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INNOVATION
IN VINEYARD

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Context and objectives of the Innovine project

The European Union (EU) is by far the largest wine producer, consumer, exporter and importer in the world. The EU has almost half of the world total vine-growing area and 60% of the global wine production. At present, the EU wine sector faces important challenges with the increasing world supply, the decreasing domestic demand, and public controversies on health impacts. To face this increasingly fierce competition, the European wine sector must combine structural improvements with competitiveness reinforcement by replacing low-quality with better and diversified quality wines. Berry quality has a huge influence on the composition and the quality of the final product and is influenced by many parameters such as vineyard management, viticultural practices, sanitary quality and varieties. Each aspect needs to be adapted and improved to optimise the composition of the wine and reach the quality desired by customers.

The quantity and quality of grapevine production is highly influenced by two environmental components, the climate and soil. So far climate change has had more beneficial than detrimental effects on it. In particular, reduction of the water availability with relatively minor degradation of the vine's hydric comfort is not necessarily negative for berry quality. Yet, adaptation to climate change is an important challenge for the wine producers. Indeed, warming accelerates all phenological stages, bringing maturation to hotter and dryer periods, making it necessary to change or even reverse practices aimed at increasing the heat undergone by the grapevine to monitor berry quality. The impact of climate change on yield and berry quality, as well as on grapevine's pests and pathogens proves to be extremely variable according to the viticulture system and its geographical situation.

The use of chemical pesticides after World War II allowed a spectacular increase in crop yield and the development of intensive farming. The aftermath of the intensive use of pesticides is a widespread contamination of the environment, the emergence of pest resistance to these products, the presence of pesticides residues in food, and the negative effects on human and wildlife health. Grapevine is a crop particularly dependent on pesticide use. 70% of the total grapevine growing costs correspond to fungicide applications in order to control two major diseases: powdery and downy mildew (INRA report, 2006). Nowadays, grape growers (about 2.4 million people over EU27) are confronted with an increasing social demand for environmental preservation and food safety followed by increasingly restrictive national and international regulations. In this context, new solutions are needed to assist the vineyard sector to change practices that combine better environmental protection (pesticide use reduction, use of organic agricultural practices and/or biological control) with long-term economic performance (grape quantity and quality).

The Innovine project (PF7, grant n°311775, www.innovine.eu) is aimed at developing knowledge, tools and genetic resources necessary to better adapt viticulture to climate change and to drastically reduce the use of pesticides in the vineyards. The aim of the project was to disseminate its findings to three different categories of end users: academics, technical advisors/service providers and growers. The main results of Innovine's activities are described in the present paper, highlighting the potential impacts.

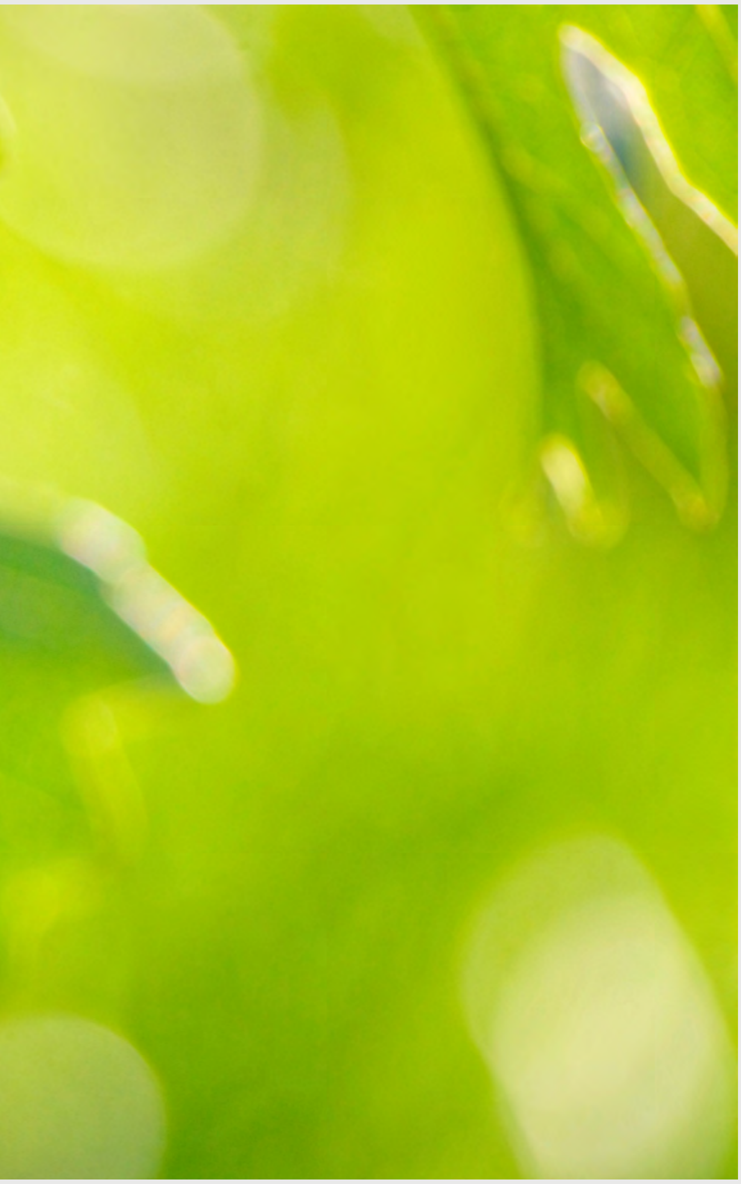
ADAPTATION TO CLIMATE CHANGE

Innovine globally led to a better understanding of the impact of vineyard practices and of various stresses alone or, which is newer, in combination, on grapevine physiology and berry composition in the context of climate change. Two to three years of data on grapevines under canopy management that altered the source/sink balance have been obtained. These studies showed the diversity of responses to similar stresses depending on grapevine varieties, as well as of effects on berry ripening and final composition (Genebra et al 2014, Poni et al 2014, Merli et al 2014, Martinez-Lüscher et al 2015, Gatti et al 2014&2015, Martinez-Lüscher et al 2015). Temperature was shown to affect the colour of white berries through photo-oxidation mechanisms (Friedel et al 2015). Deficit irrigation significantly affects berry ripening, anthocyanin accumulation and hormonal balance, while temperature is an important variable determining the improvement (moderate temperatures) or impairment (high temperatures) of berry quality by the deficit irrigation regime (Permanhani et al 2016, Chaves et al 2016) and underlying physiological and molecular mechanisms that are starting to be deciphered (Texeira et al 2013, Conde et al 2014, Genebra et al 2014, Fernandes et al 2015, dal Santo et al 2016, Zarrouck et al 2016b, 2016c, Jardal Jamoussi et al 2016, Chavez et al 2016; Martinez-Lüscher et al., 2016). Interesting links between stresses (namely elevated CO_2, elevated temperature and water deficit) and yield factors were found in Tempranillo. Two grapevine models, "HydroShoot" and "GrapevineXL", were developed to simulate the impact of environmental stimuli and viticulture practices on grapevine physiology and berry composition. Their use showed for instance that under carbon-limited conditions, the grape berry can manage the metabolic fate of carbon in such a way that sugar accumulation is maintained at the expense of secondary metabolites (Bobeica et al 2015). The two models will be further developed and

integrated to exploit genetic diversity and the response of virtual genotypes to different climatic scenarios. This will provide guidance for selection and breeding of new grapevine genotypes better adapted to future climates. Long-term experiments and platforms associated with the standardised sampling and analytical procedures that have been designed to collect Innovine's data will allow to collect in the long-term big data sets on different varieties grown under different climatic environments and viticultural practices during many vintages, which would enable in the future understanding of the most relevant parameters controlling berry composition. Several reviews of the current knowledge of different aspects of the impact of climatic factors on grapevine and berries have also been published by the partners of the project (Carvalho et al 2014; Costa et al 2016; Zarrouck et al 2016a), making the whole consortium quite visible in the field.

POTENTIAL IMPACTS OF INNOVINE ON A BETTER MONITORING OF YIELD AND QUALITY IN VITICULTURE IN RELATION WITH CLIMATE CHANGE

Several non-destructive phenotyping tools based on fluorescence, reflectance, thermal imaging, and hyperspectral imaging have been experimented and validated in the frame of Innovine to monitor the physiological status of the canopy (nutritional and water status; Cerovic et al 2015), as well as the berry content (sugars, anthocyanins, chlorophyll, carotenoids). Based on such results the acquisition system for phenotype selection



was improved, to collect automatically all data and to improve the firmware for berry selection (Cerovic et al 2014). A fluorescence sensor was also able to monitor the downy mildew infection time course from 5-6 days after inoculation (Latouche et al 2015). Various aspects regarding the calibration and implementation of predictive models of total soluble solids in grape berries using laboratory and in-field collected NIR spectra were developed (Urraca et al 2015). Thermal imaging measurements of canopy were correlated with leaf water potential, stem water potential and stomatal conductance, suggesting that thermal imaging can be feasible to assess crop conditions and may contribute to speed up field measurements (Garcia-Tejero et al 2016). A rapid, non-invasive, and low-cost method based on reflectance spectroscopy was developed to assess grapevine variety characterisation with respect to sunburn susceptibility (Rustioni et al 2014&2015) as well as to study the physiological processes involved in such symptoms (Rocchi et al 2016). The technique also gave promising results to screen for stem traits related to adaptation to drought (Rustioni et al 2016, Grossi 2016). New, easy-to-use smartphone applications were developed and tested for the automated estimation in the vineyard (i) of the number of flowers in grapevine inflorescences (vitisFlower®) and (ii) the size, number, colour and surface defect of berries (SmartGrappe). Finally, other tools allow to acquire and exploit geo-located measures provided by a series of sensors or aerial imaging to generate zones in the vineyard for differential practices or harvest are a previsible output of the project.

These tools may be used either as hand-held devices or mounted on mobile equipments (quad, tractors). The data collected can be used to draw high resolution maps of the vineyard and result in decision making tools (such as selective harvesting) or to assess the sanitary status of the vineyard and drive viticulture practices/treatments that would limit the spread of the disease. They can also be used as screening tools to investigate clonal or varietal diversity. While these approaches still need to be made more public and probably adapted in a more user-friendly way, they offer a strong potential for dissemination that has started during the project, in particular the organisation of testing days, demonstrations in the field or master courses.

INNOVINE IMPACTS ON ADAPTING VINEYARD PRACTICES TO CLIMATE CHANGE

Different adaptive strategies were tested in diversified environmental conditions and provide evidence that seasonal canopy

management practices and varietal or clonal diversification give opportunities to adapt to weather conditions or in the long-term to climate change. Some outputs of the project can now be used by growers:

- Sets of Tempranillo (syn Aragoñez) clones better adapted to various environments;
- A better understanding of the effect of various practices aiming at mitigating environmental stresses on berry quality;
- Various monitoring tools and decision support systems (DSS) for precision viticulture that should facilitate the following of the physiological state of the vine in the field.

REDUCING CHEMICAL APPLICATION IN THE VINEYARD

The Innovine project has contributed to provide the foreground for the development of strategies for a sustainable control of foliar diseases in the vineyards, i.e.: (i) more durable over long periods of time, (ii) allowing to diminish drastically the amount of pesticides used in the vineyards and (iii) still allowing economical sustainability. A very important effort has been carried out in the Innovine project for the screening of yet uncharacterised germplasm collections for resistance to powdery and downy mildews and to black rot, a secondary pathogen that becomes a real threat when the treatments against the mildews are decreased. For instance, 1179 and 883 non redundant accessions were respectively tested for resistance to downy and powdery mildew. As a result, an important list of very useful genetic resources for breeding for resistance has been delivered and will be available in the European Vitis Database (www.eu-vitis.eu). That includes information about the repository from which the grapevines of interest can be obtained for further study. In addition, the description of the notation scale for black rot tolerance, not yet present in the international descriptor lists, will be submitted to the OIV (Organisation Internationale de la Vigne et du Vin). The standardised protocols for screening mildews, black rot and phylloxera developed in the project will be used in future screening of grapevine material.

However, the partners have also shown that without any corrective measures, the populations of downy and powdery mildews will likely be able to slowly adapt on resistant varieties and overcome these resistances (Delmas et al 2016). Secondary diseases and durability of resistance will have to be taken

into account by the breeding programs for new grapevine varieties. Another important development of the Innovine project was therefore the detailed study of epidemiological traits on a set of varieties susceptible and tolerant to downy mildew and the use of these data to improve the current disease models.

POTENTIAL IMPACTS ON ADAPTING VITICULTURE PRACTICES FOR REDUCING THE USE OF PESTICIDES IN THE VINEYARD

The information collected during the project by the public and private partners when performing assays with varieties tolerant to diseases showed that the use of such varieties has the greatest economic and environmental (positive) impacts related to the production of grapes while it has no specific impacts on yield, must and wine composition. The Innovine project has on the whole provided diverse and complementary tools and knowledge that will be useful for a more environment-friendly control of diseases in the vineyards:

- Knowledge on the level of resistance of tolerant varieties in field conditions;

- A first set of strategies aimed at reducing but not suppressing the number of treatments on tolerant grapevine varieties (2-3 treatments instead of 7-13) showed to be efficient in controlling secondary diseases. It will be a way to also manage in the long-term the resistance and avoid adaptation of the populations of mildews and progressive inefficiency of the resistance;

- Alternative practices to chemicals and results of tests of canopy management practices aiming at modifying the cluster architecture for a better tolerance to botrytis (Molitor et al 2015);

- Improved DSS systems (e.g. Rossi et al 2014) that allow to be more efficient in the decisions of when spraying and what quantity of active compound and improved monitoring tools for downy mildew infection.

CONCLUSIONS

The Innovine project has enlightened two major subjects on which researchers, extension services, technical advisors and service providers will have to focus their future work to better assist grower's decisions towards a more sustainable viticulture. The first one is the need of diversification of the varieties planted. Indeed, Innovine's work strongly suggests that diversifying the genetic catalog has the greatest impact for adaptation to biotic and abiotic stresses.

However, especially regarding varieties resistant to diseases, which are completely new, there is a lot of work ahead to design viticulture systems maximising their quality in relation with the « terroir » where they will be planted. These management systems will also have to address the durability of the resistance to disease through the management of the populations of pathogens. The second is the delivery of an integrated set of user-driven services assisting grower's decisions all along the season. The Innovine project has made a step in this direction by working on web interfaces transforming the output of the models into simple and visual messages or monitored data into more classical indicators, already manipulated by growers.

These future developments will hopefully be stimulated and supported by the important efforts of dissemination towards producers, growers, advisors and policy makers of the partners. Indeed, more than 40 events were organised all along the project. The majority of the events specifically targeted advisors and viticulturists (about 70% of the workshops) while the participation of scientists and policy makers was also effective in about one third of these events, enriching the discussions from different standpoints and improving further networking. 43% of the workshops and trainings were open or targeted to students, which is a way to impact the new generations of growers, scientists and technical advisors.

Finally, in the frame of Innovine a web survey was sent more than 24,000 contacts all across Europe to understand the critical points in viticulture that should be addressed in research projects. One of their top priorities that was not addressed at all by Innovine, is the management of wood diseases. This subject of research will require interdisciplinary researches and will beneficiate from some of the results of Innovine, in particular when addressing the role in disease expression of the interplay between the fungi involved in wood diseases, the environment and the physiological state of the plant.

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