Late frost protection in Champagne

Basile Pauthier[1*], Sébastien Debuisson[1] and Arnaud Descôtes[1]
[1] Comité Interprofessionnel du Vin de Champagne, Epernay, France

*Corresponding author: basile.pauthier@civc.fr

Keywords: Late frost, Climate change, Active protection, Passive protection, Champagne.

Abstract

Probably one of the most counterintuitive impacts of climate change on vine is the increased frequency of late frost. Champagne, due to its septentrional position is historically and regularly affected by this meteorological hazard. Champagne has therefore developed a strong experience in frost protection with first experiments dating from the end of 19th century.

Frost protection can be divided in two parts: passive and active.

Passive protection includes all the methods that do not seek to modify the vine's environment or resistance at the time of frost. The most iconic passive protection in Champagne is the establishment of the individual reserve. Other common passive methods include the control of planting area, the choice of grape variety, late pruning, or the impact of grass cover and tillage.

Active frost protection is also divided in two parts. Most of the time they provide warmth (candles, heaters, windmills, heating cables), or stabilise bud temperature (water sprinkling). The other way is to enhance the resistance of buds to frost (elicitors).

The Comité Champagne evaluates frost protection methods following three main axes: efficiency, profitability, and environmental impact. This study presents the results on both passive and active protection following these three axes.

Introduction

Climate change has different impacts on viticulture. One of the most counterintuitive is the increasing frequency of spring frost. Studies warned about this problem (Inouye, 2008) with an earlier budburst due to higher temperatures and a date of last day of frost remaining around the same date. The risk of a polar jet stream destabilization by quick warming was also mentioned (Molitor *et al*, 2014). Since 2016, French vineyards and more widely Western European vineyards, including the southernmost, suffer from frost damages almost every year (Rochard *et al*, 2019). In 2021, a strong frost event stroke Europe again, Champagne lost almost the third of its harvest (Descôtes *et al*, 2022). Considering the increasing frequency of frost events, the French government decided to extend the agricultural calamity status to viticulture and arboriculture, but this grant do not replace a harvest and most of the growers need an efficient way to protect their crops from frost.

This phenomenon can take place in the following two ways: radiative frost and advective frost (Rochard *et al*, 2019). Radiative frost is the most common during spring and will occur during anticyclonic situation with a clear sky and a low wind speed. Cold air will flow down, and an inversion layer will form with negative temperatures at plant level (Hu *et al*, 2018).

Advective frost will be linked to a cold air flow. It is characterized by the presence of wind and generally a low relative humidity. The most dangerous advective frost events will be preceded by rain or snow (Pauthier *et al*, 2018). Due to its northern position, Champagne is regularly affected by frost (Fig1) and therefore has a strong experience of frost protection. Since the end of the 19th century, Champagne winegrowers try to fight against frost with different techniques. The "Association Viticole Champenoise" and after the "Comité Champagne" conducted experiments since the beginning of the 1930's to find techniques allowing to protect vine against this scourge (Pauthier *et al*, 2018).

Frost fighting can be divided into two distinct parts: passive and active (Pauthier *et al*, 2018; Rochard *et al*, 2019). Passive fight aims to prevent or compensate the loss due to frost. The most iconic passive method in Champagne is the individual reserve that allow to compensate loss due to different hazards with wines from

previous years. Grape variety choice, topography analysis, late pruning, smart tillage or weeding are also factors that can significantly enhance or limit frost damages.
Active fight tends to modify vines microclimate during a frost event or to increase the vines resistance to low temperatures. A lot of active fighting techniques are available on the market, and all are not presenting the same efficiency.
The research deal with both passive and active fight to find the most efficient, profitable, and sustainable way to reduce the impact of late frost.
The objective of this article is to present a synthesis of the most efficient ways to protect vines against different types of frost.

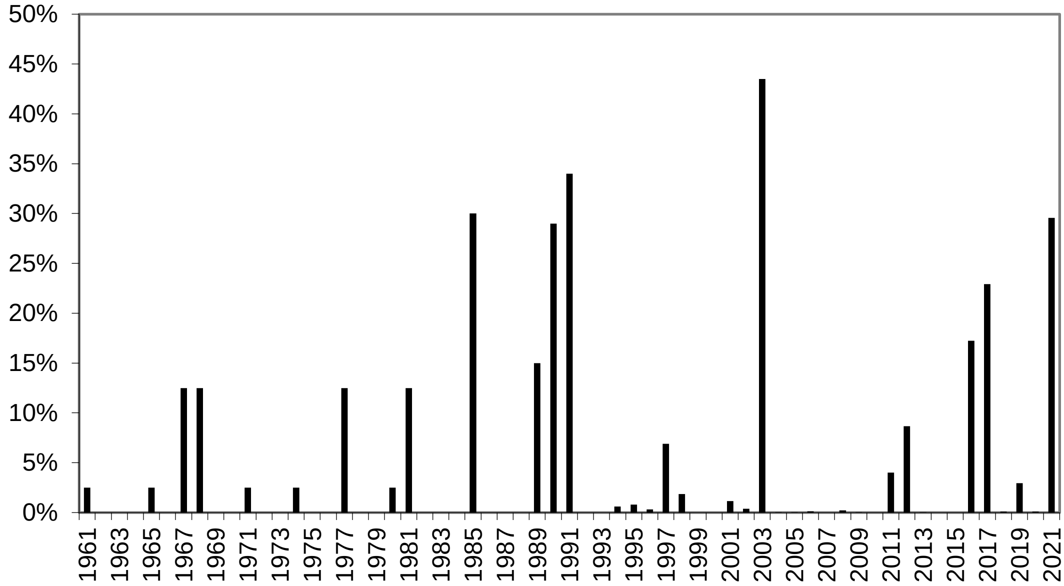

Figure 1. Annual percentage of frozen buds in Champagne appellation

Material and methods

The Comité Champagne strategy to evaluate a frost fighting technique follows three main axes:

Efficiency

To assess its efficiency, the technique is followed from the installation to the harvest. To register temperatures during the frost, one or several temperature sensors are installed in the vines depending on the type of the technique. Immediately after the frost event, a buds count is performed to assess the percentage of frozen buds in the control and in the protected modality. The secondary buds are more or less fructiferous depending on the grape variety; therefore a cluster count is carried out to assess the difference between control and protected. Finally, a weighting is done during the harvest to know the contribution of the protection technique on the yield.

Cost

Every system does not protect the same surface and the same technique can be sold at different prices depending on the seller. A market study is therefore carried out to inform Champagne winegrowers.

Sustainability

In 2003 Champagne engaged a strategy aiming to reduce its carbon footprint. Active frost fight represented in 2003 around 3% of the total carbon emissions. Considering that this activity is only occurring certain years and a few nights during the year, it was necessary to act to reduce the impact of this emissions item.
All techniques were evaluated following a life cycle analysis process to know which one could be interesting to replace or keep. Thanks to this study, and the involvement of the winegrowers, the carbon footprint of frost fight has been reduced by 1% and in 2018 was representing 2% of the total footprint of Champagne.

To continue in this direction, every new technique that gives interesting results in terms of efficiency is therefore evaluated following this process. If the results are interesting the technique will eventually be authorized within the certification "Viticulture Durable en Champagne" which is the only one in France to take into account the impact of frost fight.

Results

Passive fight

Passive fight begins before the planting with an analysis of the vineyard topography. The aim is to limit the impact of frost, in particular radiative frost which will mainly concern the lower areas. Knowing this, the choice of the grape variety and rootstock is essential to limit the risk of frost. In high-risk areas, it is necessary to choose a grape variety that has a late budburst grafted on a rootstock that does not confer haste to the scion. This will reduce the sensitivity period by delaying budburst.
It is also essential to avoid walls, embankments or hedges placed perpendicularly to the slope. This will limit the risk of cold air lakes formation.
Passive fight can be also practiced by managing certain vineyard activities like pruning, soil cover management or tillage. An experiment on late pruning (November vs March) performed from 1985 to 1993 in Champagne (Langellier *et al*, 1999) give a delay about 10 to 12 days on budburst depending on the variety (Pinot Noir, Chardonnay) and pruning method. In 2021 and 2022 the same experiment was performed on Chardonnay with two dates of pruning (November 1st vs April 1st) and two pruning methods (Guyot simple vs Chablis). A mean delay of 11 days was observed on Guyot simple and 8 days on Chablis. Another task linked to pruning is binding. For certain pruning methods, leaving the shoots unbound can allow to gain 20 to 30cm of height. During a radiative frost this difference can correspond to 1°C even 2°C (Association Viticole Champenoise, 1991).
A recent tillage increases the release of humidity by the soil and the temperature 40cm above the soil can be 3°C lower than bare ground (Langellier *et al*, 1999). Considering that humidity increases the buds sensitivity to frost (Itier *et al*, 1991) delaying soil tillage when a frost event is forecast will limit the risk of frost.
Cover management has also an influence. Above a soil covered by a dense and high grass, temperature will be 2°C lower than above a bare ground or a thin grass cover (Association Viticole Champenoise, 1991). When a frost event is forecast, mowing three to four days before the event can limit the impact of the frost without releasing humidity.
Since 2007, Champagne has set up an individual reserve that allow winegrowers to stock a certain amount of wine from one or several previous years to use during following years. This allows to maintain the quality and to face a yield affected by meteorological hazards like hail or frost.

Active Fight

All the techniques that will be mentioned has been tested for at least five years to have a representative dataset. Some others are currently tested and results will be published later.
The results will be presented according to the order listed material and methods. The efficiency will be separated in two parts for the two types of frost. The results are resumed in Table 1.
The first method is water sprinkling. When water freeze, energy is released in the form of heat (80 kcal/l). The principle is therefore to sprinkle water over the vines to form an ice layer that will be maintained over a lethal temperature by the water freezing. This method is one of the most efficient (protection up to 100%) but requires great mastery because starting too late can be fatal for the buds. The cost is mainly dependent on the water pumping technology (electric, petrol) but stay competitive. The carbon footprint is also dependent on the water pump technology but remain low even with a petrol engine. The main issue with this method is to have access to a large amount of water due to its high consumption (40 m^3/h/ha). An environmental evaluation concerning other environmental factors like leaching or erosion is in progress to assess the complete footprint of this method.
Different types of fuels are used in burners to produce heat to maintain temperature above a lethal level. The efficiency is dependent on four main factors: calorific value, burner efficiency, wind speed and burner density. For example, 200 fuel oil burners per hectare are required to maintain a non-lethal temperature during a -6°C frost event with no wind (95% protection). Most French companies stopped producing fuel oil burners and only one is still producing gas burners the cost is therefore a second-hand cost and is exploding since 2017. All these

types of installation have disappeared in Champagne because of its very poor carbon footprint (400 l/ha/h fuel oil consumption) and the particles released into the air.
Candles follow the exact same principle as fuels. Paraffin is burned to produce heat and maintain temperature above a non-lethal value. The density needs to be higher than fuels burners because of their lower efficiency. To maintain temperature during a -6°C frost event with no wind 500 to 600 candles per hectare will be needed (90% protection). In April 2022, the cost was from 10 to 13€/candle but the since a frost episode is short, return on investment is not always a given. Considering that paraffin is derived from petroleum, the carbon footprint is not compatible with a sustainable viticulture.
Since 2018, some wood pellets burners are tested in Champagne. The principle and the efficiency are the same than fuel oil burners. The density is also the same with 200 burners per hectare for a frost about -6°C (95% protection). The investment is around 40 000 € per hectare. The pellet consumption is about 1000€ per night.
Windmills are based on the inversion layer occurring during a radiative frost. Their efficiency is therefore dependent on the frost type. With the thermal inversion during a radiative frost, warm air is a few meters above the ground. The windmill goal is to mix the different air layers to maintain temperature above the lethal temperature for buds. The mean gain is about 1°C at a 100m distance for a fix windmill. The gain can be enhanced up to 3°C by the addition of a burner. The cost is around 45 000€ for a fix windmill without burner. The carbon footprint is dependent on the energy of the engine and eventually of the burner. The main problem for windmills is the noise that can disturb neighbors.
PEL-101-GV is an elicitor tested from 2004 to 2013 in Champagne. The principle is to increase the plant resistance to cold by sugar assimilation. The efficiency is dependent on the phenological stage from zero before one leaf, to 20-50% after one leaf for a -2.5°C frost. The cost is about 200€ per application. The carbon footprint is the same as for any type of spray application.
Electric heating cables have been tested in Champagne from 1992 to 2003. Some experimentations with new types of cables began in 2017 and are still in progress. The cables are tied close to the shoots which means that in Champagne this type of protection is only possible for Guyot simple and Cordon de Royat pruning methods. The results give an efficiency around 70 to 90% for a -4°C radiative frost and can decrease to 30% for a -8°C advective frost. The cost of the heating cable is between 45 000€ to 100 000€ per hectare including electric generator. The main problem of this type of protection is the very important need of power (at least 200 kW/ha). The carbon footprint is depending on the power supply nature.

Table 1. Efficiency, Cost and Carbon footprint evaluation of the different frost fighting techniques. RF is for Radiative Frost, AF for Advective frost.

Technique	RF Efficiency	AF Efficiency	Cost	Carbon Footprint
Sprinkling	+++	+++	++	+
Fuels burners	+++	++	++/+++	+++
Candles	++	+/++	+++	+++
Pellets burners	+++	++	++	+
Windmills	++	0	+/++	+/++
PEL 101GV	+/0	+/0	+	+
Heating cables	++	+	+++	+/++

Conclusion

Due to its septentrional position, Champagne has been suffering from frost damages for many years. Climate change increases the risk of loss due to frost. The research about frost protection is therefore crucial to maintain Champagne production but it takes time because of the dependence on the occurrence of a frost event. The choice of a method is linked to the local situation (topography, microclimate, frost frequency), the economic context (wine selling price, market trend…) and environmental context (noise, runoff, emissions, footprint). Thanks to the evaluations made, the Comité Champagne aims to provide to Champagne winegrowers and houses a span of fighting solutions to limit the impact of frost while limiting the impact of this fight on the environment.

References

Descôtes, A., Pauthier, B., & Panon, M. L. (2022). Assembée de l'AVC. 2 décembre 2021: Le journal de l'année. *Le Vigneron champenois*, (1), 23-79.

Hu, Y., Asante, E. A., Lu, Y., Mahmood, A., Buttar, N. A., & Yuan, S. (2018). Review of air disturbance technology for plant frost protection. *International Journal of Agricultural and Biological Engineering*, *11*(3), 21-28.

Inouye, D. W. (2008). Effects of climate change on phenology, frost damage, and floral abundance of montane wildflowers. *Ecology*, *89*(2), 353-362. https://doi.org/ 10.1890/06-2128.1

Itier, B., Flura, D., Brun, O., Luisetti, J., Gaignard, J. L., Choisy, C., & Lemoine, G. (1991). Analyse de la Gélivité des Bourgeons de Vigne. Expérimentation in situ sur le Vignoble Champenois. *Agronomie*, *11*(3), 169-174.

Association Viticole Champenoise. (1991). Les gelées de printemps. Hors série, *Le Vigneron champenois*.

Langellier, F., & Panigai, L. (1999). Lutte contre les gelées de printemps: Nouveaux acquis. *Le Vigneron champenois*, *120*(3), 65-79.

Molitor, D., Caffarra, A., Sinigoj, P., Pertot, I., Hoffmann, L., & Junk, J. (2014). Late frost damage risk for viticulture under future climate conditions: a case study for the Luxembourgish winegrowing region. *Australian Journal of Grape and Wine Research*, *20*(1), 160-168.

Pauthier, B., Debuisson, S., & Descôtes, A. (2018). Comment lutter contre le gel de printemps?. *Le Vigneron champenois*, (3), 51-59.

Rochard, J., Monamy, C., Pauthier, B., & Rocque, A. (2019). Stratégie et équipements de prévention vis-à-vis du gel de printemps et de la grêle. Perspectives en lien avec les changements climatiques, projet ADVICLIM. In *BIO Web of Conferences* (Vol. 12, p. 01012). EDP Sciences.