Impact of grapevine breeding for disease resistance on the global wine industry

L. Bavaresco[a]

Department of Sustainable Crop Production, Pomology and Viticulture Section, Centro di Ricerca sulla Biodiversità e sul DNA Antico, Università Cattolica del Sacro Cuore, Piacenza, Italy.

Abstract

***Vitis vinifera* L. is the most cultivated species in the world for grape production, covering about 94% of the commercial vineyard surface. The majority of the grapes are used for wine making, followed by fresh consumption, raisins, juices, jellies and marmalades. *V. vinifera* is protected against diseases by spray treatments that have environmental, economic and societal impacts. Wild grapevines, on the other hand, are disease resistant but of poor grape quality. A way to combine disease resistance with grape quality is breeding, which aims at obtaining new cultivars. Breeding programs were developed from the 19th century on, in both the Old (Europe) and New Worlds, as a way to promote sustainable viticulture. The main results of breeding and their impact on the production of commercial wine grapes are described, ranging from the first American hybrids to the most recent cultivars. Productive, legislative and commercial aspects for wine production are considered, especially for the European Union, where the wine sector is strongly regulated. The perspectives of breeding for disease resistance are discussed, including new breeding techniques such as cisgenesis and genome editing. The importance of interacting with society to make these innovations (obtained by both traditional and new methods) acceptable is emphasized. While fewer acceptance problems are expected with table grapes, raisins or rootstocks, more concerns can arise with wine grapes, because wine is a cultural product, especially in Europe. The role of science is to give the legislator tools to cope with sustainability and to educate society (from the grape grower to the wine consumer) to a correct understanding. Innovations can be a real advantage only if they are accepted by all actors in the wine chain.**

Keywords: hybrids, innovation, science, society

INTRODUCTION

One of the major threats to the global wine industry is the growing power of the anti-alcohol lobby (especially in Europe), which doesn't distinguish between wine and other alcoholic beverages. Wine is alcohol and alcohol is dangerous for human health, regardless of the dose. This point of view is also considered by the World Health Organisation (WHO), which includes alcohol (together with tobacco) in the list of compounds related to non-communicable diseases, and some low-cost, high-impact strategies to prevent these diseases are indicated, including tax increases, restricted access to retail alcohol, and bans on advertising (Gostin, 2014). Not everybody thinks like this, and other points of views are present, at both the scientific (Guilford and Pezzuto, 2011) and societal levels (such as Wine in Moderation, a society-responsible movement of the European wine sector). The message delivered by this association is that the abuse of alcohol (and wine) is negative for human health, but, on the other hand, moderate and conscious consumption is positive for the body and the soul (http://www.wineinmoderation.eu).

Many actions can be undertaken to face this challenge, such as those developed by the Comité Européen des Entreprises Vin (CEEV; European Committee of the Wine Industry) at

[a]E-mail: luigi.bavaresco@unicatt.it

the European Union (EU) level. Besides action from official bodies, it is crucial to create a favourable environment for conscious wine consumption, in order to demonstrate that a world without wine will be worse than a world with wine. Two main strategies can be developed, as follows:

a) To emphasize the cultural role of wine, since it has shared the history of part of humankind for millennia and is deeply rooted in many countries. Wine is a fascinating product, not only for the pleasure in sipping it, but also for immaterial aspects and emotions it stirs in the drinker; wine is rich in meaning, sometimes contradictory, representing, at the same time, science and art, history and legend, sacred and secular.
b) To promote wine as a champion of sustainability. Viticulture (for wine making) has a crucial societal role allowing agriculture to be maintained in challenging areas (very steep slopes, mountains, small islands) and providing a living for people including traditional farmers, but also former drug addicts and/or prisoners. Moreover the beauty of a vineyard landscape is beneficial for the spirit of the visitor, and beauty is a valuable amenity to be considered. The wine sector has to rely much more on environmental sustainability both in the vineyard and in the winery.

The most topical aspect of environmental sustainability in the vineyard is the reduction of inputs, especially plant protection products. In some high-vine-density areas, like Conegliano-Valdobbiadene PDO (Protected Denomination of Origin) (Italy), the population living near to growing areas is concerned about spray treatments, sometimes resulting in complaints and protests. There are many strategies to reduce pesticide impacts in viticulture (while controlling pests and diseases), such as biocontrol, the use of containment sprayers and epidemiological models, precision viticulture, and the stimulation of the natural defence mechanisms of *Vitis vinifera* cultivars by abiotic elicitors. Nevertheless, these are short-term actions, to be used every year, partially solving the problem, but allowing traditional wine-grape cultivars to be grown.

Long-term strategies to reduce spray treatments rely on the choice of proper terroirs (under low fungal pressure) and proper cultural practices (no-forcing fertilizer and water supplies), and on breeding. The latter is the most powerful tool and includes clonal selection (poor impact, mostly toward grey mould), intra- and interspecific controlled crosses, and new breeding techniques such as cisgenesis and genome editing.

TRADITIONAL BREEDING TECHNIQUES

Intraspecific controlled crosses have so far produced some botrytis-tolerant cultivars such as 'IASMA ECO1' and 'IASMA ECO2' ('Teroldego' × 'Lagrein'), and 'IASMA ECO 3' and 'IASMA ECO 4' ('Moscato Ottonel' × 'Malvasia di Candia aromatica'), obtained by FEM (Fondazione Edmund Mach) at S. Michele all'Adige, Italy (Tomasi et al., 2014). Recently, some near-eastern *V. vinifera* cultivars, such as 'Kishmish Vatkana' and 'Dzhandzhal Kara', have shown powdery mildew resistance (Riaz et al., 2013), while a Georgian cultivar ('Mgaloblishvili') showed downy mildew resistance (Toffolatti et al., 2016): these cultivars are a good source of resistance without transferring negative quality traits to the offspring.

Nowadays, interspecific controlled crosses represent the only available disease-resistant vines. The idea to combine in one individual the disease-resistance traits of wild species with the fruit (and wine) quality traits of *V. vinifera*, in order to get the ideal vine, can be traced back to the 19th century, when American and European breeders began this adventure for different contingent events. In the USA, attempts to grow *V. vinifera* cultivars failed because of their susceptibility to downy and powdery mildew and to phylloxera; the solution to get grapes for wine making was to rely on native species (*Vitis labrusca*, *Vitis aestivalis*, *Vitis rotundifolia*, etc.) or to cross them with *V. vinifera* (Olmo, 1971). Moreover, American breeders combined wild species together, such as *V. labrusca*, *Vitis riparia*, *V. aestivalis*, etc. (Munson, 1909). The results include a group of cultivars termed American hybrids ('Clinton', 'Noah', 'Niagara', 'Jaquez', 'Catawba', 'Isabella', etc.), showing good resistance but bad quality. In Europe, the traditional way of growing *V. vinifera* cultivars without a protection programme collapsed when downy and powdery mildews and the

insect phylloxera arrived in vineyards. One of the solutions (against the fungi) was hybridization, which was mainly developed in France, with unsatisfactory results because, despite the resistance, the wine quality was very poor. Despite this, these hybrids had a strong impact on the French wine system, reaching about 400,000 ha in the 1950s and flooding the market with a huge volume of bulk wine (Galet, 1988). Afterwards, the acreage decreased, also because of the effects of European regulations (Boursiquot, 1990). Many breeders in the USA and Europe worked on this subject, producing an amazing number of hybrids. Among the pioneers, we can mention T.V. Munson, an American scholar whose book Foundations of American Grape Culture lists the personal qualifications necessary in the originator as follows: theoretical and personal knowledge; experience; skills; inventive faculty; patience and perseverance; no stimulus of money-making; enthusiasm; ambition; intense love of close communion with nature; discover the great fundamental truth in ethics. The following philosophical sentence closes the list: "love breeds life; hate breeds death" (Munson, 1909).

In Europe, we can mention the great work done by French breeders such as Baco, Couderc, Seibel, Seyve Villard, etc., at the beginning of the 20th century and later on the hybrids obtained by Golodriga (former USSR), Csimazia and Kozma (Hungary), Becker and Alleweldt (Germany), and Bouquet (France). These last breeders were able to obtain new disease- resistant cultivars with an improved level of grape (and wine) quality and, in some cases, a vinifera-like wine (Alleweldt, 1980; Bouquet, 1980; Golodriga, 1978; Kozma, 2002).

Nowadays, about 6% of the global viticultural surface is covered by hybrids, and the most grown is 'Kyoho' (*V. labrusca* × *V. vinifera*), a Japanese table-grape cultivar present in China [365,000 ha; data from the Organisation Internationale de la Vigne et du Vin (OIV)]. Wine grape hybrids are mainly spread in America and Europe. According to Anderson (2013), the countries that grow large acreages of hybrids are Brazil (about 41,046 ha, 83% of the national viticultural surface), USA (~11,980 ha, 5%), Moldova (~11,656 ha, 13%), Russia (~9,430 ha, 37%), Hungary (~7,450 ha, 11%), Ukraine (~3,251 ha, 6%) and Canada (~2,680 ha, 27%).

The most grown cultivars in the above-mentioned countries are listed below (r, red; w, white):

- Brazil: 'Isabella' (r), 'Bordo' (r), 'Concord' (r), 'Niagara' (w), 'Couderc noir' (r), 'Jaquez' (r).
- USA: 'Concord' (r), 'Niagara' (w), 'Catawba' (r), 'Vidal' (w), 'Chambourcin' (r).
- Moldova: 'Isabella' (r), 'Noah' (w), 'Golubok' (r), 'Viorica' (w), 'Saperavi Severni' (r).
- Russia: 'Bianca' (w), 'Pervenest Magaracha' (w), 'Dunavsky Lazur' (w), 'Citronny Magaracha' (w), 'Saperavi Severni' (r).
- Hungary: 'Bianca' (w), 'Zalagyongye' (w), 'Kunleany' (w), 'Aletta' (w), 'Lakhegyi Mezes' (w).
- Ukraine: 'Isabella' (r), 'Pervenest Magaracha' (w), 'Podarok Magaracha' (w).
- Canada: 'Vidal' (w), 'Baco noir' (r), 'Concord' (r), 'Marechal Foch' (r), 'Niagara' (w), 'Seyval blanc' (w).

Those wine-grape cultivars include old American, French, Hungarian and Russian hybrids normally grown in challenging areas, where *V. vinifera* can suffer from abiotic and/or biotic stresses.

The new disease-resistant wine-grape cultivars (obtained mostly from the 1970s on) are so far marginally grown, such as, for instance, 'Regent' (r), which covers about 2000 ha in Germany (Eibach and Töpher, 2003). Many countries all over the world were involved in these breeding programmes, resulting in the release of new cultivars (Bavaresco, 1990, 2017); some of those are listed below.

- Bulgaria: 'Storgosia' (r), 'Pomoriiski bisser' (w), 'Dunavski lazur' (w).
- Germany: from the Staatliches Weinbauinstitut Freiburg, 'Merzling' (w), 'Johanniter' (w), 'Bronner' (w), 'Solaris' (w), 'Cabernet Carbon' (r), 'Cabernet Cortis' (r), 'Cabernet Carol' (r), 'Muscaris' (w), 'Prior' (r), 'Souvigner gris' (w), 'Monarch' (r), 'Helios' (r); from the Hochschule Geisenheim, 'Rondo' (r); from the JKI Geilweilerhof, 'Orion' (w), 'Phoenix' (w), 'Sirius' (w), 'Regent' (r), 'Reberger' (r),

'Calandro' (r), 'Villaris' (w), 'Felicia' (w), 'Calardis' (w).
- Hungary: 'Victor' (w), 'Csillam' (w).
- France: 'Artaban' (r), 'Vidoc' (r), 'Floreal' (w), 'Voltis' (w).
- Czech Republic: 'Malverina' (w), 'Erilon' (w), 'Laurot' (r).
- Serbia: 'Liza' (w), 'Petra' (w), 'Mila' (w).
- Canada: 'Vincent' (r), 'Ventura' (w), 'Veeblanc' (w), 'Festivee' (r), 'Sovereign Opal' (w).
- USA: 'Blanc du Bois' (w), 'Cayuga White' (w), 'Horizon' (w), 'Chardonel' (w), 'Traminette' (w), 'Arandell' (r), 'Aromella' (w), 'La Crescent' (w), 'Marquette' (r) (Reynolds and Reisch, 2015; Hemstad and Luby, 2003).
- China: 'Beichun' (r), 'Baotuhong' (r), 'Beibinghong' (r), 'Beihong' (r), 'Lingfeng' (r), 'Lingyou' (r).
- Italy: 'Fleurtai' (w), 'Soreli' (w), 'Sauvignon Nepis' (w), 'Sauvignon Rytos' (w), 'Sauvignon Kretos' (w), 'Merlot Kanthus' (r), 'Merlot Khorus' (r), 'Caberent Eidos' (r), 'Cabernet Volos' (r), 'Julius' (r) (Di Gaspero et al., 2012).

The main traits of the new disease-resistant wine-grape cultivars are as follows:
- Organoleptic characteristics of the wine: many varieties are vinifera-like, but do not display the same sensory profile and agronomic traits as the *V. vinifera* parent.
- Good agronomic performance.
- Disease resistance: not 100%, but some spray treatments are needed.
- Need to be grown in the environment where they were obtained.
- Some of those are winter hardy (where *Vitis amurensis or V. riparia* are present in the pedigree).

The cultivation of these new cultivars and commercialization of the wines is regulated only in the EU, while, in the rest of the world, the only ruler is the market response.

In EU, the current regulation (EU Regulation 1308/2013) states that the new disease-resistant cultivars can be grown to produce table and PGI (Protected Geographic Indication) wines, but not PDO wines (where only *V. vinifera* is allowed). That's why a topical issue is whether or not these new cultivars belong to the species *V. vinifera*, because it determines whether or not they can be grown for the production of PDO wines. Scholars are also discussing this issue at the OIV level, but without a definitive solution.

Many breeding programmes are still running in the world, using pyramiding strategies to enhance the durability of resistance (Merdinoglu et al., 2018), and some representative examples are listed below:
- USA: the main institutions involved are Cornell University (programme developed by Bruce Reisch), UC Davis (programme developed by Andy Walker, who is releasing some wine-grape cultivars that are resistant to Pierce's disease) and Florida A&M University (programme developed by Violeta Tsolova).
- Germany: JKI Geilweilerhof (programme developed by Reinhard Töpher).
- France: INRA (programme developed by Cristophe Schneider) and IFV.
- Russia: University of Krasnodar.
- China: many scientific institutions (Lu and Liu, 2015).
- Hungary: University of Pécs (programme led by Pal Kozma).
- Australia: CSIRO (programme led by Ian Dry).
- Italy: University of Udine (programme led by Enrico Peterlunger), FEM S. Michele all'Adige (programme led by Marco Stefanini), CREA-VE, Conegliano (programme begun by Luigi Bavaresco in 2012 and now led by Riccardo Velasco).

The global wine industry will therefore benefit in the future from further new cultivars that are in the pipeline.

NEW BREEDING TECHNIQUES

Promising methods to obtain disease-resistant vines quickly, while retaining the rest of the traits, have recently been made available. The most powerful is gene editing, such as CRISPR/Cas, which requires knowledge of the nucleotide sequence and function of the target site. Traditional wine-grape cultivars with different edits of known targets can be

produced in a single step and selected for advanced trials based on phenotypic traits (Scheben and Edwards, 2017). This target can be reached thanks to the great progress of the omics sciences, which include big data management (Baker, 2013).

CONCLUSIONS

To rely on breeding means to promote resilience instead of managing risks; resilience is the best way to minimize impacts from adverse events, aiming at long-term security (Erisman et al., 2015). On the other hand, risk management (traditional treatments) aims for short-term security, requires direct intervention and needs continuous monitoring.

The most important aspects of traditional breeding (controlled interspecific crosses for wine grapes) to be emphasized are as follows:

- Care of wine quality (besides durable resistance), and this is a lesson learned from the past.
- The need to develop local breeding programmes.
- The need to explore all *Vitis* world germplasm, including near-eastern *V. vinifera* cultivars.
- The need to address legislative issues.
- The need to coordinate research efforts.
- The need to address more diseases/pests.
- The need to preserve previous biodiversity (inter- and intravarietal variability), because today's diversity may include resistance to diseases considered unimportant or currently unknown.

The most important aspects of the new breeding techniques for wine grapes to be emphasized are as follows:

- Science has to take its course, solving current problems (regeneration, side effects) and reaching the target; edited resistant vines (when available) will be a new tool to be considered by policy-makers to cope with sustainability.
- Choice for utilization of edited resistant grape cultivars (when available and where allowed) will be based on political/commercial aspects (best advantage for national wine chains).
- Need to address legislative issues; in the EU, for instance, the Court of Justice has recently (25 July 2018) released a document stating that living organisms (including plants) modified by new breeding techniques, such as genome editing, have to be considered genetically modified organisms (GMOs) and are therefore banned from cultivation, according to the EU rules for GMOs (Regulation 2001/18). In countries where these new individuals (including grape) will be allowed, most likely they will be classified as clones.

Under this context, the role of the scientist is as follows:

- Science side: to guarantee excellent organoleptic wine traits together with the best level of durable resistance and to improve the resilience of the wine system in a broader way.
- Society side: to recognize that this innovation has to be shared with and accepted by the other actors in the wine chain (including consumers); the role of education becomes crucial and, in order to be effective, a commitment of resources and time is needed.
- Culture side: to emphasize wine drinking as a cultural fact and a way of life.

The scientist therefore has to move his/her sphere of influence from private and personal (where there is little impact) to societal networks, organizational, public and cultural (where there is the largest impact) (Amel et al., 2017). Some scientists are already engaged worldwide in activities other than private and personal, as members of consulting boards of private and/or public bodies, or think tanks, but we need to do more, especially on the public and cultural sides.

To deal with society is a very difficult task because, in recent decades, its relationship with science has changed a lot. In the past, scientific achievements were perceived by society as positive and useful, and the two domains interacted well. Nowadays, this is no longer the

case, because members of the public claim a stronger role in both the regulation of science and the shaping of the research agenda. This is occurring not just on the basis of the ratio of potential risks/benefits, but on the basis of values, of ethics, or, in the worst situations, on the basis of biases.

That's why scientists and the public differ greatly on hotly debated scientific issues (opinion gap), such as the role of humans in climate change, human evolution over time, the use of animals in research and the safety of eating genetically modified food. The latter issue, according to a poll by the AAAS and Pew Research Center (a think tank in Washington, DC, USA), was the one that showed the largest gap between scientists and the public (Anonymous, 2015). For many scientists, any such overlay of values on the conduct of science is anathema to core principles and historic success, but recent experiences suggest that the value dimension is here to stay, and scientists need to learn to work within this new context (Leshner, 2005). This new environment is also stressed by citizen science initiatives and crowdsourcing to conduct projects run by researchers and public together (Guerrini et al., 2018).

Coming back to viticulture and breeding for resistance, breeders have to handle carefully the issue of new breeding techniques. Even though there is no transfer of foreign genetic material in the case of gene editing, there is, all the same, a genetic manipulation, and a negative or hostile approach by the public (consumers) is likely to occur, even in countries where genome editing will be allowed. That's why education is important: a dialogue between scientists and the public on a rational basis in order to explain that this induced mutation is not producing a "Frankenstein" wine. Only if all the actors in the wine chain, including wine retailers and consumers, are convinced of the goodness of this approach will the scientific achievement (the edited vine) be a real innovation, being beneficial (from an economic and environmental point of view) for the entire wine system, and, moreover, EU policymakers will be more flexible in allowing its cultivation.

I'd like to conclude this paper with a quotation from a book written by Sir Roger V. Scruton (2009) entitled "I Drink, Therefore I Am – A Philosopher's Guide to Wine":

> "I have learned from Michelangelo about the pathos of mother love and the divinity of suffering; I have learned from Mozart about the hope that turns the deepest sadness to joy; I have learned from Dostoevskij about forgiveness and how the soul is cleansed by it. And those gifts of understanding were brought to me by art. But what I have learned from wine has welled up from within me: the drink was the catalyst, but not the cause, of what I came to know."
>
> Can a product like this be considered just a commodity or be banned?

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