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Evaluation of the fruit quality traits to illustrate the genetic diversity of apricots in France and New Zealand

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ABREVIATIONS

- FR : France ; French
- FW : Fresh Weight (la masse fraîche)
- g : Gramme
- h : heure
- INRA : Institut National de la Recherche Agronomique
- IR : Indice of Refraction
- kHz : kilo Hertz
- kPa : kilo Pascal
- meq : milli equivalents
- MIR : Mid Infrared Spectroscopy (spectroscopie moyen infrarouge)
- mL : millilitres
- N: Newton
- NIR : Near Inrafred Spectroscopy (spectroscopie proche infrarouge)
- NZ: New Zealand ; New Zealander
- PFR: Pland and Food Research
- RMSECV=Root Mean Square Error Of Cross Validation
- SSC: Soluble Solide Content
- SD : Standard deviation
- TA : Titrable Acidity
- VL : Variable Latente

Sommury

I. Background

1. Apricot

1.1.Origin and taxonomy

Apricot species is characterized by a large genetic variability organized in phylum in which a strong interaction exists between cultivars and areas of cultivation. For a century, apricot collections have been increasing year by year by new selections, which are very important to rise and to improve production and quality of apricots. Many authors have classified apricots to their variability and several geographical origins.
However, wild apricot trees are found throughout the mountains of the temperate region of Central Asia. They have been grown and domesticated for thousands of years and propagated at least two thousand years in Europe. Kostina (1969) classified apricots into four **eco-geographical groups**: the **Central Asian** group, the **Dzhungar-Zailij** group, the **Irano-Caucasian** group, and the **European** group. Therefore, Punovic (1970) created an **African** group to Kostina'classification (Faust, Surányi, and Nyujtó 2010). Apricots are also grown throughout all around the Mediterranean Basin, as well as in America, Australia, and New Zealand. Despite of this versatility as a species, most cultivars are restricted to their own particular regions (Lambert et al. 2004).
Recently with molecular technical development, apricots were re-classified using many molecular marker techniques (Bourguiba et al. 2012; Krichen et al. 2008), giving more knowledge about the ancestor origin and quality traits of apricots. *Prunus armeniaca,* known as common apricot, belongs to the *Rosaceae* family, genus *Prunus* L., the section *armeniaca* comprises five species (Hagen et al. 2002).

1.1.Biological proprieties

Botanically, apricots are drupes like peaches, plums, cherries and mangoes in which the outer fleshy part (exocarp and mesocarp) surrounds a hard stone (endocarp) with a seed inside.

The ripening of fruits is a complex coordination of various biochemical and developmental pathways regulated by ethylene, which is a gaseous phytohormone (smallest unsaturated hydrocarbon). Ethylene (C_2H_4) can easily dissolve within the cell's membrane system and thus rapidly spread its signal (Larsen 2015). It affects color, texture, nutritional quality and aroma of fruits (Barry and Giovannoni 2007). The relationship between fruit ripening and ethylene/respiration pattern allows the classification of fruits as climacteric or non-climacteric. In climacteric fruits, ethylene biosynthesis increases and shows a peak corresponding to respiration pattern, while in non-climacteric fruits the ethylene declines with fruit ripening and senescence. The delay of ethylene increase is the most common strategy used in post-harvest for prolonging the storage and increasing the shelf life. The inhibition of ethylene biosynthesis or action usually leads to an extension of shelf life of the climacteric fruits (Iqbal et al. 2017).

Apricots are climacteric fruits presenting moderate respiration but a very noticeable ethylene production rises during ripening. During this stage, the ethylene regulates firmness and color changes involving chlorophyll reduction, increase in carotenoids or anthocyanins, sugars, and biosynthesis of volatile organic compounds (VOCs) (Barry and Giovannoni 2007). Ethylene regulates fruit ripening by affecting the ACS (1-aminocyclopropane-1-carboxylic acid synthase) and ACO (1-aminocyclopropane-1-carboxylic acid oxidase) genes and the fruit

specific polygalacturonase, involved in the depolymerization of cell wall pectin during ripening (Smith et al., 1988). On the other hand, harvest maturity is not uniform on the tree. It is therefore important to harvest fruits when they reach the optimal stage of maturity in order to have a good overall quality.
The apricot fruit is very sensitive and delicate and its change is very fast during the last stages of ripening (Manolopoulou and Mallidis 1999). It is characterized by a rapid deterioration involving some problems for apricot commercialisation (Pretel et al,. 1993).
Apricot is a temperate fruit and grown in climates with well differentiated seasons. It requires a fairly cold winter and moderately high temperatures in the spring and early summer (Ahmadi et al., 2008; Guclu et al., 2006). The fruit's colour varies from yellow, orange to red, and some cultivars are cream white to greenish white (Ruiz et al., 2005; Riu-Aumatell et al., 2005).
Apricots are healthy. Fresh apricots as well as dried ones have been described to be a rich dietary source of polyphenols, vitamins and carotenoids (Tomas-Barberan et al. 2013). In particular, it has been considered as a complete dietary source of Provitamin A, because of its high content of its precursor, beta-carotene (David and José 2005).

1.2.International apricot production

The annual worldwide production of stone fruits (peaches, apricots, plums) is 38-42 million tons. Apricot is the third most important fruit worldwide among the fruit-producing rosaceous crops. The annual worldwide production of apricot is around 3,600 thousand tons, which presents an increase up to 60 % over the past two decades (Lichou, 2012).
Turkey, Iran, Uzbekistan, Italy, Pakistan, France, Algeria, Spain, Japan and Morocco are the world's top apricot producing countries (average over 1994 to 2014), according to FAO statistics (2015); *Cf.* **Annex.01 (Figure 1)**. The top European producers are Italy, France and Spain, according to FOA statistics (2013).
Therefore, apricots are transformed into pastry, jam, compote, syrup, juice, berries, or dried. It is also used in Central Asia for the production of almonds and the extraction of almond oil, in China as a forest species, in the Far East as a condiment species, and in Japan as an ornamental plant.

1.3.National apricot production in France and New Zealand

The French apricot national production is highly progressing during years (+30% in 20 years). On the top, we count about 100 varieties cultivated in France. The main apricot varieties cultivated are **Bergeron** (29%) followed by **Orangé de Provence** (10%), **Orangered** (8%), **Bergarouge** (4%) and others (50%). But, the apricot production has conserved some irregularity due to its high climatic sensitivity. Therefore, it is concentrated on three areas (Rhône-Alpes, Languedoc-Roussillon, and Provence-Alpes-Côte d'Azur), with high varietal specificity (Lichou, 2012).
New Zealand is limited in favourable area of production for apricots. However, apricots are mostly produced in Alexandra (south of the South Island), which is characterized ba dry oceanic climate climate with warm summers and cold winter. Today, 60 percent of what New Zealand grows (kiwifruit, avocado, grapes) is exported and trade with China nearly tripled in the past decade, with two-way trade rising from $8.2 billions in the June 2007 to $23 billions in the June 2016 year. In addition, total apricot for 2015-16 exports, mainly to China, was nearly 1,053 Tons. Concerning the NZ domestic market total demand is around 2,163 Tons, according to "www.stats.govt.nz".

Apricot production generates good economic returns, but the actual situation of apricot production in both countries is not equal in term of fruit quantity, which is specific for each country concerning the production surface and strategic marketing of apricot.

1.4. When to assess the apricot quality trait?

Apricot is climacteric, highly perishable fruit, and its short postharvest life is a problem for marketing. Its rapid deterioration usually induces harvest of unripe fruits which therefore cannot develop their optimal organoleptic potentialities. However, to obtain fruit with a good organoleptic quality, apricots have to be picked at a sufficiently advanced physiological stage. Also, it requires the control of the post-harvest evolution to provide fruit with an acceptable commercialization period of about a week (Chambroy et al. 1995). The assessment of fruit quality has to be carried out at an optimal harvest stage, after picking fruit. Therefore, the harvest maturity for each apricot variety is most under-provided for a long-term storage or transport of the fruit production-marketing chain (Feng et al. 2013).

1.5. How to assess fruits quality traits?

Apricot, has a significant variation of quality, which depends on *genetic factor* (variability of biochemical composition according to varieties), *physiologic behaviour* (speed of quality change link to the amount of ethylene production) (Gouble et al., 2006), also the *environment and growing conditions*.
The fruit quality is also assessed by *sensorial attributes* (appearance, texture and taste), by *biochemical characteristics* (sugar content, acidity, pigments (polyphenols, chlorophylls and carotenoids), aroma…), or *nutritional proprieties* (vitamin content, antioxidant activity…) and *physiologic measurements* (aptitude to fruit storage, ethylene production and respiratory activities).
To date, fruit quality is usually assessed individually on each fruit (firmness, color…) or on sets of fruits on the basis of size, colour, firmness, surface appearance for biochemical composition and particularly for the important traits related to the taste such as soluble solids and acidity.
Although many traditional technics,are performant to determine food quality, they are destructive and invasive (such as Flesh firmness, Soluble Solid Content and Acidity), which involve a significant manual work (Bureau et al., 2009a).

New non-destructive methods have been implemented as sufficient alternatives not only to estimate the fruit quality by Infrared spectroscopy (Wang 2016) but also to detect internal damage using technics such as MRI “magnetic resonance imaging”, X-rays imaging (Clark and Burmeister 1999) and acoustics technology (Gennisson et al. 2013).

2. Infrared Spectroscopy

2.1. Brief history and basic concepts of Infrared Spectroscopy

Infrared Spectroscopy ‘IR’ is of overtone vibrational spectroscopy in the wavenumber region (0.7–1000 μm), based on the interaction between electromagnetic radiation and tissues. IR region is conventionally subdivided into various regions of wavelengths such as near-infrared (NIR) (0.78-3 μm), mid-infrared (MIR) (3-50 μm) and far-infrared (FIR) (50-1000μm) (Z. Wang 2013).

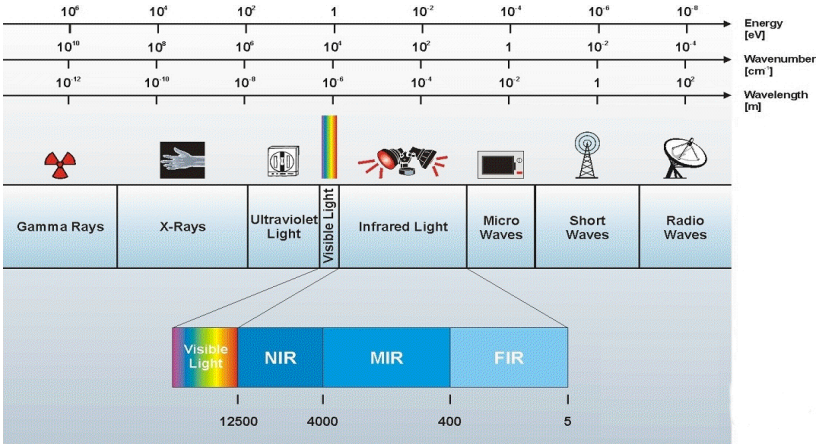

Figure 1. Electromagnetic spectrum.

3. Variability of the infrared "NIR & MIR"

3.1.Near-Infrared method

In NIR spectroscopy, the product is irradiated with NIR radiation, and the reflected or transmitted radiation is measured. While the radiation penetrates the product, its spectral characteristics change through wavelength dependent on scattering and absorption processes. This change depends on the chemical composition of the product, as well as on its light scattering properties which are related to the microstructure (Nicolaï et al. 2007).

Absorption bands in the NIR region are broad rather than sharp peaks, due to additive effects (combinations of absorbances) of two or more bonds at each wavelength. The intensity of the absorbance of energy depends on the degree of stretching or bending (anharmonicity) and decreases with each. Hydrogen atoms are the lightest atoms, thus bonds involving hydrogen vibrate with large amplitude when undergoing stretching. A NIR spectrum can provide useful information about hydrogen-bearing functional groups in a molecule even though it does not necessarily characterize a complete structure (Osborne 2000). Thus, the bonds between light atoms vibrate at higher frequencies than the bonds between heavier atoms. For example, the bonds involved carbone when the mass μ increases, the frequence decreases (Dominique and Éric 2006).

Goups :	C-H	C-D	C-O	C-Cl	C-Br
Frequence (cm^{-1}) :	3000	2800	1100	800	550

As a consequence, NIRs may be used primarily for the determination of compounds containing C-H, N-H or O-H groups, such as water, alcohols, phenols, amines and unsaturated hydrocarbons, rather than for molecular structure characterization (Giangiacomo & Nzabonimpa, 1994).

NIR, as analytical techniques for fruits and vegetables, have been developed to evaluate parameters as SSC, firmness, acidity…

Three different measurement setups for obtaining near infrared spectra are reflectance, transmittance and interactance. In my case I used the reflectance mode.

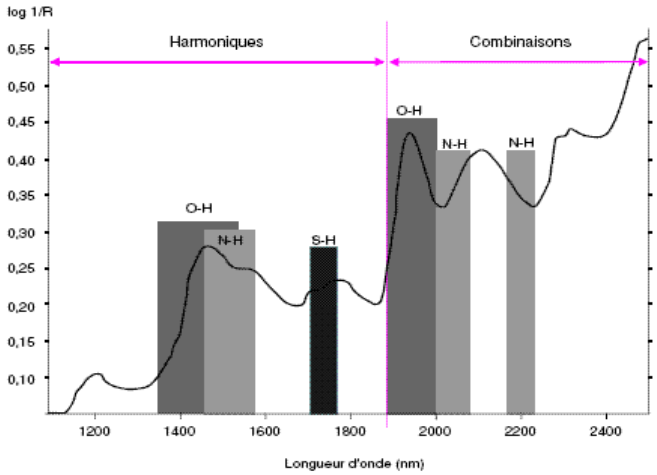

Figure 2 **:** Examples of groups absorption meseared by NIR (Bertrand, 2002).
(NB : The C-H bonds are the origin of the absorption band in the whole spectral region)

Nicolai, 2007 reviewed that it is important to know that the penetration of NIR radiation into fruit tissue decreases exponentially with the depth found a penetration depth of up to 4 mm in the 700-900 nm range and between 2 and 3 mm in the 900-1900 nm range for apple. As demonstrated (De Oliveira et al., 2014) on three different fruits (tomato, passion fruit and apricot) due to the fruit structure and probably to the depth light penetration the results are different according to the studied fruit.
Bureau et al. (2009a) demonstrate that wavelengths between 800-2500 nm could be used to predict soluble sugars (SSC) as well as titratable acidity (AT) for apricots.

3.2.Mid-Infrared method

The mid-infrared (MIR) region (2500–25000 nm or 4000–400 cm^{-1}) is the main region of vibrational spectroscopy. This region gives information on the structure, chemical bonds and functional groups, of organic molecules to be identified such as proteins, polysaccharides, and lipids. FT-MIR spectroscopy has been widely used for must and wine analysis (Fragoso et al. 2011; Fernández and Agosin 2007). Moreover, it has become an alternative method for sugar analysis, in food such as mango juices (Duarte et al. 2002), cane juices (Karoui, Downey, and Blecker 2010), soft drinks and fruit juices (Garrigues, Rambla, and de la Guardia 1998). Furthermore, this technique has been applied for the analysis of acids in fruits, and in particular apple and tomato (Irudayaraj and Tewari 2003; Beullens et al. 2006; S. Bureau et al. 2015).

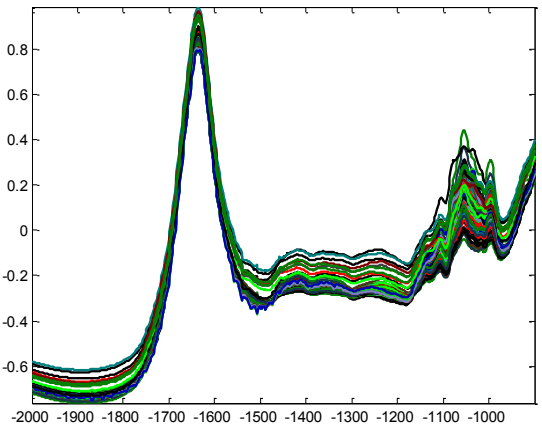

Figure 3. Representative MIR spectra (wavenumber range from 2000 to 1000cm^{-1} region).

More recently, Bureau et al. (2009) analyzed, using ATR-FTMIR reflectance spectroscopy, 757 apricots harvested at different maturation times and belonging to eight different cultivars. The most suitable spectral region lay between 1500 and 900 cm^{-1}, and excellent predictions were observed for the following parameters in apricot slurries: citric acid, malic acid, soluble solids content, and titratable acidity (Bureau et al. 2009b). This confirmed previous findings of the same research group which reported the usefulness of FT-MIR for prediction of sucrose, glucose, fructose, malic, and citric acid contents in apricot.

3.4.Chemometrics technics applied on the Infrared spectral data.

Although water absorbs near infrared radiation and fruits are dominated biochemically by water, nevertheless the near infrared spectrum of fruit is essentially composed of a large set of overtones and combinations bands. Thus, Infrared spectrum is complicated/complex by wavelength dependent scattering effects, tissue heterogeneities, instrumental noise, ambient effects and others sources of variability. Consequently, the data generated by IR spectroscopy needs mathematical techniques for handling multivariate data and led to the birth of a branch of science called Chemometrics (Osborne et al., 1993). Chemometrics (Multivariate statistical techniques) are therefore required to extract the relevant information about quality attributes which is buried in NIR spectrum (model calibration). Essentially this involves regression techniques coupled with spectral preprocessing techniques, more details have been reviewed by Nicolaï et al. (2007) such as Averaging, Centring, Smoothing, Standardization, Normalization (i.e, SNV) and Transformation. Multivariate regression techniques aim at establishing a relationship between the n x 1 vector of observed response values y (Y-variable); quality attributes of interest (reference data such as soluble solids content and firmness) and the n x N spectral matrix X (X-variables), with n number of spectra and N the number of wavelengths. Here we focus on two most approaches that we found frequently in the literature.

3.4.1. The explorative approach Principal component analysis (PCA)

The Principal component analysis is particularly adapted to the explorative approach of spectral data. PCA provides a factorial map or *Principal Components* (PCs) (or latent variables) where each spectrum is represented by a point on the graph instead of the original variables as predictors (absorbances). The advantage is that the *X*-variables (PCs) are **uncorrelated**, and that the noise is filtered (Nicolaï et al. 2007). The matrix-*X* is the sum of each factorial coordinates (*n* x 1) in *n* x *N* dimensions. More number of selected PCs (or dimensions PCA) better is the spectral reconstruction (Bertrand and Dufour 2006).

3.4.2. The predictive approach Partial Least squares (PLS) regression

PLS, as predictive method, is the best known and the most used in many field of the Infrared Spectroscopy. First, PLS-regression was introduced almost 30 years ago by Wold (1966) and it is known also as *projection to latent structure*, which better reflect the principle of the method (Bertrand, D, 2006). In PLS-regression an orthogonal basis of latent variables is constructed one by one in such a way that they are oriented along directions of maximal covariance between spectral matrix **X** and the response vector **Y.** In this way, it is ensured that the latent variables are sorted according to their relevance for predicting the Y-variable. Interpretation of the relationship between X-data and Y-data (the regression model) is then simplified as this relationship is concentrated on the smallest possible number of latent variables (Nicolaï et al. 2007). The method is well adapted when there is a large amount of correlation, or even colinearity.

Aims:

Two partners “INRA and PFR” are involved in the project named PHC (Partnership Hubert Curien) Dumont D'Urville Project dedicated to the evaluation of the apricot quality in the two countries France and New Zealand. My internship is a part of this project. So I present briefly the French and the New Zealander partners.

4. Presentation of welcome institution INRA & PFR

INRA is a public targeted research organisation and it was created in 1946 as a response to a key societal challenge. INRA’s initial goal: to feed France. In the present day, the institute focuses on three highly interconnected topics such as agriculture, the environment and nutrition. As key figures, INRA is managing an annual budget of 881 million euros for 8 165 permanent staff, within 250 research units and 48 experimental units. About 4 000 scientific publications are produced annually [1].
INRA’s PACA research centre is gather many research units which focucing on the agroecology of greenhouse and orchard systems, on the modelisation of the impact of climate change at the landscape scale and on quality and security of fruits and vegetables for consumers.
SQPOV (Security and Quality of Plant Products) and GAFL (Breeding and Improving Fruits and Vegetables), as many research units of INRA’s PACA center, interact strongly and share common research goals, in synergy with other research units based in Avignon, Saint-Maurice, Gotheron, and Sophia-Antipolis. Research focuses on the quality of fruits and vegetables, and incorporates all factors such as genetic, environmental, and practices based on crop methods, or related to processing techniques that impact quality. It also focuses on how fruits and vegetables are handled, stored and processed after harvest.

Plant & Food Research “PFR” is a New Zealand, government-owned Research Institute, which is part of long history of professional scientific research to which dates back to the early 1900s to aid agriculture and horticulture in New Zealand. With over 900 people based at sites across New Zealand, as well as in the USA and Australia. Currently, PFR is based science company providing research and innovation that add value to fruit, vegetable, crop and food products[2].

PFR research and innovation support the sustainable production of high quality produce that earns a premium in international markets, as well as driving the design and development of new and novel functional foods that offer benefits to human health and wellbeing. Indeed, PFR research sites are strategically located throughout New Zealand, allowing them to connect with their key industry partners and operate research trials near the commercial operators it supports.

In addition, INRA and PFR also well connected within the global research community and they are involved in a significant number of partnerships, strengthened by their international business team and overseas offices.

[1] http://institut.inra.fr/en
[2] http://www.plantandfood.co.nz/

5. PHC Dumont D'Urville Project on the apricot quality

In France, half of the fresh fruit production reaches consumers within a few days of harvest, because of the close proximity between production areas and large populations, and therefore fruit can be harvested at an almost ripe stage. Particularly, the cultivar Bergeron comprises the other 50% of production, which must be harvested less mature and cannot be marketed over long period.
More than 60% of the value of NZ apricot production is derived from exports to overseas market (Australia, UK, Europe and the USA). Recently, Asia identified as significant market for the NZ apricots. However, the distance to these markets means growers and marketers need to control and manage the apricot quality over long period (3-4 weeks), yet still ensure that the normal ripening process occurs. Another factor to consider is that apricots are naturally climacteric, producing ethylene which accelerates their ripening.
In both countries, apricot breeding programme has developed some varieties that have a wide diversity of SSC, firmness and ethylene production.

6. The internship context and problematic:

My internship took place as part of a PHC Dumont d'Urville (2016-2017) between INRA (SQPOV and UGAFL of Avignon) and The New Zealand Institute for Plant and Food Research. A first experiment was carried out between June and August 2016 in France. I have been involved in the second experiment taking place in New Zealand between January and April 2017. After, I joined the unit SQPOV in Avignon until the end of July 2017.
Within this context, the project objectives are to improve the ability to control fruit quality by: **i**) Evaluation of the genetic diversity of apricot varieties available in France and New Zealand, highlighting quality criteria of interest of fruit (high sugar, low ethylene..) for development of new cultivars in both countries. **ii**) The development of rapid and robust methods for characterizing the fruit quality using infrared spectroscopy on intact fruit using NIR and on pureed fruit using MIR. Two approaches were considered: the first "targeted and quantitative" with the implementation of models of prediction of the criteria of interest (sugars, acids, texture) and the second "non-targeted and qualitative" with a direct analysis of the spectra by multivariate analyses to determine some 'types' of apricot. The aim of these two approaches is therefore to characterize quickly and easily the quality of fruit and to improve the selection and breeding methods.

II. Materials and Methods:

1. Plant materials and sampling

The apricot genotypic variability is represented by 50 selected genotypes representative of the variability observed in each country. The French's cultivars are listed in **Annex.01**. They grew in different areas: Drôme (Gotheron and Crest) and Gard (Amarine)in France. The fruits were harvested at maturity (m3 stage) during the season from June to August 2016. The 50 New Zealand's cultivars (**Annex.01**) were from Clyde (Central Otago, New Zealand) where apricots were harvested at maturity (m3 stage) during the season from 01 January to mid mars 2017. I notice that I have been involved in all steps of the apricot assessment at PFR-Clyde (New Zealand), but not for the apricot assessment in France.

1.1. At Harvest:

For each variety about 36 fruits were picked up (manually and randomly) from the same tree and immediately transported to the laboratory for the assessment. Then, total of 6 fruits were

selected (at optimal eating maturity) for each of the 50 selected genotypes according to their firmness values (mean of 6 Fkg for the 6 selected fruits).

1.2.Common genotypes

In France, 4 genotypes were tested: **Orangered** (common cultivar in both countries), **Bergeron** (the typical FR cultivar), **A4034** (non-climacteric) and **Goldrich** (an orange apricot with high ethylene production). In New Zealand, **Orangered** (Common cultivar in both countries), **Clutagold** (the typical NZ cultivar), **SF14/15** (non-climacteric) and **Mac12/45** (NZ cultivar).

2. Measurements:

2.1.Physical Measurements

Physical measurements (Weigh, Pressure, Colour and Firmness) were carried out individually on all fruits. Firmness of fruit was evaluated by a non destructive compression test with a Penetrometer PELELAUP (Abbal and Planton, 1990) . It was expressed by the force (kPa) necessary to get a 3% compression of the fruit height. The ground colour of the skin was measured in the L*a*b* system with a Minolta Chromameter and expressed by the brightness (L*) and hue angle (H°).

2.2.Physiological measurement: Ethylene

In both country, the measurement method for the ethylene rate carried out as reported by (Chambroy et al. 1995). The fruits have been individually confined in a jar at 20°C. After 1h of confinement, the air have been sampled and injected by syringe in GC (Gas Chromatography). Ethylene rate was expressed in **nmol** per **kg** of fruit and per **hour** (nmol kg^{-1} h^{-1}).

2.3.Biochemical measurements

Biochemical Measurements were realized on two subsets of 3 fruits. Fruits were cut and stored at -20°C for days before analysis. Just before analyses, fruits pieces are ground to obtain a homogenised puree and then centrifuged (for 30 min at 10000 RPM) to obtained a juice for biochemical measurements and MIR spectral data acquisition.

2.3.1. Soluble solids and Sugars

Soluble solid content (SSC) was determined using a digital refractometer (PR-101 ATAGO) and expressed in °Brix. From 0.1 mL juice diluted with 0.4 mL 90% ethanol, sugars, glucose, fructose and sucrose, were determined with fucose added as the internal standard using Dionex UltiMate 3000 Series UHPLC (ThermoFisher Scientific, San Jose, CA, USA) system with a CarboPac PA20 column with electrochemical detection and expressed as g sugar per 100 g of juice.

2.4.Titratable acidity and Organic acids

Titratable acidity was determined by potentiometric titration using 0.5 mL aliquots of thawed juice on a Mettler Toledo Autotitrator, using 0.1 N sodium hydroxide as the titrant and an end point of pH 8.2. Results were expressed as g citric acid equivalents per 100 g of juice.
Malic acid and citric acid were determined using a Dionex UltiMate 3000 Series UHPLC (ThermoFisher Scientific, San Jose, CA, USA) with PDA (photodiode array) detection at 210

and 220 nm. Compound separation was achieved using a Synergi 4 µ hydro-RP column, 4.6 x 250 mm (Phenomenex, Torrance, CA, USA), maintained at 30ºC. Solvents were (A) 0.08% phosphoric acid v/v and (B) acetonitrile + 0.0125% phosphoric acid and the flow rate was 1.0 mL/min. The mobile phase, 100% A was held for 13 min, followed by a column flush at 30% B before resetting to the original conditions. Sample injection volume was 10µL. Malic acid and citric acid were quantified using pure standards of these compounds and expressed as g organic acid per 100 g of juice

3. Infrared spectroscopy

NIRs MPA "Bruker (French system used only on FR apricots) ; Blue Vis-NIR (NZ system used on intact FR and NZ apricots); FTIR=MIRS (NZ system used on NZ apricots) and MIRS Tensor 27 (French system used only for FR apricots).

3.1.Vis-NIR (Blue spectro NZ) et NIR (MPA Bruker)

NIR MPA Bruker and Blue Vis-NIR (NZ system) spectrometers have been used to measure both, the blushed and un-blushed sides of intact and individual fruits at Harvest, during post-harvest and after the cold storage.
In NZ and FR, Vis/NIR spectra (Blue spectra NZ) of intact apricots were measured with a specially developed laboratory system, that contained a wide band light source (50 W quartz halogen, RJL 5012 FL, Radium, Germany), a fruit holder/light collection fixture and a non-scanning polychromatic/diode array spectrometer (Zeiss MMS1-NIR, Germany). Apricots were placed centrally upon the fruit holder, with stem–calyx axis horizontal, and were irradiated from below by the light source. Light from the source entered the fruit through the exposed regions around the holder and diffused through the apricot flesh to exit from the fruit on the inside of the holder. The inside of the fruit holder contained a mirror and fibre optic cable for directing the exiting light into the spectrometer. A 15 bit ADC electronics unit (FEE-001, tec5, Germany) was used to amplify and digitise the spectral signal. Data acquisition and spectra storage was achieved with a PC running specially developed in-house software (NIR Fruit, HortResearch, 1999). Each apricot spectrum was accumulated over 1 s from ten contiguous acquisitions at a 100 ms integration time. All spectra were first converted to relative transmittance by dividing the measured intensity at each wavelength by the corresponding intensity from a standard reference spectrum. The standard reference spectrum, obtained by placing a 50×80×80 mm3teflon block directly above the fruit holder, was measured. Subsequent to each reference measurement the sensor dark current was measured by collecting the spectrum obtained by covering the fruit holder with a steel ball that prevented any light reaching the sensor. Two separate spectral measurements were made on each apricot, one on each opposite side around the circumference, paying no particular attention to skin colour or tone but certainly avoiding any obvious surface defects (bruises, scars etc.). As relative transmittance spectra they were averaged to provide a mean spectrum for each apricot.

In France, NIR spectra were recorded on a multi-purpose analyser (MPA) spectrometer (Bruker Optics, Wissembourg, France) equipped with an integrating sphere to provide diffuse reflectance measurements and a TE-InGaAs detector. The MPA was completely software-controlled by the OPUS software Version 5.0 which was provided by Bruker Optics. The NIR spectrum of each sample was obtained by taking the average of 32 scans. It was acquired between 800 and 2500 nm at 2 nm spectral resolution, with scanner velocity of 10 kHz and a background of 32 scans. The time required to achieve a spectral measurement was 30 s. The intact apricots were placed on an automated 30-position sample wheel, each position

corresponding to an 18 mm diameter hole. Apricots were placed at each position with their stem–calyx axis horizontal. On each apricot, a diffuse reflectance spectrum was measured on two opposite sides, the first on the un-blushed side and the second on the blushed side.

3.2.MIR (Alpha NZ et Tensor 27 FR)

In NZ, preparation for MIR analysis involved thawing tubes and vortexing to mix thoroughly. For collection of the MIR spectrum (4000-400 cm^{-1}), a small drop of juice (30 µL) was placed on the heated stage of a Bruker Alpha spectrometer (Bruker Corporation, Ettlingen, Germany). This ensured that the spectral measurement, by attenuated total reflectance (ATR) after a single bounce on the diamond cell, was conducted at a fixed temperature (31°C). Each measurement took 52 s (20 s for sample warming time, 32 s for data collection) from the application of one pipette aliquot to the next. Samples were analysed in batches of 12, with a water sample background in between each batch.

It is usual to conduct spectral analysis at a fixed temperature since molecular vibrational modes are temperature-sensitive. In our case, a temperature of 31°C was chosen as a compromise; it being sufficiently far above 'normal' laboratory operating conditions that small fluctuations in room temperature wouldn't affect spectral characteristics, but not so high that small volume samples wouldn't suffer adversely when left on the exposed ATR cell for data collection times longer than several minutes. With flow cells and samples with volatile components such as alcohol, the Bruker Alpha can be operated at temperatures as high as 40°C.

In FR, MIR spectra were collected at room temperature with a Tensor 27 FTIR spectrometer (Bruker Optics, Wissembourg, France) equipped with a horizontal attenuated total reflectance (ATR, Bruker Optics) sampling accessory and deuterated triglycine sulfate (DTGS) detector. The apricot juices were placed at the surface of the zinc selenide crystal with six internal bounces. The samples were scanned at wavenumbers ranging from 650 to 4000 cm^{-1} and corrected against the background spectrum of air. The spectrum of each sample was obtained by taking the average of 32 scans. The crystal was cleaned between measurements with deionized water and dried with lint-free tissue. Instrument control and spectral collection were performed using OPUS software (version 5.0 Bruker Optics) supplied by the equipment manufacturer.

3.3.Spectral processing and statistical analysis of data

Analysis of variance (ANOVA) and Principal component analyses (PCA) were performed using the XLSTAT (version 2011.1.03, AddinsoftARL, Paris, France) data analysis toolbox. ANOVA was carried out to determine significant differences between countries (FR and NZ) and varieties (around 50 genotypes for each country). The pairwise comparison between means was performed using LSD (Least Significant Difference) Fisher's test ($P < 0.05$ (*), 0.01(**), and 0.001 (***)). The pre-processing (SNV) and calculations were carried out under SAISIR environment (Bertrand, 2008) and DESIR interface (Lecomte, 2007) in MatLab software package (version 7.2, MathWorks, USA).

III. Results and discussion

1. Fruit quality illustration:

1.1.At harvest (by reference parameters and spectral data)

Figure 2a represents the results of physical-chemicals characterization of 50 French varieties and 50 varieties at Harvest. We have high variability presented in the littérature on apricots (Aubert and Chanforan, 2007 ; Bureau et al., 2009 ; Feng et al., 2011). Points in blue are minimum and maximum for each parameter. For SSC, the max Brix° were 21.8° and 23.6 ° for the **A4520** (Jengat) and **T18/12** corresponding to FR and NZ varieties respectively. Despite the fact that the range of variability (regarding the SSC) for the NZ varieties is much large (from 7.7 to 23.6) comparing to Fr varieties (from 9 to 18.6) but the mean and standard deviation of each set is similar for the both of them 14.70 (2.9) and 14.64 (2.13) respectively . For the skin colour, a quite similar distribution of (L*: brightness ,C*,h°) measurements of the non-blush side of apricots is observed (FR and NZ varieties). the difference (between upper and lower points) is larger for the Fr varieties. It could be explained by the variability of skin colour, not to ripening or the stage of maturity (apricots are chosen for the same stage of maturity). Moreover, the French varieties are more variable for C* and h°, which due to the variation of carotenes quantity and saturation respectively. The highest values have been recorded for **Iranien (**A2862).

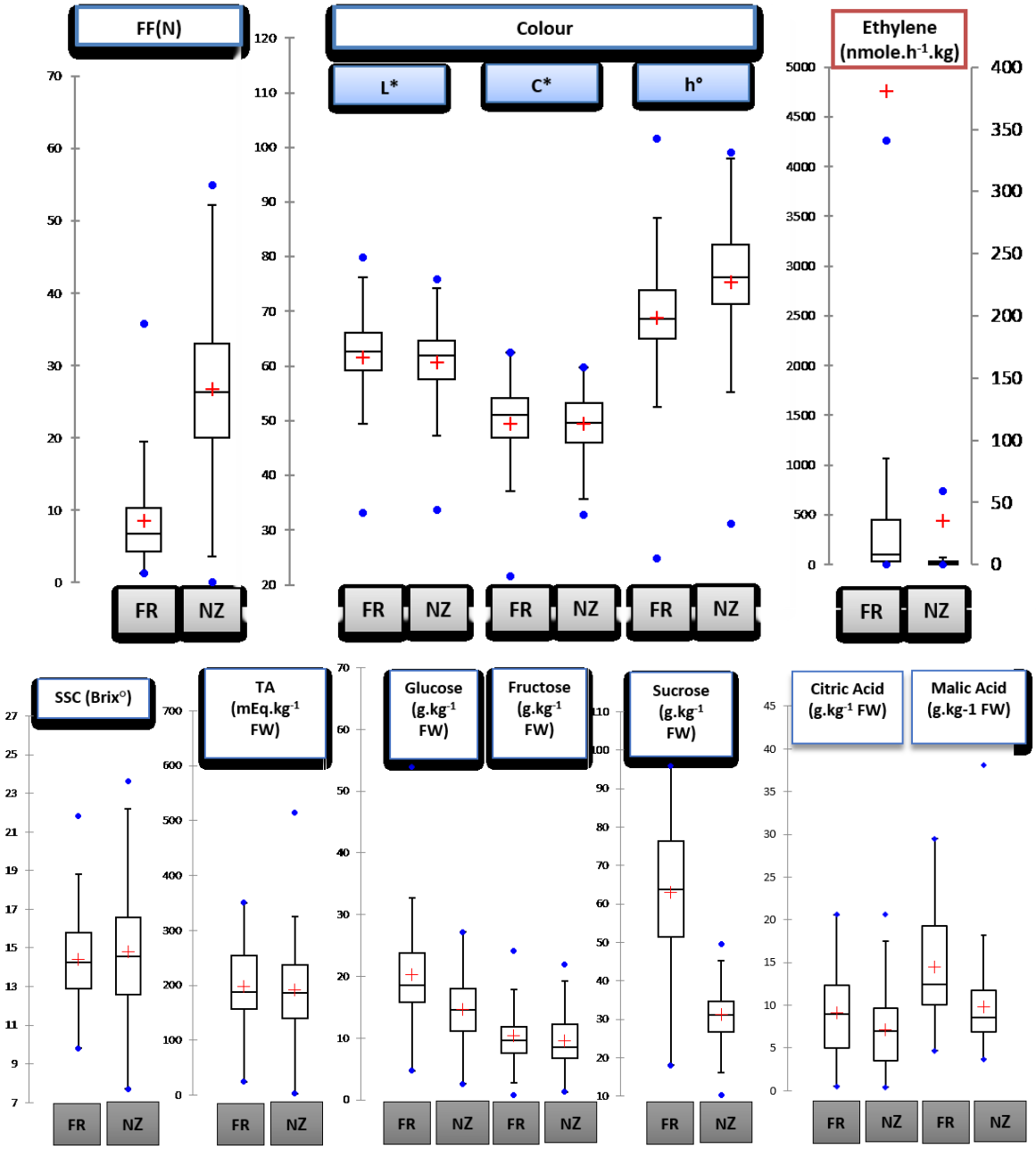

Figure 4: Box plots of physico-chemical parameters for the French (FR) and New Zelander (NZ) apricots varieties respectively at harvest.

Regarding the rate of ethylene, the FR box plot is much higher than NZ box plot, which explains why the FR varieties produce very high ethylene rate comparing to the NZ varieties. So, the maximum value are 4257 nmol/h.kg and 740 nmol/h.kg for the A4846 (Iziagat) and StB7/1 respectively; FR and NZ respectively.

Three individual sugars were determined in apricot fruit, box plots of physicochemical characterization for the French and New Zealander apricots for all varieties at Harvest are shown (Figure 3). As matter of fact, it allowed us to compare the reference data between FR and NZ for each parameter. In order to evaluate the impact of the methods used for both countries, and to be sure about the sugars rate, of FR as well as NZ apricots, are comparable.

For the sugars and organic acids, there are no large differences between them (FR & NZ) regarding the variability. Except for the sucrose concentration where it does not correlate with the Brix (Cf. figure 3). Because the results of SSC (Brix) were much similar before and after extracting the juice.

As seen in the box plot, the sucrose concentration in FR apricots is ranged between (20 to 95 g/kg FW) and the NZ is ranged between (12 to 46 g/kg FW). The average is 62.1 g/kg FW and 31.2 g/Kg FW respectively, for the FR and NZ respectively. Surprisingly, the NZ apricots contain 2-Fold sucrose less than in the FR apricots. The problematic is if the sucrose concentration of apricots is logic in spite of the methods used (enzymatic for FR and HPLC for NZ). So, we want to know with the same method (enzymatic dosage); if is there a big difference with current results (the apricot season of 2016) related to the past (2005 to 2011)?
We compared the sucrose of about 1000 apricots (at m3) measured with the enzymatic method in France during the period from 2005 to 2011 (results are not shown here). Therefore, the average of sucrose concentration was 61.3 g/kg FW (Std =1.7), which is significantly similar to the average of sucrose concentration (the apricot season of 2016) (CF box plot, it is about 62.1 g/kg FW, for FR).
In fact, it is known that the sucrose represents about 70% of Brix value. The sucrose rate represents about 70% of Brix value for the FR apricots. But compared to the NZ rate sucrose, it was not the case of NZ apricots.
Furthermore, we compared between the common varieties (see in the Annex) to understand if these rates are comparable between them. The same conclusion is that the sucrose rates in NZ apricots are less (2-Fold) than in FR apricots even for the common varieties between both countries. Regarding the literature, our amounts of sugars (especially to the sucrose) are close to those reported by Aubert and Chanforan (2007) for 28 apricot varieties (mean 63.6 g kg^{-1} FW) but higher than sucrose (mean 50.74 g kg^{-1} FW) obtained for 13 apricot varieties, reported by Schmitzer et al. 2011. The sugars have been quantified by HPLC for both authors.

1.1.1. PCA analysis

To illustrate the variability of FR and NZ apriocts and determine which parameters contributed the most to the total data variation, PCA, was applied on the reference data (physico-chemical characteristics) of apricots. Regarding the variability (Figure 5) in the PCA analysis, a total of 39.98% of difference was explained by relation between PC1 and PC2.

Dispersion of the FR and NZ genotypes on the principal components 1 and 2 of a PCA analysis. (a) FR and NZ genotypes are represented on the factorial plan. (b) Correlation plot of physical (FF, Colour, Weight) and biochemical (SSC, sugars and acid organic) parameters associated to PC1 and PC2.

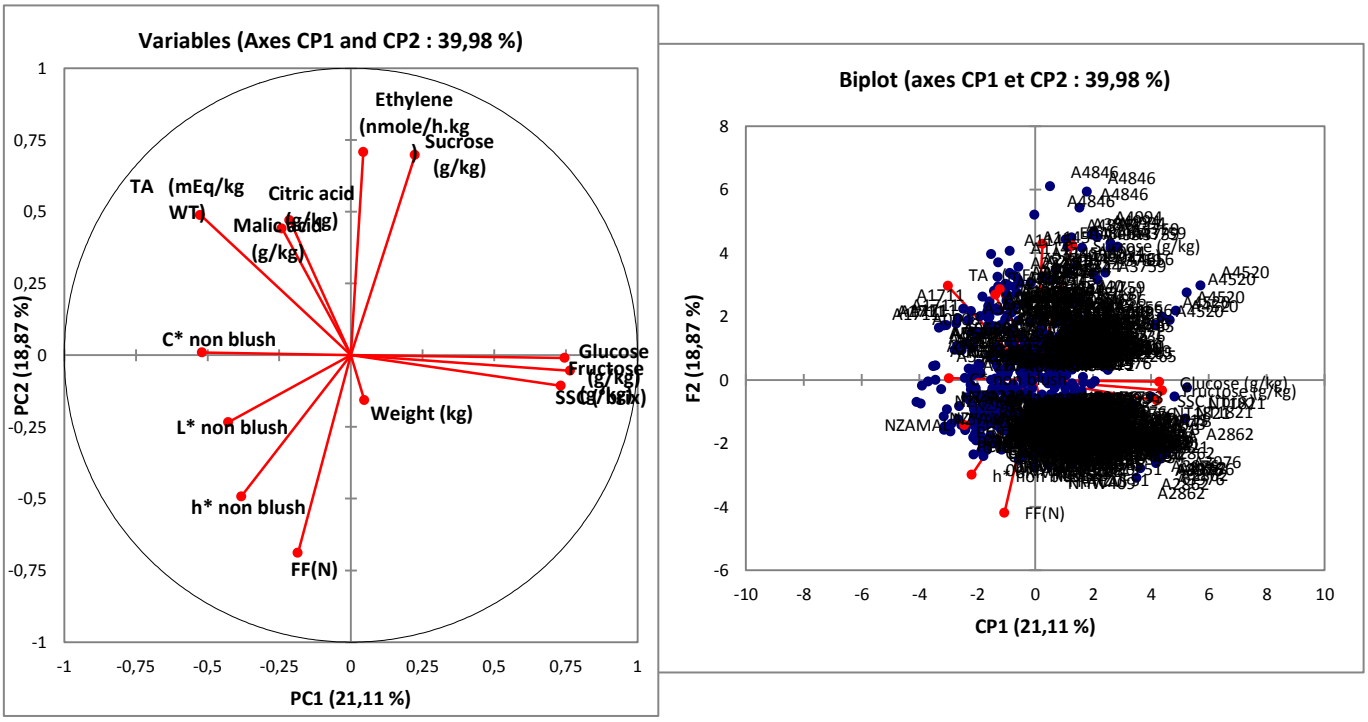

Figure 5. **Principal component analysis (PCA)** (a) Correlation plot and (b) Biplot were performed on the reference data of French and New Zealander apricots.

Moreover, many correlations between are observed between the physical and biochemical characteristics. The biochemical parameters (SSC, TA, Glucose and Fructose) are highly correlated to the factor 1 (CP1). Contrary to Flesh Firmness (FF), Ethylene rate and sucrose highly explain the factor axe 2 (CP2). Also, the glucose and fructose contents were highly linked and clearly correlated to SSC (Brix°) on the CP1. The SSC (especially for glucose and fructose) were negatively correlated to TA. Apart from the sucrose rate, which were much independent and negatively correlated to the FF and Ethylene on the axis 2.
The SSC is a good parameter to estimate the sugar content in apricots, excluding for the sucrose concentration, which is independent and correlated negatively with the C* value (among colour parameters).

1.2.Common apricot genotypes (ANOVA test)

In the aim of evaluating the genotype effect and location effect, a one-way ANOVA was directly performed on reference data of the average of six fruits for 5 genotypes communes (**A0660, A1714**, **A1963**, **A2215** and **SF1415**). As result, the effect of variety (genotype) according to the F values, was shown to be higher than the effect of location (Annexe Cf. Table ANOVA test). In fact, as indicated in the **Table 1,** it shows the extent of variability observed for quality traits of 5 common genotype in both countries.

For the country effect, the most significant parameters are: Weight, FF, SSC, TA, Glucose, Sucrose, Citrid and Malic acids. These parameters are grouping in A or B (see below), with a 95% confidence range. The NZ common genotypes are slightly firm, acid and produce less ethylene in comparison to FR genotypes (we see more details in PCA given in the Annexe figure 2). On the other hand, all parameters significantly presented a significant level (the difference is less than 0.001) for the five apricot genotype effects. The expected variability is well observed between countries and genotypes (groups).

Table 1: ANOVA analysis performed on reference data of the five genotypes communes for both countries.

	Country effect			Genotype effect					
Quality traits	**FR**	**NZ**	Significant level	**A0660 Bergeron**	**A1714 Rouget de Sernhac**	**A1963 Orangered**	**A2215 Harogem**	**SF1415**	Significant level
Weight (kg)	B	A	***	AB	B	B	A	C	***
L* non blush	A	A	ns	AB	B	B	A	C	***
C* non blush	A	A	*	AB	BC	C	A	C	***
h* non blush	B	A	***	A	A	B	A	C	***
FF(N)	B	A	***	B	B	B	B	A	***
Ethylene (nmole/h.kg)	A	B	ns	B	B	A	A	B	***
SSC (°brix)	B	A	**	D	D	C	B	A	***
TA (mEq/kg WT)	B	A	***	A	B	D	A	C	***
Glucose (g/kg)	A	B	***	A	C	A	A	B	***
Fructose (g/kg)	A	A	ns	B	C	A	A	D	***
Sucrose (g/kg)	A	B	***	D	B	C	C	A	***
Citric acid (g/kg)	B	A	***	C	C	B	A	C	***
Malic acid (g/kg)	A	B	***	A	B	D	D	C	***

Significant differences when different letters ($P < 0.05$ (*), 0.01(**), and 0.001 (***))

Therefore, a PCA analysis was performed to explore the association between the quality traits among apricot genotypes. The PCA results confirm the variety effect with a total variability of 46.04% for CP1 and CP2 (given in Annexe; figure 2). The five apricot genotypes are discriminated in form of clusters on the basis of clones and these groups don't take into account the location (effect country) but for the genotype SF1415 (non-climacteric) is discriminated for both location with a high SSC. Also, NZA2215 (Harogem) and NZA1714 are discriminated for acidity and TA. But, the FRA1714 (Rouget de Sernhac), FRA1963 (Orangered) and FRA0660 (Bergeron) are predominated by sucrose and glucose.
Finally, the ANOVA results gathered with PCA analysis, variability of fruits from common genotypes is observed between NZ and FR with**a higher firmness and acid content** and a lower ethylene production for NZ, even for the genotype characterized by producing high ethylene, as A1963 (Orangered) due to the effect location.

C_2H_4 rate:

It was one of our interest to harmonize and express the results for parameters of FR apricots as well for NZ apricots. However, we have faced some technical difficulties because we don't have the same units and conditions. Also, choice of the apricot firmness as criteria to ensure they are in the same stage of maturity.
For the NZ, the apricots were on the same level of firmness around 6 KgF (**see Annex. Fig. 8**) but it was not the case of FR apricots. In fact, the C_2H_4 rate becomes interesting as criteria when the variety produces low ethylene. Hopefully, we have the reference varieties that we allowed us to compare the maturity stage (and within C_2H_4 rate, which depends on conditions). So it may use the ethylene rate as confirmation criteria but it must be correlatee

with a good quality and maturity. Therefore, the market are more interested to the low ethylene varieties. There is link between the C_2H_4 rate and firmness.
Consequently, it is difficult to implement criteria of comparison of fruit due to other effects, such as the apricot variety, farmers' practice.

2. Spectral data (Vis-NIR)

2.1. NIRS (PCA)

In our study, the same apricots were scanned (**60** and **53** apricot varieties from France and New Zealand respectively) were assessed at harvest (Cf.Annex.01) using the Blue Vis-NIR on intact fruits.
The map is performed on the average of Vis-NIR spectra of the apricot varieties and their origins (France and New Zealand). **Fig. 6** presents the factorial map according to the first two factorial axes (CP1 and CP2) and the second two factorial axes (CP1 and CP3). These maps in Figure 1(**a-b**) show three wide parts of variability. The first group is particularly distinguished by the French varieties 'FR', as apricot genotypes: **A04034 (blanc non climacteric)**, **A03325 (Iranien)** and **A03976 (blanc non climacteric).** As seen very clearly in Figure 2, these clones are phenotypically recognized by a cream ? color of skin and belong to cream? clone cream? apricots.
Therefore, a mix superposition of the both FR and NZ varieties is observed in the second group which is more condensed by NZ varieties located on the upper part. The both PCA were based on two axes (CP1 and CP2). The third group shows more NZ varieties descrimined from the FR varieties. In despite of genetic variability, we have approximatively the main variability in the both PCA of apricots varieties that were represented on both of (CP1 and CP2) = **93.7.7%** and for the (CP1 and CP3) = **64%** (not shown here).

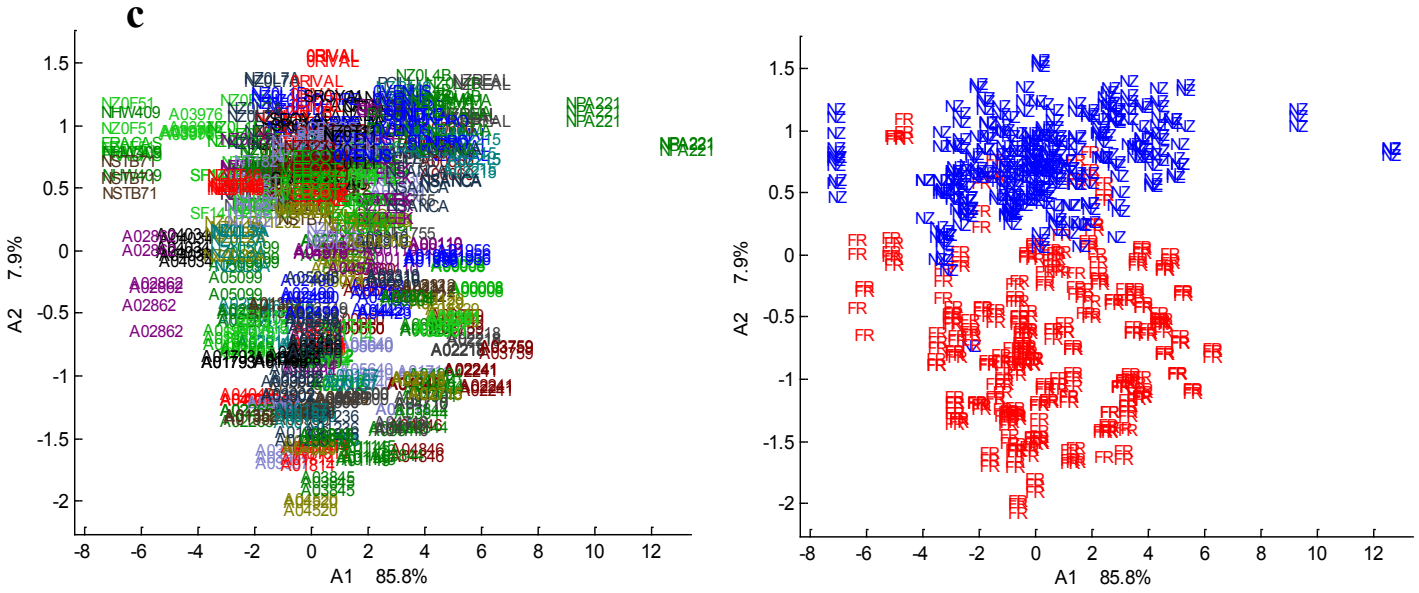

Figure 6. Dispersion of the FR and NZ apricot genotypes on the principal components 1 and 2 of a PCA analysis. Apricot Varieties are represented on the factorial plan by (a) genotypes, (b) country FR or NZ. The two PCs explained 93,7% of the total variability.

In this context, we explored the total variability of apricot varieties, we have applied many PCA analyses on apricot varieties by choosing discriminatory criteria (genetic variety, country). So we intersted to understand more the common particularity of each group among

the total variability. For that, the effect of the apricot varieties on the variability was investigated (See Table.1).

2.2. MIRS

2.2.1. FTIR (MIRS NZ system used on NZ apricots) by PLS (quantitative analysis)

The results show the potential of MIRS for the destructive prediction of SSC, Glucose, Fructose, Sucrose, TA, Citric and Malic acid of New-Zealand apricots. As we see in **Table 2**, we established also for the both variable most predicted SSC and TA a prediction model based on the calibration sample sets by Cross Validation and with Test Set Validation respectively without deleted the *outliers*.

Table 2. Results of FTMIR calibration and validation performance for quality assessment of apricot fruits (PLS models performed on spectra from the NZ set of varieties).

Quality traits	Range	Factors	Calibration (*n* = 118)		Validation (*n* = 59)		
		(LV)	R^2	RMSEC	r^2	RMSEP	RDP
SSC (%Brix)	1500–900	8	99.65	0.154	99.69	0.49	16.8
TA (meq 100 g^{-1}FW)	1500–900	8	97.17	0.077	96.88	0.077	5.95
Glucose	1500–900	6	79.01	0.217	77.03	0.2	2.18
Fructose	1500–900	5	83.74	0.153	81.04	0.14	2.48
Sucrose	1500–900	8	64.1	0.417	62.1	0.53	1.67
Malic	1500–900	8	97.18	0.087	92.47	0.113	5.95
Citric	1500–900	7	97.02	0.076	96.22	0.078	5.79

SSC: soluble solids content, TA: titratable acidity, FW: fresh weight, LV: latent variables or factors, R^2: coefficient of determination, RMSEC: root mean square error of calibration

Good prediction performance was obtained for SSC and TA with correlation coefficient of respectively 99.65 and 97.17 with low root mean square error of prediction. Also we obtained a good prediction models for organic acids because we have a high values of the correlation coefficient R^2 (correlation coefficient) that were 97.02 and 96.22 for citric acid and malic acid respectively. The errors of prediction RMSEP were relatively low and ***acceptable*** for the malic and citric acid (respectively, 7.62% and 11.13%). Therefore, the values of the root mean square error of calibration (**RMSEC**) were approximatively equivalent to the values of the root mean square error of validation (**RMSECV**) for each parameter. The values of RDP were acceptable for each parameter (RPD ≥1.5).

2.2.2. MIRS (FR system used on FR apricots) by PLS **(**quantitative analysis**)**

Calibration models, using the PLS method, were developed from spectral data measured by MIR (Tensor 27) and reference data (physical and biochemical) of FR apricots (**Table 3**). The spectral region between 2000-900 cm^{-1}, the most region to quatify sugars and organic acids, was therefore used. Good correlation of calibration were found between MIR spectra and content of glucose, Fructose, sucrose, citric, and malic acid with a determination coefficient ($\boldsymbol{R^2}$) ≥ 0.84. The values of RDP were very excellent. Therefore, the values of the root mean square error of calibration (**RMSEC**) were close to the root mean square error of validation

(**RMSECV**) for each parameter. The errors of prediction presented about 3% for SSC, 7.3% for the TA and 9% to 13.5% for the citric acid, glucose, sucrose, malic acid. The worst error is obtained for the fructose 16.3% , which is the minor sugar in the apricots.

Table 3 Performance of prediction, using MIR (Tensor27), of the quality criteria of FR set of apricots varieties.

							Calibration (*n*=560)		**Validation** (*n*=185)	
Quality traits	**Average**	**SD**	**RDP**	**Error Relative Cross Validation (%)**	**Spectral range**	**LV**	R^2	**RMSEC**	R^2	**RMSECV**
SSC	14.83	2.12	5.02	2.85	1500-900 cm^{-1}	LV5	95.8	0.42	96.4	0.42
TA	192.26	66.03	4.68	7.34	1500-900 cm^{-1}	LV7	96.9	13.13	95.9	14.12
Glucose	19.63	5.78	2.58	11.40	1500-900 cm^{-1}	LV9	94.2	2.31	84.9	2.23
Fructose	10.73	5.22	2.99	16.28	1500-900 cm^{-1}	LV10	88.5	1.73	88.9	1.74
Sucrose	61.58	14.48	1.95	12.03	1500-900 cm^{-1}	LV9	84.0	6.98	74.4	7.40
Citric Acid	9.51	5.05	5.69	9.34	1500-900 cm^{-1}	LV10	96	0.99	97	0.88
Malic Acid	13.59	6.67	3.64	13.48	1500-900 cm^{-1}	LV10	91	1.77	93	1.83

MIRS models were performed for each parameter for both set of data (FR and NZ fruit varieties). The results (see **Table 2** & **3**) were greatly showed the robustness of models of prediction performed using MIR. The good robustness was obtained for the SSC, Glucose, TA and Citric acid. Our models of prediction (high R^2 and low RMSEP results) were in agreement with earlier findings of Bureau et al., 2009. Regarding the difference of variability (concentration range; see **Figure 4**) between the set of data for FR and NZ fruits, which is the reflectin of the variability of fruit analyzed between these set (FR and NZ). The quality of prediction was very good and it confirms the precision of prediction of traits of quality of large varieties of apricots using MIRS.

IV. Conclusion

During this study, we are interested in the estimation of traits quality of apricot varieties by infrared methods (NIR and MIR). In practice, infrared spectra and biochemical and physical data obtained on two sets, one from France and New Zealand, of fifty varieties per location. It was also used a common variety for both locations to evaluate the genetic variability.

Multivariate models using the regression method (PLS) developed to predict the quality parameters of the apricot gave excellent results ($R^2 \geq 0.93$) with errors about 3% for SSC, 7.3% for the TA and 9% to 13.5% for the citric acid, glucose, sucrose, malic acid particularly in the region of the MIR. The results for sucrose are not satisfactory for either MIR tested on FR set fruits as well for NZ set fruits, possibly because of the low concentrations of this compound in the apricots.

It was found that the effect of variety (genotype) was shown to be higher than the effect of location. Additionally, it is more difficult to obtain prediction equations for the low-concentration compounds as the case of sucrose for the NZ varieties.

The biochemical characterization of the ethylene rates has therefore revealed (i) a large variability of climacteric and non-climacteric variety of apricots and (ii) in particular non-climacteric varieties which are interesting for prolonging the storage and increasing the shelf life. The genetic background of these non-climacteric varieties could be explored more for the industrial interest in France and New Zealand.

The region of the middle infrared seems more suitable for predicting the concentration of quality parameters than the near infrared. A wider wavelength range could be included for improvement of the models developed. A wavelength range of 2000-900 cm^{-1} was measured in this study. Along with the wavelengths in the MIR range, those in the visible range were also significant in the development of regression and classification models. It is suggested that spectral measurements from 4000-400 cm^{-1} may reveal more hidden information relating to fruit quality.
More research is required to understand the physical or chemical basis for measuring apricot quality. A better understanding of the internal changes associated with fruit maturation during storage and harvest and its cause could assist in decision making to improve prediction models.

Personnel balance sheet and results:

I am also grateful to my supervisors (Dr. Sylvie Bureau and Dr. Jill Stanley) for their (welcome, help and facilitation) at all levels of my study.
I am satisfied with my 1st professional experience abroad (in New Zealand) and I think that my internship was an ideal opportunity to me. During this internship, I have undoubtedly gained a significant experience on a personal level as well as professional level.

In fact, I have been involved in this research project on the quality of the apricot. Particularly, the 1st part of my internship was done in the PFR (Alexendra, Hamilton and Auckland) in New Zealand, where my work was varied between the field (moving to the orchard, fruit picking,...) and the laboratory (Assessment of fruit quality of apricot,…). Therefore, I had learned to work with the horticultural world and I learned a new skill from this field. I embraced a new technics and new contacts. I meet many researchers.
The 2nd part was thereafter done in INRA center of Avignon (in France) where I learned with Dr. Syvie Bureau how to process the data obtained using destructive (Reference data) and non-destructive methods (NIR and MIR).

I have made a proof of teamwork and communication between the two collaborators of the PHC project on quality of apricots. I met new researchers who did not spare to share their knowledge about their techniques and how they work. It is so rewarding at the professional level to have worked and participated in a joint project between 2 teams of the different world. I have learned to improve my adaptation in short time to different situations.

This work was an occasion for me will be fructified by two opportunities, the first is we will adapt my results in the aim to publish a scientific paper at the end of this year and the second, I was promoted to be recruited (CDD contract) on October 2017, as an engineer on a new project, whose mission is to process the spectral data of the apricot season of this year.

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Annex :

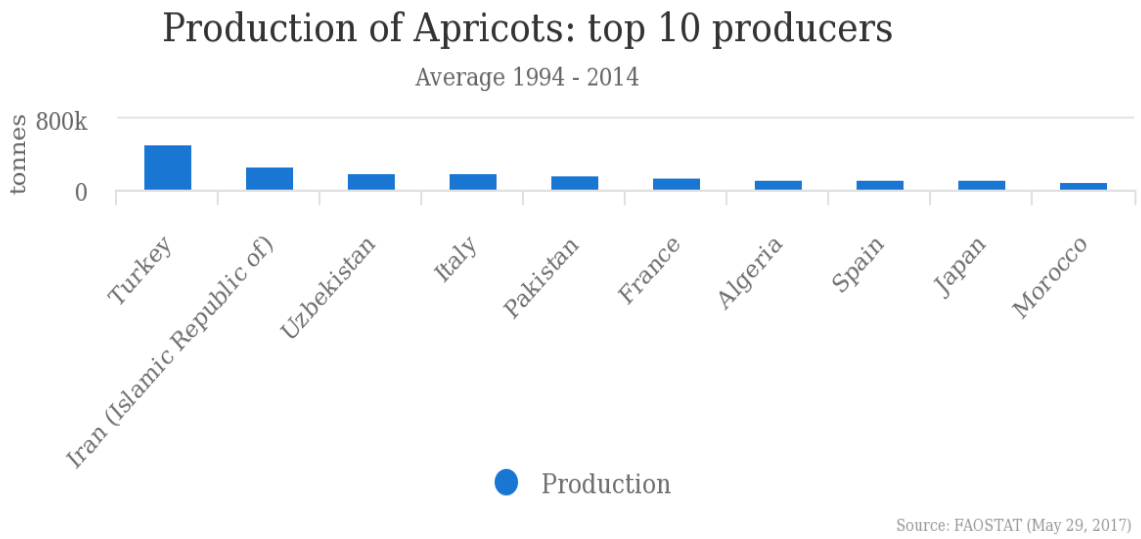


Figure 1. Production of apricots : Top 10 produces (average 1994-2014) (http://www.fao.org/faostat/en/#data/QC/visualize)

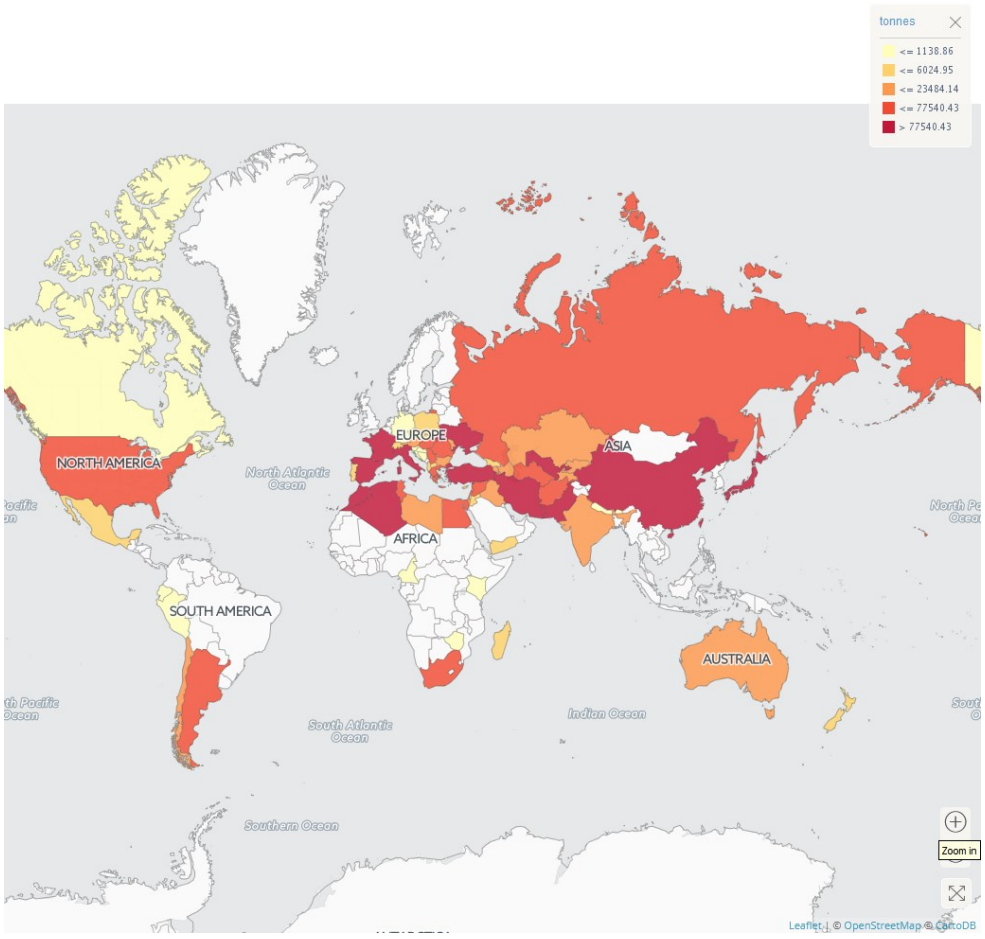


Figure 2. Production quantities of Apricots by country (Average 1994-2014) (FAOSTAT)

Table 1. Apricot varieties selected for the experiments in France and New Zealand, to determine the fruit proprieties at Harvest stage.

	Apricot varieties in New Zealand	
NUM#	**Clone variety**	**Cultivar name**
1	**0RIVAL**	Rival
2	**0VENUS**	Venus
3	**A01714**	Precose de Sernhac
4	**A02215**	Harogem
5	**BOCCUC**	Boccucia
6	**CANADA**	Canada 60011
7	**CASTEL**	Castelbright
8	**CLAIRE**	Claire
9	**CLFIRE**	Clutha Fire
10	**FRACAS**	Fracasea
11	**FRMC16**	Mac1-6
12	**MAS951**	MAS951
13	**MC0318**	Mac3/18
14	**NF1755**	F17/55
15	**NGOLDS**	Goldstrike
16	**NHW405**	HW405
17	**NHW409**	HW409
18	**NPA221**	PA2-21
19	**NSANCA**	San Castrese
20	**NT1821**	T18/21
21	**NZ0L1A**	L1A
22	**NZ0L1B**	L1B
23	**NZ0L2A**	L2A
24	**NZ0L2B**	L2B
25	**NZ0L3A**	L3A
26	**NZ0L3B**	L3B
27	**NZ0L3D**	L3D
28	**NZ0L4B**	L4B
29	**NZ0L7A**	L7A
30	**NZ0L7B**	L7B
31	**NZ0L7C**	L7C
32	**NZ0T11**	T1/1
33	**NZ0T46**	T4-6
34	**NZAMAL**	Amal
35	**NZF168**	F168 Genevieve
36	**NZGIOV**	Pelese de Giovaniela
37	**NZL3C**	L3C
38	**NZMONG**	Montgamet
39	**NZPEEK**	Peeka
40	**NZR449**	R4/49
41	**NZREAL**	Real d'Imola
42	**NZT271**	T27/1
43	**NZYAMA**	Yamagata 3
44	**PALUME**	Palumella
45	**PCILLI**	Piet Cillie
46	**RASP12**	Rasp1/2
47	**SCROSS**	Southern Cross
48	**SROYAL**	South African Royal
49	**ST1422**	StB14-22
50	**STEPNZ**	Stepnzac
51	**SUNDRO**	Sundrop
52	**VEECOT**	Veecot
53	**VIGOLD**	Viva Gold

Apricot varieties in France	
Clone variety	**Cultivar name**
A0008	Colomer
A0074	Jaubert Foulon
A0110	Kaiska
A0157	Rouge du Roussillon
A0500	Moniqui
A0660	Bergeron
A0804	Scréara
A1145	Stark Early Orange
A1236	Manicot
A1352	Polonais
A1711	Avikaline
A1714	Rouget de Sernhac
A1793	Tardif de Bordaneil type1
A1814	Hargrand
A1956	Palsteyn
A1963	Orangered
A2089	Bebeco
A2129	Rouge de Fournes
A2204	Bebeco
A2215	Harogem
A2218	Goldrich
A2241	Malice
A2243	Ivresse
A2265	Gaterie
A2310	Modesto
A2312	Flamingold
A2330	Monaco Bello
A2361	Sortilège
A2458	Royal Roussillon
A2481	Comédie
A2490	Tardif de Tain
A2712	Flavorcot
A2715	Toyuda
A2862	Iranien
A2914	Bergarouge
A3325	Iranien b
A3749	Robada
A3759	Ravilong
A3844	Ravicille
A3845	Vertige
A3902	Shamade
A3950	Bergeval
A3967	Digat
A3976	blanc non éthylène
A4034	blanc non éthylène
A4049	///
A4423	Congat
A4481	Anegat
A4520	Jengat
A4576	Koolgat
A4656	///
A4710	Select 98
A4846	Iziagat
A4994	rouge sanguin chair blanche
A5099	vertige coloré
A5248	vertige rouge
A5529	///
A5640	abricot blanc
SF06108	ST B 14/15 **SF 1415**
SF10024	G 12/92 NZ 1292

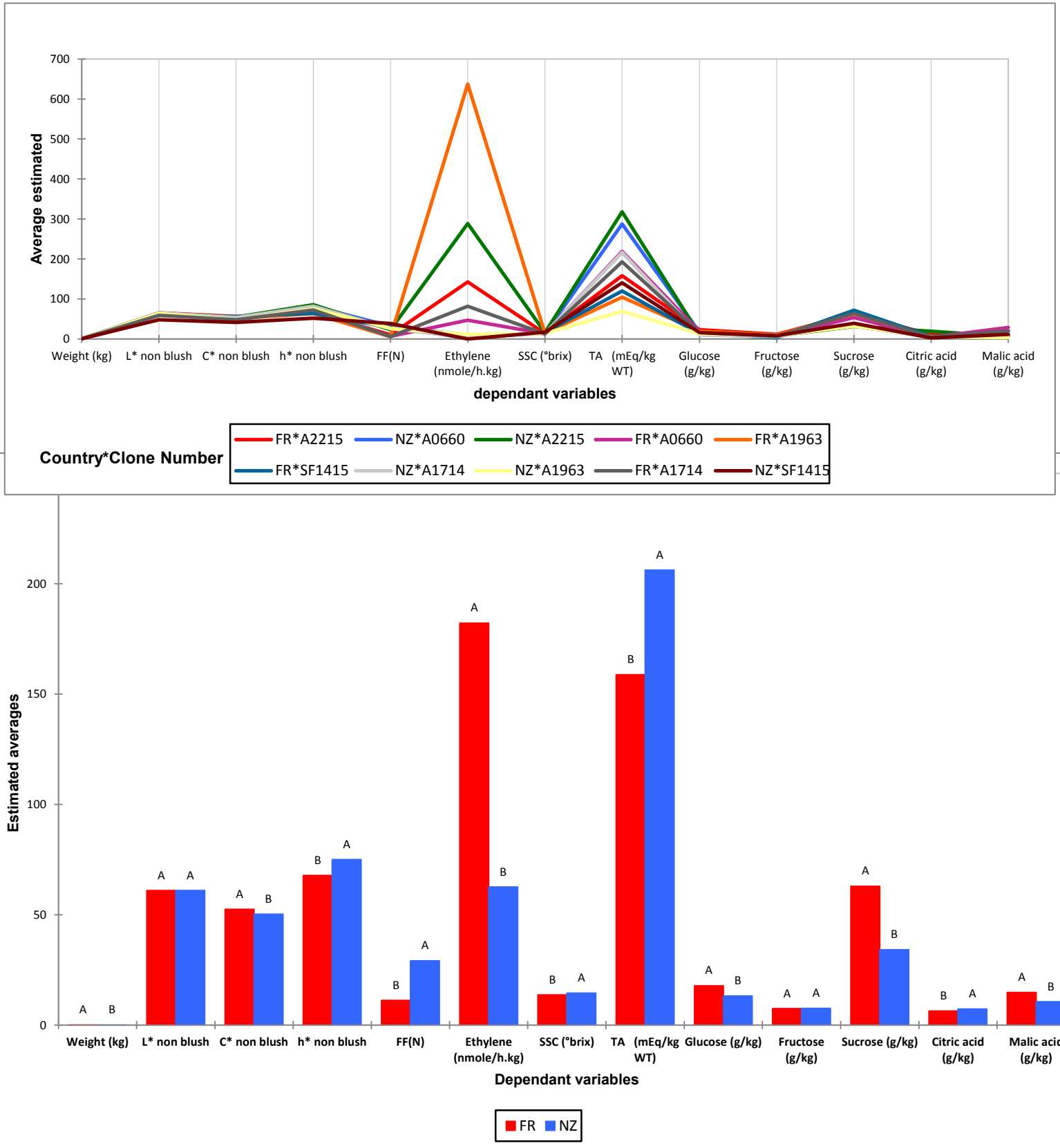
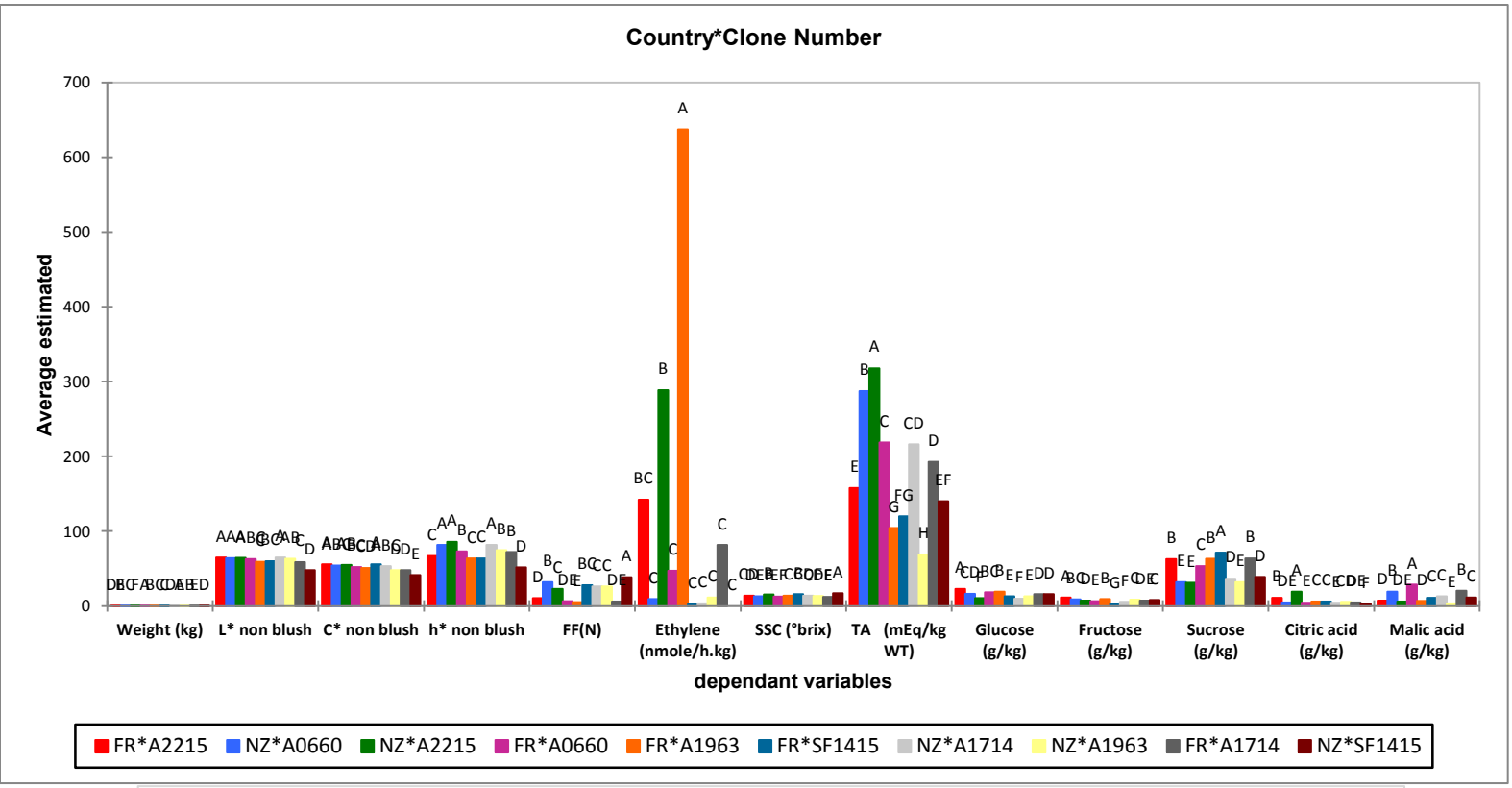


Figure 3. Profil presents the results averages of varieties communes by ANOVA analysis on data reference for both countries.



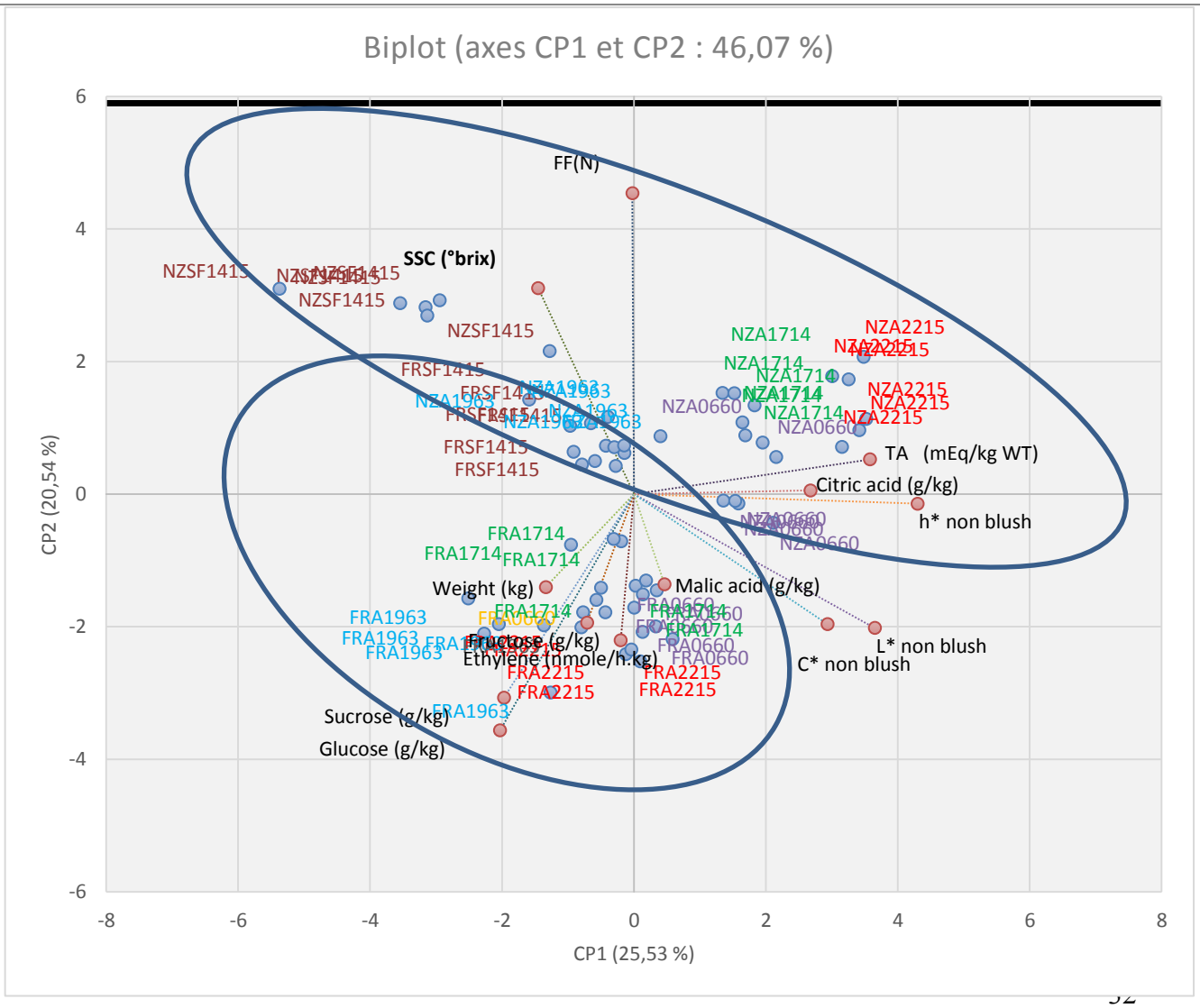
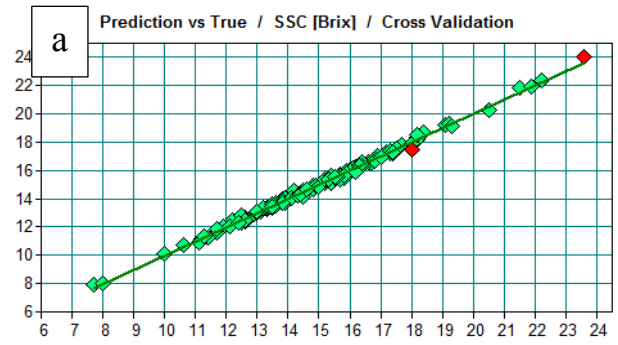
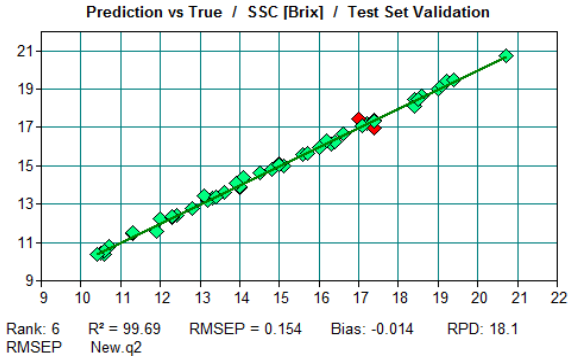


Figure 4 : PCA analysis performed on the reference varieties.

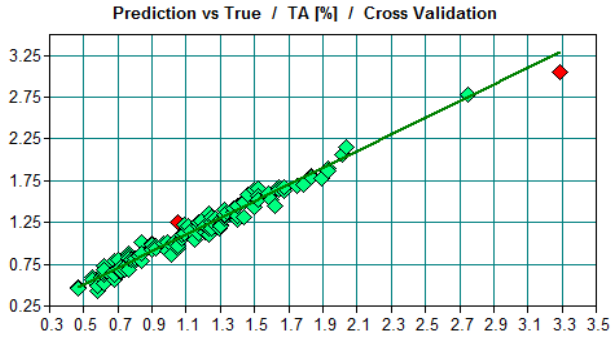
MIRS models:



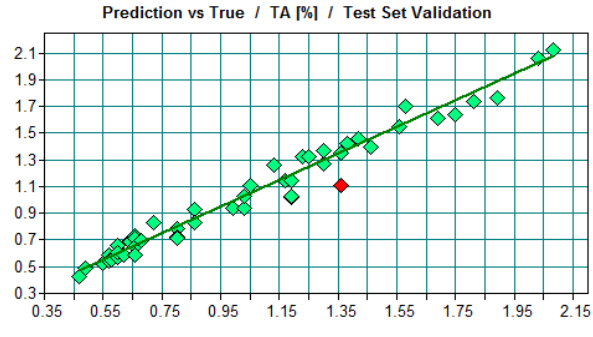
Rank: 8 R^2 = 99.65 RMSECV = 0.155 Bias: -0.00364 RPD: 16.8
RMSECV New.q2



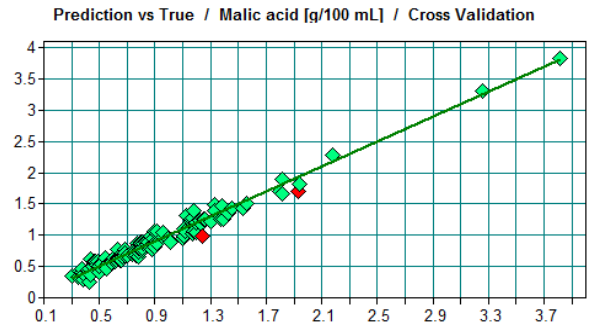
Rank: 6 R^2 = 99.69 RMSEP = 0.154 Bias: -0.014 RPD: 18.1
RMSEP New.q2



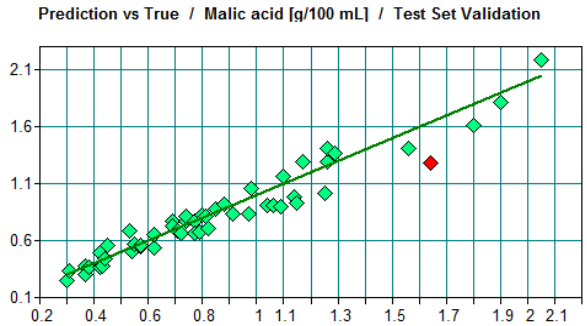
Rank: 8 R^2 = 97.17 RMSECV = 0.0775 Bias: 0.00181 RPD: 5.95
TA New.q2



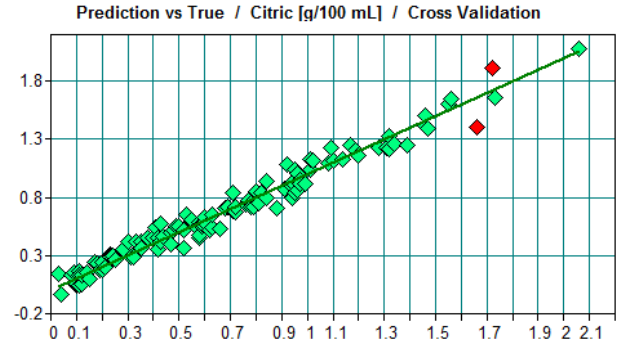
Rank: 6 R^2 = 96.88 RMSEP = 0.0776 Bias: 0.0112 RPD: 5.72
RMSEP New.q2



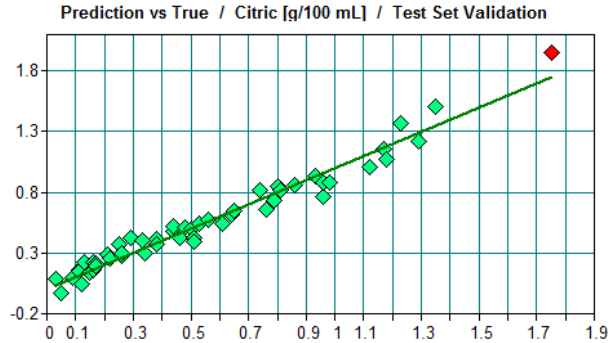
Rank: 8 R^2 = 97.18 RMSECV = 0.0873 Bias: -0.0011 RPD: 5.95
COE New.q2



Rank: 8 R^2 = 92.47 RMSEP = 0.113 Bias: 0.0341 RPD: 3.82
RMSEP New.q2



Rank: 7 R^2 = 97.02 RMSECV = 0.0762 Bias: -0.000452 RPD: 5.79
Citric-RMSECV New.q2



Rank: 8 R^2 = 96.22 RMSEP = 0.078 Bias: -0.00663 RPD: 5.16
Citric-RMSEP New.q2

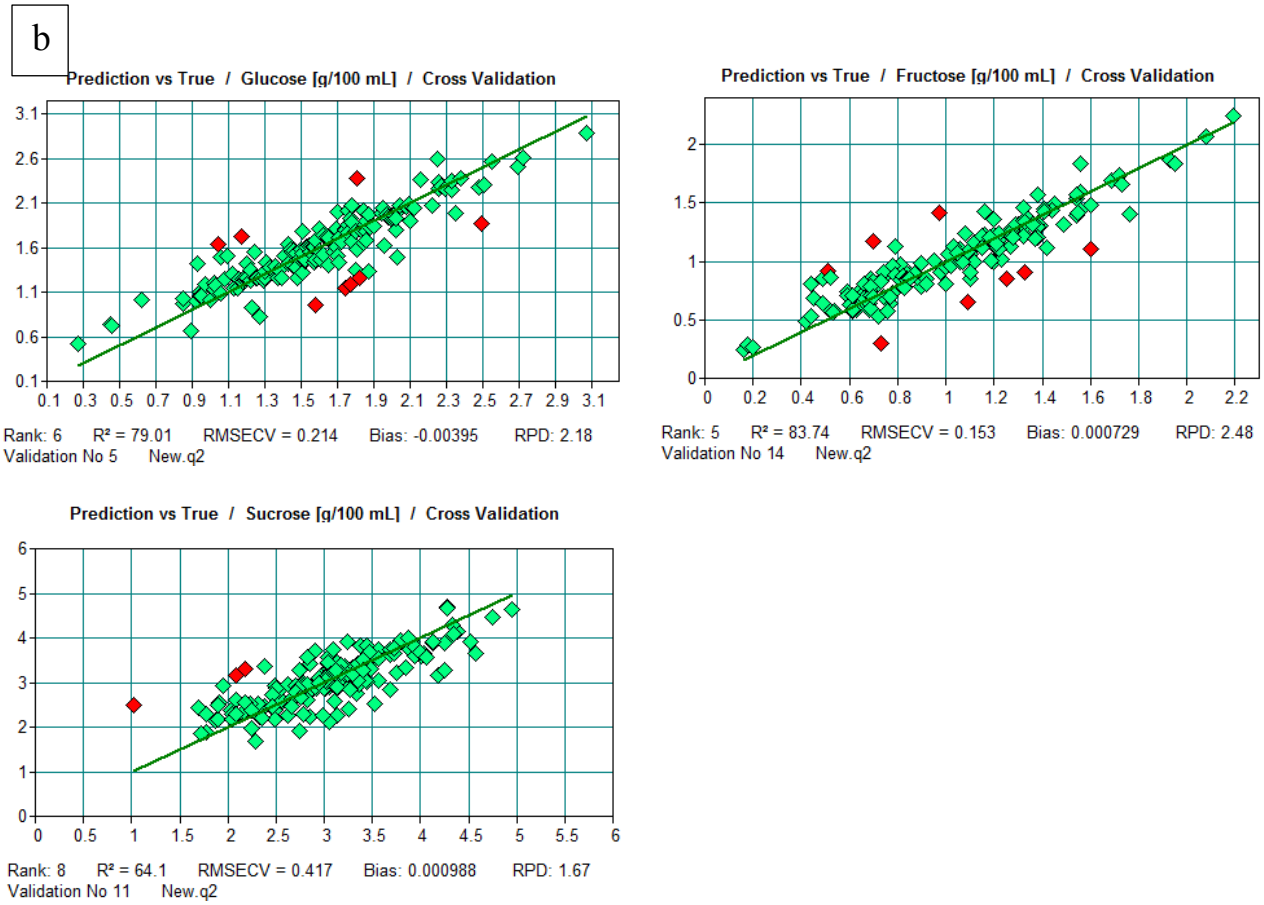


Figure 5 Graphic prediction of quanilty traits (**a)** SSC, TA and the organic (acids malic and citric acid (g/100mL juice) respectively) ; **(b)** glucose, fructose and sucrose of apricot fruits from NZ cultivars (storage and harvest). For each apricot cultivar is represented by 2 points and each point is the average of 3 single fruits which is one lot 1.

RMSEP: Root Mean Square Error of Prediction. **RMSECV:** Root Mean Square Error Cross Validation. RMSEP: root mean square error of prediction.

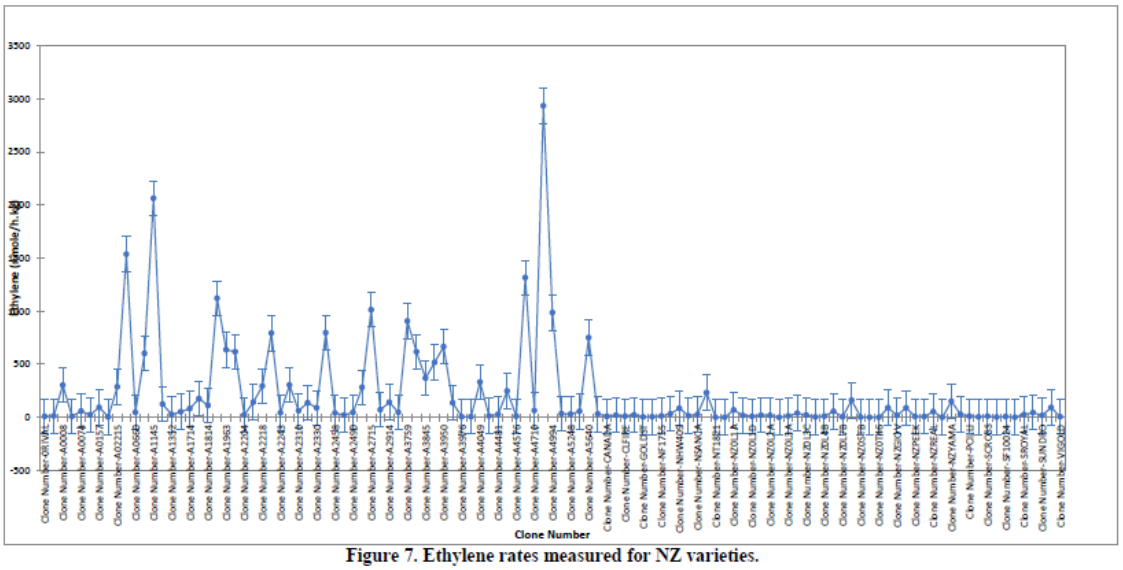


Figure 7. Ethylene rates measured for NZ varieties.

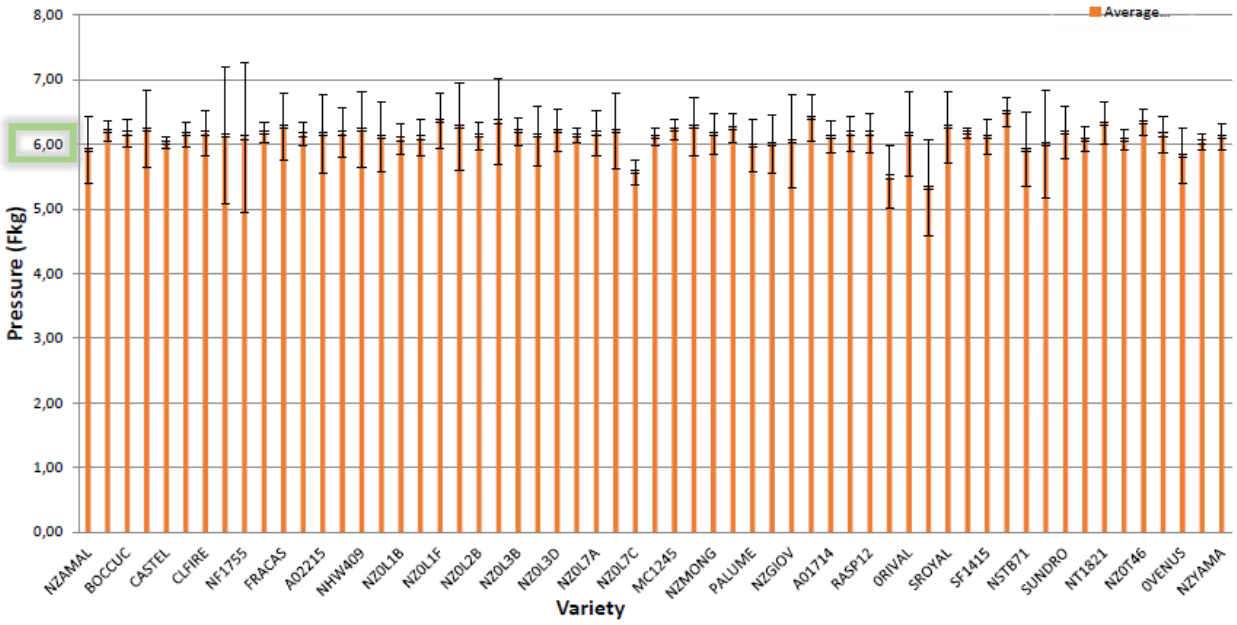


Figure 8 : Presure for NZ apricot varieties at harvest

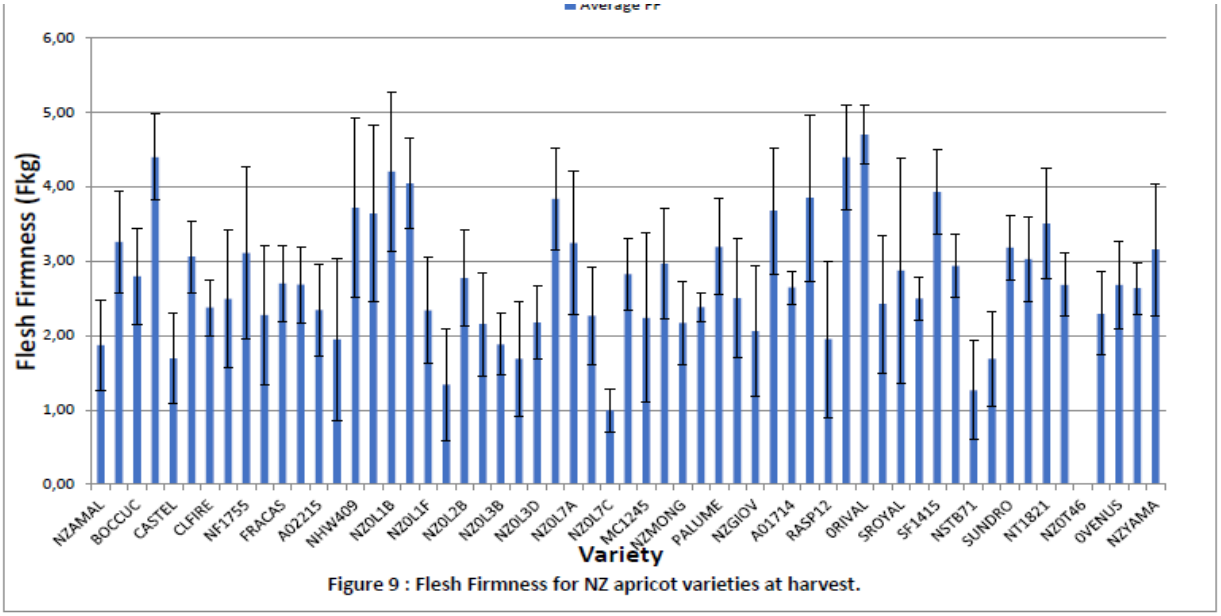


Figure 9 : Flesh Firmness for NZ apricot varieties at harvest.

Abstract

In the agriculture industry, NIR spectroscopy is a useful technique and could used to assess quality of fruit, such as SSC, TA, and sugars and organic acids content. Conventional methodologies used to determine apricot quality parameters have been fundamental to prediction of potential yields in industrial processes and also to establish commercial value of the fruit.

In contrast to this, these technics are expensive, time consuming and destructive. Therefore, the aim of this study was to assess the efficiency of mid and near infrared spectroscopy coupled to multivariate calibration to determine quality parameters and to illustrate the genetic diversity of the apricot fruit in France and New Zealand.

Multivariate models using the regression method (PLS) developed to predict the quality parameters of the apricot gave excellent results ($R^2 \geq 0.93$) with errors about 3% for SSC, 7.3% for the TA and 9% to 13.5% for the citric acid, glucose, sucrose, malic acid particularly in the region of the MIR. The results for sucrose are not satisfactory for either MIR tested on FR set fruits as well for NZ set fruits, possibly because of the low concentrations of this compound in the apricots.

Based also on the results obtained, using MID spectroscopy seemed to be the most suitable choice for quality parameters determination of the apricot fruit, since good correlations could be obtained in rapid time. Other hand, NIR spectroscopy could be used to illustrate the genetic diversity in case of marge number of apricots.

Key words:

Apricot, Fruit, Genetic diversity, Infrared Spectroscopy, Quality traits, MIR, NIR.