Identification of resistance to crown rust in Moroccan wild oats

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Abstract

A collection of 288 accessions, representing 13 species of wild oat, collected in several Moroccan regions, was evaluated in the field in 1995 for crown rust resistance at 3 different locations. Among the accessions tested, 39 revealed to be resistant in at least one site, and 25 have shown their resistance at the three locations. All resistant accessions originated from the northern regions of Morocco. Six genotypes of A. maroccana and one genotype of A. sterilis that have shown high levels of resistance to crown rust were inoculated with 4 isolates of P.coronata f.sp. avenae with different numbers of virulence genes under controlled conditions at seedling and adult stages. The types of infection, the latency period, the production of spores, and their germination were measured. The genotypes have expressed a vertical resistance. The latency period varied from 9.3 to 14 days. However, this character did not differentiate between genotypes. The genotypes have produced significantly different quantities of spores. In contrary to the latency period, the spore's production differentiated between genotypes.

***Key words**: Crown rust, resistance, wild oats*

ملـخص

تحديد هوية مقاومة الصدأ التاجي على الشوفان البري في المغرب

مجموعة مكونة من 288 عينة موزعة على 13 صنفا من الشوفان البري المنحدرة من مناطق مختلفة من المغرب تم تقييمها في الحقل في سنة 1995 لأجل مقاومتها ضد الصدأ التاجي في ثلاثة مواقع. من بين هذه المجموعات تم ضبط 39 عينة مقاومة لهذا المرض في بقعة واحدة على الأقل و25 عينة في البقع الثلاث. وتنحدر العشائر المقاومة لهذا الصدأ من المناطق الشمالية للمغرب. وقد تم تقييم ست عشائر من صنف *A. maroccana* وعشيرة واحدة من نوع *A. sterilis* في المختبر، التي برهنت على مستوى عال من المقاومة للصدأ التاجي. وقد برهنت هذه العشائر على مستوى عال من المقاومة من النوع العمودي. ويعتبر إنتاج البوغات من أحسن الصفات المعبرة على مستوى المقاومة.

كلمات مفاتح = الصدأ التاجي– المقاومة– الشوفان البري

Résumé

Identification de la résistance à la rouille couronnée dans le genre Avena spp. au Maroc

Une collection de 288 accessions, représentant 13 espèces d'avoine sauvage, collectée dans plusieurs régions du Maroc, a été évaluée au champ en 1995 pour la résistance à la rouille couronnée dans trois sites. Parmi les accessions testées, 39 ont révélés la résistance au moins dans un site et 25 ont été résistantes dans tous les sites d'évaluation. Toutes les lignées résistantes sont originaires des régions du Nord du Maroc. Six génotypes de A. maroccana et un génotype de A. sterilis qui ont montré un haut niveau de résistance à la rouille couronnée ont été inoculés avec quatre isolats de P. coronata f.sp. avenae ayant différents nombre de gènes de virulence sous les conditions contrôlées au stade plantule et adule. Les types d'infection, la période de latence, la production des spores et la germination des spores ont été mesurées. Les génotypes ont exprimé une résistance de type verticale. La période de latence varie entre 9.3 et 14 jours. Cependant, ce caractère ne différencie pas entre les génotypes. Ces derniers ont produit des quantités de spores significativement différentes. Contrairement à la période de latence, la production différencie entre les génotypes.

Mots clés : *Rouille couronnée, résistance, avoine sauvage*

Introduction

Crown rust, caused by *Puccinia coronata* Corda f.sp *avanae Eriks*, is a widely distributed disease of cultivated oat (*Avena sativa L.*) and its closely related species in Morocco. In some areas of the north, crown rust prevails regularly. Spores are present throughout the year on wild species. The frequent mild temperatures (15-25°C) and the abundance of dew are the most favourable conditions for the development of this disease.

The use of resistant cultivars is the only efficient way to overcome this disease (Simons, 1985). Wild oats originating from North Africa and the Middle East are considered as the major sources of genes resistance to *P. coronata*. Most of these genes were transferred to commercial varieties (Browning and Frey, 1981).

Most *Avena* species are present in Morocco. Populations of these species are widespread in different climatic regions, going from cold and humid mountains to dry and hot valleys (Leggett et al. 1992). The analysis of the Moroccan wild oat collections revealed the presence of many characters that could be used in cultivated oat improvement (Ladizinsky and Frainstein, 1977; Ladizinsky, 1992 and 1995; Comeau, 1982; Saidi and El Yamani, 1994). Resistance to crown rust is one of the most desirable characters to be considered when developing new oat cultivars (Browning and Frey, 1981; Sebesta, 1983; Leonard and Anikster, 1996).

Successful identification of genes for resistance to crown rust requires the screening of wild oat germplasm. A systematic screening of the material will allow the analysis of the genetic potential of the different accessions tested and the selection of the genotypes that have high levels of resistance. A large collection of genotypes must first be evaluated in the field under high pathogen selection pressure, and against a high number of races (Lenné and Wood, 1991). The screening sites must be selected according to the disease severity, observed over many years. Accessions that express resistance in the field will then be carefully tested under a limited number of races of the pathogen.

The accessions with a high level of resistance, belonging to *A. sterilis* L. and *A. moroccana* Gdgr. are the most desirable; they can be crossed to domesticated forms and used in breeding programs. The resistant oat genotypes selected in the field have to be evaluated under controlled environmental conditions.

The objective of this study is to screen a moroccan collection of wild oat species in order to identify genotypes that have high levels of resistance to crown rust.

Materials and methods

Evaluation under field conditions
Vegetative material

A collection of 288 accessions representing 13 wild oat species was assembled from seed collected during many field trips that were carried out in different regions of Morocco (Al Faiz and Souihka, 1990; Leggett et al., 1992). Table 1 shows information on the genomes, and the number of accessions for each species.

Table 1: Species, genomes, and number of accessions of the Moroccan wild oat collection that was evaluated for crown rust.

Species	Genome	Number of accessions
A. clauda Dur.	C_pC_p	2
A. eriantha Dur.	CpCp	10
A. atlantica Baum et Fedak	A_1A_1	10
A. wiestii Steud	A_sA_s	2
A. hirtula Lag.	AsAs	8
A. longiglumis Dur.	A_1A_1	10
A. damascena Rajhathy et Baum	A_dA_d	8
A. barbata Pott. ex Link	AABB	100
A. agadiriana Baum et Fedak	AABB	11
A. murphyi Ladiz.	AACC	5
A. maroccana Gdgr	AACC	17
A.byzantina C. Koch	AACCDD	3
A. sterilis L.	AACCDD	100
Total		288

Evaluation Sites

The evaluation sites were located in the north (Tangier), and in the plains of Gharb and Doukkala where crown rust is frequent and its secondary host, *Rhamnius lycioides* L. ssp. *oleoides* (L) Jahand & Maire, was reported (Rieuf, 1971).

The screenings were conducted over one year. Accessions were submitted to natural oat crown rust infections in three different sites, located at the National Institute for Agricultural Research experimental stations of Boukhalef (Tangier), Allal Tazi (Gharb), and Khemis Zemamra (Doukkala). The crop maturation in the Doukkala region is about 10 days to 2 weeks earlier than in the other locations.

Accessions were grouped by species, and sown in lines interspaced by 1.2 m at a rate of 50 seeds per accession. The variety Markton cv. was used as a susceptible check each 20 lines. The sowing date was around mid-November in the Doukkala, and at the end of the same month in the other two locations. These sowing dates were chosen so that the vegetative growth of the accessions will coincide with the rust cycle.

Scoring Method

For this study, we adopted the scoring method recommended for assessing rust infections in International Rust Nurseries. This method combines the evaluation of the severity and the infection type (Loegering, 1959). Severity is defined as the percent of the leaf surface damaged by the disease, measured according to the modified Cobb scale. It is estimated visually, thus defining the following classes: traces, 5%, 10%, 20%, 40%, 60%, and 100% of the leaf surface infected. The infection type is scored according to the following code:

0 : no infection visible on the plant

R : resistance, visible chlorosis or necrosis, with no pustules.

MR : moderately resistant, small size pustules, surrounded by necrotic tissue

MS : moderately susceptible, medium size pustules surrounded by chlorotic tissue

S : susceptible, large size pustules with little or no chlorotic or necrotic tissue.

X : heterogeneous, different size pustules, with necrosis and /or chlorosis.

The score given to an accession after its evaluation in the field includes the estimation of the severity, expressed in percent of the infected leaf surface, and the reaction indicated by a capital letter; for example: tR means traces as a severity index, and R for absence of pustules; 5RM means 5% severity index with moderate resistance, and 60S corresponds to 60% of the leaf surface infected, with pustule type corresponding to susceptibility. Scoring is based on all the leaves except the last one emerged and the one before the last. Plant scoring is the average of all observed leaves. Ten to fifty plants per accession were scored, which corresponds to one plant per genotype. In total, 12.000

plants were scored in the field. Accessions that showed at least a 20MR score at the third observation in any given site were selected as resistant.

Evaluation under controlled environmental conditions

Vegetative material

Seven genotypes, selected as having high levels of resistance in the field (in Tangier, Gharb, and Doukkala locations), were included in this study. The susceptible variety Markton was used as a check (Table 2).

Table2. Accessions selected in the field in 1995 and 1996 for their resistance to oat crown rust.

Genotypes	Species	Reaction and severity in Gharb
283/7	*A. sterilis*	20 MR
430/26	*A. maroccana*	20 MR
430/27	//	20 MR
430/35	//	5 R
430/39	//	20 MR
430/41	//	20 MR
476/43	//	10 MR
Markton cv	*A. sativa*	80 S

Isolates used

Four *P. coronata* isolates, collected from the Gharb region in 1996, combining different virulence genes, were chosen (Table 3). They were used to inoculate the accessions tested under controlled environmental conditions. The inoculum dose was 2 mg of spores in 1 ml of mineral oil (Soltrol M170); with a germination rate of more than 90%, obtained in a 2% agar solution. Several epidemiological characteristics were measured.

Table3: Identity of isolates used for the inoculation of tested genotypes under controlled conditions .

Isolate	Number of genes	Virulent to lines
G96/9	3	Pc6, Pc60, Pc67
G96/3	6	Pc40, Pc45, Pc50, Pc56, Pc64, Pc68
G96/4	11	Pc1, Pc5, Pc6, Pc38, Pc40, Pc45, Pc50, Pc56, Pc58, Pc64, Pc67
G96/2	14	Pc1, Pc6, Pc35, Pc38, Pc40, Pc45, Pc48, Pc50, Pc54, Pc56, Pc58, Pc64, Pc67, Pc68,

Plants growth conditions

Seeds were germinated in Petri dishes containing filter papers soaked with a 2% Giberrilic acid solution. In order to get homogeneous germination and growth, seeds in the Petri dishes were kept at 4°C for three days. Then, they were transferred to a growth chamber fixed at 20 ± 2°C. After germination, seedlings were transplanted into greenhouse pots (12 cm wide and 18 cm high) at a rate of 3 per pot. The pots were filled with a mixture of peat (2/3) and sand (1/3). The experimental design was a complete random design, with 3 replications.

Inoculation

Seedlings of each genotype were inoculated with spores of the 4 isolates, according to the method described by Browder (1971). A non toxic mineral oil (Soltrol M 170) was added at a dose of 0.5 ml / capsule to ease the spraying, and increase urediospores adhesion to the leaves (Rowell, 1957). Each genotype was sown in 4 pots, with 3 plants per pot. Each pot was inoculated by one isolate.

Plant reactions were scored seven days after inoculation according to Murphy (1935) scoring system. After the last observation, leaves were cut off, and plants were preserved until the emergence of the flag leaf for a second inoculation.

At maturity, flag leaves were inoculated according to Andres and Wilcoxson (1984) procedure. The inoculum was filled into capsules of gelatin suspended in a mineral oil (Soltrol M 170). This technique has been described by Browder (1971).

Variables measured

The time of latency measured is the number of days from the inoculation until the appearance of the last pustules. The inoculum produced by square centimetre of leaf surface, for each genotype, is obtained by using the spore collecting procedure described by Browder (1971). Sucked spores were put in a suspension solution of 1ml mineral oil (Soltrol M 170). The number of spores in the suspension was determined using a hemacytometer (Weber B.S. 748). The leaf surface is measured by a planimeter (Ecor 300). The number of spores by square centimetre of leaf is determined for each gentype by dividing the number of spores by the leaf surface.

The spore germination rate was measured for each genotype. Spores were sprayed on Petri dishes, containing a 2% agar solution. The dishes were placed for incubation, under complete darkness, at 20±2°C.Twelve hours later, spores were counted under a 40X binocular. The percent of spore's germination was calculated for each replication.

Statistical data analysis

Data from this test were treated by the two way analysis of variance, using SAS (1987). To get a normally distributed standard error of the variance, the variables production of spores per square centimetre and spore germination rates were converted to their log (x +1.1).

Results

Field scoring results

Under natural infections, 39 accessions were scored as resistant in Doukkala, 31 at Tangier and 20 at Gharb (Table 4).

Of the whole collection tested, 9 diploid accessions were resistant. They belong to 3 of the 7 diploid species represented in this collection. These are *A. longiglumus*, A. damascena and *A. wiestii*. Two of the 4 tetraploid species, *A. maroccana and A. barbata* carried resistance; 25 accessions were selected. For the hexaploids species, only A. sterilis presented 4 resistant accessions.

Characterisation of resistance under controlled conditions

Infection type

At the seedling stage, genotypes number 430/26, 430/35, 430/39 and 430/41 showed infection types varying between moderate and high level of resistance (Table 5). The other accessions (283/7, 430/27, and 476/43) developed largely varied reactions. Accession number 283/7 was highly resistant to G9 and G3 isolates. It produced small size pustules with necrotic tissue. However, it was susceptible to isolates G2 and G4, which produced large size pustules. Genotypes 430/27 were susceptible to G4, and moderately re-

sistant to the other isolates. Genotype 476/43 was moderately resistant to G3, but susceptible to the other 3 isolates.

Table 4 : Species and collection sites of the accessions that were selected as resistant to crown rust in Tangier, Gharb and Doukkala regions.

Species	Accession and genotype	Origin	Reaction and severity		
			Tangier	Gharb	Doukkaka
A. longiglumis	38	Ain Harouda	20S	20S	5R
	202	Kenitra	5R	5R	tR
	203	Mogran	tR	tR	tR
	207	M.Bousalham	5R	10RM	5R
A. damascena	58	Bouznika	60S	60S	10RM
	266	Fnidiq	40S	20S	10R
	267	Fnidiq	40S	40S	5R
	269	Tetouan	5RM	10RM	5RM
A. wiestii	281	El Jabha	5MR	10MR	5MR
A. barbata	10	Had. Ghoualem	20RM	10RM	5R
	11	Merchouch	5RM	10RM	5R
	14	Zhiligua	10RM	20RM	10RM
	77	Oued Cherrat	5R	60S	5R
	91	A. Harouda	5RM	10RM	5RM
	108	Azrou	60S	60S	10RM
	228	Larache	10RM	40S	10RM
	232	Larache	5R	20S	5R
	233	Tangier	10RM	40S	10RM
	237	Tangier	60S	40S	10R
	250	Tangier	tR	5R	tR
	263	Tetouan	tR	10RM	tR
	265	Tetouan	10R	60S	10R
	271	Fnidiq	5R	10RM	5R
	274	Oued Laou	10R	10RM	5R
	299	Ktama	0	tR	0
	453	El Gara	60S	60S	10R
A. maroccana	318/15	Maaziz	60S	60S	10R
	326/1	Had Brachoua	60S	60S	10R
	326/2		20RM	60S	10R

	326/36		10R	60S	10R
	402/11	Had Brachoua	60S	60S	10R
	430/26	Maaziz	10R	20RM	10R
	430/27		10RM	20RM	10RM
	430/35		tR	5R	tR
	430/39		10R	20RM	10R
	430/41		5R	20RM	10R
	476/1	Roumani	5R	10RM	5R
	476/43		5R	10R	5R
	476/49		10R	60S	10R
	484/1	Maaziz	10R	60S	10R
	484/5		5R	60S	5R
	484/7	Maaziz	10R	20RM	5R
	580/12		5R	60S	5R
	580/27		10R	10R	5R
	582/3	Merchouch	10R	60S	10R
	582/4		5R	40S	10R
	582/12		10R	60S	10R
	582/15		10R	60S	10R
	582/23		10R	20RM	5R
	587/6	Romani	40S	60S	20RM
	587/9		60S	60S	10R
	587/13		60S	60S	10R
A. sterilis	70	Bouznika	60S	60S	20RM
	76	Oued Cherrat	60S	60S	20RM
	88	Mohamedia	10R	20RM	20RM
	283	Ej Jabha	20RM	20RM	10RM
A.sativa (check)	Markton cv		80 S	80S	80S

Table 5 : Reaction under controlled conditions of Avena accessions inoculated at seedling and adult stages by the G2, G3, G4, and G9 isolates of *P. coronata* f.sp. *avenae*, carrying 14, 6, 11, and 3 genes of virulence respectively. Infection types 0 and 1 are considered as highly resistant (R), 2 and 2+ as moderately resistant (MR), and 3 and 4 as susceptible (S).

Genotype	Stage	Isolates			
		G2	G3	G4	G9
283/7	seedling	4	1	3	1
	adult	4	1	4	1
430/26	seedling	1	1	2+	1
	adult	1	1	1	1
430/27	seedling	2+	2	3	2
	adult	2+	2	3	1
430/35	seedling	2+	1	2	2
	adult	1	1	1	1
430/39	seedling	2	2	2+	2
	adult	1	1	1	1
430/41	seedling	2+	1	2+	2+
	adult	1	1	1	1
476/43	seedling	3	2+	3	3
	adult	4	2+	4	2
Markton	seedling	4	4	4	4
	adult	4	4	4	4

At plant maturity, genotypes number 430/26, 430/39, and 430/41 expressed high levels of resistance to all types of isolates (Table 5). Pustules were small and surrounded by necrotic tissue. However, the genotype 430/35 that was resistant to all isolates at seedling stage was resistant to G2, G4, and G9 but only moderately resistant to G3. Genotype 283/7 was resistant to G9 and G3, but susceptible to the other 2 isolates. Genotype 430/27 was susceptible to G4, moderately resistant to G3 and G2, and resistant to G9. Genotype 476/43 was moderately resistant to G9 and G3, but susceptible to G2 and G4. The comparison of the reactions of these accessions at seedling and maturity stages (Table 5) showed that there was little change in genotype behaviour as far as rust infec-

tion is concerned. However, genotypes 476/43 which was susceptible, and 430/35 which was moderately resistant at seedling stage to G9, became both resistant at maturity. Overall, resistance levels increased as plants matured; they went from moderate to high for most of the accessions, except for the 283/7 which reactions did not change.

Latency period

The latency period at the seedling stage varied from 8.3 days measured on 430/26-G3, to 14 days observed on the 283/7-G3 (Table 6). The differences in latency periods for different genotypes were significant ($P<0.05$). However, they were not significant among isolates. Interactions (genotypes x isolate) were highly significant. All latency periods observed were longer than that of the universal susceptible check, Markton, which is 7 days for all isolates.

The latency periods at maturity varied from 9.3 to 14 days for accessions (Table 6). Genotypes x isolates interactions, as well as the difference among genotypes were highly significant. However, the differences among isolates on the same genotype were not significant.

The latency duration at seedling and maturity were compared for each genotype (Table 6). The differences were not significant for the genotypes 283/7, 430/26, 430/27 and 430/35; the duration at the two leaves stage was similar to that of the flag leaf stage. For the other genotypes (430/39, 430/41, and 476/43) the latency duration at maturity was longer than that at the seedling stage.

Spore production

The number of spores produced by square centimetre of leaf varied from 849 produced by G3 isolate on genotype 283/7 to 20423 produced by G2 on genotype 476/43 (Table 6). Isolates x genotypes interactions were highly significant. Isolates produced different quantities of spores on different genotypes. Differences among accessions were highly significant, and differences among isolates were also significant.

Germination of spores

For all accessions, the percent of spores germinated varied from 87 to 93% (Table 7). However, the differences among genotypes or isolates were not significant. Also, isolates x genotypes interactions were not significant either.

Table 6 : Comparison of the latency duration (ld), in days for inoculations at seedling and maturity stages, and the number of spores produced (Nb spores) per square centimetre of leaf surface after inoculation of genotypes with 4 different isolates of *P. coronata f.sp. avanae*

Genotypes	Parameter	Isolates				Average
		G9	G3	G4	G2	
288/7	l d seedling	13.6	14	9.6	8.6	11.5 a
	l d adult	13.6	14	9.3	9.6	11.6 A
	Nr spores	1012	849	17851	19511	9805 *b*
30/26	l d seedling	8.6	8.3	9	9.3	8.8 d
	l d adult	9.3	9.3	10	10	9.6 B
	Nr spores	3405	2803	3219	2190	2904 *c*
430/27	l d seedling	9	9.3	9.6	11	9.7 bc
	l d adult	10	9.6	10	10.6	10 B
	Nr spores	2803	3839	2847	28117	9401 *b*
430/35	l d seedling	8.6	8.6	11	9.6	9.5 bcd
	l d adult	10.6	9.3	9.6	10.3	10 B
	Nr spores	1860	989	2650	1415	1728 *d*
430/39*	l d seedling	9.6	9.3	11	10	10 b
	l d adult	12	12	12	11.3	11.8 A
	Nr spores	1218	1500	1240	1278	1309 *d*
430/41*	l d seedling	9.6	9.3	9	8.6	9.1 cd
	l d adult	11	11.6	12	12.3	11.7 A
	Nr spores	1760	944	1105	1184	1248 *d*
476/43*	l d seedling	9	9.3	9.3	8.6	9 cd
	l d adult	12.3	12.6	10.6	10.3	11,5 A
	Nr spores.	3011	2531	15628	20423	10398 ***a***
Markton	l d seedling	7	7	7	7	
	l d adult	7	7	7	7	
	Nr spores	40800	55724	27000	38430	

Means followed by the same letter are not significantly different at P<0.05.
Small letters: for comparison seedling stage
Capital letters: for comparison adult stage
Italics letters: for comparison of spores production
**: Significant differences (P<0.05) for latency duration at seedling and maturity stages within genotypes.*

Table 7 : Percent germination of fresh spores obtained from genotypes inoculated at adult stage with isolates of P. coronata f.sp. avanae in 2% agar suspension.

Genotypes	Isolates				Average
	G9	G3	G4	G2	
283/7	90	91	92	91	91.00 a
430/26	91	93	92	92	91.70 a
430/27	90	91	91	91	90.75 a
430/35	91	90	90	88	89.50 a
430/39	89	86	89	90	88.50 a
430/41	90	90	88	87	88.75 a
476/43	93	88	91	86	89.50 a
Markton	95	98	89	93	93.75

Discussion

Accessions of *Avena* species, collected from different geographical regions of Morocco, and grouped by species, were evaluated for resistance to crown rust at three different sites during one year. Many sources of resistance were identified in this collection; 2.4% of the collection showed complete resistance in all the three sites, and 19% showed resistance in at least one site.

The low frequency of resistant plants observed in wild germplasm was reported by many authors (Dinoor, 1969 ; Lenné and Wood, 1991). Natural plant populations develop other defence mechanisms, such as escapes and host evasion that allow them to escape infections. Moreover, other interactions such as the lack of linkages between the competitive ability and the resistance or susceptibility traits are responsible for susceptible plants survival (Burdon, 1987).

No resistant accession was found in the southern regions. In this regard, Vavilov (1938) reported that populations of *Triticum* (Wild and cultivated) are deficient in rust resistance in arid environments. High temperatures and low air humidity interfere with rust development, so no selection pressure is exerted on the germplasm under these conditions. So the isolates will have the same chance of survival. Unnecessary genes of virulence are dropped from the population.

In the North West region (Tangier, Tetouan, Fnidik and, Larache), the crown rust infection is systematic. During their long life cycle in this region, wild oats are exposed for a long period to crown rust infections. Thus, selection pressure is very high, which can

explain the high frequency of resistant plants in this region. In Zaer region (Maaziz, Roumani, Had Brachoua, Had Ghoualem), resistance was encountered in spite of the fact that rust frequency is limited to rainy years (one year every 8 to 10 years). The frequency of this disease may be enough to maintain the resistance in the host populations. In the Atlantic Region (Oued Cherrat, Mohamadia, Ain Harouda, Kenitra, Moulay Boussalham, Bouznika), resistance to crown rust is rare. The populations of wild oat were reported to be early maturing in this region (Saidi, 1989; Agdour, 1991) which allows escaping the disease. The same distribution of crown rust in some populations of A. sterilis was reported by Dinoor (1970) and Wahl (1970). This latter has concluded that the climatic conditions are the main factor determining the geographical distribution of crown rust in Israel.

Resistance was identified at all ploidy levels; it was found in the diploid species, *A. longiglumis*, *A.damascena* and *A. wiestii*; in *A. maroccana* and *A. barbata*, tetraploid species, and in A. sterilis, an hexaploid species. This variation shows that resistance to crown rust in the genus *Avena* is not associated with any given species. Similar results have already been reported by Williams and Verna (1956). All these species are known to be genetically separated and do not naturally intercross with each other (Sadanaga et al., 1968 ; Rajhathy, 1971; Holden, 1966 and 1984). Thus, the genes of resistance they carry must be different.

The genotypes 283/7 belonging to *A. sterilis* and 430/26, 430/27, 430/35, 430/39, 430/41 and 476/43 of *A. maroccana* were inoculated under controlled conditions with 4 isolates of *P. coronata*. The results of the test conducted under controlled conditions indicate that isolates-genotypes interactions were highly significant for the two measured variables (Latency period, and production of spores), but not for spore germination. This reaction is called vertical resistance according to Vanderplank's (1968) definition. This resistance is expressed at both seedling and adult stages.

All the genotypes, including the susceptible ones, produced fewer spores than the check Markton. This reduction in secondary inoculums could explain the low disease severity levels observed on the accessions when tested in the field. They usually correspond to a non specific or horizontal resistance. This latter is often masked by specific resistance, and can only be observed in the case of susceptibility. This reaction has largely been studied for *P. hordei* (Niks and Kuiper, 1983). The present result suggests that specific and non specific types of resistance are independent and constitute different defense systems used by plants.

The latency period constitutes a good indicator of partial resistance to rust on wheat and barley (Parlevliet, 1979). This result has been confirmed by the present study when genotypes were compared to the susceptible check Markton. However, the latency period did not allow a differentiation among genotypes. The number of spores produced by cm2 of leaf was a characteristic that differentiated between the tested genotypes. These

results corroborate those reported by Luke et al. (1981), and Brake and Irwin (1992) who recommended the use of spore production as a measure of the partial resistance level.

The spore production, measured on Markton (universal susceptible check) is negatively correlated (-0,48) with the number of virulence genes for each isolate. Thus, isolates carrying several virulence genes (G2 and G4) produced a reduced number of spores, as compared to that produced by other isolates (G3 and G9). Virulence genes that are not needed by isolates in infecting the Markton check appear to be as a genetic load for isolates that carry them, as they reduce their aggressiveness (Vanderplank, 1968). This difference observed on the basic disease cycle, could have large consequences on the dynamic of the epidemic. The spores produced had high percentages of germination, regardless of the level of resistance of their hosts. This parameter does not seem to be associated with partial resistance in the studied accessions.

The evaluation of the parasite cycle components has permitted to characterize the resistance existing in these genotypes. The latency period is 10 to 14 days (7 days for the susceptible check) and the production of secondary inoculums is reduced 4 to 30 times as compared to the susceptible check. The two parameters can be used as good criteria to measure the partial resistance in selection programs.

Despite its richness in agronomic characters (disease resistance, and high protein content) and its homology with the cultivated species (Ladizinsky, 1992), the tetraploid species *A. maroccana* has never been used in breeding programs of the hexaploid form ($2n = 6x = 42$). The difference in chromosome numbers is an obstacle for obtaining fertile progenies from their hybridization. The successful attempts to transfer the syndrome of domestication (glabrous seeds, awnless, non shattering spiklets, ..) from the hexaploid cultivated form to wild tetraploid species *A. maroccana and A. murphyi* by Ladizinsky (1995) had a turning-point in the history of oat's genetic improvement. Thus, the genetic resources of these species are finally used in Avena breeding programs. As it was reported by the author, the domesticated forms of these species are of great interest for research as well as for oat production. They can have an immediate use as a new crop like the hexaploid form. The doubling of the chromosomes number will permit to have new synthetic hexaploids. These later present the possibility of choosing the optimum genomic combinations which express the best performances once the carrying plants are cultivated. Moreover, the domesticated tetraploids can be used as a bridge to transfer genes from diploid species to the hexaploid form.

The genotypes 430/26, 430/27, 430/35, 430/39, 430/41 and 476/43 evaluated during this study may be used in an oat breeding program. They come from natural populations well adapted to the local conditions of soil and climate, in addition to their resistance to crown rust. The domesticated forms of these genotypes will certainly be more adapted and more performing than oat cultivars developed from genetic material originated from

temperate and cold regions (USA, Canada). The use of the new generation of varieties resulting from local material will permit to extend the zone of oat cultivation in Morocco. At a regional level, the cultivation of domesticated tetraploid forms may target all cultivated areas of oat having hot climates such as North and South Africa, Australia and the Iberian Peninsula (Spain and Portugal).

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References

Agdour, J., 1991. Caractérisation et Evaluation Génétique d'une Collection Marocaine de Différentes espèces d'Avena, Mémoire de 3 ème Cycle Agronomie I.AV. Rabat 154 pp.

Al Faiz, C. & A. Souihka, 1990. Collecte des espèces d'avoine sauvage au Maroc. In INRA/GTZ, Programme Fourrages, Rabat, Rapport Annuel p.p. 26-29.

Andres, M.W. & R.D. Wilcoxson, 1984. A device for uniform deposition of liquid-suspended urediospores on seedling and adult aeral plants. Phytopathology 74:550-552.

Brake, U.M. & J.A.G. Irwin, 1992. Partial resistance of oats to *P. cornata* f.sp. avenae. Aust. J. Agric. Res. 43:1217-27.

Browder, L.E., 1971. Pathogenic specialization in cereal rust fungi, especially *Puccinia recondita f.sp. tritici*: Concepts, methods of study and application. USDA Tech. Bull. 1432. US Cov. Print Office Washington DC.

Browning, J.A. & K.J. Frey, 1981. The multilines concept in theory and practice. In : R.T. Plund and J.F. Jenkin (eds). Strategies for the control of cereal diseases. Blackwell Scientific, Oxford. p.p. 37-46.

Burdon, J.J., 1987. Diseases and Plant Population Biology. Cambridge University Press, Cambridge.

Comeau, A., 1982. Geographic distribution of resistance to barley yellow dwarf virus in *Avena sterilis*. Can. J. Plant Pathol. 4 : 147-151.

Dinoor, A., 1969. Crown rust resistance and (in) grasses in Israel. Annal of the New York Academy of Sciences 287 : 357-366.

Dinoor, A., 1970. Sources of oat crown rust resistance in hexaploid and tetraploid wild oats in Israel. Can. J. Bot. 48: 153-161.

Holden, J.H.W., 1966. Species relationships in the Avena. Chromososma 20 : 75-127.

Holden, J.H.W., 1984. Oats *Avena* spp (Gramineae-Avenae). In : Evolution of crop plants. Missond, p.p. 86-90.

Ladizinsky, G., 1992. Genetic resources of tetraploid wild oats and their utilization. Proc . 4th Int. Oat Conf. Adelaide pp 65- 70.

Ladizinsky, G., 1995. Domestication via hybridization of the wild tetraploid oats Avena magna and A. murphyi. Theor. Appl. Genet. 91 : 639-646.

Ladizinsky, G., and R. Fainstein. 1977. Introgression between the cultivated hexaploid oat *Avena sativa* and the tetraploid wild oat *A. magna* and *A. murphyi*. Can. J. Gent. Cytol. 19 : 59-66.

Leggett, J.M., G. Ladizinsky, P. Harberg, & M. Obanni, 1992. The distribution of nine *Avena* species in Spain and Morocco. Can. J. Bot. 70 : 240-244.

Lenné, J.M. & D. Wood, 1991. Plant diseases and use of wild germplasm. Ann. Rev. Pathol. 29: 35-63.

Leonard, K. J. & Y. Anikster, 1996. Oat crown rust diversity in North America and Israel, p 2. Proc. Of the 9th European and Mediterranean Cereal Rust, Powdery Mildews Conference. 2-6 September 1996, Lunteress, the Netherlands.

Loegering, W.Q., 1959. Method for recording cereal rust data. USDA International Spring Wheat Rust Nursery, 1959 pp6.

Luke, H.H., P.L Pfahler & R.D. Barnett, 1981. Influence of diseases severity and environmental conditions on low receptivity of oats to crown rust. Plant Dis. 65: 125-127.

Murphy, H. C., 1935. Physiologic specialization in *Puccinia coronata* U.S. Dep. Agric. Tech. Bull. 433:1-48.

Niks, R.E. & H.J. Kuiper, 1983. Histilogy of the relation between Minor and Major Genes for Resistance of Barley to Leaf Rust. Phytopathology 75: 55-59.

Parlevliet, J.E., 1979. Components of resistance that reduce the rate of epidemic development. Ann. Rev. Phytopathol. 17: 203-222.

Rajhathy, T., 1971 . The alloploid model in *Avena*. Stadler Genet. Symp. 3: 71-87.

Rieuf, P., 1971. Parasites et saprophytes des plantes au Maroc. Les Cahiers de la Recherche Agronomique 30 : p 520.

Rowell, J.B., 1957. Oil Inoculation of wheat with spores of *Puccinia graminis tritici*. Phytopathology 47: 689-90.

Sadanaga, K., F.J. Zillinsky, H.C. Murphy & R.T. Smith, 1968. Chromosome associations in triploid, tetraploid, and pentaploid hybrids of *Avena magna* (2n = 28). Crop Sci. 60: 594-597.

Saidi, S., 1989. Caractérisation et Evaluation préliminaire d'une collection indigène de *Avena* . Mémoire de 3ème Cycle Agronomie I.AV. Rabat 100 pp.

Saidi, S. & M. EL Yamani, 1994. Evaluation de la résistance au BYDV d'une collection indigène d'avoine sauvage. Al Awamia 84: 43-49.

SAS Institute Inc, 1987. SAS/STAT Guide for Personal Computers, Version 6 , (eds), Cary, North Carolina. 378 pp.

Sebesta, J., 1983. Race specific expression of oat crown rust resistance conditioned by major and minor genes. Euphytica 32: 857-861.

Simons, M. D., 1985. Diseases of oats in: Proceedings of the Second International Oats Conference.(eds), D. A. Lawes, H. Thomas p.p. 57-66.

Vanderplank, J.E., 1968. Disease resistance in plants, New York: Academic Press.

Vavilov, N. I., 1938. Selektsiia ustoichivykh sorov kak asnovnoi metod borby s rshavchinoi (Selection of resistant varieties as basic method for rust control) p. 3-20 in: Rshavchina zernovykh kul'tur (Rust of cereal crops). Selkhozgiz, Moscow, 286p. Russian.

Wahl, I., 1970. Prevalence and Geographic Distribution of Resistance to Crown Rust in *Avena sterilis*. Phytopathology 60: 746-749.

Williams, W. & U.N. Verna, 1956. Investigation on resistance to diseases among species of the genus Avena I. Resistance to physiologic races of *Ustilago avenae* and *U. kolleri*. Ann. Appl. Biom. 41: 405-416.