Race identification and responses of some Iranian barley genotypes to barley yellow rust in seedling and adult plant stages

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ABSTRACT

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

Barley yellow rust is becoming increasingly important in many barley growing areas in Iran, including Fars Province. This research was carried out to evaluate the responses of 27 commercial cultivars, 31 introduction lines, 36 promising lines and 12 differential barley varieties to barley yellow rust at the adult plant stage, in three locations of Fars province (Zarghan, Marvdasht and Mammassani) in two successive cropping seasons (2014-2015 and 2015-2016), and at the seedling plant stage in greenhouse. Field trials in Zarghan and Marvdasht were inoculated with barley stripe rust isolate that was collected from Passargad region. The seedling responses of the genotypes were evaluated in the greenhouse with Passargad and Mammassani barley yellow rust isolates. At the adult plant stage, the majority of the genotypes had intermediate to susceptible responses while some genotypes showed moderately resistance to resistance responses to the disease. Most of the genotypes had moderately susceptible to susceptible responses (7-8) against both rut isolates at the seedling stage. Finally, cultivars and lines with coefficient of infections (CIs) lower than 24 were selected for being recommended to farmers or used in breeding programs. Among the commercial barley cultivars, Nik, Behrohk, Fajre 30, Nimrooz, Sahra, Zarjow, Aras and Loot and from introductions and promising lines, 13 and 10 lines, respectively, were selected. Most of the barley genotypes carried adult plant resistance or in combination with seedling resistance genes. Cultivars and lines with CIs between 24 to 35 and intermediate level of resistance were also considered for further evaluation. The rust isolates from Passargad and Mammassani were determined as races PSH-74 and PSH-90, respectively, based on the reactions of barley yellow rust differential cultivars.

Key words: Barley, yellow (stripe) rust, virulence, avirulence, resistance

INTRODUCTION

Barley (*Hordeum vulgare* L.) is one of the important field crops in Iran. In 2016-17, barely was grown on about 1,470,000 ha under irrigated (632,000 ha) and rainfed (841,000 ha) in Iran and produced about 2,975,000 tons of grain barley (Ahmadi *et al*., 2018). In Fras Province barley was grown on more than 92,790 hectares under irrigated (50,320 ha) and rainfed (42,470 ha) conditions and produced more than 255,000 tons of grain

barley (Ahmadi *et al.,* 2018). Barely is used and feed and significant role in the livestock husbandry and food industry in the province. In addition, growing barley has been taken into more consideration due to the drought and water resources limitation.

Yellow (Stripe) rust caused by *Puccinia striiformis* Westend f. sp. *hordei* Eriksson is among the important diseases of barley in many areas of the world including Iran. The disease has high potential and aggressiveness to cause economic losses to barley crop when susceptible and moderately susceptible barley cultivars under favorable climatic and environmental conditions are grown (Brown *et al*., 2001; Dracatos *et al*., 2016; Dubin and Stubbs, 1986; Marshall and Sutton, 1995; Mathre, 1987; Wellings, 2011).

The occurrence of sever barley stripe rust epidemics in recent decades has caused considerable losses to barley crop in many North-west and Central European countries (Johnson, 1968; Stubbs, 1985; Wellings, 2011) and in some Asian countries such as Bangladesh, Nepal, Japan and China (Chen *et al*., 1995; Wellings, 2011). The disease was first entered to Bogota of Colombia from Europe in 1975 and then spread to other regions of South American countries like Ecuador (1976), Peru (1977), Bolivia (1978), Chile (1980) and Argentina (1982) (Dubin and Stubbs, 1986; Hill *et al*., 1995).

The outbreak of a sequence of epidemics of the disease in the South American countries particularly in Colombia caused yield losses of 30 to 70% in commercial barley cultivars (Dubin and Stubbs, 1986). The disease was occurred in Mexico and Texas in 1987 and 1991, respectively. Thereafter, the disease was seen in all barley growing areas of western states of the United States such as Colorado, Washington, California (Brown *et al*., 1993, 2001; Line and Chen, 1996; Marshall and Sutton, 1995). The disease also caused yield losses of 15, 20, 15 and 16% respectively from 1996 to 1999 in California (Chen, 2007). According to the reports, the pathogen has become endemic in Asia, Africa, Europe, and North and South America (Wellings, 2011), and is a potentially devastating threat to Australia (Dracatos *et al*., 2016).

In Iran, barley yellow rust was first reported by Esfandiary in 1947 and then was studied by other workers (Khabiri, 1958; Scharif and Ershad, 1966; Ebrahimi and Minassian, 1973). It is increasing in some barley growing areas of Iran including North-east and North-west provinces. Spreading of disease is probably due to growing of susceptible barley cultivars in areas where favorable environmental conditions prevails and pathogen variability is in favour of emergence of new virulence, in recent years (Safavi *et al*., 2012).

Early efforts to identify barley yellow rust races were made by Marshal and Sutton (1995) who used six barley cultivars introduced by Dubin and Stubbs (1986) as differential sets including Varunda, Emir, Cambrinus, Bigo, Topper and Mazurka. Due to limited number of the above proposed differential sets, it was difficult to satisfactorily differentiate barley yellow rust isolates. Chen *et al*. (1995) increased the differential set of Dubin and Stubbs to 10 cultivars by adding four cultivars Abed Binder, Hiproly, Astrix and Trumf and also replaced Helis Frankan in place of Cambrinus. Later the cultivar I5 was added to the 10 differential cultivars. Ultimately the barley cultivar 'Bancroft' was added to the differential set (Chen and Line, 2001).

The proposed race identification system by Chen *et al*. (1995) and then the suggested complementary system (Chen, 2004, 2007, 2008; Chen and Line, 2001; Chen and Penman, 2005) is currently the best tool to identify races of barley yellow rust isolates. This system is based on virulence/avirulence spectra of barley yellow rust isolates on 12 barley yellow rust differentials and PSH is the abbreviation of *Puccinia striiformis* f. sp. *hordei* and prefix of the number of each race (Chen, 2004,

2007; Chen *et al*., 1995).

From 1992 to 2005 a total of 74 barley yellow rust races were identified as PSH-1 to PSH-74 among barley yellow rust isolates collected from different areas of United State of America (Chen, 2007, 2008). In 2006, 17 races were identified among 44 barley yellow rust isolates collected from different areas of United State of America and seven of them as PSH-75 to PSH-81 were new races (Chen, 2007). In 2008 only one new race was identified as PSH-82 (Wan and Chen, 2012). Since 2009 all of the identified races in United State of America have been similiar to the previous races (Chen and Kang, 2017).

The first comprehensive study to identify barley yellow rust races in Iran was carried out by Safavi *et al*. (2014). They collected 12 barley yellow rust isolates from different areas of Iran of which 10 new races were identified, for the first time, using those 12 barley differential cultivars introduced in United State of America (Chen, 2004, 2007, 2008). Among identified races, there were seven races that had different virulence/avirulence spectra compared with those 82 races reported from United State of America and were designated as PSH-83 to PSH-89 confirmed by the race identification committee in United State of America (Safavi *et al*., 2014).

Growing resistant cultivars is the most efficient, economical and environmentally sound approach to control wheat and barley yellow rusts. Two types of resistance rust diseases including; qualitative resistance (hypersensitive or race-specific resistance) (Sandoval-Islas *et al*., 2007; Shah *et al*., 2010) and quantitative resistance (slow rusting, field resistance, partial resistance or race-nonspecific resistance) (Parlevliet, 1979; Sandoval-Islas *et al*., 1998) have been identified in wheat and barley.

In qualitative resistance, usually one or two resistance genes with major effects are can create high level of resistance in a cultivar (Boyd, 2005; Shah *et al*., 2010). The race-specific resistance follows the gene- for- gene interactions, as described by Flor (1971). This type of resistance is usually short lived and may lack durability and mostly becomes ineffective by the occurrence of new virulent races. Conversely, in quantitative resistance more resistance genes with minor effects are involved and create lower level of resistance in a cultivar. This type of resistance is mostly described as slow rusting or partial resistance (Parlevliet 1979; Sandoval-Islas *et al*., 1998). Slow rusting resistance is usually characterized by slow disease progress in the field despite of high infection type seen on the cultivar (Singh *et al.* 2005). However, this type of resistance is long lasting or durable (Boyd, 2005; Herrera-Fossel *et al*., 2007; Johnson, 1988, 1992; McIntosh and Brown, 1997; Sandoval-Islas *et al*., 1998; Shah *et* al., 2010).

There are also two types of resistance in cereal crops including wheat and barley based on the plant growth stage: seedling resistance (SR) and the adult-plant resistance (APR). The SR is effective throughout the whole life of the plant and is usually race-specific, but the APR is susceptible at the seedling stage and the resistance is expressed at post-seedling stages. APRs may be either race-specific or race-nonspecific and have been identified in many wheat and barley cultivars across the world (Chen *et al.* 2002; McIntosh and Brown, 1997; McIntosh *et al*. 1995).

Some of the resistant sources that have been incorporated in barley commercial cultivars in many parts of the world, including Iran, are qualitative types and usually lack enough durability. In a survey during 1981 to 1983 in India, 700 barley lines were tested against barley yellow rust under natural field infection of which 15 lines lacked of infectivity, 11 lines were resistant with partial infectivity and the remaining were susceptible to the disease (Mathur and Siradhana, 1990). In another study in Mexico, 500 lines derived from

joint barley breeding programs between CIMMYT and ICARDA were evaluated at seedling and adult plant stages against barley yellow rust. Among the tested lines, %85 of advanced lines were susceptible at the seedling stage but conferred high quantitative resistance at the adult plant stage (Sandoval-Islas *et al*., 1998). In the United State of America from 1990 to 2000 more than 44000 lines were screened in search for resistance sources to barley yellow rust of which different cultivars as Bancroft were released in 2000 (Brown *et al*, 2001).

Evaluation of the responses of introductions and elite barley lines to barley yellow rust in Ardabil of Iran showed that 30.5, 25 and 33.3 percent of the genotypes were resistance, moderately susceptible and susceptible responses to the disease (Safavi *et al*., 2004). Safavi *et al*. (2012) examined the virulence and avirulence of barley yellow rust isolates in three regions of Iran; Ardebil, Mashhad and Sarri during 2007 to 2010. The result from Ardebil showed the presence of virulence for the resistance genes *Rps1.b*, *Rps2, Rps3* and *Rps15* on the respective differential cultivars. In Mashhad virulence was observed for the resistance genes *Rps1.b*, *Rps2* and Bancroft. In Sarri, excluding cultivar Topper, virulence was not identified for the resistance genes of the differential cultivars. Based on the responses of the differentials, it was found that the resistance genes *RpsEm1*, *RpsEm2*, *RpsHF, Rps4, Rps1.c*, *RpsVa1*, *RpsVa2* and *RpsAst* are effective resistance genes to the disease and can be used in the national barley breeding programs in Iran.

The result of a three years' studies in four disease nurseries of Ardabil, Zarghan, Miandoab and Dezful Agricultural Research Stations in Iran showed that cultivars; Yousef, Nosrat, Rihane, Kavir, Rihane 03, Karoon, Torkman, Torsh, Goharan 4, Mehr and Afzal, and also 14 elite lines showed moderately susceptible to susceptible and susceptible responses with different levels of infection severity (Safavi *et al*., 2016). Other cultivars and elite lines demonstrated different levels of resistance to moderately susceptible with low infection severity The disease was previously observed in some of the barley growing areas in Fars province. It emerged as a major problem in many barley fields in 2013, and caused considerable levels of yield losses (Zakeri, Personal communication).

The objectives of the current research were; i) to identify the barley introduction and elite lines with acceptable level of resistance for being used in the national barley breeding programs; ii) to determine the responses of barley commercial cultivars to dominant and virulent barley yellow rust races; and iii) to identify races of barley yellow rust isolates collected in Fars province.

MATERIALS AND METHODS

Host materials

In this research, 27 barley commercial cultivars (Table 1); 31 barley introduction lines (Table 2); and 36 barley elite lines (EBYT-M-91 and EBYT-M-92) (Table 3) derived from the national barley breeding program of Seed and Plant Improvement Institute of Karaj, Iran, together with 12 barley differential varieties conferring known resistance gene(s) (Table 4) and also a susceptible check cultivar (Afzal) were evaluated.

Adult plant tests

The seed of barley genotypes was grown on one- meter long rows on ridges with 30 cm row spacing in the field in Zarghan, Marvdasht and Mammassani, Fars province, Iran. The two fields in Zarghan and Marvdasht were inoculated three times from late tillering to stem elongation stages with an isolate (92-2) of barley yellow rust collected in spring of 2013 on a farmer barley field in Passargad region in Fars province, Iran, whereas the Mammassani field was exposed to natural barley stripe rust infection.

Table 1. Response of barley commercial cultivars to barley yellow rust in adult plant stage in three locations of Fars pro seedling stage under controlled greenhouse[5] conditions

Entry No.	Cultivar	Pedigree	Adult plant stage response									
			2014-2015					2015-2016				
			Yellow rust isolate					Yellow rust isolate				
			92-2 (Passargad)					92-2 (Passargad)				95-1 (Mamass
			Zarghan		Marvdasht		Mammassani[1]	Zarghan		Marvdasht		Mammass
			Response	CI[2]	Response	CI		Response	CI	Response	CI	Response
1	Yousef	Lignee 527/Chn-01//Gustoe/4/Rhn-08/3/Deir Alla 106//Dl71/Strain 205	20MS	16	30MS	24	-	30MS	24	30MSS	27	30MS
2	Nosrat	Karoon/Kavir	20MS	16	50MS	40	-	50MS	40	50MSS	45	30MSS
3	Nik	Lignee 527/NK1272//JLB70-63 (ICB90-0399-17F5-OAP	5R	1	20MS	16	-	10MR	4	20MS	16	5MR
4	Behrohk	Novosadski-444	10MS	8	20MS	16	-	20M	12	20MS	16	10R
5	Fajre 30	Lignee131/Gerbel//Alger Ceres/3/Gloria"S"/Copal"S"	10MR	4	20M	12	-	20R	4	20MS	16	10R
6	Rihane	Rihane	30MSS	27	30S	30	-	60MSS	54	60S	60	80S
7	Nimrooz	Trompillo	20MS	16	30MS	24	-	20MS	16	30MS	24	30MS
8	Sahra	LB.Iran/Una 8271//Gloria"s"/Com"s"	5MS	4	20MS	16	-	20MS	16	20MS	16	30MS
9	Zahak	Poa/Hjo//Qiina	10M	6	20MS	16	-	30M	18	40MS	32	20M
10	Jonoob	Gloria"s"/Copal"s "	10MS	8	20MS	16	-	30MS	24	50MS	40	30MS
11	Walfajre	CI -108985	30MS	24	40MS	32	-	50MS	40	60MS	48	60MS
12	Kavir	Arivat	30MS	24	40MS	32	-	60MSS	54	80S	80	40S
13	Zarjow	Selection of an Iranian landrace	5MS	4	20MS	16	-	20M	12	30M	18	20M
14	Arass	Arumir	20MR	8	30M	18	-	30M	18	30MS	24	20M
15	Loot	Congona/Borr	10MS	8	10MS	8	-	20M	12	30MS	24	10MS
16	Rihane 03	As46//Avt/Aths	20MS	16	30MS	24	-	40M	24	60MS	48	20MS
17	Karoon	Strain205	40MS	32	50MS	40	-	90S	90	90S	90	80S
18	Dasht	Probestdwarf	30MS	24	40MS	32	-	60MS	48	70MSS	63	60MSS
19	Torkman	Rihane S"-04	40MS	32	50MS	40	-	60MSS	54	90S	90	70MSS
20	Torsh	Selection of an Iranian landrace	30MS	24	30S	30	-	90S	90	90S	90	80S
21	Shirin	Selection of an Iranian landrace	20M	12	20MS	16	-	30MS	24	50MS	40	20MS
22	Gorgan 4	Herta	30MS	24	30MSS	27	-	60MSS	54	70S	70	50MSS
23	Goharjow	Selection of an Iranian landrace	40MS	32	50MS	40	-	90S	90	70S	70	80S
24	Goharan	Rhn-03//L.527/NK1272	10MS	8	20MS	16	-	50MS	40	60S	60	70MS
25	Khatam	LB Iran /Una 8271//Gloria"s"/Com"s"/3/Kavir	20MS	16	20MS	16	-	70MSS	63	60S	60	80S
26	Mehr	Roho/Mazorka/Trompilo	30M	18	30MS	24	-	80S	80	70S	70	90S
27	Oxin	Liggnee 527/NK1272/JLB70-06375/Baca's'/3/AC253//...	10M	6	20MS	16	-	50MS	40	60MS	48	20M
Check	Afzal	Selection of an Iranian landrace	50S	50	80S	80	-	100S	100	100S	100	100S

[1] Non-emergence and establishment of the disease

[2] Coefficient of Infection

[3] APR= Adult Plant Resistance

[4] SR= Seedling Resistance

[5] The greenhouse belonged to the Cereal Pathology Unit, Cereal Research Department, Seed and Plant Improvement Institute, Karaj, Iran

Table 2. Response of barley introduction lines to barley yellow rust in adult plant stage in three locations of Fars province in 2014-15 and 2015-16 and in seedling stage under controlled greenhouse[5] conditions

Entry No.	Cultivar	Pedigree	Adult plant stage response										Seedling plant stage response		Kind of resistance
			2014-2015					2015-2016					Yellow rust isolate		
			Yellow rust isolate					Yellow rust isolate					92-2 Passargad	95-1 Mamassani	
			92-2 (Passargad)				95-1 (Mamassani)	92-2 (Passargad)							
			Zarghan		Marvdasht		Mammassani[1]	Zarghan		Marvdasht		Mammassani			
			Response	CI[2]	Response	CI		Response	CI	Response	CI	Response	CI			
1	EM-85-18	26216/4/Arar/3/Mari/Aths"2//M-Att-73-337-1	10S	10	20S	20	-	50MSS	45	50S	50	70MSS	63	7	7	None
2	EM-87-10	82S:510/3/Arinar/Aths//DS 29	5MR	2	5M	3	-	10MR	4	5MR	2	10MS	8	7	7	APR[3]
3	EM-87-19	Karroon/KAVIR//Rhodes'S'//Tb/Chzo/3/Gloria'S'	5R	1	10MR	4	-	10MR	4	40MR	16	5R	1	7	7	APR
4	EM-88-2	Kavir/Badia/3/Torsh/9cr.279-07/Bgs/4/Karoon/Kavir	10MS	8	30MS	24	-	30MS	24	30MSS	27	60MSS	54	7	7	APR
5	EM-88-5	Triton/Yazd-5	5M	3	30MS	24	-	10M	6	30MSS	27	20MS	16	7	7	APR
6	EM-88-16	ZBL-2640	5R	1	10MS	8	-	5MR	2	20MSS	18	5R	1	7	7	APR
7	EM-89-10	ICNB-105960/Torkman	10MR	4	10MS	8	-	30MR	12	40MS	32	20MS	16	7	7	APR
8	EM-89-14	Trompilo//Karoon/Kavir/3/Legia/4/Ashar	5R	1	20M	12	-	10MR	4	30M	18	10M	6	0	7	APR+SR[4]
9	EM-89-19	Assala'S'//Avt/Aths/3/(Arinar/Aths//D529)	20MS	16	40MS	32	-	50MSS	45	70S	70	40MS	32	7	7	Ineffective APR
10	EMD-87-13	Bgs/Dajia//L. 1242/3/ (L.B.Iran/Una8271//Gloria'S'/3/Alm/Ur	10MS	8	30MS	24	-	40MSS	36	50MSS	45	20MS	16	7	7	APR
11	EMD-87-15	Productive/Rhihane-03	20MS	16	50MS	40	-	60MS	48	60S	60	40MS	32	7	7	Ineffective APR
12	EMD-87-16	Bda/ Rhihane-03//ICB-107766	5R	1	20MS	16	-	10M	6	30MS	24	10MR	4	0	7	APR+SR
13	EMD-88-19	PINON/3/QUINN/ALOE//CARDO/4/CIRU	10M	6	30MS	24	-	30MSS	27	40MSS	36	30MS	24	7	7	APR
14	EM-90-3	Beecher/1-BC-80411//1-BC-80593	5MS	4	20MS	16	-	20MS	16	30MS	24	30MS	24	0; CN	4	SR±APR
15	EM-90-14	BIR-24	20MS	16	40MSS	36	-	60MS	48	80MSS	72	60MS	48	7	7	APR
16	EMD-90-10	Ataco/Comino//Aleli/3/Bichy2000/4/Arupo/K8755//Mora	5M	3	10MS	8	-	20M	12	20MS	16	10MR	4	0, C	7	APR+SR
17	EMD-90-12	Arbayan/NK 1272/4/Arar/3/Mari/Aths"2//M-Att-73-337-1	5M	3	20M	12	-	30M	18	30MS	24	20M	16	0; C	0;	SR±APR
18	EW-82-5	Beecher-Sel//Gloria"S"/Copal"S"	5MS	4	30MS	24	-	10MS	8	20MSS	18	20MSS	18	0; C	0; C	SR±APR
19	EW-82-13	Scotia/WA1356.70//WA2145…..	30MS	24	40S	40	-	60MSS	54	80S	80	30MSS	27	7	0; C	APR+SR
20	EW-86-4	Arabian Barley/3/	20MS	16	40MS	32	-	60MSS	54	70MSS	63	20MS	16	7	2C	Ineffectiv APR+SR
21	EW-86-14	Blu/Mja	20MS	16	30MS	24	-	70MSS	63	60S	60	30MS	24	7	3C	Ineffective APR+SR
22	EW-86-17	Cerraja/3/Rhodes/C114100//Lignee527/4/Delo	10MS	8	30MS	24	-	20M	12	40MS	32	20MS	16	5C	3C	SR±APR
23	EW-87-4	Alanda//Lignee 527//Arar/6/Multan/M23/4/Hopro/3/…..	20MSS	18	50S	50	-	60S	60	70S	70	80S	80	7	7	None
24	EW-87-5	Lignee527/Nk1272//JLB70-063/3/Barjouj	10MS	8	10MS	8	-	30MS	24	40MS	32	20MS	16	0	0;1	SR±APR
25	EW-88-7	Mazurka//Herilla/Coraeleco 65/3/Tropi	5M	3	30MS	24	-	30MSS	27	30MS	24	20MS	16	6C	3C	SR±APR
26	EW-89-2	Anoidium/Arbyan-01/3/Lignee 527/NK1272//JlB7o-63	5MS	4	30MS	24	-	30MS	24	40MS	32	30MS	24	7	7	APR
27	EW-89-5	Alanda//Lignee527/Arar/3/Aths	5MR	2	10MS	8	-	10M	6	20MS	16	10M	6	6C	0;1C	SR±APR
28	EW-89-16	CHENG DU 105/4/EGYPT4/TERAN78//P.STO/3/QUINA/5/ABET	5R	1	10R	2	-	20M	12	20MS	16	5MR	2	0; C	4C	SR±APR
29	EW-90-5	GOB/ALELI//CANELA/3/ARUPO*2/JET/4/ARUPO/K8755//MORA	5M	3	10M	6	-	30M	18	30MS	24	5R	1	8	2C	APR+SR
30	EW-90-14	GOB/ALELI//CANELA/3/ARUPO*2/JET/4/ARUPO/K8755//MORA	5MR	2	5MR	2	-	10M	6	10M	6	5MS	4	0	3C	SR±APR
31	EW-90-15	26216/4/Arar/3/Mari/Aths"2//M-Att-73-337-1	5M	3	10MS	8	-	10MS	8	20MS	16	5MS	4	0; C	2C	SR±APR
Check	Afzal	Selection of an Iranian landrace	50S	50	80S	80	-	100S	100	100S	100	100S	100	8	8	None

[1] No-incidence and establishment of the disease

[2] Coefficient of Infection

[3] APR = Adult Plant Resistance

[4] SR= Seedling Resistance

[5] The greenhouse belonged to the Cereal Pathology Unit, Cereal Research Department, Seed and Plant Improvement Institute, Karaj, Iran

Table 3. Response of barley elite lines to barley yellow rust in adult plant stage in three locations of Fars province in 2014-15 and 2015-016 and in seedling stage under controlled greenhouse[5] conditions

Entry No.	Cultivar	Pedigree	Adult plant stage response											Seedling plant stage response		Kind of resistance
			2014-2015					2015-2016						Yellow rust isolate		
			Yellow rust isolate					Yellow rust isolate								
			92-2 (Passargad)					92-2 (Passargad)				95-1 (Mamassani)		92-2 Passargad	95-1 Mamassani	
			Zarghan		Marvdasht		Mammassani[1]	Zarghan		Marvdasht		Mammassani				
			Response	CI[2]	Response	CI		Response	CI	Response	CI	Response	CI			
1	EBYT-M91-2	Zarjow/CM67/6/As46/Aths//SLb46-100 LPD102	10MS	8	20MS	16	-	40MS	32	40MS	32	20MS	16	8	7	APR[3]
2	EBYT-M91-3	Zarjow/CM67/3/Rhn-03/L.527/Nk1272 LPD115	10MS	8	20MS	16	-	40MS	32	60MSS	54	40MS	32	8	7	APR
3	EBYT-M91-4	Schayler/3/M.Rnb86.80/NB2905//L.527/4/Rhn-03//L.527/NK1272	10M	6	30MS	24	-	50MSS	45	60MSS	54	60S	60	8	7	Ineffective APR
4	EBYT-M91-5	L.527/Hortland//Ceres//WI2192/Emir/3/Karoon	20MS	16	30MSS	27	-	50MSS	45	50S	50	60S	60	8	7	Ineffective APR
5	EBYT-M91-6	Kavir/Arinar-C4563//WI2291/3/Karoon/Sonja/4/(L.527/Chn-01/6/UC...)	5MS	4	10MS	8	-	20MS	16	30MS	24	30MS	24	8	7	APR
6	EBYT-M91-7	Comp89-9Cr-279-07/Atem//(Alpha/HC1905//Robuty)/3/…/(Rabano/5/CM67/C	5MR	2	5M	3	-	10M	6	5M	3	5MS	4	0	0;C	SR[4]±APR
7	EBYT-M91-8	Deshud Navaro//Gloria"s"/Copal"s"/3/Rhn-03//L.527/NK1272	5MS	4	5MS	4	-	20MS	16	10MS	8	10MS	8	0C	5C	SR±APR
8	EBYT-M91-9	NP106/Mihn14433-Gvaxduois//CI10143/3/DeirAua106//Hem/BC/3/Rihanes	5R	1	10R	2	-	5M	3	10MS	8	5R	1	6C	7	APR+SR
9	EBYT-M91-10	L.527/MB2367//Alger/3/AS46/Athsza	10M	6	20M	12	-	30M	18	30MSS	27	30MSS	27	8	7	APR
10	EBYT-M91-11	L.527/MB2367//(CI7117-9/DeirAlla106)/3/Gorgan//Aths/BC	5M	3	10MS	8	-	20M	12	30MS	24	10M	6	8	7	APR
11	EBYT-M91-12	Goharjow/4/(OWB70173-24-OH//Boyer…)//LBIran/Una8271//Gloria…/Kavir	10MS	8	20MS	16	-	30M	18	30MS	24	20MS	16	3C	0;2C	SR±APR
12	EBYT-M91-13	NT122//Sonata/Arta	10M	6	30MS	24	-	80MS	64	70S	70	50MS	40	8	7	Ineffective APR
13	EBYT-M91-14	Trompilo/L.Moghan//CM	20MS	16	40MS	32	-	90MSS	81	70MSS	63	40MSS	36	8	7	APR
14	EBYT-M91-15	ZRG-11001	30MS	24	40MS	32	-	90S	90	70S	70	50MSS	45	8	7	Ineffective APR
15	EBYT-M91-16	Grace	10MS	8	30MS	24	-	70MSS	63	70MSS	63	40MSS	36	8	4C	Ineffective APR +SR
16	EBYT-M91-17	Osada	10M	6	5MS	4	-	40MS	32	30MS	24	10MS	8	,2C	4C	SR±APR
17	EBYT-M91-18	NK1272//Manker/Arig8/3/Alanda/Hamra-01/4/Avt/Attiki//M-Att-73-337-1/3/Aths	20MS	16	30MS	24	-	60MSS	54	60S	60	50MSS	45	8	0;C	Ineffective APR +SR
18	EBYT-M91-19	Anoidium//Alanda/Hamra-01/3/Lignee527/NK1272//JLB70-63	10M	6	10MS	8	-	40M	24	30MS	24	50MS	40	4C	7	APR+SR
19	EBYT-M92-2	Kmk//Rbr/Wa2196-68/3/EBC(A)/4/POA/HJO//Quina	20MS	16	50MS	40	-	60MSS	54	60S	60	50MSS	45	8	7	Ineffective APR
20	EBYT-M92-3	Rihane-03/3/Rihane//Aths/BC	10M	6	30MS	24	-	30M	18	30MS	24	20M	12	7	3C	APR+SR
21	EBYT-M92-4	Brj-88-89-F5-23	5MR	2	30MS	24	-	20M	12	30MS	24	10MS	8	7	4	APR+SR
22	EBYT-M92-5	Brj-88-89-F5-39	10M	6	20MS	16	-	20M	12	30MS	24	10MS	8	7	7	APR
23	EBYT-M92-6	Brj-88-89-F5-40	10MS	8	30MS	24	-	40M	24	50MS	40	30MS	24	8	7	APR
24	EBYT-M92-7	Brj-88-89-F5-41	20M	12	30MSS	27	-	70MSS	63	70MSS	63	50S	50	8	7	None
25	EBYT-M92-8	Brj-88-89-F5-47	10MSS	9	20MSS	18	-	30MSS	27	50MSS	45	20MSS	18	7	7	APR
26	EBYT-M92-9	AHWZ-12115	10MS	8	30MS	24	-	30M	18	40MS	32	20MS	16	7	3C	APR+SR
27	EBYT-M92-10	AHWZ-12123	10MS	8	20MS	16	-	40MS	32	50MS	40	20MS	16	7	7	APR
28	EBYT-M92-11	AHWZ-12131	20MSS	18	20S	20	-	80MSS	72	60S	60	50MSS	45	8	8	None
29	EBYT-M92-12	AHWZ-12133	20MS	16	20MSS	18	-	40MSS	36	40MSS	36	20MS	16	8	8	APR
30	EBYT-M92-13	AHWZ-12134	20MS	16	40S	40	-	50MSS	45	60S	60	40MSS	36	8	7	Ineffective APR
31	EBYT-M92-14	ZRGHN-4	20MSS	18	30MSS	27	-	80MSS	72	50S	50	30S	30	8	7	None
32	EBYT-M92-15	CIRU/M111	5MS	4	10MS	8	-	30MSS	27	30MSS	27	20MS	16	0;3CN	7	APR+SR
33	EBYT-M92-16	Rhn-03//L.527/NK1272	30MS	24	30MS	24	-	70MS	56	60MS	48	50MS	40	7	7	Ineffective APR
34	EBYT-M92-17	Manal/3/Lignee527/NK1272//JLB70-63/4/CalMr	30MS	24	30S	30	-	80S	80	60S	60	60MSS	54	7	7	None
35	EBYT-M92-18	Merzaga (Orge077)/Alanda-01	5R	1	5R	1	-	10R	2	5MS	4	5MS	4	7	7	APR
36	EBYT-M92-19	Carbo//Lignee640/Lignee527/3/Courlis/Rihane-03	10MS	8	20MS	16	-	30MS	24	50MS	40	20MS	16	7	7	APR
Check	Afzal	Selection of an Iranian landrace	60S	60	80S	80	-	100S	100	100S	100	100S	100	8	8	None

[1] No-incidence and establishment of the disease

[2] Coefficient of Infection

[3] APR= Adult Plant Resistance

[4] SR= Seedling Resistance

[5] The greenhouse belonged to the Cereal Pathology Unit, Cereal Research Department, Seed and Plant Improvement Institute, Karaj, Iran

Table 4. Response of barley differential cultivars to barley yellow rust in adult plant stage in three locations of Fars province in 2014-15 and 2015-16 and in seedling stage under controlled greenhouse[5] conditions

Entry No.	Differential cultivars	Resistance gene (s)	Adult plant stage response						Seedling plant stage response	
			2014-2015			2014-2015			Yellow rust isolate	
			Yellow rust isolate			Yellow rust isolate				
			92-2 (Passargad)			92-2 (Passargad)		95-1 Mamassani		
			Zarghan	Marvdasht	Mammassani[2]	Zarghan	Marvdasht	Mammassani	92-2 Passargad	95-1 Mamassani
			Response	Response	Response	Response	Response	Response	Response	Response
1	Topper	None[1]	10S[3]	20S	-	60S	70S	60S	7[4]	7
2	Helis Franken	*Rps4(Yr4), rpsHF*	5R	20R	-	10R	10R	5R	0;	0;
3	Emir	*rpsEm1, rpsEm2*	5R	10MR	-	10R	5R	5R	0; C	0;1C
4	Astrix	*Rps4(Yr4), rpsAst*	5R	20R	-	5R	0	5R	0	0;
5	Hiproly	*rpsHi1, rpsHi2*	5R	10R	-	5R	5R	0	7	7
6	Varunda	*rpsVa1, rpsVa2*	5R	20R	-	10R	10R	0	0	7
7	Abed Binder	*rps2 (yr2)*	10M	10MR	-	10R	20MS	5R	7	8
8	Trumpf	*rpsTr1, rpsTr2*	30MS	10MS	-	5MR	20MS	0	0;	0;
9	Mazurka,	*Rps1.c*	10MS	10MS	-	5R	10R	5MR	0	3C
10	Bigo	*Rps1.b (yr)*	5MS	5R	-	5R	10R	0	0	0;
11	I5	*Rps3 (yr3), rpsI5*	5R	5MR	-	5R	5R	5R	0	0; C
12	Bancroft	*RpsBa*	10MS	10MS	-	5R	5R	5R	7	0; C
Check	Afzal	None	50S	80S	-	100S	100S	100S	8	8

[1] Topper and Afzal did not have resistance genes against barley yellow rust

[2] No-incidence and establishment of the disease

[3] The response 50S or more were considered as virulence while those less than 50S were considered as avirulence on the differential hosts at the adult plant test

[4] The response 0-6 and 7-8 were respectively considered as avirulence and virulence of yellow rust on the differential hosts at the seedling test

[5] The greenhouse belonged to the Cereal Pathology Unit, Cereal Research Department, Seed and Plant Improvement Institute, Karaj, Iran

Responses of genotypes were scored three times, at 7-10 days intervals, when the disease reached to ≥ 60S on the flag leaf of susceptible check (Afzal) following the Modified Cobb's Scale (Peterson *et al*., 1948) for disease severity and Roelfs *et al*. (1992) for the infection type. The coefficient of infection (CI) for each genotypes was calculated by combining its severity of infection and the constant value of infection type. The related constant values for the infection types are as follow; Immune (0) = 0, Resistant (R) = 0.2, Moderately resistant (MR) = 0.4, Intermediate (M) = 0.6, Moderately susceptible (MS) = 0.8, Moderately susceptible to susceptible (MSS) = 0.9 and Susceptible (S) = 1 (Roelfs *et al*., 1992).

Seedling tests

To evaluate the seedling responses, 25 seed of each of the commercial cultivars, introduction lines, elite lines as well as the differential varieties and susceptible check were grown in one pot of 9 cm diameter and maintained at 15-20 C° for 12 days under controlled greenhouse conditions of the Cereal Research Department, Seed and Plant Improvement Institute, Karaj, Iran. Two pots were provided for each genotype. The two leaf-stage seedlings in the two pots were inoculated with barley stripe rust isolates 92- 2 and 95- 1 collected from barley fields in Passargad in spring of 2013 and in Mammassani in spring of 2016, respectively, using a mixture ratio of one gram of pathogen urediniospores and five grams of talcum powder. Seedlings were then put in the cold dark room at 10 °C and high relative humidity (95%) for 24 hours and transferred to a room under crystal covers at 17 ± 2 °C with 14 hours light at 16000 lux and 10 hours darkness for 21 days.

The responses of the genotypes were scored after 14 to 21 days when the leaves of the susceptible control (Afzal) were fully infected by the disease using the 0-9 scale of McNeal *et al*. (1971). Based on this evaluation scale, the responses 0, 1, 2, 3, 4-6 and 7-9 were considered as Immunity, high resistance, resistance, moderately resistance, intermediate and moderately susceptible to susceptible, respectively. Generally, the responses of 0-6 were considered as avirulence while those of 7-9 as virulence on the resistance gene(s) of the differentials, introduction and elite lines and commercial cultivars of barley.

It should be noted that determination of races from the two barley yellow rust isolates 92-2 from Passargad and 95-1 from Mammassani was done based on their virulence/avirulence responses on the resistance genes of the barley differential varieties and compared with the world barley yellow rust races that have been identified by the nomenclature committee for the yellow rust races located in United State of America.

Analysis of data

The responses of the host materials to the barley yellow rust at the adult plant and seedling stages obtained in this study together with their CIs to the disease were compiled and carefully analyzed for selecting superior cultivars and lines for being grown in different climatic regions in Fars province and in Iran as well as for being used in the national barley breeding programs.

RESULTS AND DISCUSSION

Adult plant tests in 2014-2015

The responses of commercial cultivars, introduction lines, elite lines and differential varieties of barley in 2014-2015 cropping season are presented in Table 1, 2, 3 and 4. In the first year of experiments the disease was established and developed in Zarghan and Marvdasht, but not in Mammassani. Among the 27 commercial cultivars in Zarghan and Marvdasht, seven and two cultivars showed R to intermediate M responses, and 20 and 25 cultivars had MS to S responses to barley yellow rust, respectively. In this regard the highest CI

value (40) was scored for cvs. Karoon, Torkman and Goharjow and the lowest CI value (1) was scored for cv. Nik (Table 1).

Among the 31 introduction lines in Zarghan and Marvdasht, 16 and seven lines had R to M responses and 15 and 24 lines showed MS to S reactions to the disease, respectively. Among the introduction lines, the highest CI value (50) scored for the line EW-87-14 and the lowest CI value (1) related to the lines EM-87-19, EM-88-16, EM-89-14, EMD-87-16 and EW-89-16 (Table 2). Among the 36 elite lines in Zarghan and Marvdasht, 13 and four lines showed R to M responses and 23 and 32 lines exhibited MS to S reactions, respectively. Among the elite lines the highest CI value (40) scored for the lines EBYT-M-92-2 and EBYT-M-92-13 and the lowest CI value (1) related to the lines EBYT-M-91-9 and EBYT-M-92-18 (Table 3). Among the differential varieties in Zarghan and Marvdasht, seven and 8 cultivars had R to M responses, four and three cultivars showed to be MS and one cultivar (Topper) showed 10S to 20S responses, respectively. Virulence was not observed for any of the differential varieties in both Zarghan and Marvdasht disease nurseries. The susceptible check (cv. Afzal) showed susceptible responses 50S and 80S with CI values 50 and 80 in Zarghan and Marvdasht, respectively.

Adult plant tests in 2015-2016

The responses of commercial cultivars, introduction lines, elite lines and differential varieties of barley in 2015-2016 cropping season are presented in Tables 1, 2, 3 and 4. In the second year of experiments among the 27 commercial cultivars in Zarghan, Marvdasht and Mammassani, eight, one and seven cultivars showed R to M responses and 19, 26 and 20 of the cultivars showed MS to S responses to barley yellow rust, respectively. In this relation the highest CI value (90) was allocated to the cvs. Karoon, Torkman, Goharjow, Torsh and Mehr (Table 1). The lowest CI value (2) scored for cvs. Nik, Behrohk and Fajre 30 (Table 1). Among the 31 introduction lines in Zarghan, Marvdasht and Mammassani, 14, four and nine lines had R to M responses and 17, 27 and 22 lines showed MS to S reactions to the disease, respectively (Table 2). The highest CI value (80) scored on line EW-82-13 and EW-87-4 and the lowest CI value (1) was related to the lines EM-87-19, EM-88-16 and EW-90-5 (Table 2). Among the 36 elite lines in Zarghan, Marvdasht and Mammassani, 12, one and three lines showed R to M responses and 24, 35 and 33 lines had MS to S reactions, respectively. Among the elite lines the highest CI value (90) was given to the line EBYT-91-15 and the lowest CI value (1) was related to the line EBYT-M91-9. It should be noted that the majority of commercial cultivars and introduction and elite lines conferred APR alone or combined with seedling resistance. Some of the commercial cultivars and lines carried seedling resistance that may accompanied by APR.

Among the differential varieties in Zarghan, Marvdasht and Mammassani, 11, 9 and 11 cultivars had R to MR responses, 0, 2 and 0 cultivars showed MS, and cv. Topper (Topper) exhibited 60S, 70S and 60S responses, respectively. Except for Topper, virulence was not observed for any of the other differential varieties in the three locations. The susceptible check (cv. Afzal) showed 100S response) with the highest CI value (100) in the three locations.

Seedling tests to isolate from Passargad

The results of seedling test to isolate from Passargad are presented in Tables 1, 2, 3 and 4. Among the 27 commercial barley cultivars seven cultivars had high R (0;-3C)**,** three cultivars had M **(**4C- 6C**)** and 17 cultivars showed MS- S (7- 8) responses. Among the 31 introduction lines 10 lines had high R (0- 0;CN), three lines had M **(**5C- 6C**)** and 18 lines showed MS- S (7- 8) responses. Among the 36 elite lines five lines exhibited high R (0- 3C)**,** two lines

had M (4C- 6C) and 29 lines showed MS-S (7-8) responses. Among the differential varieties, virulence with MS (7) response was observed for the cultivars number 1 (Topper), 5 (Hiproly), 7 (Abed Binder) and 12 (Bancroft), and avirulence with R responses (0- 0;C) was observed for the remaining eight differential varieties (Tables 4 and 5). The susceptible check (cv. Afzal) showed S (8) response.

Seedling tests to isolate from Mammassani

The results of seedling test to isolate from Mammassani are presented in Tables 1, 2, 3 and 4. Among the 27 commercial barley cultivars, three cultivars had high R (0;- 2C), one cultivar had M (4) and 23 cultivars showed MS- S (7-8) responses. Among the 31 introduction lines, 12 lines had high R (0- 3C), two lines had M (4-6) and 17 lines showed MS- S (7-8) responses. Among the 36 elite lines, five lines exhibited high R (0;C- 3C), four lines had M (4C- 5C) and 27 lines showed MS- S (7-8) responses. Among the differential varieties, virulence with MS- S (7-8) was observed for the cultivars number 1 (Topper), 5 (Hiproly), 6 (Varunda) and 7 (Abed Binder), and avirulence with R (0-0;C) was observed for the remaining eight differential varieties (Tables 4 and 5). The susceptible check (cv. Afzal) showed susceptible response (i.e. 8).

The results of the present study showed that incidence and development of the disease varied between the two growing seasons. In 2014-15, development and severity of the disease were higher in Marvdasht than in Zarghan. Therefore, CIs for most cultivars and lines were higher in Marvdasht than in Zarghan. This difference was due to more favourable environmental conditions for incidence and development of the disease in Marvdasht than in Zarghan. In 2015-16, development and severity of the disease was higher on all barley genotypes, in the three locations, and the majority of the genotypes showed MS-S responses to barley yellow rust in the three locations. Therefore, the results of 2015-16 were used as criteria for the assessment and screening of the barley genotypes. However, CI can also be used as a selection criterion for screening genotypes having acceptable level of resistance to the disease (Roelfs *et al*., 1992).

Although a considerable proportion of the barley genotypes conferred M- MS responses to the disease, nevertheless some had low CIs. In International wheat breeding programs, the CIs less than 16 are the criterion for choosing genotypes with desirable responses, thus, wheat and barley genotypes with ICs less than 80R, 40MR, 27M, 20MS and 16S to the disease are acceptable (Rajaram *et al.,* 1988; Roelfs *et al*., 1992; Herrera-Fossel *et al.,* 2007). Past experiences in the world have shown that many of the wheat and barley cultivars confer low infection severities of MR, M and MS responses, have acceptable field resistance to the disease without chemical control. On this basis some genotypes across the world have shown to have long lasting and durable resistance to the disease (Brown *et al*., 2001; Sandoval-Islas *et al*., 1998; Singh *et al*., 2005).

With respect to the above description and considering environmental factors in Fars province and other similar climatic conditions in Iran, the incidence of the disease epidemic is once in every few years, and mostly develops as local to intermediate levels. Therefore, accepting CIs $\leq$ 24 that include responses 60MR, 40M, 30MS, 26MSS and 24S leads to choosing more genotypes that increases genetic diversity of resistance to the disease.

According to these criteria among the commercial cultivars; Nik, Behrokh, Fajre 30, Nimrooz, Sahra, Zarjow, Arass, and Loot, and among introduction lines; EM-87-10, EM-87-19, EM-88-16, EM-89-14, EMD-87-16, EM-90-3, EMD-90-10, EMD-90-12, EW-82-5, EW-89-5, EW-89-16, EW-90-5, EW-90-14, EW-90-15, and among elite lines; EBYT-M-91-6,

Table 5. Virulence and avirulence pattern of barley yellow rust isolates from Passrgad and Mammassani on barley differential varieties in seedling stage under controlled greenhouse[4] conditions

Entry No.	Differential cultivars	Resistance gene(S)	Passargad rust isolate (92-2)		Mammasani rust isolate (95-1)	
			Virulence (Vi) Avirulence (Av)	Effective resistance genes (+) Ineffective resistance genes (-)	Virulence (Vi) Avirulence (Av)	Effective resistance genes (+) Ineffective resistance genes (-)
1	Topper	None[1]	Vi	-	Vi	-
2	Helis Franken	*Rps4(Yr4), rpsHF*	Av	+	Av	+
3	Emir	*rpsEm1, rpsEm2*	Av	+	Av	+
4	Astrix	*Rps4(Yr4), rpsAst*	Av	+	Av	+
5	Hiproly	*rpsHi1, rpsHi2*	Vi	-	Vi	-
6	Varunda	*rpsVa1, rpsVa2*	Av	+	Vi	-
7	Abed Binder	*rps2 (yr2)*	Vi	-	Vi	-
8	Trumpf	*rpsTr1, rpsTr2*	Av	+	Av	+
9	Mazurka,	*Rps1.c*	Av	+	Av	+
10	Bigo	*Rps1.b (yr)*	Av	+	Av	+
11	I5	*Rps3 (yr3), rpsI5*	Av	+	Av	+
12	Bancroft	*RpsBa*	Vi	-	Av	+
Check	Afzal	None	Vi	-	Vi	-
		Virulence formula	(1, 5, 7, 12)[2]	(1, 5, 6, 7)[3]		
		Race name	PSH-74	PSH-90		

[1] Topper and Afzal did not have resistance genes against barley yellow rust
[2] The race was identified from Passargad rust isolate had virulence on the resistance genes of differential hosts with numbers 1, 5, 7 and 12
[3] The race was identified from Mammasani rust isolate had virulence on the resistance genes of differential hosts with numbers 1, 5, 6 and 7
[4] The greenhouse belonged to the Cereal Pathology Unit, Cereal Research Department, Seed and Plant Improvement Institute, Karaj, Iran

EBYT-M-91-7, EBYT-M-91-8, EBYT-M-91-9, EBYT-M-91-11, EBYT-M-91-12, EBYT-M-92-3, EBYT-M-92-4, EBYT-M-92-5 and EBYT-M-92-18 had CIs ≤ 24 in all three locations.

Commercial cultivars, particularly Nik, Fajre 30, Nimrooz, Zarjow and Loot that had APR or in combination with SR can be grown in Fars province and climatic conditions in Iran. Behrohk, Sahra and Arass had SR that may possess APR (Table 1). Further evaluation is required to confirm this speculation. The introduction and elite lines, particularly those that had APR or in combination with SR and high grain yield and desirable agronomic characteristics can be considered for being released as new cultivars (Tables 2 and 3).

The second group included cultivars and lines with 24 ≤ CI ≤ 3, in one or all locations. Cvs. Yousef and Zahak which had APR and the introductions lines; EM-88-2, EM-88-5, EM-89-10, EW-86-17, EW-87-5, EW-88-7 and EW-89-2, and the elite lines; EBYT-M-91-2, EBYT-M-91-10, EBYT-M-91-17, EBYT-M-92-9 and EBYT-M-92-15 that had APR or in combination whit SR consisted the second group. Some of these cultivars and lines had resistances that may protect the crop against low to intermediate epidemics. However, their resistances levels are not sufficient to protect the barley crop loss due to sever and vast epidemics of the disease in hot spots, therefore, fungicides foliar applications may be required. Under such circumstances, timely chemical application of suitable and quality fungicides would help to prevent likely yield losses.

Cultivars and lines that had resistance in both seedling and adult plant stages may only confer SR that is effective from seedling stage and continues until the end of plant lifecycle. Some of these genotypes may possess APR in addition to SR that needs complementary study to confirm this speculation. The cultivars and lines that had MS-S (7-8) responses to both barley yellow rust isolates at the seedling stage but showed resistance responses at the adult plant stage confer only APR or some of which probably carry ineffective SR in combination with APR to the isolates tested. Further investigations are required to confirm this assumption.

In addition, the cultivars and lines that were susceptible to one of the isolates but resistant to the other isolates at the seedling stage and also had resistance at the adult plant stage were shown to have both types of resistances. Past experiences in the world have shown that seedling resistances are short lived (usually 4 to 5 years) and mostly are race- specific and easily broken by strong and aggressive rust races (Brown *et al*., 2001; McIntosh and Brown 1997; Pathan and Park, 2006; Rajaram *et al*., 1988; Sandoval-Islas *et al*., 1998, 2007; Singh *et al*., 2005; Wan and Chen, 2012). Accordingly most of the breeding programs in the world try to use resistance sources possessing APR genes that carry quantitative resistance, particularly slow rusting resistance types or sources conferring APR in combination with SR which enhances the level of resistance by additive effects and prevent the break of resistance, hence slows down the risk of disease epidemics incidence (Brown *et al*., 2001; Herrera-Fosse *et al*., 2007; McIntosh and Brown, 1997; Safavi *et al*., 2012; Sandoval-Islas *et al*., 2007; Singh *et al*., 2005; Wan and Chen, 2012).

The presence of two to three resistance genes preferably APRs or in combination with SRs usually result in increase in the resistance level and protect the crop yield against the rust diseases of wheat and barley (McIntosh and Brown, 1997; Rajaram *et al*., 1988; Sandoval-Islas *et al*., 2007; Singh *et al*., 2005; Wan and Chen, 2012). Cultivars and lines in the present study with CIs ≥ 35 are usually damaged under intermediate epidemics, but are highly damaged under sever epidemics. However, some of them that carry APR genes can be used in breeding programs for pyramiding resistance genes and enhance

the durability in new cultivars.

The responses of differential varieties to Passargad and Mammassani isolates in the adult plant stage in the field showed that except Topper, virulence was not detected for the remaining 11 cultivars in any of the three locations. This implies the presence of effective APR genes in the differential varieties to the barley yellow rust isolates tested in this study.

The responses of commercial cultivars and introduction and elite lines to Passargad and Mammassani isolates in the seedling stage showed that most of them conferred M-MS (4-7) to S (8) responses. Fewer cultivars and lines showed resistance (0- 3) responses to the disease. The responses of 12 differential varieties to Passargad and Mammassani isolates of barley yellow rust at the seedling stage showed that virulence existed for the resistance genes in Topper, Hirproly, Abed Binder and Bancroft to Passrgad isolate, and for Topper, Hiproly, Varunda and Abed Binder to Mammassani isolate. The two isolates showed to have identical virulence pattern on the three of the differential cultivars; Topper, Hiproly and Abed Binder. The only difference in virulence was observed for Bancroft to the Passrgad isolate and for Varunda to the Mammassani isolate. This difference in virulence pattern between the two isolates resulted in two distinct barley yellow rust races. The identified race from Passargad isolate based on the published reports (Chen, 2007, 2008; Wan and Chen 2012) and the recent comprehensive list of nomenclature barley yellow rust races in the world (Chen and Kang, 2017) was PSH-74. This race was identified and reported from Iran (Safavi *et al*., 2014) and from America (Chen, 2007, 2008, Chen and Kang, 2017).

The race identified from Mammassani isolate has no conformity with any of the races that have been identified in the world. Therefore, the Mammassani race is a new race for Iran and the world that should be named PSH-90 following the instructions by the International Nomenclature Committee of the Barley Yellow Rust Races in the world and as the last race after PSH-89 reported before (Chen, 2007, 2008, Chen and Kang, 2017). To complete the procedures, the authors are communicating with the International Nomenclature Committee of the Barley Yellow Rust Races.

The two identified barley yellow rust races had strong aggressiveness and wide virulence spectra on the barley commercial cultivars and barley introduction and elite lines. The majority of cultivars and lines showed moderately susceptible to susceptible responses with CI $\geq$ 24 to these races in adult plant stage which may cause economical losses under conducive and other environmental conditions.

The pathogen can survive on wild barley grasses, and new virulence may evolve due to mutation. Therefore, determining of responses and the resistance genes in barley genotypes used in this study to barley yellow rust needs further complementary studies. Regular virulence survey of the pathogen can also greatly help in replacing the susceptible cultivars and provides useful information for barley breeding programs.

CONCLUSION

The results showed that some of the commercial cultivars and introduction and elite lines of barley used in the present study had acceptable levels of resistance to barley yellow rust disease. Considering the results of this study and other investigation in the world, it is recommended that those barley cultivars and lines with CI $\leq$ 24 and 24 $\leq$ CI $\geq$ 35 that confer APR or APR in combination with SR with acceptable level of resistance can be grown in Fars province and similar climatic conditions in Iran as well as used in the national barley breeding programs.

The two barley yellow rust races identified and their potential derivatives are able to cause severe infections and crop losses on some of the commercial cultivars, introduction and elite lines under conducive

environmental conditions. Therefore, regular virulence surveys should be conducted. The results of this study are useful in choosing suitable resistance barley cultivars, barley crop management as well as for the national barley breeding programs.

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