Methodology for phenoclimatic observations and modelling of *Castanea sativa* Mill. traditional cultivars and revitalizing chestnut growers' local knowledge in France, ROC-CHA project

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Abstract

The ROC-CHA project is a joint project of researchers co-led by the CNRS (National Center for Scientific Research) and the SNPC (National Union of Chestnut Producers) in France. Our partners include INRAE Bordeaux, and associations involved in the development of chestnut cultivation in France, RENOVA in Ariège, Epi de Mains in Lozère, Groupement Régional des Producteurs et Transformateurs de Châtaignes et Marrons de Corse (GRPTCMC) in Corsica, as well as individual expert chestnut growers in Ardèche, Lozère, Corsica and Ariège and Agricultural Chambers (Ardèche and Corsica). This project aims at establishing a network for observation and conservation of chestnut cultivars at farm level and create synergies between scientific and chestnut grower's local knowledge in France; with as main objectives to: 1) develop phenoclimatic observations and modelling of chestnut cultivars within the context of climate change, and 2) consolidate local knowledge and know-how of chestnut growers through peer-to-peer exchanges within a network of reference sites. These sites are on-farm living labs where we use a methodology developed by the "Observatoire des Saisons", a research and citizen knowledge platform in France, that we refined and adapted through a co-construction process. Indeed, with some 20 chestnut growers, a practical approach for developing comparative observation of major phenological stages of chestnut cultivars development has been put together. The results presented in this paper are our methods for the follow-up of these phenological stages which are the budburst, initial opening of leaves, the flowering of first male flowers, the fruiting, and senescence, i.e., changes in leaf colouring and finally fallen leaves. All sites are associated to data loggers in order to obtain a database of temperatures, at the pace of one data per hour, 24 per day. We explain the approach that links researchers and chestnut growers, the observation processes, modelling and some preliminary results. We also present the experimental set up of peer-to-peer exchange of knowledge between chestnut growers, based on ethnoecological approaches for reconstructing fragmented local knowledge, the experimental setups that favour the emergence of almost lost knowledge, and we present some results regarding how this type of knowledge enables a better characterizing of numerous local varieties of these four regions. In conclusion, we consider that both, observation of phenological stages, and revitalizing local understanding of characteristics of chestnut cultivars, leads to a better understanding of how best to face climate change.

Keywords: chestnut growers, phenoclimatic observation and modelling, co-constructed methodology, revitalizing local knowledge, Ardèche, Lozère, Corsica, Ariège.

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INTRODUCTION

This paper explains the methods of the ROC-CHA[b] project which is a Network for Observation and in situ Conservation of traditional *Castanea sativa* Mill. cultivars and co-constructed local and scientific knowledge established since 2020. This project aims at recovering a robust and productive mountain chestnut agroecosystem, within a context of land abandonment and climate change through improving farmer's capacity to adapt to climate change, as well as identify in situ repositories of chestnut genetic resources and associated co-constructed local and scientific knowledge for chestnut growers.

The ecological heterogeneity of chestnut agroecosystems located in mountainous conditions, poor and acidic soils, the difficulties of irrigation, mechanization, the nature of the products (chestnuts, an uncommon staple food from trees) associated with animal husbandry and wood production, characterize this agroecosystem poorly understood by agricultural policies. In addition, these agroecosystems were abandoned since late 19th to early 20th century with agricultural industrialisation that favoured agricultural productions in the plain areas in France and more generally in Europe at the expense of heterogeneous mountain areas (Bruneton-Governatori, 1999; Grove and Rackham, 2003). As a result, chestnut production has steadily decreased since the end of the 19th century, but started to recover since the 2010s, currently reaching about 0.15 million t year^{-1}, thanks to the resilience of chestnut growers and renewed interest of consumers. Movements of resilience for example in Ardèche, Cévennes, Corsica (Dupré, 2002; Michon, 2011; Aumeeruddy-Thomas et al., 2012) and a favourable fabric of industries, local processing units installed in Ardèche, Lozère and Corsica and the obtention of the protected designation of origin (PDO) labels, show both entrepreneurship and high attachment to chestnut cultivars in these territories despite the fact that they have endured a deficiency of support by public policies (Michon, 2011) and EU agricultural policies, in the commercialization chain and difficulties to have access to land for young farmers. The multiple values of this agroecosystem offer however substantial cues to think of sustainable chestnut production models in future in the context of ecological transition absolutely required within the present context of environmental crisis. Monovarietal approaches for chestnut cultivation, although highly productive, are likely to become more vulnerable within the context of climate change due to decrease in access to water, available chemical inputs and increase in pathogen attacks.

The high agrobiodiversity represented by the diversity of chestnut cultivars, and associated biodiversity (pollinating insects, ectomycorrhizal associations, birds, bats, lichens, etc.) contribute to the multiple valuing of agrobiodiversity, a solution put forward as a potential path to address ecological transition by IPBES[c] (2022). Associated local knowledge and practices are the foundations of diversified chestnut-based products that are also recognized for their positive value for human health (Eurocastanea, 2022).

We further identified a progressive loss of local knowledge and know-how, including the capacity to identify cultivars, to graft, renovate ageing orchards and develop proper soil management approaches (Aumeeruddy-Thomas and Ramet, 2021). This constitutes a threat to traditional cultivars and associated knowledge, and limits the adaptive capacities of these territories, especially within the context of climate change. Indeed, chestnut is sensitive to climatic change, which could also increase its sensitivity to pathogens (Freitas et al., 2021). This situation enhances the need to look more closely at the adaptive capacity of polyvarietal chestnut orchards.

In this context, ROC-CHA has founded a new solidarity between researchers, chestnut growers and other stakeholders of this sector. In a first step, we developed a network of key sites and expert farmers with whom we have jointly built-up methodologies in a participatory manner in order to conduct our main activities and test our hypotheses with the following major activities: i) to use these in situ network of reference sites to carry out research for modelling each chestnut cultivar's phenological response to climate that may afterwards be

[b]Réseau d'Observation et de Conservation in situ des variétés de CHÂtaignes et des savoirs co-construits locaux et scientifiques associés

[c]Intergovernmental Platform for Biodiversity and Ecosystem Services

used to predict chestnut cultivars' capacity in relation to IPCC predictions; ii) to facilitate the transmission of local knowledge co-constructed between chestnut growers from the most experienced to younger farmers within each of the project's four territories and between territories.

In this paper, we first show the methodology to co-construct the network and identify expert chestnut growers. Then, as part of our results, we give a comprehensive presentation of the methodologies regarding the two above activities, with some preliminary results in order to illustrate their efficiency and limits.

STUDY SITES, MATERIALS AND METHODS

Reference sites

The distribution of the network of reference sites (hereafter RS) of ROC-CHA is shown in Figure 1 below. Several RF are followed by the same person (hereafter referent) but are distinguished because they present different topoclimatic situations (with a variation in altitudes or exposition). The RF have been chosen with the help of stakeholders and partners of ROC-CHA[d], in three major chestnut regions of France that still have significant mountain chestnut agroecosystems, namely Ardèche, Lozère, Corsica and one area under renovation of chestnut production after abandonment, Ariège. These areas have the following gradients regarding different subjects of concern in this project: 1) importance for chestnut production in France; 2) climatic gradients found within each region in relation to altitudes or latitudes, and general climatic conditions; 3) level of transgenerational knowledge. Other criteria were: presence of local chestnut transformation units, existence of other institutions (e.g., PDO, IGP or National and Regional parks that could be consulted for the appropriation of the project's results).

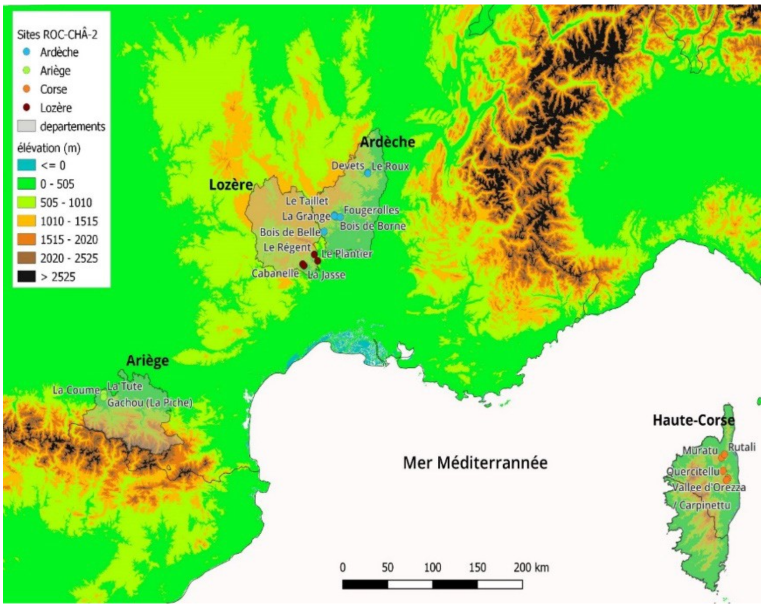

Figure 1. This map shows the location and names of the 19 reference sites (RS) followed by the ROC-CHÂ project, that are living labs for phenological observations, local knowledge transmission and on-farm conservation of traditional cultivars.

[d]SNPC (National Union of Chestnut Producers) in France, associations involved in the development of chestnut cultivation in France, RENOVA in Ariège, Epi de Mains in Lozère, Groupement Régional des Producteurs et Transformateurs de Châtaignes et Marrons de Corse (GRPTCMC) in Corsica, Agricultural Chambers (Ardèche and Corsica), as well as individual expert chestnut growers in Ardèche, Lozère, Corsica and Ariège.

In Table 1 we show these different gradients and additional indicators. Partners at regional levels identified expert chestnut growers associated to the sites, recognized by peers for their knowledge, or highly engaged in renovating chestnut farms. Discussions with the latter helped in identifying the appropriate sites. RF are inhabited chestnut farms including rainfed chestnut orchards, with an undergrowth cleared manually, mechanically or with the help of flocks of domestic animals (mostly sheep flocks, a few cows, more rarely goats or donkeys). Farms are not made of a continued plot, but can be dispersed in different places with different types of tenure (property, location, shareholdings, etc.), having therefore different topographic and climatic (hereafter topoclimatic) conditions, in relation to the heterogeneity in topography, altitude and exposition. RS is a site associated to a referent (hereafter referent), is the farmer or any other person responsible for follow-ups, co-construction of methodologies with researchers, organizing workshops. In other words, these farms are living labs based on partnerships between farmers and scientists and in which farmers are retributed for time spent on the project. The two sites in Ariège are run by a group of producers, RENOVA, that revitalized chestnut cultivation from a situation where chestnut had almost totally disappeared from nearly all farms. Through renovating an old chestnut farm for demonstration, they created a remarkable live chestnut conservatory with some 40 chestnut cultivars grafted on pollarded spontaneous chestnut young trees. To date, 10 of the main cultivars have been sent to professional nurseries and some 50 farms have started cultivating them.

Table 1. Eighteen sites, in 4 regions, representing a range of 19 topoclimatic situations.

	Production	Trans-generational knowledge	Climatic variation in each region	Local entreprises	Other institutions	No. of sites and topoclimatic situations	Cultivars observed
Ardèche	High	HIGH: uninterrupted despite abandonment	HIGH: Large altitudinal variations	High	High	7	Aguyane, Bouche-Rouge, Comballe & Petite Pourette
Lozère	Medium	MEDIUM	HIGH Large altitudinal variations	High	Medium	4	Figarette, Gascaise, Pellegrine
Haute Corse (northern Corsica)	Medium	HIGH: uninterrupted despite abandonment	HIGH Large altitudinal variations	High	Medium	5	Campanese, Ghjentile, Morianinca, Tighjulane, A Tunada
Ariège	Low	LOW almost total loss of local knowledge	LOW	High	High	3	Patte de Loup, Précoce rousse

The major requirement at each site is to have at least 5 individuals of the same cultivar within one plot, with the same topoclimatic condition and at least two cultivars common among the farms of the same region. The chestnut orchards are all polyvarietal, that is with a mix of cultivars that vary between our sites from 5 to 20. Most individual trees are more than 50 years, grafted upon spontaneously growing seedlings with a haphazard distribution of trees (Aumeeruddy-Thomas et al., 2012).

Chestnut cultivars

Chestnut cultivars found in mountain chestnut agroecosystems are predominantly the European chestnut, *Castanea sativa* Mill. (*Fagaceae*), although a few individuals of the hybrids of *C. sativa* × *C. crenata* Siebold & Zucc. the Japanese chestnut or *C. sativa* × *C. molissima* Blume can be found. These hybrids were developed in the 1980s (Pereira-Lorenzo et al., 2016).

Mountain chestnut cultivars have been selected over historical times by farmers and are termed in this paper as traditional *Castanea sativa* cultivars. Farmers use a large set of criteria to choose preferred cultivars, the major ones being productivity, taste (especially sweetness), easiness of peeling, drying, but also phenology through considering how early or late the fruiting is to obtain the most spread-out production for reasons including marketing price but also organization of labour for collection. *Castanea sativa* is strictly allogamous and requires cross fertilization because of the species self-incompatibility (Larue et al., 2021).

Phenology is an important criterion to consider in general for the functioning of agroecosystems because different cultivars may be more or less sensitive depending on the period of the different phenotypic and potential climate impacts. For example, farmers commonly acknowledge that lack of water, and especially the lack of rain, especially mid-august and mid-September storms, would affect size and biomass of chestnuts at harvest time. The phenological calendar such as bud burst, foliage extension and development, flowering, fruiting and senescence identified by leaf abscission, and bud dormancy represents an overall cycle, one stage affecting the functional ecology of the following phenological stage. The chestnut floral structure and phenology is complex; it comprises a unisexual male catkin which blooms earlier than the female (which has a long receptivity) and male bisexual catkin. This rare flowering system has two peaks of pollen emission that do not overlap and are very unequal, the first one being an order of magnitude greater than the second one in terms of number of flowers produced and amount of pollen released.

Local knowledge of chestnut growers

Few works have assessed in a systematic way the knowledge of chestnut growers and ROC-CHA started a series of studies on farmer's indicators of impacts of climate change (Ponsa, 2022) and their understanding of tree health and related soil management (Basset, 2021). Some technical books have described cultivars of a given region (Reyne, 1984) for Breisch (1995) at the national level, based upon what farmers were able to explain and direct observations by agricultural technical staff. Despite these compilations, very few cultivars are proposed for reproduction to farmers. The entirety of this knowledge including the hundreds of cultivars that are known and still managed in relatively disconnected farms due to abandonment, remains highly underestimated. As of today, the PDO approach in Ardèche includes 65 cultivars but only some ten among them are carefully followed, reproduced/grafted by the unions of growers and agricultural chamber and distributed to growers. This situation added to the impacts of abandonment translates into an important decrease in knowledge transmission regarding cultivar diversity and their characteristics, thus leading to major losses in the overall capacity to locate and identify the full sets of cultivars traditionally cultivated, as shown during previous workshops (Aumeeruddy-Thomas and Ramet, 2021). Moreover, new comers on these territories have no access to chestnut related knowledge or almost no transgenerational transmissions even though many have tried to collect local memory and have built up farms based on legacies of previous farms (trees) and elderly persons' guidance (Aumeeruddy-Thomas et al., 2012).

Farmers' knowledge also pertains to their evaluation of the needs of the trees. It extends from pruning techniques considered by some as a key approach to keep the trees healthy and prevent phytosanitary problems, such as the chestnut blight (*Cryphonectria parasitica* (Murr), Barr), to soil management techniques meant to ensure a better nutrition and growth, and a better resistance to climate change impacts. On soils, many attempts are made by farmers who are constantly experimenting a diversity of techniques (Basset, 2021). From these experiments, new pools of knowledge are either re-emerging from lost knowledge or recreated de novo, sometimes in collaboration with researchers or agricultural technical advisors. This reinforces the idea of using reference sites as living labs for co-constructing knowledge.

RESULTS

Methodology of phenoclimatic observations and preliminary results

The establishment of phenological observations through a citizen approach required in-depth discussions at the inception of the project. Farmers proved to be fully aware of phenological changes related to the general increase in temperature and had a keen interest in jointly conceiving with researchers a common method that would improve their capacity to predict. They were however more accustomed to following bud-burst variations among cultivars and periods of production, than flowering or senescence.

A first set of data collected through a monthly visit by CNRS technical staff and researchers to 4 sites in 2020, based on joint observations with the owners of the site, showed the following diversity in cultivar and percentage of a given phenological stage at a fixed observation date for all cultivars (Figure 2). These observations aimed at gaining a general understanding of the span and diversity of phenology and their variations among cultivars. Joint observations with the chestnut growers were also meant to adjust what to observe, how to observe, disentangle the complexities of each phenological phase. In the data collection sheet distributed to farmers, there was space left for remarks regarding each observation since many factors may affect the results. For instance, chestnut flowers were particularly complex to observe due to their high diversity and morphologies. Indeed, sterile male catkins (astaminate) posed many questions of how to observe their development, which is far more obvious when they are longistaminate male catkins.

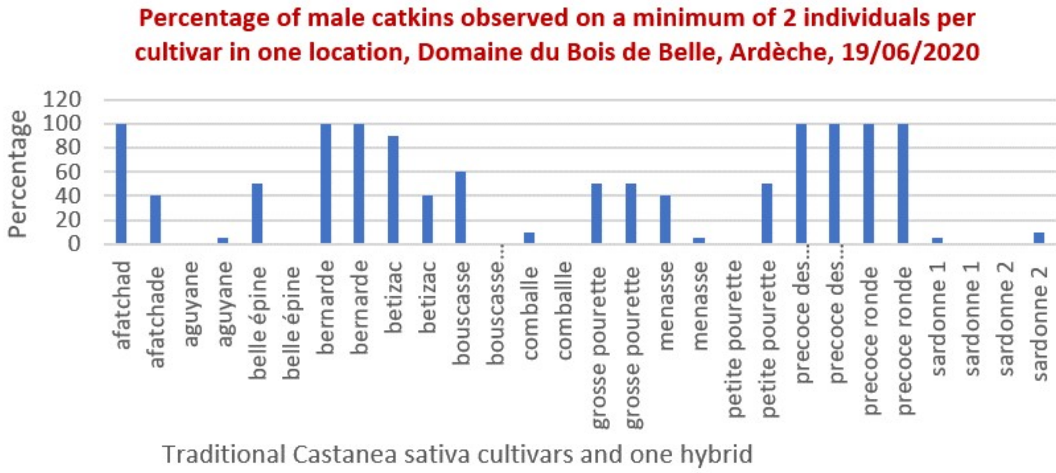

Figure 2. Phenology of traditional cultivars, expressed in percentage of development of flowers in a polyvarietal farm, the Bois de Belle in Ardèche.

This first step enabled to define the polyvarietal nature of our sites and diversity of cultivars' phenology. At Bois de Belle Site in Ardèche, observations on a specific date during flowering, as shown in Figure 2, traditional *Castanea sativa* early cultivars 'Afachad', 'Bernarde', 'Précoce des Vans' and 'Précoce Ronde', mid-early (or mid-late) ones, 'Belle épine', 'Grosse Pourette', 'Ménasse' and late cultivars, 'Sardonne 1' and 'Sardonne 2', 'Aguyane', and 'Comballe'. Variations within a given cultivar can be attributed either to environmental heterogeneity, the history of tree pruning, or to the rootstock. The number of individuals of the same cultivar observed was insufficient to draw robust results. This experience nevertheless helped developing joint learning processes between growers and researchers.

Drawing on extensive experience of the Observatoire des Saisons (OBS) (https://www.obs-saisons.fr) (Badeau et al., 2017) regarding citizen approaches for observation of plant phenology, and guidance from Isabelle Chuine, member of ROC-CHA and scientific head of OBS, we submitted in 2021 to chestnut growers an approach based on their involvement in phenological observations, and the monitoring 2-3 times per week along two weeks, of the development of each stage. Indeed, the large-scale observations envisioned in four regions, Ardèche, Lozère, Corsica and Ariège, with farms dispatched across landscapes, and the difficulty to "catch" specific percentages achieved for each stage needed for modelling purposes (10 and 50%) could only be based on regular monitoring. This can materially be conducted only by the persons who inhabit these farms. Farmers were keen to continue this experience because they acknowledged that observing closely and regularly their trees helped them in gaining insights in relation to unprecedented climate impacts on chestnuts.

This method was tested in 2021 on 3 farms in Lozère where we calibrated the observations with the help of a student on site, co-observing with the chestnut growers. We focused the observations on the dates of two significant levels of development of each phenological stage: i) 10% of each stage has been achieved, meaning that the tree has effectively initiated this stage, ii) 50% of the same stage has been achieved, meaning that the tree is in its “cruising speed”, but has not yet finished this particular stage.

The results of this second step showed that the data were sufficient to calibrate a one phase model (PMP 5) in which we included temperature data of the Lozère sites, based on the instrumenting of all sites with data loggers. Farmers also started developing similar observations in Ardèche and all sites were instrumented in both regions. Through the use of the PMP 5 model (Chuine et al., 2013), a process-based modelling approach developed from previous reflections on the necessity to find a unified model especially for the bud burst stage (Chuine, 2000). It has been confirmed that the number of days required to reach 10 and 50% for the foliar development (formal BBCH stages 11 and 15) and the temperature data collected, could be used to further develop a robust approach for modelling chestnut trees’ development. Indeed, we found a high level of concordance between the number of days calculated by the model and the number of days observed, which was a first step for validating this model for *Castanea sativa*, although more data and parameters for each stage are still needed for a multiphase model that integrates the whole cycle of the tree. In 2022, we developed jointly with all referents, a standardized methodology for observation. This methodology is published in the form of a guide to be posted on the project website of the ROC-CHA-2 project by the end of 2023. We further developed the adequacy of the model with Ponsa (2022) who looked at a larger number of distinct and contrasted localities, in Ardèche in a sample of 7 topoclimatic situations, and a sample of 4 cultivars observed (Table 1). We reduced the number of cultivars observed per site to a maximum of 2-3 with contrasted phenologies (early and late), in order to reduce time spent by farmers in the previous attempts, but we increased the number of individuals per cultivars (at least 5).

Based on these new sets of data, Ponsa (2022) refined the model parameters for the budburst stage and confirms the importance of chilling during winter period. These results suggest that higher than usual winter temperatures, could affect chestnuts negatively, especially the lifting of endodormancy, with distinct responses between cultivars that have distinct phenological cycles. Previous studies emphasize the role of temperatures for adequate tree development and especially the role of chilling requirement during dormancy (Freitas et al., 2017; Ramos et al., 2005). However, further research is needed to understand the different responses among cultivars and the importance of maintaining a high diversity within contexts of unpredictable interannual climatic variations.

Chestnut identity and characterization: peer to peer exchanges

Experimental set ups of peer-to-peer exchanges during workshops have taken place in ROC-CHA since 2020 at four sites in Lozère and Ardèche and continued in 2022 and 2023, including Corsica and Ariège, at a pace of two workshops per year with approximately the same group of people each year. The aim is to bring together a group of knowledgeable and less knowledgeable chestnut growers in situ in a chestnut farm, chosen by the referent, most often at his farm to exchange and consolidate local knowledge.

The methodology is as follows: the referent, often with regional level groups or institutions and an ethnoecologist discuss the group composition and size of the group. At least one other expert, in addition to the referent, and any other person keen to participate are invited. The approaches to be taken during the workshop is developed beforehand and a flyer is elaborated jointly to invite participants. This may include issues of confidentiality, explanations of the purpose and consequent use of the data obtained. Two types of approaches have been tested: i) field discussions through walking in the reference site to observe jointly the trees, their leaves, the fruits, etc., and ii) assembling around a table with specific elements, flowers and leaves in spring and fruits in fall during harvest season. While in 2022, materials used were only from the reference sites, in 2023, we called for people to bring samples of all cultivars from their farms, attached to a label in order not to mix up the different cultivars.

Our preliminary results show that the first method reveals a tree level appreciation, including architecture, grafting, tree crown, branching specificities, reactions to pruning, resistance to drought, importance of soils. The second method of assembling around a table reveals more refined characteristics through comparisons between cultivars. The referent, firstly leads the discussions between growers to facilitate exchanges. The ethnoecologist, after allowing ample free exchanges between participants, uses a set of previous indicators discussed by farmers at the level of all previous workshops in all sites and analysed prior to the workshop. This scientist also takes notes and records all exchanges for further analyses. He-she uses the previous indicators to confirm collectively with the group whether a given cultivar is characterized (or not) by the sets of characters not yet discussed. Through this iterative process, the group progressively gains more and more depth of understanding of the cultivars based on a large set of indicators. Figure 3 shows a preliminary representation of the range of indicators mobilized for the full set of cultivars examined to date, that is 60 cultivars across the 4 regions.

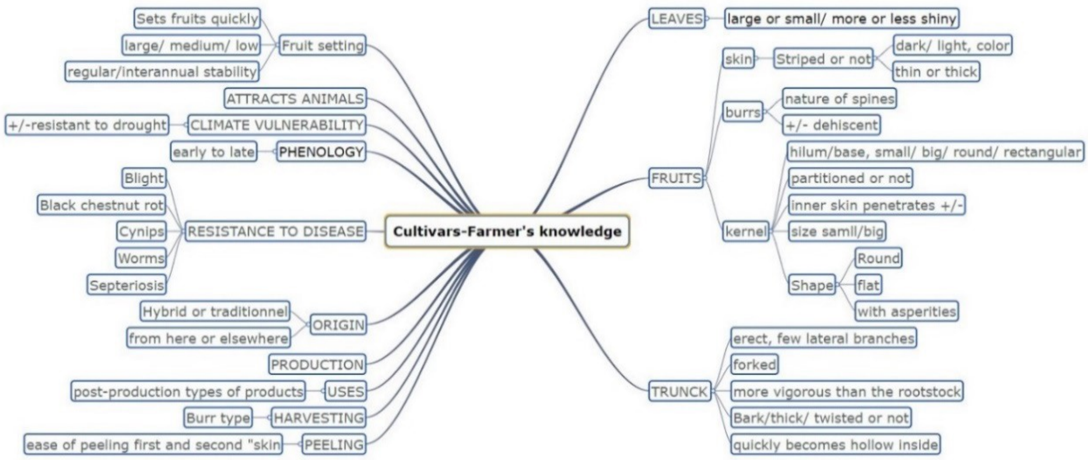

Figure 3. Four large groups of criteria: visible morphological criteria, ecological and biological, production and post-production criteria, and origin and distribution.

CONCLUSIONS

We may conclude that a network of sites on farm that facilitates synergies between scientists and chestnut growers is a useful instrument that is operational. It provides a co-construction approach carefully thought-out for a real participation of farmers and stakeholders at all steps of the research process. Phenoclimatic modelling based on citizen observation by farmers can help better understand the needs of chestnut trees climate-wise and allow to draw predictions on cultivars' capacity to survive within the context of climate change. Process-based models built through tools like PMP 5 already give promising results, but the models created still require to be further parametrized and refined for all phenology stages (Ponsa, in preparation). The exploration of farmer's local knowledge for the characterization of traditional cultivars of *Castanea sativa* show multiple intertwined social, ecological, economic dimensions that mirror farmers' age-old interest for polyvarietal orchards. This potentially also indicates possible future pathways to gain flexibility within contexts of environmental crisis. Phenoclimatic modelling and consolidating farmers' local knowledge are the two ends of a common thread required to evaluate the composition of new porte-folio of cultivars that will be required within the context of climate change, in order to make choices in the future.

ACKNOWLEDGEMENTS

We are thankful to all referents and growers who have participated actively to ROC-CHA field activities, in addition to authors included above, namely, J.M. Bouchatd, R. Bouat, A. Delayre, A. Mercier, D. Mathieu, V. Morney, E. Desjobert, H. Giudicelli, F. Tomasi, C. Fessler, N. Viola, C. and F. Charbonnier, C. Vidal, and regional associations, RENOVA in Ariège, Epi de Mains in Lozère, the GRPTCMC Corsica. We also thank Eric Bertoncello for technical support at SPPC. Thanks also to CEFE-CNRS scientific and technical team, D. McKey, I. Chuine, A. Ramet, O. Cobelli, S. Perret, A. Lucas, D. Degueldre for their continuous support to ROC-CHA.

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