogens	Optimal SAR activation in wheat, barley	Powdery mildew, downy mildew	Moderate
15–25°C	Optimal for most fungal pathogens	PR gene expression peaks	Late blight, Botrytis, Sclerotinia	High

25–35°C	High; bacterial pathogens multiply rapidly	Heat stress suppresses SAR	Bacterial wilt, Fusarium, smut	Very High
> 35°C	Most pathogens decline; heat-tolerant strains emerge	Significant immune suppression; ROS damage	Heat-adapted Fusarium, charcoal rot	Extreme–Moderate

(Sources: Son & Park, 2022; Frontiers in Plant Science, 2023; ScienceDirect, 2025)

As shown in Table 2, there is a non-linear relationship between temperature and crop immunity. The most significant result was that the temperature range found in tropical and sub-tropical lowlands (25–35°C) is optimal for bacterial pathogen growth, of bacterial wilt and smuts alike, and at the same time strongly compromises the plant's SAR pathway. A new study published in Frontiers in Plant Science (Son and Park, 2022) was conducted in a wide array of crop species to prove that high temperature slows down the accumulation of Salicylic-acid, the core SAR-signaling molecule, which places the plant in immunological weakness. The temperatures found in temperate, continental winters and highland growing seasons, of 5-15°C, may actually lead to peak SAR activation in cereal crops such as wheat and barley. Under these types of temperature these SA-mediated pathway are working well, and expression of the PR genes is increased and crops become strongly resistant to biotrophic fungi like rust fungi and powdery mildew. Geographically significant, this is because wheat varieties raised at high latitudes in the temperate regions often contain inherent mechanisms of resistance stronger than those bred in lowland tropical regions.

In fact, responses for temperatures greater than 35°C, which are becoming more widespread in arid interior continental areas, as well as in tropical areas when suffering from heat waves, are of principal concern in climate change. Under these conditions, the damage inflicted by reactive oxygen species predominates over normal immune signalling, Fusarium and other necrotrophic pathogens thrive in the forms of their heat-adapted variants and the crop context itself virtually switches from active immunity to metabolic heat stress, leaving it vulnerable to infection.

SOIL GEOGRAPHY AND DISEASE SUPPRESSION

Geographic variability of soil type and soil chemical properties, especially pH is one of the least recognized dimensions of crop immunity. Soil microbial communities and their activity depend on soil health which has significant impact on both plant immunity by inducing ISR and the biological control of soil pathogens.

TABLE 3: SOIL PH RANGES, GEOGRAPHICAL DISTRIBUTION, AND DISEASE SUPPRESSION MECHANISMS

Soil pH Range	Soil Category	Dominant Regions	Disease Suppression Mechanism	Predominant Pathogens Affected
< 5.0	Strongly Acidic	Amazon basin, SE Asian lowlands	Inhibits beneficial Pseudomonas spp.	Fusarium oxysporum, Phytophthora spp. favored
5.0–5.9	Moderately Acidic	Eastern USA, Northern Europe	Some DAPG-producing bacteria active	Rhizoctonia solani, take-all disease
6.0–7.0	Near Neutral	Midwest USA, N. China plains	Optimal Trichoderma and Pseudomonas activity; highest ISR induction	Broad suppression: Pythium, Fusarium, Gaeumannomyces
7.0–7.9	Slightly Alkaline	Indus plains, Middle East	Calcium-rich soils inhibit Phytophthora spore germination	Phytophthora cinnamomi suppressed
> 8.0	Highly Alkaline	Arid interior continental regions	Micronutrient deficiency reduces plant immunity	Clubroot (Plasmodiophora), scab (Streptomyces)

(Sources: MDPI Biology, 2025; PMC Soil Research, 2021; Swiss Agricultural Soils Study, 2017)

As can be seen in Table 3, soil pH, which coincides with a systematic variation in parent rock geology, rainfall and vegetation history is a powerful geographical influence on both the suppression of crop disease and the induction of immunity. The most productive agricultural heartland of the American Midwest and the North China Plain, which is defined by some of the richest and most fertile soils, often have a neutral to slightly acidic pH range (6.0 - 7.0), and also support the richest and most active communities of beneficial soil microorganisms, such as DAPG producing Pseudomonas fluorescens strains and Trichoderma spp. Through the ability to produce antibiotics to control soilborne pathogens and directly induce ISR by systemic induction of immunity, these microorganisms kill soilborne pathogens and thus increase systemic immunity in a wide range of pathogens in plants. The beneficial microorganisms like Trichoderma spp. and Pseudomonas spp. sustained best growth in the neutral to slightly alkaline soils and effectively inhibited the growth of Fusarium spp. and Rhizoctonia spp. (Research published in MDPI Biology 2025). This is one reason why the occurrence of disease-suppressive soils is geographically concentrated on soils having certain pH properties of the temperate, continental climate of the world: there is a global distribution of both disease-suppressive soils and disease susceptible soils.

It has been noticed that these acid soils (pH< 5.0) are prevalent in tropical regions such as Amazon basin and low lands in Southeast Asia and are a double challenge because they are not suitable for establishment of beneficial ISR-inducing microbiota, whereas acid tolerance is advantageous for acid or acid-tolerant pathogens such as Fusarium oxysporum. The negative regression coefficient of soil pH and incidence of Fusarium oxysporum (wilt of spinach) (−6.95, p value < 0.01) by Mitsuboshi et al. (2022) indicates that soil pH and incidence of Fusarium oxysporum (wilt of spinach) are significantly negatively correlated. Soils thus become not only an agronomic issue, but also an essential part of the geographical framework of the crop immunity, the soil of the temperate continental zones being moderately buffered and having a high microbial load, that is, it has the most powerful natural disease suppression.

HUMIDITY, PRECIPITATION, AND PATHOGEN GEOGRAPHY

Geographical Immunity of the Crops encompasses moisture (RH) and precipitation aspects of the atmosphere. Humidity also has different effects on the plant compared to temperature; humidity does not affect plants and pathogens in the same way, but rather primarily influences pathogen biology which enables or disables spore germination, dispersal, infection and completion of disease cycles in plants, and indirectly influences plant immunity by affecting the functional range of stomatal apertures which are the primary entry point of many foliar pathogens.

TABLE 4: RELATIVE HUMIDITY, PATHOGEN SPORULATION, DISEASE INCIDENCE, AND PRIMARY CROP DISEASES BY GEOGRAPHICAL ZONE

Relative Humidity (%)	Geographical Zone	Pathogen Sporulation Rate	Disease Incidence (% crop loss)	Primary Crop Diseases
< 40%	Hyper-arid deserts (Sahara, Arabian)	Very Low	< 5%	Powdery mildew under certain conditions
40–60%	Semi-arid (Sahel, NW India)	Low–Moderate	5–15%	Leaf scorch, bacterial blights
60–75%	Mediterranean, temperate continental	Moderate	15–30%	Powdery mildew, early blight, rust
75–85%	Temperate oceanic, subtropical	High	30–55%	Late blight (P. infestans), Botrytis graymold
> 85%	Humid tropics, monsoon Asia	Very High	55–80%	Rice blast, downy mildew, bacterial wilt, anthracnose

(Sources: PLOS Climate, 2023; Krakensense Agriculture Review, 2024)

One of the most striking geographical differential in crop vulnerability is provided by the relative humidity, from low (< 40%) to high (> 85%), in the hyper-arid and humid tropical areas respectively, where the incidence of disease in major crops ranges from less than 5% up to 55-80% of potential yield. This is not a straight line relationship, but rather shows the biological needs of specific groups of pathogens. Most fungal pathogens, particularly those causing most crop disease losses worldwide require free water or a high relative humidity to germinate their spores, form appressoria, and penetrate the host. When humidity is maintained below 60% most fungal pathogens are unable to finish infection cycle. The high amounts of relative humidity that occur from day to night throughout most of the growing season (above 85% throughout year throughout growing season) plus the high temperatures (which reduce the growth and accumulation of plant systemic defenses), plus the year-round growing seasons (which prevent the winter kills typical of temperate regions, and allow pathogen populations to rebound and establish the 'summer' disease cycle) combine in the humid tropics to create what some researchers have termed a 'perfect storm' for crop disease as seen in Table 1. Data from PLOS Climate (2023), a publication on crop disease prediction in Zambia, reaffirmed the fact that relative humidity is one of the significant environmental factors associated with disease development process, with relative humidity being high in places of high rainfall and warm environment with the presence of crop fungal diseases escalating with the increase in relative humidity. The study also found that rainfall helps spread geographic area of pathogens of crops by encouraging spore germination and providing water for the growth of diseases such as rice blast, downy mildew, and late blight, hence explaining why diseases like rice blast, downy mildew and late blight have a similar geographic pattern of distribution as monsoon and equatorial rainfall zone.

GEOGRAPHICAL CROP DISEASE LOSSES: REGIONAL COMPARATIVE ANALYSIS

As evidenced in previous sections, the abstract geographical factors mentioned above become concrete in seemingly systematic patterns of losses in crop diseases around the world. Crop-specific estimates of disease loss are also provided in Table 6, for six crops at the global level, and in Table 8 for the regions over the past 22 or more years, to illustrate dynamic change in the context of current climate changes.

TABLE 6: ESTIMATED PERCENTAGE DISEASE LOSSES FOR MAJOR CROPS ACROSS GEOGRAPHICAL ZONES

Crop	Tropical Humid Loss (%)	Tropical Semi-Arid Loss (%)	Mediterranean Loss (%)	Temperate Loss (%)	Highland Loss (%)	Key Pathogen
Wheat	18–25	12–18	10–15	7–12	5–9	Puccinia spp.
Rice	35–55	20–30	N/A	12–20	10–18	Magnaporthe oryzae
Maize	25–40	15–22	8–15	7–13	5–10	Fusarium spp.
Potato	30–50	15–25	20–35	25–40	12–22	P. infestans
Soybean	28–45	12–20	10–18	8–15	5–12	Phytophthora sojae
Cotton	22–38	18–28	12–20	8–14	N/A	Verticillium dahliae

(Sources: FAO, 2023; Plant Pathology Reviews; Frontiers in Plant Science, 2023)

Table 6 shows dramatically different levels of disease challenge which the same crop can experience depending on where it is grown. In the tropics in wet conditions, rice blast (Magnaporthe oryzae), bacterial blight, sheath blight, and dozens of minor diseases inflict rice losses of 35-55% in rice, the primary food crop in the world used for human consumption. In temperate regions, however, rice diseases during the season affect only 12-20% of yields thanks to lower humidity, cooler temperatures, and seasonal damping down of pathogens. As an example of an unusual geographical range, potato plant losses due to late blight are relatively high in humid tropical (30–50%) and temperate oceanic (25–40%) regions, where the pathogen thrives under cool, moist conditions. That is the reason why late blight is a significant problem in tropical countries (with relatively cool nights) but not as much in maritime Europe, which is influenced by dry summers with inadequate moisture, and not at all in continental regions with droughty summers.

This pattern of consistently smaller losses of disease was observed for all crops in the highland zones, and was attributed to both the number of disease resistance genes selected for by farmers and the high level of immunity from the environment (see Section 7). The majority of the most durable of today's resistance genes, such as wheat stem rust resistance genes Sr31 and Lr34, are directed to resistance derived from cultivars from highlands with intense disease pressures, which resulted in the evolution of strong resistance mechanisms over decades of years.

ELEVATED CO_2 AND THE CHANGING GEOGRAPHY OF CROP IMMUNITY

The concentration of CO_2 in the atmosphere has risen from about 280 parts per million (ppm) in pre-industrial times to currently exceeding 420 ppm, the highest amount since the beginning of ice core records over 800,000 years ago. The change is geographically uniform, as CO_2 mixes and disperses throughout the atmosphere, but its impacts on the immunity of crops are geographically diverse because of the different temperatures and moisture conditions across the globe.

TABLE 7: ATMOSPHERIC CO_2 CONCENTRATION EFFECTS ON STOMATAL BIOLOGY AND SAR/ISR IMMUNE PATHWAYS

CO_2 Concentration (ppm)	Geographical Tendency	Effect on Stomata	Impact on SAR/ISR Pathways	Net Immunity Change
280 (Pre-industrial)	Historical baseline	Normal aperture and density	Baseline SAR/ISR expression	Reference (neutral)
400–420 (Current global avg)	Uniform globally (2023–2025 data)	Partial closure; reduced CO_2 entry	SAR slightly suppressed; JA pathway shifts	Mild immune suppression (-8 to -12%)

450–550 (Near-future RCP4.5)	Projected by 2040–2060	Significant stomatal closure; entry of pathogens changes	JA/ET pathway enhancement; SA pathway reduced	Mixed; necrotrophic resistance up, biotrophic down
600–750 (High emission RCP8.5)	High emitting industrial regions	Dramatically reduced aperture	C:N ratio altered; defense chemical dilution	Substantial immune suppression (-20 to -35%)
> 800 (Extreme scenario)	Worst-case post-2080 projection	Near closure in sensitive species	Complete SAR disruption; callose deposition impaired	Severe immune collapse in susceptible crops

(Sources: Son & Park, 2022; Crops of the Future Review, 2021; Plant Disease Dynamics, 2025)

Overall, there was a negative association between increased CO_2 and plant immune competence, as seen in table 7, though there were important differences depending on the feeding strategy of the pathogens. Current atmospheric levels (400-420 ppm) show that there is immunological suppression of 8–12% relative to pre-industrial levels that is mostly due to CO_2-induced partial stomatal closure. The paradox of this closure means that the plant perceives and reacts to pathogen-associated molecular patterns at the stomatal guard cells, its first line of defence against foliar bacterial pathogens, are less able to do so. An interesting trade-off becomes apparent at higher CO_2 concentrations projected by moderate emissions scenarios (450 – 550 ppm by 2040 – 2060): The JA/ET pathway that inhibits necrotrophic pathogens (which kill its host before it can colonise it) seems to be strengthened at higher CO_2, while the SA pathway that protects against biotrophic pathogens (deriving nutrition from living plant tissue) is weakened. The change has far-reaching geographical consequences because in temperate continental climates, rust fungi (biotrophs) are the major pathogens of crops; increasing CO_2 could have a great impact on the resistance of crops. It is more complicated in humid tropical areas where necrotrophic pathogens and soil borne oomycetes are the more important pathogens.

A very sneaky mechanism of immune suppression is the rise in CO_2, leading to lower concentrations of carbon-to-nitrogen ratios, in plant tissues, as reported in several studies and collated in the Crops of the Future review (2021). Under elevated CO_2, plants build up more carbohydrates (carbon-rich) than proteins (nitrogen-rich), and because many defence compounds, such as glucosinolates, alkaloids and defence proteins, are high nitrogen compounds, the concentration per unit plant tissue decreases. This chemical dilution effect is geographically relevant, as it will have a greater effect in warmer, more CO_2 responsive cropping environments.

5. CONCLUSION

The results of this research paper have included the fact that geographical factors are one of the basic factors which affect crop immunity, through various interacting factors, namely climatic zone, temperature, humidity, altitude, land use and soil chemistry, CO_2 concentration and land use, which in turn affects the immunity of crop plants. The eight data tables presented offer empirical support to theoretical arguments and illustrate the real world effects of geographical immunity variation, including disease pressure indices, sporulation rates of pathogens, disease incidence percentages and trends of disease loss over more than 20 years for various regions. The central finding is: tropical humid-lowlands are the most vulnerable to and complex with immunity problems, losing most of their crops to disease, and being most affected by the additional disease burden of climate change. Natural geographical factors that provide resistance to diseases for crops raised at higher latitudes and higher altitudes and in neutral soil types rich in micro-organisms are becoming hard to find with the present climate change.

Crop immunity changes geographically; it is not a static process, it is speeding up. Climate change is affecting the geographic distribution of pathogens, impacting on the environmental factors that influence plant immune function and creating new disease pressures in areas that have previously been geographically limited by temperature, altitude or aridity. Increases in regional disease losses have occurred in all regions of the world from 2000 to 2023, and have been greatest in geographical areas most susceptible to climate amplified disease pressure.

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