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CROP PRODUCTION

Linear relationships in sunflower genotypes in the state of Rio Grande do Sul, Brazil

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ABSTRACT: The state of Rio Grande do Sul (RS) is the third largest sunflower producer in Brazil. This study verified the existence of linear relationships between grain yield, oil content, and oil yield in sunflower (*Helianthus annuus* L.) genotypes evaluated in RS. The data on grain yield (GY), oil content (OC), and oil yield (OY) were obtained from 73 sunflower cultivar trials in 21 municipalities in RS from 1999 to 2018. Scatter diagrams were createdto investigate the relationships between the variables GY, OC, and OY. Then, Pearson's linear correlation coefficient (r) was calculated between the variables, and the Student's t-test was performed at a 5% significance level. There is a positive and significant linear relationship between PG and OY. However, no linear relationship was found between grain yield and oil content in sunflower genotypes. Additionally, a positive linear association of high magnitude (r = 0.9672) was observed between grain yield and oil yield, while a low magnitude (r = 0.2245) was found between oil content and oil yield.
Key words: *Helianthus annuus* L., grain yield, oil content, oil yield, correlation.

Relações lineares em genótipos de girassol no estado do Rio Grande do Sul, Brasil

RESUMO: O estado do Rio Grande do Sul (RS) é o terceiro maior produtor de girassol do Brasil. O objetivo deste trabalho foi verificar se há relações lineares entre a produtividade de grãos, teor de óleo e produtividade de óleo em genótipos de girassol (*Helianthus annuus* L.), avaliados no RS. Foram utilizados os dados de produtividade de grãos (PG), teor de óleo (TO) e produtividade de óleo (PO), obtidos em 73 ensaios de competição de cultivares de girassol em 21 municípios do RS, no período de 1999 a 2018. Para investigar as relações entre as variáveis PG, TO e PO foram construídos diagramas de dispersão. Depois, foi calculado o coeficiente de correlação linear de Pearson (r) entre as variáveis e realizado o teste t de Student, a 5% de significância. Há relação linear positiva e significativa entre PG e PO. Não há relação linear entre produtividade de grãos e teor de óleo em genótipos de girassol. Há associação linear positiva de alta magnitude (r = 0,9672) entre a produtividade de grãos e de óleo e de baixa magnitude (r = 0,2245) entre teor e produtividade de óleo.
Palavras-chave: *Helianthus annuus* L., produtividade de grãos, teor de óleo, produtividade de óleo, correlação.

INTRODUCTION

Sunflower (*Helianthus annuus* L.) is an oilseed plant of global importance. The oil produced from achenes is one of the main vegetable oils used in the human diet due to its nutritional quality. The average Brazilian sunflower grain yield in the 2020/2021 and 2021/2022 crop seasons was 1143 kg ha^{-1} and 1042 kg ha^{-1}, respectively (CONAB, 2022). This productivity can be considered low compared to other sunflower-producing countries (SOARES et al., 2019). Sunflower cultivation in Brazil is concentrated in the South, Southeast, and Midwest regions. Rio Grande do Sul is the third-largest producing state, with production of 4.7 thousand tons (CONAB, 2023).

Sunflower grain yield can be influenced by several factors, notably climate conditions, phytosanitary and soil management, and cultivars (NOBRE et al., 2015; HIOLANDA et al., 2018). The adoption of cultivars with better adaptability to the productive environment provides an increase in the crop's grain yield (BIRCK et al., 2017; DALCHIAVON et al., 2016). To this end, experiments with new hybrids, developed each year, need to be conducted to identify the most adapted genotypes and verify how these hybrids respond together in productive terms, aiming for new progress in the genetic improvement of the species (OLIVEIRA et al., 2017).

Trial networks play an important role in the positioning of cultivars. Current studies focused

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on evaluating the performance of sunflower cultivars have prioritized not only grain yield and oil yield (THOMAZ et al., 2012; SCHWERZ et al., 2015; DALCHIAVON et al., 2016) but also oil content (SCHWERZ et al., 2015; DALCHIAVON et al., 2016). It can be important when choosing cultivars, as grain yield is a multigenic trait, and factors such as lack of water availability, associated with the vegetative cycle, can be essential for grain yield.

Increasing the sunflower seed oil content, as well as improving its quality, making it compatible with industrial demands, is an important objective of the genetic improvement of the crop (RAUF et al., 2017). There is evidence of interest in genotypes with high grain and oil yield, associated with a high oil content that provides better industrial efficiency for its extraction.

However, when considering various environments under study, there is a probability of different productive responses of grains and oil due to the interaction between genotype and environment, requiring the continuous evaluation of new materials in different cultivation systems and producing regions (VALADÃO et al., 2020). Studies on linear relationships in sunflower cultivation have been conducted by authors such as AMORIM et al. (2008), DALCHIAVON et al. (2016), and HLADNI et al. (2016). The presence or absence of correlations between these traits can contribute to the right choice of the observed characteristics to improve the efficiency of sunflower genotype selection criteria (RADIC, 2021). Therefore, knowledge of the relationships between traits is of paramount importance for plant improvement studies in sunflower cultivation (NOBRE et al., 2018).

In this context, this study verified whether there are linear relationships between grain yield, oil content, and oil yield in sunflower (*Helianthus annuus* L.) genotypes evaluated in the state of Rio Grande do Sul, Brazil.

MATERIALS AND METHODS

Data on grain yield (GY, in kg ha^{-1}), oil content (OC, in %), and oil yield (OY, in kg ha^{-1}) from 281 sunflower (*Helianthus annuus* L.) genotypes were used in 73 trials from the evaluation testing network (Table 1). The trials were conducted in 21 locations in the state of Rio Grande do Sul from 1999 to 2018 (Table 1 and Figure 1).

The data were obtained from reports on the evaluation of sunflower genotypes published annually by the Brazilian Agricultural Research Corporation (EMBRAPA) (Table 2). The reports are published annually and result from the cooperation of universities and research institutions, which collaborate with the national sunflower testing network (CARVALHO et al., 2022).

All trials were conducted in a randomized block design, with four replications. The experimental units consisted of four rows spaced 0.5 m wide and 6.0 m long. The area of the plots was 12.0 m^2, with a useful area of 5.0 m^2.

Minimum, percentiles 1, 2.5, 25, 50 (median), 75, 97.5, and 99, maximum, range, mean, variance, standard deviation, standard error, coefficients of variation, skewness, kurtosis, and P-value of the Kolmogorov-Smirnov normality test were calculated for the three variables (GY, OC, and OY) evaluated in all genotypes of the 73 trials (1,137 observations). The means of GY, OC, and OY were also calculated per agricultural year regardless of the location and per location regardless of the agricultural year.

Scatter diagrams were created to investigate the relationships between the variables GY, OC, and OY. Subsequently, Pearson's linear correlation coefficient (r) was calculated between the variables and Student's t-test was performed at a 5% significance.

Statistical analyses were conducted using the Microsoft Office Excel® and Genes applications (CRUZ, 2016).

RESULTS AND DISCUSSION

The minimum and maximum values of GY, OC, and OY of the genotypes evaluated in the 73 trials ranged from 375.90 to 4484.00 kg ha^{-1}, 20.34 to 53.42%, and 160.11 to 1913.76 kg ha^{-1}, respectively (Table 3). CV ranged from 8.37 to 34.92%, with the highest CV observed in GY and OY. Similarly, LIRA et al. (2017) and DALCHIAVON et al. (2016) found higher variation in GY and OY and lower variation in OC.

The mean of the variables was similar to the median, and the coefficient of skewness was close to zero ($-0.67 \leq$ skewness ≤ 0.39). The coefficient of kurtosis for GY and OY was −0.22 and 0.02, respectively, indicating a mesokurtic distribution, while OC presented a leptokurtic distribution. The Kolmogorov-Smirnov test indicated adherence of data for all variables to a normal distribution (P-value ≥ 0.05). Therefore, the statistical results showed that the data is representative of the study of linear relationships.

Table 1 - Number of trials in each location and year and total trials per location and year conducted in the sunflower (*Helianthus annuus* L.) genotype testing network from 1999 to 2018 in the state of Rio Grande do Sul, Brazil. Number of genotypes evaluated each year.

Location	1999/2000	2000/2001	2001/2002	2002/2003	2003/2004	2004/2005	2005/2006	2006/2007	2007/2008	2008/2009	2009/2010	2010/2011	2011/2012	2012/2013	2013/2014	2014/2015	2015/2016	2016/2017	2017/2018	2018/2019	Total
Bom Progresso	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	1
Caxias do Sul	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	1
Coxilha	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-		1	1	-	-	3
Cruz Alta	-	-		1		1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	3
Encruzilhada do Sul	-	-	-	-	-	-	-	1	-	-	1	-	1	-	-	-	-	-	-	-	3
Hulha Negra	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	1
Ibirubá	-	-	-	-	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2
Ijuí	-	1	1	-	-	1	2	-	-	1	-	-	-	-	-	-	-	-	-	-	6
Palmeiras das Missões	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	1
Passo Fundo	1	1	-	1	-	-	1	2	-	1	1	-	1	1	1	1	-	-	-	-	12
Pelotas	-	-	-	-	-	-	-	-	-	-	-	1		-	-	-	-	-	-	-	1
Rio Pardo	-	-	-	-	-	-	-	-	-	1	-	1	1	1	-	-	-	-	-	-	4
Santa Cruz do Sul	-	-	-	-	-	-	-	1	1	-	-	-	-	-	-	-	-	-	-	-	2
Santa Maria	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	1	1	3
Santa Rosa	-	-	-	-	-	-	-	1	-	1	1	-	-	-	-	-	-	-	-	-	3
São Borja	-	-	-	-	-	-	-	1	-	1	1	-	-	1	-	-	-	-	-	-	4
São Gabriel	-	-	-	-	-	-	-	1	-	-	-	-	1	-	-	-	-	-	-	-	2
Três de Maio	-	-	-	1	1	1	1	-	1	1	1	1	-	-	1	1	1	1	1	1	14
Uruguaiana	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	1
Vacaria	-	-	-	-	-	-	-	-	-	-	1	1	1	-	-	-	-	-	-	-	3
Veranópolis	-	-	-	-	-	-	-	1	-	-	1	-	1	-	-	-	-	-	-	-	3
Total trials	1	2	1	3	2	4	5	10	2	6	8	5	8	3	2	2	2	3	2	2	73
Total genotypes in the year	24	24	19	22	13	10	26	40	42	34	31	28	25	23	28	17	18	17	15	14	281

- absence oftrial.

The mean GY and OY in the 20 agricultural years ranged from 1450.02 to 2798.49 kg ha^{-1} and 623.18 to 1205.13 kg ha^{-1}, respectively (Table 4). The lowest means for these variables were observed in 2010/2011, while the highest means were observed in 2003/2004 (Table 4). It indicates that higher GY means are related to higher OY. OC presented higher mean magnitudes in 2000/2001 (46.12%), with smaller variations between the means, with the lowest performance observed in 2001/2002 (37.46%). The results of GY, OC, and OY are consistent with values observed in other studies with sunflower cultivation (DALCHIAVON et al., 2016; CARVALHO et al., 2015).

The overall means of GY, OC, and OY of the sunflower genotypes in the 20 years of trials was 2030.24 kg ha^{-1}, 42.91%, and 870.83kg ha^{-1}, respectively. According to CONAB (2023), the national mean of sunflower grain yield in the 2022/2023 crop season was 1436 kg ha^{-1}. Therefore, the overall mean of GY in the study was higher than the national mean. The evaluated variables showed means with a low variation in the last six years of testing. Furthermore, GY means were higher than 2000 kg ha^{-1} in this same period. It indicated higher stability and potential of the new genotypes and higher efficiency in the used management.

The highest means of GY were observed in Pelotas and Palmeira das Missões (Table 5), which presented values above 3000 kg ha^{-1}, followed by Caxias do Sul, which hada mean of 2859.25 kg ha^{-1}. These values are higher than those found by DALCHIAVON et al. (2016), who obtained maximum yields of 2259 kg ha^{-1} in experiments with 16 cultivars and 10 experimental locations.

The oil content, with the same magnitude of importance for sunflower cultivation, had a similar response: the highest means were verified in Pelotas,

Figure 1 - Geographic representation of 21 locations where the sunflower genotype testing network was conducted from 1999 to 2018in the state of Rio Grande do Sul, Brazil.

Encruzilhada do Sul, and Caxias do Sul, with values of 46.40, 45.61, and 44.15%, respectively. These values are higher than the mean values (43.6%) found by DALCHIAVON et al. (2016) and GRUNVALD et al. (2014). Therefore, among the locations with higher grain yield and oil content, only the experimental sites of Palmeira das Missões and Encruzilhada do Sul showed changes.

Moreover, Pelotas and Caxias do Sul presented the highest oil yield, followed by Palmeira das Missões, with values of 1475.93, 1263.80, and 1257.22 kg ha^{-1}, respectively. DALCHIAVON et al. (2016) observed higher values, with a maximum yield of 1012 kg ha^{-1}.

It is justified by the fact that these locations have high sunflower grain yield values and high oil contents than other experimental locations. However, almost all the mentioned locations had experiments in only one growing season, except for Encruzilhada do Sul, where three years of experiments were carried out.

Thus, Pelotas and Caxias do Sul have considerable production potential for sunflower grains, while Encruzilhada do Sul has a high potential

Table 2 - List of documents published annually by the Brazilian Agricultural Research Corporation (EMBRAPA) in partnership with public and private institutions, referring to the sunflower (*Helianthus annuus* L.) genotype testing network from 1999 to 2018 in the state of Rio Grande do Sul, Brazil.

Agricultural year	Document	Authors	Home and end pages	Number of trials
1999/2000	Doc. 137 – Informes da avaliação de genótipos de girassol, 1998/1999 e 1999. 99p.	Oliveira & Leite (1999)	30-31	1
2000/2001	Doc. 174 – Informes da avaliação de genótipos de girassol, 2000/2001 e 2001. 100p.	Oliveira et al. (2001)	25-26; 44-45	2
2001/2002	Doc. 205 – Informes da avaliação de genótipos de girassol, 2001/2002 e 2002. 88p.	Oliveira et al. (2003)	32-33	1
2002/2003	Doc. 226 – Informes da avaliação de genótipos de girassol, 2002/2003 e 2003. 97p.	Carvalho et al. (2003)	23-24; 38-39; 40-41	3
2003/2004	Doc. 250 – Informes da avaliação de genótipos de girassol, 2003/2004 e 2004. 91p.	Carvalho et al. (2004)	21-22; 25-26	2
2004/2005	Doc. 271 – Informes da avaliação de genótipos de girassol, 2004/2005 e 2005. 121p.	Carvalho et al. (2006)	20-21; 22-23; 24-25; 26-27	4
2005/2006	Doc. 285 – Informes da avaliação de genótipos de girassol, 2005/2006 e 2006. 120p.	Carvalho et al. (2007)	20-21; 22-23; 24-25; 35-36; 37-38	5
2006/2007	Doc. 295 – Informes da avaliação de genótipos de girassol, 2006/2007 e 2007. 108p.	Carvalho et al. (2008)	21-22; 23-24; 25-26; 36-37; 38-39; 40-41; 42-43; 44-45; 46-47; 48-49	10
2007/2008	Doc. 316 – Informes da avaliação de genótipos de girassol, 2007/2008 e 2008. 106p.	Carvalho et al. (2009)	21-22; 35-36	2
2008/2009	Doc. 320 – Informes da avaliação de genótipos de girassol, 2008/2009 e 2009. 109p.	Carvalho et al. (2009)	22-23; 24-25; 47-48; 49-50; 51-52; 53-55	6
2009/2010	Doc. 326 – Informes da avaliação de genótipos de girassol, 2009/2010 e 2010. 107p.	Carvalho et al. (2011)	21-22; 23-24; 25-26; 27-28; 42-43; 44-45; 46-47; 48-49	8
2010/2011	Doc. 329 – Informes da avaliação de genótipos de girassol, 2010/2011 e 2011. 98p.	Carvalho et al. (2011)	21-22; 23-24; 35-36; 37-38; 39-40	5
2011/2012	Doc. 340 – Informes da avaliação de genótipos de girassol, 2011/2012 e 2012. 101p.	Carvalho et al. (2013)	22-23; 24-25; 26-27; 28-29; 39-40; 41-42; 43-44; 45-46	8
2012/2013	Doc. 355 – Informes da avaliação de genótipos de girassol, 2012/2013 e 2013. 105p.	Carvalho et al. (2014)	39-40; 41-42; 43-44	3
2013/2014	Doc. 360 – Informes da avaliação de genótipos de girassol, 2013/2014 e 2014. 104p.	Carvalho et al. (2015)	24-25; 42-43	2
2014/2015	Doc. 367 – Informes da avaliação de genótipos de girassol, 2014/2015 e 2015. 108p.	Carvalho et al. (2015)	24-25; 38-39	2
2015/2016	Doc. 381 – Informes da avaliação de genótipos de girassol, 2015/2016 e 2016. 94p.	Carvalho et al. (2016)	24-25; 36-37	2
2016/2017	Doc. 396 – Informes da avaliação de genótipos de girassol, 2016/2017 e 2017. 116p.	Carvalho et al. (2017)	24-25; 40-41; 42-43	3
2017/2018	Doc. 409 – Informes da avaliação de genótipos de girassol, 2017/2018 e 2018. 82p.	Carvalho et al. (2018)	20-21; 34-35	2
2018/2019	Doc. 421 – Informes da avaliação de genótipos de girassol, 2018/2019 e 2019. 87p.	Carvalho et al. (2019)	19-20; 31-32	2

Table 3 - Number of observations, minimum, percentiles 1, 2.5, 25, 50 (median), 75, 97.5, and 99, maximum, range, mean, variance, standard deviation, standard error, coefficient of variation (CV), skewness, kurtosis, and P-value of the Kolmogorov-Smirnov normality test of variables evaluated in sunflower (*Helianthus annuus* L.) genotypes from 1999 to 2018 in the state of Rio Grande do Sul, Brazil.

Statistic	Grain yield (kg ha^{-1})	Oil content (%)	Oil yield (kg ha^{-1})
Number of observations	1137	1137	1137
Minimum	375.90	20.34	160.11
Percentile 1	726.63	34.10	288.53
Percentile 2.5	914.40	35.80	369.97
Percentile 25	1528.00	40.60	650.88
Median	1973.00	43.02	844.93
Percentile 75	2503.00	45.30	1073.14
Percentile 97.5	3514.98	49.44	1533.89
Percentile 99	3777.52	51.00	1652.92
Maximum	4484.00	53.42	1913.76
Range	4108.10	33.08	1753.65
Mean	2030.24	42.91	870.83
Variance	479204.55	12.90	92485.91
Standard deviation	692.25	3.59	304.11
Standard error	20.53	0.11	9.02
CV (%)	34.10	8.37	34.92
Skewness	0.39	-0.67	0.44
Kurtosis	-0.22	2.69	0.02
P-value	0.07	0.09	0.05

Table 4 - Means of grain yield, oil content, and oil yield of sunflower (*Helianthus annuus* L.) genotypes per agricultural year evaluated from 1999 to 2018 in 21 locations in the state of Rio Grande do Sul, Brazil.

Agricultural year	Grain yield (kg ha^{-1})	Oil content (%)	Oil yield (kg ha^{-1})
1999/2000	1978.08	43.06	854.48
2000/2001	1695.78	46.12	777.17
2001/2002	2304.42	37.46	852.89
2002/2003	1639.37	40.54	666.69
2003/2004	1450.02	42.52	623.18
2004/2005	1814.43	41.78	755.66
2005/2006	1647.59	43.63	716.21
2006/2007	2218.78	43.22	955.98
2007/2008	2097.91	41.25	872.38
2008/2009	1816.17	43.97	796.50
2009/2010	1755.38	43.71	766.36
2010/2011	2798.49	42.81	1205.13
2011/2012	2150.18	43.66	944.06
2012/2013	1820.19	41.56	757.75
2013/2014	2359.38	42.51	1004.14
2014/2015	2321.26	44.05	1023.50
2015/2016	2028.32	40.23	822.65
2016/2017	2207.28	42.26	931.14
2017/2018	2376.13	42.28	1003.76
2018/2019	2435.12	40.92	995.83
Mean	2030.24	42.91	870.83

Table 5 - Means of grain yield, oil content, and oil yield of sunflower (*Helianthus annuus* L.) genotypes per location evaluated from 1999 to 2018 in 21 locations in the state of Rio Grande do Sul, Brazil.

Location	Grain yield (kg ha^{-1})	Oil content (%)	Oil yield (kg ha^{-1})
Bom Progresso	2718.13	41.66	1133.89
Caxias do Sul	2859.25	44.15	1263.80
Coxilha	2624.17	43.48	1146.34
Cruz Alta	1714.46	43.16	729.16
Encruzilhada do Sul	1693.20	45.61	778.91
Hulha Negra	1393.08	40.15	559.23
Ibirubá	2122.48	42.80	905.42
Ijuí	1713.01	43.19	727.46
Palmeiras das Missões	3064.56	40.79	1257.22
Passo Fundo	1897.12	43.12	819.49
Pelotas	3178.56	46.40	1475.93
Rio Pardo	2746.32	42.47	1172.50
Santa Cruz do Sul	2376.71	41.83	996.72
Santa Maria	2263.93	41.79	945.14
Santa Rosa	2285.47	43.89	1002.62
São Borja	1351.56	43.76	592.19
São Gabriel	2535.43	42.95	1079.44
Três de Maio	1683.93	41.98	711.96
Uruguaiana	1824.81	43.90	805.94
Vacaria	2645.84	42.68	1122.71
Veranópolis	1953.46	42.48	828.66
Mean	2030.24	42.91	870.83

for oil content, as it presented a mean oil content of 45.61% in three years of experiments. This factor may be associated with environmental conditions, such as daytime and nighttime temperature fluctuations. According to THOMAZ et al. (2012) and REGITANO NETO et al. (2016), higher mean temperatures lead to a decrease in oil content.

The variables GY and OC showed no significant correlation, indicating the non-existence of a variation trend for one variable relative to an increase or decrease of the other (Figure 2). In contrast, correlations were observed between OY and OC, which were significant and had a Pearson correlation coefficient of 0.2245.This result is similar but shows a smaller magnitude than that found by GHAFFARI et al. (2019), who obtained significant correlations for OY × OC of 0.72 and 0.64 in different experimental locations. However, OC established a non-significant correlation with GY, as observed by AMORIM et al. (2008).

The correlation established between GY and OY leads to a response of increased oil yield, with an increase in sunflower grain yield and a significant positive correlation of 0.9672. DALCHIAVON et al. (2016) also observed a positive and significant correlation for GY and OY.

Sunflower has the potential for cultivation in grain-producing regions in the state of Rio Grande do Sul even though there are variations in soil types and altitude between the northern and southern half of the state. It is not clear whether there is a trend toward a region with higher production potential for the crop over a period of 20 years, which may also be associated with the crop rusticity and ability to adapt to different soil types and environmental variables, particularly the air temperature, as higher altitudes predominate in the northern half of the state compared to the southern half of the state of Rio Grande do Sul.

CONCLUSION

Therefore, no linear relationship was observed between grain yield and oil content in sunflower genotypes in the state of Rio Grande do Sul. A positive linear association of high magnitude (r = 0.9672) was observed between grain yield and oil yield and of low magnitude (r = 0.2245) between oil content and oil yield.

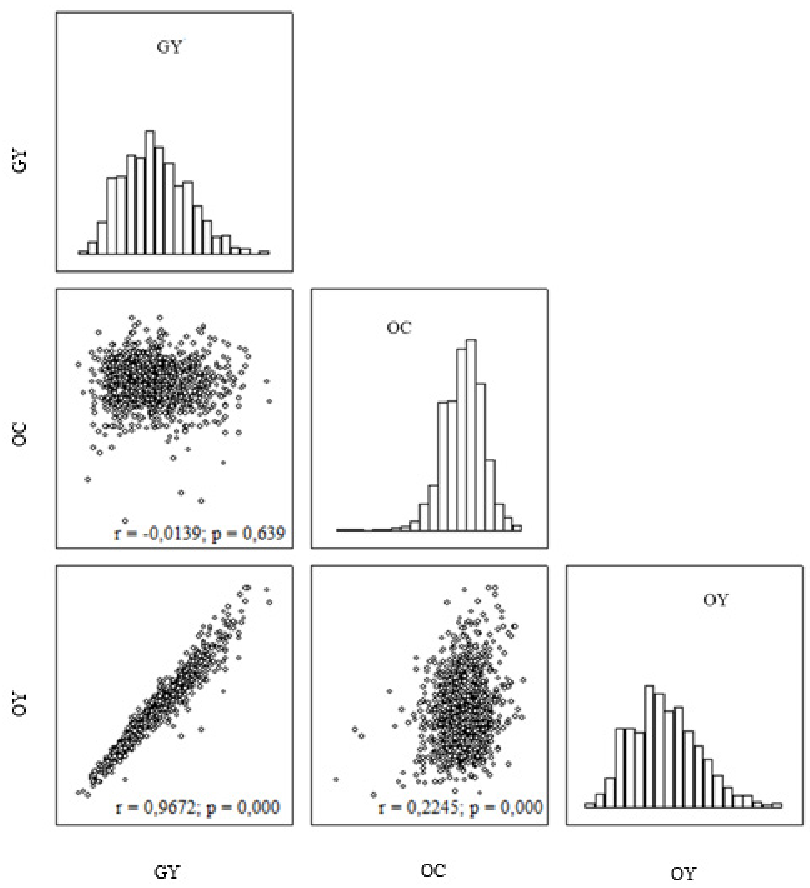

Figure 2 - Matrix with frequency histogram (on the diagonal) and scatter diagrams (off the diagonal) between grain yield (GY), oil content (OC), and oil yield (OY) of sunflower (*Helianthus annuus* L.) genotypes evaluated from 1999 to 2018 in the state of Rio Grande do Sul, Brazil. Pearson's linear correlation coefficients (r) between variables and Student's t-test P-value.

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DECLARATION OF CONFLICT OF INTERESTS

The authors declare no conflict of interest.

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