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Genetic progress in sunflower crop in Rio Grande do Sul State, Brazil

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ABSTRACT. The sunflower has adaptability to growing regions with different climatic and soil characteristics, showing drought tolerance and high-quality oil production. The State of Rio Grande do Sul is the third largest sunflower producer in Brazil, with research related to the sunflower breeding initiated after the decade of 1950. The aim of this study was to evaluate the genetic progress for grain yield, oil content, and oil yield of sunflower (*Helianthus annuus* L.) in the State of Rio Grande do Sul. Data of grain yield, oil content, and oil yield obtained from 58 sunflower cultivar yield trials in 19 municipalities in Rio Grande do Sul during the period from 2005 to 2014 were used. Genetic progress was studied according to the methodology proposed by Vencovsky and data from sunflower cultivar yield trials were used. Annual genetic progress of sunflower during the period of 10 years (2005-2014) was 132.46 $kg \cdot ha^{-1} \cdot year^{-1}$ for grain yield, -0.17%/year for oil content, and 48.11 $kg \cdot ha^{-1} \cdot year^{-1}$ for oil yield. The sunflower-breeding programs in the State of Rio Grande do Sul were efficient for

the traits grain yield and oil yield and presented no efficiency for oil content.

Key words: *Helianthus annuus* L.; Genetic breeding; Grain yield; Oil content; Oil yield

INTRODUCTION

The sunflower is an oleaginous plant with great importance worldwide, producing oil with excellent quality. Sunflower genetic breeding in Brazil has initial records in 1932 in São Paulo and from the decade of 1950 in Rio Grande do Sul. Among the highlighted characteristics, it has wide adaptability, drought tolerance, and excellent expansion perspectives in Brazil, arousing the interest of public and private companies in the development of breeding programs with the crop (Castiglioni and Oliveira, 2005).

Sunflower cultivation concentrates mostly in the Central-Southern region of Brazil. The Brazilian production in the 2012/2013 agricultural year was 108,100 ton in 68,700 hectares of growing area. The State of Rio Grande do Sul is the third largest producer in Brazil, with production of 4000 ton in 2700 hectares of growing area (CONAB, 2013).

The main sunflower product commercialized is its oil intended for human consumption and used as biofuel. Studies and selections to increase the oil content of sunflower achenes were initially developed in Russia, where Pustovoit developed an efficient method for genotype selection in breeding programs. It allowed the selection of genotypes with oil content higher than 50% and the method became known worldwide as the method of reserves (Castiglioni and Oliveira, 2005).

Current studies that assess the performance of sunflower cultivars prioritize oil yield in addition to grain yield (Porto et al., 2008; Thomaz et al., 2012, Schwerz et al., 2015; Dalchiavon et al., 2016) and oil content (Schwerz et al., 2015; Dalchiavon et al., 2016). It demonstrates the interest in genotypes with high grain yield and oil yield associated with a high oil content, which provides better industrial performance for its extraction.

The efficiency of plant-breeding programs in providing genotypes with greater yield potential can be assessed by studying the genetic progress (Borges et al., 2009). Among the possibilities of evaluating the genetic progress, the method developed by Vencovsky et al. (1988) presents an advantage of using trials that have been performed on cultivar yield trial networks, besides the advantage of measuring genotypes in the closest possible growing conditions performed by farmers due to carrying out trials on a large number of locations. Another advantage that can be attributed to this methodology is the cost reduction (Faria et al., 2007) because the installation of a particular experiment is not necessary to perform the study (Toledo et al., 1990).

Studies regarding the breeding program efficiency with sunflower can be found in Argentina, indicating genetic progress of grain yield (Pereira et al., 1999), grain yield, oil content, and oil yield (de la Vega et al., 2007), and oil yield (de la Vega, 2012). Also in South Africa, studies of grain yield, oil content, and oil yield (Chigeza et al., 2012). It is assumed that for the State of Rio Grande do Sul, there was genetic progress for sunflower grain yield, oil content, and oil yield during the period of 2005 to 2014.

Thus, the aim of this study was to evaluate the genetic progress for grain yield, oil content, and oil yield of sunflower (*Helianthus annuus* L.) in the State of Rio Grande do Sul.

MATERIAL AND METHODS

Data of grain yield (GY, in kg/ha), oil content (OC, in %), and oil yield (OY, in kg/ha) of 58 trials belonging to the sunflower (*H. annuus* L.) genotype yield trial network were used. Trials were performed in 19 municipalities of Rio Grande do Sul during the period of 2005 to 2014 (Figure 1). Data were obtained from the Reports of the sunflower genotype assessments published annually by the Brazilian Agricultural Research Corporation (EMBRAPA) (Table 1).

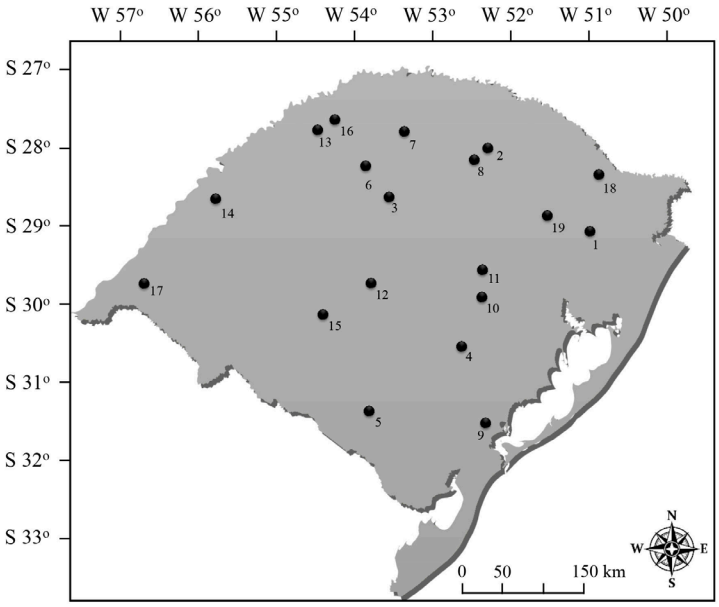

Figure 1. Geographical representation of the 19 locations of cultivar trials of the Official Sunflower Yield Trial Network in Rio Grande do Sul during the period of 2005 to 2014. 1 = Caxias do Sul; 2 = Coxilha; 3 = Cruz Alta; 4 = Encruzilhada do Sul; 5 = Hulha Negra; 6 = Ijuí; 7 = Palmeira das Missões; 8 = Passo Fundo; 9 = Pelotas; 10 = Rio Pardo; 11 = Santa Cruz do Sul; 12 = Santa Maria; 13 = Santa Rosa; 14 = São Borja; 15 = São Gabriel; 16 = Três de Maio; 17 = Uruguaiana; 18 = Vacaria; 19 = Veranópolis.

Table 1. List of documents published annually by the Brazilian Agricultural Research Corporation (EMBRAPA) in partnership with public and private institutions regarding the sunflower (*Helianthus annuus* L.) cultivar yield trial network during the period of 2005 to 2014 in the State of Rio Grande do Sul, Brazil.

Year	Document	Authors	Initial and final pages	Number of trials
2005/2006 and 2006	Document 285 - Reports of the sunflower genotype assessment, 2007. 120p.	Carvalho et al. (2007)	20-21; 22-23; 24-25; 35-36; 37-38; 39-40	6
2006/2007 and 2007	Document 295 - Reports of the sunflower genotype assessment, 2008. 108p.	Carvalho et al. (2008)	21-22; 23-24; 25-26; 27-28; 36-37; 38-39; 40-41; 42-43; 44-45; 46-47; 48-49	11
2007/2008 and 2008	Document 316 - Reports of the sunflower genotype assessment, 2009.106p.	Carvalho et al. (2009a)	19-20; 20-21; 33-34; 35-36	4
2008/2009 and 2009	Document 320 - Reports of the sunflower genotype assessment, 2009. 122p.	Carvalho et al. (2009b)	22-23; 24-25; 26-27; 47-48; 49-50; 51-52; 53-54; 56-58	8
2009/2010 and 2010	Document 326 - Reports of the sunflower genotype assessment, 2011. 108p.	Carvalho et al. (2011a)	21-22; 23-24; 25-26; 27-28; 42-43; 44-45; 46-47; 48-49	8
2010/2011 and 2011	Document 329 - Reports of the sunflower genotype assessment, 2011. 98p.	Carvalho et al. (2011b)	21-22; 23-24; 35-36; 37-38; 39-40	5
2011/2012 and 2012	Document 340 - Reports of the sunflower genotype assessment, 2013. 104p.	Carvalho et al. (2013)	22-23; 24-25; 26-27; 28-29; 39-40; 41-42; 43-44; 45-46	8
2012/2013 and 2013	Document 355 - Reports of the sunflower genotype assessment, 2014. 105p.	Carvalho et al. (2014)	22-23; 39-40; 41-42; 43-44	4
2013/2014 and 2014	Document 360 - Reports of the sunflower genotype assessment, 2015. 104p.	Carvalho et al. (2015a)	24-25; 42-43	2
2014/2015 and 2015	Document 367 - Reports of the sunflower genotype assessment, 2016. 106p.	Carvalho et al. (2015b)	24-25; 38-39	2

All trials were carried out using the randomized block design arranged with four replications. The experimental units consisted of four rows with 6 m long and spacing 0.80 m. Plot area was 19.2 m^2 with useful area of 8.0 m^2.

The calculation of genetic progress was performed for the State of Rio Grande do Sul with the results obtained from cultivar trials performed in the municipalities of Caxias do Sul, Coxilha, Cruz Alta, Encruzilhada do Sul, Hulha Negra, Ijuí, Palmeira das Missões, Passo Fundo, Pelotas, Rio Pardo, Santa Cruz do Sul, Santa Maria, Santa Rosa, São Borja, São Gabriel, Três de Maio, Uruguaiana, Vacaria, and Veranópolis (Table 2).

Table 2. Number of trials in each location and year and totals per trial and per year, carried out in the network of sunflower (*Helianthus annuus* L.) cultivar trials from 2005 to 2014 in Rio Grande do Sul, Brazil and total number of sunflower cultivars assessed in each year.

Locations	Years										Total
	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	
Caxias do Sul	-	-	-	-	-	-	1	-	-	-	1
Coxilha	-	-	-	-	-	1	-	-	-	-	1
Cruz Alta	1	-	-	-	-	-	-	-	-	-	1
Encruzilhada do Sul	-	1	1	-	1	-	1	-	-	-	4
Hulha Negra	-	-	-	-	-	-	1	-	-	-	1
Ijuí	2	-	-	1	-	-	-	-	-	-	3
Palmeira das Missões	-	1	-	-	-	-	-	-	-	-	1
Passo Fundo	2	2	-	1	1	-	1	1	1	1	10
Pelotas	-	-	-	-	-	1	-	-	-	-	1
Rio Pardo	-	-	-	1	-	1	1	1	-	-	4
Santa Cruz do Sul	-	1	1	-	-	-	-	-	-	-	2
Santa Maria	-	1	-	-	-	-	-	-	-	-	1
Santa Rosa	-	1	-	1	1	-	-	-	-	-	3
São Borja	-	1	-	1	1	-	-	1	-	-	4
São Gabriel	-	1	1	-	-	-	1	-	-	-	3
Três de Maio	1	-	1	1	1	1	-	1	1	1	8
Uruguaiana	-	-	-	-	1	-	-	-	-	-	1
Vacaria	-	1	-	1	1	1	1	-	-	-	5
Veranópolis	-	1	-	1	1	-	1	-	-	-	4
Total of trials	6	11	4	8	8	5	8	4	2	2	58
Total of cultivars in each year	26	40	42	34	31	28	25	28	28	17	173

(-) Absence of trial.

Trials were designed to generate information for recommendation of cultivars with better performance on exposure to different growing environments. Cultivars with unsatisfactory performance were discarded and replaced by others, supposedly with greater yield potential. Cultivars that exhibited proper performance were maintained for evaluation in the following year.

The methodology proposed by Vencovsky et al. (1988) was used in order to study the genetic progress. This methodology is based on the data generated in the regional cultivar trials. Moreover, it is intended to obtain genetic gain estimates, being the genetic progress balance performed by the method of generalized least squares (Cruz, 2001).

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

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

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

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

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

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

Following, genetic gain was estimated in every 2 years, with the linear regression model proposed by Vencovsky et al. (1988), consisting of:

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

where $\hat{G}g$ = Estimate of genetic gain; $\bar{y}1$ = Overall mean of cultivars in the trial of year 1; $\bar{y}2$ = Overall mean of cultivars in the trial of year 2; $\bar{y}c1$= Overall mean of common cultivars in the trial of year 1; $\bar{y}c2$= Overall mean of common cultivars in the trial of year 2.

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

Subsequently, the genetic progress balance was determined by the method of generalized least squares, as described in Cruz (2001). Genetic gain mean of the period $(\mu\hat{G}g)$ (was obtained in kg ha^{-1} year^{-1} for GY and OY, and in %/year for OC. Then, the percentage of annual genetic progress was calculated by the formula:

$$\frac{\mu\hat{G}g}{\bar{y}1} * 100 \quad \text{(Equation 6)}$$

For statistical analysis, the Microsoft Office Excel application and Genes software (Cruz, 2013) were used.

RESULTS AND DISCUSSION

Of the 58 sunflower cultivar assessment trials carried out during the period of 10 years (2005-2014) in the State of Rio Grande do Sul, 173 genotypes were assessed (Table 2). The year with the highest number of assessed genotypes was 2007 with 42 genotypes and the year of 2014 was the year with lower number of genotypes, presenting 17 genotypes.

Means of inclusion (33.4%), deletion (37.33%), and maintenance (29.23%) rates of cultivars during the period from 2005 to 2014 were relatively lower than the renewal rate (52.79%) (Table 3). The renewal rate of cultivars was high compared to the values found in genetic progress studies in wheat with 33% (Cargnin et al., 2008) and 29% with rice (DoVale et al., 2012). These results demonstrate that the sunflower-breeding program is dynamic, with constant investments in research for the release of new cultivars.

Table 3. Rates of inclusion, deletion, maintenance, and renewal of cultivars assessed in the sunflower cultivar trial network during the period of 2005 to 2014 in Rio Grande do Sul, Brazil.

Bienniums	Inclusion (%)	Deletion (%)	Maintenance (%)	Renewal (%)
2006-2005	55.17	31.03	13.79	80.00
2007-2006	36.51	33.33	30.16	54.76
2008-2007	33.33	46.03	20.63	61.76
2009-2008	34.62	40.38	25.00	58.06
2010-2009	31.11	37.78	31.11	50.00
2011-2010	30.00	37.50	32.50	48.00
2012-2011	41.86	34.88	23.26	64.29
2013-2012	31.71	31.71	36.59	46.43
2014-2013	6.67	43.33	50.00	11.76
Mean of nine bienniums	33.44	37.33	29.23	52.79

Considering all locations and years, the overall mean for GY was 2075.57 kg/ha, 43.24% for OC and 897.71 kg/ha for OY (Table 4). The year with the lowest GY mean was 2005 with 1543.65 kg/ha. Meanwhile, the year with greater GY was 2010 with 2775.86 kg/ha. These values demonstrate crop yield increase in the State of Rio Grande do Sul, possibly by the release of new cultivars and improvements related to crop management. Globally, the expansion and establishment of sunflower occurred with the introduction of new cultivars, where they contributed with the increase of 60% in GY (Castiglioni and Oliveira, 2005).

Table 4. Means of grain yield, oil content, and oil yield of cultivars assessed in the sunflower (*Helianthus annuus* L.) cultivar trial network during the period of 2005 to 2014 in the State of Rio Grande do Sul, Brazil.

Year	Grain yield (kg/ha)	Oil content (%)	Oil yield (kg/ha)
2005	1543.65	43.83	674.66
2006	2113.69	43.76	921.92
2007	2136.74	41.85	897.24
2008	1723.66	43.62	750.16
2009	1765.48	43.79	772.55
2010	2775.86	42.46	1185.99
2011	2150.70	43.84	948.10
2012	1874.12	42.25	792.20
2013	2358.88	42.68	1007.76
2014	2312.88	44.31	1026.49
Mean of the period	2075.57	43.24	897.71

The genetic progress of sunflower cultivars in the State of Rio Grande do Sul during the period from 2005 to 2014 was 132.46 kg·ha^{-1}·year^{-1} (8.58% per year) for GY, -0.17%/year (-0.38% per year) for OC, and 48.11 kg·ha^{-1}·year^{-1} (7.13% per year) for OY (Table 5). Thus, it can be inferred that the breeding programs were efficient in releasing cultivars for GY and OY traits and the breeding programs demonstrated no efficiency for the OC trait.

Studies on the genetic progress for GY with sunflower were reported in Argentina, with genetic progress of 49 kg ha^{-1} year^{-1} (Pereira et al., 1999), 11.9 kg·ha^{-1}·year^{-1} (de la Vega et al., 2007), and in South Africa with 24 kg·ha^{-1}·year^{-1} (Chigeza et al., 2012). Genetic progress for OC of 0.19%/year (de la Vega et al., 2007) and 0.12%/year (Chigeza et al., 2012) was also found. Genetic progress for OY of 16.1 kg·ha^{-1}·year^{-1} (de la Vega et al., 2007), of 12 kg·ha^{-1}·year^{-1} (Chigeza et al., 2012), and of 6.22 to 10.54 kg·ha^{-1}·year^{-1} (de la Vega, 2012) was found by growing regions.

The genetic progress of sunflower for the State of Rio Grande do Sul was greater for GY than the studies found in the literature (Pereira et al., 1999; de la Vega et al., 2007; Chigeza et al., 2012). Moreover, it was also greater for OY than other studies (de la Vega et al.,

Table 5. Annual genetic progress and percentage of annual genetic progress for grain yield, oil content, and oil yield of sunflower cultivars (*Helianthus annuus* L.) of the State of Rio Grande do Sul during the period of 2005 to 2014.

Bienniums	Grain yield (kg/ha)	Oil content (%)	Oil yield (kg/ha)
	Annual genetic progress		
2006-2005	-156.19	-1.09	-98.12
2007-2006	658.50	-0.40	261.86
2008-2007	385.60	0.92	163.76
2009-2008	74.11	0.08	33.11
2010-2009	168.24	1.12	116.83
2011-2010	157.75	1.61	105.41
2012-2011	-74.33	-1.43	-57.81
2013-2012	-304.64	-0.59	-144.25
2014-2013	-225.76	-0.48	-104.19
	Balance of the annual genetic progress		
Genetic gain per year	132.46	-0.17	48.11
Genetic gain in %/year	8.58	-0.38	7.13

2007; Chigeza et al., 2012; de la Vega, 2012). However, genetic progress for OC was below those found in other countries (de la Vega et al., 2007; Chigeza et al., 2012). One explanation for this can be the elevated OC levels present in Brazilian genotypes (mean of 43.24% in studies performed from 2005 to 2014 in Rio Grande do Sul), hindering selection for release of cultivars with higher oil levels.

The OY is the trait with greater economic interest in sunflower and its increase has being achieved in sunflower with increasing GY. Regarding GY in other crops, recent studies indicated genetic progress of 0.92%/year for wheat in Brazil (Beche et al., 2014), 1%/year for wheat in China (Wu et al., 2014), 0.67%/year for rice in Brazil (Breseghello et al., 2011), and 1.1%/year for soybean in Argentina (Felipe et al., 2016).

The genetic progress for sunflower was greater than in other crops, which can be justified by the sunflower allogamous reproductive system, enabling high genetic information exchange with different sources of germplasm during the initial phase of breeding, expanding its genetic basis. Furthermore, it can be used to produce open population cultivars or genetic basis for the formation of inbreed lines, which are benefiting from the hybrid vigor resulting from the heterosis present in hybrid sunflower cultivars.

CONCLUSION

Annual genetic progress of sunflower during the period of 10 years (2005-2014) was 132.46 $kg \cdot ha^{-1} \cdot year^{-1}$ for grain yield, -0.17%/year for oil content, and 48.11 $kg \cdot ha^{-1} \cdot year^{-1}$ for oil yield. The sunflower-breeding programs in the State of Rio Grande do Sul were efficient for the traits grain yield and oil yield and presented no efficiency for oil content.

Conflicts of interest

The authors declare no conflict of interest.

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