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Effect of maturity stage at harvest on the ensilability of maize hybrids in the early and late
FAO classes, grown in areas differing in yield potential

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Assessment of the attitude to ensilability of different FAO classes and maturities at harvest of maize hybrids grown in areas with different yield potential

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Keywords:	Maize silage, attitude to ensilability, hybrid, maturity at harvest, yield potential.

1 **Assessment of the attitude to ensilability of different FAO classes and maturities at harvest of** 2 **maize hybrids grown in areas with different yield potential**

3 Running title: Effect of different factors on maize ensilability

4

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14

15 **Abstract**

16 The aim of this study was to verify the influence of the FAO class of maize hybrids harvested at
17 different levels of maturity and grown with different yield potential on their attitude to ensilability,
18 described by their fermentation products and summarized by a fermentation quality index (FQI).
19 Maize hybrids belonging to early (n = 14) and late (n = 15) FAO classes, were grown in low, medium
20 and high potential yield areas and harvested at 1/3 (EH), 2/3 (MH) and 5 d after the 2/3 milk line
21 phase (LH), according to a factorial design with two replications. Upon harvest, each sample (n =
22 522) was chopped and analysed for dry matter (DM) and water-soluble carbohydrates (WSC) before
23 being ensiled in vacuum-packed bags (n = 1044). After 60 days of conservation samples were
24 analysed for DM and fermentation products. In the pre-ensiling phase DM was higher in early
25 hybrids, low yield area and at LH maturity, whereas the WSC content was higher in early hybrids,
26 medium yield area and at EH maturity. As regards maize silage, early hybrids led to a higher FQI
27 than late hybrids and in the early ones the FQI was optimised in areas with high production compared
28 with the others and at an EH maturity compared with MH and LH maturity. Late hybrids seemed to
29 be better suited for low yield areas compared with early hybrids and had a higher FQI at an early or
30 medium maturity than at LH maturity. Further research is warranted.

31 **Keyword:** maize silage, attitude to ensilability, hybrid, maturity at harvest, yield potential.

1. INTRODUCTION

Maize (*Zea mays*, L.) silage represents one of the most important forages used in dairy cows and beef cattle rations in temperate regions (Grant and Adesogan, 2018; Marchesini et al., 2017), owing to its high productivity, ease of ensiling and nutritional profile, including both starch and physically effective fiber (Grant and Ferraretto, 2018; Khan et al., 2015). For these reasons it is often included in the rations at over 30 – 40 % of dry matter (DM) and over 50 % of ration's fodder (Castillo-Lopez et al., 2014., Grant and Adesogan, 2018; Silva et al., 2018).

It is therefore evident the importance of maize silage quality in terms of DM and nutrients composition (Krämer-Schmid et al., 2016), absence of harmful compounds (Cavallarin et al., 2011; Driehuis, 2013), fermentation profile (Gallo et al., 2016; Kung et al., 2018) and aerobic stability (Borreani et al., 2014; Elferink et al., 2000) to obtain high performance by healthy animals.

This is even more true when highly productive animals are fed, because they have very high metabolic needs and are easily affected by any alterations of the ration that can lead to reduced DM intake (DMI), performance (Gerlach et al., 2013; Grant and Ferraretto, 2018) and poor health (Borreani et al., 2008).

The main purpose of ensiling is to prevent the loss of DM and energy from a substrate and the production of inedible and toxic compounds by aerobic and anaerobic microbial activity (Grant and Adesogan, 2018). Immediately after harvesting, in the presence of air, an oxidative degradation of organic compounds and proteolysis occur as a result of the activity of enzymes present in the plant tissue. Furthermore, when oxygen is in contact with plant tissue, either in the early phases of ensiling or during feed-out processes, aerobic microbial activity occurs, especially by means of moulds and yeasts, leading to a decay of the substrate (McDonald et al., 2011). On the other hand, when anaerobic conditions are achieved, it is necessary to prevent the activity of undesirable microorganisms, such as clostridia and enterobacteria which increase DM, aminoacid and energy losses (Pahlow et al., 2003), by lowering the pH of the substrate (Kung et al., 2018; McDonald et al., 2011).

Ideally, during the anaerobic fermentation, all water-soluble carbohydrates (WSC) should be metabolised by homolactic acid bacteria to lactic acid, which contributes the most to the decline in pH and minimize energy and DM loss (Pahlow et al., 2003), but a great number of factors, including the DM content, the amount of WSC and the buffering capacity of the substrate, lead to a more complex array of compounds such as volatile acids, alcohols and esters which can alter many nutritive characteristics of a forage (Kung et al., 2018). Their analysis, along with the measure of pH, still

63 represents the main way of assessing maize silage fermentation quality (Andrighetto et al., 2018;
64 Kung et al., 2018).

65 Ethanol, for example, is produced by yeasts, enterobacteria and heterofermentative bacteria (Mc
66 Donald et al., 1991; Nishino et al., 2004, Weiss et al., 2016), whereas others derive from clostridia
67 metabolism (propionate, butyrate and ammonia) and protein or aminoacid degradation (ammonia),
68 as reported by Muck (1988), Pahlow et al. (2003) and Khun et al. (2018). These compounds
69 alltogether are associated with a loss of silage DM and a drop in animal DMI and performance
70 (Borreani et al., 2018). Acetic acid, that after lactic is the most abundant acid found in silage, when
71 is present in moderate concentration seems to be beneficial, as it improves silage aerobic stability,
72 owing to its antifungal activity (Nishino et al., 2004). However, in order to guarantee an optimal
73 silage quality, the lactic/acetic acid ratio should not be lower than 2.5 (Kung et al., 2018), with the
74 exception of silages treated with *L. buchneri* which show a lower lactic/acetic acid ratio without
75 affecting the overall silage quality. This result is due to the metabolism of some lactic acid to acetic
76 acid, as reported by Kleinschmit and Kung (2006).

77 There are many factors that can affect the fermentation processes of a silage, such as the DM content
78 and chemical characteristics of the green chopped whole plant, stage of maturity at harvest,
79 mechanical processing, speed of packing, pack density, addition of inocula, sealing material used on
80 silos, etc. (Borreani et al, 2018; Ferraretto et al., 2018; Wilkinson and Rinne, 2018). However, to
81 optimize the ensiling processes, it would also be necessary to better characterize the different maize
82 hybrids or maize hybrid classes about their attitude to ensiling, through verifying their fermentative
83 response to different growing conditions and management factors, such as their maturity at harvest.
84 The knowledge of the response of each hybrid to these conditions would allow both the farmer to
85 choose the most suitable varieties in order to attain the best yields together with the best silage quality,
86 and the seed companies to better plan their strategies for improvement.

87 In this regard, there are numerous studies on the use of inocula during ensiling (Holzer et al., 2003;
88 Kleinschmit and Kung, 2006; Wilkinson and Davies, 2013) and on different hybrids and maturity at
89 harvest (Ferraretto et al., 2015; Gerlach et al., 2018; Hunt et al., 1989; Johnson et al., 2002), but to
90 our knowledge few researches have focused on the effect of the interaction between the FAO class
91 of hybrids, maturity at harvest and the yield potential of an area on the fermentative characteristics of
92 maize silage, nor have included such a number of hybrids in order to assess the variability of their
93 response to these conditions.

94 In this regard, a possible help, at least as screening phase, can derive from studies involving the use
95 of different hybrids, ensiled in standard and controlled conditions in lab-scale silos and without the
96 use of inocula. The different response of a hybrid or hybrid class in terms of silage fermentation
97 quality at given growing conditions could also give information about the most suitable inocula to
98 use. This would help on one hand to optimize the fermentation process and the stability of the
99 substrate, and on the other, to advise the farmer when it is necessary using inocula and on what
100 inoculum fits better. Extending the knowledge in this field could help farmers to select a hybrid or a
101 hybrid class not only on the basis of its productivity, but even because it shows the best fermentation
102 profile in certain environmental conditions and could give them more information about the proper
103 time of harvest.

104 The aim of this study was to verify the influence of the FAO class of maize hybrids harvested at
105 different levels of maturity and grown in areas with different yield potential on their attitude to
106 insilability, described by their fermentations products and summarized by a fermentation quality
107 index (FQI).

108 **2. MATERIALS AND METHODS**

109 *2.1. Experimental design*

110 The trial was performed in the summer of 2016 in the Po Valley (Northern Italy), using 29 maize
111 hybrids of early (FAO class 200, $n = 14$) and late (FAO class 600-700, $n = 15$) maturity classes, which
112 reflect the whole plant DM concentration (Gerlach et al., 2018). All the hybrids were grown in 3
113 localities (Baura: Ferrara province; Granze and Montagnana: Padova Province) with different
114 pedoclimatic characteristics, that on the basis of historical maize silage crop production data (the
115 areas were planted with monocrops of maize for the last three years), could be referred as areas of
116 low (466 q/ha), medium (563 q/ha) and high (686 q/ha) potential yield, respectively. Baura is a high
117 stressed area with a medium-heavy soil, characterised by a very poor water availability for irrigation,
118 a medium crop drydown and a medium to poor yield potential. Granze is a medium-high stressed area
119 with a medium soil, characterised by a poor water availability for irrigation, a medium crop drydown
120 and a medium to poor yield potential. Montagnana is a high stressed area with a light clay soil,
121 characterised by a high water availability for irrigation, a fast crop drydown and a high yield potential.
122 In each locality the different hybrids were grown in adjacent plots under the same tillage and
123 fertilization practices, applying 300 kg/ha of N, 150 kg/ha of P and 150 kg/ha of K.

124 The plants were harvested at three maturity phases which were determined through the observation
125 of the kernel milk line (Ferraretto et al., 2015): early (EH, 1/3 milk line phase), medium (MH, at 2/3
126 milk line phase) and late (LH, 5 d after the 2/3 milk line phase). Early and late hybrid populations

were sown at the standard densities recommended by the Italian Ministry of Agriculture for the different FAO classes, corresponding to 95000 and 70000 plants/ha, respectively. Each hybrid was subjected to each growing and harvesting condition in a factorial design. At the time of cropping, whole plants belonging to each hybrid were randomly sampled from the central area of each plot and were chopped at a theoretical length of cut of 2 cm on a self-propelled forage harvester. Two replicates were made for each thesis, up to a total of 522 samples.

2.2. Sample collection, preparation and analysis

In order to verify the attitude to ensiling of a large number of different hybrids grown and harvested under different conditions, it was necessary to reduce the differences related to the ensiling system and the management factors as much as possible (Gallo et al., 2016). For this reason it was decided to standardize the ensiling phase using the vacuum-packed bags technique and avoiding the use of inocula, which could mask the initial attitude to ensiling of whole maize plants.

Each whole maize sample was immediately chopped and subjected to the determination of DM and water-soluble carbohydrate (WSC) content by means of a portable near infrared (NIR) system (poliSPEC^{NIR}, ITPhotonics, Breganze, Italy). After the analysis, for each of the 522 whole maize samples, two replicates (n = 1044) were immediately ensiled in vacuum-packed bags (Orved 2633040, Orved SpA, Musile di Piave, VE, Italy) as described by Andrighetto et al. (2018).

All the replicates were stored at 23°C and opened for the analysis of maize silage after 60 days of conservaton. The silage content of each vacuum-bag was scanned in duplicate (n = 2088) using a FOSS NIRSystem 5000 scanning monocromator (FOSS NIRSystem, Silver Spring, MD, USA) using the calibration curve, reported by Andrighetto et al. (2018), for the analysis of dry matter (DM), lactic, acetic, propionic and butyric acids, ethanol, ammonia and pH. All these fermentation products were used to assess the quality of fermentation, as reported also by Kung et al. (2018) and besides, the concentrations of lactate, ammonia, ethanol, acetate and butyrate were used to calculate an index of maize silage fermentation quality (FQI), described by Andrighetto et al. (2018) as index I5.

2.3. Statistical analysis

Statistical analyses were performed using SAS release 9.4 (SAS Institute Inc., Cary, NC, 2012). All data of whole maize plant and maize silage composition and FQI were first tested for normality with the Shapiro–Wilk test (> 0.9 = normally distributed) and then submitted to an ANOVA model with hybrid class (two levels: early and late), yield potential (three levels: low, medium and high), maturity at harvest (three levels: EH, MH and LH) and their interactions, as fixed effects. Within each maturity

class whole maize plant, maize silage composition and FQI were submitted to a second ANOVA model with hybrid (14 levels for FAO class 200 and 15 levels for FAO class 600-700), yield potential (three levels: low, medium and high), maturity at harvest (three levels: EH, MH and LH) and their interactions, as fixed effects. In both models post-hoc pairwise comparisons were run between factor levels using Bonferroni correction. Assumptions of the linear model on the residuals were graphically tested.

As this paper focussed more on the effect of hybrid maturity class than on the effect of single hybrids, for practical reasons, in the tables reporting the hybrid effect on whole plant and silage characteristics, only the range of values was shown (Tables 2, 4 and 5).

169

170 3. RESULTS

At the time of harvest, as reported in Table 1, the early varieties had a higher DM content than the late ones ($p = .001$). Despite their higher level of DM, the hybrids of the class 200 showed a higher content of WSC than hybrids of the class 600-700 ($p < .001$).

The DM content of maize in low and high yield areas, was the the highest and the lowest, respectively ($p < .001$). Unlike DM, WSC showed the highest concentration in the medium yield area and the lowest content in the low yield area (Table 1).

As the maturity stage progressed, an increase in the percentage of dry matter was observed ($p < .001$), whereas an opposite trend was observed for the content of WSC ($p < .001$).

Within each FAO class the effect of the hybrid was significant both for DM ($p < .001$) and WSC ($p < .01$), as reported in Table 2. A significant interaction between hybrid and maturity at harvest was observed only for DM in the class 600-700. Significant interactions were found also for DM and WSC between maturity at harvest and yield potential and between hybrid and yield potential, with the exception of DM in hybrids of Class 200.

As reported in Figures 1 and 2 the relationship between DM and WSC content is poor when the class 600-700 ($R^2 = 0.19$, $p < .001$) is taken into account (Fig. 1), whereas it is better ($R^2 = 0.55$, $p < .001$) when the hybrids of the class 200 are considered (Fig. 2).

The fermentative characteristics of maize silage were affected by the FAO class, maturity at harvest, yield potential and their interactions (Table 3).

189 Overall, as reported in Table 3 the FQI was higher in the maize silage ripening class 200 compared
190 with the class 600-700 ($p < .001$), indicating a better quality of fermentation, characterized by a
191 slightly reduced production of ammonia ($p = .002$), acetic acid ($p < .001$) and propionic acid ($p =$
192 $.002$). The early hybrids led also to higher DM content ($p < .001$) and slightly higher pH ($p < .001$).

193 The area characterized by high yield, compared with the others, led to higher FQI ($p < .001$), lower
194 ethanol ($p < .001$), propionic acid concentration ($p = .02$) and to an intermediate level of pH (Table
195 3). High and medium yield areas were instead similar and led to lower DM and to higher ammonia,
196 lactic and butyric acid concentrations compared with low yield areas.

197 The progressive maturity at harvest, led to a progressive decrease of the fermentation quality index
198 (Table 3), with the early harvest leading to the lowest DM and pH and the highest lactic acid,
199 ammonia, ethanol, propionic and butyric acid concentrations. Acetic acid concentration was similar
200 between EH and MH and the lowest in LH (Table 3).

201 The plant maturity at harvest and the yield potential had different effects on the fermentation profile
202 depending on the FAO class, as there were found significant interactions between these two factors
203 and the FAO class (Table 3).

204 As regards the interactions between factors it should be noted that in the class 200, passing from EH
205 to LH there was a progressive and significant reduction of FQI (Fig. 3), while in the class 600-700,
206 the FQI was not different between EH and MH, while it was significantly lower ($p < .001$) in LH
207 (Figure 3). Besides, the difference in FQI between the two FAO classes seems negligible at the 2/3
208 milk line phase.

209 With regards to yield potential, it can be noticed that there was a significant increase in the
210 fermentation quality index in the class 200 passing from low to high yield (Fig. 4), whereas in the
211 class 600-700 there was not such a trend and the lowest FQI was found in the medium yield area
212 (Figure 4).

213 Furthermore, as reported in Figure 5, the FQI in class 200 was generally lower in the low yield area
214 and in such conditions there was no difference between the different maturity phases at harvest.

215 In the hybrids of class 600-700 the FQI declined when the harvest was done at the LH phase, no
216 matter the yield potential of the area and reached its minimum value in the medium yield area (Figure
217 6).

Table 4 shows the maximum and minimum values of FQI and the various parameters of the fermentation profile measured in the different hybrids belonging to the class 200. For all the parameters the effect of hybrid was significant. As regards the interactions between hybrid and maturity and between hybrid and yield potential, they were not significant either for FQI or for any parameter, with the exception of lactic and butyric acids. The interaction between maturity and yield potential was always significant.

The effect of the hybrid within the class 600-700 on the fermentative profile is reported in Table 5, in which it could be noticed that the interaction between hybrid and maturity at harvest is significant for pH and lactic acid, while the interaction between hybrid and yield potential is significant for FQI and for all the parameters, excluding acetic acid.

4. DISCUSSION

Given the outstanding spread of maize silage as main ingredient both in dairy cows and beef cattle rations (Borreani et al., 2018; Grant and Adesogan, 2018; Wilkinson and Rinne, 2018), it was decided to investigate some of the many factors that could affect its quality, and especially its fermentative profile, that is known to be related with DMI, feed refusal and DM losses during conservation (Elferink et al., 2000; Grant and Ferraretto, 2018; Mc Donald et al., 2011; Muck, 1988).

In this regard, we focused on the effect of hybrids and their FAO classes (early vs. late maturity) grown in areas characterized by different yield potential (low vs. medium vs. high) and harvested at different maturity phases (1/3, 2/3 and 5d after 2/3 of milk line phase).

The whole maize plant content of DM and WSC at harvest was in line with data reported in literature (Ferraretto et al., 2015; Hatew et al., 2016; Lynch et al., 2013) for whole maize crops intended for the production of maize silage.

The highest DM and WSC content of hybrids belonging to class 200 was likely due to their higher radiation use efficiency that led to a higher speed in the synthesis of carbohydrates before flowering (Andrieu et al., 1993) and in the deposition of starch during the period of grain filling (Martins et al., 2017), as also reported by Millner et al. (2005) and Lynch et al. (2013) who found a higher percentage of grain in the early maturing hybrids, compared with late hybrids.

The higher DM and the lowest WSC content of plants grown in the low yield area was expected, because non-optimal conditions of soil texture, hydration and presence of nutrients, lead to a slower

248 maturation of the plant, affecting the content of cell walls, carbohydrate synthesis and grain
249 development (Andrieu et al., 1993).

250 As the plant grows, it increases its DM (Hatew et al., 2016; Martins et al., 2017), along with its crude
251 protein and lignin content (Ferraretto et al., 2015) and the deposition of starch in the grain, which
252 derives from both the photosynthesis and the conversion of WSC (Lynch et al., 2013). This also
253 justifies the highest DM and the lowest content in WSC observed in plants harvested 5 days after the
254 2/3 milk line phase, compared with the ones harvested earlier.

255 Within each FAO class the differences between one hybrid and another are significant both for the
256 DM and the WSC content. Furthermore, looking at the interactions between factors, it can be noticed
257 how the interactions between hybrid and maturity at harvest and between hybrid and yield potential
258 for DM are not significant in the hybrids of class 200, while they are significant for that of class 600-
259 700. The same difference there is also for the content in WSC, but limited to the interaction between
260 hybrid and maturity at harvest. This means that with regard to class 600-700, there are hybrids which
261 are specifically suited to areas with different yield potential and different harvest times, whereas for
262 class 200 this differentiation and specialization among hybrids is lacking. This is partly confirmed by
263 the lower coefficient of determination between DM and WSC found in late hybrids compared with
264 early hybrids. As reported in the literature (Andrieu et al., 1993; Lynch et al., 2013) in fact, the increase
265 of the DM corresponds to a decrease in the WSC of the plant, as the WSC synthesized in the flowering
266 phase and stored at the level of the stem and leaves are used to synthesize the starch contained in the
267 grains, which contributes for the most part to the increase of the DM (Andrieu et al., 1993). However,
268 relationship is better in early ($R^2 = 0.55$) than in late hybrids ($R^2 = 0.19$), because some of the late
269 hybrids showed a low WSC content even when the DM content was low. This could be likely due to
270 different proportions of the morphological constituents of the plant (grain, cob, leaf, stem), as reported
271 by Millner et al. (2005).

272 The FAO class, the level of maturity at harvest and the different yield potential of the areas have also
273 significantly affected the fermentative profile of maize after the ensiling process.

274 In this study, the fermentation quality was measured using fermentation products such as lactic acid,
275 volatile acids, ethanol, ammonia and pH, as reported in literature (Kung et al., 2018) and was
276 summarized by an index tested and validated by Andrighetto et al. (2018), that resulted to be
277 particularly suitable for discriminating the differences in the quality of fermentations obtained under
278 controlled ensiling conditions, such as those obtained using vacuum-packed bags (Andrighetto et al.,
279 2018; Johnson et al., 2005). This index, ranging from 1 to 100, weighs the presence of compounds

280 such as lactate, ethanol, acetate, butyrate and ammonia, that are produced during homolactic,
281 heterolactic, clostridia and yeast fermentations and characterize the fermentation quality of maize
282 silage (Nishino et al., 2004; Romero et al., 2017).

283 This type of ensiling usually leads to high quality silages (Romero et al., 2017), with rather low values
284 of ethanol, acetic, butyric and ammonia, as can be seen by comparing the attained values with those
285 suggested by Kung et al. (2018). For this reason it was decided to use the above reported FQI to
286 summarize the quality characteristics of fermentation, because it proved to be particularly sensitive
287 in diversifying the quality of fermentation between silages with low, medium and high levels of DM,
288 obtained in lab conditions (Andrighetto et al., 2018).

289 In this study, all the hybrids showed a FQI value higher than 48.2, which according to Andrighetto et
290 al (2018) represents the cut-off between excellent and not excellent maize silage, from a fermentative
291 point of view, confirming the goodness of the ensiling method used. In this regard, the early hybrids
292 have generally shown a slightly lower production of ammonia, acetic and propionic acid, as also
293 reported by Gerlach et al. (2018), although both compounds have a concentration well below the
294 suggested critical limit (Kung et al., 2018). Better fermentations were also found in plants grown in
295 the area characterised by the highest fertility, and in those harvested earlier.

296 In the most suitable growing areas, where water, nutrients and temperature are not limiting factors,
297 plants quickly develop grain and increase the ratio between cytoplasmic carbohydrates and cell wall
298 constituents, affecting the composition of the whole plant and facilitating the fermentation process
299 accordingly (Andrieu et al., 1993). On the other hand, when the growing conditions are difficult the
300 synthesis of WSC is less intense and the hemicelluloses of the cell wall, which together with WSC
301 are used by micro-organisms as substrate for fermentations (Gerlach et al., 2018) are less available.
302 Moreover, as the plant ages the WSC content decreases (Andrieu et al, 1993) and DM content
303 increases, leading to a reduction in bacterial growth caused by low availability of water (De Bedrosian
304 et al., 2012; Ferraretto et al., 2015) and consequently to a lower content in lactic acid which can
305 explain the better FQI of the plants harvested earlier compared with the ones harvested last.

306 Through a more accurate investigation, it can be seen how the effects of yield potential and maturity
307 at harvest vary depending on whether early or late hybrids are taken into account. Delaying the harvest
308 from the 1/3 milk line ripening phase till 5 days after the 2/3 milk line phase resulted in a progressive
309 reduction of the fermentation quality in the early hybrids, while in the late ones this reduction was
310 observed only in the last phase.

On the basis of these results, it can therefore be stated that, after taking into account productivity, from a fermentation perspective, when using early maturity hybrids it is advisable to harvest at an early stage of maturity, whereas with the late hybrids the harvest can be delayed until the 2/3 milk line phase without reducing the fermentation quality. This would give to the farmer a wider time interval to wait for the most suitable weather conditions. This rule, however, does not seem to be valid either for early hybrids grown in low yield areas, where the FQI is low no matter the maturity at harvest, or for late hybrids grown in high yield areas, where it is still convenient to harvest at 1/3 milk line phase.

As regards the yield potential, growing early maize hybrids in more and more suitable conditions led to a progressive increase in fermentation quality, whereas this trend was not seen in late hybrids. Besides, in good and excellent areas the early hybrids led to a better FQI than late hybrids, whereas in the worst conditions the FQI was higher in hybrids of class 600-700. This result implies that in the presence of good or excellent areas, it is better to use early hybrids, while in the poor ones, stressful for plants, from a point of view of the fermentation profile, it is better to use late FAO hybrids.

Within each FAO class, the difference between the various hybrids was always significant both for the FQI and for the various fermentation parameters, indicating that different hybrids within a class lead to a diversified fermentation quality. However, based on the interactions between factors, as seen for DM and WSC in the whole plants, it seems that early hybrids did not behave differently in different yield potential areas and harvesting conditions and that, on the other hand, late hybrids displayed fermentations of different quality depending on the yield potential of an area and therefore appeared to be more suitable for specific growing conditions.

332

5. CONCLUSIONS

This study showed that the attitude to ensiling measured in lab-scale ensiling conditions of maize silage can be significantly affected by the FAO class of the hybrid, the single hybrid and its interaction with the yield potential of an area and the maturity at harvest. In particular, it seems that early maize hybrids led to a better fermentation quality of maize silage, but mainly in very favorable areas and when harvested at an early maturity phase. On the other hand, the hybrids of class 600-700 appeared to guarantee a good ensilability even in medium or low yield potential areas and when they are harvested within a wider period that goes from 1/3 up to 2/3 of the of the milk line phase. These results show also that lab-scale ensiling and FQI are effective tools in comparing the different attitude to ensiling of a large number of hybrids and the effect of the different factors involved. Further research is warranted in order to confirm these results at field level.

344

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348

349 **CONFLICT OF INTEREST**

350 The authors declare there is no conflict of interest.

351

352 **REFERENCES**

- 353 Andrieu, J., Demarquilly, C., Dardenne, P., Barrière, Y., Lila, M., Maupetit, P., Rivière, F., &
354 Femenias, N. (1993). Composition and nutritive value of whole maize plants fed fresh to
355 sheep. I. Factors of variation. *Annales de zootechnie, INRA/EDP Sciences*, 42, 221-249.
356 <https://hal.archives-ouvertes.fr/hal-00888945>
- 357 Andrighetto, I., Serva, L. □, Gazziero, □ M., Tenti □, S., Mirisola, □ M., Garbin, E., Contiero, B.,
358 Grandis, D., & Marchesini, G. (2018). Proposal and validation of new indexes to evaluate
359 maize silage fermentative quality in lab-scale ensiling conditions through the use of a
360 receiver operating characteristic analysis. *Animal Feed Science Technology*, 242, 31-40.
361 <https://doi.org/10.1016/j.anifeedsci.2018.05.009>
- 362 Badu-Apraku, B., Hunter, R. B., & Tollenaar, M. (1983). Effect of temperature during grain filling
363 on whole plant and grain yield in maize (*Zea mays* L.). *Canadian Journal of Plant Science*,
364 63, 357-363. <https://doi.org/10.4141/cjps83-040>
- 365 Borreani, G., Bernades, T. F., & Tabacco, E. (2008). Aerobic deterioration influences the
366 fermentative, microbiological and nutritional quality of maize and sorghum silages on
367 farm in high quality milk and cheese production chains. *Revista Brasileira de Zootecnia*
368 37, 68-77. <http://dx.doi.org/10.1590/S1516-35982008001300009>
- 369 Borreani, G., Piano, S., & Tabacco, E. (2014). Aerobic stability of maize silage stored under
370 plastic films with different oxygen permeability. *Journal of the Science of Food and*
371 *Agriculture*, 94, 2684-2690. <https://doi.org/10.1002/jsfa.6609>
- 372 Borreani, G., Tabacco, E., Schmidt, R. J., Holmes, B. J., & Muck, R. E. (2018). Silage review:
373 Factors affecting dry matter and quality losses in silages. *Journal of Dairy Science*, 100,
374 1812-1828. <https://doi.org/10.3168/jds.2017-13837>

- Castillo-Lopez, E., Clark, K. J., Paz, H. A., Ramirez Ramirez, H. A., Klusmeyer, T. H., Hartnell, G. F., & Kononoff, P. J. (2014). Performance of dairy cows fed silage and grain produced from second-generation insect-protected (*Bacillus thuringiensis*) corn (MON 89034), compared with parental line corn or reference corn. *Journal of Dairy Science*, 97, 3832–3837. <https://doi.org/10.3168/jds.2014-7894>
- Cavallarin, L., Tabacco, E., Antoniazzi, S., & Borreani, G. (2011). Aflatoxin accumulation in whole cropmaize silage as a result of aerobic exposure. *Journal of the Science of Food and Agriculture*, 91, 2419–2425. <https://doi.org/10.1002/jsfa.4481>
- Der Bedrosian, M. C., Kung, L. Jr., & Nestor, K. E. Jr. (2012). The effects of hybrid, maturity and length of storage on the composition and nutritive value of corn silage. *Journal of Dairy Science*, 95, 5115–5126. <https://doi.org/10.3168/jds.2011-4833>
- Driehuis, F. (2013). Silage and the safety and quality of dairy foods: A review. *Agricultural and Food Science*, 22, 16–34. <https://doi.org/10.23986/afsci.6699>
- Ferraretto, L. F., Crump, P. M., & Shaver R. D. (2015). Effect of ensiling time and exogenous protease addition to whole-plant corn silage of various hybrids, maturities and chop lengths on nitrogen fractions and ruminal in vitro starch digestibility. *Journal of Dairy Science*, 98, 8869–8881. <https://doi.org/10.3168/jds.2015-9511>
- Ferraretto, L. F., Shaver, R. D., & Luck, B. D. (2018). Silage review: Recent advances and future technologies for whole-plant and fractionated corn silage harvesting. *Journal of Dairy Science*, 101, 3937–3951. <https://doi.org/10.3168/jds.2017-13728>
- Gallo, A., Bertuzzi, T., Giuberti, G., Moschini, M., Bruschi, S., Cerioli, C., & Masoero, F. (2016). New assessment based on the use of principal factor analysis to investigate corn silage quality from nutritional traits, fermentation end products and mycotoxins. *Journal of the Science of Food and Agriculture*, 96, 437–448. <https://doi.org/10.1002/jsfa.7109>
- Gerlach, K., Weiss, K., Ross, F., Buscher, W., & Sudekum, K. H. (2013). Changes in maize silage fermentation products during aerobic deterioration and its impact on feed intake by goats. *Agricultural and Food Science*, 22, 168–181. <https://doi.org/10.23986/afsci.6739>
- Gerlach, K., Pfau, F., Pries, M., Hünting, K., Weiß, K., Richardt, W., & Südekum, K.-H. (2018). Effects of length of ensiling and maturity group on chemical composition and in vitro ruminal degradability of whole-crop maize. *Grass and Forage Science*. 73, 599–609. <https://doi.org/10.1111/gfs.1236>

- Grant, R. J., & Adesogan, A. T. (2018). Journal of Dairy Science Silage Special Issue: Introduction. *Journal of Dairy Science*, 101, 3935–3936. <https://doi.org/10.3168/jds.2018-14630>
- Grant, R. J., & Ferraretto, L. F., (2018). Silage review: Silage feeding management: Silage characteristics and dairy cow feeding behaviour. *Journal of Dairy Science*, 101, 4111–4121. <https://doi.org/10.3168/jds.2017-13729>
- Hatew, B., Bannink, A., van Laar, H., de Jonge, L. H., & Dijkstra, J. (2016). Increasing harvest maturity of whole-plant corn silage reduces methane emission of lactating dairy cows. *Journal of Dairy Science*, 99, 354–368. <https://doi.org/10.3168/jds.2015-10047>
- Hunt, C. W., Kezar, W., & Vinande, R. (1989). Yield, chemical composition, and ruminal fermentability of corn whole plant, ear, and stover as affected by maturity. *Journal of Production Agriculture*, 2, 357–361. <https://doi.org/10.2134/jpa1989.0357>
- Johnson, H. E., Merry, R. J., Davies, D. R., Kell, D. B., Theodorou, M. K., & Griffith, G. W. (2005). Vacuum packing: a model system for laboratory-scale silage fermentations. *Journal of Applied Microbiology*, 98, 106–113. <https://doi.org/10.1111/j.1365-2672.2004.02444.x>
- Johnson, L. M., Harrison, J. H., Davidson, D., Robutti, J. L., Swift, M., Mahanna, W. C. & Shinnors, K. (2002). Corn silage management I: Effects of hybrid, maturity, and mechanical processing on chemical and physical characteristics. *Journal of Dairy Science*, 85, 833–853. [https://doi.org/10.3168/jds.S0022-0302\(02\)74143-X](https://doi.org/10.3168/jds.S0022-0302(02)74143-X)
- Khan, N. A., Yu, P., Ali, M., Cone, J. W., & Hendriks, W. H. (2015). Nutritive value of maize silage in relation to dairy cow performance and milk quality. *Journal of the Science of Food and Agriculture*, 95, 238–252. <https://doi.org/10.1002/jsfa.6703>
- Kleinschmit, D. H., & Kung, L. Jr. (2006). The effects of *Lactobacillus buchneri* and *Pediococcus pentosaceus* R1094 on the fermentation of corn silage during various stages of ensiling. *Journal of Dairy Science*, 89, 3999–4004. [https://doi.org/10.3168/jds.S0022-0302\(06\)72443-2](https://doi.org/10.3168/jds.S0022-0302(06)72443-2)
- Krämer-Schmid, M., Lund, P., & Weisbjerg, M. R. (2016). Importance of NDF digestibility of whole crop maize silage for dry matter intake and milk production in dairy cows. *Animal Feed Science and Technology*, 219, 68–76. <https://doi.org/10.1016/j.anifeedsci.2016.06.007>
- Kung, L. Jr., Shaver, R. D., Grant, R. J., & Schmidt, R. J. (2018). Silage review: Interpretation of chemical, microbial, and organoleptic components of silages. *Journal of Dairy Science* 101, 4020–4033. <https://doi.org/10.3168/jds.2017-13909>

- Lynch, J. P., O'kiely, P., & Doyle, E. M. (2013). Yield, nutritive value and ensilage characteristics of whole-crop maize, and of the separated cob and stover components – nitrogen, harvest date and cultivar effects. *Journal of Agricultural Science*. 151, 347–367. <https://doi.org/10.1017/S0021859612000342>
- Marchesini, G., Serva, L., Garbin, E., Mirisola, M. & Andrighetto, I. (2017). Near-infrared calibration transfer for undried whole maize plant between laboratory and on-site spectrometers. *Italian Journal of Animal Science*, doi.org/10.1080/1828051X.2017.1345660
- Martins, K. V., Dourado-Neto, D., Reichardt, K., Favarin, J. L., Sartori, F. F., Felisberto, G., & Mello, S. C. (2017). Maize dry matter production and macronutrient extraction model as a new approach for fertilizer rate estimation. *Anais da Academia Brasileira de Ciências*, 89, 705–716. <http://dx.doi.org/10.1590/0001-3765201720160525>
- McDonald, P., Henderson, N., & Heron, S. (1991). The biochemistry of silage (2nd ed.). Aberystwyth: Chalcombe Publications. <https://doi.org/10.1017/S0021859600067162>
- McDonald, P., Edwards, R. A., Greenhalg, J. F. D., Morgan, C. A., Sinclair, L. A., & Wilkinson, R. G. (2011). Silage. In *Animal Nutrition* (7th ed.). Harlow, England: Pearson Education Limited, 499–520.
- Millner, J. P., Vill Aver, R., & Hardacre, A. K. (2005). The yield and nutritive value of maize hybrids grown for silage. *New Zealand Journal of Agricultural Research*, 48, 101–108. <https://doi.org/10.1080/00288233.2005.9513637>
- Muck, R. E. (1988). Factors influencing silage quality and their implications for management. *Journal of Dairy Science*, 71, 2992–3002. [https://doi.org/10.3168/jds.S0022-0302\(88\)79897-5](https://doi.org/10.3168/jds.S0022-0302(88)79897-5)
- Nishino, N., Wada, H., Yoshida, M., & Shiota, H. (2004). Microbial counts, fermentation products, and aerobic stability of whole crop corn and a total mixed ration ensiled with and without inoculation of *Lactobacillus casei* or *Lactobacillus buchneri*. *Journal of Dairy Science* 87, 2563–2570. [https://doi.org/10.3168/jds.S0022-0302\(04\)73381-0](https://doi.org/10.3168/jds.S0022-0302(04)73381-0)
- Elferink, S. J. W. H. O., Driehuis, F., Gottschal, J. C., & Spoelstra, S. F. (2000). Silage fermentation processes and their manipulation. *FAO Plant Production and Protection Paper*, 161, 17–30. <https://20013033291>
- Pahlow, G., Muck, R. E., Driehuis, F., Elferink, S. J. W. H. O., & Spoelstra, S. F. (2003). Microbiology of ensiling, in: Buxton, D. R., Muck, R., Harrison, J. (Eds), *Silage Science and Technology*, (pp. 31–93). Madison, WI: ASA, CSSA, SSSA.

- Romero, J. J., Zhao, Y., Balseca-Paredes, M. A., Tiezzi, F., Gutierrez-Rodriguez, E., & Castillo, M.S. (2017). Laboratory silo type and inoculation effects on nutritional composition, fermentation, and bacterial and fungal communities of oat silage. *Journal of Dairy Science* 100, 1812–1828. <https://doi.org/10.3168/jds.2016-11642>
- Silva, G. G., Takiya, C. S., Del Valle, T. A., de Jesus, E. F., Grigoletto, N. T. S., Nakadonari, B., Cortinhas, C. S., Acedo, T. S., & Rennó, F. P. (2018). Nutrient digestibility, ruminal fermentation, and milk yield in dairy cows fed a blend of essential oils and amylase. *Journal of Dairy Science*, 101, 1–12. <https://doi.org/10.3168/jds.2018-14789>
- Weiss, K., Kroschewski, B., & Auerbach, H. (2016). Effect of air exposure, temperature and additives on fermentation characteristics, yeasts count, aerobic stability and volatile organic compounds in corn silage. *Journal of Dairy Science*, 99, 8053–8069. <https://doi.org/10.3168/jds.2015-10323>
- Wilkinson, J. M., & Davies, D. R. (2013). The aerobic stability of silage: key findings and recent developments. *Grass Forage Science*, 68, 1–19. <https://doi.org/10.1111/j.1365-2494.2012.00891.x>
- Wilkinson, J. M., & Rinne, M. (2018). Highlights of progress in silage conservation and future Perspectives. *Grass Forage Science*, 73, 40–52. <https://doi.org/10.1111/gfs.12327>

491 **TABLE 1**
492 Content of dry matter (DM) and water-soluble carbohydrates (WSC) in pre-ensiled maize belonging
493 to different FAO classes (class 200 vs. class 600-700), grown in different yield potential areas (low
494 vs. medium vs. high) and harvested at different maturity phase (early, LH vs. medium, MH vs. late,
495 LH). (ls means and standard error of means [SEM])
496

FAO class	DM (g/kg)	WSC (g/kg DM)
- Early (200)	366 ^a	100 ^a
- Late (600-700)	343 ^b	89.0 ^b
SEM	4.40	1.50
<i>p</i>	.001	< .001
Yield potential		
Low	373 ^a	88.7 ^c
Medium	353 ^b	102 ^a
High	333 ^c	93.0 ^b
SEM	1.50	1.00
<i>p</i>	< .001	< .001
Maturity at harvest		
EH	310 ^c	106 ^a
MH	351 ^b	94.4 ^b
LH	403 ^a	83.0 ^c
SEM	1.50	0.90
<i>p</i>	< .001	< .001
FAO class × Maturity at harvest		
<i>p</i>	< .001	.042
FAO class × Yield potential		
<i>p</i>	< .001	< .001
Maturity at harvest × Yield potential		
<i>p</i>	< .001	< .001

497 ^{a-c} Means within columns not sharing a common superscript are significantly different (*p* < 0.01).

TABLE 2
 Effect of maize hybrids belonging to classes 200 and 600-700 on dry matter (DM) and water-soluble carbohydrates (WSC) content range at harvest, before the ensiling process. (Is means and standard error of means [SEM])

	FAO class			
	200		600-700	
	DM (g/kg)	WSC (g/kg DM)	DM (g/kg)	WSC (g/kg DM)
Minimum	339	88.0	326	83.9
Maximum	416	111	362	100
SEM	4.60	2.82	4.10	2.71
<i>p</i>	< .001	< .001	< .001	.002
Hybrid × Maturity at harvest				
P-value	.1054	.174	.014	.203
Hybrid × Yield potential				
P-value	.217	.029	< .001	< .001
Maturity at harvest × Yield potential				
<i>p</i>	< .001	< .001	< .001	< .001

502

TABLE 3
Fermentation profile and DM recovery (DMR %) of maize silage. belonging to different FAO classes (class 200 vs. class 600-700), grown in different yield potential areas (low vs. medium vs. high) and harvested at different maturity (early, LH vs. medium, MH vs. late, LH). (Is means and standard error of means [SEM])

	DM (g/kg)	pH	Ammonia (%Nitrogen)	Ethanol (g/kg DM)	Lactic acid (g/kg DM)	Acetic acid (g/kg DM)	Propionic acid (g/kg DM)	Butyric acid (g/kg DM)	FQI
FAO class									
Early (200)	360 ^a	3.87 ^a	5.70 ^b	11.2	52.2	8.51 ^b	0.02 ^b	0.563	57.0 ^a
Late (600-700)	333 ^b	3.83 ^b	5.97 ^a	11.6	50.1	9.80 ^a	0.04 ^a	0.643	53.5 ^b
SEM	1.11	0.002	0.023	0.191	0.294	0.130	0.001	< 0.001	0.29
<i>p</i>	< .001	< .001	.002	.510	.134	< .001	.002	.002	< .001
Yield potential									
Low	362 ^a	3.89 ^a	5.68 ^b	10.3 ^b	48.3 ^b	8.92	0.04 ^a	0.562 ^b	54.1 ^b
Medium	336 ^b	3.82 ^c	5.90 ^a	14.5 ^a	52.2 ^a	9.50	0.04 ^a	0.604 ^a	53.5 ^b
High	341 ^b	3.85 ^b	5.91 ^a	9.30 ^c	53.0 ^a	9.13	0.01 ^b	0.602 ^a	58.1 ^a
SEM	1.40	0.003	0.029	0.240	0.360	0.162	< 0.001	< 0.001	0.360
<i>p</i>	< .001	< .001	< .001	< .001	< .001	< .001	.002	< .001	< .001
Maturity at harvest									
EH	301 ^c	3.82 ^b	6.13 ^a	12.9 ^a	57.9 ^a	10.1 ^a	0.05 ^a	0.640 ^a	58.8 ^a
MH	341 ^b	3.87 ^a	5.79 ^b	9.82 ^c	50.8 ^b	9.90 ^a	0.02 ^c	0.591 ^b	55.8 ^b
LH	398 ^a	3.86 ^a	5.57 ^c	11.4 ^b	44.9 ^c	7.54 ^b	0.03 ^b	0.530 ^c	51.1 ^c
SEM	1.40	0.003	0.029	0.240	0.360	0.162	< 0.001	< 0.001	0.360
<i>p</i>	< .001	< .001	< .001	< .001	< .001	< .001	.002	< .001	< .001
FAO class × Maturity at harvest									
<i>p</i>	< .001	< .001	< .001	.206	< .001	.004	< .001	< .001	< .001
FAO class × Yield potential									
<i>p</i>	< .001	< .001	.312	< .001	< .001	< .001	< .001	< .001	< .001
Maturity at harvest × Yield potential									
<i>p</i>	< .001	< .001	< .001	< .001	< .001	< .001	.011	< .001	< .001

^{a-c} Means within columns not sharing a common superscript are significantly different (*p* < 0.01).

510 **TABLE 4**

511 Effect of hybrid within class 200 on fermentation profile and DM recovery of maize grown in
 512 different yield potential areas and harvested at different maturity phases. (Is means and standard
 513 error of means [SEM])

	pH	Ammonia (%Nitrogen)	Ethanol (g/kg DM)	Lactic acid (g/kg DM)	Acetic acid (g/kg DM)	Propionic acid (g/kg DM)	Butyric acid (g/kg DM)	FQI
Minimum	3.81	5.58	8.10	45.8	8.10	0.01 ^b	0.570	52.4 ^b
Maximum	3.86	6.59	14.3	57.1	11.3	0.07 ^a	0.650	62.2 ^a
SEM	0.009	0.091	0.730	1.11	0.510	0.007	< 0.001	1.10
<i>p</i>	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001
Hybrid × Maturity at harvest								
<i>p</i>	.733	.164	.194	.007	.646	< .001	.014	.130
Hybrid × Yield potential								
<i>p</i>	.137	.200	.103	< .001	.887	.187	< .001	.400
Maturity at harvest × Yield potential								
<i>p</i>	< .001	< .001	< .001	< .001	< .001	.323	< .001	.013

514 ^{a-b} Means within columns not sharing a common superscript are significantly different ($p < 0.01$).

515

TABLE 5
Effect of hybrid within class 600-700 on fermentation profile and DM recovery of maize grown in different yield potential areas and harvested at different maturity phases. (Is means and standard error of means [SEM])

	pH	Ammonia (%Nitrogen)	Ethanol (g/kg DM)	Lactic acid (g/kg DM)	Acetic acid (g/kg DM)	Propionic acid (g/kg DM)	Butyric acid (g/kg DM)	FQI
Minimum	3.85	5.47	7.20	54.0	7.40	0.02 ^b	0.500	51.2 ^b
Maximum	3.94	5.94	13.8	58.7	9.60	0.07 ^a	0.600	58.7 ^a
SEM	0.009	0.091	0.730	1.11	0.510	0.007	0.010	1.13
<i>p</i>	< .001	.001	< .001	< .001	.059	< .001	< .001	< .001
Hybrid × Maturity at harvest								
<i>p</i>	.026	.194	.116	.001	.371	.408	.079	.487
Hybrid × Yield potential								
<i>p</i>	.002	< .001	< .001	.005	.241	.165	.006	.052
Maturity at harvest × Yield potential								
<i>p</i>	< .001	.287	< .001	< .001	.049	< .001	< .001	< .001

^{a-b} Means within columns not sharing a common superscript are significantly different ($p < 0.01$).

522 **FIGURE 1** Relationship between DM (g/kg) and WCS (g/kg DM) taking into account the maize
523 hybrids belonging to the late FAO class (class 600-700).

524 **FIGURE 2** Relationship between DM (g/kg) and WCS (g/kg DM) taking into account the maize
525 hybrids belonging to the early FAO class (class 200).

526 **FIGURE 3** Effect of the interaction between FAO class (class 200 vs. class 600-700) and maturity
527 at harvest (Early, EH vs. medium, MH vs. late, LH) on the fermentation quality index (FQI). ^{a-d} Means
528 not sharing a common letter are significantly different ($p < 0.01$).

529 **FIGURE 4** Effect of the interaction between FAO class (class 200 vs. class 600-700) and yield
530 potential (low vs. medium vs. high) on the fermentation quality index (FQI). ^{a-d} Means not sharing a
531 common letter are significantly different ($p < 0.01$).

532 **FIGURE 5** Effect of the interaction between yield potential (low vs. medium vs. high) and maturity
533 at harvest (Early, EH vs. medium, MH vs. late, LH) in class 200 hybrids on the fermentation quality
534 index (FQI). ^{a-c} Means not sharing a common letter are significantly different ($p < 0.01$).

535 **FIGURE 6** Effect of the interaction between yield potential (low vs. medium vs. high) and maturity
536 at harvest (Early, EH vs. medium, MH vs. late, LH) in class 600-700 hybrids on the fermentation
537 quality index (FQI). ^{a-c} Means not sharing a common letter are significantly different ($p < 0.01$).

FIGURE 1 Relationship between DM (g/kg) and WSC (g/kg DM) taking into account the maize hybrids belonging to the late FAO class (class 600-700).

FIGURE 2 Relationship between DM (g/kg) and WSC (g/kg DM) taking into account the maize hybrids belonging to the early FAO class (class 200).

FIGURE 3 Effect of the interaction between FAO class (class 200 vs. class 600-700) and maturity at harvest (Early, EH vs. medium, MH vs. late, LH) on the fermentation quality index (FQI). ^{a-d} Means not sharing a common letter are significantly different ($p < .01$).

FIGURE 4 Effect of the interaction between FAO class (class 200 vs. class 600-700) and yield potential (low vs. medium vs. high) on the fermentation quality index (FQI). ^{a-d} Means not sharing a common letter are significantly different ($p < .01$).

FIGURE 5 Effect of the interaction between yield potential (low vs. medium vs. high) and maturity at harvest (Early, EH vs. medium, MH vs. late, LH) in class 200 hybrids on the fermentation quality index (FQI). ^{a-c} Means not sharing a common letter are significantly different ($p < .01$).

FIGURE 6 Effect of the interaction between yield potential (low vs. medium vs. high) and maturity at harvest (Early, EH vs. medium, MH vs. late, LH) in class 600-700 hybrids on the fermentation quality index (FQI). ^{a-c} Means not sharing a common letter are significantly different ($p < .01$).