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Review Article

AN OVERVIEW OF LEAF RUST RESISTANCE GENES IN TRITICUM AESTIVUM

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Abstract: *Wheat is the world's third big crop producing 600 million tonnes yearly. For example, wheat harvest in 2007 was 607 million tonnes compared to rice and maize production of rice was 652 million tonnes and production of maize was 785 million tonnes. Although, due to fungus diseases, we lose 10% of our crops yearly. Leaf rust (Lr), Stripe rust (Sr), and yellow rust (Yr) are the three types of rust that are present in wheat. In this article, we discussed leaf rust and its resistance genes. Leaf rust is also known as "Brown Rust". This disease is caused by the fungus Puccinia recondita f. sp tritici, which is the most serious in common wheat (Triticum aestivum). These fungal pathogen-caused resistance genes degrade the amount and quality of wheat fields. Leaf rust is primarily found on leaves, but it can also infect glumes. Scientists studying the illness have discovered that there are many types of resistance genes present in Leaf rust, which is also known as Lr. Until today there are 80 resistance genes have been discovered in leaf rust (Lr). So, the resistance genes Lr1 to Lr3ka, Lr10 to Lr13, Lr14b to Lr17b, Lr20, Lr22b, Lr27, Lr30, Lr31, Lr33, Lr34, Lr46, Lr48, Lr49, Lr52, Lr60, Lr67 to Lr70, Lr73 to Lr75, Lr78 and Lr80 theses all resistance genes of leaf rust (Lr) present in wheat (Triticum aestivum). These genes, Lr9 and Lr76 were discovered in (Aegilops umbellulate). Lr14a is a subset of Lr14 (Triticum dicoccum). Lr18 and Lr50 (Triticum timopheevii). Lr19, Lr24, Lr29 (Thinopyrum ponticum). Lr21, Lr22a, Lr32, Lr39, Lr42 (Aegilops tauschii). Lr23, Lr61 and Lr72 are different LRs (Triticum turgidum ssp. Durum). Lr25, Lr26, and Lr45 (Secale cereale). Lr28, Lr35, Lr36, Lr47, Lr51, Lr66 (Aegilops speltoides). Lr37 is an abbreviated form of the word (Triticum ventricosum). Lr38 is a slang name for a (Thinopyrum intermedium). Lr44, Lr65 and Lr71 (Triticum aestivum spelta). Lr53 and Lr64 (Triticum dicoccides). Lr54 is the resistance gene assigned to (Aegilops kotschyi). Lr55 is slang (Elymus trachycaulis). Lr56(Aegilops sharonensis). Lr57(Aegilops geniculate). Lr58(Aegilops triuncialis). Lr59(Aegilops peregrina). Lr62 (Aegilops neglecta). Lr63 (Triticum monococcum). Lr77 (Santa Fe). Lr79 (Triticum durum). Different varieties of wheat include these resistance genes. These resistance genes were identified because farmers don't use spares or toxic chemicals on wheat. After all, these chemicals affect human health, so these resistance genes were identified to save human health.*

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Introduction

Wheat (*Triticum aestivum* L.) is the crop which ranked the third number globally. This crop is widely farmed in more areas than other crops such as rice etc. wheat was first cultivated in southwestern Asia (Feldman & Levy, 2015). Still, we just discovered that wheat production is very good in Syria, Jordan, and Turkey. Wheat is a staple food in both developed and developing countries. Producing more wheat is forecast to become the most important consideration as the world population of countries expand rapidly, with an estimated population of above 9 billion before 2050 (Levy & Feldman, 2022). As Dixon and his colleagues reported, from 2004 to 2006, the wheat product was six hundred twenty-one million tonnes, an average of two hundred seventy million (Dixon et al., 2009). In 2014 FAO reported that wheat production increased by 659.7 million tonnes from 2012 to 2013, and from 2013 to 2014, the production rate was 715.1 million tonnes. Wheat is a major field in the middle of economically and growing countries, in terms of manufacturing and utilization; in 76 developing countries in 2007 produced wheat, 52 of them consumed 50 kg per person, and even more than 50 kg they consumed

(Brennan et al., 2014). There are only 9 developing countries out of 23 whose income source is less than 1,000 dollars per year. Notable wheat buyers consume more than 50 kilograms per year. And 8 developing countries produce more than 50 kg per year, even more than 0.5 million tonnes. Some countries control 150% or more than 150% of wheat products. Such countries are East Africa, the Middle East, and North Africa. In 2009 FAOSTAT reported that the product and demand for wheat and wheat-related items is increasing rapidly to 760 million tonnes, and their annual growth is 1.6%, 880 million tonnes increase in 2020 to 2050 (Jørgensen et al., 2020; Wang et al., 2014).

Biological and abiotic factors have an impact on crop products around the world. Diseases, insects, and weeds, among other biotic stress, can wipe out 31 to 42% of all crops yearly (Agrios, 2005; Balqees et al., 2020; Farooq et al., 2021; Fatima, Saeed, Khalid, et al., 2022; Fatima, Saeed, Ullah, et al., 2022; Iqbal et al., 2021; Iqra et al., 2020). Diseases account for roughly 14% of these losses, amounting to US 220 dollars annually. Pathogens also strike wheat or viruses like parasitic fungi, rust, bacteria, and viruses, which effectively destroy wheat production. Rusts are one of the most important diseases found in cereal fields, and this disease is more often found in wheat production. Due to the disease, we face a lot of losses in wheat production (Ghafoor et al., 2020; Idrees et al., 2022; Naseem et al., 2020; Park et al., 2011; Sarwar et al., 2021; Singh et al., 2008; Tahir et al., 2020).

Rust is produced by fungi which belong to *Basidiomycetes* class and order *Pucciniales*. There are now three types of rust found in the production of wheat that is stem rust which is also known as (Black rust), the second one is leaf rust which is known as (Brown rust); and the third one is stripe rust which is known as (Yellow rust). And there three diseases belong to the wheat diseases, which are produced by the pathogens *P. triticina (*Pt*), Puccinia graminnins f. sp tritici* (Pgt), and *P. striformis f. sp. trici* (Pst). Rust fungi are extremely esoteric viruses that vary greatly in terms of virulence/virulence and host-fighting genes (Friebe et al., 1996; Herrera-Foessel et al., 2014).

The shape, the life cycle and the environmental options which produce and develop rust pathogen. *Pgt* is found in hot and humid environments, whereas *Pst* prefers cooler temperatures, *Pst* pathogens also adapted the warmer temperatures (Milus et al., 2015). And the last one, Pt adapted to a vastly greater variety of circumstances, making these rust diseases more common (Bariana et al., 2007). Infections further play the most important role in destroying or reducing the wheat crop output in Eastern Africa, particularly Ethiopia. The restricted genetic basis for resistance (Beteselassie et al., 2007) and the fast rate of the virus's development are the major reasons for wheat cultivars' vulnerability to diseases like *Pgt*. For example, the discovery of *Pgt* race "Ug99" in Uganda in 1998 (Pretorius et al., 2000), there is a large virulence spectrum for fighting genes or resistance genes such as *Sr31*, which spread to Kenya and Ethiopia, posing a severe danger to Africa's food security. In Australia, the product of wheat has been challenged by stem rust disease since European arrival in the 1800s (McIntosh & Brown, 1997).

The use of genetic resistance to pathogens, as well as fungicides, is essential for the effective control of grain rust infections (Brennan & Quade, 2006). In Australia, diseases cost between AUD 2-11 dollar million per year (Brennan & Murray, 1998); when rust is controlled utilizing genetic resistance, saved AUD 99, 85, and 161 dollars each year for stripe, stem rust and leaf rust. And the savings from chemical sprays annually, on the other hand, were estimated to be over AUD 12 million across these three rusts. We control rust infections by resistance genes. This is the most suitable and most cost-effective way in wheat production to control these diseases in low-yielding and low-returns systems (Singh et al., 2008).

Wheat

Wheat is a widely farmed cereal in many settings, including high rainfall, irrigated dry, warm humid, and dry and cold. Wheat can thrive in a cool environment because it is a C_3 plant (Monneveux et al., 2006). Lowest and most temperatures for the sake of wheat growth are 3°C to 4°C, 25°C, 30°C TO 32°C (Briggle, 1980). They tolerate varying moisture levels, from xerophytic to littoral. In winter wheat, the heading occurs late and necessitates a time of cold conditions. In most cases, in springtime, wheat is spread (Curtis et al., 2002). Even though increasing the region seeded towards wheat has largely stopped to see one key origin about enhanced wheat yield, global wheat product climbed dramatically between 1951 and 1990 (Reynolds, 1996). Wheat is also used extensively in the homeland where it is grown, with barely 1/5 of the year yield exchanged. In 2014/2015, the trade of wheat globally was anticipated to be 149.5 million tonnes, and in 2013/2014, we lost 1 million tonnes because of rust diseases (Iqbal et al., 2014), with developing countries importing most of it. Wheat output must expand at 2% each year to fulfil rising human requirements, with no other land required (Gill et al., 2004). Understanding the function and structure of the wheat genome is critical to overcoming this obstacle.

Gene-for-gene hypothesis

Flor discovered the genetics of the flax (*Linum unsitatissimum*)- flax rust pathogens *Melampsora lini* interaction. Building on these findings, he discovered gene-for-gene hypothesis, which is stated that the single pathogen a virulence (Avr) genes and host resistance ® genes are distinct (Flor, 1971). The unsuitable is created by the recognition of a fighting genes which is present in the host and compatible virulence genes in the pathogens or may be lack of about each of two such genes across host or pathogen. In the disease functional alleles are inherited as a presiding factor. But a single host plant can have a variety of R genes which is aimed at a specific virus, and a pathogen have a variety of a virulence genes (Bent, 1996). It shows that pathogen biotype has a recessive allele to all relevant virulence genes which avoid detection by a potential host (Keen, 1990). The identification of pathogens a virulence gene by homologous R genes which is present in the host which triggers plant defensive system such as limit of cell death or may be inflammation reaction which prevents that pathogen from spreading beyond the infection site (Dangl et al., 1996).

Wheat leaf rust

Nature of pathogens

The most prevalent and universally issue rust disease of wheat is leaf rust, which is caused by *Puccinia triticina (Pt*). fungus is heteroecious so to complete its life cycle it needs a *telial/uredinial* host, typically wheat, as well as another pycnial/aecial host (*Thalictrum speciossissimum* or *Isopyrum fumaroides*) this host we need to complete its life span (Bolton et al., 2008).

Geographical distribution and its significance

Pt is also known as leaf rust. Leaf rust is also common and has a wider distribution than *Pgt* or *Pst*. The stage of plant growth determines the extent of leaf rust damage at the time of infection. In highly susceptible cultivars, the virus mostly targets only the leaf blades; maybe it also infects the sheet and glumes of the leaf. If the infection is caught early enough, it can result in 60-70% significant field loss. During a spike emergency, infection of the flag leaf shows in grain output losses up to 30%, while infection on the soft dough stage shows less than 7% result. If infection occurs early, yield loss can be significantly more than 50% (Crespo-Herrera et al., 2018).

Although leaf rust caused smaller damage than stem and stripe rust, it is thought to generate higher overall global losses due to its more frequent and broad presence (Herrera-Foessel et al., 2012). When extensive regions of a single variety or closely similar cultivars are seeded to a single variety or cultivars, damage from leaf rust becomes more severe, as it does with all rust diseases. Winter wheat yield losses can be significant (Roelfs, 1985; Samborski, 1985). Outbreaks in winter wheat have become increasingly common in some parts of the United States; for example, from 2000 to 2004, more than 3 million tonnes were lost, estimated at more than 350 dollars (Herrera-Foessel et al., 2012). During 1976-1977, a Pt epidemic devastated commercial farms in northwest Mexico (Samborski, 1985).

Life cycle and host range

The survival of the *Pt* uredinial phase in the middle of the age and wheat crops for epidemic consent is determined by weather factors, for example, appropriate climate and quantity of moisture present (Levy & Feldman, 2022). At around 20°C, infection can occur in three hours with dew or less, but larger dew times need more infection to develop (Roelfs, 1985). Leaf rust survives between cropping cycles using volunteer-sensitive wheat plants or another host. However, green bridge Leaf rust principal host is *Triticum aestivum*; it has a reduced impact on *T. turgidum L.*, especially in the centre of the east, as well as in India and Ethiopia, in these areas' durum wheat is found more often (Roelfs, 1985).

Management

Alternate host

To live from a single season to come, *Pt* requires a living host. Several species act as other hosts and become a source of sexual reproduction for leaf rust. Such species are Thalictrum, Anchusa, Isopyrum, Clematis, Boraginaceae and Ranunculaceae. This phase is crucial to the recombination of many virulences and virulence components, as well as other genetic characteristics. As a result, eliminating these alternate hosts aids in the reduction of disease inoculum levels (Roelfs, 1992).

Fungicides

Because the average net return to the wheat grower precludes the use of the fungicides on a trial-and-error basis, an accurate leaf rust foresees structure is required in case fungicides are effective and cost-effective in minimizing cost (Everseyer 1970). Following the effective development of systemic fungicides, although the use of pesticides grew. Fungicide forces the disease to be utilized as a backup if new Pt are emerging and no new resistance varieties are usable. (Samborski 1985).

Resistance genes

The most significant and effective control technique is using genes that give *Pt* resistance. Many cultivars have been produced that are resistant to the pathogen's current pathotypes in their cultivation area. 70% loci are confirmed in wheat crops that show resistance to leaf rust; according to McIntosh and Brown in common hexaploidy (McIntosh & Brown, 1997), these loci tetraploid durum wheat and many wild wheat diploid species are described o these loci. Maximum leaf rust resistance genes are present in *Triticum aestivum*. However, they do originally receive into common wheat from wild species, *Lr9* leaf rust resistance gene is *Aegilops umbellulate*, and further, *Lr21, Lr22a, Lr32, Lr39, Lr40, Lr41, Lr42,* and *Lr43* theses are present in *Aegilops squarrosa*, and other leaf rust resistance genes such found in *Agropyron elogatum* such resistance genes are *Lr19, Lr24, and Lr2* (Park et al., 2011). *Lr, Lr3a, Lr13, Lr17a*, and *Lr24* are Australian spring wheat's leaf rust resistance genes (McIntosh & Brown, 1997). *Lr13 and Lr34 are* also present in several spring wheat varieties, which is present in South America. *Lr13 Lr3a* and *Lr26* are relatively prevalent in European winter wheat (Park et al., 2011). On the other hand, winter wheat has had less genetic work done on it than spring wheat (Samborski, 1985).

More persistent *Pt* resistance genes were identified in wheat crops (Singh et al., 2008). Including *Lr34* (Lagudah 2006). Lr13, these resistance genes are present in the South American wheat variety "Fontana" and other sources (McIntosh 1995). "Fontana" and "Exchange" have been widely used worldwide, and these resistances are long-lasting. In wheat, a blend of *Pt* resistance genes *Lr13* and *Lr34*, or maybe *Lr12* and *Lr34* (Roelfs, 1992). That produces long-term resistance. *Lr34* capacity interacts with other genes, giving effective increased resistance (Samborski, 1985). In 1997 Kloppers and Pretorius discovered that resistance conferred by gene combinations is higher than that conferred by single genes. Some resistance genes are most indicated in adult plants, which are helpful after growth phases. These resistance genes are *Lr12, Lr13, and Lr22a* (Milus et al., 2015). Pathogen assault throughout heading the adult stage of plants produces substantial production compared to the seedling stage because of the less floret set. Hence there are some uttering resistance genes at the adult stage of plants which is a major profitable in wheat breeding (Roelfs, 1992).

In wheat, there are 66 loci present, and 73 are resistance genes/alleles which have been identified to date, providing resistance to *P. triticina* there are resistance genes which were abandoned due to a lack of reference stocks or duplication with previously described loci and these resistance genes are that *Lr1* to *Lr73* they show symbols *Lr4, Lr5, Lr6, Lr7, Lr8, Lr40, Lr41*, and *Lr43*. About half of the approved resistance genes were discovered in *Triticum aestivum*, with the rest coming from grass species and being transferred into common wheat. Most leaf rust resistance genes in wheat transmit ASR, and 11 confer APR. Some resistance genes show allelic variation, such as *Lr2, Lr3, Lr14, Lr17*, and *Lr22*. However, there are 2 alleles which are reported at the *Lr14* locus (Lr14a and Lr14b). they merged in recent studies, indicating that they are tightly connected but not real alleles. This leaf rust disease has been managed in many countries by deliberately introducing resistance genes into new kinds. In Australia, it was projected in 2009 that developing and cultivating leaf rust- rust-resistant cultivars would save about 152 million dollars each year.

Conclusion

In this review article, we identified 80 *Lr* leaf rust resistance genes. Because of these resistance genes, we can control this rust disease. In further studies, we work more and more on these resistance genes because farmers sprayed toxic chemicals to kill these rust pathogens, which is very harmful to human health. Due to these resistance genes, we cannot use toxic chemicals and spray on wheat.

Conflict of interest

The authors declared absence of conflict of interest.

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