DELIVERABLE TITLE: Holistic feasibility study of COPPEREPLACE proposed solutions

DELIVERABLE Nº: 5.1.

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ORGANIZATION RESPONSIBLE FOR THE DELIVERABLE: ADVID

<u>P5.1. – Holistic feasibility study of COPPEREPLACE proposed solutions</u>

GT leader: ASSOCIAÇÃO PARA O DESENVOLVIMENTO DA VITICULTURA DURIENSE - ADVID

Involved partners: PTV, IFV, UPC, EURECAT, GREENUPORTO, CVAN, SOGRAPE VINHOS SA, MIGUEL TORRES SA, UVIGO, SVBNA, GERARD BETRAND

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1. Framework

Copper (Cu) has been used in agriculture for more than 100 years, with the use of Bordeaux mixture (copper sulfate + lime), and still represents one of the few alternatives for the efficient management of bacterial and fungal diseases on crops. Currently, Cu is approved as an active substance in Plant Protection Products (PPP) for more than 50 different diseases in several crops, including the vineyard. One of the main advantages of copper is its wide spectrum of activity against microorganisms, high efficacy under conditions of rain, its multisite mechanism of action that minimises the risk of development of resistant pathogen strains, the relatively low acute toxicity for terrestrial vertebrates, and the low costs (Tamm *et al*., 2022). In fact, copper-based pesticides still represent one of the few alternatives for the efficient management of bacterial and fungal diseases on crops, including downy mildew (*Plasmopara viticola*).

However, being a non-degradable contaminant, long-term copper use raises concerns about their long-term sustainability owing to the accumulation of the metal into the soil with consequent damage to the soil microbiota, long-term phytotoxicity, and potential food and groundwater contamination (Lamichhane *et al*., 2018). Besides, the potential accumulation of Cu in the soil could bring risks to farm workers, birds, and mammals. Therefore, environmental consequences of Cu use must be properly acknowledged and weighted, and most importantly, not neglected.

Recognition of the negative environmental effects of Cu-based products has led to the imposition of restrictions on their use. Copper use has been strongly questioned by various national and European bodies, with increased restrictions on Cu application and ongoing threat of a total ban. Also, since 2015, Cu has been on the list of candidate molecules for substitution at European level, mainly because of its non-degradability and its cumulative effect in the soil. In some countries (mainly the Netherlands and some Scandinavian states), its use as a pesticide is prohibited, although the use of Cu as a fertiliser remains allowed (INRAE, 2018). The increasing restrictions on authorised Cu doses, represents a challenge for growers, particularly for organic growers, who are prohibited from using synthetic fungicides. The main problem of limiting the use of copper for the winegrower is the loss of crop yield as the goal is to have a good production of healthy grapes. Additionally, the EU has a long and complex procedure to authorise the placing on the market of novel PPPs, which requires substantial efforts and investments.

Although many fungicidal active substances have been discovered, copper-based PPPs are still widely used in organic and conventional agriculture, due to their many advantages. Although there are several alternative products available, none of them can compete with copper in terms of spectrum of activity, efficacy, and price for growers (Tamm *et al*., 2022). Furthermore, the urgent need for highly active fungicidal compounds of natural origin has been recognized (e.g., *Equisetum arvense* L., *Salix* spp.), as well as refined inorganic compounds (e.g., calcium carbonate or calcium hydroxide). Even though the most advanced compounds show promising levels of efficacy and seem to cover different uses, none of these alternatives has been authorised as a plant-protection product so far in the EU (Tamm *et al*., 2022). Thus, there is an increasing demand for identification and developing alternatives to Cu that are environmentally safe and economically viable.

The main goal of COPPEREPLACE Project was to validate integrated and innovative solutions to reduce the use of Cu in vineyards in the SUDOE region (Portugal, Spain, and France), while accessing its environmental, social, and economic impact. These solutions must enable sustainable production, in line with European policies.

In order to assess viability of proposed itineraries to reduce copper, this document provides a holistic study, including regulatory viability, as well as the environmental, social and economic impacts of proposed solutions. This report is based on the results of the work carried out in field trials of GT1 and GT4, as well as the data obtained through interviews and questionnaires to producers and the stakeholders' perception on new solutions.

1.1. COPPEREPLACE's proposed solutions and itineraries for copper reduction in the vineyard

Early in the project, a screening and selection of alternative products for mildew control was performed, according to their applicability and their innovation maturity (**Table 1**). Then, three types of trials were conducted:

1. Lab tests: aiming to obtain more information on the effectiveness of the products on their own, without the influence of weather conditions, by inoculating treated leaves with downy mildew.
2. Micro-plot tests: test the products on small plots of 10 vines, repeated 4 or 5 times.
3. Large-plot tests: test some of the products already assessed in the micro-plot trials in commercial vineyards.

Within selected products, in large-plot trials, only products with a marketing authorisation were tested. Salix and Equiset are authorised basic substances used for disease control. On the contrary, and although available on the market, Glucosei is promoted as a deficiency corrector (or foliar fertilizer) and cannot be used alone in a phytosanitary program. However, due to its composition (Cu heptagluconate), it could revendicate a phytosanitary effect without a high amount of Cu.

Since Glucosei was the product showing the more promising results both in lab tests and micro-plot trials, allowing a reduction of Cu with similar efficacy in downy mildew control, this product was tested in large-plot trials. None of the other innovative products selected could be tested in large-scale testing due to the difficulties of obtaining derogation in France and other countries in Europe (unless destroying the entire harvest). To this is added the automatic downgrading of the harvest in organic production mode in case of the use of a non-referenced input.

Table 1. Selected products, respective manufacturing company, active substance, category, and recommended dose.

PRODUCT	SOCIETY	ACTIVE SUBSTANCE	CATEGORY	RECOMMENDED DOSE	LAB TESTS (2022)	MICRO-PLOT TESTS	LARGE-PLOT TESTS
GLUCOSEI	SEIPASA (SP)	Cu heptagluconate 8% (p/p)	Basic substance	3L/ha	IFV (Nîmes)	IFV (Bordeaux, Nîmes) Sogrape	VBNA Château l'Hospitalet Sogrape
SALIX	BIOVITIS (FR)	Salix cortex 74 g/L	Basic substance	5 L/ha	IFV (Nîmes)	IFV (Bordeaux, Nîmes) Sogrape	VBNA Château l'Hospitalet Sogrape
EQUISET	ASCENZA	Equisetum 2 g/L	Basic substance	2 L/ha	IFV (Bordeaux, Nîmes)	IFV (Bordeaux, Nîmes) Sogrape	VBNA Château l'Hospitalet Sogrape
ALFOSITOL	FUTURECO (SP)	Cu 2,6% (p/p), P_2O_5 23% (p/p), K_2O 20% (p/p)	Fertilizer	1.5 to 2.25 L/ha	-	Sogrape	-
FOSFIMAX	FUTURECO (SP)	P_2O_5 20% (p/p), Zn 5% (p/p)	Fertilizer	150 cc/hl	-	Sogrape	-
VICURE	SYMBIOTEC (FR)	Concentrated extract of symbiotic plants	-	14 L/ha	IFV (Bordeaux, Nîmes)	IFV (Bordeaux, Nîmes)	-
-	IMMUNRISE (FR)	Microalgae 5 g/L	-	500 g/ha	IFV (Bordeaux, Nîmes)	IFV (Bordeaux, Nîmes) Sogrape	-
HYP PLUS	BIOMEDE (FR)	Plant infusion	-	4000 g/ha	IFV (Bordeaux, Nîmes)	IFV (Bordeaux, Nîmes)	-
GI20OD06	GREEN IMPULSE (FR)	Plant extract	-	0.2 L/ha	IFV (Bordeaux, Nîmes)	IFV (Bordeaux, Nîmes) Sogrape	-
LEMOCIDE	VIVAGRO	Sweet Orange essential oil	Crop protection product	0.8%	-	IFV (Bordeaux)	VBNA Château l'Hospitalet Sogrape
BELVINE	CERIENCE	Components of *Saccharomyces cerevisiae* lysate	Plant defence stimulator	3 L/ha	IFV (Bordeaux, Nîmes)	IFV (Nîmes)	-

The protection achieved by Glucosei can be complemented with Sweet Orange oil (PREV-AM®). PREV-AM®, from Rovensa Group, is an all-in-one natural insecticide, fungicide and acaricide and authorised in organic farming. It has a wide spectrum of action, which is not crop specific, having a curative mode of action and focused on the target. According to the company, the high volatility of the active substance from the plant allows application close to the harvest, being also a "resistance breaker" to go down the cycle of resistance build-up on some conventional pesticides, with minimal impact on the population of beneficial insects.

In 2022, field trials were placed in three SUDOE regions: Portugal (Quinta do Sairrão) under certified integrated production; Narbonne (Chateau l'Hospitalet) and Bordeaux (Château Rioublanc), both under certified organic production. At each site, three modalities were established, comprising the following protection strategy against downy mildew:

- CTL: Non-treated Control: a small area without any treatment against downy mildew.
- UTP: Usual Treatment Protocol: in this area the usual protection strategy against downy mildew at each site was applied.
- NTP - New Treatment Protocol: in this area the low-copper protection strategy against downy mildew developed by COPPEREPLACE project was applied (**Table 2**).

Table 2. Detailed NTP modality, doses and starting stages.

PRODUCT	Portugal - Douro	France - Narbonne	France - Bordeaux
WHEN TO START	At visible bunches (F, BBCH 53)	At budbreak (E, BBCH 14)	50% at 3-4 leaves (E, BBCH 14)
COPPER	25% of the usual copper dose. For example, if the usual dose in 300 g copper per hectare, 300x0.25=75 g Cu/ha was applied. Weighted in function of the vegetative growth at the moment of spraying. For example, if the growth is at 25 % of full leaf area, 75x0.25=19 g/ha was applied.		
GLUCOSEI	25% of the usual copper dose. For example, if the usual dose in 300g copper per hectare, 300x0.25=75 g Cu/ha was applied. Glucosei (8%) doses 80 g Cu/L, this translated as 0.94 L Glucosei per hectare. Weighted in function of the vegetative growth at the moment of spraying. For example, if the growth is at 25% of full leaf area, 0.94x0.25=23 L/ha was applied.		
ORANGE OIL	Maximum dose: 1.6 L/ha. To be applied with each copper treatment, except during blossom (H-J, BBCH 57-71), as it is forbidden. Maximum 6 applications during growth cycle, with 7 days interval between applications.		

Together with new products, smart spraying techniques were also tested aiming to optimize pulverization:

- Dosaviña App: To determine the optimal application volume in pesticide spray applications in vineyard based on canopy conditions and the sprayer used;
- Water-Sensitive Papers (WSP): To verify quality (coverage homogeneity) of pulverization;
- Variable Rate Application (VRA): To adjust application volume according to leaf area, based on vigor maps.

2. Regulatory feasibility of proposed solutions

Being biologically active chemicals, Plant Protect Products (PPP) are carefully tested for their safety and efficacy before being launched on the market.

Requirements for the approval of active substances, synergists, protectives and co-formulants are introduced by Regulation (EC) No 1107/2009. This document also contributes to the harmonisation of procedures and rules in Member States (MS), establishing rules and detailed deadlines for the evaluation and decision for placing PPP on the market, to update and simplify the approval and authorisation procedures, enhance free movement of such products, and ensure their availability in the MS, ensuring a high level of protection for humans, animals, and the environment, as well as the competitiveness of community agriculture.

According to this document, PPP can only be placed on the market or used if it has been authorised in the MS in question. In addition, the Regulation clearly defines the situations in which a commercial authorisation is not required, such as:

- Products containing only basic substances;
- Production, storage or transport of plant protection products intended to be used in another MS or for export;
- In case of parallel trade permission;
- Authorisation for phytosanitary emergency situations (120 days);
- Authorisation for experimentation purposes.

To enable a harmonised and efficient system to apply for authorisation of a PPP, a zonal system operates in the EU. Europe is divided into three geographical zones (**Figure 1**), considered to be uniform, across the various areas of assessment of an authorisation, so that an authorisation granted in one MS of that zone can be given in another MS of the same zone. All the active substances contained in the product must first have been authorised at Community level.

Figure 1. EU division for PPPs approval and placing in the market.

An application for the approval of an active substance is submitted by the producer of that substance to a zonal Rapporteur Member State (zRMS), together with a summary and a complete dossier demonstrating that the active substance fulfills the Regulation approval criteria. This application must be made in each MS where authorisation is sought, and its evaluation is commented or audited by the other MS of the zone. Applications for authorisation should be prepared bearing in mind not only the intended uses in a specific MS in the zone, but all the intended uses in each MS in that zone, in order to reflect the relevant conditions throughout the zone.

To further minimise barriers to PPPs commercialization, a parallel trade permit is available. This is an authorisation to "import" a product already authorised in another MS. The main requirements for authorisation are that the product to be "imported" is identical to a product already authorised in the MS of introduction (reference product), and that the purposes and conditions of use are identical. PPPs are considered identical to reference products if: 1) they have been manufactured by the same company or by an associated company, according to the same manufacturing process; 2) they are identical in the specifications and content of the active substances, protectors and synergists, and in the type of formulation; and 3) they are identical or equivalent with regard to the co-formulants present, the size and shape of the packaging and the material of which it is made, in terms of potential negative effects of the product regarding human and animal health or the environment.

Regarding Cu, Regulation (EC) No 2018/1981 restricts the use of PPP containing Cu compounds to a maximum application rate of 28 kg/ha of Cu over a period of 7 years (i.e. average 4 kg/ha/year), in order to minimise the potential accumulation in soil and the exposure for non-target organisms, while taking into account agroclimatic conditions. This limit may be exceeded in a given year, provided that the average quantity used during the seven-year period does not exceed 28 kg/ha. This limit has become more restricted in the last decades, and Cu is on the list of candidate molecules for substitution at European level (Part E of the Annex to Regulation 540/2011, 16), being already prohibited in several European countries. Until 2025, the list of active substances approved will be revised and Cu could be removed.

Copper-based pesticides still represent one of the few alternatives for the efficient management of downy mildew in the vineyard, especially in organic farming. For organic producers, the increasing restrictions on authorised Cu doses and the possible removal of copper-containing products from the market, represent a challenge, since they are prohibited from using synthetic fungicides. Therefore, significant demand thus exists for agricultural research to identify and develop solid alternatives to Cu.

In this context, a demand for alternatives to Cu do exist, but it's important to mention that the process to obtain new products which can substitute Cu must be optimized.

PPP authorisation process follows a strict methodology based on harmonised scientific criteria, including evidence that a substance can be used without harm to human health and the environment, as well as a risk analysis based on guidelines. This assessment is done by the European Food Safety Agency (EFSA) and then examined by the European Commission. If the active substance is authorised, it is included in the Annex to regulation EU/540/2011, the European list of approved active substances. This is a laborious, time consuming and costly process, making it daunting. Therefore, even if promising substitutes may arise, the process involved can stop their entry on the market.

Proposed alternative, Glucosei, is a Cu gluconate-based product (8% p/p), a form of Cu that is easily absorbed, ensuring rapid and optimal assimilation by the plant. This formulated product is already on the market, however promoted to be a deficiency corrector (or foliar fertiliser). For this reason, and according to regulation, it cannot be used as a pesticide, i.e., used alone in a phytosanitary program. Nevertheless, due to its composition. In fact, besides being suitable for use in multiple crops (citrus, vine, table grapes, nut trees, olive tree, Solanaceae, Cucurbits, Bulbs, Brassicaceae, and berries), this product has several advantages, namely:

- Has both contact and penetrating action;
- Allows reducing the amount of Cu metal per hectare;
- Greater persistence in crops;
- Reduces considerably the risks of phytotoxicity and effects against beneficial insects;
- Reduces environmental contamination and the accumulation of Cu in the soil;
- Promotes cicatrisation in horticultural crops.

Due to its benefits, and although not eliminating the use of Cu, solutions such Glucosei may represent a viable alternative to control mildew disease, while reducing Cu doses and therefore environmental impacts.

Basic substances such as Glucosei are active substances, and even though not authorised as PPP, they have fungicidal effects and are of interest for crop protection, but for which the economic interest in applying for approval may be limited. Such substances are defined and listed in Article 23 of Regulation (EC) No. 1107/2009 and can be used in organic farming. In this context, the use of already existing basic substances (*Equisetum arvense* L., *Salix* spp., *Urtica* spp., Fructose) could help overcome the constraints already mentioned.

Because the adoption of alternative solutions to Cu is currently slowed down by legal framework, associated costs and lack of product's supply, to overcome these issues, a rapprochement with the manufacturers could be envisaged to reflect on a potential registration of the product in the phytosanitary category.

With increasing restrictions on copper use and its possible removal of approved active substances list, there's an urge to find alternatives to its use. However, the use of alternative products to copper is slowed down by the current legislative framework around Plant Protection Products. Therefore, it is necessary that policy makers act quickly on optimizing authorisation processes, as well as allowing large-scale tests on such alternatives.

3. Efficacy and technical feasibility of new itineraries in downy mildew control

During field trials, because of unfavorable weather conditions to downy mildew development, very low disease pressure was registered in Douro and Narbonne, with no spot of any disease observed even on control (CTL) rows. This suggests that in some years, under very dry climate, no Cu is required to ensure no contamination of downy mildew on the vines.

At Bordeaux, this trial confirmed the benefit of using a form of copper with a different formulation (Cu heptagluconate, Glucosei), allowing for a significant dose reduction while providing adequate protection under a normal downy mildew pressure. However, a hailstorm in July clearly weakened the plot, facilitating the spread of mildew. In this case, NTP did not provide sufficient protection to obtain the same yield as the usual winegrower strategy (UTP). Unfortunately, these unexpected events are forecasted to increase, compromising the use of treatments with lower levels of copper.

No technical point likely to avoid integrating Glucosei in phytosanitary programs was identified. In addition, no investments regarding machinery and/or equipment were needed to implement proposed itinerary. Also, workers do not need any specific training to perform the new treatment which is an advantage for its adoption.

Although results are promising, the alternative formulation used (Glucosei) still had copper and therefore could only be used to reduce applied doses and not for replacing copper. In integrated production (PRODI) mode, under low downy mildew pressure, the use of copper can be totally avoided. Nevertheless, the experience obtained during the field trial allowed us to understand that, when treatments are made preventively, a small dose of copper can be used, and it is possible to finish the season with an extremely low total of copper applied in years without any pressure. This allows producers to manage copper quantities through the years, having the possibility to use more copper to resist the disease when confronted with a season with high pressure, while keeping up with legislation. In any case, close monitoring of weather conditions, crop growth and disease risk by local observation is paramount to avoid unnecessary copper applications with both environmental and economic advantages, while securing yields and quality of grapes.

A regulatory limiting point for feasibility of adopting this new protocol is the classification of Glucosei as a foliar fertiliser, meaning it cannot be used for phytosanitary purposes, which limits its application, particularly under organic farming, for which it is necessary to justify every foliar fertiliser input.

Additionally, low commercial availability of alternatives such as Glucosei may influence feasibility of implementing alternative products, becoming a limiting factor in reducing Cu amounts. In this sense, a joint work with the manufacturer, as well as possible changes in regulation could be a way of solving this obstacle by obtaining a registration of this and other possible alternative products under development in the phytosanitary category.

In the Douro region, the scarce and dwindling labour availability is also an obstacle as the use of these products offering lower safety against sudden outbreaks requires the capacity to react quickly in terms of product application and canopy management. If temporary labour is not available at the right time, these itineraries may become an undesired liability.

To increase technical viability, it is very important to disseminate results from credible trials conducted with adequate experimental design and a sound use of statistical analysis. Making cooperative field trials together with independent organisations and wine estates seems very useful to advance in the issue of reducing copper use.

Although results are promising, Glucosei does not replace copper, but can help reducing applied doses. Under low-moderate downy mildew pressure, this product provided good protection, while reducing copper inputs. This allows producers to manage copper quantities through the years, having the possibility to use more copper to resist the disease when confronted with a season with high pressure, while keeping up with legislation. Nevertheless, a contingency plan is always need in case of sudden events, having in mind the context where it is applied, considering weather conditions, crop growth and disease risk by local observation.

4. Environmental impact of proposed solutions

The long-term use of Cu-based fungicides caused high accumulation of this element in vineyard soils, posing a high risk for the environment, if Cu is transferred to subsurface and groundwaters or soil biota. For this reason, it is important to assess Cu impacts on environmental parameters, such as bioavailability, toxicity, leaching capacity, and its effect on soil microorganisms.

The New Treatment Protocol (NTP) uses the same amount of water and fuel, when compared with conventional treatments, however with less copper applied, as NTP enables Cu dose reduction by around 40%. However, this reduction is not reflected equally, regarding Cu accumulation in leaves, grapes and soil.

In leaves, NTP appeared to have resulted in a significantly lower concentration than UTP, as expected, related to lower Cu inputs by the new treatment. This is true for Organic Production, as no alternatives to Cu are available. On the contrary, in Integrated Production, producers have other options, allowing the use of Cu to be completely avoided. Nevertheless, it is important to mention that these alternative products are synthetic pesticides, and therefore also have environmental impacts.

Cu levels in grapes did not vary significantly between UTP and NTP, staying within permitted values, which can also be related to lower inputs of Cu due to low disease pressure.

In the soil, total and available Cu didn't vary significantly among treatment modalities (UTP vs. NTP), which can be explained by the low number of applications during the trial year, due to low downy mildew pressure (resulting in a low input of Cu). Anyhow, product formulation may interfere, and soil characteristics should also be considered when evaluating Cu environmental impact. Also, it is important to note that one season is not enough to evaluate Cu impacts in soil, since the input is very low when comparing with the amount already existing in soils. In the long term, it is expected to have differences, since a lower amount of Cu is being applied.

Regarding Cu leaching, COPPEREPLACE results reveal that soil pH is the most influential factor in Cu leaching and in Cu effect on the tested organisms. In the other hand no clear relationship was observed for organic matter. Thus, acidic soils present much higher risk than soils with neutral or basic pH values.

With regard to Cu bioavailability, estimated through chemical extractions (chemical available fraction that given an estimation of the bioavailable fraction), results show that the soil with the lowest pH (4.59) had the higher risk of increasing water-soluble Cu, comparing with the other soils (pH≥5.60). It was also found that the bioavailable Cu (extracted with DTPA) is clearly related with total accumulated Cu, having soil characteristics low effect.

In summary, NTP may bring some context-dependent advantages in providing an adequate level of protection against low to medium downy mildew disease risk, while significantly reducing copper input to the environment. If yield is to be protected, it is important to underscore that, when using NTP, a contingency plan for quick action is essential to respond to an event suddenly increasing disease risk (heavy rain downpours over several days, hail, etc.). Even with such a plan, in such situations, severe losses of yield may be unavoidable under NTP.

Cu toxicity towards soil biota has been extensively reported, being extremely dependent on soil properties and characteristics: both pH and organic matter content present a great influence on Cu bioavailability and toxicity on soil microorganisms (Oorts, 2013). Through the results obtained in COPPEREPLACE, for the terrestrial plant *Medicago sativa*, lower pH correlates with Cu bioavailability and toxicity. An increase of the organic matter content of soils seems to provide some level of protection to Cu toxicity, at least to some extent. To the most vulnerable terrestrial macro-organisms, like earthworms, soil pH and organic matter don't significantly influence bioavailability of Cu. Thus, for each individual study case, Cu application, restrictions and remediation must be targeted accordingly to soil attributes.

It is important to mention that, as Glucosei is a foliar fertilizer, phytotoxicity problems may arise. Anyhow, more studies are needed to assess this issue.

When it comes to Cu reduction, smart spraying techniques are important to apply only the necessary quantity to ensure good protection. The use of Dosaviña is helpful when it comes to reducing and adjusting application volumes of pesticides in those farms where application rate is higher than what is recommended. Farmers who already work with tight and adequate volumes, do not benefit from this tool. The use of Water Sensitive Papers is also very important to adjust equipment for optimum coverage. Finally, the use of Variable Rate Application, together with the determination of copper doses based on the label indications of the commercial product, has resulted in considerable reductions in both application volumes (11-29%) and copper applied (34-59%) (**Figure 2**). Additionally, VRA allows similar leaf deposition while reducing the amount of copper in high vigour zones, suggesting that this is a more efficient application strategy than the conventional one. This indicates that its use would be in line with the pesticide use reduction requirements set by the European Union. It is also important to note that results may vary with climatic conditions and disease pressure.

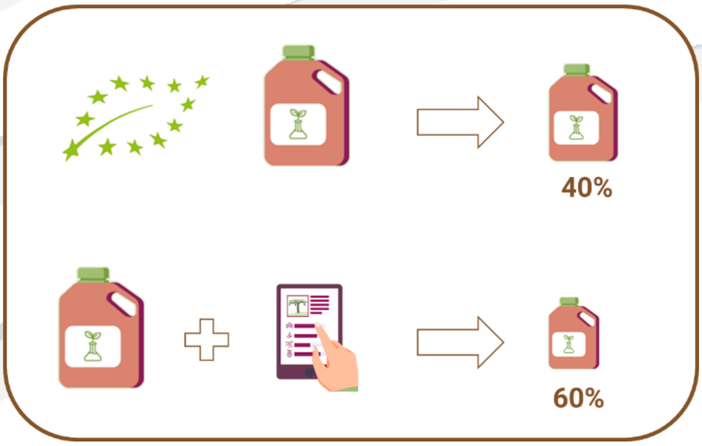

Figure 2. Copper reduction provided by the new treatment and together with VRA.

Having in mind that Cu formulation is important, the use of biodegradable capsules was tested. Encapsulation in biopolymer matrices has been recognised as an effective method of controlled release of a bioactive agent used in plant protection. The release of copper cations from microcapsules and its prolonged presence on leaves can lead to a reduction in the levels required for effective crop protection.

The microencapsulated product was developed by EURECAT, a partner in this project, and tested in 2021 and 2022. Results on the application of Cu microcapsules are promising in terms of leaf deposition, guaranteeing between 30 and 40% more deposition than in the traditional application. Nevertheless, low disease pressure during the trial years, washing of the product due to heavy rains in June 2021 and the hail event in 2022 must be considered. In this sense, it is necessary to test the biological efficacy of this new technology under higher downy mildew pressure conditions, as well as to study the persistence of this microencapsulated copper product in the soil and its possible leaching into groundwater. Even so, this technique seems an interesting way to reduce Cu rates as it opens doors to the development of new procedures for formulating active substances. In addition, this method reduces the quantity of water used, contributing for a better management of this scarce resource.

When it comes to the impact of copper, soil characteristics play a major role, with soil pH being the most influencing parameter. New solutions provided good efficacy against downy mildew while reducing copper inputs, demonstrating the importance of copper formulation. The use of smart spraying techniques has proved to be important to further reduce copper use, reinforcing the need to have a context-dependent integrated strategy in downy mildew control.

5. Profitability and economic sustainability of proposed solutions

To producers, when adopting new technologies/solutions, economic factors play a huge role: 1) How the cost of innovation translates into the final price of grapes/wine; 2) Operating costs; and 3) Initial investment required (products, equipment, training).

In this sense, to evaluate economic viability of proposed solutions, cost and profit must be accounted for.

COPPEREPLACE proposed itineraries for Cu reduction do not require any investment regarding equipment/machinery, nor additional manpower (or its training) to perform new treatments. This is of major importance, as the producer does not have additional costs other than the products. However, the price of Glucosei and PREV-AM® is higher than the products used in the usual treatment, making the average cost per treatment and per hectare higher, especially when pressure disease is higher since more frequent treatments are needed (**Figure 3**). Therefore, in order to provide a good protection, the proposed new treatment may be significantly more expensive than the usual treatment.

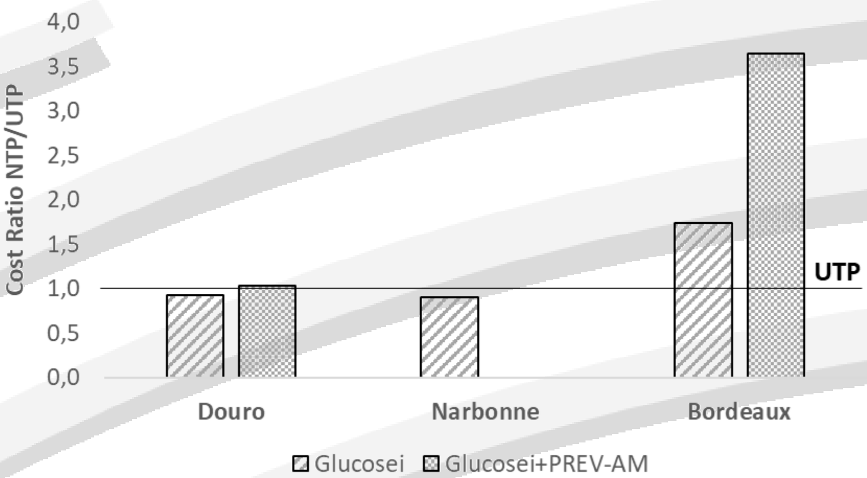

Figure 3. Average cost ratio of NTP (Glucosei or Glucosei+PREV-AM®) comparing to UTP.

This ultimately hinders the transition to such solutions. For the contrary, with low disease pressure, profit is not affected by the adoption of new itineraries (**Figure 4**). Nevertheless, profit simulations show that only a 50% yield reduction compared to average translates in substantial profit decrease, regardless of treatment modality cost, suggesting that yield (kg/ha) has more impact on total profit than the actual treatment cost.

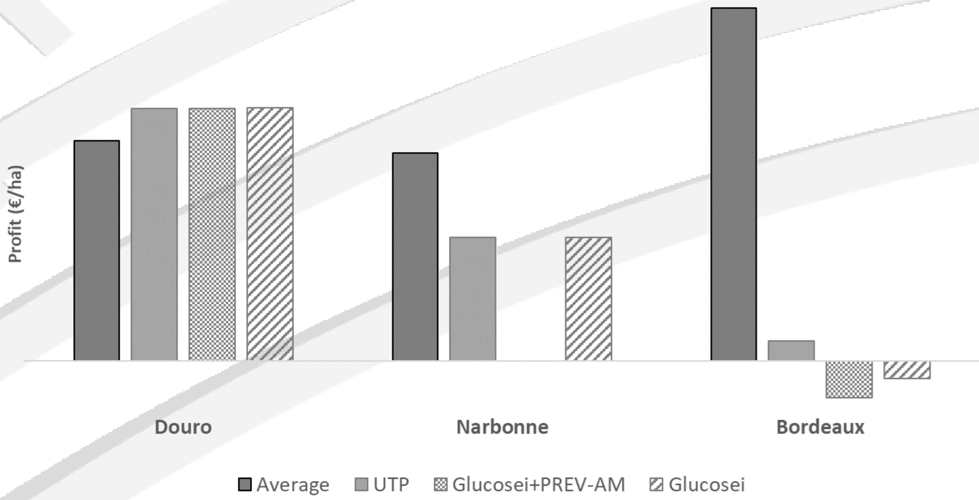

Figure 4. Profit (€/ha) in each plot and each treatment modality, comparing to 2018-2021 average.

It is also important to note that smart spraying techniques such as VRA can be a clue to allow product quantity reduction, and overall better targeting of the product, allowing optimum leaf coverage, and better disease control, lowering the costs. In this sense, an integrated vision of vineyard management is crucial, having in mind not only the products used, but most importantly joint strategies to further reduce Cu.

One of the main constraints to the use of Glucosei is its classification as a fertiliser, meaning that it cannot be used as a tool to control downy mildew, as organic producers can lose certification and clients/market position as a result. In this sense, government support is also needed to implement new solutions, not only regarding legislation, but also financial support. Another important aspect is that the registration of new alternative products to Cu is a costly process. It is acknowledged that the European Commission has made efforts to optimise the registration of products, but quick and focused action in this sense is needed.

Although new products' price is higher than the conventional ones, under low-moderate mildew pressure, alternatives may be economically viable, with the plus that the adoption of new solution does not represent any additional cost to the producer other than the product itself. Under high disease pressure, proposed alternatives may lead to production loss, reflecting on lower profit. This could be overcome with a contingency plan for quick action to respond to an event suddenly increasing disease risk.

6. Social impact of proposed solutions

When adopting new technologies/solutions for downy mildew control, there are three major factors impacting such adoption by producers: 1) consumer pressure towards more sustainable solutions; 2) feeling of support; and 3) improvement of the company image on the markets. This means that the innovation must generate return, not only economically, but also in terms of market advantage. Moreover, producers need to feel that this is a joint effort among winemakers towards a more sustainable and resilient wine sector.

Although age and schooling/agricultural training didn't compromise the results of new treatments, implementation of new technologies/solutions may be affected by such factors, as older workers may be very attached to traditional practices, making it more difficult to implement such alternatives. In this sense, it is important to raise awareness among workers on the importance of sustainability, while integrating them in activities related to the validation of such alternatives.

Nowadays, a relevant factor to consider when evaluating social impact is the importance of technological innovation for rural areas and agricultural development, due to their potential to improve rural economies. Technological conversion can offer economic growth possibilities and opportunities for better and more diverse jobs, increasing gradually the educational level of the communities, supporting the transition towards a low-carbon economy. Regarding the application of the COPPEREPLACE's tested solutions, namely innovative precision application techniques (spraying calibration, optimum application volume determination, VRA), when analyzing in an integrated way, together with the application of the products proposed in the project, it translates into technological conversion of farms.

Another important social indicator is job creation. In the short-term, the adoption of the proposed solutions does not represent additional manpower, not translating therefore into new jobs. However, we must emphasize that the implementation of precision practices, which in the scope of this study were applied with the help of the technicians involved in the project, may contribute, in the medium-long term, to an increase in the workers' training, and may even promote the creation of new positions of responsibility within the company, which may also be reflected in a salary increase (increasing employment quality).

When evaluating social impacts, environmental health, workers' health and safety, as well as food safety, must also be considered, as they integrate aspects related to the changes arising from technological adoption in the accumulation of Cu in the soil and berries, as well as the use of fuel and water. New itineraries do not require more labor hours, fuel nor water. Additionally, they account for around 40%, or even 60% when implemented together with implementation of new precision approaches. In the medium-long term, such factors may be reflected in a reduction of environmental impact, and an increase in human well-being and security. Additionally, precision application techniques can also contribute to increasing workers' safety, as they minimize product dispersal risks. Regarding food safety, project's results showed no improvements by the products tested, having the Cu values found in berries similar between modalities. However, more trials over a longer period of time are needed, since one-year trial does not provide enough information.

It is important to mention that the limitations related to development of this project are reflected in a short-term analysis. In this way, an assessment of limitations and potential in the medium-long term may be different (**Figure 5**).

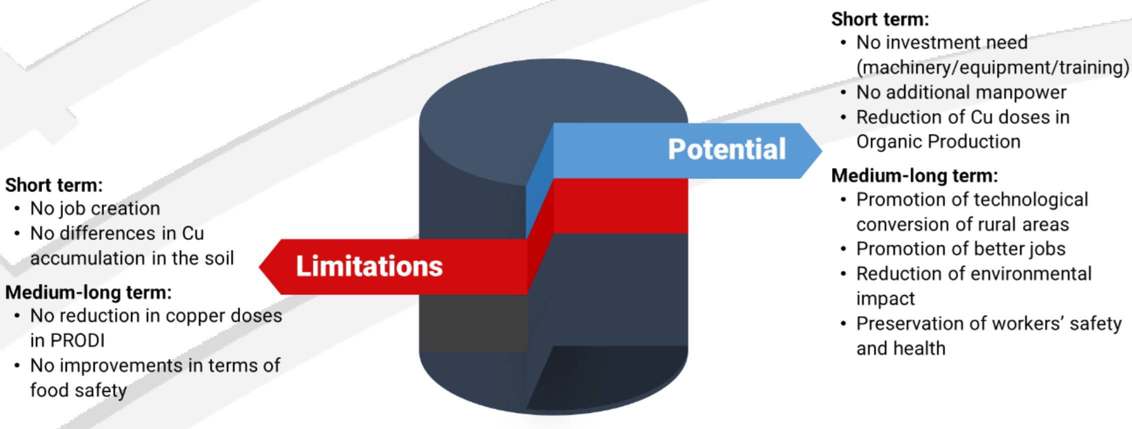

Figure 5. Main potentialities and limitations of the solutions proposed by COPPEREPLACE Project in Social Economy.

7. Viability of proposed solutions across different scenarios

To replicate the approaches and results obtained in this work, it is essential to consider the context where it will be applied. Soil vulnerability, climate and usual farming practices will need to be considered to manage the risk of disease adequately.

Regarding soil, plots with more vulnerable soils (low pH and organic matter) are at greater risk of Cu contamination. For instance, Douro schistous, low pH anthrosols present higher vulnerability to copper contamination with potential impacts in soil and water organisms, which may reduce local biodiversity and important ecosystem functions such as nutrient recycling, competition with pathogens or pest antagonism. In these cases, a copper reduction strategy is essential, and all opportunities are valuable.

In relation with climate conditions, this relates with disease pressure. In the case of high pressure for downy mildew, more treatments (and more product) are needed. Therefore, and having in mind present legislation (limiting Cu to 28kg/ha over a 7-year period), it is necessary to compensate during years with low or no downy mildew pressure. In this sense, proposed solutions can help to reach Cu reduction objective, as the possibility to use less copper when there is less pressure is a huge advantage, increasing doses in years with higher pressure. Nevertheless, in years with extreme climate events (e.g., hailstorms), new solutions may not provide enough protection and production losses can take place.

When it comes to farming practices, under integrated production mode, the possibility to alternate cupric formulations with other protection products can significantly lower copper use and, for places and years with very low downy mildew pressure, totally replace its use by PRODI-approved active substances, reducing the values of copper found in soils, leaves, and berries. This means that Integrated Production offers a reliable and sustainable way of balancing plant and environmental protection at a reasonable cost. On the contrary, in certified Organic Production, there are no alternatives to copper, meaning that this is still the only safe way to control downy mildew. In this case, alternatives that contribute to copper reduction are of major importance. However, it is necessary to guarantee that such products provide good protection.

In any case, because of the absence of downy mildew pressure in the field trial year, specific feasibility evaluations for place/mode of production binomes are not accurate. In this way, a SWOT analysis (**Figure 6**) is meant to provide guidance in such replication and tries to draw conclusions for the experiences in all three sites for application to the SUDOE space.

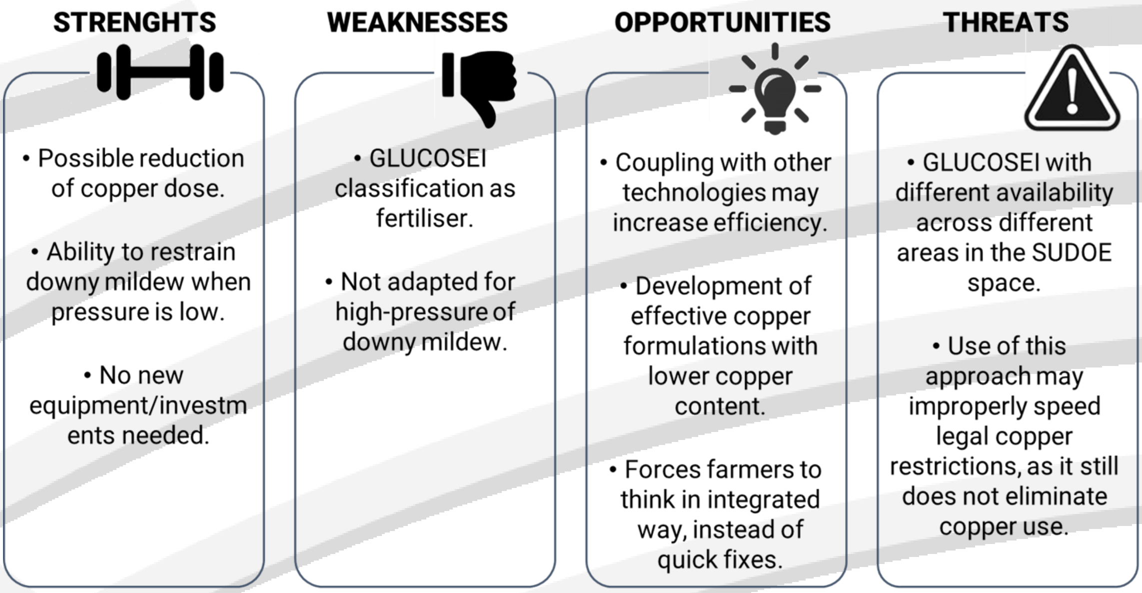

Figure 6. SWOT analysis of COPPEREPLACE new treatment protocol.

8. Main conclusions and recommendations

The increasing restrictions on authorised Cu doses represent a challenge for producers, especially for organic growers, who are prohibited from using synthetic fungicides.

The COPPEREPLACE´s results have reaffirmed the **importance of product formulation** in finding better ways to reduce the environmental impact of plant protection in viticulture, as **a better formulated cupric product provided acceptable protection at a reduced Cu dosage** at least in the presence of low downy mildew pressure**.**

While not eliminating the use of Cu, COPPEREPLACE´s tested solutions allow the reduction of its input by up to 60%, when combining their use with remote sensing monitoring technology to adapt Cu dosage to vegetation volume. These practices, while preserving crop value, also reduce the loss of sprayed products and present a good business case for cost management in viticulture. Besides, looking in **an integrated way** and **in a medium-long term,** the use of the combined strategies (products + precision techniques) may contribute for the **technological conversion of rural areas, improving the quality of employment in such zones**. All these factors, ultimately, may lead to the attraction of people to geographic areas with low population density, thus contributing to the **development of the local economy.**

It was confirmed the great difference that exists between winegrowing regions, **which is reflected in the impact of Cu, depending on the production mode, soil characteristics, disease pressure and climate conditions.** On this matter, a **specific and integrated approach must** be adopted to obtain satisfactory results. **Under Integrated Production and low downy mildew pressure, the use of Cu can be totally avoided**, alternating its use with other active substances against downy mildew, a practice that accounted for lower Cu inputs while ensuring adequate protection and overall sustainable production. **This may not be the case, however, in years with high disease pressure or extreme climatic events**, being difficult to conclude its efficacy. In this case, **caution and contingency plans** are of the essence for any strategy to reduce copper usage under these conditions.

It was also observed that the cost of new treatments may vary with disease pressure, being **more expensive than the conventional treatment when disease pressure is high.** However, they **do not represent any additional costs regarding equipment/machinery, manpower or its training**. When **disease pressure is low-moderate, profit is not affected**. However, while recognizing the importance of reducing Cu, **producers are willing to test new solutions**, but have **reservations about the effectiveness** of the products (especially in years of higher disease pressure).

When evaluating the viability of a given solution, the concept of “true value accounting”, i.e., the impacts on the natural and social environment in which the company operates, must be considered, as it plays a crucial role in companies’ sustainability. For this reason, and **considering environmental and social impact/cost, such difference in cost may be acceptable**. Nevertheless, the **adoption of new solutions and/or technologies must improve the company's image on the markets**.

The **adoption of these solutions is currently slowed down by legal framework**, associated costs and lack of product`s supply. A major challenge in progress towards Cu reduction is highlighted: **the impossibility of large-scale testing of new products of interest that have not yet obtained authorisation** (except on condition that the entire harvest is destroyed). To overcome these issues, a **rapprochement with the policy makers and manufacturers** could be envisaged to reflect on the registration of PPP. Also, the harmonisation of phytosanitary product labels is considered important to further help winegrowers with dose reduction.

Currently, it is not feasible to provide adequate plant protection in either organic or integrated productions by totally avoiding Cu use. Inversely, **reducing copper use by employing better lower-impact copper formulations does seem a possible way of lowering Cu dispersion to the environment**. This requires, however, **better knowledge of context conditions** for all situations, namely, soil vulnerability to Cu contamination and climate drivers of disease risk, spray dispersal and copper leaching in soils, as this project clearly demonstrated that any product or treatment protocol cannot be implemented without **field validation**, given the great impact of environmental conditions on their effectiveness. Additionally, it's important to note that the timeframe of this project was particularly limited, and that **one-year trials do not provide enough information and security, and conclusions can’t be precise**. Furthermore, to overcome uncertainty caused by annual climatic variability, the protocols and the products need to be repeated at least for three years.

Although this project did not find an effective solution to replace Cu, it has led to progress on several fronts. The **dissemination of these results through exchanges between research actors, professionals and policymakers** remains an essential part for the wide implementation of these methods and technologies in the SUDOE space. The best tool for this will be the continuation and strengthening of the stakeholder network setup by COPPEREPLACE (GT6), perhaps even by converting it into a community of practice. This should also become the place for **discussion with public authorities and**

policymakers so that the latter has a clear vision of the progress achieved, the existing limitations and obstacles to the feasibility of any proposed solutions, in order to best adapt regulatory developments and foster the increasing adoption of copper-smart viticulture practices.

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