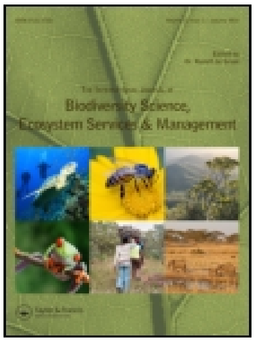

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# Adaptability of old Italian flint maize (*Zea mays* L.) varieties to different weed control systems

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The current diffusion of high-yielding hybrid maize varieties has relegated old Italian flint varieties for polenta dishes to domestic scale. However, increasing demands for traditional foods as well as the exploitation of the local biodiversity furnish the base for the rediscovery of old flint varieties. Their cultivation represents an important source of income for low-input agricultural systems, marginal areas and organic systems. Information is currently lacking on the management of old flint varieties. This article provides information on the management of three flint maize varieties, concerning yield level and the adaptations found under chemical and mechanical weed control methods. The varieties *Marano*, *Nostrano dell'Isola*, *Pignoletto* and *Ottofile* were described and evaluated. The varieties assayed were shown to completely recover from damage caused by mechanical weed control means and to tolerate herbicide treatment with foramsulfuron and bromoxynil. In our study we observed increasing presence of *Ambrosia artemisiifolia*, *Chenopodium album*, *Galinsoga ciliata* and *Panicum dichotomiflorum* in the non-chemical system in comparison with the chemical system. No differences of weed infestation were recorded among varieties. The yield obtained was about 4 t ha$^{-1}$ in both chemical and mechanical weed control strategy.

**Keywords:** polenta; local biodiversity; flint corn; phytotoxicity; weed control

## Introduction

A cauldron hanging from the chain of the stone fireplace in an old Italian farmhouse, a woman's hand turning a golden treasure within the smoking cauldron, the snow slowly falling outside – there is a lot of poetry in this imaginary picture, and in this romantic image the 'polenta', a traditional peasant food obtained from boiled flint maize meal, is the focal point. No other food source in Italy was as commonly used as polenta, and no other food had saved the population from hunger and famine as it had (Biasin 1994).

Cristoforo Colombo wrote in his diary on 5 November 1492 that the crew received a kind of grain crop called 'Mahiz' from the indigenous population. But they did not know that several cultures, such as the Mayas, Incas and Aztec, had lived and also prospered with this crop (Brandolini 1970; Biasin 1994). The first report of maize (*Zea mays* L.) cultivation in Europe dates back to 1500, when it was grown for botanical interest in Madrid and the Andalusia region (Brandolini and Brandolini 2009). In Italy it was certainly introduced before 1539, because Venetian traders sent grain samples in Germany to the botanist Bock, who gave a description of the plant, but after some years this species disappeared from the literature. The diffusion of maize into Europe started from Veneto, the region of the famous Venetian merchants. Thanks to the well-known Venetian ability to trade all over the world, Venetians started not only to consume and appreciate maize, but also to spread it throughout the world (Rebourg et al. 2003). This plant was immediately introduced in normal crop rotation and maize was commonly used in traditional cuisine. Notice of maize cultivation in Italy started in 1554 in the Polesine di Rovigo area and around the city of Verona (Paoletti and Lorenzoni 1989). Despite the positive flavour obtained by this cultivation, some populations associated diseases like pellagra (vitamin deficiency) to the crop (Hampl JS and Hampl WS 1997) and thereupon suddenly abandoned maize (Finan 1948).

The rural population of Italy continued to produce maize, especially for its easy cultivation: higher yield level with reduced labour than other crops at that time, making it an important part of the traditional poor cuisine (Leng et al. 1962). The maize grain yield obtained from the surface was approximately 3 million tons. At that time it was estimated that at least two-thirds of all grains were eaten as polenta (Biasin 1994), replacing wheat bread and thereby saving more than 1 million tons of winter wheat. Until the utilization of the modern combine harvester, cereal grains such as wheat, barley and oats were collected earlier with complete maturity generally obtained in the farmyard or field. This agricultural practice permitted the removal of the previous crop in early summer, allowing the use of the land for the following harvest. In many cases the successive crop was represented by maize, particularly in irrigated areas.

In 2006 more than 1.4 million hectares maize was grown, a roughly stable area since the beginning of the twenty-first century. Its associated production was around 9 million tons, with an obtained yield of more than 99% with hybrid varieties (Sismondo 2008). This production was primarily used as animal feed, in the form of grain or silage (Barrière et al. 2010). Increased meat consumption in the modern Italian diet, which started since the second half of 1900, led to increased maize yields, after the

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introduction of hybrid varieties from the United States, thus relegating flint maize for polenta to small domestic scale (Ferrero et al. 2007). Significantly increased maize yield and the effective cost–benefit ratio strongly favoured the hybrids (Griliches 1957, 1958, 1980). Italian farmers hesitated to abandon old flint varieties mainly due to seed costs and the impossibility of utilizing the seeds obtained from the hybrid cultivation in the following years, as well as the lower quality of dent maize hybrids for human consumption (Duvick 2001).

The widespread utilization of hybrid varieties from 1950 completely changed the situation for the cultivation of maize, as it led to the progressive replacement of traditional flint maize by dent hybrid varieties. Over the last few decades, flint maize has been conserved in gene banks. In Italy, flint maize varieties are still cultivated, particularly in the mountain regions where traditional farming systems are still utilized. Their cultivation is linked to the production of polenta, for which dent maize is not as suitable as flint maize, from a milling point of view (Venturelli et al. 1990).

In the era of modern agriculture, dent maize hybrids are universally cultivated, increasing the demand for natural and traditional foods; the rediscovery of old tastes, such as polenta, represents niches that farmers are trying to capitalize upon. In particular, the combination of products related to peasant traditions may represent an important source of income for low-input agricultural systems. Nowadays these varieties are mainly cultivated in organic farms for the higher remuneration of the product obtained with this system.

A farmer Antonio Fioretti started cultivating in 1890 in Marano Vicentino (Northern Italy) with an accurate selection of plants with at least two well-developed cobs. For several years Fioretti decided to select for quality and ear healthiness, with the goal of obtaining a higher yielding variety. Fioretti's sons continued this practice until 1934, when the Experimental Station on Maize (Stazione Sperimentale di Maiscultura) in Lonigo decided to spread the variety in the Vicenza area, with a restriction to the cultivation of other varieties around Fioretti's farm: in order to avoid pollination from other maize selections. In 1940 this variety, called Marano, gained the national trademark. Marano presented a cylindrical size ear, generally no longer than 20 cm, with red orange kernels and white cob. The production was about 4 t ha$^{-1}$, with a 65% grain milling efficiency and a weight of 165 g 1000 seeds$^{-1}$ (Zapparoli 1939b).

Even though the exact origin of the Nostrano dell'Isola is unknown, this variety was cultivated in the area between the Adda and Brembo rivers and in the central part of the Lombardia region. This variety showed important agronomic traits such as resistance to drought stress and high adaptability to different environmental conditions and presented excellent milling qualities. By contrast, it showed high variability in plant height, length of the growing cycle and kernel aspect. An ear of Nostrano dell'Isola is generally longer than that of Marano, usually reaching more than 30 cm and 200 g 1000 seeds$^{-1}$ weight, characteristics which allow this variety to attain higher yielding results than that obtained with Marano. Kernel colour is intense orange (Zapparoli 1939a; Brandolini 1970). Today the potential production ranges from 3.5 t ha$^{-1}$ in poor soil to 9 t ha$^{-1}$ in favourable conditions (Ferrero et al. 2007).

The Pignoletto varieties were almost abandoned at the end of Second World War. The origin of this variety is unknown; it was primarily cultivated in the Piemonte region (north-west Italy). The name of this variety comes from the ear shape and the particular tip on the kernel which resembles the form of a pine cone, called 'pigna' in Italian. The ear is conic, with red-orange kernels, is tipped at the end and has more than 210 g 1000 seeds$^{-1}$ weight. Following the classification made by FAO for hybrid maize varieties, the maturity cycle of this variety may be compared to FAO group 300–400 as it flowers and matures earlier than Marano and Nostrano dell'Isola, but the yield might be compared to that obtainable with the latter (Ferrero et al. 2007).

Ottofile has a literal translation of 'eight rows', due to the fixed number of kernel rings per ear. This variety was widespread throughout northern Italy, and Ottofile is therefore considered typical in several regions. The limited number of seeds produces bigger kernels (300 g 1000 seeds$^{-1}$) and presents this variety as one of the best grain milling qualities for polenta. Kernel colour is orange-yellow, with a cylindrical ear and completely white cob. Compared to the other flint varieties Ottofile requires the longest growing cycle (Ferrero et al. 2007).

Despite the increasing interest in these varieties, little information is available in literature regarding the management of old maize flint. Several cultivation trials have been carried out at a national level, primarily focusing their attention on total yield, but due to the high natural variability of flint varieties, results may vary across cultivated areas. Beside the assessment of the potential yield level obtained with some of the most common flint varieties cultivated at the beginning of the last century in northern Italy (Marano, Nostrano dell'Isola, Pignoletto and Ottofile), this study also evaluated the adaptability of these varieties on weed control strategies of both chemical and non-chemical systems.

## Methods

### *Experimental plan*

The study was conducted in 2008 on the farm of the Park of the 'Villa Cavour', located in the town of Santena (north-west Italy). Annual mean temperature was 11.4°C, with a maximum temperature of 33°C recorded in July, and annual average rainfall of 751 mm, with almost 400 mm falling during the maize cultivation season. The experiment took place on a sandy-loam texture alluvium soil (Typic Udifluvents) with a pH 7.6. At 0–30 cm the sand, silt and clay contents of the soil were 480, 430 and 90 g kg$^{-1}$, respectively. Organic C was 11.5 g kg$^{-1}$ and organic N was

1.39 g $kg^{-1}$. The field was ploughed at a depth of 35 cm on 25 April, following a harrow application the same day. All plots were broadcast fertilized with 150 kg $ha^{-1}$ of nitrogen fertilizer (46% of N), 100 kg $P_2O_5$ $ha^{-1}$ and 200 kg $K_2O$ $ha^{-1}$ after ploughing in the chemical plots, while similar quantities of nutrients were applied with 4.5 t $ha^{-1}$ of farmyard manure in the non-chemical plots. Seedbed preparation was obtained with a single passage of a rotary harrow. Marano, Ottofile, Pignoletto and Nostrano varieties were obtained from the Department Agroselviter. The hybrid variety Maranello (FAO 400), obtained from the variety Marano, was included in the study as a reference. All varieties were seeded on 28 April with a pneumatic machine operating at 0.75 m between rows and 0.21 m on rows to deliver 63,800 seeds $ha^{-1}$, while the hybrid Maranello was seeded at 0.19 m on rows with a total density of 70,200 seeds $ha^{-1}$. Flint varieties were seeded at lower density in comparison with the hybrid Maranello due to the leaves' architecture. Leaves in hybrid varieties present an angle closer with the stalk and may tolerate higher density (Pendleton et al. 1968).

Experimental plots were 4.5 m wide × 30 m long, with three replications. Plots were arranged in a completely randomized block design. Weed control was carried out in chemical plots utilizing a single herbicide application composed of 56.25 g a.i. $ha^{-1}$ of foramsulfuron and 264 g a.i. $ha^{-1}$ of bromoxynil when the maize reached the 4-leaf stage. Herbicides were applied using experimental equipment with three nozzles mounted on a 1.5 m spraying bar, adjusted to deliver 400 l $ha^{-1}$. In the non-chemical system, weed management was attained only by mechanical means, before crop emergence, utilizing a spring tine harrow working at 7 km $h^{-1}$. After emergence, two in-row harrowing passages at 3–4 and 6–7 leaf stages, respectively, were applied at a speed of 6 km $h^{-1}$. The second application was coupled with a ridge till harrow. No irrigation was applied during the growing season due to the high level and uniform distribution of precipitation that occurred.

Weed presence, density and ground cover due to weeds, was determined 44 days after seeding (7–8 leaf stage). The effects of the weed control strategy adopted were evaluated using the guidelines EPPO/OEEP n. 62 by attributing a score value ranging from 0 (no phytotoxicity towards crop) to 100 (crop destroyed) at 6, 12 and 18 days after the herbicide application or from the last in-row harrowing in non-chemical plots, respectively. The reference for crop damage was represented by corn plots of all varieties in which weeds were removed manually. Yield and moisture content of maize grain were obtained on 9 October by manually harvesting the cobs of the whole plot, and subsequent graining.

Data collected were subjected to ANOVA analysis with the statistical software SPSS (version 16.0 for Windows, SPSS Inc., Chicago, IL, USA), and groups of homogeneity were detected with the Tukey post hoc test. Before ANOVA the data were tested for homogeneity utilizing the Levene test. The effects of this cropping system on weed composition were assessed using a paired sample $t$-test. Crop damage coming from the different assessment dates were pooled together after evaluation with a $t$-test ($P \geq 0.05$).

## Results

### *Weed infestation*

Crop emergence occurred 8 days after seeding (5 May) for the hybrid Maranello, while all other varieties required two more days. The application of spring tine harrowing delayed weed emergence in non-chemical plots, in comparison with that of chemical, in which no weed control was carried out at that time. Considering the singular species recorded in the weed flora (Figure 1), in comparison with the chemical plots, in the non-chemical system higher presence of *Ambrosia artemisiifolia* L., *Chenopodium album* L., *Galinsoga ciliata* (Raf.) SF Blake and *Panicum dichotomiflorum* Michx. was recorded. Overall *A. artemisiifolia* was the most represented dicot weed, while *P. dichotomiflorum* was the most abundant monocot species. The species *Artemisia vulgaris* and *Setaria viridis* were completely controlled by herbicide treatment.

No variety effect was recorded on total weed density and ground cover, while important differences were observed between the weed control methods, showing a weed density lower than 85% in chemical plots in comparison with the non-chemical system (Table 1). Between the two weed control methods, a 64% difference in terms of ground cover caused by weed pressure was observed. The absence of differences among the varieties in terms of weed infestation likely demonstrated that the competitive ability against weed is similar, even between the group of the chemical varieties and the hybrid Maranello. Even if not significant, in terms of weed density a lower weed control was observed with the variety Pignoletto in both chemical and non-chemical weed control systems.

### *Crop damage and crop yield*

The effect of mechanical weed control strategies, not always selective against maize, was never higher than 20, considering a scale from 0 (no damage) to 100 (crop completely destroyed) (Figure 2). Even if not significantly different, herbicide application had the least affect on crop growth; in fact the highest damage recorded was about 6 in Ottofile, followed by Marano and Nostrano ($p \geq 0.05$, Figure 2). The hybrid Maranello showed the least injury level, both with herbicide treatment and after mechanical weed control strategies. Similar behaviour with respect to mechanical interventions was observed with Pignoletto and Nostrano dell'Isola, even if the latter variety suffered a slightly higher damage due to herbicide treatment. Ottofile was the most susceptible variety to weed control strategies, followed by Marano. The symptoms observed on Maranello due to bromoxynil application were similar to those recorded on the other varieties, visible by necrosis of the peripheral part of the leaf.

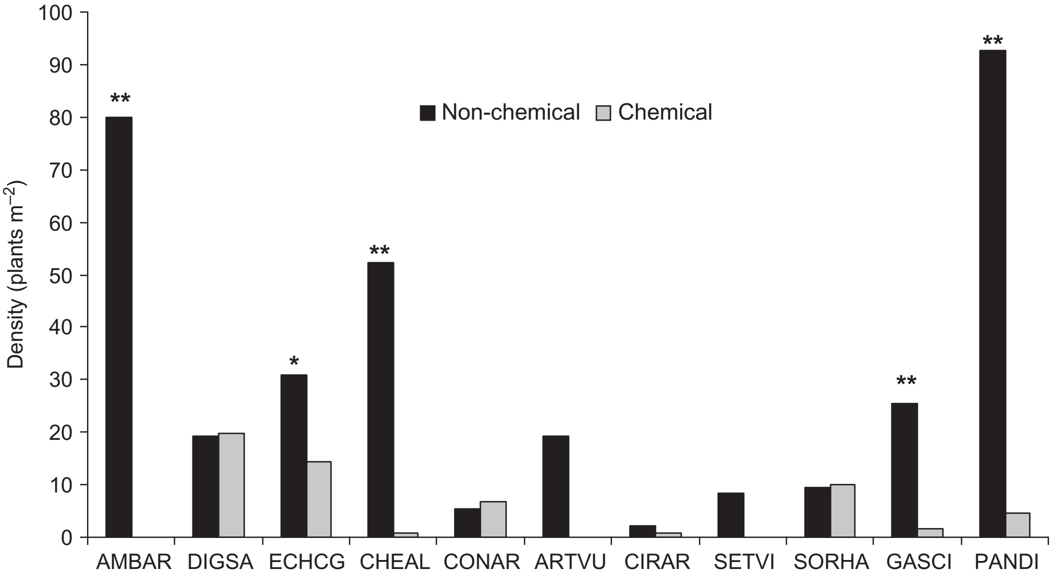


Figure 1. Weed composition assessed with maize at 7–8 leaf stage.
Notes: Significant differences between weed control systems are indicated for $P \geq 0.05$ (with *) and $P \geq 0.01$ (**). AMBAR, *Ambrosia artemisiifolia*; DIGSA, *Digitaria sanguinalis*; ECHCG, *Echinochloa crus-galli*; CHEAL, *Chenopodium album*; CONAR, *Convolvulus arvensis*; ARTVU, *Artemisia vulgaris*; CIRAR, *Cirsium arvense*; SETVI, *Setaria viridis*; SORHA, *Sorghum halepense*; GASCI, *Galinsoga ciliata*; PANDI, *Panicum dichotomiflorum*.

Table 1. Weed presence assessed with maize at 7–8 leaf stage (± SE with $n = 9$).

| Variety | Weed control system | Density (plants m$^{-2}$) | Ground cover (%) |
|---|---|---|---|
| *Marano* | Non-chemical[b] | 320.0 ± 48.88 | 68.3 ± 3.33 |
| | Chemical[a] | 48.0 ± 24.44 | 21.7 ± 1.67 |
| *Nostrano* | Non-chemical[b] | 314.7 ± 53.33 | 56.7 ± 3.33 |
| | Chemical[a] | 53.3 ± 32.44 | 11.7 ± 4.41 |
| *Ottofile* | Non-chemical[b] | 277.3 ± 14.11 | 61.7 ± 7.26 |
| | Chemical[a] | 21.3 ± 10.67 | 28.3 ± 1.67 |
| *Pignoletto* | Non-chemical[b] | 352.0 ± 117.94 | 55.0 ± 7.64 |
| | Chemical[a] | 69.3 ± 37.33 | 26.7 ± 11.67 |
| *Maranello* | Non-chemical[b] | 309.3 ± 14.11 | 55.0 ± 2.89 |
| | Chemical[a] | 37.3 ± 5.33 | 18.3 ± 4.41 |

Note: [a] and [b]indicate significant differences between weed control system (Tukey post hoc test with $P \geq 0.05$).

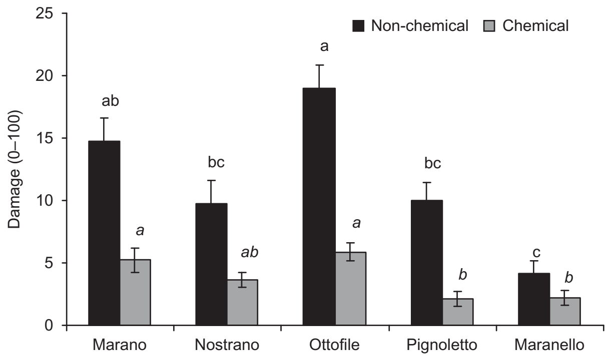


Figure 2. Damage caused by weed control strategies (herbicide treatment or mechanical applications).
Notes: Bars refer to standard error of mean ($n = 9$). Values sharing the same letter are not significantly different in non-chemical (normal letters) and chemical (italic letters) systems (Tukey post hoc test with $P \geq 0.05$).

Grain yield collected in the plots was about 8 t ha$^{-1}$ for the hybrid Maranello and 4.5 t ha$^{-1}$ for the other flint varieties (Figure 3). By contrast no differences were observed between the non-chemical and chemical yields and among the flint varieties. Among the traditional flint varieties Nostrano dell'Isola had the highest yielding level in non-chemical cultivation while Ottofile was the most productive in chemical cultivation. The highest moisture content was observed in the non-chemical plots, in Ottofile, Pignoletto and Maranello in particular, with more than 25% (Figure 4). In the case of chemical weed control only Maranello resulted in a higher moisture content in comparison with the other varieties. Marano and Nostrano dell'Isola were the varieties with the lower moisture content in both weed control systems. Surprisingly, even if Pignoletto was the variety with the longest growing cycle, it showed a moisture content similar to the other flint

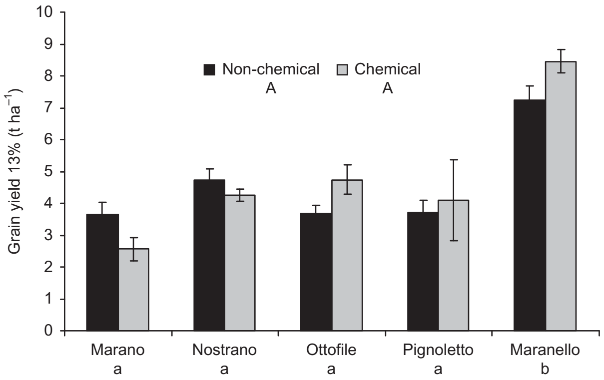


Figure 3. Maize grain yield at 13% moisture content.
Notes: Bars refer to standard error of mean ($n = 3$). Values sharing the same letter are not significantly different (Tukey post hoc test with $P \geq 0.05$). Uppercase and lowercase letters refer to weed control systems and varieties, respectively.

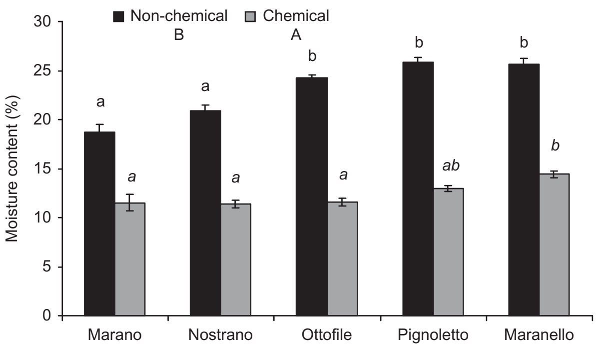


Figure 4. Moisture content at harvest.
Notes: Bars refer to standard error of mean ($n = 3$). Values sharing the same letter are not significantly different (Tukey post hoc test with $P \geq 0.05$). Uppercase letter refers to weed control systems, while lowercase and italics letters refer to differences among varieties in non-chemical and chemical systems, respectively.



varieties in chemical cultivation and higher in the case of non-chemical cultivation.

## Discussion

The varieties included in this study confirm their ability to be cultivated in both chemical and non-chemical systems. The similar yield level observed between the two weed control systems suggests that the cultivation of these varieties may be more profitable if cultivated with the non-chemical weed control methods as a higher price can be obtained. Moreover, all varieties considered completely recovered from the damage caused by mechanical weed control. A description of these varieties is also given, as their characteristics are generally only reported in Italian, even if their cultivation can be extended to other areas with similar climatic conditions.

This study can contribute to the lack of knowledge regarding the sensitivity of flint varieties, non-hybrid varieties in particular, to herbicides (Bunting and Blackman 1951). In fact, Pignoletto presented similar growth inhibition to the hybrid Maranello, and even if the other flint varieties presented a higher level of injury, this damage did not significantly affect the final yield.

The introduction in the crop rotation of the old flint maize varieties may furnish a new source of income for marginal fields, for the promotion of maize flour in farmer markets or as attraction for the gastronomic rural tourism. Moreover, the grain yielded can be used as seeding material for the following year contributing to the sustainability of the system at farm scale. The old flint corn varieties, such as varieties of other crops, have been generally selected for pest resistance, drought stress, competitive and allelopathic traits and adaptability to several environmental conditions (Tesio and Ferrero 2010). For these reasons, the described varieties may be used by farmers who wish to reduce the inputs into the cropping system.

## Conclusion

With the final aim of attaining a sustainable crop production, an adequate income level for farmers operating in marginal rural areas, together with the maintenance of an important genetic biodiversity, this study indicates that old flint corn varieties cultivated in Italy in the past can be profitably grown in both chemical and non-chemical weed control systems.

Moreover, information regarding the characteristics of these genetic materials can be used for the selection of new varieties, or hybrid varieties, with similar positive traits (Bitocchi et al. 2009). Further work should be done to strengthen the attention on the evaluation of the response of local flint varieties under different environmental conditions, particularly taking into consideration all the yielding parameters such as the specific weight and the milling quality.

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