Plant Protection (Scientific Journal of Agriculture)

48(2), Summer, 2025

10.22055/ppr.2025.48938.1790

Assessment of partial resistance in commercial barley cultivars and promising lines against barley stripe rust

S. Safavi[*1], M. Yassaie [2]

1. ***Corresponding Author:** Associate Professor, Seed and Plant Improvement and Breeding Department, Ardabil Agricultural and Natural Resources Research and Education Center, Agricultural Research, Education and Extension Organization, Ardabil, Iran (safaralisafavi@yahoo.com)
2. Assistant Professor, Crop and Horticultural Science Research Department, Fars Agricultural and Natural Resources Research and Education Center, Agricultural Research, Education and Extension Organization, Zarghan, Iran

Received: 3 February 2025 Revised: 19 April 2025 Accepted: 12 May 2025

Abstract

Barley stripe (yellow) rust, caused by *Puccinia striiformis* f. sp. *hordei*, is one of the most important barley diseases in some regions of the world that threatens barley production. Host resistance is the most economical and safe approach to managing stripe rust. In this study, the partial resistance parameters, including coefficient of infection (CI), final rust severity (FRS), and relative area under the disease progress curve (rAUDPC), were evaluated for 70 barley genotypes (27 cultivars, 43 candidate lines) along with a susceptible control during two consecutive cropping years from 2022-2023 to 2023-2024. This study was conducted at two Agricultural Research Stations (Ardabil and Zarqhan) under field conditions with artificial inoculation. The results of the evaluations for resistance parameters showed that the cultivars Nosrat, Rihan 3, and candidate lines C-98-13, C-99-5, C-99-6, and M-99-3, along with the susceptible cultivar (Afzal) had the highest FRS, CI, and rAUDPC values, and therefore were grouped as susceptible genotypes. Twenty-four (34.3%) out of 70 genotypes had low values of different parameters and were categorized as a group with a high level of partial resistance. Fourteen (20%) genotypes, including; Oksin, Nik, Behrokh, Lout, Jolge, Azaran, Mahtab, Matin, Yousef, C-99-18, C-00-13, C-96-10, M-99-11, and C-99-4 having moderate values of CI (21-40), were classified as a group with moderate level of partial resistance. The rest cultivars and candidate lines with high values of FRS, CI, and rAUDPC were grouped as genotypes with low partial resistance levels. Cluster analysis based on the different parameters at the adult plant stage classified cultivars and candidate lines in different groups, indicating the high diversity among genotypes in response to barley stripe rust disease. Genotypes with high and moderate levels of partial resistance can be used in cultivar introduction or barley breeding programs.

Keywords: Barley, Yellow rust, Durable resistance, Puccinia striiformis f. sp. hordei, Cluster analysis

Associate editor: S. Abbasi (Ph.D.)

Citation: Safavi, S. & Yassaie, M (2025). Assessment of partial resistance in commercial barley cultivars and promising lines against barley stripe rust. *Plant Protection (Scientific Journal of Agriculture)*, *48*(2), 13-33. https://doi.org/10.22055/ppr.2025.48938.1790.

گیاه‌پزشکی (مجله علمی کشاورزی)
جلد ٤٨، شماره ٢، تابستان ١٤٠٤

10.22055/ppr.2025.48938.1790

ارزیابی مقاومت نسبی ارقام تجاری و لاین‌های امیدبخش جو نسبت به بیماری زنگ نواری جو

صفرعلی صفوی *[1]، محسن یاسائی [2]

۱- * **نویسنده مسوول**: دانشیار، بخش تحقیقات اصلاح و تهیه نهال و بذر، مرکز تحقیقات و آموزش کشاورزی و منابع طبیعی استان اردبیل، سازمان تحقیقات، آموزش و ترویج کشاورزی، اردبیل، ایران (safaralisafavi@yahoo.com)

۲- استادیار، بخش تحقیقات علوم زراعی و باغی، مرکز تحقیقات و آموزش کشاورزی و منابع طبیعی استان فارس، سازمان تحقیقات، آموزش و ترویج کشاورزی، زرقان، ایران

تاریخ دریافت: ۱۴۰۳/۱۱/۱۵ تاریخ بازنگری: ۱۴۰۴/۰۱/۳۰ تاریخ پذیرش: ۱۴۰۴/۰۲/۲۲

چکیده

زنگ نواری (زرد) جو با عامل *Puccinia striiformis* f. sp. *hordei* یکی از مهمترین بیماری‌های جو در برخی از مناطق جهان است که تولید جو را تهدید می‌کند. مقاومت میزبانی، اقتصادی‌ترین و سالم‌ترین روش مدیریت زنگ نواری است. در این مطالعه، شاخص‌های مقاومت نسبی شامل ضریب آلودگی (CI)، شدت نهایی بیماری (FRS)، و مقدار نسبی سطح زیر منحنی پیشرفت بیماری (rAUDPC) برای ۷۰ ژنوتیپ جو(شامل ۲۷ رقم تجاری و ٤٣ لاین نامزد معرفی) همراه با شاهد حساس طی دو سال زراعی از ١٤٠٢-١٤٠١ تا ١٤٠٣-١٤٠٢ ارزیابی شدند. این مطالعه در ایستگاه تحقیقات کشاورزی اردبیل و زرقان در شرایط مزرعه با آلودگی مصنوعی انجام شد. نتایج ارزیابی پارامترهای مقاومت نشان داد که ارقام نصرت، ریحان ۳ و لاین‌های C-98-13، C-99-5، C-99-6 و M-99-3 به همراه رقم حساس (افضل) بالاترین مقادیرFRS، CI و rAUDPC را داشتند و بنابراین به عنوان ژنوتیپ‌های حساس گروه بندی شدند. از کل ۷۰ ژنوتیپ، ٢٤ ژنوتیپ (٣٤/٣ درصد) مقادیر پایینی از شاخص‌های FRS، CI و rAUDPC را نشان دادند و به‌عنوان گروه با مقاومت نسبی بالا دسته‌بندی شدند. چهارده ژنوتیپ (۲۰ درصد) شامل اکسین، نیک، بهرخ، لوت، جلگه، مهتاب، آذران، متین، یوسف، C-99-18، C-00-13، C-96-10، M-99-11 و C-99-4 با مقادیر متوسط CI (٤٠-٢١) و سایر شاخص‌ها به‌عنوان گروه با سطح مقاومت نسبی متوسط طبقه بندی شدند. بقیه ارقام و لاین‌های منتخب با مقادیر بالای- FRS، CI و rAUDPC به‌عنوان ژنوتیپ‌های با مقاومت نسبی پایین گروه‌بندی شدند. تجزیه خوشه‌ای بر اساس مقادیر شاخص‌های مقاومت نسبی در مرحله گیاه کامل، ارقام و لاین‌ها را در گروه‌های مختلفی قرار داد که این حالت نیز بیانگر تنوع بالای ژنوتیپ‌ها از نظر واکنش نسبت به بیماری زنگ زرد جو بود. ژنوتیپ‌های دارای سطح بالا و متوسط مقاومت نسبی می‌توانند در معرفی رقم یا در برنامه‌های به نژادی جو مورد استفاده قرار گیرند.

کلیدواژه‌ها : جو، زنگ زرد، مقاومت پایدار، Puccinia striiformis f. sp. hordei، تجزیه خوشه‌ای

دبیر تخصصی: دکتر سعید عباسی

Introduction

Barley is the world's fourth most important cereal crop after wheat, rice, and maize (Rodríguez-García et al., 2021). The cultivated barley is one of the oldest crops domesticated around 10,000 years ago in 'Fertile Crescent' (Middle East) and then moved to other parts of the world (Nevo, 2013; Kumar et al., 2020).

This cereal crop is well adapted to dry areas and poor soils and is often grown in low-yield production systems (Newman & Newman, 2006). Biotic stresses, especially barley stripe rust, cause significant yield reductions in some barley growing areas (Chen, 2007). The disease has caused severe epidemics in South and East Asia (Bahl & Bakshi, 1963; Chen et al., 1995; Luthra & Chopra, 1990), West Asia (Dubin & Stubbs, 1986), South America (Capettini, 2005), and North America (Chen, 2007, 2008).

Some severe and important epidemics of barley stripe rust have caused yield losses of 30- 70% in barley crops in South America (Dubin & Stubbs, 1986). In Iran, barley stripe rust was first reported by Esfandiari in 1947 (Esfandiari, 1947). The disease also causes damage in some parts of Iran, especially in Ardabil, Khorasan Razavi, Fars, and Khuzestan (Safavi et al., 2014; Zakeri et al., 2018). In a study conducted by Safavi et al. (2012), the yield components reduction due to barley stripe rust disease in Ardabil on susceptible cultivars and cultivars with slow rusting resistance was estimated at 50% and 20%, respectively.

Durable resistance is the most useful, effective, and environmentally safe method for managing stripe rust (Park, 2008). In cereal rusts, two types of resistance have been generally described: seedling/all-stage resistance (ASR) and adult plant resistance (APR) (Chen & Kang, 2017; Gyawali et al., 2018). It has been demonstrated that seedling resistance is effective at all stages of plant development and is often associated with a hypersensitive reaction in the plant, while adult plant resistance (APR) is effective only at the adult plant stage and is often considered as slow rusting or partial resistance (Park, 2008). Several studies have been conducted on ASR and APR in barley leaf rust caused by *P. hordei*, while little information is available on APR to barley stripe rust. For example, several resistance genes, such as *Rph1* and *Rph19* (Golegaonkar, 2009), *Rph21*(Sandhu et al., 2012), and *Rph22* (Johnston et al., 2013), that confer high levels of resistance to *P. hordei* have been reported. Recently, some researchers have identified QTLs for *psh* resistance at the seedling stage using North American and European stripe rust pathotypes (Dracatos et al., 2016; Esvelt Klos et al., 2016).

Many mutations in the virulence genes of rusts often lead to the failure of seedling resistance genes in the host within a short time after their introduction (Park, 2008). In contrast, APR resistance, which is essentially quantitative and is also referred to as incomplete or non-race-specific resistance, often has additive effects (Singh et al., 2015). Therefore, APR resistance genes are effective for a long time.

Like other cereal rust fungi, there is considerable variation among barley stripe rust populations. Until recently, 90 pathotypes of barley stripe rust have been identified based on the US system for differentiating *Psh* pathotypes. Most of them were identified in the US Chen & Kang, 2017), and some pathotypes were identified from Iran (Safavi et al., 2014; Zakeri et al., 2018) and other countries (Cheng et al., 2016; Verma et al., 2018). Furthermore, hybridization between two formae specialis *Puccinia striiformis* f. sp. *tritici (Pst)* and *Psh* can create new virulent pathotypes that have virulence on some barley and wheat resistance genes (Safavi et al., 2017; Cheng et al., 2016; Lei et al., 2016).

So far, 28 genes or QTL have been identified and used for resistance to barley stripe rust (Chen & Kang, 2017). However, most of these genes, except for *RpsBa,* which confer high-temperature adult plant resistance (HTAPR), are race-

specific and will become ineffective in controlling pathogen populations as new pathotypes emerge. The average lifespan of race-specific resistance genes globally is estimated to be approximately 5 years (Kilpatrick, 1975).

Two types of quantitative resistance, partial (slow rusting) and HTAPR, have been extensively studied (Line, 2002). In many cereal-rust pathosystems, quantitative concepts of resistance have been described, and its values at the adult plant stage are estimated by measuring disease severity (DS) at a specific stage of plant growth, the relative area under the disease progress curve (rAUDPC), the apparent infection rate (r), and the average coefficient of infection (ACI) (Pathan & Park, 2006; Hei et al., 2015; Safavi & Malihipour, 2020). Many researchers have used these parameters to quantify the resistance of cultivars and lines under field conditions (Sandoval-Islas et al., 2007; Ali et al., 2009; Shah et al., 2014; Safavi & Afshari, 2017, Huerta-Espino et al., 2020, Srinivas et al., 2023; Dawana et al., 2024). In these investigations, a high correlation was found between the parameters of final disease severity, coefficient of infection, and area under the disease progress curve.

Numerous studies have been conducted in different parts of the world to evaluate barley cultivars' resistance and lines' resistance to stripe rust (Mathur & Siradhana, 1990; Sandoval-Islas et al., 1998; Brown et al., 2001b; Gyawali et al., 2017; Verma et al., 2018). Also, several studies have been carried out on assessing varieties and lines against barley stripe rust in Iran (Safavi et al., 2013; Zakeri et al., 2018; Zahravi et al., 2023). However, little information exists about different levels of adult plant partial resistance in Iranian commercial barley cultivars and candidate lines. Therefore, this research aimed to 1) characterize different levels of adult plant partial resistance among new barley genotypes and 2) determine the diversity of the studied barley genotypes based on the levels of resistance against stripe rust.

Materials and Methods

Plant material*:*

The seeds of 70 different barley genotypes (27 commercial cultivars and 43 candidate lines) were obtained from the Cereal Research Department of Seed and Plant Improvement Institute (SPII), Karaj, Iran. The details of these commercial barley cultivars/candidate lines are given in Tables 2 and 3. All these barley genotypes were evaluated for resistance to stripe rust at the adult plant stage to identify and determine different level of adult plant partial resistance**.**

Description of study area

Field assessment was conducted at two locations; Ardabil Agricultural Research Station Ardabil, Iran (latitude 38°17′59″ N; longitude 48°39′58″ E and 1365m above sea level), and Zarghan Agricultural Research Station Zarghan, Iran (latitude 29°46′41″ N; longitude 52°42′13″ E and 1604m above sea level) during 2022-2023 and 2023-2024 cropping years. The averages of meteorological data for the two research locations are presented in Table 1.

Experimental design and treatment

In evaluating the adult plant response, various parameters of partial (slow rusting) resistance including; the coefficient of infection (CI), final rust severity (FRS), and relative area under disease progress curve (rAUDPC) were evaluated. In the middle of the autumn season, each of the cultivars/candidate lines was sown at a rate of ten grams on two one-meter lines with a distance of 30 centimeters from each other on a ridge. After every ten genotypes and also in the entire margin of the experiment, the susceptible variety Afzal was planted on two one-meter lines. During the growing season, cultural practices such as irrigation, weeding, and fertilization were performed. Artificial inoculation of the nursery was carried out between the time of tillering and before the emergence of flag leaves with a mixture of spores of barley stripe rust pathotypes (collected in the previous years) and talcum powder by dusting. Spores (urediniospres) collected

the previous year for artificial inoculation were kept to dry in a desiccator containing silica gel for 24 hours, then stored at -80˚C for use the following year. Based on the last virulence and avirulence analysis of barley stripe rust pathotypes, populations of Ardabil had virulence on the resistance genes *Rps4, rpsHF, rpsAst, rpsHi1, rpsHi2, rps2, rpsTr1, rpsTr2, Rps1.c, Rps1.b, Rps3, RpsI5, RpsBa* and avirulence on *rpsEm1, rpsEm2, rpsV1, rpsV2*. (Safavi *et al*., 2014) and in the location of Zarghan, had virulence on the resistance genes *rpsHi1, rpsHi2, rpsV1, rpsV2, rps2, Rps1.c, RpsBa* and avirulence on *Rps4, rpsHF, rpsEm1, rpsEm2, rpsAst, rps2, Rps1.c, Rps1.b, Rps3, RpsI5* (Zakeri *et al*., 2018). Besides artificial inoculations, natural infections could be happened by different barley stripe rust pathotypes that hadn't been collected and identified before.

Data collection

Disease severity recording in the field was conducted at weekly intervals for three consecutive periods starting from 50% appearance of the symptom until the susceptible cultivar (Afzal) reaches 100% severity using the modified Cobb scale of 0%–100% (Peterson *et al*., 1948). The host plant reaction to infection was scored according to Roelfs et al. (1992). Host response refers to the infection type and is classified based on the following scale: 0 (no visible infection); R (resistant; necrotic areas with or without small pustules); MR (moderately resistant; small pustules surrounded by necrotic areas); M (intermediate; pustules of variable size; some necrosis and/or chlorosis); MS (moderately susceptible; medium-sized pustules; no necrosis, but some chlorosis possible); MSS (moderately susceptible to susceptible; medium to large sized pustules without chlorosis or necrosis) and S (susceptible; large pustules, no necrosis or chlorosis).

Data analysis

The data on disease severity and host response were combined and the coefficient of infection (CI) was calculated from their combination. The coefficient of infection was obtained by multiplying the disease severity by the constant values of the host response (immune=0.0, R=0.2, MR=0.4, M=0.6, MS=0.8, MSS= 0.9, and S=1) (Stubbs et al., 1986). The disease severity data were used to estimate the area under the disease progress curve (AUDPC). Estimation of the area under the disease progress curve (AUDPC) and relative area under the disease progress curve (rAUDPC) was performed as follows (Milus & Line 1986):

AUDPC = $[N_1(X_1+X_2)/2] + [N_2(X_2 + X_3)/2]$

Where X_1, X_2, and X_3 are the rust intensities recorded on the first, second and third recording dates. N_1 is the interval day between X_1, X_2, and N_2 is the interval day between X_2, and X_3.

rAUDPC = [line AUDPC/susceptible AUDPC] × 100

The commercial barley cultivars and candidate lines were grouped based on different values of partial (slow rusting) resistance parameters according to the method of Patahn & Park (2006) and Hei et al. (2015). Cluster analysis of the studied genotypes was also performed using SPSS software (version 18).

Table 1. The average of meteorological data for two experimental locations during two copping years (2022-2023 and 2023-2024).

Location	Average of meteorological data during two cropping years							
	2022-2023				2023-2024			
	Max. T (˚C)	Min. T (˚C)	Precipitation (mm)	Av. Humidity (%)	Max. T (˚C)	Min. T (˚C)	Precipitation (mm)	Av. Humidity (%)
Ardabil	14.42	2.7	217.3	67.9	15.24	2.87	260	62.8
Zarghan	22.9	7.2	326	51	24.2	7.1	247.6	47.7

Results

Adult plant partial resistance parameters

Adult plant partial (slow rusting) resistance evaluation and phenotyping of the 70 barley genotypes were carried out against pathotypes of stripe rust under artificial field epiphytotic conditions. Adult plant partial resistance was assessed based on the host response, and different epidemiological parameter estimates (CI FRS, and rAUDPC) are given in Tables 2 and 3 and summarized classification is also presented in Table 4.

CI value

The data on disease severity and host reaction were combined to calculate the coefficient of infection (CI). According to Pathan & park (2006) and Hei et al. (2015), commercial cultivars/candidate lines with CI values of 0-20, 21-40, and 41-60 were regarded as possessing high, moderate, and low levels of partial (slow rusting) resistance, respectively. The cultivars Negin, Makouee, Sahra, Nouroz, Zahak, Dasht, Golchin, Nobahar, Nimrouz, Fajre 30 and candidate lines C-97-4, EH-85-9, M-99-16, SE-96-12, W-98-16, C-98-2, W-99-10, C-00-4, SE-96-17, EH-87-4, W-00-10, C-00-3, W-97-6, W-00-14 were grouped in the first category (Table 2, 3 and 4). Oksin, Nik, Behrokh, Lout, Jolge, Azaran, Mahtab, Matin, Yousef, C-99-18, C-00-13, C-96-10, M-99-11, C-99-4 were marked as having a moderate level of partial resistance. Goharan, Bahman, Golshan, Khatam, Mehr, Armaghan, C-00-2, W-99-6, C-99-11, M-99-4, C-98-3, C-98-18, M-00-4, M-00-5, M-00-10, M-99-12, W-00-3, M-00-8, C-98-4, M-00-3, M-00-9, M-98-8, M-00-11, W-99-11, W-98-10, C-99-17 were designated as having a low level of partial resistance. Nosrat, Rihan 3, C-98-13, C-99-5, M-99-3, and C-99-6, exhibited a CI value greater than 60, and were grouped as susceptible.

Disease pressure was considerably high as indicated by the CI of the susceptible check (Tables 2 and 3). The average maximum CI recorded among tested genotypes was 66-74% of the susceptible check for six genotypes (i.e. Nosrat, Rihan 3, C-98-13, C-99-5, M-99-3, C-99-6), while the remaining 64 genotypes were up to 59% of the susceptible check. Based on the results, common pathotypes of barley stripe rust in Ardabil and Zarghan were considered virulent on most of the evaluated cultivars/candidate lines (Tables 2 and 3). According to the results of other researchers (Johnson 1988, Huerta-Espino *et al*., 2020), and in terms of the reaction of the adult plant stage (R/MR infection type) in this study, the cultivars/candidate lines Makouee, Negin, Shara, C-97-4, EH-85-9 and M-99-16 may carry race-specific resistance genes or a combination of race-specific resistance genes, which are effective against all virulences used. These genotypes have all-stage resistance with most probably the presence of *rpsEm1*, *rpsEm2*, or other unknown resistance genes.

It is important to note, that cultivars/candidate lines with race-specific resistance often become susceptible within a few years after their release. This is because of the rapid evolution of new virulent pathotypes of the pathogens (Hovmøller et al., 2016; Chen & Kang, 2017). For this reason, the cultivars Makouee, Negin, Shara, C-97-4, EH-85-9, and M-99-16 need further inheritance studies or need marker-assisted identification of resistance. The genotypes having MS or MR infection type may carry durable resistance genes (Brown et al. 2001a; Singh et al. 2005). Consequently, cultivars/candidate lines with a low-level CI and other quantitative resistance parameters will most probably have partial resistance genes, such as HTAP and slow rusting genes, and their resistance can last for a long time. Since this kind of resistance is controlled by more than one gene, it is also called polygenic (Dehghani & Moghaddam, 2004).

The cultivars/lines with different level of partial resistance are approved to be more durable (Singh et al. 2005; Dawana et al.,

2024). Cultivars/lines with an acceptable degree of partial (slow rusting) resistance reduce the epidemic development rate and do not directly influence the evolution of pathotypes. These cultivars/lines are, however, controlled by several minor genes; overcoming them in the field will take longer. There are rusts fungi that have more potential to change due to different events such as mutation, migration over long-distances, somatic recombination and selection pressure of cultivar genotypes on pathogen genotypes (Hovmøller et al., 2016, Chen & Kang, 2017). Concerning this potential to change, researchers should deploy non-race specific or a combination of non-race specific non-race specific with race-specific resistance instead of using only race-specific. If 4-5 non-race-specific resistance genes are combined in a genotype, its resistance will be close to complete or immune (Singh et al., 2011; Huerta-Espino et al., 2020).

rAUDPC value

Based on the rAUDPC values, commercial barley cultivars/candidate lines were categorized into two distinct groups according to Hei et al. (2015) and Srinivas et al. (2023). One group included the genotypes exhibiting rAUDPC values up to 30% of the check, and the other included the cultivars/candidate lines showing rAUDPC values up to 60% of the check. In these genotypes, rust initiated and sporulated but with final chlorotic and necrotic strips (MR and/or MS infection types). Subsequently, the progress of rust development remained slower and restricted. The genotypes in group 1 were marked as having better partial (slow rusting) resistance and that of group 2 were marked as having moderately partial (slow rusting) resistance. The reasons for the markings were because they also developed epiphytotic of very low potential as indicated by their rAUDPC values, despite the ultimate expression of high infection type. Genotypes with such traits are expected to possess genes that confer partial (slow rusting) resistance (Parlevliet, 1988; Safavi & Afshari, 2017, Srinivas et al., 2023; Dawana et al., 2024). The Cultivars Negin, Makouee, Sahra, Nouroz, Zahak, Dasht, Golchin, Nobahar, Nimrouz, Fajre 30, Nik, Jolge, Matin and candidate lines C-97-4, EH-85-9, M-99-16, SE-96-12, W-98-16, C-98-2, W-99-10, C-00-4, SE-96-17, EH-87-4, W-00-10, C-00-3, W-97-6, C-99-18, C-00-13, C-96-10 exhibited rAUDPC mean values less than 30% of Afzal and were marked as having better partial resistance. Except for seven genotypes (Nosrat, Rihan3, W-98-10, C-99-17, C-98-13, C-99-3, C-99-6), the rest of the cultivars/candidate lines having rAUDPC mean values up to 60% of the susceptible check were grouped as moderately partial resistance in group 2. Both groups 1 and 2 were composed of cultivars/candidate lines with varying degrees of partial resistance. Moreover, cultivars/candidate lines with acceptable levels of partial or slow rusting resistance restrict the evolution of new virulent pathotypes of the pathogen. This is because multiple-point mutations are extremely scarce (Ali et al., 2007).

Final rust severity

Data on the final rust severity of the 70 genotypes along with the susceptible check (Afzal) are shown in Tables 2 and 3. High disease pressure was recorded at the testing sites (especially in Zarghan) as maximum average FRS - up to 100% for Afzal, followed by Rihan 3 (80%), C-99-6 (80%), and Nosrat (78%) classified as susceptible. Based on the results, the pathotypes of Zarghan were more aggressive than the pathotypes of Ardabil and had pathogenicity on most of the evaluated cultivars and lines (Table 2, 3). This result may be due to new pathotypes that hadn't been collected or identified before, or may be weather conditions in Zarghan were more favorable than that of Ardabil. In this investigation, our results also indicated that none of the tested genotypes were recorded to be immune.

Table 2. The evaluation results of adult plant partial resistance parameters (FRS, CI, and rAUDPC) in commercial barley cultivars against stripe rust in Ardabil and Zarghan during two consecutive years (2023 and 2024).

		Partial resistance parameters evaluated during 2022-2023						Partial resistance parameters evaluated during 2023-2024						Average of different parameters		
		Ardabil			Zarghan			Ardabil			Zarghan					
No.	Cultivars	FRS & IT	CI	rAUDPC	FRS & IT	CI	rAUDPC	FRS & IT	CI	rAUDPC	FRS & IT	CI	rAUDPC	FRS	CI	rAUDPC
1	**Negin**	10MR	4	9	10R	2	9	5R	1	6	10R	2	9	**9**	**2**	**8**
2	**Makouee**	30MR	12	23	5R	1	6	5R	1	6	5R	1	5	**12**	**4**	**10**
3	**Sahra**	20MR	8	17	20MR	8	20	10MR	4	7	10R	2	9	**15**	**6**	**14**
4	**Nouroz**	10R/MR	3	10	10MR	4	7	10MR	4	10	20MS	16	16	**13**	**7**	**11**
5	**Zahak**	10MR	4	10	50MR	20	46	10MR	4	7	30MR	12	20	**25**	**10**	**21**
6	**Dasht**	30MS	24	23	20MR	8	14	10MR	4	7	30R	6	25	**23**	**11**	**18**
7	**Golchin**	10MR	4	10	50M	30	46	5R	1	6	20MR	8	20	**22**	**11**	**21**
8	**Nobahar**	10MR	4	10	60MS	48	37	10MR	4	7	20MS	16	11	**25**	**18**	**17**
9	**Nimrouz**	20MR	8	19	60M	36	27	30M	18	13	20MR	8	18	**33**	**18**	**20**
10	**Fajre 30**	40MR	16	35	40MS	32	43	30M	18	16	10MR	4	10	**30**	**18**	**26**
11	**Oksin**	10MR	4	10	50M	30	46	5R	1	9	80M	48	68	**37**	**21**	**33**
12	**Nik**	10R/MR	3	10	70S	70	58	5R	1	6	40MS	32	28	**32**	**27**	**26**
13	**Behrokh**	20MR	8	19	50MR	20	46	20MR	8	19	90S	90	45	**45**	**32**	**33**
14	**Lout**	30MR	12	23	70MS	56	55	20MR	8	13	80MS	64	45	**50**	**35**	**34**
15	**Jolge**	10R/MR	3	13	60MS	48	49	5R	1	6	90S	90	34	**42**	**36**	**26**
16	**Azaran**	10R/MR	3	10	70MSS	63	66	20M	12	19	80MS	64	55	**45**	**36**	**38**
17	**Mahtab**	30MR	12	25	50MSS	45	38	10MR	4	7	90S	90	55	**45**	**38**	**32**
18	**Matin**	10MR	4	10	70MS	56	35	20M	12	12	80S	80	35	**45**	**38**	**23**
19	**Yousef**	10R/MR	3	10	80MSS	72	83	30M	18	13	80MS	64	53	**50**	**40**	**40**
20	**Goharan**	10MR	4	13	80MS	64	77	10MR	4	15	90S	90	75	**48**	**41**	**45**
21	**Bahman**	10R/MR	3	10	90MS	72	86	5R	1	6	90S	90	73	**49**	**42**	**44**
22	**Golshan**	30MR	12	23	90MSS	81	86	30M	18	16	90MSS	81	63	**60**	**49**	**48**
23	**Khatam**	20MR	8	21	100S	100	95	20MR	8	10	100S	100	98	**60**	**54**	**56**
24	**Mehr**	30MR	12	23	100S	100	97	20MR	8	13	100S	100	98	**63**	**55**	**58**
25	**Armaghan**	40MS	32	42	90MS	72	86	30MS	24	18	100S	100	90	**65**	**57**	**59**
26	**Nosrat**	40MS	32	42	90S	90	92	80MSS	72	62	100S	100	88	**78**	**74**	**71**
27	**Rihan 3**	50MS	40	50	90MSS	81	86	80MSS	72	56	100S	100	70	**80**	**74**	**66**
Check	**Afzal**	**70S**	**70**	**100**	**100S**	**100**	**100**	**100S**	**100**	**100**	**100S**	**100**	**100**	**93**	**93**	**100**

Partial resistance parameters including; FRS= Final rust severity, CI=Coefficient of Infection, rAUDPC= relative Area under disease progress curve.
IT=Infection Type

Table 3. The evaluation results of adult plant partial resistance parameters (FRS, CI, and rAUDPC) in candidate lines against stripe rust in Ardabil and Zarghan during two consecutive years (2023 and 2024).

No.	Candidate lines	Partial resistance parameters evaluated during 2022-2023						Partial resistance parameters evaluated during 2023-2024						Average of different parameters		
		Ardabil			Zarghan			Ardabil			Zarghan					
		FRS & IT	CI	rAUDPC	FRS & IT	CI	rAUDPC	FRS & IT	CI	rAUDPC	FRS & IT	CI	rAUDPC	FRS	CI	rAUDPC
1	**C-97-4**	10R/MR	3	10	5MR	2	6	10MR	4	7	5MR	2	6	**8**	**3**	**7**
2	**EH-85-9**	10R	2	10	5R	1	6	20MR	8	15	30MR	12	25	**17**	**6**	**14**
3	**M-99-16**	10R/MR	3	10	30MR	12	23	5R	1	6	30MR	12	25	**19**	**8**	**16**
4	**SE-96-12**	10MR	4	10	30MS	24	29	5R	1	7	30MR	12	25	**19**	**11**	**18**
5	**W-98-16**	30MR	12	25	40M	24	40	10MR	4	10	10MS	8	10	**23**	**12**	**22**
6	**C-98-2**	10R	2	10	40MS	32	38	5R	1	7	40MR	16	30	**24**	**13**	**22**
7	**W-99-10**	5R	1	4	30MS	24	15	20M	12	13	40MR	16	30	**24**	**14**	**16**
8	**C-00-4**	5R	1	4	40MS	32	34	5R	1	6	40M	24	38	**23**	**15**	**21**
9	**SE-96-17**	10R	2	10	40MS	32	32	20M	12	13	40MR	16	35	**28**	**16**	**23**
10	**EH-87-4**	10MR	4	4	70MS	56	55	20MR	8	13	10MR	4	10	**28**	**18**	**21**
11	**W-00-10**	5R	1	4	50M	30	40	10MR	4	9	50MS	40	38	**29**	**19**	**23**
12	**C-00-3**	5R	1	4	70M	42	59	10MR	4	7	50M	30	38	**34**	**20**	**28**
13	**W-97-6**	10R/MR	3	10	70MS	56	74	5R	1	9	40MR	16	25	**32**	**20**	**30**
14	**W-00-14**	10MR	4	6	50MR	20	45	20MR	8	21	80M	48	63	**40**	**20**	**34**
15	**C-99-18**	10R/MR	3	10	40MR	16	29	10MR	4	12	90S	90	65	**38**	**29**	**29**
16	**C-00-13**	5R	1	4	50MR	20	33	30MR	12	18	90S	90	55	**44**	**31**	**27**
17	**C-96-10**	10MR	4	10	40M	24	38	30MS	24	15	90MSS	81	43	**43**	**34**	**27**
18	**M-99-11**	30MR	12	23	80MSS	72	83	20MR	8	21	70MS	56	53	**50**	**37**	**45**
19	**C-99-4**	30MS	24	25	70MS	56	63	20M	12	18	80MS	64	65	**50**	**39**	**43**
20	**C-00-2**	10MR	4	10	80MS	64	57	10MR	4	12	90S	90	73	**48**	**41**	**38**
21	**W-99-6**	5R	1	4	70MS	56	49	20MR	8	13	100S	100	93	**49**	**42**	**40**
22	**C-99-11**	30MR	12	25	90MS	72	75	20MR	8	15	90MSS	81	73	**58**	**44**	**47**
23	**M-99-4**	40MS	32	42	70MSS	63	74	30MR	12	26	80MSS	72	60	**55**	**45**	**51**
24	**C-98-3**	20MR	8	19	90MS	72	86	10MR	4	18	100S	100	85	**55**	**46**	**52**
25	**C-98-18**	40MS	32	42	70MR	28	60	40MS	32	26	90S	90	68	**60**	**46**	**49**

Partial resistance parameters including; FRS= Final rust severity, CI=Coefficient of Infection, rAUDPC= relative Area under disease progress curve.
IT=Infection Type

Table 3. Continued from previous page…

No.	Candidate lines	Partial resistance parameters evaluated during 2022-2023						Partial resistance parameters evaluated during 2023-2024						Average of different parameters		
		Ardabil			Zarghan			Ardabil			Zarghan					
		FRS & IT	CI	rAUDPC	FRS & IT	CI	rAUDPC	FRS & IT	CI	rAUDPC	FRS & IT	CI	rAUDPC	FRS	CI	rAUDPC
26	**M-00-4**	20MR	8	19	60MSS	54	63	30MS	24	24	100S	100	95	**53**	**47**	**50**
27	**M-00-5**	10MS	8	14	80MSS	72	84	20MR	8	13	100S	100	88	**53**	**47**	**50**
28	**M-00-10**	5R	1	4	100S	100	95	10MR	4	12	90S	90	70	**52**	**49**	**46**
29	**M-99-12**	10R/MR	3	10	90S	90	86	10MR	4	12	100S	100	88	**53**	**50**	**49**
30	**W-00-3**	5R	1	4	80S	80	76	30M	18	16	100S	100	83	**54**	**50**	**45**
31	**M-00-8**	5R	1	4	90S	90	94	20MR	8	10	100S	100	90	**54**	**50**	**50**
32	**C-98-4**	20MS	16	21	80MS	64	54	30MSS	27	22	90S	90	70	**55**	**50**	**42**
33	**M-00-3**	10MR	4	14	80S	80	84	30MS	24	16	100S	100	90	**55**	**52**	**51**
34	**M-00-9**	10MR	4	14	100S	100	95	10MR	4	9	100S	100	90	**55**	**52**	**52**
35	**M-98-8**	10R/MR	2	13	100S	100	92	10MR	4	12	100S	100	95	**55**	**52**	**53**
36	**M-00-11**	5R	1	4	100S	100	95	20MR	8	21	100S	100	88	**57**	**53**	**52**
37	**W-99-11**	5R	1	10	70MS	56	49	60MSS	54	38	100S	100	90	**60**	**53**	**47**
38	**W-98-10**	30MS	24	25	100S	100	95	40M	24	44	90MSS	81	78	**65**	**58**	**61**
39	**C-99-17**	40MR	16	42	90MS	72	80	50MSS	45	38	100S	100	85	**70**	**59**	**62**
40	**C-98-13**	60MSS	54	71	70MSS	63	58	50MSS	45	32	100S	100	75	**70**	**66**	**60**
41	**C-99-5**	30MS	24	25	90MSS	81	78	70MSS	63	29	90S	90	78	**70**	**65**	**53**
42	**M-99-3**	40MS	32	38	90MSS	81	86	60MSS	54	53	100S	100	95	**73**	**67**	**68**
43	**C-99-6**	50MS	40	54	90MSS	81	80	80MSS	72	62	100S	100	88	**80**	**74**	**71**
-	**Afzal**	**70S**	**70**	**100**	**100S**	**100**	**100**	**100S**	**100**	**100**	**100S**	**100**	**100**	**93**	**93**	**100**

Partial resistance parameters including; FRS= Final rust severity, CI=Coefficient of Infection, rAUDPC= relative Area under disease progress curve.
IT=Infection Type

Similarly based on FRS, the tested cultivars/candidate lines were grouped into three groups of partial resistance, i.e. high, moderate, and low levels of partial resistance having 1-30%, 31-50%, and 51-70% FRS, respectively. Genotypes Negin, Makouee, Sahra, Nouroz, Zahak, Dasht, Golchin, Nobahar, Fajre 30 and candidate lines C-97-4, EH-85-9, M-99-16, SE-96-12, W-98-16, C-98-2, W-99-10, C-00-4, SE-96-17, EH-87-4, W-00-10 were included in the first group. The cultivars/candidate lines Oksin, Nimrouz, Nik, Behrokh, Lout, Jolge, Azaran, Mahtab, Matin, Yousef, Goharan, Bahman, W-00-14, W-97-6, C-99-18, C-00-13, C-96-10, M-99-11, C-99-4, C-00-2, W-99-6, C-99-11 were marked as having a moderate level of partial resistance. The rest of the genotypes were designated as having a low level of partial resistance. Broers et al. (1996) and Dawana et al., (2024) also carried out a field assessment of quantitative resistance to stripe rust for ranking the cultivars and lines. According to the resistance level based on disease severity along with other partial (slow rusting) resistance parameters; they found that resistance levels ranged from very low to very high among the tested genotypes

Genetic diversity based on cluster analysis

Cluster analysis of cultivars and candidate lines, which was performed based on the values of different parameters (FRS, CI, and rAUDPC) at the adult plant stage, are presented separately in two dendrograms (Figures 1 and 2). The susceptible cultivar (Afzal) with the greatest genetic distance was separated from the other genotypes and placed in a separate group in two presented dendrograms (Groups D and C, Figures 1 and 2, respectively). In the case of the studied cultivars, the other genotypes (except Afzal) were classified into three main groups (Figure 1). In the main group A, nine cultivars were included, that had moderate to high values of adult plant disease severity and infection type, and therefore moderate to low levels of partial resistance. The second main group (B), including 12 genotypes with low or moderate values of different parameters, was categorized into groups with high to moderate levels of partial resistance. The last main group (C) was divided to two subgroups. In the first subgroup (C1), two cultivars; Nosrat and Rihan 3, having high values of partial resistance parameters and therefore, were placed in the susceptible group (group C1). Another subgroup (C2), which contains four cultivars Armaghan, Mehr, Khatam and Golshan with high values of FRS, CI, and rAUDPC were classified into groups having low level of adult plant partial resistance.

Table 4. Promising levels of adult plant partial resistance characterized against barley stripe rust

Partial resistance level	Number	Cultivars and candidate lines
High	24	Negin, Makouee, Sahra, Nouroz, Zahak, Dasht, Golchin, Nobahar, Nimrouz, Fajre 30, C-97-4, EH-85-9, M-99-16, SE-96-12, W-98-16, C-98-2, W-99-10, C-00-4, SE-96-17, EH-87-4, W-00-10, C-00-3, W-97-6, W-00-14
Moderate	14	Oksin, Nik, Behrokh, Lout, Jolge, Azaran, Mahtab, Matin, Yousef, C-99-18, C-00-13, C-96-10, M-99-11, C-99-4
Low	26	Goharan, Bahman, Golshan, Khatam, Mehr, Armaghan, C-00-2, W-99-6, C-99-11, M-99-4, C-98-3, C-98-18, M-00-4, M-00-5, M-00-10, M-99-12, W-00-3, M-00-8, C-98-4, M-00-3, M-00-9, M-98-8, M-00-11, W-99-11, W-98-10, C-99-17
Susceptible	6	Nosrat, Rihan 3, C-98-13, C-99-5, M-99-3, C-99-6

In the case of candidate lines, except for susceptible check (Afzal), other genotypes were classified into two main groups (Figure 2). The main group A was also divided into two subgroups. In the first subgroup (A1), 20 candidate lines were included, which had low values of different epidemiological parameters, and therefore, were classified as groups with high to moderate levels of partial resistance. In the second subgroup (A2), six candidate lines were placed. This subgroup having high values of FRS, CI, and rAUDPC, were classified in susceptible group (candidate lines C-98-13, C-99-5, M-99-3, and C-99-6) and low-level partial resistance group (two candidate lines C-99-17 and W-98-10). Another main group (Figure 2, B), included 17 candidate lines. In this group, 14 genotypes having low values of FRS, CI and rAUDPC were categorized as a group with high level partial resistance and three genotypes (C-99-18, C-00-13, C-96-10) having moderate values of FRS, CI and rAUDPC were classified as a group with moderate level partial resistance.

Ali et al. (2009) and Safavi & Afshari (2017), also reported high variability among the studied wheat cultivars or lines for stripe rust based on the cluster analysis of slow rusting resistance parameters. The variability observed in the present study, can be used in breeding programs for barley stripe rust. This will prevent the cultivation of genotypes having low genetic diversity in resistance to stripe rust.

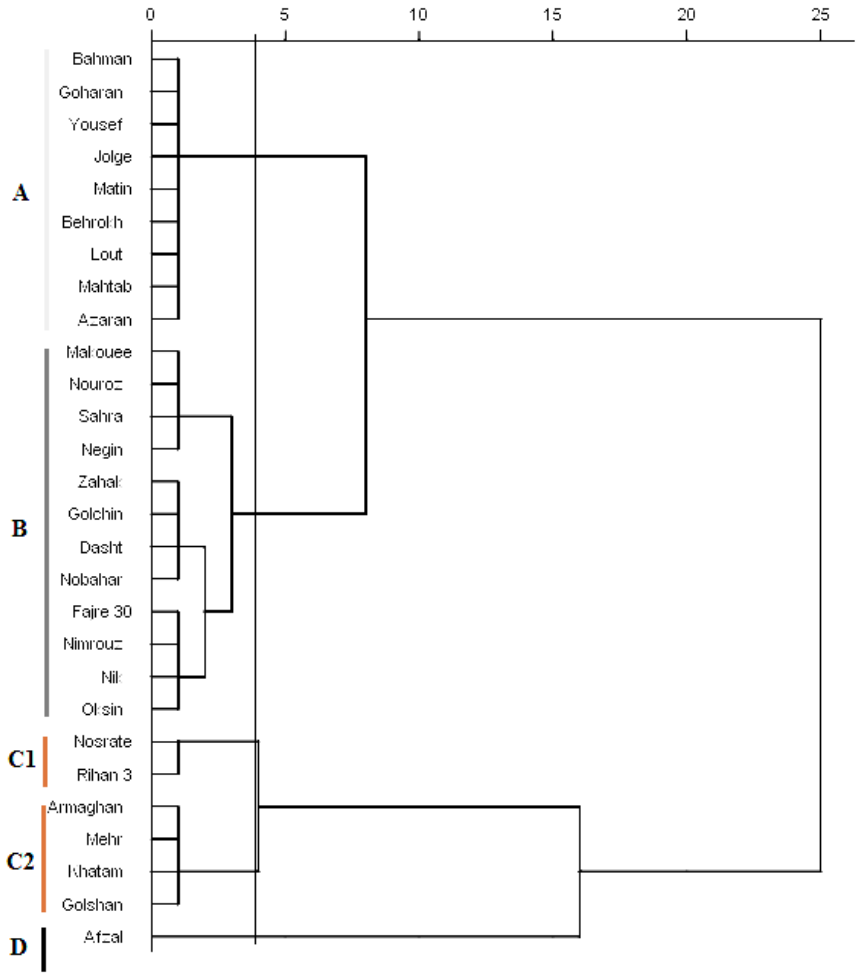


Figure 1. Classification of commercial barley cultivars based on the values of adult plant partial resistance parameters against stripe rust using cluster analysis

Discussion

The present study used three parameters, CI, FRS, and rAUDPC, to appraise the partial resistance. However, all three resistance parameters are very important and have been used by many researchers (Sandoval-Islas et al., 2007; Ali et al., 2009; Shah et al., 2014; Safavi & Afshari, 2017, Huerta-Espino et al., 2020, Srinivas et al., 2023; Dawana et al., 2024). Despite this, the parameter rAUDPC is paramount in field evaluations of partial resistance. The rAUDPC is a quantitative measure of total resistance and characterizes all resistance components such as infection frequency, infection latency, uredinium size, and sporulation in leaf area (Milus & Line, 1986). The reason for studying the adult plant partial resistance parameters under the field conditions is the low correlation of some components of partial resistance in greenhouse conditions (seedlings) with the mentioned components at the adult plant stage (Sandoval-Islas et al., 2007). On the other hand, since the expression of non-race-specific resistance genes (such as partial resistance) occurs at the adult plant stage (Singh et al., 2011), in the present study, the parameters of partial (slow rusting) resistance were also studied at the adult plant stage under field conditions.

The continually evolving populations of *Puccinia striiformis* f. sp. *hordei* have sometimes been the major challenge for barley production in some barley-growing provinces of Iran, leading to great economic losses (Safavi et al., 2014; Zakeri et al., 2018). The situation is not also different in other parts of the world where the deployment and cultivation of barley genotypes with different stripe rust resistance genes has led to serious stripe rust epidemics when the genes became ineffective (Mathur & Siradhana, 1990; Sandoval-Islas et al., 1998; Brown et al., 2001b; Gyawali et al., 2017; Verma et al., 2018). This study has provided insights into the variability of commercial barley cultivars/candidate lines to infection by *Psh* in two important sites and hot spots of stripe rust in Iran. Our result also showed that some of the barley genotypes that are part of the current production systems by farmers have a diverse source of rust-resistant gene pool that may help develop novel resistant germplasm.

Our investigation found that virulent pathotypes of the *Psh* were present on most barley genotypes, albeit it is difficult to characterize which genes are responsible. Previously under greenhouse conditions, pathogenicity has been found in Ardabil and Fars provinces for differential cultivars carrying resistance genes *Rps4*, *rpsHF*, *rpsAst*, *rpsHi1*, *rpsHi2*, *rps2*, *rpsTr1*, *rpsTr2*, *Rps1.c*, *Rps1.b*, *Rps3*, *RpsI5*, *RpsBa*, *rpsV1*, *rpsV2* (Safavi et al., 2014; Zakeri et al., 2018). Additionally, there are reports of the pathogen's increasing virulence factor by hybridization between two formae specialis (*Pst* and *Psh*) in various regions worldwide (Cheng et al., 2016; Safavi et al., 2017; Chen **&** Kang, 2017). Given that some barley genotypes were found to be moderately susceptible or susceptible to the pathogen, most likely due to the breakdown of effective resistance governed by dominant genes, the pathogenicity patterns of the pathogen populations in the current study may involve virulence factors against most of the resistance genes deployed on the improved cultivars in Iran. Accordingly, it is paramount to use promising genetic materials that render resistance to the most dominant pathotypes of the pathogen under investigation. The genetic resources identified with varying levels of adult plant partial resistance could complement the ongoing search for new sources of resistance germplasm to combat the disease.

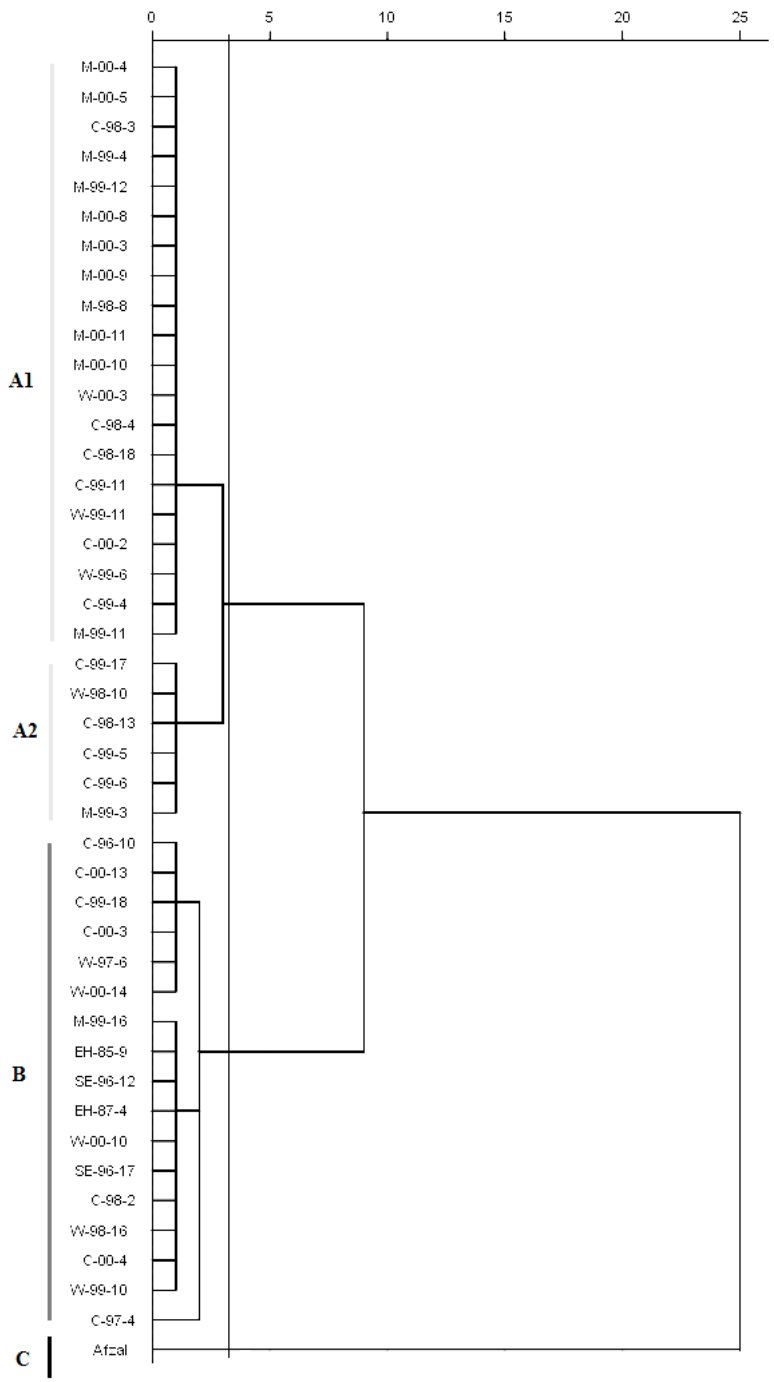


Figure 2. Classification of barley candidate lines based on the values of adult plant partial resistance parameters against stripe rust using cluster analysis

Our findings also demonstrated that the commercial barley cultivars and candidate lines contain a wide variety of partial (slow rusting) resistance germplasm, which may have a long-lasting and robust effect on disease control. As indicated by the results of the most important parameters, such as the rAUDPC, FRS, and CI, that are usually considered for measuring quantitative resistance in rusts (Sandoval-Islas et al., 2007; Ali et al., 2009; Shah et al., 2014; Safavi & Afshari, 2017, Huerta-Espino et al., 2020, Srinivas et al., 2023; Dawana et al., 2024), some genetic materials have demonstrated effectiveness against stripe rust at the adult plant stage. This was

important as investigating effective adult plant-stage resistance genes has been the main focus of recent rust management strategies worldwide (Huerta-Espino et al., 2020, Srinivas et al., 2023; Dawana et al., 2024; Omrani et al., 2024). Furthermore, it can be postulated that the Iranian commercial barley cultivars and candidate lines indicate a wide range of resistance levels, from low to high, which makes them attractive for the selection of prospective genetic materials for stripe rust management based on all the evidence of disease resistance parameters studied in this investigation. Based on the other reports (Parlevliet, 1988; Alemu et al., 2020), genotypes with partial (slow rusting) resistance are considered extremely important to perform effective stripe rust management, even though the low level of resistance might not actively delimit the development of the disease.

Numerous research divided wheat and barley genotypes into three categories of partial (slow rusting) resistance based on the average CI and final severity of infection (Ali et al., 2007; Safavi & Afshari, 2012; Srinivas et al., 2023; Dawana et al., 2024). It is possible under this classification method that some commercial cultivars and candidate lines that were resistant or moderately resistant to *Psh* at the adult plant stage may include useful minor genes that identify the appropriate particular gene for avirulence against the pathogen (Bux et al., 2012; Parlevliet, 1997). Other studies have also found adult plant resistance against stripe rust using rAUDPC value (Jeger & Viljanen-Rollinso, 2001; Sandoval-Islas et al., 2007; Safavi **&** Afshari, 2017, Srinivas et al., 2023; Dawana et al., 2024). If this parameter is supported with lower disease progress rate values per day, as indicated for some commercial barley cultivars and candidate lines with comparable rAUDPC values and lower disease progress rate per day in this study, the result can provide a true measurement of slow rusting characters (Camp- bell, 1998; Sandoval-Islas et al., 2007; Dawana et al., 2024). According to Parlevliet (1988), genotypes with variable field infection types of MR-MS are also expected to possess genes that confer partial resistance, provided that the rAUDPC values are lower than the most susceptible ones, as observed in this study (Sandoval-Islas et al., 2007; Safavi et al., 2013; Safavi **&** Afshari, 2017, Srinivas et al., 2023; Dawana et al., 2024). Such classification methods have provided useful information about the existence of a wide range of resistance mechanisms in the currently analyzed commercial barley cultivars and candidate lines conferring different levels of resistance at the adult plant stage.

The cluster analysis revealed clear divisions of the barley genotypes into different resistance groups based on the quantitative characteristics of the stripe rust dissimilarity responses. According to this analysis method, some commercial barley cultivars and candidate lines were identified to form distinct branches, with the group possessing high or moderate levels of partial resistance. These particular clusters of barley genotypes were moderately resistant to moderately susceptible to *Psh* pathotypes. This holds great promise for a future long-lasting stripe rust resistance breeding program of barley. There have also been earlier reports on the possibility of classifying wheat genotypes according to cluster analysis (Ali et al., 2009; Safavi **&** Afshari, 2017; Dawana et al., 2024). However, future work should also focus on identifying and characterizing the nature of these resistance genes.

Conclusion

The evaluated commercial barley cultivars and candidate lines in the current study indicated diverse responses to barley stripe rust. Among the studied genotypes, different types of resistance, including complete and partial resistance, were observed. Twenty-four cultivars/candidate lines (Negin, Makouee, Sahra, Nouroz, Zahak, Dasht, Golchin, Nobahar, Nimrouz,

Fajre 30, C-97-4, EH-85-9, M-99-16, SE-96-12, W-98-16, C-98-2, W-99-10, C-00-4, SE-96-17, EH-87-4, W-00-10, C-00-3, W-97-6, W-00-14) that showed low or moderate (R, MR, M, MS) infection types at adult plant stage and low values of different parameters (CI, FRS, rAUDPC), most likely have high level of partial (slow rusting/ non-race-specific) resistance and it may be durable. If 4-5 non-race-specific resistance genes are combined, the resistance of these genotypes will be near to complete or immune resistance. The genotypes, having high or moderate levels of partial resistance, can be used for cultivation or be candidates for introduction. Moreover, genotypes with good levels of partial resistance can be used in breeding programs. In introducing varieties, in addition to emphasizing durable resistance, it is recommended to consider stable resistance to other important barley diseases so that the varieties have sustainable production.

Acknowledgment

This research was carried out with the financial support of the Seed and Plant Improvement Research Institute (SPII), under projects number 0-37-03-075-010713 and 01-37-03-077-020780. We hereby express our gratitude and appreciation to all the respected colleagues of the Institute and Ardabil Agricultural and Natural Resources Research and Education Center who helped us in carrying out this research.

Conflict of interest statement

The authors declare no conflicts of interest.

References

Alemu, S. K., Huluka, A. B., Geletu, K. T., & Uauy, C. (2020). Genome-wide association mapping identifies stripe rust resistance locus in Ethiopian durum wheat germplasm. *PLoS ONE, 16* (5), e0243675.

Ali, S., Shah, S. J. A., Khalil, I. H., Rahman, H., Maqbool, K., & Ullah, W. (2009). Partial resistance to stripe rust in introduced winter wheat germplasm at the north of Pakistan. *Australian Journal of Crop Science, 3*, 37-43.

Ali, S., Shah, S. J., & Ibrahim, M. (2007). Assessment of wheat breeding lines for slow stripe rusting (*Puccinia striiformis* West. *tritici*). *Pakistan Journal of Biological Sciences, 10* (19), 3440–3444. https:// doi.org/10.3923/pjbs.2007.3440.3444

Bahl, P. N., & Bakshi, J. S. (1963). Genetics of rust resistance in barley- II. The inheritance of seedling resistance to four pathotypes of stripe rust. *Indian Journal of Genetics & Plant Breeding, 23*, 150–154.

Broers, L. H. M., Cuesta-Subias, X., & Lopez-Atilano, R. M. (1996). Field assessment of quantitative resistance to stripe rust in ten spring bread wheat cultivars. *Euphytica, 90*, 9-16.

Brown, W. M. J., Hill, J. P., & Velasco, V. R. (2001a). Barley stripe rust in North America. *Annual Review of Phytopathology, 39*, 367-384.

Brown, W. M., Hill, J. P., **&** Velasco, V.R. (2001b). Identification of barley rust resistance in the Americas: A case study of successful international cooperation. Abstracts of *First Regional Stripe Rust Conference for Central & West Asia and North Africa.* 8- 14 May 2001, Karaj, Iran. Pages 8-9.

Bux, H., Rasheed, A., Siyal, M. A., Kazi, A. G., Napar, A. A., & Mujeeb- Kazi, A. (2012). An overview of stripe rust of wheat (*Puccinia striiformis* f. sp. *tritici*) in Pakistan. *Archives of Phytopathology and Plant Protection, 45*, 2278–2289. https://doi.org/10.1080/03235408.

Campbell, C. L. (1998). Disease progress in time: Modeling and data analysis. In D. G. Jones (Ed.), *The epidemiology of plant diseases* (pp. 181–206). Springer**.**

Capettini, F. (2005). Barley in Latin America. In: S. Grando & H. G. Macpherson (Eds.), Food barley: Importance, uses and local knowledge(x+156 pp). Proceedings of the *international workshop on food barley improvement*, 14-17 January 2002. Hammamet, Tunisia: ICARDA, Aleppo, Syria, En.

Chen, X. M. (2007). Challenges and solutions for stripe rust control in the United States. *Australian Journal of Agricultural Research, 58*, 648–655.

Chen, X. M. (2008). Pathotypes of *Puccinia striiformis* f. sp. *hordei* in the United States from 2004 to 2007. *Barley Newsletter*, 51: WABNL51.

Chen, X. M., & Kang, Z. S. (2017). Stripe Rust. Dordrecht: Springer. 719 PP.

Chen, X. M., Line, R. F., & Leung, H. (1995). Virulence and polymorphic DNA relationships of *Puccinia striiformis* f. sp. *hordei* to other rusts. *Phytopathology*, 85: 1335-1342.

Cheng, P., Chen, X. M., & See, D. (2016). Grass hosts harbor more diverse isolates of *Puccinia striiformis* than cereal crops. *Phytopathology, 106*, 362–71.

Dawana, D., Dessie, B., Kebede, M., & Shimelash, D. (2024). Pathogenicity of *Puccinia striiformis* f. sp. *tritici* and quantitative traits on bread wheat landraces in Ethiopia. *Crop Science*, *64*(2), 651-666. https://doi.org/10.1002/csc2.21187.

Dehghani, H., & Moghaddam, M. (2004). Genetic analysis of the latent period of stripe rust in wheat seedlings. *Journal of Phytopathology*, *122*, 325-330. https://doi.org/10.1111/j.1439-0434.2004.00848.x

Dracatos, P. M., Khatkar, M. S., Singh, D., Stefanato, F., Park, R. F., & Boyd, L. A. (2016). Resistance in Australian barley (*Hordeum vulgare*) germplasm to the exotic pathogen *Puccinia striiformis* f. sp. *hordei*, the causal agent of stripe rust. *Plant Pathology*, *65*, 734–743.

Dubin, H. J., & Stubbs, R. W. (1986). Epidemic spread of barley stripe rust in South America. *Plant Disease, 70*, 141-144.

Esfandiari, E. (1947). Les rouilles de cereales en Iran [Cereal rusts in Iran]. *Applied Entomology & Phytopathology*, *4*, 67–76.

Esvelt Klos, K., Gordon, T., Bregitzer, P., Hays, P., Chen, X. M., del Blanco, I. A., & Bonman, J. M. (2016). Barley stripe rust resistance QTL: Development and validation of SNP markers for resistance to *Puccinia striiformis* f. sp. *hordei*. *Phytopathology*, *106*, 1344–1351.

Golegaonkar, P. G., Singh, D., & Park, R. F. (2009). Evaluation of seedling and adult plant resistance to *Puccinia hordei* in barley. *Euphytica, 166* (2), 83–197.

Gyawali, S., Verma, R.P.S., Kumar, S., Bhardwaj, S.C., Gangwar, O.P., Selvakumar, R., Shekhawat, P.S., Rehman, S., & Sharma-Poudyal, D. (2018). Seedling and adult plant stage resistance of a world collection of barley genotypes to stripe rust. *Journal of Phytopathology*, 166 (1): 18-27. https://doi.org/10.1111/jph.12655.

Hei, N., Shimelis, H. A., Laing, M., & Admassu, B. (2015). Assessment of Ethiopian wheat lines for slow rusting resistance to stem rust of wheat caused by *Puccinia graminis* f. sp. *tritici*. *Journal of Phytopathology,163*, 353–363.

Hovmøller, M. S., Walter, S., Bayles, R. A., Hubbard, A., Flath, K., Sommerfeldt, N., Leconte, M., Czembor, P., Rodriguez-Algaba, J., Thach, T., & Hansen, J. G. (2016). Replacement of the European wheat stripe rust population by new pathotypes from the centre of diversity in the near-Himalayan region. *Plant Pathology, 65*(3), 402–411. https://doi.org/10.1111/ppa.12433.

Huerta-Espino, J., Singh, R., Crespo-Herrera, L.A., Villaseñor-Mir, H.E, Rodriguez-Garcia, M.F., Dreisigacker, S., Barcenas-Santana, D., & Lagudah, E. (2020). Adult plant slow rusting genes confer high levels of resistance to rusts in bread wheat cultivars from Mexico. *Frontiers in Plant Science, 11,* 824.

Jeger, M. J., & Viljanen-Rollinson, S. L. H. (2001). The use of the area under the disease-progress curve (AUDPC) to assess quantitative disease resistance in crop cultivars. *Theoretical and Applied Genetics, 102* (1), 32–40. https://doi.org/10.1007/s001220051615.

Johnson, R. (1988). Durable resistance to stripe (stripe) rust in wheat and its implications in plant breeding. In: Simmonds, N. W. and Rajaram, S. (eds.) Breeding *strategies for resistance to the rusts of wheat*, p. 63-75. Mexico, D. F. CIMMYT.

Johnston, P. A., Niks, R. E., Meiyalaghan, V., Blanchet, E. & Pickering, R. (2013). *Rph22*: mapping of a novel leaf rust resistance gene introgressed from the non-host *Hordeum bulbosum* L. into cultivated barley (*Hordeum vulgare* L.). *Theoretical and Applied Genetics*. *126* (6), 1613-25. doi: 10.1007/s00122-013-2078-9.

Kilpatrick, R. A. (1975). New cultivars and longevity of rust resistance, 1971-1975. U.S *Agricultural Research Service*, ARS-NE 64, 20 pp.

Kumar V., Shekhawat P. S., Vishwakarma S. R., Bharadwaj S. C., Kumar S., Kharub A. S., & Singh G. P. (2020). Identification of resistant sources against spot blotch and stripe rust of barley. *Journal of Cereal Research, 12* (1), 50-54. DOI: 10.25174/2582-2675/2020/88973.

Lei, Y., Wang, M. N., Wan, A. M., Xia C. J., See, D. R., Zhang, M., & Chen, X. M. (2016). Virulence and molecular characterization of experimental isolates of the stripe rust pathogen (*Puccinia striiformis*) indicate somatic recombination. *Phytopathology*, *107*, 329–44.

Line, R. F. (2002). Stripe rust of wheat and barley in North America: A retrospective historical review. *Annual Review of Phytopathology, 40*, 75-118.

Luthra, J. K., & Chopra, V. L. (1990). Genetics of stripe rust resistance in barley. *Indian Journal of Genetics, 50,* 390–395.

Mathur, A. K., & Siradhana, B. S. (1990). Screening of indigenous and exotic barley germplasm against indian pathotypes of stripe rust. Indian *Journal of Mycology and Plant Pathology, 20,* 182.

Milus, E. A., & Line, R. F. (1986). Gene action for inheritance of durable, high– temperature, adult plant resistances to stripe rust in wheat. *Phytopathology*, *76*, 435-441.

Nevo E. (2013). Evolution of wild barley and barley improvement. Advance in barley sciences. In: *Proceedings of the 11th International Barley Genetics Symposium*, Zhang G., Li C., and Liu X. (Eds), Dordrecht: Zhejiang University Press and Springer Science C Business Media, 1-23.

Newman, C. W., & Newman, R. K. (2006). A brief history of barley foods. *Cereal Food World, 51* (1), 4–7.

Omrani, A., Afshari, F., Shahbazi, F. & Kabiri, A. (2024). Investigating the reaction of resistance to stripe rust disease (*Puccinia striiformis* f. sp. *tritici*) in commercial cultivars and promising wheat lines (candidate to be introduced as a commercial cultivar). *Plant Protection (Scientific Journal of Agriculture)*, 47(3), 79-97. https://doi.org/ 10.22055/ppr.2024.48221.1769.

Park, R. F. (2008). Breeding cereals for rust resistance in Australia. *Plant Pathology*, *57*, 591–602.

Parlevliet, J. E. (1988). Strategies for the utilization to partial resistance for the control of cereal rust. In N. W. Simmonds, & S. RaJaram (Eds.), *Breeding strategies for resistance to the rusts of wheat* (pp. 48–62). CIMMYT.

Parlevliet, J. E. (1997). Durable resistance. In H. Hartleb, R. Heitefuss, & H. H. Hoppe (Eds.), *Resistance of crop plants against fungi* (pp. 238–253). Gustav Fisher.

Pathan, A. K. & Park, R. F. (2006). Evaluation of seedling and adult plant resistance to leaf rust in European wheat cultivars. *Euphytica*, *149*, 327-342.

Peterson, R. F., Campbell, A. B. & Hannah, A. E. (1948). A diagrammatic scale for estimating rust intensity of leaves and stems of cereals. *Canadian Journal of Research, 26,* 496-500.

Rodríguez-García M. F., González-González M., Huerta- Espino J., & Solano-Hernández S. (2021). Fungicides evaluation against stripe rust (*Puccinia striiformis* f. sp. *hordei*) in six barley cultivars. *Revista Mexicana De Fitopatología*, *39* (3), 414-434. DOI: https://doi. org/10.18781/r.mex.fit.2106-5.

Roelfs, A. P., Singh, R. P. & Saari, E. E. (1992). Rust diseases of wheat: Concepts and Methods of Diseases Management. Mexico, CIMMYT. 81pp.

Safavi, S. A. & Afshari, F. (2017). A seven-year assessment of resistance durability to stripe rust in some wheat cultivars in Ardabil province, Iran. *Journal of Crop Protection*, *6* (3), 409-421.

Safavi, S. A., & Afshari, F. (2012). Quantitative resistance of some Elite wheat lines to *Puccinia striiformis* f. sp. *tritici. Archives of Phytopathology & Plant Protection, 45,* 740-749.

Safavi, S. A., & Malihipour , A. (2020). Partial resistance of some wheat cultivars and candidate lines against stem rust (*Puccinia graminis* f. sp. *tritici*). *Plant Protection (Scientific Journal of Agriculture)*,43(1), 31-52.

Safavi, S. A., Afshari, F., Arzanlou, M. & Narmani, A. (2017). First report of hybridization between two Formae Speciales *Puccinia striiformis* f. sp. *hordei* and *Puccinia striiformis* f. sp. *tritici* in Iran. *Journal of Plant Pathology*, *99* (3), 800-800.

Safavi, S. A., Babai Ahari, A., Afshari, F. & Arzanlou, M. (2014). Virulence genes and pathotypes of *Puccinia striiformis* f. sp. *hordei*, causing stripe rust on barley in some areas of Iran. *Seed and Plant Improvement Journal*, *30*, 733-760.

Safavi, S. A., Babai-Ahari, A., Afshari, F. & Arzanlou, M. (2013). Slow rusting resistance in Iranian barley cultivars to *Puccinia striiformis* f. sp. *hordei*. *Journal of Plant Protection Research*, *53*, 5-11. https://doi. org/10.2478/jppr-2013-0001.

Safavi, S. A., Babai-Ahari, A., Afshari, F., & Arzanlou, M. (2012). Effect of stripe rust on yield components of barley cultivars with race-specific and slow rusting resistance to stripe rust. *Archives of Phytopathology & Plant Protection*, *45*, 1488–1498.

Sandhu, K. S., Forrest, K. L., Kong, S., Bansal, U. K., Singh, D., Hayden, M. J., & Park, R. F. (2012). Inheritance and molecular mapping of a gene conferring seedling resistance against *Puccinia hordei* in the barley culti-var Ricardo. *Theoretical & Applied Genetics*, *125* (7), 1403–1411.

Sandoval-Islas, J. S., Broers, L. H. M., Vivar, H., & Osada, K. S. (1998). Evaluation of quantitative resistance to stripe rust (*Puccinia striiformis* f. sp. *hordei)* in the ICARDA/CIMMYT barley breeding programe. *Plant Breeding*, *117*, 127-130.

Sandoval-Islas, J. S., Broers, L.H.M., Mora-Aguilera, G., Parlevliet, J.E., Osada, K.S., & Vivar, H. E. (2007). Quatitative resistance and its components in 16 barley cultivars to stripe rust, *Puccinia striiformis* f. sp. *hordei*. *Euphytica*, *153*, 295-308.

Shah, S. J. A., Hussain, S., Ahmad, M., Farhatullah, M. & Ibrahim, M. (2014). Characterization of Slow Rusting Resistance against *Puccinia striiformis* f. sp. tritici in Candidate and Released Bread Wheat Cultivars of Pakistan. *Journal of Plant Pathology and Microbiology*, 5, 223. https://doi:10.4172/2157-7471.1000223

Singh, D., Dracatos,P., Derevnina,L., Zhou, M., & Park, R. F. (2015). *Rph23*: A new designated additive adult plant resistance gene to leaf rust in barley on chromosome 7H. *Plant Breeding*, *134*, 62–69.

Singh, R. P., Huerta-Espino, J., & William, H. M. (2005). Genetics and breeding for durable resistance to leaf and stripe rusts in wheat. *Turkish Journal of Agriculture & Forestry*, *29* (2), 121-127.

Singh, R. P., Huerta-Espino, J., Bhavani, S., Herrera-Foessel S. A., Singh D., Singh, P. K., Velu, G., Mason, R. E., Jin, Y., Njau, P., & Crossa, J. (2011). Race non-specific resistance to rust diseases in CIMMYT spring wheats. *Euphytica*, *179*, 175–186.

Srinivas, K., Singh, V. K., Srinivas, B., Sameriya, K. K., Kumar, U., Gangwar, O. P., Kumar, S., Prasad, L. & Singh, G. P. (2023). Documentation of multi-pathotype durable resistance in exotic wheat genotypes to deadly stripe and leaf rust diseases. Cereal Research Communications, *52* (1), 189-201. https://doi.org/10.1007/s42976-023-00364-8.

Stubbs, R. W. (1986). Stripe rust. In A. P. Roelfs, & W. R. Bushnell (Eds.), *The cereal rusts II: Diseases, distribution, epidemiology and control* (pp. 61–101). Academic Press, Inc.

Stubbs, R. W., Prescott, J. M., Saari, E. E. & Dubin, H. J. (1986). Cereal Disease Methodology Manual. CIMMYT: Mexico, D. F. 46pp.

Verma, R., Selvakumar, R., Gangwar, O. P., Shekhawat, P. S., Bhardwaj, S. C., Rehman, S. U., Sharma-Poudyal, D., & Gyawali, S. (2018). Identification of additional sources of resistance to *Puccinia striiformis* f. sp. *hordei* (PSH) in a collection of barley genotypes adapted to the high input condition. *Journal of Phytopathology*, *166*(5), 355–364. https://doi.org/10.1111/JPH.12693.

Zahravi, M., Safavi, S. A. & Ghazvini, H. (2023). Identification of sources of resistance to stripe rust in barley landpathotypes of the northwest regions of Iran. *Iranian journal of genetics and plant breeding*, *10*(2), 13-23.

Zakeri, A., Afshari, F., Yassaie, M., Ghazvini, H., Hassani, F., Safavi, S. A., & Minoo, M. J. (2018). Race identification and responses of some barley genotypes to barley stripe rust in seedling and adult plant stages. *Crop Breeding Journal*, *8*(1 & 2), 31-47.



© 2025 by the authors. Licensee SCU, Ahvaz, Iran. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution-NonCommercial 4.0 International (CC BY-NC 4.0 license) (http://creativecommons.org/licenses/by-nc/4.0/.