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Genetic progress in oat associated with fungicide use in Rio Grande do Sul, Brazil

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ABSTRACT. The State of Rio Grande do Sul (RS) is the largest producer of oat in Brazil with the aid of consolidated breeding programs, which are constantly releasing new cultivars. The main objectives of this study were to: 1) evaluate the annual genetic progress in grain yield and hectoliter weight of the oat cultivars in RS, with and without fungicide use on aerial parts of plants; and 2) evaluate the efficiency of oat breeding programs in introducing disease-resistant genes in the released cultivars through network yield trials conducted with and without fungicide use on aerial plant parts. The data on grain yield and hectoliter weight were obtained from 89 competition field trials of oat cultivars carried out from 2007 to 2014 in nine municipalities of RS. Of the total 89 trials, 44 were carried out with fungicide application on aerial plant parts and

45 were carried out without fungicide application. The annual genetic progress in oat cultivars was studied using the methodology proposed by Vencovsky (1988). The annual genetic progress in oat grain yield was 1.02% with fungicide use and 4.02% without fungicide use during the eight-year study period in RS. The annual genetic progress with respect to the hectoliter weight was 0.08% for trials with fungicide use and 0.71% for trials without fungicide use. Performing network yield trials with and without fungicide use on the aerial plants parts is a feasible method to evaluate the efficiency of oat breeding programs in introducing disease-resistant genes in the released cultivars.

Key words: *Avena sativa* L.; Cultivars; Breeding, Genetic gain; Disease resistance

INTRODUCTION

The oat crop is highlighted with great importance in grain production systems as well as for crop-livestock integration in southern Brazil (Lângaro and Carvalho, 2014). Moreover, it is an economical alternative for winter season and assists in the adoption of no-tillage system of agriculture. The modern oat cultivars released in Brazil are the result of efficient plant breeding programs, which increase the grain quality and yield, and thus support the country in reducing oat importation. In addition, oat cultivation promotes the growth of small-scale processing industries (Federizzi et al., 2005).

The Brazilian oat-cultivated area has progressively increased, with an area of 171,300 ha during the 2013-2014 agricultural year. In this agricultural year, the average grain yield was 2230 kg/ha, representing an increase of 1.5% in area and 4.3% in grain yield over the previous agricultural year. Rio Grande do Sul (RS) stands out as the largest oat-producing state in Brazil, with an oat-cultivated area of 102,500 ha and average grain yield of 2691 kg/ha in the 2013-2014 agricultural year (Conab, 2013). Thus, oat has occupied the position of the second most cultivated cereal in southern Brazil (Deuner et al., 2014).

The oat crop (*Avena sativa* L.) has remained highlighted due to the constant efforts of public and private institutions carrying out plant breeding research. These efforts can be measured by studying genetic progress in the new oat cultivars released in the market. Studying genetic progress is important to evaluate the efficiency of plant breeding programs (Borges et al., 2009). If required, this study can suggest possible changes in the strategies and methodologies used in plant breeding programs (Faria et al., 2007). For the oat crop, the studies developed by Barbosa Neto et al. (2000) in Brazil and by Redaelli et al. (2008) in Italy can be emphasized. In addition, the studies with cereals from the same family as wheat (Nedel, 1994; Rodrigues et al., 2007; Cargnin et al., 2008; Oury et al., 2012; Beche et al., 2014; Thomas and Graf, 2014; Wu et al., 2014), rice (Borges et al., 2009; Breseghello et al., 1999, 2011; DoVale et al., 2012), and popcorn (Ribeiro et al., 2012) can be highlighted.

The use of cultivar competition trials in different locations and years of evaluation in order to estimate the annual genetic progress was proposed by Vencovsky et al. (1988). Genetic progress in cultivars is estimated by replacing the existing cultivars with the supposedly superior new cultivars. One of the main advantages of using data from the previously performed field trials is the cost reduction as compared to the other methods (Toledo et al., 1990).

The State of Rio Grande do Sul (RS) has a great potential to increase oat yield. However, leaf diseases, such as leaf rust, have been recognized as potentially aggressive diseases (Chaves and Martinelli, 2005), which reduce the yield and quality of oat grains (Martinelli et al., 2009). Dividing the cultivar trials with and without fungicide use is relevant. In France, different estimates of genetic progress were obtained for wheat cultivars grown with and without fungicide use (Oury et al., 2012). In Brazil, differences in oat trials with and without fungicide use have been reported in the studies of cultivar stability and adaptability (Lorencetti et al., 2004) and stratification of environments (Benin et al., 2005).

The selection criteria have great importance in oat breeding programs, wherein the increased number and quality of grains are prioritized in the final selection for disease resistance. The quantitative traits, such as grain filling duration, hectoliter weight, hull/grain ratio, and industrial yield, can be attributed to grain quality (Federizzi et al., 2005). According to Lângaro and Carvalho (2014), the yield and industrial quality of oat grains play an important role in their commercialization, wherein the industry takes into account the thousand grain weight, hectoliter weight, and the percentage of grains larger than two millimeters.

The introduction of foreign germplasm can benefit oat breeding programs in Brazil, providing a gene pool with new groups of genes and alleles, and hence crops genetic gains (Luche et al., 2013). From the 1970s onwards, several breeding program partnerships were established between the United States and Brazilian research institutions; these programs introduced the sources of resistance mainly to leaf and stem rust in oat (Federizzi et al., 2005). Leaf rust is a major disease of oat (Zambonato et al., 2012), causing reduction in its grain quality (Doehlert et al., 2001). It was assumed that genetic progress in grain yield and hectoliter weight was associated with fungicide use on aerial plant parts of oat cultivars in RS. Thus, the objectives of this study were: 1) to evaluate genetic progress in grain yield and hectoliter weight of oat cultivars in RS, with and without fungicide use on aerial plant parts; and 2) to evaluate the efficiency of oat breeding programs in the introduction of disease-resistance genes in the released cultivars through network yield trials carried out with and without fungicide use on aerial plant parts.

MATERIAL AND METHODS

The data of grain yield (kg/ha) and hectoliter weight (kg/100 L) were obtained from 89 field trials belonging to the competition network of oat cultivars. The field trials were carried out during the period from 2007 to 2014 in nine municipalities of RS (Figure 1). Data were obtained from the annals of the Brazilian Committee of Oat Research meeting (RCBPA), published annually in the Congress of RCBPA (Table 1).

All trials were carried out using the randomized block design with three replications. The experimental units consisted of five rows with a spacing of 0.17 to 0.20 m. All experimental units were 5.0-m long. The experimental unit area ranged from 4.25 to 5.0 m^2. The number of cultivars ranged from 13 to 25, totaling up to 36 during the entire experimental period (Table 2).

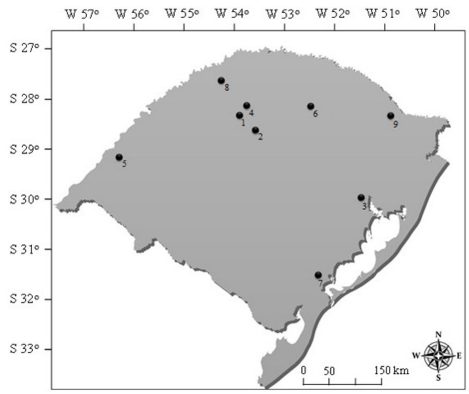

Figure 1. Geographical representation of the nine locations where the oat trials organized by the Brazilian Committee of Oat Research were carried out in Rio Grande do Sul, Brazil, during the period from 2007 to 2014. 1 = Augusto Pestana; 2 = Cruz Alta; 3 = Eldorado do Sul; 4 = Ijuí; 5 = Itaqui; 6 = Passo Fundo; 7 = Pelotas; 8 = Três de Maio; 9 = Vacaria.

Table 1. Chronological list of the scientific studies from the Brazilian Committee of Oat Research meeting used in this study.

Summary	Year	Main reference	Page		No. of trials
			Initial	Final	
1	2007	RCBPA, 2008	143	146	2
2	2007	RCBPA, 2008	159	161	2
3	2007	RCBPA, 2008	162	165	2
4	2007	RCBPA, 2008	166	168	2
5	2007	RCBPA, 2008	185	187	2
6	2008	RCBPA, 2009	358	360	2
7	2008	RCBPA, 2009	361	362	2
8	2008	RCBPA, 2009	363	365	2
9	2008	RCBPA, 2009	366	369	2
10	2008	RCBPA, 2009	370	377	2
11	2008	RCBPA, 2009	401	405	4
12	2009	RCBPA, 2010	343	346	2
13	2009	RCBPA, 2010	351	354	2
14	2009	RCBPA, 2010	357	360	2
15	2009	RCBPA, 2010	361	366	2
16	2009	RCBPA, 2010	367	369	2
17	2009	RCBPA, 2010	370	374	2
18	2010	RCBPA, 2011	365	372	2
19	2010	RCBPA, 2011	388	392	2
20	2010	RCBPA, 2011	393	395	2
21	2010	RCBPA, 2011	404	409	2
22	2010	RCBPA, 2011	425	429	2
23	2011	RCBPA, 2012	1	4	2
24	2011	RCBPA, 2012	1	3	2
25	2011	RCBPA, 2012	1	9	2
26	2011	RCBPA, 2012	1	4	2
27	2011	RCBPA, 2012	1	5	2
28	2012	RCBPA, 2013	1	4	2
29	2012	RCBPA, 2013	1	3	2
30	2012	RCBPA, 2013	1	4	2
31	2012	RCBPA, 2013	1	4	2
32	2012	RCBPA, 2013	1	5	2
33	2013	RCBPA, 2014	1	4	2
34	2013	RCBPA, 2014	1	3	2
35	2013	RCBPA, 2014	1	4	2
36	2013	RCBPA, 2014	1	4	1
37	2013	RCBPA, 2014	1	4	2
38	2013	RCBPA, 2014	1	4	2
39	2014	RCBPA, 2015	1	4	2
40	2014	RCBPA, 2015	1	3	2
41	2014	RCBPA, 2015	1	4	2
42	2014	RCBPA, 2015	1	4	2
43	2014	RCBPA, 2015	1	33	2
44	2014	RCBPA, 2015	1	4	2

Table 2. Years, locations, and number of trials and cultivars evaluated in the network of oat cultivars competition trials (*Avena sativa* L.) from 2007 to 2014 in Rio Grande do Sul (RS), Brazil, with and without fungicide use on aerial plant parts.

Year	Locations									No. of trials	No. of cultivars
	Augusto Pestana	Cruz Alta	Eldorado do Sul	Ijuí	Itaqui	Passo Fundo	Pelotas	Três de Maio	Vacaria		
With fungicide											
2007	-	1	1	-	-	1	1	1	-	5	13
2008	-	1	1	1	-	1	1	1	1	7	14
2009	-	-	1	1	-	1	1	1	1	6	18
2010	1	-	1	-	-	1	1	1	-	5	25
2011	1	-	1	-	-	1	1	1	-	5	25
2012	1	-	1	-	-	1	1	1	-	5	25
2013	1	-	1	-	1	-	1	1	-	5	22
2014	1	-	1	-	1	1	1	1	-	6	22
Without fungicide											
2007	-	1	1	-	-	1	1	1	-	5	13
2008	-	1	1	1	-	1	1	1	1	7	14
2009	-	-	1	1	-	1	1	1	1	6	18
2010	1	-	1	-	-	1	1	1	-	5	25
2011	1	-	1	-	-	1	1	1	-	5	25
2012	1	-	1	-	-	1	1	1	-	5	25
2013	1	-	1	-	1	1	1	1	-	6	22
2014	1	-	1	-	1	1	1	1	-	6	22
Total	10	4	16	4	4	15	16	16	4	89	36

"-" indicates absence of trial.

Calculation of genetic progress was performed individually for the municipalities of Eldorado do Sul, Passo Fundo, Pelotas, and Três de Maio. The trials were carried out during all years of the study period in these locations. For the calculation of genetic progress in RS, the cultivar trials carried out during the study period in all nine municipalities, including Augusto Pestana, Cruz Alta, Eldorado do Sul, Ijuí, Itaqui, Passo Fundo, Pelotas, Três de Maio, and Vacaria, were considered.

The trials were designed to generate information for recommending cultivars with better performance on exposure to different growing environments. Cultivars with unsatisfactory performance were discarded and replaced by other cultivars with supposedly greater yield potential. Cultivars that exhibited satisfactory performance were maintained for evaluation in the following year.

Genetic progress in oat cultivars was studied using the methodology proposed by Vencovsky et al. (1988), which is based on the data generated in the regional cultivar trials. In addition, genetic gain estimates and genetic progress balance were determined using the method of generalized least squares (Cruz, 2001).

Thus, initially, the rates of included (I), deleted (D), maintained (M), and renewed (R) cultivars in the trials were estimated using the following formulas:

$$\%I = \frac{100I}{M + D + I} \quad \text{(Equation 1)}$$

$$\%\mathrm{D} = \frac{100D}{M + D + I} \quad \text{(Equation 2)}$$

$$\%\text{M} = \frac{100M}{M + D + I} \quad \text{(Equation 3)}$$

$$\%R = \frac{100I}{M + I} \quad \text{(Equation 4)}$$

where I is the number of cultivars included in the following year; D is the number of cultivars deleted in the previous year; M is the number of cultivars maintained from one year to another; and R represents the renewal of cultivars (Cruz, 2001).

Subsequently, genetic gain was estimated for every two years, using the linear regression model proposed by Vencovsky et al. (1988):

$$\hat{G}g = (\bar{y}2 - \bar{y}1) - (\bar{y}c2 - \bar{y}c1) \quad \text{(Equation 5)}$$

where $\hat{G}g$ is the estimate of genetic gain; $\bar{y}1$ is the overall mean of cultivars in the year 1 trial; $\bar{y}2$ is the overall mean of cultivars in the year 2 trial; $\bar{y}c1$ is the overall mean of common cultivars in the year 1 trial; and $\bar{y}c2$ is the overall mean of common cultivars in the year 2 trial.

In this methodology, the gross difference was obtained by ($\bar{y}2 - \bar{y}1$) and the environmental difference was obtained by ($\bar{y}c2$ - $\bar{y}c1$). Thus, genetic gain estimate was obtained by subtracting the environmental difference from the gross difference (Vencovsky et al., 1988).

Subsequently, the genetic progress balance was determined using the method of generalized least squares, as described by Cruz (2001). The average genetic gain ($\mu\hat{G}g$) for a period was obtained in $kg \cdot ha^{-1} \cdot year^{-1}$ for grain yield and in $kg \cdot 100\ L^{-1} \cdot year^{-1}$ for hectoliter weight. The percentage of annual genetic progress was calculated by the formula $(\frac{\mu\hat{G}g}{\bar{y}1} * 100)$. For statistical analysis, Microsoft Office Excel application and Genes software (Cruz, 2013) were used.

RESULTS AND DISCUSSION

Evaluation trials of oat cultivars assessed during an eight-year period in the State of RS (Table 2) exhibited a balanced distribution among cultivars with and without fungicide use on aerial plant parts. Mainly, they presented proper balance with respect to the locations of trials installation, highlighting the trials carried out in Eldorado do Sul, Pelotas, and Três de Maio with and without fungicide, and in Passo Fundo without fungicide. Moreover, these trials were present in all evaluation years with good annual representation of the locations, which presented minimal variation of the five locations and maximum variation of the seven locations during the study period. However, the same balance was not observed in the study regarding genetic progress in irrigated rice in the State of Minas Gerais, where among the four study locations, none was present in all evaluation years and the variation of trial locations per year was one to four trial locations (DoVale et al., 2012). Therefore, it can be inferred that the database was suitable to evaluate genetic progress in oat during this period.

Means of I (13.6%), D (7.5%), and R rates (14.8%) of cultivars during the period from 2007 to 2014 were relatively lower than the M rate (78.8%) (Table 3). The M rate of oat cultivars was elevated in comparison to the values found in genetic progress studies in wheat with 52% (Cargnin et al., 2008) and rice with 58% (DoVale et al., 2012).

Table 3. Rates of inclusion, deletion, maintenance, and renewal of cultivars in the network of oat cultivars competition trials (*Avena sativa* L.) from 2007 to 2014 in Rio Grande do Sul, Brazil.

Bienniums	Inclusion (%)	Deletion (%)	Maintenance (%)	Renewal (%)
2007-2008	7.1	0.0	92.9	7.1
2008-2009	26.3	5.3	68.4	27.8
2009-2010	30.8	3.8	65.4	32.0
2010-2011	19.3	19.4	61.2	24.0
2011-2012	7.4	7.4	85.2	8.0
2012-2013	0.0	12.0	88.0	0.0
2013-2014	4.3	4.3	91.3	4.5
Mean of 8 years	13.6	7.5	78.9	14.8

In all nine locations (Augusto Pestana, Cruz Alta, Eldorado do Sul, Ijuí, Itaqui, Passo Fundo, Pelotas, Três de Maio, and Vacaria) and years (2007 to 2014) and in the overall RS state, the mean grain yield of the oat cultivars in trials with fungicide use was greater than that of the oat cultivars in trials without fungicide use on aerial plant parts (Table 4). The same behavior was observed for hectoliter weight, except for the locations of Pelotas and Vacaria in 2008 and Passo Fundo in 2012, where the mean hectoliter weight was greater in trials without fungicide use.

Considering all trial locations and years, the overall mean grain yield was 2863.37 kg/ha with fungicide use and 1941.56 kg/ha without fungicide use. The difference in the mean grain yield between trials with and without fungicide use was 921.81 kg/ha, corresponding to a reduction of 32.19%. Meanwhile, the mean hectoliter weight was 46.79 kg/100 L with fungicide use and 41.28 kg/100 L without fungicide use. Thus, the fact of not using the fungicide reduced the hectoliter weight by 11.78%. These results demonstrated that the chemical control application using fungicides helps in the maintenance of yield potential and grain quality.

The reduction in yield potential and industrial quality in oat grown without fungicide use might be linked to the presence of pathogens, environmental conditions favorable to pathogens, and genetic susceptibility of cultivars to the pathogen. Deuner et al. (2014) stated that because oat is the second most cultivated cereal in southern Brazil, an increase in cultivated area increases the risk of epidemics. Some of the most important fungal diseases of oat include leaf rust, stem rust, and *Helminthosporium* leaf spot, which are caused by *Puccinia coronata* f. sp *avenae*, *P. graminis* f. sp *avenae*, and *Drechslera avenae*, respectively. Leaf rust, being the most destructive disease of oat (Chaves and Martinelli, 2005), reduces the quality and yield of grains by approximately 50%. According to Martinelli et al. (2009), the effectiveness of the pathogen-resistance genes in oat is low and the virulence of the races found in southern Brazil is complex. This scenario justifies the efforts in performing trials with and without the use of foliar fungicide in oat.

Oat cultivar trials with and without fungicide use demonstrated satisfactory results, since genetic progress from 2007 to 2014 was greater in trials without fungicide use at all locations (Table 5), except Passo Fundo. Moreover, the same cultivars were evaluated with and without fungicide use, suggesting efficient gene introgressions and gene pyramiding for resistance to the main pathogens in oat. The influence of fungicide use on oat crop has been reported in several adaptability and stability studies. These studies have reported a necessity for the stratification of environments depending on the treatment with or without fungicide; the fungicide use was found to influence the results (Lorencetti et al., 2004; Benin et al., 2005).

Table 4. Means of grain yield, in kg/ha, and hectoliter weight, in kg/100 L, with and without fungicide use on the aerial parts of cultivars evaluated in the network of oat cultivars competition trials (*Avena sativa* L.) during the period from 2007 to 2014 in nine locations (Augusto Pestana, Cruz Alta, Eldorado do Sul, Ijuí, Itaqui, Passo Fundo, Pelotas, Três de Maio, and Vacaria) and in the overall mean of the Rio Grande do Sul (RS) State, Brazil.

Location/State	2007	2008	2009	2010	2011	2012	2013	2014
	Grain yield with fungicide use (kg/ha)							
Augusto Pestana	-	-	-	2119.08	3012.48	3961.68	3572.59	2517.34
Cruz Alta	1026.85	1360.57	-	-	-	-	-	-
Eldorado do Sul	3080.23	4116.00	3896.72	3570.88	4863.56	2601.84	4196.73	3210.97
Ijuí	-	1622.43	2499.94	-	-	-	-	-
Itaqui	-	-	-	-	-	-	1292.86	1292.81
Passo Fundo	2429.85	1719.64	3453.72	3428.36	4072.48	1502.88	-	2570.15
Pelotas	1247.92	1884.21	1591.28	2532.04	4136.76	2455.00	2564.45	1281.90
Três de Maio	2604.15	3311.64	3598.72	2204.28	2792.44	2979.96	4491.86	2707.00
Vacaria	-	3899.79	4270.83	-	-	-	-	-
Mean (RS)	2077.80	2559.18	3218.54	2770.93	3775.54	2700.27	3223.70	2263.36
	Grain yield without fungicide use (kg/ha)							
Augusto Pestana	-	-	-	1508.04	2282.04	2864.32	2236.14	1486.20
Cruz Alta	564.38	657.29	-	-	-	-	-	-
Eldorado do Sul	1906.77	1826.79	3367.39	2016.84	3374.00	1864.08	3208.36	1648.76
Ijuí	-	544.36	1764.06	-	-	-	-	-
Itaqui	-	-	-	-	-	-	1172.68	1172.77
Passo Fundo	1704.31	762.64	2362.67	2429.88	3185.08	1427.00	2090.55	1308.96
Pelotas	528.85	850.86	1494.83	1712.04	3201.64	1142.12	1985.41	783.19
Três de Maio	1772.23	1660.21	3201.83	1797.24	1549.96	1836.80	3259.41	1591.14
Vacaria	-	2741.29	2724.61	-	-	-	-	--
Mean (RS)	1295.31	1291.92	2485.90	1892.81	2718.54	1826.86	2325.42	1331.84
	Hectoliter weight with fungicide use (kg/100 L)							
Augusto Pestana	-	-	-	46.46	52.10	49.60	51.64	48.31
Cruz Alta	-	-	-	-	-	-	-	-
Eldorado do Sul	53.02	53.79	52.50	54.08	49.85	43.53	52.77	52.13
Ijuí	-	45.40	40.67	-	-	-	-	-
Itaqui	-	-	-	-	-	-	43.05	43.05
Passo Fundo	50.66	40.01	52.50	49.88	54.41	40.42	-	46.64
Pelotas	48.85	34.86	46.67	45.16	54.36	51.65	51.23	46.40
Três de Maio	40.06	43.42	39.67	36.71	44.00	44.80	47.05	27.24
Vacaria	-	43.82	45.33	-	-	-	-	-
Mean (RS)	48.15	43.55	46.22	46.46	50.94	46.00	49.15	43.96
	Hectoliter weight without fungicide use (kg/100 L)							
Augusto Pestana	-	-	-	40.82	49.37	43.13	45.27	44.57
Cruz Alta	-	-	-	-	-	-	-	-
Eldorado do Sul	43.68	40.46	50.11	45.28	41.06	37.02	46.18	40.97
Ijuí	-	36.06	33.44	-	-	-	-	-
Itaqui	-	-	-	-	-	-	42.73	42.75
Passo Fundo	40.21	31.23	45.00	44.40	50.28	44.17	38.86	37.58
Pelotas	33.10	44.71	44.67	39.74	51.15	41.33	46.32	37.63
Três de Maio	34.37	33.57	37.44	33.72	37.77	38.73	43.41	23.45
Vacaria	-	43.89	41.56	-	-	-	-	-
Mean (RS)	37.84	38.32	42.04	40.79	45.93	40.87	43.80	37.83

"-" indicates absence of trial.

Genetic progress in grain yield of oat cultivars in the state of RS during the period from 2007 to 2014 was 21.17 kg·ha^{-1}·year^{-1} (1.02% per year) with fungicide use and 52.12 kg·ha^{-1}·year^{-1} (4.02% per year) without fungicide use (Table 5). Meanwhile, the hectoliter weight presented genetic progress of 0.04 kg·100 L^{-1}·year^{-1} (0.08% per year) with fungicide use and 0.27 kg·100 L^{-1}·year^{-1} (0.71% per year) without fungicide use. Therefore, it can be inferred that genetic progress was superior in trials carried out without fungicide use.

Table 5. Annual genetic progress and percentage of annual genetic progress in grain yield and hectoliter weight of oat cultivars (*Avena sativa* L.) calculated in four locations (Eldorado do Sul, Passo Fundo, Pelotas, and Três de Maio) and in the overall Rio Grande do Sul State during 2007 to 2014.

Location/State	Grain yield		Hectoliter weight	
	Genetic progress ($kg \cdot ha^{-1} \cdot year^{-1}$)	Annual genetic progress (%)	Genetic progress ($kg \cdot 100\ L^{-1} \cdot year^{-1}$)	Annual genetic progress (%)
With fungicide use				
Eldorado do Sul	32.30	1.05	0.17	0.32
Passo Fundo	86.86*	3.57	0.33*	0.65
Pelotas	1.18	0.09	0.08	0.16
Três de Maio	18.68	0.72	-0.06	-0.15
Rio Grande do Sul	21.17	1.02	0.04	0.08
Without fungicide use				
Eldorado do Sul	73.96	3.88	0.56	1.28
Passo Fundo	42.86	2.51	0.31	0.77
Pelotas	34.68	6.56	0.14	0.42
Três de Maio	66.48	3.75	0.28	0.81
Rio Grande do Sul	52.12	4.02	0.27	0.71

*Genetic gain estimated with seven trials in eight years.

The annual genetic progress in grain yield obtained in recent studies with wheat was 0.92% in Brazil (Beche et al., 2014), 0.67% in Canada (Thomas and Graf, 2014) and 1.00% in China (Wu et al., 2014). Similarly, the annual genetic progress in rice was 0.67% in Brazil (Breseghello et al., 2011); however, no genetic progress was observed in the dry-land rice program of the State of Minas Gerais (Borges et al., 2009). Furthermore, for carioca common bean in the State of Minas Gerais, the annual genetic progress was 6.74% (Barili et al., 2016). However, in oat, no comparative studies could be found.

The results of this study showed that the breeding program strategies are effective in increasing the hectoliter weight of oat. It is important to study genetic progress in hectoliter weight as it is a measure of grain quality (Lângaro and Carvalho, 2014) and considered a selection criterion in oat breeding programs in southern Brazil (Federizzi et al., 2005). During 1957 to 1996, Barbosa Neto et al. (2000) reported an annual genetic progress of 0.3% in the hectoliter weight of oat.

Pathogen attack, increase in foliar diseases, and action of hormones, such as ethylene, lead to elevated energy spending and leaf senescence as defense strategies in plants (Taiz and Zeiger, 2013). The lower leaf area resulting from the higher rate of leaf senescence rate can explain the greater genetic progress in trials without fungicide use. In trials without fungicide use, the new cultivars suffer less damaging effect on their vegetative growth upon introduction of major pathogen-resistant genes in them. The reduction in growth due to reduced leaf area was observed in species of the same family as wheat (*Triticum aestivum* L.). An increase in artificial defoliation rate has been found to result in progressive reduction of grain yield and hectoliter weight of wheat (Souza et al., 2013).

Genetic progress from 2007 to 2014 differed among the four individually studied locations (Eldorado do Sul, Passo Fundo, Pelotas, and Três de Maio). The highest annual genetic progress in grain yield with fungicide use was observed in Passo Fundo (3.57%) and the lowest in Pelotas (0.09%). Meanwhile, opposite grain yield results were obtained in trials without fungicide use, with the highest annual genetic progress in Pelotas (6.56%) and the lowest in Passo Fundo (2.51%) (Table 5). These results can be associated with different climatic conditions in these locations because of the huge difference in the altitudes of Passo Fundo (687 m) and Pelotas (13 m). Consequently, in low-altitude environments, the relatively higher average air temperature leads to higher growth rate of pathogens. In trials with fungicide use, the lowest annual genetic progress in the hectoliter weight was found in Três de Maio with -0.15%, followed by Pelotas with 0.16% and Eldorado do Sul with 0.32%, and the highest in Passo Fundo with 0.65%. Meanwhile, in trials without fungicide use, the annual genetic progress in the hectoliter weight oscillated between 0.42% in Pelotas and 1.28% in Eldorado do Sul (Table 5).

In Italy, genetic progress in oat differed among the studied locations (Redaelli et al., 2008). Furthermore, in China, genetic progress in wheat varied depending on the growing region, and the researchers suggested reformulating the breeding programs strategies for regions with low genetic progress rates (Wu et al., 2014).

Studies similar to the present study can be performed in other crops that use comparative trials with and without fungicide use. The differentiation in trials with and without fungicide use was also observed in wheat, which showed higher genetic progress in trials without fungicide, indicating that breeding programs aimed at releasing disease-resistant cultivars present additive effects on grain yield (Oury et al., 2012).

CONCLUSION

The annual genetic progress in oat grain yield was 1.02% with fungicide use and 4.02% without fungicide use during the eight-year study period in RS. Regarding the hectoliter weight, the annual genetic progress was 0.08% for trials with fungicide use and 0.71% for trials without fungicide use. Performing network yield trials with and without fungicide use on aerial plant parts is feasible to evaluate the efficiency of oat breeding programs aimed at introducing disease-resistance genes in the released cultivars.

Conflicts of interest

The authors have no conflict of interest to declare.

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