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URS Brava – a new oat cultivar with partial resistance to crown rust

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Abstract – *The cultivar URS Brava, obtained from a simple cross between the line 'UFRGS 995078-2' and the cultivar 'URS 21', shows high grain yield and stability, high grain quality, desirable agronomical traits and partial resistance to crown rust, caused by the fungus* Puccinia coronata *f. sp.* avenae.

Keywords: Avena sativa *L., oat breeding, seed production.*

INTRODUCTION

Cultivated oat (*Avena sativa* L.) is an important crop species that is grown as a source of food and feed worldwide. Oat is a self-pollinated and allohexaploid (2n=6x=42) species that originated in the Mediterranean and has been adapted to a wide range of environments. In subtropical environments where two crops can be grown in a single year, such as southern Brazil, oat plays an important role in the crop management system. During the winter-spring seasons, oat can be cultivated in rotation with wheat or barley, which may reduce damages caused by diseases that survive on crop residues. Furthermore, oat allows for the establishment and maintenance of the no-tillage system and represents an excellent option for grain production in succession with soybean (Locatelli et al. 2007).

According to the Food and Agriculture Organization of the United Nations (FAO), global oat production in 2013 was approximately 23.88 million tons per year harvested over an area of 9.78 million hectares (FAOSTAT 2015). However, the global production of oat has decreased in recent decades, including in the largest oat-producing countries, which include Russia, Canada, Australia and Poland. This decreasing trend can be explained by the reduced production of oat grains for feed, especially for horses, and by the substitution of oat with more cost-effective crops, such as soybean and maize, in the northern hemisphere where oat is cultivated in the spring-summer. However, an increasing and sustainable trend has been observed in the production, yield and cultivated area of oat in Brazil over recent decades. The data from the historical series made available by the National Food Supply Agency (CONAB 2015) show this increase, in which oat production went from 37.4 thousand tons collected in 1976 to more than 300 thousand tons estimated for the harvest of 2014, although the Brazilian production has already reached 500 thousand tons in 2005.

The continuous development of new oat cultivars is essential to guarantee the survival and progress of this crop in Brazil. Therefore, the Oat Breeding Program of the Federal University of Rio Grande do Sul (Universidade Federal do Rio Grande do Sul - UFRGS) aims to develop cultivars with wide adaptability, high grain yield, high milling yield, excellent agronomical traits such as the vegetative cycle (Nava et al. 2012), plant height, lodging tolerance, frost tolerance, and toxic aluminum tolerance (Nava et al. 2006), as well as with an adequate level of genetic resistance to the main crop diseases (Graichen et al. 2011, Zambonato et al. 2012).

BREEDING METHOD

The oat cultivar URS Brava was derived from a simple cross between the line UFRGS 995078-2 and the cultivar URS 21 cultivar. The genealogy of the line UFRGS 995078-2 is 'UFRGS 10 / PAUL', and the genealogy of the cultivar URS 21 is 'UFRGS 10 / CTC 84B993'. URS Brava and both of the parental genotypes were developed by the Oat Breeding Program of the Federal University of Rio Grande do Sul (UFRGS). The artificial hybridizations of the parental

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genotypes UFRGS 995078-2 and URS 21 were performed in 2001 at the Agronomy Experimental Station of the UFRGS, which is located in Eldorado do Sul, Rio Grande do Sul State, Brazil. The line UFRGS 995078-2 was used as the female parent and the cultivar URS 21 was used as the male parent according to the open flower method described by Bertagnolli and Federizzi (1994). Only one seed from the first filial generation (F_1) was obtained from this cross, and it was sown in the field in July 2002 under identification number 22a, which corresponded to the control number of the cross performed during the previous year. All of the F_1 plant panicles were collected and bulk-threshed to yield seeds for the second filial generation (F_2).

The segregating population obtained from the cross between UFRGS 995078-2 x URS 21 was advanced by the modified genealogical method during all of the generations of self-pollination and selection (from F_2 to F_6) at the Agronomy Experimental Station of the UFRGS. The main modifications of the method consisted of advancing the F_2 population in a semi-dense planting system and harvesting one panicle from each selected plant. In the 2003 growing season (June to November), the F_2 seeds were sown in six double rows (2.0 m long) in the field, with a spacing of 0.20 m between single rows and 0.40 m between double rows. During sowing, approximately 100 seeds were sown in each double row, representing a population of approximately 600 plants. The F_2 population was identified using the combination of numbers 032029, in which '03' represents the year 2003, '2' represents the F_2 generation and '029' represents the number of the evaluated population. From the F_2 generation, 22 panicles were selected in the field, threshed individually and evaluated in the laboratory for traits related to grain quality, such as filling, size, shape, uniformity and health. A total of 20 panicles were selected in the laboratory, yielding 20 $F_{2:3}$ families.

The $F_{2:3}$ families were sown in 2004 under the identification numbers 043023-1 to 043023-20. From the family 043023-2, four panicles were selected in the field, and two panicles were selected in the laboratory to yield the $F_{3:4}$ generation. The two $F_{3:4}$ families were sown in 2005 and identified as 054053-1 and 054053-2. From the 054053-2 family, 10 individual panicles were selected in the field, and five panicles were selected in the laboratory to yield the $F_{4:5}$ generation. The $F_{4:5}$ lines were sown in 2006 and identified as 065037-1 to 065037-5. From the 065037-4 family, seven individual panicles were selected in the field, and only three panicles were selected in the laboratory to yield the $F_{5:6}$ generation.

At the $F_{4:5}$ generation, abundant chlorosis and necrosis on the leaf laminae were observed around small pustules of crown rust on the 27 lines available for the population UFRGS 995078-2/ URS 21, belonging to nine different families. In addition, the presence of early telia on green leaf tissue was also observed. These signs had been previously observed in association with partial resistance to crown rust and were later confirmed in a study with the cultivar URS 21 and other oat genotypes showing partial resistance to crown rust (Graichen et al. 2011). Thus, the expectation was that the population under selection could have high levels of partial resistance to crown rust, the most destructive oat crop disease.

The three $F_{5:6}$ lines were sown in 2007 under the identification numbers 076053-1 to 076053-3. In this year and generation, the 076053-3 line was collected, bulk-threshed and coded as 'UFRGS 076053-3'. The new line was then tested in a preliminary yield trial, which was conducted at the Agronomy Experimental Station of the UFRGS in 2008, and compared with three check cultivars.

The UFRGS 076053-3 line was superior in the preliminary yield trial, and it surpassed the three check cultivars in grain yield and test weight. Thus, the line was promoted to the regional yield trial of oat lines, which was conducted by the Brazilian Oat Research Committee (Comissão Brasileira de Pesquisa de Aveia - CBPA), in 10 locations in the growing season of 2009. In this test, the UFRGS 076053-3 line showed a 5% higher average grain yield than the best check cultivar, which is the minimum required by the standards of the CBPA to move on for testing in the national yield trial of oat lines from the first and second years, which was conducted in 2010 and 2011 in nine locations for each test. In the three years of cooperative tests, the UFRGS 076053-3 line achieved sufficient agronomical merit according to the standards established by the CBPA to be released as a new cultivar, and it received the commercial name URS Brava. The name "Brava" was given because the word means to have or show courage and to have a lack of fear of dangerous or difficult situations. Thus, this name was selected because the cultivar showed high grain yield and stability over the years it was tested as a line and because it showed resistance to crown rust, caused by the fungus *Puccinia coronata* f. sp. *avenae*.

AGRONOMICAL PERFORMANCE

In the first year of the grain yield test, which was conducted for the preliminary yield trial in 2008, the UFRGS 076053-3 line was compared with the check cultivars URS 21, URS Guapa and Barbarasul. The best check in the trial was the cultivar URS 21, which had an average grain yield

of 3276 kg ha^{-1}. The UFRGS 076053-3 line had an average grain yield of 4065 kg ha^{-1}, corresponding to 124.1% of the best check. The UFRGS 076053-3 line also stood out with regard to its test weight (TW), which was 55.7 kg hL^{-1}, compared with the best check for this trait, which was also URS 21 and had a TW of 50.6 kg hL^{-1}, corresponding to a 110% increase of the best check.

The results for the grain yield, TW and thousand kernel weight (TKW) traits obtained for the UFRGS 076053-3 line and check cultivars evaluated in the regional yield trial of oat lines (2009) and the national yield trial of oat lines from the first and second years (2010 and 2011), as well as the number of locations where the experiments were conducted in each test are shown in Table 1. In the regional test, the UFRGS 076053-3 line was compared with the check cultivars URS 21, URS Guapa and Barbarasul in 10 experiments to determine the grain yield trait. These cultivars are representative of the oat crops in the states of Rio Grande do Sul, Paraná and São Paulo. The cultivar URS 21 was the best check, and it had an average grain yield of 2637 kg ha^{-1}, whereas the UFRGS 076053-3 line had an average grain yield of 2890 kg ha^{-1}, which corresponded to 109.6% of the best check. The cultivar URS 21 was the best check, and it had an average TW of 46.6 kg hL^{-1}, whereas the UFRGS 076053-3 line had an average TW of 51.7 kg hL^{-1}, which corresponded to 111% of the best check. The cultivar URS Guapa was the best check with regards to TKW, with an average value of 32.7 g, whereas the UFRGS 076053-3 line obtained an average TKW of 29.7 g, which is equivalent to 90.8% of the URS Guapa (Table 1). The results for grain yield described above indicate that the UFRGS 076053-3 line met the standards of the CBPA, in which lines that achieve a grain yield equal to or greater than 5% of the best check when averaged according to environments can be advanced to the next test stage (Federizzi et al. 2012).

In the national yield trial of oat lines from the first and second year, which was conducted in 2010, the UFRGS 076053-3 line was compared with the URS 21, URS Guapa and Barbarasul check cultivars in nine experiments for the grain yield trait. The cultivar Barbarasul was the best check and presented an average grain yield of 3465 kg ha^{-1}, whereas the line UFRGS 076053-3 had an average grain yield of 3438

Table 1. Grain yield, test weight, and thousand kernel weight of the line UFRGS 076053-2 and check cultivars evaluated in the regional yield trial of oat lines (2009) and in the national yield trial of oat lines from the first and second year (2010 and 2011)

Cultivar	**Grain yield** (kg ha^{-1})				
	2009	**2010**	**2011**	**BC annual**[†]	**BC$_{URS\ 21}$**[§]
URS 21	2637	3302	3891	98.4	100
URS Guapa	2320	2630		81.9	83.4
Barbarasul	2361	3465	3532	93.4	95.2
URS Taura			3667	94.2	94.2
UFRGS 076053-3	2890 (109.6)*	3438 (99.2)	3964 (101.9)	**103.6**	104.7
Number of locations	10	9	9	28	28
	Test weight (kg hL^{-1})				
URS 21	46.6	49.0	51.7	100	100
URS Guapa	40.7	42.3		86.8	86.8
Barbarasul	43	47.8	47.7	94.0	94.0
URS Taura			51.3	99.2	99.2
UFRGS 076053-3	51.7 (111.0)	52.2 (106.4)	55.1 (106.7)	**108.0**	**108.0**
Number of locations	9	9	10	28	28
	Thousand kernel weight (g)				
URS 21	29.0	28.9	31.3	93.9	100
URS Guapa	32.7	30.8		100	109.6
Barbarasul	27.4	28.7	28.5	89.1	94.9
URS Taura			31.6	100	101.1
UFRGS 076053-3	29.7 (90.8)	29.6 (96.0)	32.5 (102.9)	**96.6**	**102.8**
Number of locations	8	6	6	20	20

[†]Average relative to the best check cultivar, representing the best check within each year of yield test. [§]Average relative to the check cultivar URS 21, which was the best check for grain yield and test weight over the three test years of the new oat line UFRGS 076053-2. *Values shown in brackets for the line UFRGS 076053-2 demonstrate its cultivar performance when compared to the best check within the year of assessment and expressed as a percentage. The locations where the experiments were conducted in the regional yield trial, in 2009 included: Augusto Pestana, Eldorado do Sul, Passo Fundo, Pelotas, Vacaria, Guarapuava, Londrina, Mauá da Serra, Ponta Grossa and Capão Bonito. The locations where the experiments were conducted in the national yield trial of oat lines from the first year, in 2010 included: Augusto Pestana, Eldorado do Sul, Passo Fundo, Pelotas, Guarapuava, Londrina, Mauá da Serra, Ponta Grossa, Capão Bonito and São Carlos. In this year, the data obtained São Carlos were not used in calculating the overall grain yield average due to the high coefficient of variation. The locations where the experiments were conducted in the national yield trial of oat lines from the second year, in 2011 included: Augusto Pestana, Eldorado do Sul, Passo Fundo, Pelotas, Guarapuava, Londrina, Mauá da Serra, Pato Branco, Ponta Grossa and São Carlos. In this year, the data obtained in Pato Branco were not used in calculating the overall grain yield average due to the high coefficient of variation.

kg ha^{-1}. Although the grain yield of the UFRGS 076053-3 line was similar to that of the best check, it was smaller and therefore corresponded to 99.2% of the best check. For the test weight, URS 21 was the best check with a TW of 49 kg hL^{-1}, and UFRGS 076053-3 had a TW of 52.2 kg hL^{-1}, which corresponded to 106.4% of the best check. For the TKW, the cultivar URS Guapa was the best check and had a TKW of 30.8 g, and the line UFRGS 076053-3 line achieved a TKW of 29.6 g, which corresponded to 96% of the best check (Table 1).

In the national yield trial of oat lines from the second year, which was conducted in 2011, the grain yield of the UFRGS 076053-3 line was compared with those of the URS 21, Barbarasul and URS Taura check cultivars in nine experiments. The URS 21 cultivar was the best check and presented an average grain yield of 3891 kg ha^{-1}, whereas the UFRGS 076053-3 line had an average grain yield of 3964 kg ha^{-1}, which corresponded to 101.9% of the best check. For the test weight, the best check was URS 21, which had a TW of 51.7 kg hL^{-1}, whereas the UFRGS 076053-3 line obtained a TW of 55.1 kg hL^{-1}, which corresponded to 106.6% of the best check. The URS Taura cultivar was the best check with a TKW of 31.6 g, and the UFRGS 076053-3 line achieved a TKW of 32.5 g, which corresponded to 102.9% of the best check (Table 1).

Considering the three years of tests of the Value for Cultivation and Use (VCU), the UFRGS 076053-3 line was tested for grain yield in 28 experiments, and it achieved an average yield of 3431 kg ha^{-1}. Thus, the UFRGS 076053-3 line showed a 103.6% yield compared with that of the average of the best check cultivar from each year. When the line was compared with the best check averaged over time, which was URS 21, UFRGS 076053- 3 showed a 104.7% yield (Table 1). These results demonstrate the high adaptability and grain yield stability of the cultivar URS Brava cultivar over the years and across the environments it was tested.

The cycle of the line UFRGS 076053-3, which is expressed by the number of days from emergence to heading was 86, 77 and 87 days on average in 2009, 2010 and 2011, respectively, with an average of 83.5 days in the three test years. When the UFRGS 076053-3 line was compared with the check cultivar URS 21, the line showed a cycle delayed by approximately two days in annual averages. For the number of days from emergence to maturation, the UFRGS 076053-3 line showed a cycle delayed by one day compared with URS 21 (Table 2). These results show that the cycle of the UFRGS 076053-3 line is similar to that of the check cultivars evaluated during the testing period. For plant height, the UFRGS 076053-3 line was slightly higher

Table 2. Days from emergence to heading, days from emergence to maturation, and plant height of the UFRGS 076053-2 line and check cultivars, evaluated in the regional yield trial of oat lines (2009) and in the national yield trial of oat lines from the first and second year (2010 and 2011)

Cultivar	**Days from emergence to heading** (days)				
	2009	**2010**	**2011**	**BC annual**[†]	**BC$_{URS\ 21}$**[§]
URS 21	82.1	75.7	85.6	101.3	100
URS Guapa	80.6	75.3		100	98.8
Barbarasul	84.9	76.1	86.7	103.0	101.8
URS Taura			84.3	100	98.5
UFRGS 076053-3	86.4 (107.1)*	76.9 (102.1)	87.2 (103.4)	**104.2**	102.9
Number of locations	8	9	8	25	25
	Days from emergence to maturation (days)				
URS 21	121.5	117.8	124.0	100.9	100
URS Guapa	118.9	117.5		100	98.8
Barbarasul	125.6	118.4	125.5	102.6	101.7
URS Taura			123.8	100	99.8
UFRGS 076053-3	124.0 (104.2)	118.3 (100.6)	125.6 (101.5)	**102.1**	**101.3**
Number of locations	7	7	6	20	20
	Plant height (cm)				
URS 21	119.2	110.3	120.5	113.1	100
URS Guapa	111.0	100.5		100	92.1
Barbarasul	113.4	108.2	111.8	105.5	95.3
URS Taura			98.6	100	81.9
UFRGS 076053-3	128.4 (115.7)	111.5 (111.0)	122.7 (124.4)	**117.0**	**103.6**
Number of locations	9	10	9	28	28

[†]Average relative to the best check cultivar, representing the best check within each year of yield test. [§]Average relative to the check cultivar URS 21. *Values shown in brackets for the line UFRGS 076053-3 demonstrate its performance when compared to the best check within the year of assessment and expressed as a percentage. The trial locations in each test year were the same as described in Table 1.

than the tallest check cultivar URS 21 over the three test years (Table 2).

The grain yield stability of the URS Brava cultivar can be attributed mainly to its partial resistance to crown rust. Under the subtropical conditions of southern Brazil, crown rust is devastating, and a near total loss can be observed in crops that have not been treated with fungicide due to the loss of resistance to this disease. After its release, the cultivar URS Brava was tested in the national yield trial of oat cultivars with and without the application of fungicide, under the coordination of the CBPA. The data obtained in these tests in 2012 and 2013 for averages of grain yields and test weights are shown in Table 3, for the cultivars URS Brava (partially resistant to crown rust) and URS Fapa Slava (susceptible to crown rust). Greater grain yield stability was observed in the average values according to location and time for URS Brava compared with URS Fapa Slava. The average values for the 31 experiments showed that the grain yield for URS Brava without the application of fungicide suffered a reduction of only 12.7% compared with the yield following treatment with fungicide; however, an average loss of 57.4% was observed in the grain yield for URS Fapa Slava following treatment without fungicide (Table 3).

The higher grain yield stability without the application of fungicide for the URS Brava cultivar can also be observed based on the standard deviation from the averages of this trait in each experiment, which was approximately 43% of the observed averages, whereas URS Fapa Slava achieved standard deviations of approximately 82% of the averages. With the application of fungicide, both cultivars showed a standard deviation of grain yield corresponding to approximately 38% of the averages for this trait in the different experiments of the test of oat cultivars in 2012 and 2013 (Table 3).

The national yield trial of oat cultivars was conducted in 17 locations in southern Brazil, where the environmental conditions differed for the development of crown rust; thus, in certain locations, the grain yield did not show differences between the treatments with and without fungicide for any of the cultivars. However, in locations favorable to the development of crown rust, the reductions in grain yield were up to 89.4% for the susceptible cultivars, whereas for the URS Brava cultivar, a maximum reduction of 34.3% in grain yield was observed (Table 3).

Similarly, the average reductions in the test weight were only 2.9% for URS Brava and 20.4% for URS Fapa Slava for the 19 experiments conducted between 2012 and 2013, in 12 different locations in southern Brazil. In addition, reductions were not detected in the test weight of grains in certain locations without the application of fungicide, which is consistent with the results for grain yield. However, the maximum decrease in the test weight without the application of fungicide was 25% for URS Brava, whereas it was almost double that value for URS Fapa Slava (Table 3). The standard deviation of the average test weight values without fungicide for the different locations and test years

Table 3. Average values, standard deviation, minimum and maximum values of grain yield and test weight of the cultivars URS Brava and URS Fapa Slava, obtained in the national yield trial of oat cultivars in 2012 and 2013, in the states of Paraná, Rio Grande do Sul, Santa Catarina and São Paulo

Cultivar		Average	S.D.†	S.D./Average* (%)	Minimum	Maximum
	Grain yield – GY (kg ha^{-1})					
URS Brava§	GY without fungicide	4078	1753	43.0	1731	8251
	GY with fungicide	4673	1781	38.1	1651	8434
	GY loss without fungicide (%)	12.7	12.2		-5,7	34.3
URS Fapa Slava‡	GY without fungicide	1869	1537	82.2	256	5884
	GY with fungicide	4385	1698	38.7	1351	7790
	GY loss without fungicide (%)	57.4	24.3		4.9	89.4
Number of experiments = 31						
	Test weight – TW (kg 100 L^{-1})					
URS Brava	TW without fungicide	49.4	4.9	10.0	36.0	57.7
	TW with fungicide	50.8	3.7	7.3	45.1	58.0
	TW loss without fungicide (%)	2.9	8.1		-12.8	25.0
URS Fapa Slava	TW without fungicide	36.1	7.5	20.7	24.0	49.4
	TW with fungicide	45.4	5.2	11.5	34.3	56.2
	TW loss without fungicide (%)	20.4	15.8		-3.3	47.2
Number of experiments = 19						

†Standard deviation of the average values obtained in the different experiments.
*Standard deviation of the average values in comparison to the overall average, in percentage.
§ URS Brava: partially resistant to crown rust.
‡ URS Fapa Slava = susceptible to crown rust.

showed a similar pattern to that observed for the grain yield compared with the overall test weight average. The test weight trait value for the cultivar susceptible to crown rust (URS Fapa Slava) was approximately 20% compared with 10% for URS Brava (Table 3).

After the commercial release, the cultivar URS Brava was registered in the Ministry of Agriculture, Livestock and Supply (Ministério da Agricultura, Pecuária e Abastecimento - MAPA) under number 32338, and a protection certificate was issued by the National Service for Cultivar Protection (Serviço Nacional de Proteção de Cultivares) under number 20140186 on December 19, 2014. The production and distribution of seeds from the URS Brava cultivar followed the flowchart used by the Oat Breeding Program of the Federal University of Rio Grande do Sul (UFRGS) as described by Federizzi et al. (2012).

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