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P Prashant
Research Scholar, School of Agriculture, Lovely Professional University, Jalandhar-Delhi Grand Trunk Road, Punjab, India

Jyothi Anna Kurian
Research Scholar, School of Agriculture, Lovely Professional University, Jalandhar-Delhi Grand Trunk Road, Punjab, India

Corresponding Author:
P Prashant
Research Scholar, School of Agriculture, Lovely Professional University, Jalandhar-Delhi Grand Trunk road, Punjab, India

Puccinia spore movement in India compared to other sub-continent of the World: A review

P Prashant and Jyothi Anna Kurian

Abstract
Rust diseases are among the deadliest that may infect food crops, and they have historically resulted in massive yield losses around the world. Rust pathogens develop a significant number of spores in a short length of time, which are quickly spread by the wind across a vast area for re-infection of the crop. This feature of rust infections allows for several infection cycles over a vast geographical area in a short amount of time throughout the growing season, and can result in total yield losses in epidemic conditions. This document discusses the rust diseases that can be found in Canada comparing it with the rust pathogen movement in Indian Sub-continent, as well as the various management techniques utilised to combat them. Among all fungal groups, rust fungus have distinct systematic traits. For generations, mycologists have been fascinated by the fact that a single species of rust fungus can develop up to five morphologically and Cytologically unique spore-producing structures.

Keywords: Rust, pathogen, disease, fungi

Introduction
Puccinia is a genus of rust fungi that includes several species known to cause devastating diseases in various plant species, including wheat (*Triticum spp.*). Among the most economically significant pathogens affecting wheat crops are *Puccinia graminis*, *Puccinia striiformis*, and *Puccinia triticina*, which cause stem rust, stripe rust, and leaf rust, respectively. *Puccinia graminis*, commonly known as stem rust, has a long history of posing a significant threat to global wheat production. This pathogen affects wheat plants by forming characteristic orange to reddish-brown pustules, or uredinia, on the stems, leaves, and even glumes (Singh *et al*., 2015) [1]. The uredinia contain masses of rust spores called urediniospores. Upon maturation, these spores disperse and spread to nearby plants through wind, initiating new infections and accelerating disease progression. The life cycle of *Puccinia graminis* is complex, involving two host plants - the primary and alternate hosts. Wheat serves as the primary host, while species of barberry (*Berberis* spp.) act as the alternate host (Sharan *et al*. 2011) [2]. The pathogen overwinters as mycelium in the barberry host, and in spring, it produces Basidiospores that infect wheat. Once wheat becomes infected, the pathogen goes through several stages, including the formation of pustules and the release of urediniospores, which play a critical role in the disease's spread. *Puccinia striiformis*, commonly known as stripe rust or yellow rust, causes yellow-orange stripes of pustules on the leaves, glumes, and stems of wheat plants (Shrivastava *et al*., 2004) [3]. This disease often emerges during cool and moist weather conditions, making it more prevalent in regions with temperate climates. The pathogen produces urediniospores within stripe-like pustules that can be spread over long distances by wind (Singh *et al*., 2015) [1]. The rapid spread of *Puccinia striiformis* can lead to severe epidemics, causing significant yield losses and challenging wheat production in affected regions. *Puccinia triticina*, or leaf rust, is another significant wheat pathogen that affects the leaves and leaf sheaths. It forms small, reddish-brown pustules, which contain urediniospores, leading to the production of new infections. The pathogen can rapidly cycle through several generations in a single growing season, contributing to its potential for rapid spread and high disease severity. The impact of *Puccinia* rusts on wheat crops extends beyond direct yield losses. Severe rust infections can weaken the plant, making it more susceptible to secondary infections and reducing its overall vitality. Additionally, susceptible wheat varieties may require multiple fungicide applications to control rust outbreaks, leading to increased production costs and potential environmental concerns. To manage *Puccinia* rust diseases effectively, various approaches are employed. Breeding for resistance is one of the most sustainable strategies, as it reduces reliance on chemical controls and minimizes the

environmental impact (Gupta *et al*., 2018) [5]. Resistance genes are identified and introgressed into elite wheat cultivars to provide durable and broad-spectrum protection against different rust races. Furthermore, monitoring rust populations and pathogen movement is essential for early detection and timely deployment of control measures.

The primary infection usually begins with urediniospores, which are the most common and prevalent spore stage of *Puccinia* fungi. These spores are produced within pustules or uredinia, often visible on the surface of infected plant parts (Huerta *et al*., 2011) [11]. Urediniospores are airborne and can be carried over considerable distances by wind currents, facilitating the rapid spread of the disease. When urediniospores land on a susceptible host plant, they germinate, and the hyphae penetrate the plant's surface. Once inside the host, the fungus forms specialized structures called haustoria, which extract nutrients from the plant cells (Wellings *et al*., 2011) [8]. This nutrient extraction weakens the host and leads to the characteristic rust symptoms, such as yellowing, chlorosis, and the formation of pustules containing new Urediniospores. As the disease progresses, the rust pathogen undergoes a series of asexual cycles, with Urediniospores continuously re-infecting new host tissues, leading to repeated cycles of infection. This process can cause rapid disease development and exacerbate epidemics, especially under favorable environmental conditions for spore germination and infection. In certain rust species, another spore type known as Teliospores develops as the infection progresses (Jin *et al*., 2007) [10]. Teliospores are usually darker in color and are often formed within the same pustules as Urediniospores. Unlike Urediniospores, Teliospores are thicker-walled and are capable of surviving harsh environmental conditions, such as winter or dry periods. Teliospores serve as the overwintering stage for many *Puccinia* species, enabling the pathogen to survive adverse conditions until the next growing season (Ali *et al*., 2014; Singh *et al*., 2011) [4, 6]. When conditions become favorable again, teliospores germinate, producing basidiospores that infect the alternate host plant (if present in the life cycle) or lead to the formation of new urediniospores, completing the rust's life cycle. The infection of both the primary and alternate host plants contributes to the genetic diversity and evolution of *Puccinia* pathogens. The alternation of generations between different host species can lead to the development of new rust races with different virulence profiles, which can overcome previously resistant host cultivars.

Movement of spore in Indian subcontinent

Puccinia is a genus of fungi that includes many species that are plant pathogens. Some of the species in this genus cause rust diseases in crops such as wheat, barley, and other cereals. The movement of *Puccinia* pathogens in India can depend on a variety of factors, including environmental conditions, crop cultivation practices, and the movement of infected plant material. The movement of *Puccinia* pathogens in India is monitored by the Indian Council of Agricultural Research (ICAR) and other organizations responsible for crop protection (Singh *et al*., 2015) [1]. These organizations track the movement of rust diseases by conducting regular surveys of crop fields and analyzing samples of infected plant material. They also disseminate information on disease outbreaks and provide guidance to farmers on how to manage and control the spread of these diseases (fig. 1.). One notable example of *Puccinia* disease in India is wheat rust, caused by the *Puccinia triticina* and *Puccinia striiformis* fungi. Wheat rust has been a persistent problem in India for many years, with periodic outbreaks causing significant crop losses. To combat this disease, ICAR and other organizations have developed rust-resistant wheat varieties and promote the use of fungicides and other control measures. Overall, the movement of *Puccinia* pathogens in India is a complex issue that requires ongoing monitoring and management to minimize crop losses and ensure food security.

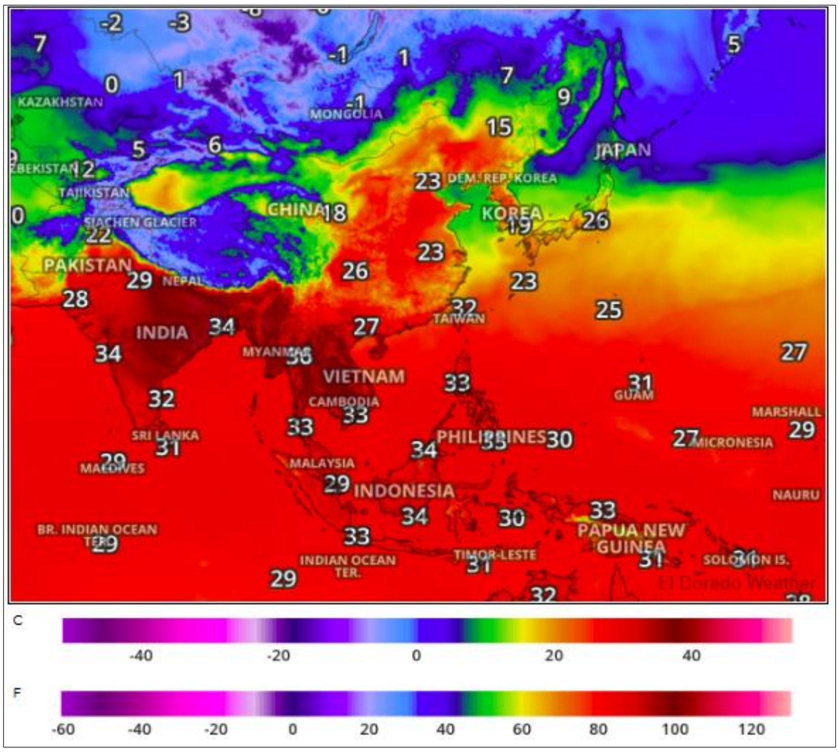

Fig 1: Thermal map of Asian sub-continent temperature ranging from -1 ºC low in north china and 34ºc high in south east Asian sub-continent.

Movement of spore in African Continent

One study published in Plant Disease in 2013 investigated the genetic diversity and population structure of *P. graminis* in Ethiopia. The authors collected stem rust samples from different regions of the country and used molecular markers to analyze the genetic diversity of the pathogen. They found that *P. graminis* populations in Ethiopia were highly diverse, with multiple genetic lineages present (Abate *et al*. 2013) [11]. The authors suggested that the movement of infected plant materials and windborne spores could be responsible for the widespread distribution of the pathogen (fig. 2.). Another study, published in Phytopathology in 2020, investigated the movement of *P. graminis* in East Africa. The authors used genomic sequencing to analyze the genetic diversity of the pathogen in different countries, including Kenya, Ethiopia, and Uganda. They found that *P. graminis* populations in East Africa were highly diverse, with multiple genetic lineages present. The authors suggested that the movement of infected plant materials, as well as windborne spores, could be responsible for the widespread distribution of the pathogen. A study published in Plant Pathology in 2019 investigated the genetic diversity and population structure of *P. striiformis* in Ethiopia. The authors collected stripe rust samples from different regions of the country and used molecular markers to analyze the genetic diversity of the pathogen (Bockus *et al*., 2009; Johnson *et al*., 2012) [12, 13]. They found that *P. striiformis* populations in Ethiopia were highly diverse, with multiple genetic lineages present. The authors suggested that the movement of infected plant materials and windborne spores could be responsible for the widespread distribution of the pathogen.

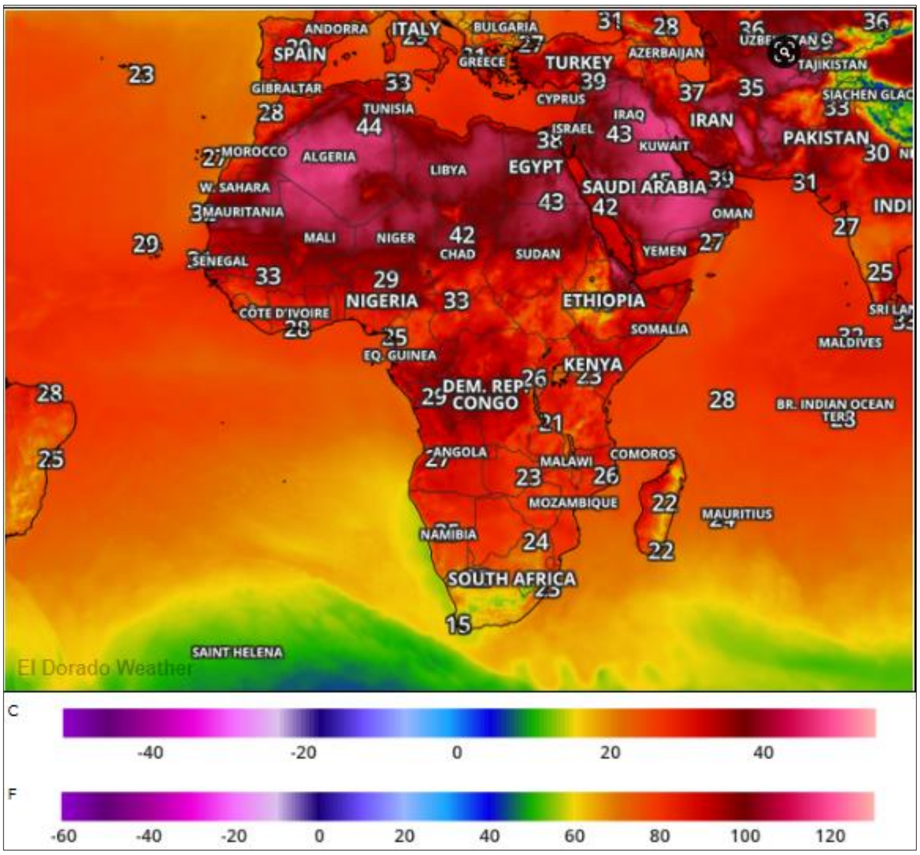

Fig 2: Thermal map of African Continent. Temperature ranging from 15 °C low South Africa and $4 °C high in Democratic Republic of Congo.

Movement of spore in North-American and Canadian Sub-Continent

Puccinia is a genus of rust fungi that includes many species which can cause plant diseases. These fungi produce spores that can be easily dispersed by wind, water, and other means. The movement of *Puccinia* spores in the North American subcontinent can be influenced by several factors, including weather patterns, host plant distribution, and human activities. One example of the movement of *Puccinia* spores in North America is the spread of *Puccinia graminis*, a fungus that causes stem rust in wheat and other cereal crops (Chen *et al*., 2002) [14]. This fungus is known to produce airborne spores that can travel long distances and infect crops in new areas. In the early 20th century, stem rust caused devastating losses in wheat production in North America, leading to the development of rust-resistant wheat varieties (fig. 3). Another example is the movement of *Puccinia* Psidii, a fungus that causes myrtle rust, a disease that affects a wide range of plants, including eucalyptus, guava, and other species in the myrtle family (Carnegie *et al*., 2010) [15]. This fungus is believed to have been introduced to North America from Australia, where it is a major problem for the forestry industry. In North America, myrtle rust has been found in Hawaii, California, and Florida, and its spread is closely monitored by plant health officials. In general, the movement of *Puccinia* spores in North America is influenced by a complex set of factors, including climate, plant distribution, and human activities such as trade and travel. Plant health officials use a variety of tools and strategies to monitor and manage the spread of these fungi, including quarantine measures, disease-resistant crop varieties, and biological control agents.

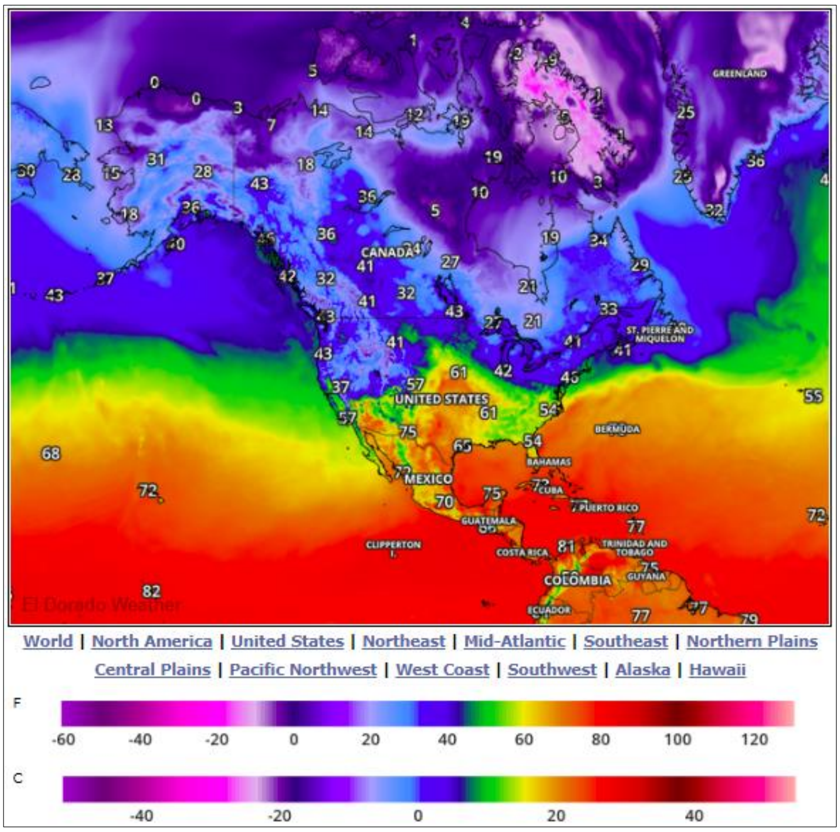

Fig 3: Thermal map of North American sub-continent. Temperature ranging from 0 °C low in north American/Canada and 77 °C high in South America

Movement of *Puccinia* path in the south-east Asia

One of the main ways in which *Puccinia* path spreads in Southeast Asia is through windborne spores. Studies have shown that the pathogen can travel long distances on wind currents, allowing it to quickly infect new regions and cause widespread damage to wheat crops. For example, a study conducted in 2014 found that *Puccinia* spores were able to travel over 1,500 km from the wheat-growing regions of China to the Himalayan foothills in India. The movement of *Puccinia* path in Southeast Asia is also influenced by the diversity of host plants (fig. 1.). The pathogen can infect several species of grasses, including wheat, barley, and rye, as well as some wild grasses. The presence of these alternate hosts can provide a source of inoculum for the pathogen and increase the risk of infection in wheat crops (Duveiller *et al*., 2007) [16].

Climate is also an important factor in the movement of *Puccinia* path in Southeast Asia. The pathogen is known to thrive in cool and humid conditions, making the winter season an ideal time for its spread. Studies have shown that the incidence of wheat rust in Southeast Asia is highest during the winter season, particularly in the wheat-growing regions of the Himalayas (Joshi *et al*., 2007) [17]. Agricultural practices such as the use of susceptible wheat varieties and the absence of crop rotation also contribute to the spread of *Puccinia* path in Southeast Asia. Studies have shown that the use of resistant wheat varieties can significantly reduce the incidence of wheat rust in Southeast Asia (Pretorius *et al*., 2000). Similarly, crop rotation can reduce the build-up of pathogen inoculum in the soil, making it less likely for *Puccinia* path to establish in a given region (Duveiller *et al*., 2007) [16].

Movement of *Puccinia* Spore in Russian Sub-Continent

Climate is another important factor in the movement of *Puccinia* path in Russia. The pathogen is known to thrive in cool and humid conditions, making the spring and early summer seasons an ideal time for its spread. Studies have shown that the incidence of wheat rust in Russia is highest during the spring season, particularly in the wheat-growing regions of the southern part of the country (Kolmer *et al*., 2011) [19]. Human activities such as the movement of infected plant material and the use of susceptible wheat varieties also contribute to the spread of *Puccinia* path in Russia (fig. 4.). Studies have shown that the use of resistant wheat varieties can significantly reduce the incidence of wheat rust in Russia (Morgounov *et al*., 2012) [20]. Similarly, the implementation of strict quarantine measures can help prevent the movement of infected plant material and reduce the risk of pathogen spread (Kolmer *et al*., 2011) [19].

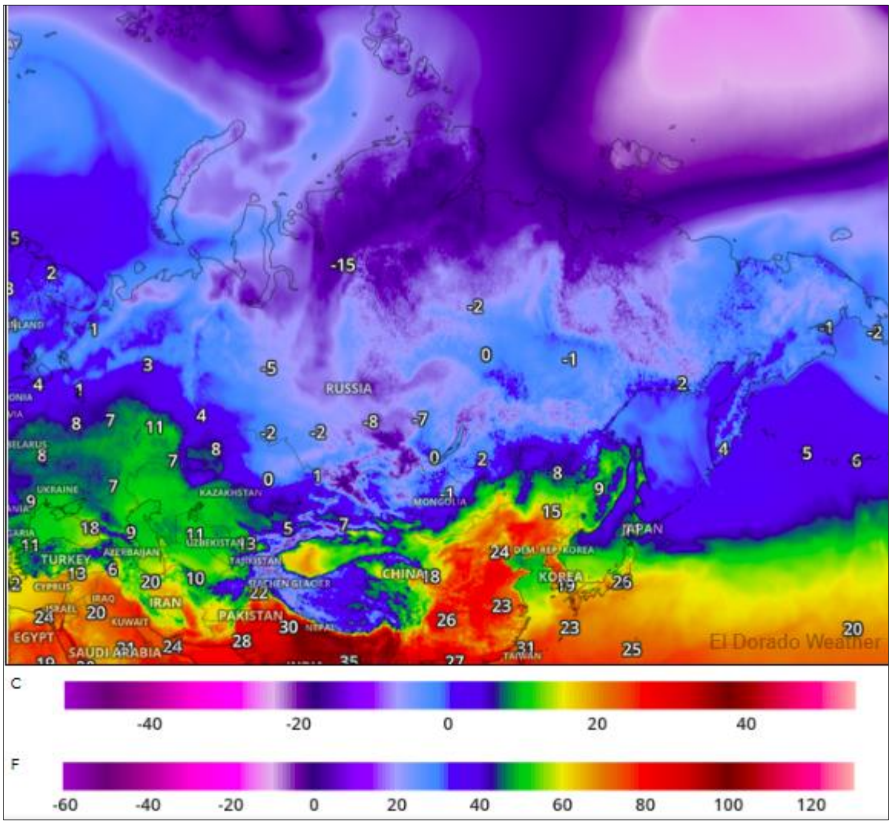

Fig 4: Thermal map of North Russia. Temperature ranging from -15C low in North Russia and 31 ºC high in South Russia/Indo-China.

Movement of *Puccinia* Path in the Australia continent

To monitor the movement of *Puccinia* pathogen in Australia, a national surveillance program is in place, which involves the collection and analysis of wheat rust samples from across the country (Wellings *et al*., 2017) [22]. The surveillance data is used to track the movement of the pathogen and to identify the emergence of new patho types that may be more virulent or resistant to fungicides. In addition to the surveillance program, various management strategies are employed to minimize the impact of *Puccinia* pathogen on wheat production in Australia (fig. 5.). These include the use of resistant wheat cultivars, the application of fungicides, and the use of cultural practices to reduce the inoculum load (Park *et al*., 2016) [21].

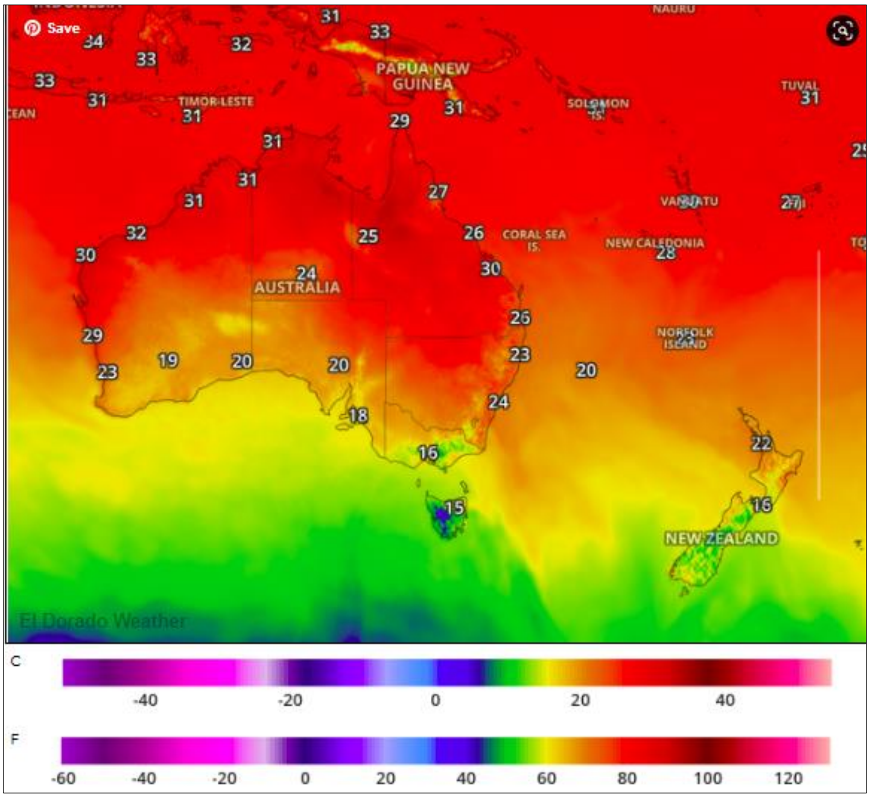

Fig 5: Thermal map of Australia. Temperature ranging from 15C low and 34 ºC high in South.

Discussion and Conclusion

In conclusion, the movement of *Puccinia* spores, which cause wheat rust, is a complex and dynamic process that varies across different continents and countries of the world. Wind-borne spores play a crucial role in long-distance dispersal, allowing the pathogen to quickly spread and establish in new regions. Climate and weather patterns also influence the movement of *Puccinia* spores, as the pathogen thrives in cool and humid conditions, and its incidence is often highest during specific seasons. While the movement of *Puccinia* spores is a global challenge, scientific research and international cooperation have provided valuable insights into the dynamics of pathogen dispersal. By understanding and addressing the factors influencing the movement of *Puccinia* spores, we can work towards sustainable and resilient agriculture, safeguarding wheat production worldwide. In summary, the movement of *Puccinia* spores is a multifaceted phenomenon that varies across different continents and countries. Through comprehensive research and coordinated efforts, we can develop effective strategies to combat wheat rust and protect global food security.

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