Review on Barley Scald Disease Management

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Abstract— *Barley (Hordeum vulgare L.) is one of the ancient grain crops cultivated and used worldwide. In Ethiopia, barley is among important staple crops next to tef, maize, wheat and sorghum mainly grown on about 1 million ha of land with average yield of 2.1t ha. Leaf scald is one of the most important diseases of barley in the worldwide where the crop is grown and it causes significant reduction in yield and quality. In Ethiopia, barley is the predominant cereal in the high altitudes and it accounts nearly 25% of the total production in Africa. In addition, Ethiopia is the second largest barley producer in Africa.*

Leaf scald is one of the most important diseases of barley in the worldwide wherever the crop is grown and it causes significant reduction in yield and quality. Yield loss due to scald disease reaches up to 100% in susceptible cultivars under severe epidemics. In Ethiopia, scald is among widely distributed and destructive diseases in cool highland areas and yield losses reaching about 67% have been recorded. This review discusses recent information on economic importance, epidemiology, life cycle, geographical distribution and disease management of barley leaf scald disease. It also presents the barley leaf scald disease management methods such as cultural, chemical, use of host resistance methods as well as integrated barley leaf scald disease management. Under host resistance method, information on types of resistance, sources of resistance have been presented.

Keywords— Barley, Scald disease, Management, Methods, Cultural, Chemical, Host resistance.

I. INTRODUCTION

Barley (*Hordeum vulgare* L.) is one of the ancient grain crops cultivated and used worldwide (; Baik and Ullrich, 2008). It has been grown in the Middle East about 10,000 years ago (Zohary and Hopf, 2000) and is mainly produced for feeding and malting worldwide. Moreover, barley occupies 57 million hectares of the world's agricultural land area, and is a staple food for many people globally, in addition to its uses in malting and as an animal feed (Newton *et al.,* 2011).

In Ethiopia, barley is among important staple crops next to tef, maize, wheat and sorghum mainly grown on about 1 million ha of land with average yield of 2.1t ha (CSA, 2017). Ethiopia is the second largest barley producer in Africa (FAO, 2014). Ethiopia accounts nearly 25% of the total production in Africa (FAO, 2014). Scald is a serious foliar disease in barley (*Hordeum vulgare* L.) and occurs worldwide wherever barley is grown (Shipton, 1974). It can cause up to 40% yield loss in susceptible cultivars and also has a detrimental impact on grain quality. Thus, scald is considered as one of the most economically important barley disease worldwide predominantly in the cool and semi-humid barley growing areas (Zhan *et al.,* 2008).

II. ECONOMIC IMPORTANCE OF SCALD DISEASE OF BARLEY

Scald, caused by the fungus *Rhynchosporium commune*, occurs wherever barley is grown from northern and central Europe to the Middle East, Central Asia, North and South Africa, the Americas, Australia and New Zealand (Shipton *et al.,* 1974; Beigi *et al.,* 2013) and is one of the most economically important diseases of barley worldwide (Beer, 1991), causing yield and grain quality reduction (Zhan *et al.,* 2008). The disease is particularly significant in cool, semi-humid areas, where crop canopies are aggregated and leaves are exposed to prolonged wet conditions (Shipton *et al.,* 1974). This pathogen can cause dramatic yield reductions, up to 40%, along with reductions in grain quality (Jenkins & Jemmett, 1967) and losses of nearly 100% can occur on susceptible barley cultivars (Yahyaoui, 2004). Yield losses occur mainly through reduced 1000 grain weights, although other above ground parts may be reduced as well (James *et al.,* 1968). There is also a report that indicates

the national barley yield loss of UK in 2005, due to scald disease was estimated£ 10.8million per annum (at a price of £225/tonne) despite fungicide treatment (HGCA, 2011). It affects barley on several million hectares in North Africa, West Asia, East Africa (Eritrea and Ethiopia), Yemen, Central Asia, the Andean countries (Peru, Colombia, Bolivia, and Ecuador), and the Far East (Yahyaoui *et al.,* 1999). Scald is particularly damaging in areas where barley is cultivated continuously such as in West Asia, in central and southern parts of North Africa, the highland regions of Peru and Nepal, and large areas in Eritrea and Ethiopia. In Ethiopia, it can reduce yields by up to 67% (Chilot *et al*., 1998).

III. EPIDEMIOLOGY OF BARLEY SCALD DISEASE

Rhynchosporium commune is a polycyclic barley disease causing pathogen that involves several pathogen generations during a growing season (Fitt *et al.,* 1989). It is splash dispersed and mainly overwinters on crop debris, seed and infected soil surfaces. Thus, Sources of primary inoculum for infection of barley plants include, crop debris (Fitt *et al.,* 2012), infected soils (Zhan *et al*., 2008), infected seeds (Topp *et al.,* 2019), barley volunteers infected from the debris of previous crops(Jenkins and Jemmet, 1967) as well as wind-borne ascospores (Fountaine *et al.,* 2010). The inoculum from these sources infects barley plants during the next growing season (Stefansson *et al*. 2013). Nevertheless crop debris is considered the most important source of primary inoculum (Nielsen & Jensen, 2001) and sporulation potential of *Rhynchosporium commune* on crop debris in the field could survive for up to 12 months (Murray *et al*., 1999). Unlike to crop debris, soil surface is not a major source of primary inoculum because the fungus has limited survival ability in soil due to its weak competitive saprophytic ability (Shipton *et al,* 1974). On the other hand, Fountaine *et al.* (2010) indicated that infected seeds might play an important role in the introduction of scald disease to new geographical areas (Fountaine *et al.* 2010). Interestingly it has been recently reported that the pathogen can infect seeds without the appearance of visual symptoms (Fountaine *et al.,* 2010).

Scald on barley (*Hordeum vulgare* L.) is a hemibiotrophic fungal disease caused by *Rhynchosporium commune*, which was recently verified to be a distinct species from the rye and triticale pathogen *R. secalis* through phylogenetic analysis (Linde *et al.,* 2003; Zaffarano *et al.,* 2011). In the previous years, there was uncertainty regarding the host specificity of what was known as *R. secalis*, although it had been noted in the early 20th century that isolates taken from one species tended only to cause disease on the same species (Caldwell 1937). Now it is understood that *R. commune* belongs to a group of closely-related cereal pathogens, each with a relatively narrow host range (Zaffarano *et al.,* 2011). *R. commune* has also been observed to cause disease in various other wild barley (*Hordeum*), brome (*Bromus*), and ryegrass (*Lolium*) species (Zaffarano 2011).

In addition, *Rhynchosporium commune*has also long been considered to be exclusively asexual and is known only from its conidial morph and host specialization nature. In recent findings, scholars reported that *Rhynchosporium commune* is heterothallic (Linde *et al.*, 2003), which imply that sexual reproduction does take place in this species but no sexual fruiting bodies have been described. Based on phylogenetic analyses of the ITS-rDNA region, it was predicted that, if a sexual morph of *R. commune* exists, it would be a species of *Oculimacula* (Goodwin 2002). Analyzing distribution and frequencies of mating type alleles within populations are good indications of the occurrence of a sexual cycle in fungal species. In populations with approximately equal frequencies of mating alleles, it is possible that sexual recombination does take place (Linde *et al*. 2003). Mating type idiomorphs have been cloned and characterized in *R. commune* and a multiplex polymerase chain reaction (PCR) method has been developed for one-step determination of its mating type identity in *R. commune* (Linde *et al*. 2003). Analyses of distribution and frequencies of mating type alleles among *R. commune* populations have revealed the occurrence of *MAT1-1* and *MAT1-2* types at broadly similar ratios in most barley growing regions (Linde *et al*. 2003).

Rhynchosporium commune fungal growth in barley occurs in four phases: germination (occurring approximately 12 hrs. after inoculation), then penetration (from approximately 24 hrs. after inoculation), leaf colonization with a slow increase in fungal biomass, followed by exponential growth with a massive gain of biomass (at around 10 days after inoculation), and a late stationary phase during which a dense stroma forms producing sporulation (Ayesu-Offei and Clare, 1970; Zhan *et al*., 2008).

Conidia are two-celled and characteristically beak-shaped and germination optimum is reported between 15-21°C and at least 95 % air humidity (Beer, 1991). The conidia can germinate with several germ tubes and appressoria develop at the tips of the germ tubes (Shipton, *et al*., 1974; Ayesu-Offei, 1970).Germination of up to 80 % of spores occurs within 24 hours (Ryan & Clare, 1975) when conditions are dark and moist (Jackson, 1997). After a conidium germinates on a leaf surface, *R. commune* penetrates the epidermis of the host with an appressorium and penetration peg directly by penetrating the cuticle (Ayesu-Offei, 1970) and initially grows subcutaneously and intracellularly (Caldwell1937; Zhan 2008. The developed

hyphae penetrate the epidermal cell layer, particularly at the junction of guard and epidermal cells and this action causes stomata to open more to light, due to an alteration of the turgor relations between guard cells and the surrounding epidermal cells. Conidia on the stroma results in the separation and eventual cracking of the cuticle, thus superficially exposing the stroma. Approximately nine days after infection starts, mesophyll cells in contact with the mycelium collapse and the fungus begins to grow inter-cellularly. The timing of the mesophyll collapse corresponds with the appearance of water-soaked grayish lesions (Caldwell 1937). Four days later, the lesions dry out, and become first chlorotic and then necrotic (Jackson 1997). Furthermore, the scald like lesions of the disease is visible on the leaf blades and sheaths. Thereafter, the water-soaked appearances of the lesions soon fade to a bleached, scalded appearance and are surrounded by a brown-pigmented ring (Bockelman, *et al*., 1981). New *R. commune* conidia are produced on conidiophores, which erupt through the leaf cuticle in apparently healthy leaf regions Davis *et al*., 1994).

The latent period has been reported between 8 and 14 days at 20°C and about twice as long at 5°C (Beer, 1991; Jackson, 1997). Lesion growth rate has been observed at 2 mm day-1 (Xue & Hall, 1991). Conidia production is reported to be poor beyond 5 and 30°C and retarded between 27 and 37°C with optimum between 15 and 20°C (Jackson, 1997). Ayesu-Offei (1971) counted conidia production, and recorded 0.5-1.3 × 106 conidia produced in 48 hours, from groups of 2-3 lesions collected in the field and allowed to sporulate in the laboratory under optimal conditions. Spore release is favoured by rainfall and wind following rainfall, confirming that the conidia are splash dispersed and with rain may be picked up by the wind (Ayesu-Offei & Carter, 1971).

Sources of secondary inoculum (infection) are splash-dispersed conidia from infected leaves (Fitt et al., 1989). The disease is spread from leaf to leaf by rain splash (Skoropod, 1960). During each generation these conidia germinate and infect new host tissues. Spread of the disease is associated with rainfall rather than wind as the conidia are embedded in mucilage (Skoropad, 1959). Long-distance transmission can occur by sowing infected seed or movement of stubble as hay, spreading R. commune to new geographical locations. As yet, the sexual form of R. commune is unknown, thus the possibility of long-distance dispersal of ascospores remains as another pathway for the spread of disease.

Although splash dispersal of *R. commune* conidia contributes to the short-distance spread in the field (McDonald *et al*., 1999; Shipton *et al*., 1974), transport of infected seeds may be responsible for the long-distance dispersal of inoculum in general, as well as the spread of new physiological races.

Initial symptom of scald disease of barley is oval, water-soaked, grayish-green spots, 1.0-1.5 cm long. As the disease develops the centers of the lesions dry and bleach, becoming light gray, tan, or white with a dark brown margin (Avrova and Knogge, 2012). The lesions are not delimited by the leaf veins and often coalesce, allowing them to appear as large blotches anywhere on the leaf (Jackson1997. In extreme cases, the disease can completely kill the leaf tissue of the plant (Jackson1997). The typical disease symptoms, necrotic lesions, occur after a latent period lasting from a few days up to several weeks, when mesophyll cells in leaf regions that are heavily colonized by the fungus collapse (Kirsten *et al*., 2012).

IV. GEOGRAPHIC DISTRIBUTION OF BARLEY SCALD DISEASE.

Scald is a globally-distributed disease. The fungus causing the disease on rye was originally described in 1897 in Holland and, as early as the 1920s, was noted to have a range including North America, Europe and Australia (Brooks 1928). A decade later, Africa and South America had been added to its recorded range (Caldwell 1937). It is hypothesized that *Rhynchosporium* species became pathogens of barley and rye about 2,500 years ago in Scandinavia, the center of *Rhynchosporium* diversity, and then traveled southwards to the Fertile Crescent and Africa. Limited genetic diversity in *Rhynchosporium* populations in North America, Australia, and New Zealand indicate that infected seed probably traveled with European colonists to these locations within the past 500 years (Linde *et al.*, 2009).

V. LIFE CYCLE OF BARLEY SCALD PATHOGEN (RHYNCHOSPORIUM COMMUNE)

Rhynchosporium commune, the causal agent of barley scald disease has been thought that it has no sexual stage of reproduction and in the absence of a sexual life stage the fungal life cycle is comprised by conidia production, host infection and hyphal growth. Skoropad & Grinchenko (1957) observed micronidia produced in flask-shaped branches of older parts of the mycelium but attempts to germinate these microconidia failed (Skoropad & Grinchenko, 1957) and no function has been reported. However, recent findings, which indicate that the fungus is heterothallic (Linde *et al*., 2003), imply that sexual reproduction does take place in this species but no sexual fruiting bodies have been described. In the absence of any known sexual structures, the fungi probably survives between cropping seasons as mycelia in infected host residues, but may also by transmitted via seeds (Jackson, 1997). However, left over residues from previous year's crops are considered the most

important source of primary inoculum (Nielsen & Jensen, 2001). Sporulating potential of fungal material on crop residues left in the field could survive for up to 12 months (Murray *et al.,* 1999). Overwintering mycelia will produce spores when environmental conditions are favourable, serving as primary inoculum to initiate an epidemic.

Conidia are two-celled and characteristically beak-shaped and germination optimum is reported between 15-21°C and at least 95 % air humidity (Beer, 1991).Germination of up to 80 % of spores occurs within 24 hours (Ryan & Clare, 1975) when conditions are dark and moist (Jackson, 1997). The conidia can germinate with several germ tubes from one or both cells and appresoria develop at the tips of the germ tubes (Ayesu-Offei, 1970; Shipton *et al.,* 1974). The optimum temperature for germ tube growth is 15-21^{0}c (Caldwell, 1937; Fowler and Owen, 1971) within the range of 2^{0}c to 31^{0}c (Reed, 1957). Penetration takes place by penetrating the cuticle with the help of penetration peg on the appresoria (Ayesu-Offei, 1970). Infection is followed by formation of a subcuticular mycelium, which develops into a stroma, one to several cells in thickness (Ayesu-Offei and Clare, 1970; Caldwell, 1937). Later, hyphae penetrate the epidermal cell layer, particularly at the junction of guard and epidermal cells (Ayesu-Offei and Clare, 1969). Infection causes stomata to open more to light, due to an alteration of the turgor relations between guard cells and the surrounding epidermal cells (Ayres, 1972). Infection causes mesophyll cells to collapse, which is evident on the leaf surface as water soaking and scalding of the tissues (Caldwell, 1937; Ayesu-Offeiand Clare, 1970). The optimum temperature for the hyphal growth of *Rhynchosporium commune* in barley leaves is 16-18^{0}C, with a maximum at 25-30^{0}C and a minimum of 0^{0}C (Fowler and Owen, 1971). The latent period has been reported between 8 and 14 days at 20°C and about twice as long at 5°C (Beer, 1991; Jackson, 1997). Similarly, optimum temperature for spore production (sporulation) is 15-20^{0}C.

VI. BARLEY SCALD DISEASE MANAGEMENT

Scald is a stubble and seed-borne disease which is favoured by high rainfall environments. This disease is most damaging in the high rainfall. However, severe epidemics have been observed in medium rainfall areas under favourable conditions. Disease management is best achieved by knowledge of the pathogens involved and manipulation of the interacting factors. Scald of barley is more likely to be a problem when infected trash remains from a previous barley crop, or when infected barley grass is present.

Based on the complexity of the pathogen, control of the disease requires an integrated and multifaceted approach, including application of fungicides, manipulation of sowing date, cultural disease management, and the use of resistant cultivars (McLean and Hollaway, 2018); though using resistant varieties provide the easiest and most effective option to manage the disease. Thus, for effective management of the disease, it is important to use the integrated disease management practices that focus on the factors affecting the disease. Furthermore, the high genetic variability of *Rhynchosporium commune* can result in rapid adaptation of pathogen populations to render some of these control strategies ineffective when they are used alone (Shipton *et al.,* 1974)). Therefore, sustainable control of *Rhynchosporium* needs to integrate major-gene-mediated resistance, partial resistance and other strategies such as customized fungicide programmes, species or cultivar rotation, resistance gene deployment, clean seed and cultivar mixtures.

6.1 Cultural Practice

Different cultural practices such as crop rotation, cultivation, use of cultivar mixtures, manipulation of sowing date or sowing rate or agronomic treatments and planting clean seeds can be used to manage scald disease in barley. Moreover, the disease can be managed using an integrated approach that includes growing resistant varieties, avoiding early sowing, using seed dressings and not sowing into infected crop residues. Furthermore, the amount of primary inoculum available for initiating epidemics may be decreased by rotation, so that there is a break of several seasons with non-susceptible crops between successive barley crops, or by ploughing after harvest to bury infected debris and diseased volunteer barley (Shipton et al., 1974). By contrast, short rotations and minimum or reduced tillage practices which leave infected debris on the soil surface may result in severe *Rhynchosporium* epidemics in crops exposed to more primary inoculum.

Crop rotation with a non-host crop will minimise initial inoculum levels for next season's crop. Continuous cropping with the same susceptible host plant will result in the inoculum build-up of the pathogen population. Crop rotation avoids this and is often associated with a reduction in crop diseases. Similarly, crop rotation is useful in reducing inoculum of *R. commune* which can be spread from crop debris (Oxley and Burnett 2009). Rotations involving consecutive barley crops should be avoided. A minimum of 2 years is required between crops for residue to break down sufficiently. Rotating any crop other than barley between barley crops in a field will significantly reduce the potential for barley scald disease. Continuous barley cultivation leads to the accumulation of crop debris in the field and, with it, to a build-up of inoculum (Elen, 2002). Over 40

years ago, Hansen and Magnus reported an increase in scald that might have been caused by the shift from crop rotation to continuous barley cultivation (Hansen and Magnus, 1969). Reports showed that crop rotation, or even a 1-year interruption with oats, is effective in controlling the occurrence of the disease on barley (Elen, 2002).

Cultural practices such as incorporating the residue into the soil or removing it completely by burning will reduce the abundance of the pathogen and the disease pressure. Stubble may be reduced by baling and grazing; however, these methods only result in a small reduction in the disease pressure. Stubble reduction must be balanced against the increased risk of soil erosion by wind or water. Tillage has indirect effects on pathogen spread and can also be used to reduce pathogen inoculum in the soil. Deep tillage can bury pathogens deeper in the soil where they are less likely to become a problem. Reduced tillage or no-tillage is often associated with higher microbial biomass and activity in upper soil layers compared to regular tillage (ploughing) (van Diepeningen *et al.,* 2005). This concentration of crop debris in the top layers of the soil can promote the over-wintering and survival of numerous pathogens, prompting concern that reduced tillage practices might lead to increased disease and reduced yields. Indeed, this has proved to be true under certain circumstances, although there have been reports of reduced incidence of soil-borne pathogens following reduced tillage (Sturz *et al.,* 1997). Moreover, reduced tillage leads to the accumulation of crop debris in the field and, with it, to a build-up of inoculum. More recently, reduced tillage and continuous spring barley cultivation have led to an increase in the occurrence of *Rhynchosporium* in the Nordic countries (Arvidsson, 1998).

In barley scald disease, infected straw provides a reservoir of inoculum for splash dispersal when weather conditions favour the development of *R. commune* infection (Fitt *et al*., 1987). *Rhynchosporium commune* can survive on straw for about 1 year, depending on the ambient conditions, but cannot over summer in straw left in the open field or buried in soil (Skoropad, 1959). Thus, Reducing infected stubble and barley grass by grazing, burning or cultivation decreases the carry-over of the fungus between crops (Mayfield and Clare, 1984). Furthermore, stubble management can also have an impact on reducing inoculum of all stubble-borne diseases of cereals and burning or cultivating stubble can significantly reduce the level of inoculum prior to sowing and will reduce or delay disease development in the subsequent crop. More recently, reduced tillage and continuous spring barley cultivation have led to an increase in the occurrence of *Rhynchosporium* in the Nordic countries (Arvidsson, 1998).

One of the important cultural practices in management of scald disease of barley is green bridge management. A green bridge of self-sown barley leading into the cropping season provides host material for the pathogen increases the risk of its early onset. Removing this green bridge as early as practicable before seeding will greatly reduce the risk of early crop infection. Managing 'Green Bridge' volunteers reduces inoculum sources. Volunteers should be controlled before sowing to ensure that spores produced on these plants are not viable by the time of crop emergence.

Another important cultural practice used to manage scald disease of barley is use of mixtures of resistant and susceptible isogenic lines, cultivars or even species. This method of managing scald disease of barley may decrease severity of epidemics through decreasing the rate of secondary disease spread by spores dispersed from affected susceptible plants. Classically, such mixtures have been used to control diseases such as mildews and rusts caused by biotrophic pathogens with gene-for-gene interactions with their hosts, and wind-dispersed spores. Simulation modelling suggests that use of mixtures will be most effective against such wind-dispersed pathogens with shallow spore dispersal gradients. However, it has also been shown that mixtures can provide effective control of diseases with secondary spread by splash-dispersed spores with steep spore dispersal gradients and less clear gene-for-gene interactions, such as barley *Rhynchosporium* (McDonald *et al*., 1988), although this was not always the case (Abbott *et al*., 2000). Use of highly heterogeneous cultivar or cereal species mixtures can decrease severity of *Rhynchosporium* epidemics by half, and correspondingly increase yield by up to 15% (Newton *et al.,* 1997).

Likewise, altering the time of sowing to avoid high levels of pathogen inocula or conditions conducive for development of a particular disease can lead to reduced severity of several diseases. For example, it has been reported that in the UK, late sowing may be recommended for autumn-sown barley crops, in order to decrease exposure of newly emerging seedlings to inoculum of *Rhynchosporium commune* produced on previous barley crops in the area . Moreover, early sown crops develop higher levels of scald. Early sown crops may be exposed to the heaviest release of spores from infected residues. The disease can develop in the upper leaves of the plant when conditions favour spread of disease. Therefore, it is important to avoid early plantings because scald is worse in early-sown crops and when conditions favour disease development late plantings are less damaged. So, avoiding early sowing of susceptible varieties, especially in high-rainfall areas, will reduce the loss caused by scald.

Correspondingly, scholars reported that planting healthy seeds is equally important to other cultural practices used to manage scald disease of barley. Scald of barley disease can be seed-borne. Sowing infected seed can introduce disease into a new crop. Therefore clean seed should be used wherever possible. Fungicide seed dressings can reduce the risk associated with sowing infected seed. Seed treatments that suppress early scald infection are an essential part of effective scald management. A seed dressing or fungicide applied in-furrow with fertiliser should be used in medium to high rainfall areas or if the seed is from an infected crop. It is important to use good quality seed with high germination and vigour and if the seed is from an infected crop it should be treated with recommended treatment at proper rates. Moreover, seed treatments with fungicides based on maneb, prochloraz, and thiabendazole is important in decreasing the impact of early season *Rhynchosporium* epidemics (Lee *et al*., 2002). Likewise, physical seed treatment (hot water at 51°C for 12 min) is also found effective in removing *R. commune* infection (Habgood, 1971). The location of the fungal pathogen on the seed can have important consequences for the ease of control. Leaf scald symptoms have been observed on the outer structures of the seed and lesions have been used to re-isolate the pathogen (Kay and Owen 1973).

6.2 Chemical Control

The aim of foliar fungicide application in the crop is to delay disease development and to maintain green leaf area which reduces disease impact on yield and grain quality. In barley, the most important contributors to yield are leaf 2 (flag-1), leaf 3 (flag-2), the ear and upper stem. Protecting leaf 2 and leaf 3 is the highest priority in effective disease control. Fungicides can provide very high levels of disease control and are widely used to protect crops. Nevertheless, indiscriminate fungicide use, together with pathogen adaptability can reduce fungicide efficacy considerably. Foliar fungicides are used on most barley crops in Europe. However, the long-term effectiveness of fungicides depends on the ability of pathogens to evolve fungicide resistance.

The cost effectiveness of foliar fungicide applications depends on disease severity, susceptibility of the variety, yield potential of the crop, grain quality outlook and the environment where the crop is growing. When susceptible varieties are grown in conditions favorable for disease development, such as disease prone areas or high rainfall seasons, fungicide can be cost effective in reducing the disease impact where yield potential is over 2.0 t/ha. Reliance on fungicide is much greater in medium to high rainfall areas than in low rainfall regions due to higher disease pressure and longer growing seasons during which the disease epidemic may increase. For instance, in the medium rainfall region a single application of fungicide may be required at late stem elongation to flag leaf emergence stage. In a long season, high rainfall area two fungicide sprays are often required: one at early stem elongation and a follow-up spray at or just prior to flag leaf emergence. Moreover, in Europe, in winter barley crops, fungicides applied in the early spring at GS25-30 can greatly decrease disease development and therefore increase yield, but the best fungicide timing is generally at GS31-32 (Young *et al*., 2006). In spring barley crops, fungicide treatments are generally recommended where the disease is found on the upper three leaves of a susceptible cultivar. Under high disease pressure, using higher fungicide rates will give longer residual protection. In addition, it is important to apply fungicide before head emergence if hot spots within the crop are frequently observed during stem elongation or active infections are present on middle canopy leaves. Fungicides should be applied in mixtures or using alternation in modes of action to limit the rapid development of fungicide resistance**.** In order to minimise the risk of fungicide resistance, it is recommended that two-or three-way fungicide mixtures are used for controlling *R. commune* (Home-Grown Cereals Authority HGCA 2011). For example, at GS 31, a mixture of an effective triazole, a strobilurin, and a succinate dehydrogenase inhibitor (SDHI), will provide a good foundation for disease control (Home-Grown Cereals Authority HGCA 2011).

Use of fungicide mixtures has helped to impede selection for resistance to triazole fungicides in *Rhynchosporium commune* populations (Cooke *et al*., 2004), and fungicides such as epoxiconazole continue to be useful for control of *Rhynchosporium*, when used in mixtures. Fungicides with different modes of action from the strobilurin (Quinone outside Inhibitor, QoI) and anilinopyrimidine group are the most effective mixture for controlling the disease and maintaining yield. During the 1970s and 1980s, *R. commune* was effectively controlled by the application of the methyl benzimidazole carbamates (MBCs) and demethylation inhibitors (DMIs; 'triazoles'), alone or in mixtures. Since the first detection of resistance to MBC fungicides in the early 1990s, the frequency of resistant isolates has increased rapidly (Kendall *et al*., 1994; Taggart*et al*., 1998, 1999). Resistance to MBCs is now widespread in *R. commune* populations in the UK (Locke and Phillips, 1995; Taggart *et al*., 1999). Exposure to flusilazole, tebuconazole and epoxiconazole can result in a 10-fold decrease in the sensitivity of the *R. commune* population to these fungicides (Cooke *et al*., 2004), indicating erosion in their effectiveness. Although there is cross-resistance between the different triazoles, no cross-resistance between the imidazole and triazole (DMI) has been found (Kendall *et al*., 1993). Despite the partial loss of DMI efficacy in some parts of the UK and Europe, DMIs remain one of the

most important fungicide groups for the control of barley diseases (Walters *et al*., 2012). However, it is recommended that they be used mixed with other fungicides with a different mode of action.

In Ethiopia, of several fungicides evaluated, Tilt 250EC and Bayleton 25WP were registered for official use in cereals including barley (Abdurahman, 1997; Abdurahman and Berhanu, 1999). Similarly, in Kenya, scald is controlled by use of fungicides such as Bayleton (Triadimefon), Cercobin, Propiconazole (Tilt), Carbendazim (Bravocarb), Triadimenal (Bayfidan), Frutriafol (Impact) and Prochloraz (Sportak) (Kenya Breweries Ltd., 1990). In Britain, fungicides Captafol, Chlorothanil, Prochloraz, Propico-nazole Tridemefon and Benzimidazoles (alone or in combination with other materials) has been found effective in controling of this disease (Atwood, 1985

6.3 Host Plant Resistance

Resistant varieties are the simplest, most effective, economical and eco-friendly means of managing crop diseases including barley scald disease (Wenzel, *et al*., 1996). *R. commune* is highly variable pathogenically and this enables it for rapid selection to overcome newly released resistance genes (Genger *et al.* 2003). Thus, the most sustainable strategies for *R. commune* management are to develop and deploy disease-resistant barley cultivars through the introgression and pyramiding of different resistance genes (major or minor).

6.3.1 Types of Host Plant Resistance

Barley leaf blotch or scald is one of the most destructive diseases of barley crops. The disease occurs in all of major barley growing regions in the world and can cause significant reductions in barley yield and malting quality (Shipton et al., 1974). *R. commune* is a highly variable pathogen (Goodwin, *et al.,* 1993; Salamati *et al.*, 2000), possibly attributing to its large effective population size (McDermott *et al.,* 1989) high gene flow (Goodwin, *et al.,* 1993; McDonald *et al*., 1999), high mutation rate (Goodwin et al., 1994;), frequently sexual reproduction (Salamati *et al*., 2000) and somatic recombination (Forgan *et al.,* 2007). Recently, the pathogen was re-named as *R. commune* (Zaffarano *et al.,* 2011). Barley resistance to *R. commune* can be race-specific or race-nonspecific. Both types of resistance affect pre- and post- penetration stages of pathogen development but in different ways.

6.3.1.1 Race-specific resistance

Active non-host resistance (NHR) of plants to potential pathogens is based on the recognition of race-nonspecific, microbe associated molecular patterns (MAMPs) by pattern recognition receptors (PRRs) present in the plant cell membrane. Race-specific resistance arises after successful suppression of NHR by a pathogen. It involves major plant resistance (*R*) genes, which directly or indirectly recognize the products of certain pathogen effector genes, termed avirulence (*Avr*) genes. This triggers a qualitative resistance response called effector-triggered immunity (ETI) (Jones and Dangl, 2006).

In barley, several major *R* genes against *R. commune* have been described (Shipton *et al*., 1974). Of these, seven different *R* genes [*Rrs1* (11 alleles), *Rrs2* (two alleles), *Rrs3*, *Rrs4* (two alleles), *Rrs12*, *Rrs13* and *Rrs14*], as well as four unconfirmed *R* genes (*Rh5, rh8*, *Rh10* and *rh11*) have been reported. The major scald resistance genes discovered so far have been mainly identified through experiments with seedlings via inoculation with specific isolates and the problem with using major scald resistance genes in breeding programs is a lack of durability. Overall, at least 17 major resistance gene loci have been described (Wagner *et al.,* 2008).

6.3.1.2 Race non-specific resistance

Race non-specific resistance which is also termed as minor gene, quantitative, horizontal, partial or adult plant resistance is based on multiple genes with partial effects, which may control different mechanisms (Poland *et al*., 2009). Quantitative resistance may affect different stages in the life cycle of *R. commune*. It can influence the development of scald epidemics in barley crops by decreasing the leaf area affected by lesions (Williams and Owen, 1975) or by affecting sporulation (Kari and Griffiths, 1993). Although less obviously differentiated by specific gene-for-gene interactions, partial resistance (Kari and Griffiths 1993) also involves genetic interactions between the host and pathogen, but displays a more continuous distribution. The partial scald resistance found in barley landraces and many improved cultivars is thought to be reasonably durable because there is less selection on the pathogen population (Walters *et al*., 2012) and it has been suggested that pyramiding these genes could reduce the ability of *R. communes* to rapidly acquire new virulence combinations. However, it is possible that strains with higher aggressiveness will increase in frequency due to directional selection on partially resistant cultivars that are grown over a large area for many years, eroding the effectiveness of the resistance (McDonald and Linde,

2002). Several quantitative trait loci (QTLs) have been mapped, occurring on all of barley's chromosomes except for 5H (Wagner *et al.* 2008).

VII. CONCLUSION

Barley is one of the world's most important crops providing food and related products for millions of people. Diseases continue to pose a serious threat to barley production and one of the most economically important diseases of barley is leaf scald which is caused by a fungus known as *Rhynchosporium commune*. *Rhynchosporium* is one of the most destructive diseases of barley worldwide, especially in areas with cool temperate climates. It can cause yield losses up to 100% and decrease grain quality, thus discounting prices for quality uses such as malting. Therefore, there should be sustainable management strategies to tackle the impact of barley leaf scald on barley production. Sustainable management strategies of barley leaf scald needs to integrate major-gene-mediated resistance, partial resistance and other strategies such as customized fungicide programmes, species or cultivar rotation, resistance gene deployment, clean seed and cultivar mixtures. In general, barley leaf scald disease is best managed by integrated and multifaceted approach, including application of fungicides, manipulation of sowing date, cultural disease management, and the use of resistant cultivars.

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