

Assessment of yield attributes and industrial quality parameters of oat cultivars (*Avena sativa* L.) using multivariate techniques (PCA, PLS-DA and OLS-R)

Running title: yield and industrial parameters of oats

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Abstract

Triazoles and strobilurins group of fungicides have been reported to have dual properties (growth regulator and fungicide) and have been used to prevent the plant lodging. In this study four subsequent field experiments with oat cultivars with and without fungicide application were conducted from 2012 to 2015 aiming to find if fungicide application can improve some yield attributes and quality parameters of oats and find yield attributes that most affect the quality parameters of oats. Multivariate techniques were applied in order to find the most important variables that contribute to sample classification. Fungicide application has a role in reducing the plant stature of oat cultivars with consequent decreasing in lodging index of oat cultivars. Fungicide application reduces the plant stature and lodging index, contributing to best quality

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parameters of oats. Multivariate techniques (PCA, PLS-DA, OLS-R) were capable in finding the important variables that affect yield attributes and quality parameters and can be applied in a broad range of agricultural systems for predicting important aspects that affect plant growth and development.

27

Keywords: oats, fungicide application, de-hulling index, yield attributes, quality parameters, multivariate techniques, plant stature.

30

31 **Abbreviations**

32 PCA-Principal component analysis; PLS-DA –Partial least squares discriminant analysis; OLS-R –
33 Ordinary least squares regression, LV-latent variables, VIP-variable importance projections, AIC-
34 akaike information criterion.

35

36

37 **1. Introduction**

38 Oats (*Avena sativa* L.) are an important spring cereals (Sánchez-Martín et al. 2014; Soltani et al.
39 2012). They are fast growing and produces significant amount of fresh fodder within short period
40 (60-70 days) with adequate nutritional value (Bilal et al. 2017). Independent of the end use,
41 quality requirements are of great importance. The identification of agronomic traits that meet
42 the demand of farmers, industry quality and final consumers, and their incorporation into elite
43 oat germplasm are crucial to the development of successful new oat cultivars. Some of the most
44 important traits selected by the Brazilian Oat Breeding Program include wide adaptation, high
45 grain yield and grain quality, short plant cycle, reduced plant height, lodging resistance, frost
46 tolerance, aluminum tolerance, and genetic resistance to the main diseases, such as crown and
47 stem rust, leaf spot, fusarium, and barley yellow dwarf virus (Nava et al. 2016). In this research

48 the use of a mixture of fungicides claimed to have growth retardant effect is explored aiming a
49 better assessment of yield attributes and quality parameters of oats.

50

51 Triazole fungicides are one of the top ten classes of current-use pesticides and have higher
52 consumption as compared to other fungicides available worldwide (Zhou et al. 2016). They inhibit
53 the biosynthesis of fungal ergosterol (Song & Nes, 2007) and provide a broad spectrum of
54 activities (Yang et al. 2014) such as plant growth regulators (Yang et al. 2014). The mechanism of
55 regulatory effect appears to be that they shift the phytohormone balance in plant tissues and
56 inhibit the biosynthesis of gibberellic acid, which leads to a transient raise in abscisic acid content
57 in plants (Yang et al. 2014) Tebuconazole (TEB) is one of a common triazole fungicide that has
58 been extensively used in grains, vegetables and fruits for the control of plant pathogenic fungi
59 (Yang et al. 2014; Marin et al. 2013; Patyal et al. 2013). Additionally, the strobilurins are a new
60 class of fungicidal compounds and among them is the recently introduced trifloxystrobin
61 (Reuveni, 2000; Diamantopoulou et al. 2006) that is highly effective against several plant
62 pathogens (Veloukas et al. 2007; Bubici et al. 2006; Pérez et al. 2002). Mode of action of the
63 strobilurins towards pathogenic fungi was found to block the mitochondrial respiratory electron
64 transfer chain between cytochrome b and cytochrome c1 at the ubiquinol oxidizing site (Qo) of
65 the complex III, ultimately leading to losses of ATP synthesis and inhibition of cellular respiration,
66 which is also deemed to contribute its broad-spectrum antifungal activity (Cao et al. 2015).

67 Triazoles and strobilurins have been reported to have secondary properties (e.g., growth
68 regulator) and have been used to prevent the plant lodging (Matysiak & Kaczmarek, 2013). From
69 a biochemical point of view, the properties of some triazoles are due to their dual effect on
70 plants: inhibition of the biosynthesis of gibberellins in the plant (retardant properties), and
71 inhibition of the biosynthesis of sterols (fungicide properties - Matysiak & Kaczmarek, 2013). As
72 growth regulators their act not only as chemicals that modulate plant growth but they also act as

73 signal molecules under various biotic and abiotic stresses (Spence & Bais, 2015). As growth
74 retardants, triazoles and strobilurins are applied in agronomic and horticultural crops to reduce
75 unwanted longitudinal shoot growth without lowering plant productivity. Most growth retardants
76 act by inhibiting gibberellin (GA) biosynthesis (Rademacher, 2000). Currently, it is a common
77 practice in crop protection to apply multiple pesticide mixtures instead of individual pesticides.
78 This form of pesticide application likely results in the combined effect (Wang et al. 2016). In this
79 research the retardant effect of the fungicides is explored in oat cultivars aiming to ameliorate
80 the lodging index and thereby improve yield and quality requirements of oats. Multivariate
81 techniques were used to assess yield attributes and quality requirements of oat cultivars
82 subjected to two different treatments (without and with fungicide application)

83 **2. Materials and Methods**

84 *2.1. On farm experiments*

85 Subsequent on farm experiments were conducted in Lages (Santa Catarina State, Southern Brazil,
86 on an experimental research field of the Santa Catarina State University) from 2012 to 2015,
87 using split plot design with and without aerial fungicide application of a mixture of tebuconazole
88 (triazole group) (150 g/Ha) and trifloxystrobin (strobilurin group) (56 g/Ha). All other agronomic
89 practices (such as soil fertilization, weed and disease control) were performed following the
90 Brazilian commission for oat research recommendations ("Comissão Brasileira de Pesquisas em
91 Aveia"-2006). Each plot (useful area) consisted of 5 central lines of 5m of length spaced at 0.2m. 3
92 repetitions (blocks) were used. A mechanized harvest of the oat grains was done for subsequent
93 laboratory analyses. A total of 21 oat cultivars were evaluated (see supplementary Table 1) during
94 four subsequent years (from 2012 to 2015).

95

96 *2.2. Yield components analysis*

97 Yield attributes such as plant stature (cm), grain yield (Kg/Ha) and weight of 1000 grains and sieve
98 yield (>2mm) were evaluated at each experiment (2012-2015). Other yield attributes were
99 evaluated previously (unpublished data from 2007 to 2010).

100

101 2.2.1 Plant stature (cm):

102 Evaluated on plants at growth stage GS91 (pre-harvest maturity) by measuring 10 plants in a
103 random points in each plot by the use of a ruler. The measurements were done from the soil
104 surface until the apical spikelet located on the top of the panicle and values expressed as mean of
105 10 plants according to equation 1.

$$106 \quad \left[PS (cm) = \frac{\sum_{n=1}^{n=10} ps}{N} \right] \text{ (Eq. 1)}$$

107 Where PS is the plant stature in cm; ps-individual plant stature, N is the total number of plants evaluated
108 in each plot (10).

109

110 2.2.2 Sieve yield (> 2 mm)

111 Refers to the percentage of grains with transverse diameter greater than 2 mm, This was
112 evaluated after harvest, by weighing a sample of 250g and then submitted the sieve with regular
113 stirring during a minute; in a sieve of 40 cm x 30 cm dimensions, rectangular, containing holes
114 (sieve) of 2 mm x 20 mm. This process was done twice. The result was expressed by the fraction
115 between the grain weight retained on the sieve and the initial weight (250 g) as represented in
116 the equation 2.

$$117 \quad \left[Sy(\%) = \frac{RGW}{IGW} * 100 \right] \text{ (Eq. 2)}$$

118 Where Sy is the sieve yield (>2mm); RGW is the retained grain weight in a sieve and IGW is the
119 initial grain weight (250g for this experiment).

120

121 2.2.3 Yield (Kg/Ha):

122 The grain yield was measured from each experimental plot (4 central linear meters of each plot,
123 spaced at 0.2m, in a useful area of 2.4m²). The yield was then converted to hectare after weight
124 correction using a standard moisture content of 13% according to equation 3.

$$125 \quad \left[yield = \frac{\left(ww * \left(\frac{100 - rm}{100 - 13} \right) \right)}{2.4 * 10000} \right] \text{ (Eq. 3)}$$

126 Where: ww – wet weight (Kg) and rm is the real weight moisture (%).

127 2.2.4 Weight of 1000 grains (Wg):

128 A sample of a thousand grains', obtained from each experimental plot were electronically
129 counted (Sanick ESC 2011) and weighted using a precision balance and expressed in grams (g).

130

131 2.3 Quality parameters

132 Quality requirement parameters of the grains independent of end use such as lodging index,
133 weight of hectoliter (Kg/100L), and the de-hulling index were evaluated.

134

135 2.3.1 The lodging index

136 Estimated visually and expressed as a percentage, taking into account the angle formed in the
137 vertical position of the plant stem in relation to the ground. 5m² of area was used. The
138 methodology of Moes and Stobbe (1991) was used and the lodging index expressed according to
139 the equation 4.

$$140 \quad [Li(\%) = I * A * 2]_{(Eq.4)}$$

141 Where (Li) is the lodging index; (I) -the degree of inclination of plants, ranging from 0 to 5, where
142 0 represents absence of inclination (all plants in a vertical position), while 5 indicates that all
143 plants are completely bedridden (horizontally); (A) represents the area with lodged plants,
144 ranging from 0 to 10, where 0 corresponds to the absence of lodged plants in the plot, and 10 all
145 plants lodged.

146

147 2.3.2 Weight of hectoliter (Kg/100L):

148 The weight of hectoliter was measured according to the Brazilian official wheat grain quality roles
149 (Brazil, Ministry of Agriculture, Livestock and supply, Normative role 38, from November 30 of
150 2010), using an hectoliter weight analyzer (Dalle-Molle, model T40EL, 0.25L of capacity). Briefly,
151 grain samples from each experimental plot were placed in the analyzer for volume determination
152 and then weighed. The hectoliter weight (HW) was then expressed according to equation 5.

$$153 \quad [HW = W_v * 0.4]_{(Eq. 5)}$$

154 HW is the hectoliter weight; W_v represent the weight of the sample after volume determination in
155 analyzer and 0.4 is a calibration coefficient of the equipment.

156

157 2.3.3 De-hulling index (%):

158 A sample of 1000 grains was weighed, de-hulled manually and then weighed again. The de-hulling
159 index expressed as in equation 6.

$$160 \left[DHI (\%) = \frac{W1000g}{wdh} * 100 \right] \text{ (Eq. 6)}$$

161 DHI is the de-hulling index, W1000g the weight of 1000 grains before de-hulling and wdh is the weight of
162 the sample after de-hulling.

163

164 *2.4 Data mining and Statistics*

165 Data from each year were summarized, subjected to normality test, homogeneity of variance
166 test, analysis of variance using a split plot design and where differences were found, Tukey HSD
167 ($P < 0.05$) was used to test if the differences are statistically significant. Non-supervised
168 multivariate analysis (principal component analysis-PCA) was also applied aiming to observe
169 similarities between the tested cultivars and find variables main related to the similarities.
170 Ordinary least squares regression models (OLS-R) were also applied aiming to find the importance
171 of each variable and those mostly affected the cultivars and quality parameters. A second
172 approach (supervised techniques) namely partial least squares discriminant analysis (PLS-DA)
173 aiming to better classify the samples and find the main variables related to quality parameters
174 were used for dimensionality reduction and find the between and within class variance of the
175 dataset. All statistical analyses were done in R software (R core team, 2017, version 3.3.3) using
176 functions, R packages and scripts produced by our research group. A report is also available as
177 supplementary data for data reproducibility.

178

179 **3. Results and discussions**

180 Results of the analysis of variance (ANOVA) and multiple comparison tests (Tukey test, 5% of
181 probability) of the four field experiments (2012 to 2015) showed to exist differences between

182 cultivars and the effect of fungicide application regarding the de-hulling index (DHI), hectoliter
183 weight (HW), loading index (Li), weight of 1000 grains (Wg), plant stature (PS), sieve yield (Sy) and
184 grain yield (Yield- see supplementary report for ANOVA and multiple comparison tests).
185 Statistically significant higher value of DHI was found for cultivar URS-BRAVA and the lower value
186 observed for URS-FAPA-SLAVA (Tukey test, $p < 0.05$). Cultivars URS-GURIA and URS-TARIMBA
187 presented higher loading index and lower indices were observed for IPR-AFRODITE, URS-TAURA
188 and UPFA-OURO. Regarding the plant stature, cultivars URS21 and URS-GURIA presented plants
189 with superior stature and URS-TAURA with lower stature. The sieve yield was higher in UPFPS-
190 FARROUPILHA, URS-TORENA, URS-TAURA, URS-CORONA and URS-GUAPA and lower in the
191 cultivar URS-FAPA-SLAVA. The weight of 1000 grains was found to be higher in the cultivars
192 FAEM006 and UPFPS-FARROUPILHA and lower in cultivars URS-FAPA-SLAVA, BARBARASUL,
193 BRISASUL and URS-ESTAMPA. Finally, the grain yield was higher in UPFA-OURO and IPR-AFRODITE
194 and lower in URS-ESTAMPA and FAEM5-CHIARASUL. Regarding the fungicide effect in all
195 parameters evaluated, it was observed that fungicide application improved all parameters.
196 Interestingly, the lodging index was higher without fungicide application (see supplementary
197 report).

198

199 Previous studies (Bilal et al. 2017; Iannucci et al. 2011; Lodhi et al. 2009) have reported that
200 cultivars have significant differences in plant height and variations are due to genetic make-up
201 and can also be affected by nitrogen. According to Brunava et al. (2015), higher yield was found in
202 plants with lower plant height. This parameter can be affected by agronomic management
203 practices such as seeding rates, chemical seed treatments and foliar fungicide. In a research of
204 Mourtzins and co-workers (2015), seeding rate and seed treatments did not show effect on oat
205 yield, plant height and lodging index, but foliar fungicide application was considered mainly if
206 disease is expected and improved the grain yield (Mourtzinis et al. 2015; Oliveira et al 2012).

207 Higher values of the weight of 1000 grains were correlated with dough periods, good processing
208 quality and are dependent of cultivar (Brunava et al. 2015).
209
210 Follmann and co-workers (2016) studying the genetic progress of oat cultivars with fungicide
211 application reported an annual genetic progress in yield in 1% with fungicide and 0.08% without
212 fungicide application. They reported that Fungicide application is feasible method. Fungicide
213 application also improved the hectoliter weight. The hectoliter weight (HW) is a measure of the
214 bulk density of the grain and is indicator of grain quality and millability. To ensure effective
215 milling, the HW should be above 50 Kg.h⁻¹ for oats, as consequence, grains with high HW
216 commands a higher price per ton, but the measured value is a combination of grain
217 characteristics including friction, grain shape and polydispersity (Follmann et al 2016). HW was
218 claimed to be influenced by moisture during storage and nitrogen adubation (Gutkoski et al 2006;
219 Kolchinski & Schuch, 2003). Emvula (2012) reported that HW can be affected plant stress, soil
220 fertility, and environmental conditions, i.e., anything that impacts the movement of nutrients to
221 the kernel during grain filling.
222
223 De-hulling index is another important characteristic in oat grains. High hull content of oats limits
224 use as on farm-feed. The oat hull is mainly fibre, hemicellulose, cellulose and lignin. There are low
225 levels of protein, fats, starch and water-soluble carbohydrates. As a result, digestibility of oat hull
226 is low. For these reasons, high hull content of oat groat is a major determinant of decreasing
227 nutritional quality, which is important if oat is used for feed. Reduction of the proportion of hulls
228 in grains evidently results in marked increase in metabolized energy content when it's used in
229 animal feed (Biel et al. 2014).
230
231 Lodging in small grains such as oat is a problem of considerable importance. Its effects on yield,
232 HW, seed quality and other characteristics have been reported. The need for lodging resistant

233 cultivars is becoming more urgent. Lodging was reported to be affected by environmental
234 conditions attending the development of the plant as well as genetic make-up of the plant itself
235 (Hancock & Smith, 1963). Lodging will always have a negative effect on yield. Yield losses in
236 lodged crops come as a result of poor grain filling, head loss and bird damage (Hancock & Smith,
237 1963). Lodging alters the plant's growth and development, affecting flowering and interfering
238 with photosynthesis and carbohydrate movement within the plant. It can interfere with plant's
239 ability to extract nutrients and moisture from the soil, resulting in incomplete grain fill and
240 smaller kernels. This can give yield losses of up to 40% depending on the severity and timing of
241 the lodging (Hancock & Smith, 1963). In this sense of ideas, fungicide application can be an
242 alternative to reduce lodging in oat plants.

243

244 Aiming to better understand if there is an association of all variables studied, a Pearson
245 correlation was performed (Table 1). Interestingly, fungicide application was positively correlated
246 with all variables except for lodging index where a negative association was found, that prompt
247 us to speculate that the application of fungicide reduce the lodging of oat plants. Lodging index
248 was negatively associated with sieve yield, weight of 1000 grains and yield, important parameters
249 in oat industry.

250

251 Looking to find the important variables in our dataset and dimensionality reduction, a second
252 approach (non-supervised (principal component analysis -PCA, hierarchical cluster analysis -HCA)
253 and supervised multivariate techniques (partial least squares discriminant analysis -PLS-DA,
254 ordinary least squares regression -OLS-R)) was applied. When PCA was applied to the dataset
255 (Figure 1A) an interesting insight was observed. A good separation from cultivars where fungicide
256 was applied and not applied was clearly observed (Figure 1A) except for cultivars URS-TORENA,
257 URS-BARAVA, URS-CORONA, IPR-AFRODITE who showed to be similar with those where fungicide

258 was applied (Figure 1A). A similar trend was also found for URS-FAPA-SLAVA (without fungicide
259 application) who showed to be similar with BRISASUL and URS-TAURA (with fungicide
260 application). The total variance explained by PCA was 66.05%, being 45.50 and 20.55% for
261 component 1(PC1) and 2 (PC2) respectively. The loading values are also presented in the Figure
262 1B. The important variables that classified samples can be observed in squared loadings (Figure
263 1B) and were the grain yield, de-hulling, hectoliter, sieve yield and plant stature. Plant stature and
264 the lodging index highly affected cultivars without fungicide application. Fungicide application
265 mostly affected the yield, de-hulling index, hectoliter weight and the sieve yield. Interestingly, our
266 findings prompt us to state that taller plant stature observed without fungicide lead to high
267 lodging index for the same plants. Sample clustering in PC1 were duo hectoliter weight, de-
268 hulling index, sieve yield and grain yield (see supplementary report for contribution of the
269 variables) and in PC2 duo to lodging index, plant stature and yield. In general manner, the
270 variables hectoliter weight, yield, lodging index and de-hulling most contributed to the data
271 variability. The scores of PCA indicated that 09 cultivars highly contributed to the variability (URS-
272 FAPA-SLAVA, URS-TARIMBA, URS-ESTAMPA, URS-GURIA, URS-TAURA, BARBARASUL, UPFA-OURO,
273 BRISASUL and IPR-AFRODITE). A hierarchical cluster dendrogram (HCA) is also presented in the
274 **Figure 2**. As it can be observed, a clear separation of the cultivars was found. 3 different groups
275 can be observed in the HCA. URS-FAPA-SLAVA (without fungicide application) grouped alone.
276 Samples where fungicide was applied grouped together except of a simple misclassification for
277 UPSPF-FARROUPILHA and URS-BRAVA. HCA analysis reinforced the results previously observed in
278 PCA analysis that lead us to state that the application of fungicide have a role in agronomic and
279 quality parameters of oat cultivars evaluated.

280

281 The second approach applied in data screening and finding important variables was the use of
282 regression models, at this time, an ordinary least square regression (OLS-R). The influence of all

283 variables was measured. Firstly in the model 1 was tested the influence of the cultivars and in the
 284 model 2 was tested the effect fungicide application on quality parameters (hectoliter weight, de-
 285 huuling index and lodging index). Ordinary least squares (OLS) or linear least squares is a method for
 286 estimating the unknown parameters in a linear regression model, with the goal of minimizing the
 287 differences between the observed responses in some arbitrary dataset and the responses predicted by the
 288 linear approximation of the data. The resulting estimator can be expressed by a simple formula, especially
 289 in the case of a single regressor on the right-hand side. The results from OLS-R models are summarized in
 290 the Table 2 together with the akaike information criterion (AIC) and the variance explained by each model
 291 are presented. Looking for the second model (with better AIC), quality parameters were positively
 292 influenced by the plant stature. Without fungicide application, sieve yield, weight of 1000 grains and yield
 293 are affected.
 294
 295 Finally, the dataset was also subjected to partial least squares discriminant analysis (PLS-DA). Partial least
 296 square (PLS) is a versatile algorithm which can be used to predict either continuous or discrete/categorical
 297 variables. Classification with PLS is termed PLS-DA, where the DA stands for discriminant analysis. The PLS-
 298 DA algorithm has many favorable properties for dealing with multivariate data; one of the most important
 299 of which is how variable collinearity is dealt with, and the model's ability to rank variables' predictive
 300 capacities within a multivariate context. PLS-DA is performed in order to sharpen the separation between
 301 groups of observations, by hopefully rotating PCA (Principal Components Analysis) components such that
 302 a maximum separation among classes is obtained, and to understand which variables carry the class
 303 separating information. Results from PLS-DA analysis are presented in the **Figure 3A**. The accuracy
 304 of the model, the error rate or misclassification error is also provided. The loadings, scores and
 305 confusion matrix are provided in the supplementary report. PLS-DA model was satisfactory in
 306 classifying samples, a good separation from samples with and without fungicide was also found.
 307 The total variability captured was 62.02%, being 49.41% and 12.61% for latent variable (LV) 1 and
 308 2 respectively. Cultivar **URS-FAPA-SLAVA.1** separated alone. Besides, URS-BRAVA, UPFPS-
 309 FARROUPILHA, IPR-AFRODITE and URS-CORONA (without fungicide) clustered with those where

310 fungicide application was performed. An error rate of 11.90% was found for our model. The circle
311 of correlations (Figure 3B) clearly indicates that cultivars without fungicide application were
312 mostly affected by the lodging index and those with fungicide application by yield, de-hulling
313 index and hectoliter weight. The loadings indicated that the first latent variable (LV1) was
314 negatively influenced by all variables except the lodging index. LV2 was positively affected by
315 lodging index and the grain yield. PLS-DA was the best technique in classifying samples beside the
316 lower variability captured than PCA.

317

318 **4. Conclusions**

319 Fungicide application affects the plant stature and lodging index in oat cultivars. The lodging
320 index is negatively related to plant stature, and consequently influences the grain yield, the
321 hectoliter weight and the sieve yield. Quality parameters of oats (hectoliter, de-hulling and
322 lodging indices) are negatively affected by plant stature and positively by fungicide application.
323 Multivariate techniques (PCA, PLS-DA, OLS-R) classified samples according to fungicide
324 application and were capable in finding the important variables that affect yield attributes and
325 quality parameters and can be applied in a broad range of agricultural systems for predicting
326 important aspects that affect plant growth and development.

327

328 **5. Supplementary data**

329 A report in html format is provided for data reproducibility. Detailed statistical analysis not shown
330 in the manuscript can be found here.

331

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337

338 **Author's contribution**

339 The first author drafted and performed the data mining in R software. All other authors
340 contributed equally in data collection, analysis and discussion. All authors read and approved
341 the final manuscript.

342

343 **Conflict of interest**

344 None declared

345 **7. References**

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437 **Table and Figure captions**

438 Table 1: Pearson correlation matrices between all variables studied in the datasets. The
 439 significance level for each correlation is also provided.

440

441 **Table 2:** Results of OLS-regression. Values in the table represent the coefficients of the ordinary
 442 least square regression models using a generalized linear model (glm) and standard errors for
 443 each coefficient or independent variable in parenthesis. The Akaike Information Criterion (AIC)
 444 for each model is also provided.

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446 **Figure 1:** (A) Score plots and (B) squared loadings of the principal component analysis (PCA) of oat
 447 cultivars studied.

448 **Figure 2:** Hierarchical cluster dendrogram of all cultivars studied showing sample similarities and
 449 dissimilarities. A cophenetic correlation of 92% was found

450 **Figure 3:** (A) Score plot of partial least squares discriminant analysis oat cultivars dataset and (B) the circle
 451 of correlations showing the variables most correlated with and without fungicide application

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457 **Tables and Figures****Table 1: Pearson correlations of all variables studied**

	HW	Li	PS	Sy	Wg	Yield	Application
HW							
Li	-0.19* * * *						
PS	0.18* * * *	0.47* * * *					
Sy	0.38* * * *	-0.16* * * *	0.16* * * *				
Wg	0.41* * * *	-0.33* * * *	0.06	0.29* * * *			
Yield	0.47* * * *	-0.34* * * *	-0.18* * * *	0.09	0.26* * * *		
Application	0.30* * * *	-0.06	0.06	0.14* *	0.07	0.40* * * *	
Cult	0.00	0.08	0.02	0.00	-0.07	-0.07	0.00

458 Significance levels: $p < .0001$ ^{1*****1}; $p < .001$ ^{1***1}, $p < .01$ ^{1**1}, $p < .05$ ^{1*1}

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Table 2: Results of OLS Regression

	<i>Dependent variable:</i>	
	Cult	HW + DHI + Li
	(1)	(2)
DHI	0.06 (0.05)	
HW	0.05 (0.09)	
Li	0.01 (0.01)	
PS	-0.02 (0.03)	1.56*** (0.12)
Sy	0.01 (0.04)	-0.42** (0.20)
Wg	-0.06 (0.06)	-1.69*** (0.28)
Yield	-0.0004 (0.0003)	-0.004*** (0.002)
Application	0.09 (0.61)	4.93 (3.17)
Cult		0.38 (0.24)
Constant	8.90** (4.31)	97.71*** (20.38)
Observations	504	504
Akaike Inf. Crit.	3,256.78	4,935.05
Note:	* p<0.1; ** p<0.05; *** p<0.01	

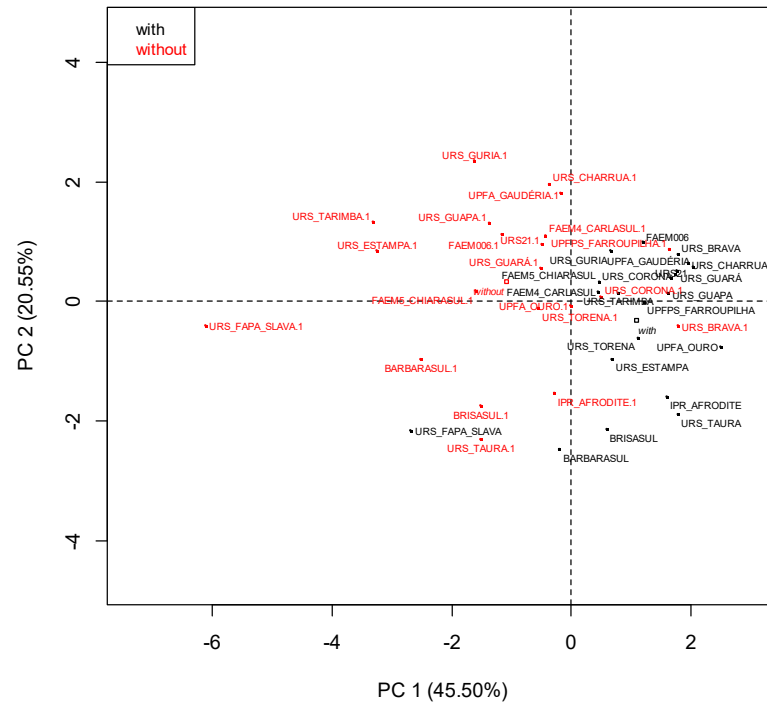
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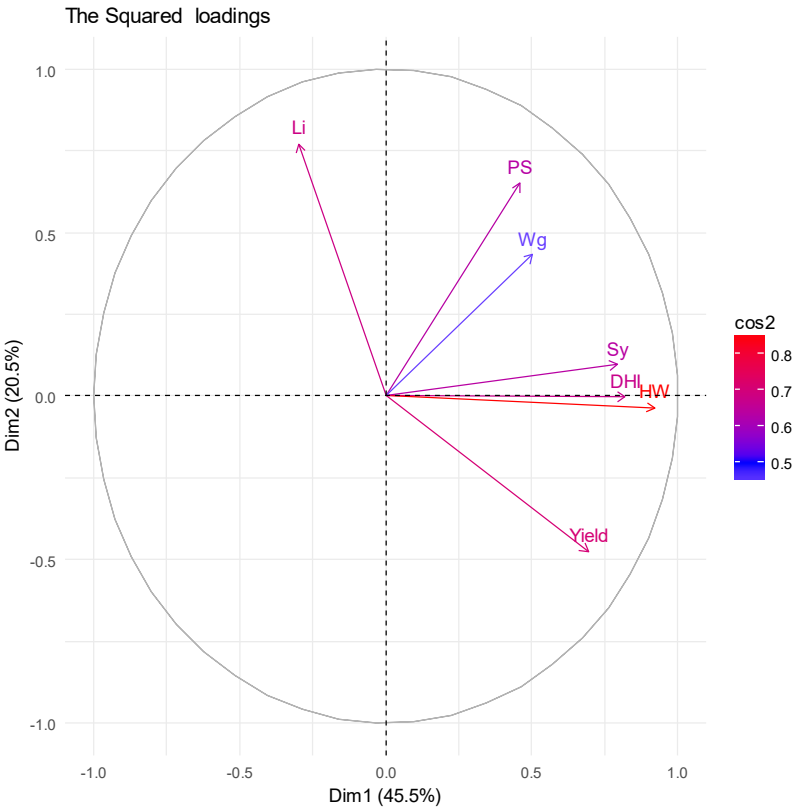
483 Figure 1A



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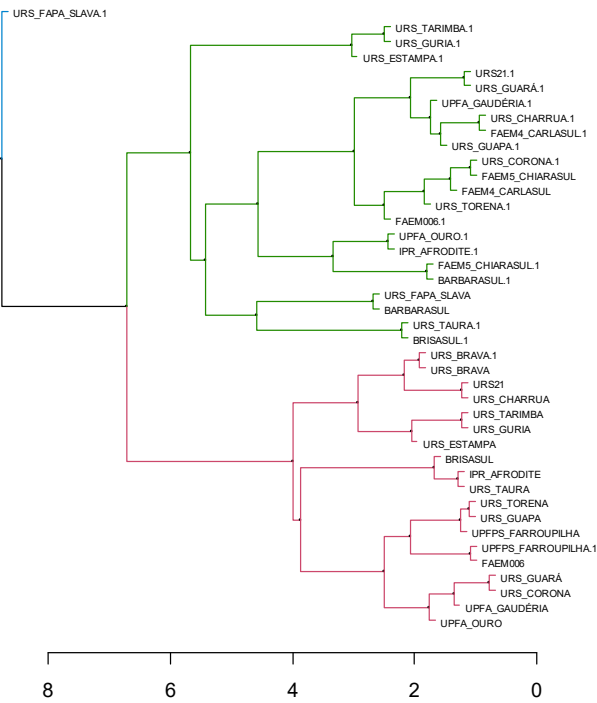
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501 Figure 2



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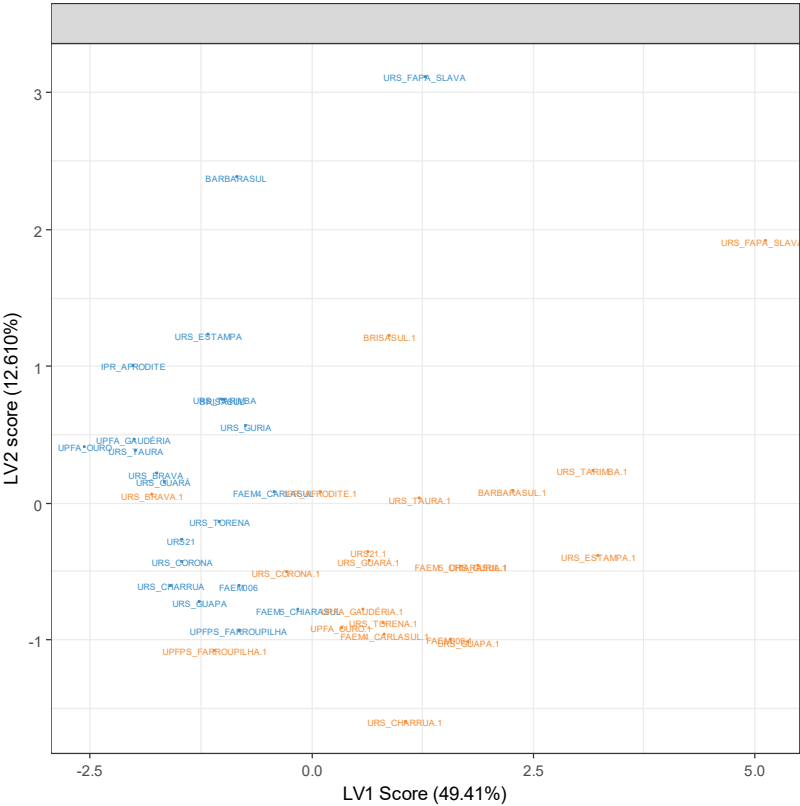
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510 Figure 3a



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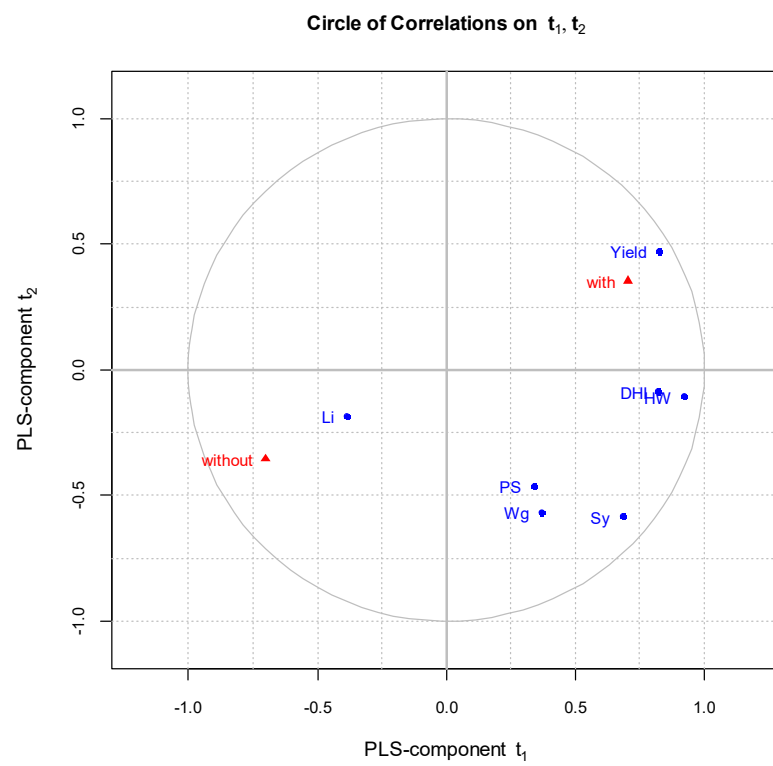
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519 Figure 3B



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