Agropolis Foundation flagship project final report

"Interfaces": The interface between production and processing, a key point in linking the variability of raw materials and the adaptability of transformations for innovative food systems

A. Introduction

The aim of the “Interfaces” project is to understand which factors, by influencing the characteristics of fresh fruits, allow the characteristics of processed fruits to be modulated. The main objective is to create a research continuum between the development of agricultural raw material and its transformation in order to define the margins of flexibility (technological and economic) that exist with regard to the variability of the raw material.

This interface between production and processing is characterized by discontinuities: i) it is not the same scientific disciplines that are mobilized, ii) it is not the same socio-economic actors, and iii) it is not the same logics that are at work. It is obvious that the characteristics of the raw materials largely determine the qualities of the finished products, and specifically for fruits, which are, often little processed. However, the expected changes in production take into account the need to adapt to new agricultural systems and environmental conditions, but not or very rarely, the fate of the product between the field and the plate. Conversely, the demands of processors are not necessarily adapted to these new raw materials.

The objective of the project is thus to demonstrate that it is possible to make scientists work together on both sides of this interface to better build together the qualities of the products ultimately consumed, taking into account their variability. The project is structured in five “workpackages” answering scientific questions

- How to identify and quantify the variability and heterogeneity of fruits through the development of indicators and tools allowing rapid qualification as well as the integration of operator knowledge, from the field to the plant (WP1)
- How the microstructure of fruits, itself influenced by pre-harvest conditions, can influence the characteristics of processed products, and how this microstructure can interact with unit operations (WP2)
- What is the microbial ecosystem of fruits, a major cause of invisible variability in the production chain from tree to plate? Do the culture systems and conditions influence the

microbial communities that produce mycotoxins or the microorganisms responsible for alterations, or even possibly protective species allowing the biopreservation and production of fermented food (WP3)

- How does the interaction between the environment and cropping systems modulate the quality of the fruit at harvest? How will this information allow the estimation of fruit variability at harvest and allow the design of agronomic practices to obtain the desired processed fruit? Is it possible to link the pre and post-harvest models? (WP4)
- How to take into account the variability in the fruit in the value chain? What are the challenges of the different stakeholders and how can the market be regulated? Are there generic questions that could be used to guide the identification of quality? (WP5)

The project approach applies to three fruits for which there are major effects of the raw material on the finished products (apple - mash, mango - dried mango, grape - wine). These fruits represent important issues economically by their production volumes.

The “Interfaces” project brings together **five entities of the Agropolis Fondation** network: UMR SQPOV and UMR Qualisud as coordinators, UR PSH and HORTSYS, UMR SPO and UMR MOISA. INTERFACES had an impact on the relationship of this research community on several fronts of research.

From its start, the project encouraged **doctoral training** with the integration of seven PhD students in the different WPs, as well as two post-doctoral scientists.

The **scientific results** are substantial; they have enabled 16 published papers, 4 submitted papers, 13 manuscripts in preparation and at least 22 oral communications and posters in national and international conferences (in the context of the Covid19 pandemics).

The project has established bridges with the **private sector** by soliciting representative bodies of companies, by organizing feedbacks of the most applied results and by better integrating the needs and requests for innovations.

The project started in January 2017 for a contractual period of 4 years. Finally, with an extension, the project ended in June 2021. A symposium organized in November 2020 enabled us to return most of the results to the scientific community. Unfortunately, the **closing meeting** planned for 2021 could not take place due to health restrictions. Follow-ups are planned as part of the inter-unit collaborations set up in this flagship project.

B. Scientific highlights

We have selected a dozen highlights from INTERFACES, distributed among the different WPs of the project. These choices are not exhaustive, but aims at giving a global vision of the scientific advances made possible by this flagship project.

Part of these highlights are finalized research such as fruit sorting tools, fruit quality assessment or methods to predict the properties of finished products by spectrometric measurements.

The project has also generated many scientific results. Those chosen as highlights have given rise to publications. They concern the understanding of the relationships between the initial maturity and therefore the biochemical profiles of the fruits and the quality of the finished

products. This understanding of the impact of post-harvest treatments on sugars profile was made possible by significantly improving the models of sugar metabolism in fruits.

Progress has also been made on knowledge of the surface microbial diversity of mangoes, in particular as a function of their situation before harvesting and on the evolution of this microbial ecology during post-harvest. Finally, at the chain level, we now have a better understanding of how operators considers variability in the fruit value chain.

WP1. Indicators and measurements to characterize variability and heterogeneity

1. A non-destructive tool for sorting mangos according to their maturity stages and to the specific properties of their purees

Labaky, P., Grosmaire, L., Ricci, J., Wisniewski, C., Louka, N., and Dahdouh, L.

Mango has an abundant production leading to important post-harvest losses. Mango processing is an alternative to reduce these losses. Nowadays, the lack of instrumental tools suitable to sort mangos according to their ability to be processed into products with specific quality is a main setback for their processing. The aim of this study was to develop new tools, mainly non-destructive, to sort easily fresh mangos according to their maturity stage and to the specific properties of their purees. To this end, an innovative experimental strategy combining textural, rheological and physico-chemical analyses was proposed to characterize mangos and their purees. The instrumental characterization of fresh mangos and mango purees were carried out to identify relevant indicators of mangos heterogeneity and purees variability. Results showed that mango firmness is a great indicator of mango maturity and has an important impact on the properties of mango purees. In this work, a non-destructive compression test was proposed to measure accurately the loss of mango firmness during maturation without damaging the fruits. This fast and easy measurement allowed also to trace-back the solid-like behavior of mango measured by destructive rheological analysis. In addition, results indicated that the firmness of fresh mangos governed the particles size distributions and the rheological properties of mango purees. According to these observations, it was possible to predict the particles size of the mango purees based on the firmness of the fresh mangos. Concerning, purees rheological properties (viscosity and solid- like behavior), compression test enabled discriminating mainly mango purees at early stages of maturation [0-10 days] from the other stages [10-25 days].

PCA results confirmed that the investigated variables in this work (textural, rheological, physical and physico-chemical) seem to be good indicators to characterize the heterogeneity of fresh mangos and mango purees. It was possible to discriminate mango and puree into 3 main groups (early maturation stages, intermediate stages and a late maturation stage) based mainly on total soluble solids, dry matter, firmness, particles size and rheological properties.

This work provided new knowledge in mango field and an innovative and simple tool to sort mango according to firmness in relation with their maturity stage. This tool could be also of great interest to anticipate the characteristics of mango puree according to mango firmness. As the proposed compression test is fast and easy to perform, this sorting strategy could be easily applied not only for mango fruits but also for many other juicy stone fruits in transformation units to reduce post-harvest losses.

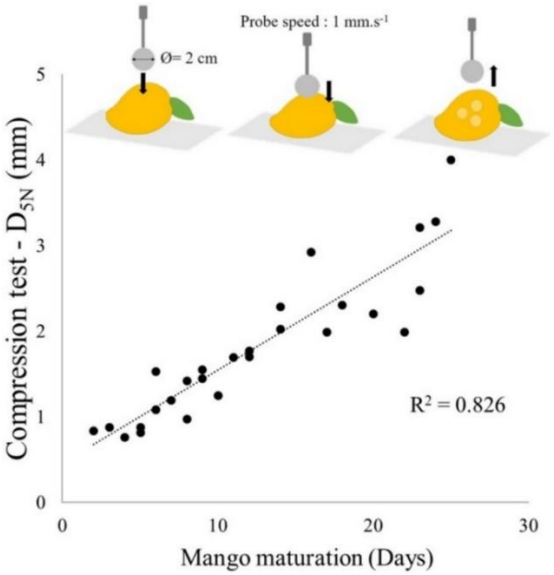


Figure 1: The evolution of D_{5N} (mm), indicator of mango's firmness, during maturation (days).

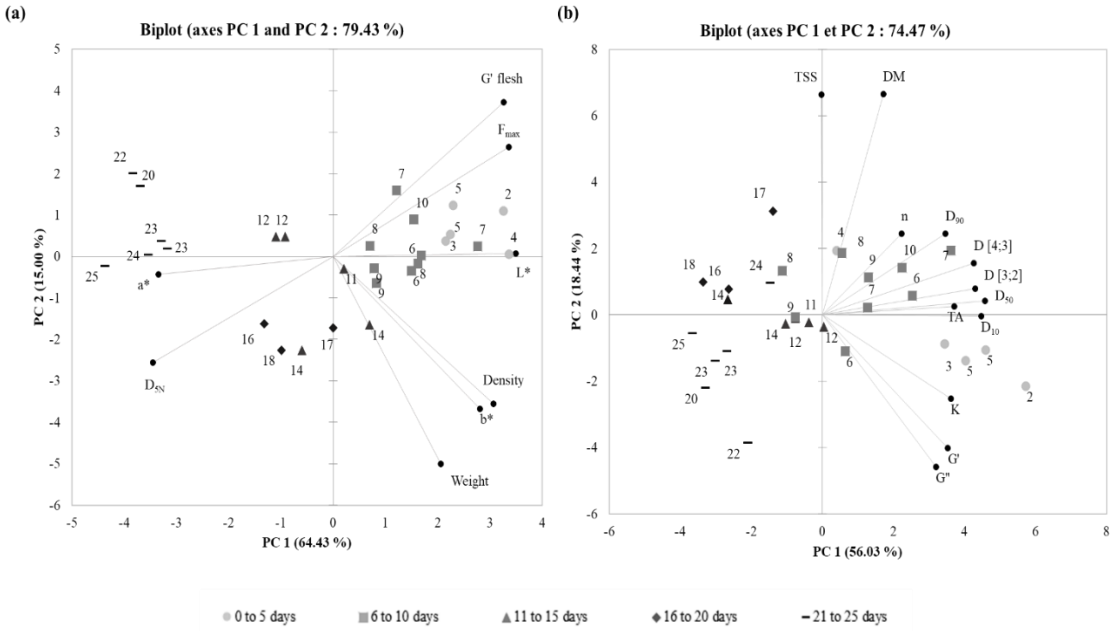


Figure 2: Principal component analysis (PCA) on instrumental indicators of (a) mangos and (b) purees at different maturity stages. a*: red to green transition , b*: blue to yellow transition, DM: dry matter (g / 100 g puree), D_{5N}: distance of compression at 5N (mm), D [3;2]: Sauter mean diameter (µm), D [4,3]: Brouckere mean diameter (µm), D_{10}, D_{50} and D_{90}: particle size statistical diameters (µm), F_{max}: maximum value of the peak force (N) , G': storage modulus (Pa), G": loss modulus (Pa), K: consistency index ($Pa.s^n$), L*: lightness (black to white transition), n: flow behavior index, TA: titratable acidity (g citric acid/ 100 g puree), TSS: total soluble solids (°Bx).

Publication : Labaky, P., Grosmaire, L., Ricci, J., Wisniewski, C., Louka, N., and Dahdouh, L. (2020) Innovative non-destructive sorting technique for juicy stone fruits: textural properties of fresh mangos and purees, Food and Bioproducts Processing, 123, 188-198.

2. The impact of mango ripening on the physical and biochemical properties of mango purees

Labaky, P., Dahdouh, L., Ricci, J., Wisniewski, C., Louka, N., and Grosmaire, L.

This study proposed to investigate the impact of ripening on the physical properties of mango purees. An extensive study of the particle size and rheological properties of mango purees and their dispersed phase was performed through particle size measurements and small deformation rheology. The feasibility of using simultaneous rheometry coupled with *in situ* FTIR spectroscopy as a fast tool to determine (on a reduced sample size) the impact of ripening on the solid like-behavior and on the sugar content of mango puree was evaluated.

The results highlighted a sharp decrease in the size and the specific cohesion energy of the mango purees' SIS, mostly during the 10 first days of ripening. Mango purees from early ripening days (< 10 days) were also characterized by their specific gel-structure with higher solid-like behavior and higher network strength (higher A' values (1206 - 436 Pa.s^n) and lower n''values (0.16 - 0.22). The higher n' and n'' values obtained for mango purees from ripening stages beyond 10 days revealed also a higher frequency dependency of the viscoelastic moduli (G' and G") for these mango purees, confirming their weaker gel behavior. These results showed the important impact of changes occurring during the first 10 days of mango ripening on the specific rheological and the particle size properties of their purees. Simultaneous rheometry and *in situ* FTIR spectroscopy measurements performed on the mango purees highlighted the simultaneous decrease in solid-like behavior and the sucrose content, and the significant increase in the fructose content of mango purees after 10 days of ripening. This innovative technique could be interesting to monitor - in a quick and easy way - the rheological and the spectral changes that might occur in mango during ripening. The experimental strategy and the innovative simultaneous rheometry and *in situ* FTIR spectroscopy proposed in this work could be also used for other fruits to monitor the impact of ripening, as well as processing, on the properties of fruit-based suspensions properties.

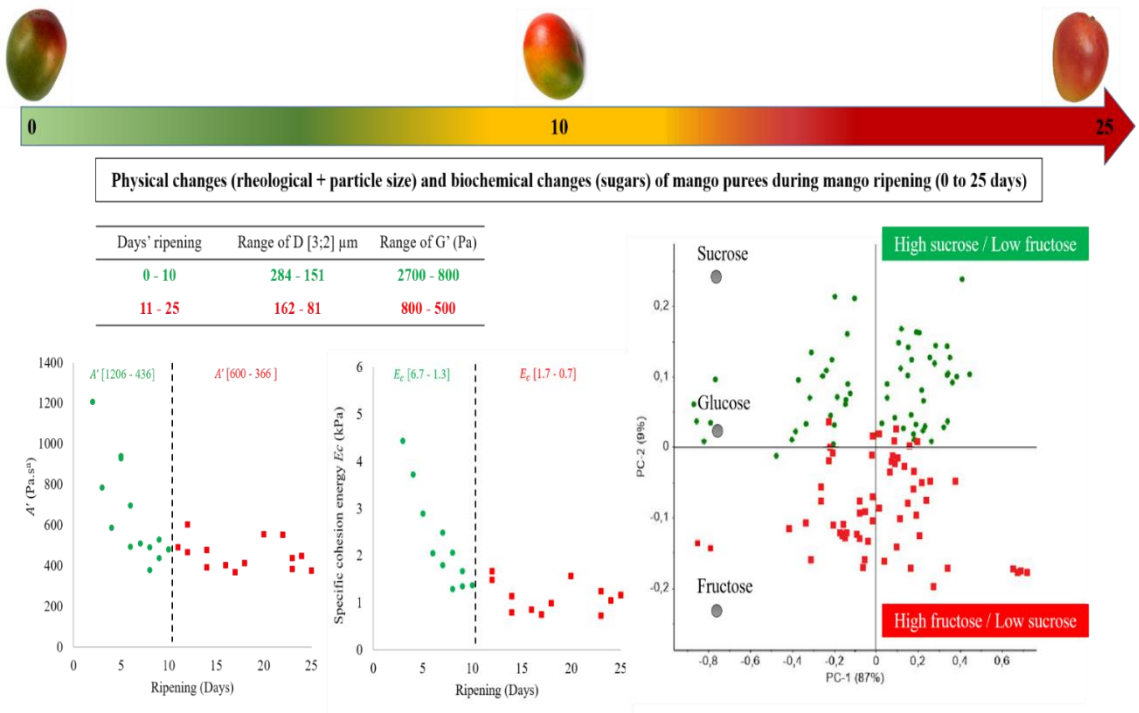


Figure 1: The physical changes (rheological and particles size) and the biochemical changes (sugars) of mango purees during mango ripening (0 to 25 days).

Publication: Labaky, P., Dahdouh, L., Ricci, J., Wisniewski, C., Louka, N., and Grosmaire, L. (2021) Impact of ripening on the physical properties of mango purees and application of simultaneous rheometry and *in situ* FTIR spectroscopy for rapid identification of biochemical and rheological changes, Journal of Food Engineering, 300, 110507.

3. ATR-FTIR, a potential tool to evaluate apple puree rheology and structure

Lan, W., Renard, C. M., Jaillais, B., Leca, A., & Bureau, S.

According to previous works, MIRS (or FTIR) has been known to identify fruit variability and predict their composition. However, it stayed limited to predict cell wall content impacting fruit texture and puree rheology. That could be due to the low sensitivity and limited specific signals of chemical compositions probably due to some strong interactions with water in hydrated samples. Sampling preparation is a key point for MIR spectral analysis to improve prediction results, such as freeze-drying to reduce the water interferences or extracting cell wall materials for removing major soluble chemicals.

Therefore, the possibility of MIR technique to obtain sufficient information for chemical, textural and rheological properties based on fresh (NF), freeze-dried (FD) and cell wall materials (CWM) of raw apples and their corresponding purees was studied. The MIR spectra of 36 apple sets and the corresponding 72 purees, issued from different varieties, agricultural practices, storage periods and processing conditions were explored in order to: i) Evaluate how much sample preparation improved the prediction of chemical, textural and rheological characteristics of purees (number of quality traits and the precision of prediction), ii) Identify signals specific of the changes, which occur during apple processing.

The models performance were compared using the coefficient of determination R^2 and the residual predictive deviation (RPD). A RPD between higher to 2.5 corresponds to good and excellent prediction accuracy.

Results: Acceptable to good predictions of soluble solids content, titratable acidity, dry matter content, fructose and malic acid were obtained on fresh and/or freeze-dried purees, giving $R^2 \geq 0.9$ and RPD from 3.1 to 5.2 (NF) and from 3.6 to 7.6 (FD) respectively.

Surprisingly, prediction was acceptable ($R^2 \geq 0.9$, RPD > 3.1) for rheological parameters such as puree viscosity (η_{50} or η_{100}) and visco-elasticity (G', G'' in both amplitude and frequency sweep tests and yield stress) on FD samples with less than 10 LVs and was better than on NF and CWM samples. But, to evaluate the particle size, both d(4:3) and d(3:2), fresh NF samples were the suitable sample type with a good performance of the PLS models (RPD > 3.0).

Another quality trait of interest is the CWM content, which contributes to the rheological properties of the processed apple purees products. The prediction of CWM content was acceptable with RPD of 3.3 on FD purees, when expressed in dry matter (DW).

These results demonstrated the possibility of ATR-FTIR technique to accurately estimate viscosity, elasticity and the particle distributions directly on freeze-dried purees (FD). However, ATR-FTIR on fresh purees (NF) had a good ability to directly evaluate the particle size and

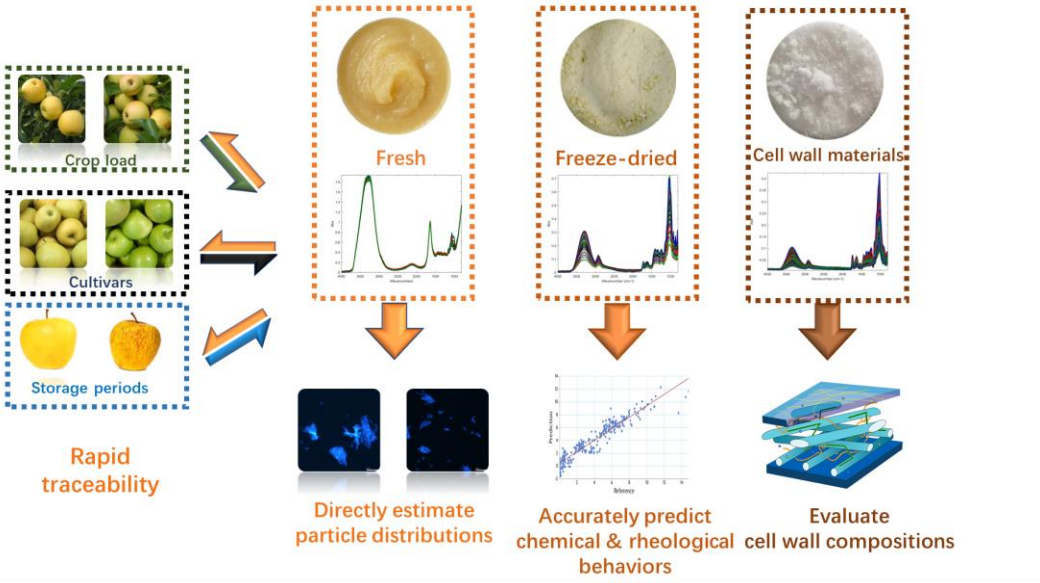
properties (RPD > 3.0), and also can probably to be used to evaluate the rheological behaviors (viscosity and viscoelasticity) according the results of RPD values over 2.5.

In summary:

-MIR on fresh purees could predict particle size and volume (RPD > 3.0) affecting texture.

-MIR on freeze-dried purees improved assessment of chemical properties (RPD > 3.2) and assess viscosity and viscoelasticity (RPD> 3.1).

-MIR on cell wall extract could highlight the changes of cell wall during processing.



Publication : Lan, W., Renard, C. M., Jaillais, B., Leca, A., & Bureau, S. (2020). Fresh, freeze-dried or cell wall samples: Which is the most appropriate to determine chemical, structural and rheological variations during apple processing using ATR-FTIR spectroscopy? Food chemistry, 127357.

4. NIR spectroscopy on fresh apples can predict processed purees properties

Lan, W., Jaillais, B., Leca, A., Renard, C. M. G. C., & Bureau, S.

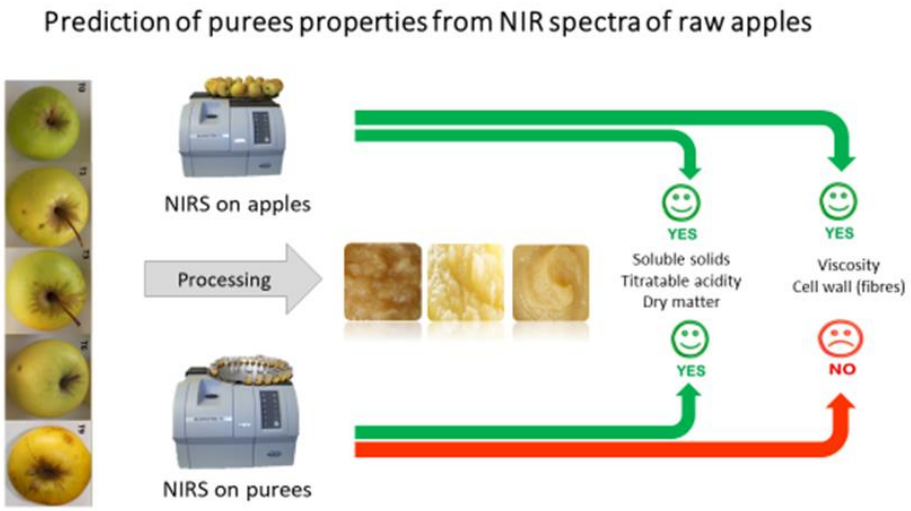
How to face the variability and heterogeneity of agricultural products and optimize their processing into food? Fruit manufacturers encounter difficulties to maintain an expected and constant quality level of the processed products. The challenge was to test the possibility of Near infrared spectroscopy (NIRS) to evaluate the processed puree properties based on the spectra of raw apples.

Purees were made with a large variability of apples, involving different varieties, agricultural practices, cold storage periods and puree mechanical refining levels. Good relationships of titratable acidity ($r^2 > 0.91$), soluble solids content ($r^2 > 0.79$), dry matter content ($r^2 > 0.72$) and physical properties (textual and rheological parameters ($r^2 > 0.79$) were obtained before and after apple processing.

The originality of this work was to evaluate the puree properties from the spectra of the raw apples: the partial least square models gave good predictive values of viscosity ($R^2 > 0.82$),

cell wall content (R^2 > 0.81), dry matter content (R^2 > 0.83), soluble solids content (R^2 > 0.80) and titratable acidity (R^2> 0.80). Near infrared technique applied on the raw apples has the potential to non-destructively predict the texture and taste of purees.

This opens the possibility to sort or select apples according to the expected purees. By systematically scanning all apples, this could provide some objective data to predict the final product characteristics and thus reduce waste along the processing chain. Up to now, in apple industry, manufacturers use their experience and knowhow to make blend of apples in order to obtain purees with almost the same quality of taste and texture. Our innovative work provides a great development prospect to offer a practical and suitable strategy to estimate the quality of fruits, to monitor their processing, and to control the quality of fruit products.



Publication : Lan, W., Jaillais, B., Leca, A., Renard, C. M. G. C., & Bureau, S. (2020). A new application of NIR spectroscopy to describe and predict purees quality from the non-destructive apple measurements. Food Chemistry, 310, 125944. DOI: 10.1016/j.foodchem.2019.125944.

WP2. Managing variability and heterogeneity in processing

5. The quality of fresh mangoes, the dominant determinant of the dried product, whatever the pre-post-harvest

Alioune Diop, Charlotte Delpech, Jérôme Minier, Mathieu Léchaudel, Jean-Michel Méot

It was known that the quality of natural dried mangoes strongly depends on the quality of the fresh mangoes from which they are derived. The latter is essentially determined by pre- and post-harvest factors such as the variety choice, the stage of maturity at harvest and the storage conditions - ripening of the mangoes. By an incomplete design of experiments combining 2 varieties, 3 advancements in harvesting, 3 stages of maturity at harvest, 3 ripening temperatures and 5 ripening times per temperature, it has been shown that good drying always respect quality of fresh mangoes (Figure 1), even if this raw material is very variable.

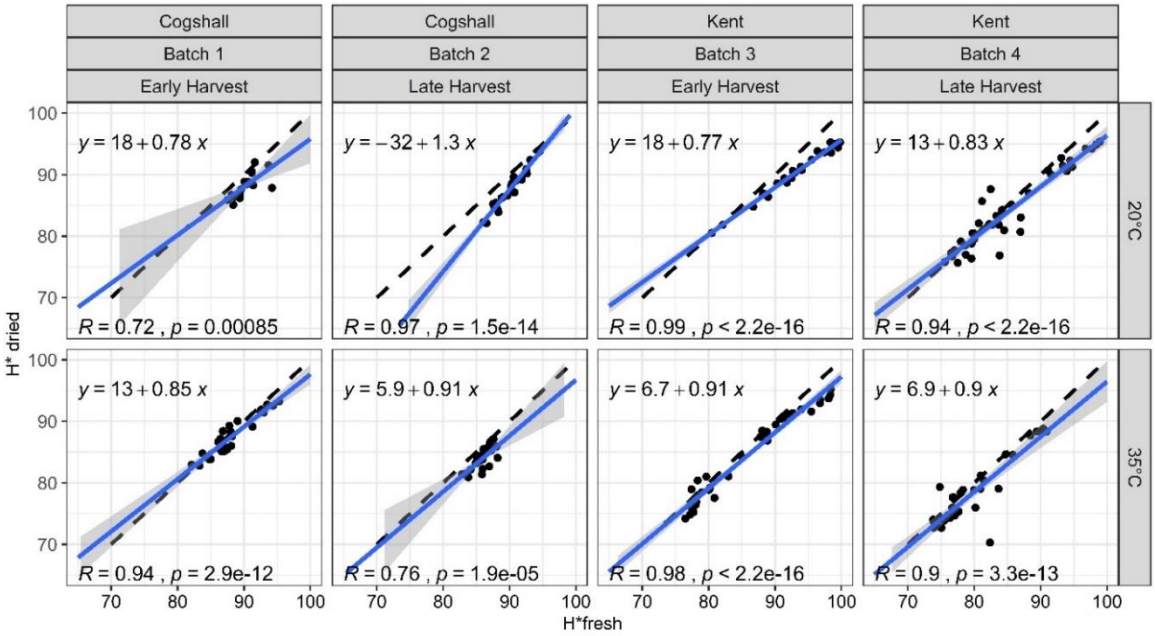


Figure 1. Example of statistical relations (H *: color; 2 varieties, 2 advancements in the season, 4 batches) showing (i) the almost absence of modification of the color by good drying and the absence of particular points whatever the pre-post-harvest route.

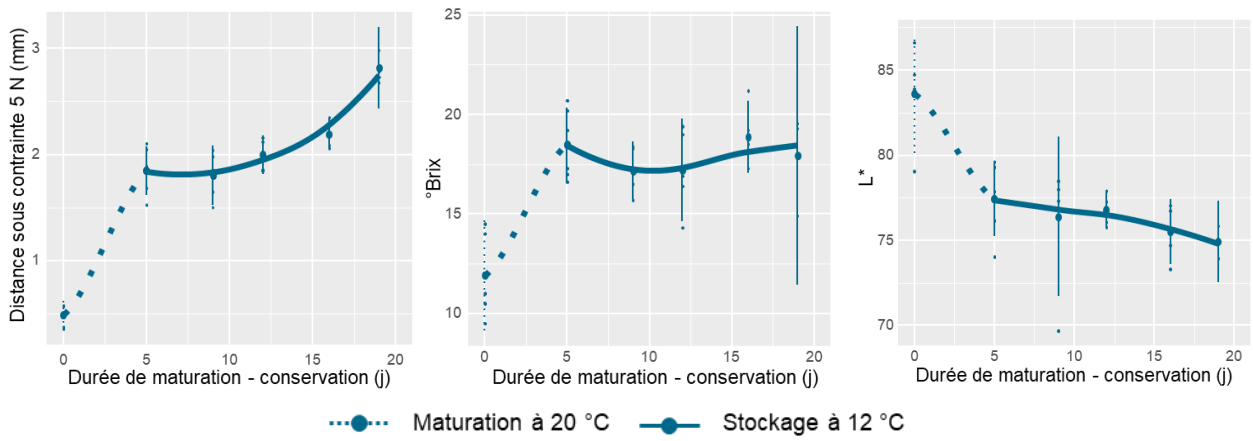
6. Reduce supply constraints for dryers by storage at 12 ° C

Alioune Diop, Charlotte Delpech, Jérôme Minier, Mathieu Léchaudel, Jean-Michel Méot

Currently, the average maturity of the batches supplied by the mango drying units and their heterogeneity remain poorly controlled. Obtaining a quantity of “good” fresh mangoes each day to load the dryers well, without wasting any, is a challenge. The same is true for fresh sales.

The storage test at 12 ° C of mangoes estimated at 1 day of optimal maturity for drying showed that their quality was maintained, in the fresh state for 11 days.

Having cold available would facilitate production, reduce losses, and allow the drying campaign to be extended by 30%.



(a) (b) (c)

Figure 1. Stabilization of near-ripe mangoes by storage at 12 ° C; (a) firmness of whole fruits by non-destructive measurement, (b) brix and (c) luminance of the pulp.

7. Impact of grape variety, berry maturity and size on the extractability of skin polyphenols during model wine-like maceration experiments

Elissa Abi-Habib, Céline Poncet-Legrand, Stéphanie Roi, Stéphanie Carrillo, Thierry Doco, Aude Vernhet

Skin cell walls modulate anthocyanin and tannin extraction from grape skins. However, relationships between the composition of alcohol-insoluble cell wall solids (AIS) and extraction are still unclear. Our objectives were to characterize the impact of variety, berry size and ripeness on skin AIS composition (polysaccharides, proteins) and polyphenol extraction during maceration. Grape skin composition and its impact on polyphenol extraction was compared for two varieties – Carignan and Grenache – with skins of berries sorted according to their size and density. Extractions were performed under model wine-like maceration conditions. Fresh skins had similar content of polymeric tannins, but strongly differed in their anthocyanin content (higher in Carignan and in the ripest berries) and composition (higher proportions in coumaroylated anthocyanins in Carignan). Anthocyanin extraction was proportionally much higher in Grenache, which was not just related to the Carignan's higher levels in coumaroylated anthocyanins. Chemical reactions decreased anthocyanin concentrations in solution for both varieties. Tannin extraction for Grenache was slightly higher and faster than for Carignan. Skin AISs differed slightly between the two varieties in their carbohydrate composition and protein content, but not between modalities. Polyphenol analyses in the precipitates evidenced at the end of the maceration and in residual skins highlighted differences between the two varieties

and between berries with different ripeness. Structural information on the cell wall network and on its changes during maceration, along with a better understanding of the chemical reactions of anthocyanins and tannins, is needed to better relate grape and wine polyphenol composition.

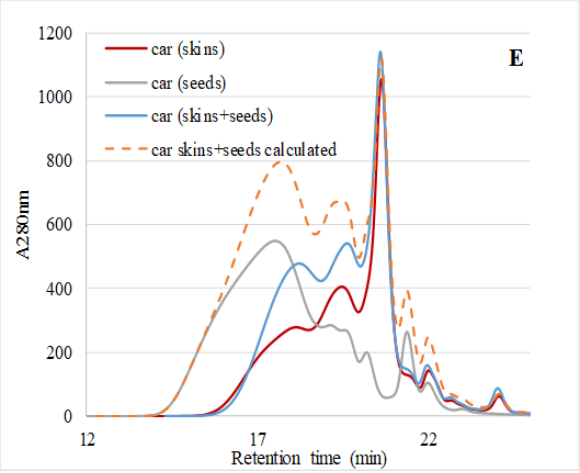


Figure : Comparison of the HPSEC profiles of the vol^{+}deg^{+} (E) and vol^{+}deg^{-} (F) modalities of Grenache and Carignan at the end of t_1 and t_5.

Publication: Abi-Habib E, Poncet-Legrand C, Roi S, Carrillo S, Doco T, Vernhet A. 2020. Impact of grape variety, berry maturity and size on the extractability of skin polyphenols during model wine-like maceration experiments. J Sci Food Agric 2021; 101: 3257–3269

WP3. Microbial communities dynamics from the tree to the plate

8. Deciphering the microbial communities (bacteria and fungi) on the mango surface and their variations on the tree

Taîbi A, Rivallan R, Broussolle V, Pallet D, Lortal S, Meile J-C and Constancias F

The objectives of this present study were: (i) to provide an exhaustive characterization of both the fungal and bacterial communities associated with mango surface, (ii) to identify and (iii) rank the pre-harvest factors influencing bacterial and fungal communities.

To this end, The diversity of both bacterial and fungal communities associated with mango surface was explored using a metabarcoding approach targeting fungal ITS2 and bacterial 16S (V3-V4) genomic regions. Fruits were collected in Reunion Island from two different orchards according to a sampling method which allowed the effect of several pre-harvest factors such as geographical location (terroir), cultivars, fruit parts, tree position in the plot, fruit position on the tree (orientation and height), as well as the harvest date to be investigated. A total of 4,266,546 fungal and 2,049,919 bacterial reads were recovered then respectively assigned to 3,153 fungal and 24,087 to bacterial amplicon sequence variants (ASVs). Alpha and beta diversity, as well as differential abundance analyses revealed variations in both bacterial and fungal communities detected on mango surfaces depended upon the studied factor.

For each studied location, mango fruit from each cultivar shared a core microbiome, and fruits of the same cultivar harvested in two different locations shared about 80% fungal and bacterial family taxa. The various factors tested in this study affected bacterial and fungal taxa differently, suggesting that some taxa could act as geographical (terroir) markers and in some cases as cultivar fingerprints. The ranking of the factors investigated in the present study showed that in decreasing order of importance: the plot (terroir), cultivar, fruit parts, harvest date and the position of the fruits are respectively the most impacting factors of the microbial flora, when compared to the orientation and the fruit position (height) on the tree. Overall, these findings provided insights on both bacterial and fungal diversity associated with the mango surface, their patterns from intra-fruit scale to local scale and the potential parameters shaping the mango microbiota.

This study contributes to a more in-depth knowledge of mango fruit microbiota which could lead to fruit microbiota-based orchard management, future biological control strategies, and processing and could be used for the development of a strategy based on mango microbiome manipulation to prevent post-harvest decay.

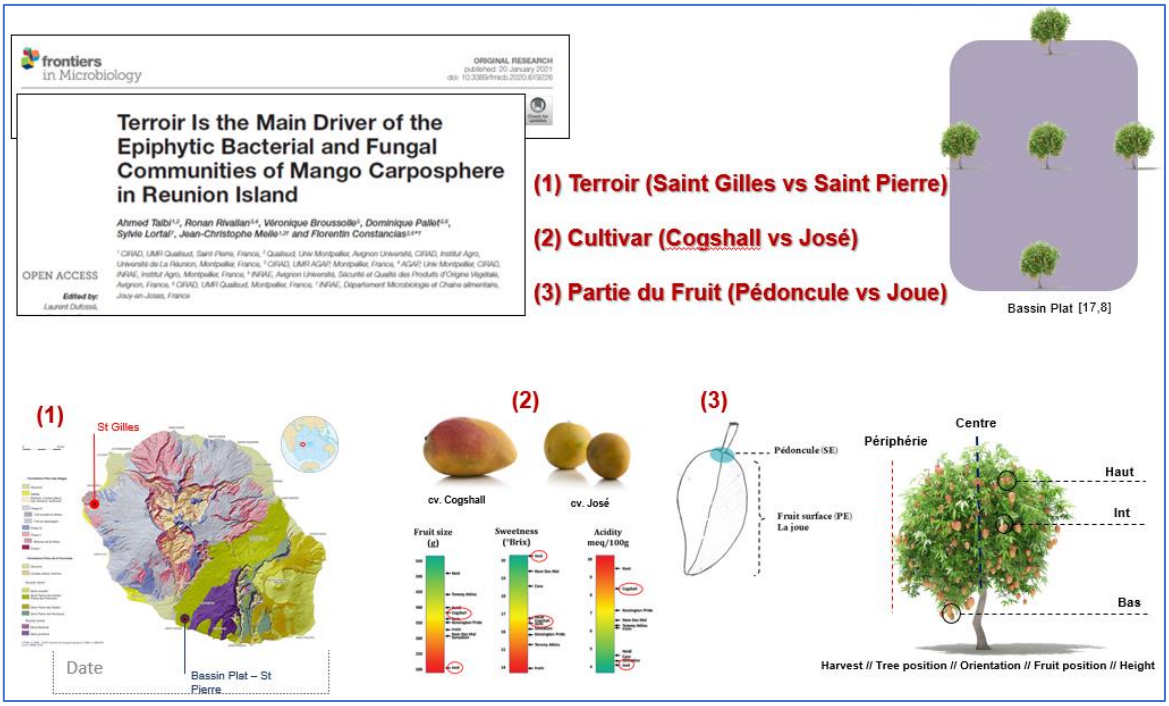


Figure : Pre-harvest factors ranking according to their effect on mango microbial communities

Publication: Taîbi A, Rivallan R, Broussolle V, Pallet D, Lortal S, Meile J-C and Constancias F (2021) Terroir Is the Main Driver of the Epiphytic Bacterial and Fungal Communities of Mango Carposphere in Reunion Island. Front. Microbiol. 11:619226. doi: 10.3389/fmicb.2020.61922

9. Impact of processing and shelf-life on microbial diversity and composition

Ahmed Taïbi, Christian Soria, Jérôme Minier, Sylvie Lortal, Florentin Constancias and Jean-Christophe Meile

Mango processing, such as drying, is essential to limit waste and reduce production losses. Metabarcoding and microbial enumeration methods, allowed us to get insight into both epiphytic and endophytic mango microbiota, as well as their evolution after processing. Two ripening stages of mango cv. Cogshall were selected and processed into dried slices. After processing, mango were stored at room temperature and analyzed at various storage duration times. Microbiological and physicochemical quality parameters of the fruit products were monitored during storage.

Metabarcoding analyses allowed a total of 1,043,729 high-quality fungal and 1,092,163 high-quality bacterial DNA sequences to be recovered and assigned respectively to 1,423 and 5,121 ASVs. Members of the Proteobacteria phylum were dominant in mango surface and accounted for 73.16 %, followed by Actinobacteria (10.16 %), Bacteroidetes (7.82 %) and Firmicutes (6.68%). Burkholderiaceae, Enterobacteriaceae, Beijerinckiaceae, Lactobacillaceae, Moraxellaceae were the only family taxa shared between all samples (peel surface and dried slices). Members of the Ascomycota phylum were dominant at the mango surface and accounted for 90.76 % of the total number of detected sequences, followed by Basidiomycota (9.21 %). In total, 300 microbial family taxa were associated with mango surface (157 bacterial and 143 fungal). Alpha and beta diversity analyzes revealed differences in fungal and bacterial communities in fruit peel and dried slices during storage. Mango processing shows a significant impact on the dynamics of the mango microbiota during storage and thus the shelf life of mango products. Data revealed that ripening stages influence the bacterial and fungal composition and diversity, and physicochemical parameters may play a crucial role in these differences. It was shown that processing (washing, peeling and drying) reduced the richness and the microbial diversity (bacterial and fungal) associated with mango. The drying of mango slices limited the development of cultivable microorganisms during storage in such extend that the final product remained microbiologically stable for at least one year.

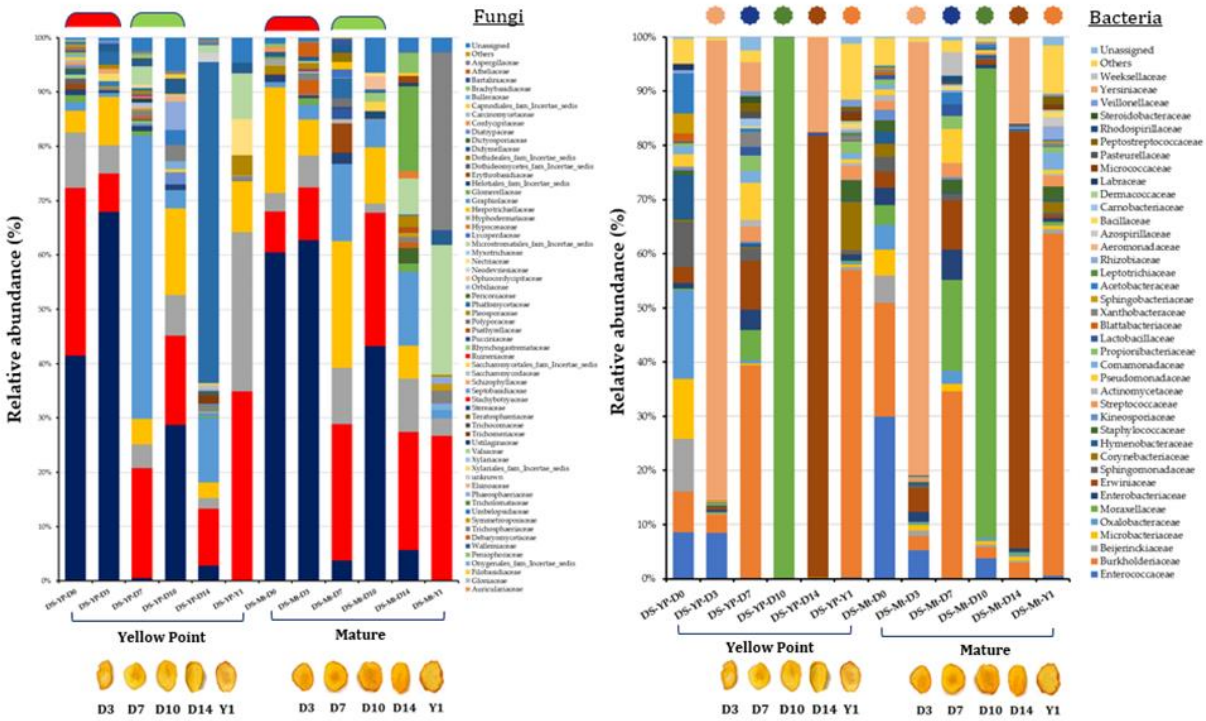


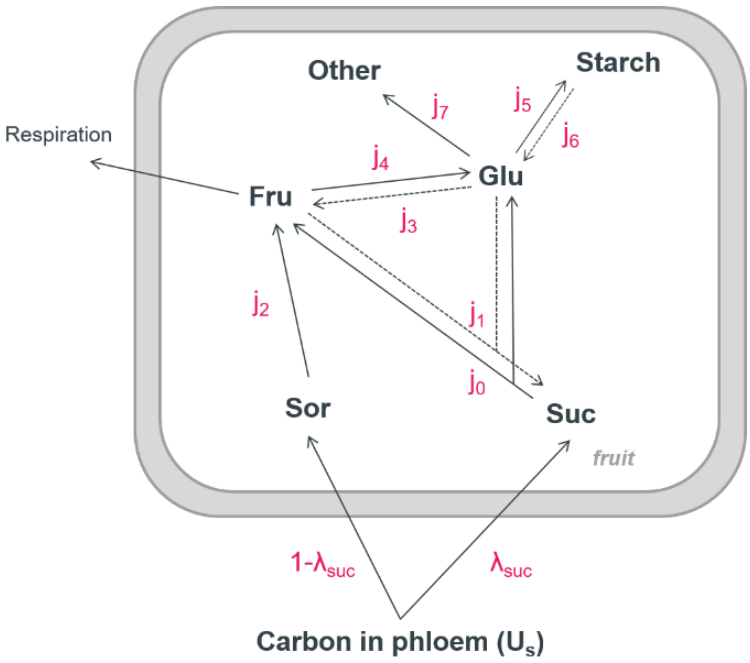
Figure : Evolution of Microbial Communities structures i.e. fungal (left) and bacterial (right) families abundance of dried mangoes during storage for up to one yea

WP4. Connecting pre and post-harvest models

10. A temperature-dependent model of sugar metabolism in fruits: effect of pre- and post-harvest treatments on the sweetness build-up of apple fruits

Yannick Laridon, Gilles Vercambre, Michel Génard

In order to study the effect of cultural practices and storage conditions on apple fruit sweetness a coupled experimental/simulation approach was used. Existing metabolic model was updated to take into account specificities of apple fruit sugar metabolism, but also to be able to adopt a wider point of view by including the post-harvest stage of storage into the analysis (Figure 1).



Erreur ! Source du renvoi introuvable. Metabolic model. Mass influx U_s is split between sorbitol (Sor) and sucrose (Suc), to a ratio of about 25% for the first, 75% for the latter (λ_{suc}, the parameter dealing with this ratio, is fitted experimentally). The carbohydrate equilibrium is then assured by a mass balance system of conversion fluxes j_i. For each carbohydrate, the mass balance is the difference between incoming and outcoming fluxes.

This yielded a metabolic model that can take the season and the instantaneous temperature variation into account. The model was used to investigate the sugar composition build-up in details. We concluded that in apples the fruit load mainly impacts the sucrose and sorbitol metabolism, letting other metabolisms virtually unchanged. If storage temperature can be used to modulate the carbohydrate partitioning during the post-harvest stage, the main factor remains the cultural practices during the pre-harvest stage.

11. Towards simple predictive models of apple puree quality from fresh matter characterization

Alexandre Leca, Alexandra Bürgy, Weijie Lan, Agnès Rolland-Sabaté, Sylvie Bureau, Catherine Renard

Either measured from laboratory reference methods or fast IR techniques, specific quality traits of apple puree (obtained by thermal and mechanical treatment of fresh apples directly at harvest or having been stored in a cold chamber) were well correlated to those of fresh apples. This led to build simple statistical models (Fig. 1) in order to estimate the soluble solid content (SSC), titratable acidity (TA), and puree yellowness, as well as a rough prediction of the viscous behavior of puree as a function of fruit storage and processing conditions.

These could be used as simple and fast tools to predict final product quality or as decisional aid to reach target quality traits by controlling the apple storage duration and the specific temperature and/or grinding speed of the process.

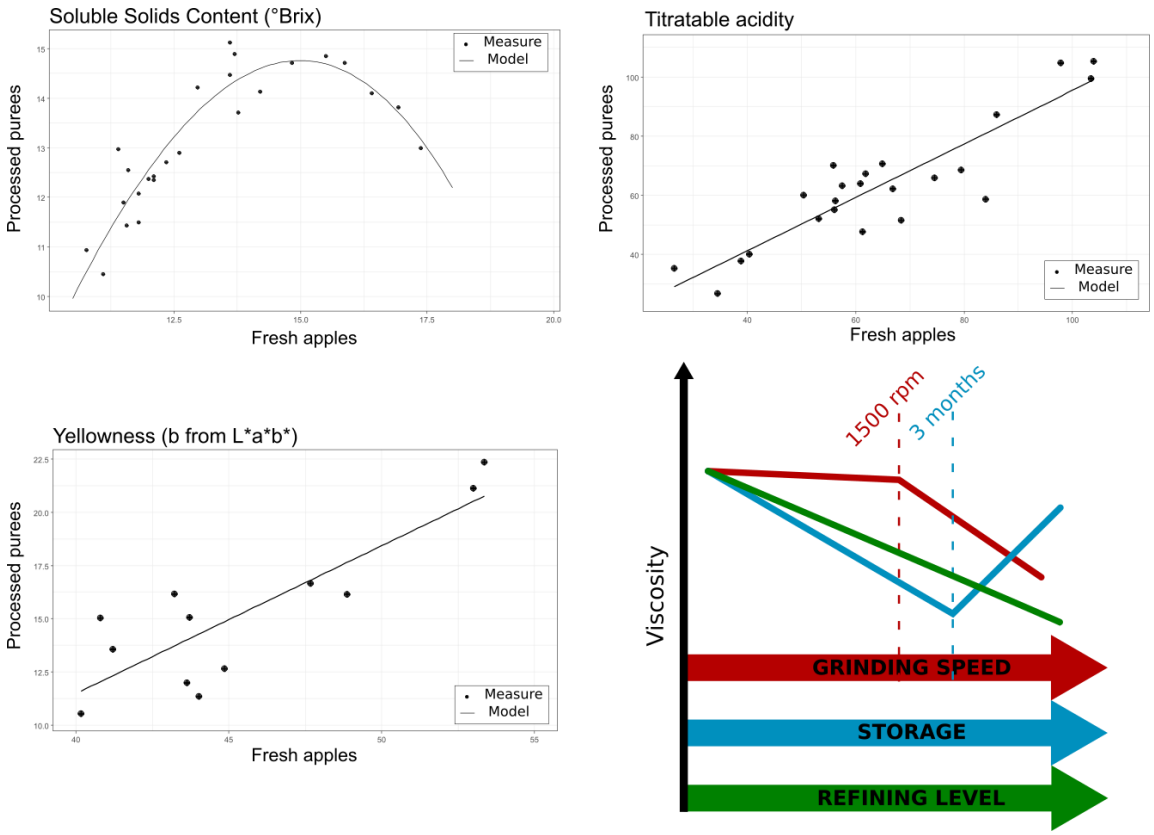


Figure 1 – Regression curves to model SSC (top left), TA (top right), yellowness (bottom left) and illustration of the viscous behavior of purees as a function of fruit storage duration and processing conditions (refining and grinding speed).

12. A virtual fruit model: a generic framework to assess the effect of pre- and post-harvest treatments on mango fruit quality

In order to study the effect of cultural practices and storage conditions on fresh mass and sweetness of mango fruits, a coupled experimental/simulation approach was used. Existing metabolic model was updated to take into account specificities of mango fruit sugar metabolism and coupled with existing models of fruit growth in dry and fresh matter, respectively predicted based on carbon- and water-related eco-physiological and biophysical processes (Léchaudel et al. 2015, 2017). The virtual fruit model developed for mango fruits relied on a general framework that included specificities for the pre-harvest stage of fruit growth (Figure 1A) and the post-harvest stage of fruit storage (Figure 1B).

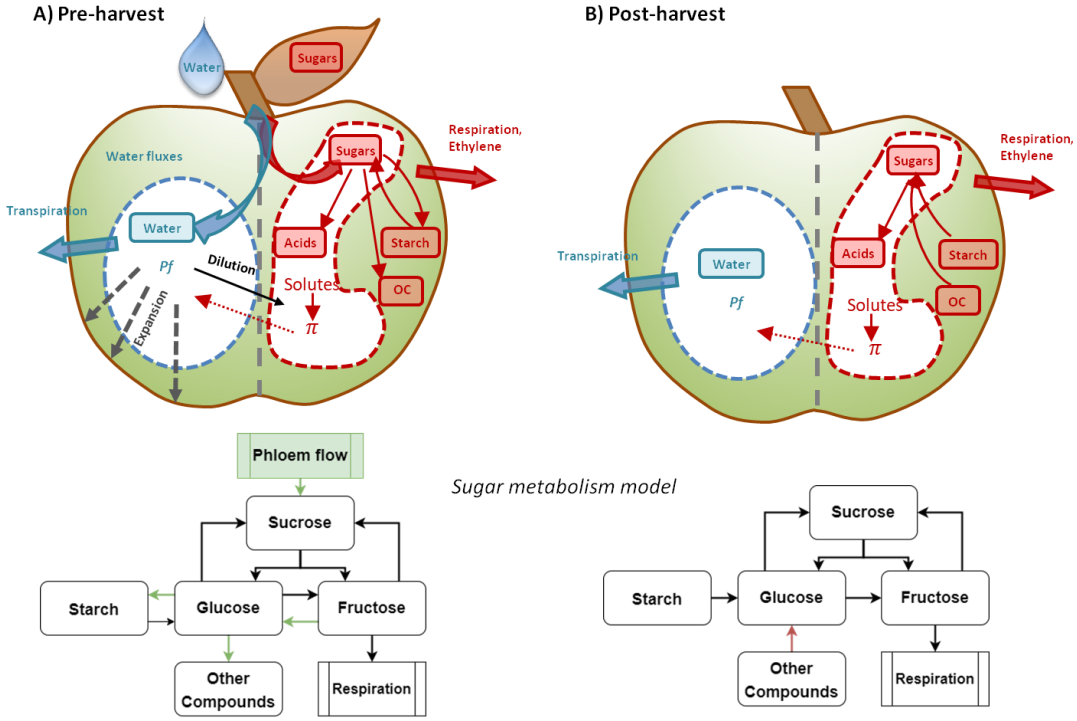


Figure 1. General structure of the virtual fruit model for mango with specificities for the pre-harvest (A) and post-harvest-stages (B). Arrows in the sugar metabolism model represent carbon flows between carbohydrate compounds

The virtual fruit model was used to investigate the effect of cultural practices and storage conditions on several fruit characteristics that can be of interest for mango processing or fruit consumption. They included fruit fresh mass and composition of the pulp in terms of dry matter content, soluble sugars, and starch concentrations.

WP5. Taking variability into account in the fruit chain

13. Sustainability standards governing transactions of agrifood chains

Pavez I., Saïsset L-A, Temri L., Bouhsina Z

The uncertainty linked to product quality rises when compliance with requirements is not observable by the buyer, whether an intermediate firm within the supply chain, e.g. the processor, or the final consumer. Nowadays, compliance with production standards must comply with economic, social and environmental factors, in line with the sustainability goals. How to explain differences in sustainability signalling in food chains? In this article, we analyse three contrasting cases: apple and mango purees, and wine chains. Using data gathered through interviews with French managers, we first answer the question: How do firms signal their sustainability compliance? then, we focus on the retailer-consumer level and ask: What are the signals of sustainability used in consumer products? Applying a multivariate coincidence text analysis, we analyse the labelling information of 716 apple purees 115 mango purees, 1,349 wines sold in France. In the wine chain, the asset-specificity of raw materials (varieties) and of the final product (brand) is higher and its institutional framework stronger. At the other extreme is the mango chain, with apples occupying an intermediate position. Wine supply chain shows more labels related to the territory, quality, environment and social concerns. The apple chain labels are more environmentally and socially oriented, e.g. responsible agriculture, nutrition. Mango chain labels mostly relate to social and economic issues, e.g. fair trade, complemented by organic certifications. The wine market is highly segmented and this can lead businesses to adopt stricter sustainable approaches in order to differentiate themselves from competitors. The production of apples and mangoes is mostly intended for the fresh market, which explains why processing transactions are mostly governed by fruit quality standards for fresh consumption that are not visible to consumers. Firms adapt their BtoB quality management mechanisms within the supply chains to reassure the consumer according to the length of the food chain.

Publication: Pavez I., Saïsset L-A, Temri L., Bouhsina Z. Sustainability standards governing transactions of agrifood chains « Systèmes Alimentaires/Food Systems » Journal (under review).

14. The effect of quality uncertainty and asset specificity on the coordination of fruit supply chains

Pavez, I., Bouhsina, Z.

This study explores how do firms manage the variability and the heterogeneity of apple and mango supply chains. Variability and heterogeneity are intrinsic attributes of agricultural products and strongly linked with food quality. Using a case study method, we gathered primary information, from firms at the grower-processor stage of the supply chains. Our study is framed in TCE and Institutional Analysis literature. Results show that transactors measure the characteristics of the products and coordinate transactions through technical specifications that correspond to micro institutions embedded in meso and macro institutional levels. As supply chains of apples and mangoes are mostly oriented to the fresh market, fruit not complying with technical requirements for fresh consumption, mostly related to appearance, are diverted to the processing channels. Growers dealing with niche markets such as baby food, allocate dedicated orchards to comply with specific requirements of this industry, these transactions are normally covered by pre-harvest contracts or by hierarchical governance. Firms participate in multiple configurations of the supply chains. These configurations of supply

chains emerge from the fact that firms may play simultaneously different roles in the value chains.

Publication: Pavez, I., Bouhsina, Z., 2020. The effect of quality uncertainty and asset specificity on the coordination of fruit supply chains, in: Academy of International Business Conference, 2020 AIB Oceania Chapter. Auckland, New-Zealand, p. 25.

15. The interface between production and processing, a key point to link raw material variability and processing adaptability for innovative food systems

Pavez, I. & Bouhsina, Z.

Organized in videoconference on November 30, 2020, the focus group brought together 3 researchers, 2 technical managers, a manager of the interprofession of processors and 2 moderators researchers in economics. This meeting, based on the presentation of the results of the interfaces project, allowed to highlight the application of scientific results in industry. It also allowed researchers to better understand the processors' questioning and interests. Concretely, for mango, what are the indicators to predict the quality of the processed product (e.g. dried mango, mango puree) according to the physiological and physico-chemical characteristics of the raw material. French processors who buy intermediate products, in particular puree, are interested in linking quality indicators of purees to the sensory qualities of the finished product. Also, to link the variety of mango and the final characteristics of the purees. For apples, the methods used by researchers to predict the quality of the puree (texture, viscosity, acidity, brix, etc.) on the basis of the characteristics of the apple have attracted the most attention from industry. Processors showed much interest on the "near infrared" technique, which they believe would enable them to better target batches of apples according to the desired purée. This technique could save time during the first stages of the transformation process (sorting of batches). Researchers showed interest in how manufacturers choose and mix the different apple varieties they use. However, as these are sorting differences in relation to the fresh market, manufacturers do not, with rare exceptions, always have a choice of varieties. Results of this focus group can facilitate future collaborations between academic research and industry.

Publication: Pavez, I. & Bouhsina, Z., (2021), "The interface between production and processing, a key point to link raw material variability and processing adaptability for innovative food systems ", Focus group report to Interfaces Project, Montpellier, Agropolis Fondation.

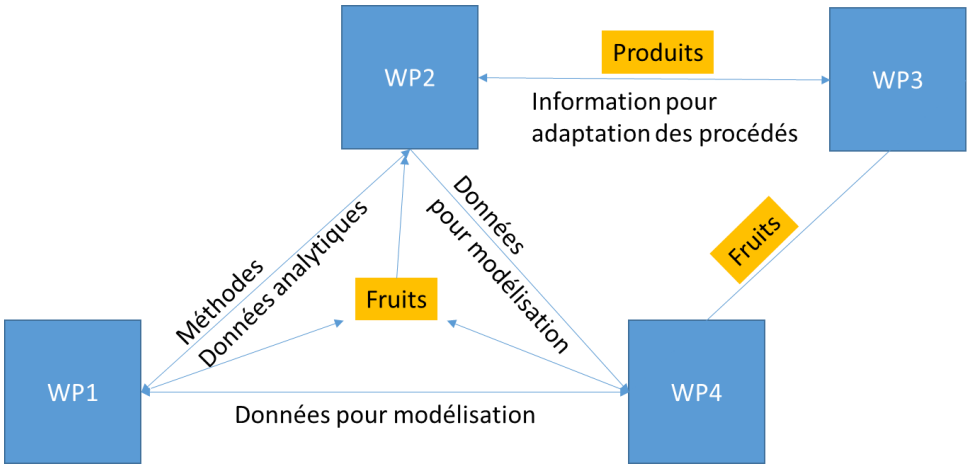
C. Impacts of the INTERFACES project on the structuring of teams.

An important link between the WPs concerns the fruits and products themselves: the fruits of WP4 were characterized in WP1, and the fruits used in WP2 were largely derived from the approaches and experiments developed in WP4; they were systematically characterized in WP1, as the products. The fruits used in WP3 also came from plots linked to WP4.

In return, there was information flow between the WPs: the methods and indicators defined in the framework of the WP1 were used in the WP2, and the rheological and structural data

produced in the WP2 were integrated in the methods developed in the WP1. The data obtained in WP1 and WP2 were transmitted to WP4 for modeling purposes.

Thus, a certain number of data associated with fruits (spectral, physico-chemical, microbiological and technical itineraries data) can be pooled.



These functional links thus led to collaborations between teams: between PSH and SQPOV on biochemical and rheological data on apples, between PSH and Hortsys for virtual fruit models in pre-harvest, between HortSys and QualiSud for the collection of experimental data on mango and biochemical data, between Qualisud and SQPOV on analytical methods (infra-red, chemometrics, methods of analyzing the texture of fresh and processed fruits).

The development of tools and methods for characterizing microbial flora should be noted as a very structuring approach. This innovative approach really enabled the SQPOV and QualiSud teams to collaborate closely throughout the duration of the project.

The exchanges were less obvious between the units working on apple and mango matrices on one hand, and the SPO unit working on grapes on the other hand. This is because grape extraction and fermentation operations are really different from what is applied on other matrices. It should also be recalled that the SPO team integrated lately the INTERFACES project on the recommendation of the Scientific Council of Agropolis Fondation.

The link is less direct with the SHS activities developed in WP5, the deliverables have been made but interactions with the MOISA UMR responsible for these activities were limited.

D. Partnership with the private sector

The theme of the project on the interactions between production methods (*sensu largo*) and transformations is of increasing interest in the context of current developments in agriculture.

For a first opening towards the private sector, “Interfaces” project was invited to be presented within the framework of the GIS fruit (November 2017).

During this first confrontation of the project concept with companies in the fruit production and processing sectors, it was decided:

- to invite representative companies to INTERFACES meetings. This principle was followed throughout the project.
- to organize a specific workshop with the industrial representative (April 2018)
- to set up an "advisory board" constituted by members of the GIS fruit (inter-branch managers, technical centers, a few manufacturers)

Many specific requests from the private sector were noted during these open meetings. For instance the problem of qualifying new varieties (or clones) and measure their suitability for processing, test it during selection before industrial trials, which involve dozens of hectares.

The European project (CSA) Eufruit “European Fruit Network” is a network aiming to improve the implementation of research outcomes into practical and applicable knowledge that will directly benefit the European fruit sector. This network invited “Interfaces” to present our methodology and results.

It is notable that most of the INTERFACES WP5 activities, such as focus groups and surveys, were carried out in close collaboration with the private sector.