Sustainable hybrid rice cultivation in Italy. A review

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REVIEW ARTICLE

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Abstract Rice (*Oryza sativa* L.) is the premier food crop in the world, being a major staple food for more than half of the world's population. The potential for a further increase in grain yield will be limited in the future, and more food will need to be produced from the same available arable land. Italy has a long history of rice cultivation, but is now facing challenges to develop new strategies to maintain competitiveness of this sector in the global market. To prepare for the inevitable reduction of both rice prices and incentives from the European Community, and market protection, growers are evaluating the potential of hybrid rice cultivation to increase yields and maintain high quality standards for milling industries. Here we reviewed the characteristics of the Italian rice sector and the first experiences of hybrid cultivation in north Italy during 2012, using them to project the potential challenges and opportunities for both breeders and rice growers. If well managed this technology can represent a solution for sustainable rice production in Italy and in the other European rice growing countries. With hybrid vigor increased yield are obtained from reduced seed rate, lower nitrogen fertilizer, lower reliance on chemical treatments to control diseases, which helps compensate for the increased seed costs. Moreover, partially in contrast with current beliefs, it is shown that it may be possible to produce rice in rather rich countries obtaining a local production.

Keywords Hybrid rice · Price reduction · *Oryza sativa* · Clearfield®

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1 Introduction

In terms of foreign exchange, rice (*Oryza sativa* L.) is one of the most economically important crops in Italy, with a cultivation area that is mostly located in the Po Valley in the provinces of Alessandria, Ferrara, Novara, Pavia, and Vercelli, and to some extent in Sardinia, in the southern part of the Country (Fasola and Ruiz 1996). Altogether these areas are actually the largest rice producers in the European Union, accounting for almost 2/3 of European rice production. Rice grown there is mainly exported to other EU countries within the Mediterranean basin and Eastern Europe (Russo and Callegarin 2007). During the period 2001–2012, the Italian rice growing region reached a peak of almost 247,000 ha in 2010, and then showed a decreasing tendency in 2011 and 2012 (Fig. 1). The trend of rice cultivation is cyclical, with growth periods followed by decreasing ones, and an average duration of the cycle of approximately 3 years, even if with the actual contingency the surface is expected to be reduced in the following years (Ente Nazionale Risi 2013). The steepest surface growth was recorded from 2008 to 2010, mainly due to the positive price conditions and the higher incentives provided by the Community Agricultural Policy (CAP) to rice sector in comparison with other cereals (Frandsen et al. 2003; Rude 2008). The privileges granted to rice producers were due to the multiple benefits of this crop. In addition to its role in providing nutrition, rice cultivation helps

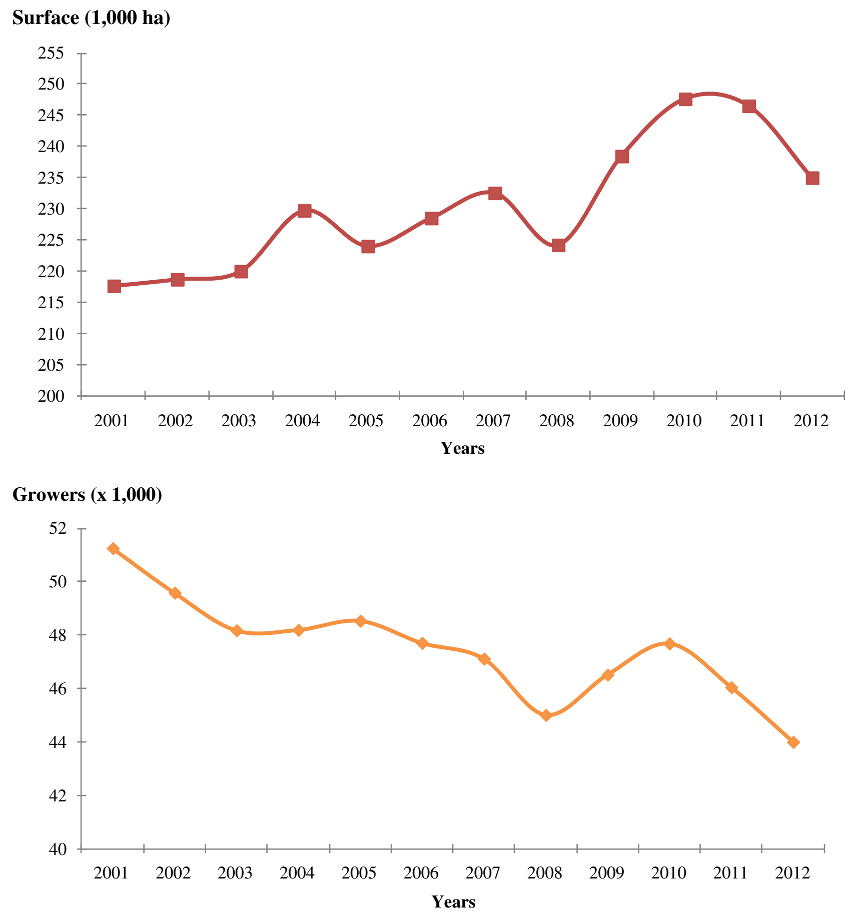

Fig. 1 Rice surface in Italy (*above*) and number of rice growers (*below*) during the period 2001–2012 (source: Ente Nazionale Risi 2013). The combination of the two trends indicates the increased average surface per each rice farm, and an overall reduction of rice cultivation

sustain the management of wetland ecosystems (Longoni et al. 2007), forms an integral part of managing water system in these regions (Zedler and Kercher 2005), prevents salination of farmland (Kotb et al. 2000), and provides important breeding grounds for waterfowl (Fasola and Ruiz 1996) as well as offering unique landscapes for local populations (Busch 2006).

The free trade meeting of the World Trade Organization has frequently identified agricultural subsidies as an area needing reform, especially in the European Union CAP (Yu et al. 2002). Moreover, public opinion is currently questioning the benefits of subsidies paid to intensive agriculture, rather than a more focused payment to sustainable agricultural practices (Latacz-Lohmann and Hodge 2003). Public concern, together with the enlargement of the European Community to include eastern countries made the current support to rice cultivation no longer financially viable, with a constant decrease in subsidies received by farmers (Donald et al. 2002; Erjavec et al. 2009).

The trends observed in the last years confirm that the decrease observed starting from 2003 reflect a strong market price and CAP incentive reductions (Bryden et al. 2011). The incentive received by growers for rice is becoming similar to that for other cereals cultivated, with a direct effect on the planned crops (Moro and Annesi 2012). In these years, rice growers look more to crop market prices to plan crop rotation than they did in the past. The sustained prices of other commodities such as maize and soybean gained attention among farmers. While the demand for biofuels was an important factor in some grain markets, its influence on recent rice market behavior seems to have been tangential at best (Rosegrant et al. 2008; Don et al. 2011).

Certainly, the reduction of the overall income obtainable per hectare of rice cultivation strengthens the tendency to increase average farm surface, a trend that began in the second half of the previous century (Lambert 1963). A reduction in the number of growers is related to the increased farm surface (Fig. 1), and aging of growers (Potter and Lobley 1992; Busch 2006). Even if an important increase in the number of farmers was observed from 2008 to 2010, this was mainly due to the positive rice quotation and CAP subsidies as reported above, factors that induced growers to come back to rice cultivation and take advantage of the positive contingency (Buckwell 2007; Laborte et al. 2012). It should be noted that rice cultivation requires particular environmental conditions (weather and soil type) and a constant amount of water availability (Gravois and Helms 1992; Bouman et al. 2007), thus a rapid increase of farm surface to compensate for lack of remuneration is not realistic in the short and medium terms.

Rice is divided into three commodity types based on seed size: long grain, medium grain, and short grain. Long grain rice is the most versatile and popular worldwide (Redona and Mackill 1998). The grains remain firm, fluffy, and separate when cooked. It can, however, become sticky if overcooked or stirred frequently during cooking (Golam and Prodhan 2013). Short grain rice has a higher amylose/amilipectine ratio becomes quite tender and sticky when cooked (Williams et al. 1958; Suwannaporn and Linnemann 2008; Kasem et al. 2012). A singular division, based on seed size, characterizes the rice market in Italy: round medium (internationally recognized as short grain), long A "parboiled," long A "risotto" and long B (Juliano and Hicks 1996; Mohapatra and Bal 2006). This two kinds of long grains (A and B) differ from each other in that long A grain presents a length–width ratio between 2 and 3, while long B grain shows a ratio higher than 3. During the last 10 years, the market share of the different grain types cultivated has changed (Fig. 2). Despite a consistent cultivation of medium grain, a decreasing tendency was observed for long A parboiled and other grain types cultivated mainly for export. By contrast, a growing tendency was recorded for round, long A "risotto" and long B, likely due to the better quotation obtained.

Over the last few years, major changes to the European Community rice regime and resetting of European import tariffs for rice have led to a fundamental reshaping of the rice market. The general quotation declined, particularly for short- and medium-grain varieties (Dawe and Slayton 2010). On average, rice quotation in the period ranging from the end of the year through late spring gives growers a higher price window, in particular for long A grain for internal market as risotto. Varieties included in this group historically achieved better prices and were thus able to cover the higher production costs. In the last commercialization seasons, this trend was not recorded, and long A grain for national market suffered the most net income reduction (Pesolillo et al. 2012). The long B grain advantage is represented by production costs being generally lower than the long A varieties, and a slightly higher yielding performance (Fan et al. 2000; Ferrero and Tinarelli 2008).

Cultivation of varieties belonging to long B group increased 45 % from 2001 to 2011. On top of the more interesting turnover for this grain class, an important influence to surface growth was recorded in 2007 and 2008 thanks to the introduction of Clearfield® technology (Ferrero and Tinarelli 2008). During cultivation, the Clearfield system for rice is currently the only mechanism that rice producers have to control red rice (*O. sativa* L.); the weed and the crop belong to the same genus and species, and therefore having the same sensitivity to herbicides (Rao et al. 2007; Andres et al. 2012). This technology consists of crops developed with traditional plant breeding to obtain plants resistant to imidazolinone herbicides, for example imazamox in Europe or imazethapyr in Brazil (Fig. 3). Non-tolerant plants such as red (or wild) rice seedlings are therefore controlled by the herbicide treatment without affecting the tolerant crop (Steele et al. 2002; Sha et al. 2007; Kuk et al. 2008).

Rice has long been the subject of research around the world and today this includes the field of modern plant biotechnology (Tu et al. 2000; Bajaj and Mohanty 2005; Chen et al. 2011). Although research continues, the European authorities have approved no genetically modified rice varieties (Levidow et al. 2000), a decision ratified by the Italian government.

2 Hybrid rice

Commercial exploitation of hybrid vigor is one of the most important applications of genetics in agriculture (Duvick 1999). It has not only contributed to food security, but has

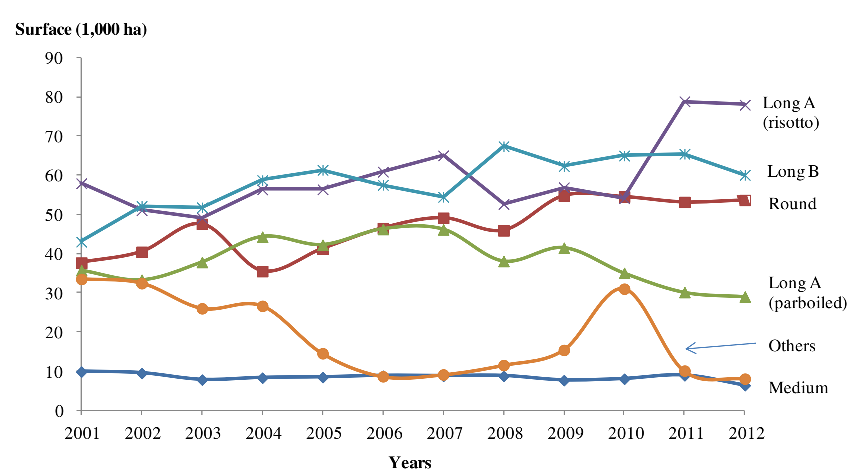

Fig. 2 Surface distribution (in hectare) for the different rice grain types (data from Ente Nazionale Risi—http://www.enterisi.it/servizi/notizie/notizie_homepage.aspx) during the period 2001–2012. Over this period, a growing tendency was recorded for round, long A "risotto" and long B

Fig. 3 Temporary damage on Clearfield® hybrid rice of treatment with imazamox and the adjuvant Dash

also established the basis of a billion-dollar agribusiness that has generated significant employment opportunities all over the world (Kloppenburg 2005). Paul Mangelsdorf, a maize geneticist, went still further, asserting that hybrid varieties had contained the spread of Communism after World War II by ensuring an adequate food supply for a decimated Western Europe (Wolfe 2012).

Since the release of hybrid rice in China during the 1970s, the cultivated area has increased consistently (Peng et al. 1999). In this country, hybrid varieties could obtain about 30 % grain yield advantage over inbred (pure-line) varieties. In the first 20 years of cultivation, hybrid rice was cropped on about 50 % of the national rice surface, and helped China to increase rice yield from 5.0 t/ha of conventional rice to 6.6 t/ha, reaching consistently 7.5 t/ha in the Sichuan province (Yuan 2003). Hybrid rice has now become a commercial success in several Asian countries, such as Vietnam, India, the Philippines, Bangladesh, and an estimated 6 million ha of extra production area would be required if hybrid rice had not been developed (Tu et al. 2000). In the last few decades, USA, Brazil, and other southern American countries have also begun the commercial production of hybrid rice.

Hybrid rice not only has a distinct yield advantage over conventional varieties, it is more reactive to fertilizer and more adaptable to different environments than conventional varieties. These traits however are sometime associated with vulnerability to disease epidemics and insect outbreaks—related to the presence or absence of resistant genes in the parental lines—with the incidence of insect pests, especially stem borers, and diseases more frequent in hybrid rice than in inbred varieties (Tu et al. 2000). Several researchers improved hybrid rice resistance through the addition of resistance genes to many diseases, both with normal breeding and genetic engineering (Song et al. 1995; Zhu et al. 2000).

The cytoplasmic male sterility, a genetic system that maintains male sterility, and a genetic system that restores male fertility are generally accepted as the necessary basics for producing hybrid seed of crops (Huang et al. 2013). Hybrids possessing positive traits become potential targets for the transfer of key genes (genes for fertility restoration, cytoplasmic male sterility, photosensitive or thermosensitive male sterility, and wide compatibility) absolutely necessary for the exploitation of heterosis in rice (Shahid et al. 2013). One of the major limitations in the successful use of the above elements in rice, as well as in other naturally self-pollinated cereals, is insufficient pollen dispersal to ensure economic production of hybrid seed. Thus, the low rate of viable F_1 seeds obtained make seed production cost higher than a normal inbred variety. Screening combinations for superior F_1 performance and strong heterosis is the most costly and time-consuming process in hybrid rice breeding programs. It has been estimated by Xiao et al. (1996) that at least 20,000 rice crosses were made and evaluated in fields each year at Hunan Hybrid Rice Research Center—China, to identify combinations possessing high yielding potential.

3 Why hybrid rice in Italy?

The risky nature of the agricultural business is a key factor in farmers' acreage allocation and input use decisions. Risk perception may play a pivotal role in determining the willingness to adopt a new crop or even only a new cultivation technique. In fact, if allocating land to different species or different techniques is a risk-reducing strategy, the risk-averse farmer would broaden the techniques (Harwood et al. 1999). In the Italian rice-growing area, where this crop is the prevalent cultivation, farmers tend to increase techniques rather than change species (Stoate et al. 2001; Tesio et al. 2013).

For many decades, governments around the world have intervened in order to try to help farmers cope more effectively with risk. Both national and international developments have led many countries to re-address their agricultural policies toward deregulation and a more market-oriented approach (Frandsen et al. 2003). Much of the protection that many farmers had from the unpredictable volatility of quotations has therefore been removed. Higher protection, mainly in the form of superior market price and incentives, is still active for organic farming. This strategy was followed with variable success in rice crop, mainly related to mycotoxins (González et al. 2006; Badgley et al. 2007) and weed control in this particular environment, where plant infestation is closely related to the aquatic ecosystems (Clark et al. 1999; Bàrberi 2002; Tesio and Ferrero 2010).

To counter the reduction of rice price, CAP incentives, and market protection, the first attempts of growers were to reduce costs and/or to increase grain yields. Since several agronomic practices for rice cultivation such as fertilization, soil tillage, and water management are already well managed by growers (Ferrero and Tinarelli 2008), another factor that could be exploited, and available in the short term, was the genetic potential (Sharma et al. 2012). The impossibility of growing genetically modified crop to improve yield performance in Italy, as well as in the other European rice producing countries, increased the interest in cultivating hybrid rice varieties.

4 First experiences of hybrid cultivation in Italy

Even if at experimental scale some varieties were cultivated on some hectares in 2010 and 2011, the first hybrid registration, with the cultivar CL XL 745 of RiceTec Inc (USA), occurred in Italy at the end of 2011, enabling cultivation during the 2012 growing season. This hybrid was developed for the US market, has a medium–long growing cycle (about 150 days), and endows the Clearfield® technology. In 2012, the provinces interested in the cultivation were Alessandria (AL), Milano (MI), Pavia (PV), Novara (NO), and Vercelli (VC), all located in the northwestern part of the Country. The surface dedicated to cultivation was almost 1,800 ha, about 0.8 % of the total rice growing area, but equal to 3 % of all long B varieties, and 4 % of the Clearfield® genotypes (long A and long B), in comparison with the previous year (2011).

Recommended seed rate was 26.5 kg/ha, in order to obtain an optimal density of 80–100 plants/m^2. Sowing in dry soil conditions was needed according to the seeding rate, which was far lower than that generally used for conventional varieties (from 100 to 180 kg/ha). Due to the growing cycle, the suggested seeding period ranged from the end of March to the first half of April. Despite that, the highest volume of rain occurred from the end of March through the end of April, which delayed several sowings and the emergence of seedlings planted before the rain period. The combination of rainfall and lower temperatures in comparison with the long term trend resulted in soil saturation with a consequent reduction of plant density, ranging from 20 to 50 % lower than optimal in almost all provinces.

Fertilization was carried out with an amount similar to conventional varieties, but nitrogen fraction broadcasted during the beginning of tillering stage (BBCH 20-21) was higher, to promote tiller proliferation. The hybrid vigor was particularly evident in this stage, as tillering ability was expressed at best due to low plant density, with an average number of tillers per plant higher than 20 (Fig. 4), in comparison with the two to three of a similar inbred variety. To facilitate a fast establishment of the crop, weed competition during the first stages was in almost all cases avoided thanks to pre-emergence treatments with pendimethalin or oxadiazon, or with a mixture of the two active ingredients. Red rice and remaining weeds were controlled with two post-emergence applications of imazamox (Beyond) at rate of 35 $g_{a.i.}$/ha plus the adjuvant Dash HC (0.5 %*v*/*v*). In some cases, additional treatments were required, as suggested in both conventional and Clearfield® varieties, to control difficult infestations of *Echinochloa* spp. populations or species belonging to Cyperaceae family such as *Cyperus difformis* L. and *C. esculentus* L., or *Murdannia keisak* (Hassk.) Handel-Mazz (Catizone 1983; Vidotto et al. 2007; Ferrero et al. 2012).

Fig. 4 Evidence of tillering ability due to hybrid rice vigor. Picture taken at the moment of harvest in Vercelli

The delay that occurred during April and May was widely recovered in the growing season. The stabilization of temperatures to values similar to those of the long-term trend together with a reduced number of rainy days permitted the crop to receive a good amount of light and adequate temperature needed to reach maturity. Days from sowing to 50 % of rice flower heading (BBCH 55) were subjected to the regression analysis using a logistic model (Ritz and Streibig 2005). From the fitted curve, it is possible to appreciate the flexibility of the hybrid as the days to reach BBCH 55 ranged from 135 to 105 when sowings were carried out at the end of March or at the beginning of May, respectively (Fig. 5). The model used indicates the first 10 days of May as the asymptotic lower limit, meaning that starting from that period further reduction in the growing cycle was no longer possible for the considered growing season.

Only a very small occurrence of disease was observed in hybrid rice. This is mainly due to the intrinsic high blast (*Pyricularia oryzae*) resistance (Branson *et al*. 2008) together with a medium-low infection risk recorded during the season.

Harvest operations started around September 10 and finished before the end of October thanks to the positive weather conditions. Yield obtained varied greatly among provinces and also among growers due to the unfavorable weather conditions recorded during the beginning of the

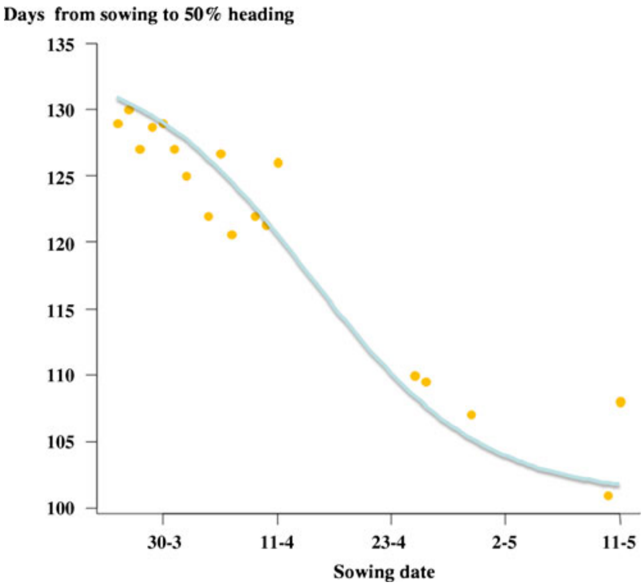

Fig. 5 Regression between days from sowing to 50 % of flower heading (BBCH 55) and sowing data indicating the flexibility of the hybrid in the considered period

season. Despite that, the average grain yield was higher than 9 t/ha at 13 % moisture content, with 13 % of fields with more than 10 t/ha and 3 % higher than 11 t/ha. The grain moisture content at harvest was about 22 %. Using the yield response obtained in 90 farms that cultivated both the hybrid rice and the traditional inbred Clearfield® varieties, a comparison was carried out. Considering data for each province, the best performance was attained in Milano as more than 25 % of yield gain was attained on conventional varieties (Fig. 6). Yield can also be considered higher than inbred varieties in Alessandria (+14 %), Novara (+8 %), Pavia (+7 %), and Vercelli (+8 %). The increased yields obtainable

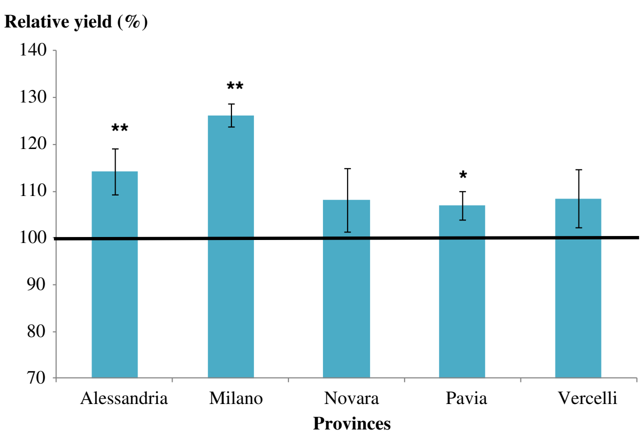

Fig. 6 Relative hybrid rice grain yield (in percent) referred to similar long B Clearfield® varieties in the different provinces. The *black line* represents the average yield of conventional varieties obtained (equal to 100 %). *Bars* represent the standard error of the mean. $**p<0.01$; $*p<0.05$ (paired samples *t* test), values significantly different from the black line

with the cultivation of the hybrid were partially frustrated by the excellent performance recorded for other similar Clearfield® varieties, seldom recorded in the area. Average head milling yield values were always higher than 60 %, with the best performance observed in Milano.

5 Challenges and opportunities for breeders and growers

As observed for other crops such as maize and sunflower, the yield advantage obtained with cultivation of hybrid varieties may cover the higher cost of seed material (Duvick 1999). In the case of rice, with the actual market price and production costs, the cultivation of hybrid become profitably if the performance is higher than 15 % of inbred varieties (Tesio et al. 2013). Already in the first year of cultivation this result was attained by part of the growers, but the technique needs to be refined by most of farmers, and tailored in the different situations. The yield advantage obtained with the heterosis in the first year in comparison to inbred check rice varieties has the potential to increase in more locations and reached by more growers.

In Italy, rice is mainly seeded in flooding conditions, where seeds are broadcasted in presence of a water layer on the paddy, but the first experiences of hybrid cultivation in this country were conducted in dry-seeding conditions. This technique simplifies sowing operations in paddy fields, as rice is distributed uniformly in the field favoring a correct seeding rate and, at the same time, a better seedling vigor during emergence. With this method, problems related to water management and straw fermentations, algae presence and animal pests are generally avoided (Harris et al. 2002). Hybrid rice capitalize on this technique for the easiness of delivering such a small amount of seed, and these conditions favor faster rooting and better tillering (Chauhan and Opeña 2013). During the last several years, an increased adoption of dry seeding was observed, particularly in Pavia and Milano provinces where a historically longer tradition of dry-seeded rice is established in comparison with Vercelli and Novara (Ente Nazionale Risi 2013). In these two provinces, the adoption of dry seeding is less widespread due to higher clay and silt contents that pose obstacles to seedbed preparation. Moreover, drainage required for dry-seeding may result difficult in small fields located among others where paddies are submerged for flooding sowing. For a wider adoption of hybrid cultivation in areas forced to seed under flooding conditions, in Italy as well as at European level, the seeding methods in these fields should be carefully evaluated. Further studies should strengthen the knowledge on the amount of seed delivered, the depth of the water layer to be maintained and the water management system, as well as the distribution of pre-soaked or dry seeds. Pre-soaked seeds may be easily distributed (less air resistance resulting in longer distance during broadcasting) and prompt germination but are, by contrast, more susceptible to mechanical damage (Ashraf et al. 2005; Farooq et al. 2011).

The first year of cultivation was carried out with a cultivar already developed for the US cultivation area, with a growing cycle considered long for the Italian climatic conditions. The hybrid demonstrated an ability to fit with the local environmental conditions and to reach maturity even with an unfavorable situation during the first part of the growing cycle, mainly because of the positive weather conditions observed during the summer. Growers decided to cultivate a variety with longer maturity because the hybrid includes the Clearfield® technology, which permits the highest red rice control during crop growth. Without the possibility of controlling red rice during cultivation, farmers generally need to proceed with the false seed bed preparation to subsequently destroy emerged weed seedlings, or with specific pre-seeding treatment, delaying seeding time to a more uncertain period. For example, in a year with an important amount of spring rain as in 2012, the false seed bed preparation to control red rice could had had further postponed dry seeding. Future hybrids released for the Italian market may take advantage of a shorter growing cycle, for a better adaptation to the local environmental conditions, and for the potential cultivation of non-Clearfield® varieties. This could also grant the adoption of hybrid rice cultivation in countries such as France, were Clearfield® technology is not yet in use.

The future potential availability of hybrid seed obtained locally could represent a series of challenges, such as the identification of the right locations for seed production and the development of man power.

The main advantage for commercial seed producers of F_1 hybrids in agriculture is the drawback of the F_2 generation. The new F_2 obtained is really variable and with lower yield and growth potential. Some of the F_2 generation will be high in homozygous genes, showing depression in yield and lacking the hybrid vigor (Zhang et al. 2008). Beside the disadvantage for growers that need to buy seeds every year, they have controlled material, free from weed seeds, red rice in particular, and habitually treated with chemicals to control soil born disease during the first growth stages. Especially with the Clearfield® technology, where plants needs to tolerate the herbicide treatment, the adoption of next generation seeds that may have partially lost this trait can result in lower plant density (Shivrain et al. 2007).

As often happens during the release of a new technology, the introduction of hybrid rice was accompanied by a series of factiousness rumors, aiming in this case to overemphasize negative aspects of the hybrid. Possible negative traits were represented by high shattering at maturity, and the consequent volunteer germination in the following year. Shattering was observed in few fields, and generally associated with plant movement caused by the combine harvester operation. The assessments carried out by the authors after harvest confirmed farmer's impressions regarding the amount of hybrid grain left on the ground, with results similar to that of other long B varieties. Hybrid shattering was likely reduced, delaying the drainage of paddy fields at harvest time. This measure probably permitted a complete maturity and avoided plant stresses at the end of the growing cycle. Volunteers may represent an issue in case of high shattering due to hailstorms. Volunteer control in the following year may be partially obtained with the cultivation of a Clearfield® variety because some seedlings will no longer include the genetic resistance against the herbicide imazamox due to segregation (Zhang et al. 2008), while decisive control is attainable with the false seed bed preparation and a subsequent herbicide treatment to destroy emerged seedlings before rice sowing. In this case, higher control can be achieved if plowing is avoided in favor of reduced soil tillage. This permits a wider range of emergence and prevents seed dispersion along the soil profile, and minimizes the risk of later emergence due to dormancy (Ferrero et al. 1996; Subudhi et al. 2012). Other efficient solutions are presented by leaving the field unplowed during the fall to permit hybrid grain germination and their death during winter, or the submersion of paddy field during the fall. Seed imbibitions result in grain death caused by the unfavorable period for rice survival during the fall–winter period (Chauhan 2012).

The hybrid cultivar used in 2012 fitted in the grid regarding product category (round, medium, long A, and long B) as long B. The future introduction of new hybrids in Italy, as well as other inbred varieties, should carefully consider the strict legislation regarding rice grain classes. The lack of fit in a class of the grain parameters with the approved grid will shift the harvested production to a generic class, with a consequent lower price paid to growers. The risk to obtain grains not classifiable in a precise group is highly perceived by farmers and warns them against cultivation of a variety without clearly defined grain type.

6 Conclusions

More food will need to be produced from the same available arable land in the near future, but the potential for a further increase in grain yield will be limited (Popp et al. 2013).

Italian dealers and millers largely appreciated the good milling quality obtained in 2012, the first hybrid growing season. The above average yield obtained with unfavorable weather conditions during the spring for direct seeded varieties, together with grain quality of the first hybrid variety used for cultivation, posed the basis for a wider adoption of this technique in Italy, as well as a possible introduction in other European rice cultivation areas that are facing the problem of decline in rice quotation and CAP incentives. In fact, in the following cultivation season the number of hectares is almost doubled, together with an increased number of interested growers. This technology can represent a bias toward the goal of a sustainable rice production as with hybrid vigor increased yield are obtained from reduced seed rate, possible lower nitrogen fertilizer and possible lower chemical treatments to control diseases, which helps compensate for the increased seed costs.

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