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Valorization of Red Beetweed "Beta Vulgaris L." From The Vakinankaratra Region in Wine in Circular Economy with Zero Waste

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Abstract:

Beet (Beta vulgaris L.) is a vegetable, but its sweet taste prompted us to explore its use in wine-making. After TXRF analysis and phytochemical screening, the richness in micronutrients and chemical families of its pulp and peel led to the use of whole beet in the winemaking process. The temperature observed in each trial is well within the temperature range for red winemaking (22.0°C- 28.8°C). the pH decreases as a function of fermentation time, due to ethanol production and the consumption of part of the malic acid by the yeasts. The pH of musts and wines is generally between 3 and 4. The sugar conversion is not total for all the trials but we can say that the fermentation is accelerating. There is still a small sugar-to-alcohol conversion scale equal to 0.2%. During the fermentation, the alcoholic strength depends on the hydrolysis type and the glucose release rate. The total acidity values in H2SO4 were found to range from 3.867 to 4.586. According to the results of the analyses, the physico-chemical characteristics of the beet wine comply with European regulations. The vinasse was recycled and underwent a composting process. The C/N ratio (15.16), P (0.95%), Ca (3.05%), Mg (2.25%), K (5.16%) and Na (0.24%) contents were determined. The vinasse compost was used to prepare a beet nursery, and then allowed the young plants from the nursery to grow normally. Beet farming in a zero-waste circular economy.

Keywords:
beet; wine; temperature; pH; alcohol; vinasse; compost

I. Introduction

The incredible aptitude of the soil to adapt to any type of plantation, the abundance of water on the territory and the adaptation of the climate to the practice of agriculture have made the Vakinankaratra region the main production basin of vegetables in the big island. Vegetables represent 83.7% of the food crop. The production of red beet, a vegetable rich in sucrose, remains limited despite its adaptation to the climatological conditions of the central highlands. The inaccessibility of means of production and the selling prices of the products do not allow producers to intensify their activities. Therefore, several actions should be undertaken to increase the value of vegetables.

Numerous studies have been carried out on the elaboration of the wine, but mainly from fruits. The production of wine from vegetables is still little exploited. A number of research projects are looking into the practice of organic farming. However, the implementation of this method requires the use of very effective natural inputs. Beet can be used to produce ethanol, wine, and subsequently vinasse which is an interesting organic fertilizer.

1.1 Materials

The use of beet in Madagascar is generally as a food seasoning and as a biological food coloring. Beet is not widely consumed like all existing vegetables. Moreover, this vegetable is very perishable, it can only be kept fresh for a few days at room temperature, hence the need to process it.

a. Taxonomy and Morphology

Kingdom: Plantae
Class: Equisetopsida
Subclass: Magnoliidae
Order: Caryophyllales
Family: Chenopodiaceae
Genus: Beta
Species: Beta vulgaris
Subspecies: Beta vulgaris subsp. vulgaris

Beet is a subspecies of plant in the family Chenopodiaceae. The systematic classification of beet is as follows.

Beet is a tuberous plant with a very large, swollen root, topped by a rosette of leaves. The general shape of the cultivated beet can be perfectly understood by studying the wild beet. It has adapted to a very particular environment and these particular adaptations can be found in cultivated plants.

Its leaves are oval, long-stalked, elongated and can reach 30 to 60cm long. The flowers are arranged in the axils of the leaves and form a spike-like inflorescence. Each flower consists of a perianth of five persistent greenish sepals and in front of which are five stamens. The pistil is finished by three stigmas, and made up of three carpels welded in a single cavity, at the bottom of which is a single ovule called: basilar placentation. The root has an elongated or round shape, rich in sugar. Its color varies according to the varieties red, yellow and white. The seed has a thin outer integument and comprises a curved embryo, surrounding a special reserve tissue (CTPS, 2020).

b. Beet as Vegetable

The vegetable beet has the particularity to store carbohydrates (sugars) during the last phases of its vegetative development. It contains 8 to 10 g of carbohydrates for 100 g of flesh, that is to say, more than most fresh vegetables (in which the rate of carbohydrates is around 2 to 4 g of carbohydrates for 100 g of flesh). (Gruska and al., 2022)

Like the sugar beet (of which it is a close relative), the red beet has the characteristic to have its carbohydrates constituted almost exclusively by sucrose. They are accompanied by small quantities of pentosans and hexosans (carbohydrates with 5 and 6 carbon atoms), as well as traces of glucose and fructose.

Because of this relative glucidic richness, the energy contribution of the red beet is rather high for a vegetable: on average 40 Kcal (167 KJ) to 100 G against 28.56 Kcal (119 KJ) for 100g of carrots. It comes mainly from carbohydrates, the other energy constituents such as proteins and lipids being present only in a small proportion (respectively 1.5 g and 0.1 g per 100g of flesh). (Tanghe, 2010)

Sugar beet is not cultivated on Malagasy soil. The existing variety in Madagascar is the red beet. The production of this variety is concentrated in regions with low temperatures. Exploring the chemical families of red beet tubers allows it to be converted into wine, which is beneficial to health if consumed in moderation (Artero, 2015; Wurz, 2019; Jackson, 2020).

II. Research Methods

2.1 Determination of Chemical Characteristics of Red Beet

a. Micronutrients

The current trend is to savor the minerality of wine (Van Casteren, 2012; Ballester et al., 2013; Le Fur and Gautier, 2013; Deneuli et al., 2014; Deneulin and Bavaud, 2016). Analytical approaches can determine the origin of wine, which could also form an important part of global efforts to fight wine fraud (Wilkes et al., 2016). By TXRF method, many minerals and trace elements have been detected in red beet during its vegetal growth. 5g of sample was placed in the test device (Robijaona Rahelivololoniaina, 2023a). The test was repeated three times for each sample, and the average of the three values given by the device is the actual value according to the protocol of the Office des Mines Nationales et des Industries Stratégiques laboratory.

b. Phytochemical Families

Wine's taste and health benefits depend on its secondary metabolites (Nemzer et al., 2022; Gutiérrez-Escobar et al., 2021; Wen et al., 2014). Phytochemical screening was conducted at the Nanisana Laboratory of Chemistry and Microbiology and the Ankatso Laboratory of Biochemistry Applied to Medical Sciences. Screening tests were carried out using dry powder samples and various extracts thereof.

1. Preparation of Extracts

Various extracts have been prepared for this phytochemical screening protocol.

- Acid extract: 1g of sample powder is macerated in 10 ml of 2N HCl. The mixture is left overnight (approx. 8 hours) at +4°C, then stirred and filtered with filter paper. The filtrate obtained is the acid extract.
- Dichloromethane extract: 1g of powder is diluted in 10 ml of dichloromethane. The mixture is left to macerate overnight at +4°C, then filtered after shaking. The filtrate thus obtained is the dichloromethane extract. Dichloromethane can generally be substituted for chloroform, since the extracts obtained perform the same functions.
- Aqueous extract: 1g of sample powder is diluted in 20ml of distilled water, allowed to decoct and macerate overnight at +4°C. The decoctate is then filtered, the filtrate thus obtained being the aqueous extract.
- Alcoholic extract: 50g of powder from each sample was macerated in 500 ml of 96° alcohol. The mixtures were left for 24 hours, then filtered with filter paper. The filtrates obtained correspond to the alcoholic extracts.

2. Alkaloid Screening

The acid extract is dispensed into 3 test tubes. The first is for the Mayer test, the second for the Wagner test and the last for the Dragendorff test.

- In tube n°1, 3 drops of Mayer's reagent are poured into 0.5ml of extract. The appearance of a white precipitate indicates the presence of alkaloids.
- In tube n°2, 3 drops of Wagner's reagent are added to 0.5ml of extract. The appearance of a white precipitate indicates the presence of alkaloids.
- In tube n°3, 3 drops of Dragendorff reagent are added to 0.5ml of extract. The appearance of a white precipitate indicates the presence of alkaloids.

3. Flavonoid and Leucoanthocyanin Screening

Alcoholic extract is dispensed into 3 test tubes. The first is for the Bate Smith test (leucoanthocyanin screening), the Wilstater test and the modified Wilstater test (flavanoid screening).

1) Bate Smith test

0.5ml of concentrated HCl is added to 3ml of extract. The solution is heated in a 100°C water bath for 30 minutes, then left to cool. The appearance of a purplish-red coloration indicates the presence of leuconthocyanins.

2) Wilstater test (T1) and modified Wilstater test (T2)

- T1: 0.5ml concentrated HCl and 3 turns of Mg are added to 3ml extract.
- T2: 0.5ml concentrated HCl, 1ml distilled water, 1ml isoamyl alcohol and 3 turns of Mg are added to 3ml extract.

The color change to red denotes the presence of flavones, purple denotes the presence of flavonols, and purplish red denotes the presence of flavanones and flavanols.

3) Screening for polyphenols and tannins

- 1% gelatin test: 5 drops of 1% gelatin are added to 0.5ml aqueous extract. The appearance of a precipitate indicates the presence of polyphenols.
- Salted gelatin test: 5 drops of salted gelatin are added to 0.5ml of aqueous extract. The appearance of a precipitate indicates the presence of tannins.
- FeCl3 in MeOH test: 5 drops of 10% FeCl3 in methanolic solution are added to 0.5ml aqueous extract. A blue-green or green-black color change identifies the presence of condensed tannins, and a bluish-black color identifies the presence of hydrolyzable tannins.

A negative reaction to salted gelatin accompanied by green or blue-black coloration with FeCl3 indicates the presence of phenolic compounds other than tannins.

4) Quinone screening

Quinone screening is called the Bornträgen test. 1ml benzene and 5 drops NH4OH 25% are poured into 0.5ml aqueous extract. After shaking, the red coloration of the alkaline phase (upper phase) indicates the presence of anthraquinones.

5) Terpenoid and steroid screening

Screening for terpenoids and steroids is known as the Liebermann-Burchard test. 3 drops of acetic anhydride and 3 drops of H2SO4 are poured into 0.5ml of dichloromethane extract. After shaking and incubation for 30 minutes, two phases appear (upper phase and lower phase). The blue-green coloration of the upper phase denotes the presence of terpenoids, while the appearance of a violet-red ring on the interphase denotes the presence of steroids. 1ml H2SO4 is added to 0.5ml dichloromethane extract. The appearance of a red or violet ring denotes the presence of unsaturated sterols. This is the Salkowski test.

6) Screening for deoxyoses

Screening for deoxyoses is called the Keller-Killiani test. 0.5ml FeCl3 10% aqueous solution and 0.5ml glacial acetic acid are added to 0.5ml aqueous extract. After stirring and adding 0.5ml H2SO4 36.76N, the appearance of a purple-red separation ring indicates the presence of deoxyoses.

A specific test called the hydrochloric acetone test identifies the presence of 6-deoxy-hexoses. 1.5ml of acetone and 10ml of concentrated HCl are poured into 10mg of powder. The solution is placed in a boiling water bath for 10 minutes. A red color indicates the presence of 6-deoxy-hexoses.

7) Saponin screening

Saponin screening is known as the foam test. Put 10g of powder in 10 liters of distilled water, shake vigorously for 30 seconds and leave for 10 minutes. Persistent foaming indicates the presence of saponins.

8) Cardiac glycoside screening

2ml chloroform and a few drops of H2SO4 sulfuric acid are added to 1ml extract. The appearance of a reddish-brown coloration indicates the presence of cardiac glycosides.

2.2 Methods of Wine Making

The beets were purchased at the Sabotsy market in Antsirabe. The leaves were removed. The process of vinification of Beta vulgaris L. was done in four stages, including pre-treatment, must treatment, wine treatment and conservation (Robijaona Rahelivololoniaina, 2023b; Maicas, 2021; Bisson and Karpel, 2010).

a. Pre-treatment

The roots have been washed to remove dirt and other contaminants. They are sorted to keep only the red ones, very fresh. Then they are rinsed with tap water and distilled water.
Then 1 kg of the root is cut into small pieces and crushed in a blender with an addition of water to remove the maximum of juice.

b. Treatment of the must

In the treatment, four steps include hydrolysis, addition of leaven, chaptalization and yeasting (Benito and al., 2015; Benito and al., 2016; Maicas & Mateo, 2020; Maicas, 2021).

1. Hydrolysis

As a vegetable, the sugar molecule contained in beet pulp cannot be split by the yeast Saccharomyces. Hydrolysis is then used to split this molecule in order to obtain glucose and fructose. Yeast will ferment glucose more actively than fructose.
Two types of hydrolysis are carried out in our experimental trials:
- Hydrolysis by heating, which consists of boiling the pulp for 15 minutes over low heat.
- Hydrolysis in the presence of citric acid: the beet juice obtained after mixing is heated in a water bath at 70°C, then citric acid of concentration Ca = 1mol/l is added while stirring the reaction mixture for 3 minutes.

2. Addition of sourdough

The main difficulty in making wine from beet is to start the fermentation. It requires wild yeasts. The problem is solved by using pre-made yeast for wine. It is the test obtained after hydrolysis by heating that requires this operation. The yeast is added after the must has cooled in the open air. We used dried grapes purchased in supermarkets.

3. Chaptalization

Chaptalization consists of adding sugar to the must to increase the alcohol content of the wine. The total sugar content of the juice is obtained by measuring the Brix degree with a refractometer.

The sugar present in the beet juice does not exceed 6.7% or the equivalent of 0.067kg/L. Chaptalization is therefore necessary in the case of beet winemaking. A calculation must be made to determine the exact mass of sugar to add to the must. This calculation is based on the potential alcohol content expected for the wine. This alcohol content is correlated with the yield of ethanol from the yeast.

Generally, it is between 0.016 and 0.017 kg/L of sugar for 1 degree (% vol) of ethanol. For the rest of the calculations we took 0.017 kg/L for 1 % of ethanol and we tried to have 12 % of alcohol.

Calculation of the amount of sugar to add:

1 % ⟶ 17 g/L of sugar

12 % ⟶ 204 g/L of sugar

If the must already contains X g/L of sugar, it remains to add:

204 x X = Y g/L of sugar to have 12% of alcohol.

The type of sugar used for this operation is commercial sugar: sucrose. However, the yeasts do not assimilate sucrose directly: they must invert it into glucose and fructose, thanks to an enzyme that they secrete (invertase). This process takes time and energy, which slows down the fermentation.

Fermentation speed can be accelerated by inverting the sugar: simply mix the sugar with water by boiling it for a few minutes and adding a small dose of citric acid, avoiding caramelization. This syrup will then be mixed with the must before fermentation.

4. Yeasting

Just after the chaptalization, the yeast is added. These will transform the sugars present in the must into alcohol and carbon dioxide.

The yeast is added in an amount of 4.2g per liter of must. It is enough to rehydrate them in 10 times their volume of must at 30° C for 15 minutes to obtain a live and very active culture active culture before introducing it into the must.

The yeast used is selected baker's yeast, essentially composed of Saccharomyces cerevisiae.

c. Fermentation

The fermentation of the must is carried out in plastic tanks of 5 liters' volume. These tanks are pierced at the top by plastic pipes, the other end of which is immersed in a water container. This pipe at the top ensures the release of CO2 without air or other substances entering the fermentation medium.

This stage of alcoholic fermentation is complex because it involves many biological, chemical and physical processes that lead to a continuous evolution of the composition and physical-chemical properties of the medium.

The ideal temperature for the vinification is between 20 and 30°C. During the vatting of the must, the place of the tanks must not be cold in order to avoid the risk of the death of the yeasts which will stop the fermentation.

The alcoholic fermentation determines the strength and quality of the final product. Therefore, precise controls on the fermentation process improve its productivity.

Fermentation monitoring in our experiments was done every 4 days by measuring temperature, pH and % Brix.

d. Wine Treatment

The end of fermentation is signaled by the end of the release of carbon dioxide. The yeasts have died by autolysis. They settle at the bottom of the fermenter and form what is

called "lees". It is now time for the various physical and chemical treatments necessary to ensure good conservation and a good presentation of the wine.
This treatment was done in four steps including sulfiting, pre-filtration, clarification and sulphurization.

1. Sulfiting

As soon as fermentation is complete, sulfite is introduced into the must as potassium metabisulfite (K2S2O5). It is sufficient to add a quantity of 0.04g/l.
The purpose of this step is to reduce the oxidation phenomena harmful to the product's quality and prevent the growth and development of bacteria responsible for the alteration of the wine.

2. Pre-filtration

This step involves passing the must through a strainer and a coffee filter. It must be pressed as well in order to separate the wine from the must.

3. Clarification

The clarification is the total separation of the clear wine from the remaining clouds after the filtration. Egg albumin is used, which constitutes positively charged proteins that neutralize the negatively charged colloidal particles. This neutralization causes the precipitation of colloidal particles and their sedimentation. The suspended particles are left to settle for two weeks before the clear wine is drawn off.

4. Sulphurization

After decanting, the racking is the transfer of the wine from one container to another. It is carried out in the absence of air to avoid oxidation. This operation aims to separate the wine from the debris of the clarification which is deposited at the bottom of the container.

e. Conservation

After sulphurization, the wine is stored in sterilized and opaque glass bottles. In order to prevent the activity of micro-organisms present in the wine at the time of treatment, the bottled wine is heated by immersing the bottle in hot water (70°C) for 5min, followed by cooling. The increase in temperature must not cause any alteration in the appearance, color, smell or taste of the wine. It is the operation of pasteurization.

Sufficient space will be provided under the cork to allow for volume expansion of the wine and precautions have been taken to avoid the explosion of the bottles due to exaggerated overpressure, then bottles are stored in cool and dark places.
The conditions of each test are in the following table.

Table 1. Experimental conditions

Experiences	**1**	**2**	**3**	**4**
Quantity of pulps (kg)	0.875	1.019	0.975	0.898
Quantity of water added (l)	2.750	4.000	4.000	4.000
Initial volume of the must (l)	3.500	5.000	4.750	4.500
Must treatment	Agitation	Heating (30min)	Heating (30min)	Acid hydrolysis
Volume of must after treatment (l)	3.500	3.250	3,000	3.000
Brix of the must after treatment (%)	4.000	5.600	5.700	6.500

Amount of leaven (g)			100.000	
Sugar content (%)			46.670	
Amount of sugar added (g)	241.500	207.000	72.930	158.000
Final volume of the must (l)	3.750	3.4	3.750	2.500
Final Brix of the must (%)	17.140	20.40	22.120	20.290
pH of the must	4.00	3.54	3.42	3.18

During the experiments, four trials were performed with different parameters

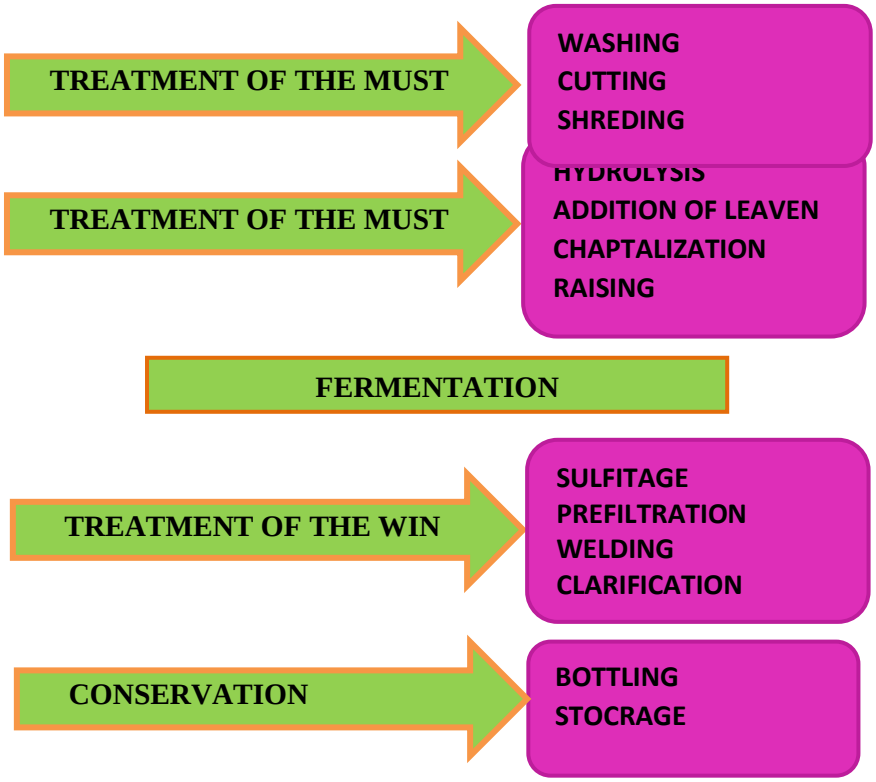

Figure 1. Flow chart of beet wine production

The different steps of the manufacturing process of this wine are given in the form of a flow chart, taking as a reference of the red winemaking.

2.3 Methods of Composting

Generally, vinasses are wine lees or fermented must residues. In the case of wine processing, 55.66% of residues remain. Recycling this waste is therefore of considerable interest. In-bin composting was chosen for its ease of control (Devesa-Rey and al., 2011; Mateo and Maicas, 2015; Maicas and Mateo, 2020).

Vinasses with a C/N ratio greater than 8 are classified under the code of good practice.

a. Composting process at the FOFIFA /CENRADERU laboratory

FOFIFA/CENRADERU (Centre National de Recherche Appliquée au Développement Rural) laboratory specializes in fertilizers and compost. The wooden composter is much simpler, sturdier and, above all, more accessible to good aeration. The oxygen supply is sustained for proper decomposition of organic matter by turning the compost once every two

days. The compost bin should be at room temperature, since the ideal temperature for the initial composting phase is between 20 and 45°C.

To ensure the proper development of micro-organisms, humidity is maintained at around 50% by watering with 1 liter of water every other day. To incorporate vinasses into compost, it is necessary to have solid material available.

Table 2. Carbonaceous and nitrogenous matter in the composter

Type of waste	Quantity	Roles and characteristics
Dry waste: dead leaves	2	Carbonaceous materials: source of energy for decomposers: heat
Wet waste: fermented beet beet wort, all waste obtained during pre-treatment	2	Nitrogenous matter: suppliers of water and food for micro-organisms.

Before being placed in the composter, all waste is shredded to facilitate aerobic decomposition. A layer of small dry branches should be placed at the bottom of the compost bin to facilitate air circulation and improve drainage. Next, nitrogenous materials are introduced, followed by carbonaceous materials.

b. Chemical analysis of dry materials

After 35 days of composting, the physical characteristics of the resulting compost must be checked.

- Weigh 100g of compost
- Dry at 70°C for 48 hours
- Cool
- Grind finely

Calculation method:

$$\text{DM (\%)} = \frac{\text{FW} - \text{DW}}{\text{FW}} \text{ x } 100$$

DM: Dry materials
FW: Weight of fresh sample
DW: Weight of dry sample

c. Determination of pH

Compost acidity is determined as follows:
- Weigh 5g of sample
- Add 25 ml distilled water
- Leave in contact for 30 min, stirring occasionally with a glass rod.
- After calibrating the pH meter, carefully introduce the electrode into the suspension and read the pH
- Do not shake the suspension during measurement

d. Determination of organic carbon

- Weigh approximately 0.1g of the 0.5mm diameter compost and note the exact weight.
- Transfer to a 250ml Erlenmeyer flask
- Add 10ml 1N potassium dichromate ($K_2CR_2O_7$) and disperse the compost in the solution
- Quickly add 20ml of concentrated H_2SO_4, swirl the Erlenmeyer and then shake vigorously for 1min
- Leave to stand for 30min
- Add 200ml distilled water

- Add 4 drops of ortho-phenantroline, and titrate the solution with ferrous sulfate FeSO4 0.5N
- At the end of the reaction, the color changes from intense green to purplish red
- Perform a blank test (without compost sample) under the same conditions.

Calculation method

$$\text{Organic carbon (C\%)} = \frac{(N \times V) - (N' \times V') \times 0.39}{WC}$$

N: Concentration of $K_2CR_2O_7$
N': Concentration of $FeSO_4$
V: Volume of $K_2CR_2O_7$
V': Volume of $FeSO_4$ poured
WC: Weight of compost
Organic material (OM%) = C % x 1,72

e. Determination of P, Ca, Mg, K, Na

Preparation of dosing solution

- Weigh 1g of ground compost into a 25 ml porcelain crucible.
- Place in a muffle furnace at 500 ± 50°C for approx. 5 hours
- Cool
- Add 2ml concentrated HCl
- Evaporate on a hot plate for one hour
- Add 5ml HNO_3 (2N) and mix well to dissolve residues
- Filter through filter paper into a 50ml flask using hot distilled water
- After cooling, add cold distilled water up to the mark
- Make a series of dilutions at 1/10, 1/100, 1/1000

Solution determination: Use the dilution series to determine P, Ca, Mg, K, Na

- Ca and Mg by atomic absorption spectrophotometer
- P by UV spectrometer
- Na and K by flame spectrophotometer

Calculation method

Xppm = lecture x dilution x 50

$$X\,\% = \frac{Xppm}{10.000} \qquad X\,‰ = \frac{Xppm}{1000}$$

Xppm: diluted solution

f. Determination of total nitrogen by the Kjeldahl method

Nitrogen analysis by the Kjeldahl method involves the following steps:

Preparation of mineral nitrogen:

- Place approximately 0.1g of ground sample in a compost digestion tube (glass mat)
- Add 10ml of concentrated H_2SO_4 + 0,4g $CuSO_4$ + 1,75g K_2SO_4 for mineralization
- Place in a digestion block at 430°C and continue digestion for 1h (nitrogen mineralization)
- Cool down
- Add water to tube contents
- Shake
- Transfer to a 50ml flask

Nitrogen distillation:

- Pipet 10ml of the prepared solution
- Add 10ml NaOH (10N) to the distillation apparatus
- Collect the distillate (NH_4 vapor) in a 125ml Erlenmeyer flask containing 20ml 2% boric acid solution
- Titrate with 0.01N sulfuric acid solution.

Calculation method

$$\%N = \frac{0.07 \times VH2SO4 \text{ poured}}{WC}$$

%N: percentage of nitrogen
WC: Weight of compost

III. Result and Discussion

3.1 Chemical Characteristics of Red Beet

a. Micronutrients

They are abundant (more than 1000 mg per 100 g) and well diversified as illustrated in the following table.

Table 3. Minerals and trace elements in beet

Minerals and trace elements	Average content for pulp	Average content for peels
Mg(%)	1,67	1,09
Al(%)	4,86	5,68
Si(%)	0,98	1,30
P(%)	0,35	0,48
S(%)	0,00	0,00
K(%)	4,34	4,19
Ca(%)	0,00	0,01
Ti(%)	0,12	0,21
V(%)	0,01	0,02
Cr(%)	0,04	0,02
Mn(%)	0,08	0,00
Fe(%)	0,47	1,05
Co(%)	0,00	0,00
Ni(%)	0,04	0,04
Cu(%)	0,02	0,02
Zn(%)	0,04	0,04
As(%)	0,01	0,01
Se(%)	0,01	0,00
Sn(%)	0,00	0,00
Sb(%)	0,00	0,00
Ag(%)	0,02	0,02
Mo(%)	0,01	0,00
Zr(%)	0,08	0,08
Rb(%)	0,05	0,07
Sr(%)	0,05	0,06
Ba(%)	0,04	0,04
W(%)	0,05	0,04
Ta(%)	0,00	0,00
Au(PPM)	0,00	0,00
Hg(PPM)	0,00	0,00
Pb(%)	0,00	0,00
Cd(%)	0,00	0,00

Both pulp and peel contain the same elements, but at different levels.
Neither pulp nor peel contains heavy metals.

b. Phytochemical screening

After the various steps and different reagents suitable for phytochemical screening, the results are summarized in the table below.

Table 4. Chemical composition of *Beta vulgaris* L.

Chemical family	**Pulp**	**Peel**
Saponoside	-	t_0 = 1cm, t_{30} = 0.5 cm, slightly positive
Leucoanthocyane	-	-
Anthocyane	+	+
Flavonoide	-	-
Anthraquinone	-	-
Deoxyose	-	-
Tannin	++	-
Other phenolic compound	-	-
Coumarin	-	+

Both pulp and peel contain anthocyanins, responsible for beet's red color.
Tannins give beet an astringent taste.
In view of the results of the micronutrient and chemical families common to pulp and peel, fermentation was carried out using whole, unpeeled beet.

3.2 Monitoring of fermentation

a. Monitoring of the temperature

The follow-ups and controls carried out were during 17 days for the 4 experimental trials.

Table 5. Monitoring of the evolution of the temperature of each test

	TEMPER			
DAYS	TRIAL 1	TRIAL 2	TRIAL 3	TRIAL 4
D_1	22.0	24.0	24.0	24.0
D_5	23.3	26.0	25.8	26.2
D_9	24.4	25.0	24.9	27.0
D_{14}	25.0	27.0	27.0	28.8
D_{17}	26.2	28.6	28.9	-

To better follow the temperature evolution after 17 days of these different experimental trials, a graphical representation is the most expressive.
For trial 1, the temperature evolves slowly. This means that heat transfer between the ambient environment and the reaction medium is very slow.

In trials 2 and 3, the temperature drops on day 9, but this does not prevent yeast activity, and the temperature continues to rise on day 14. It can be said that the reaction is proceeding well.

In Trial 4, the temperature evolution was good, i.e. there was rapid heat transfer from the yeast to the yeast. there is rapid heat transfer from the reaction medium to the surrounding environment.

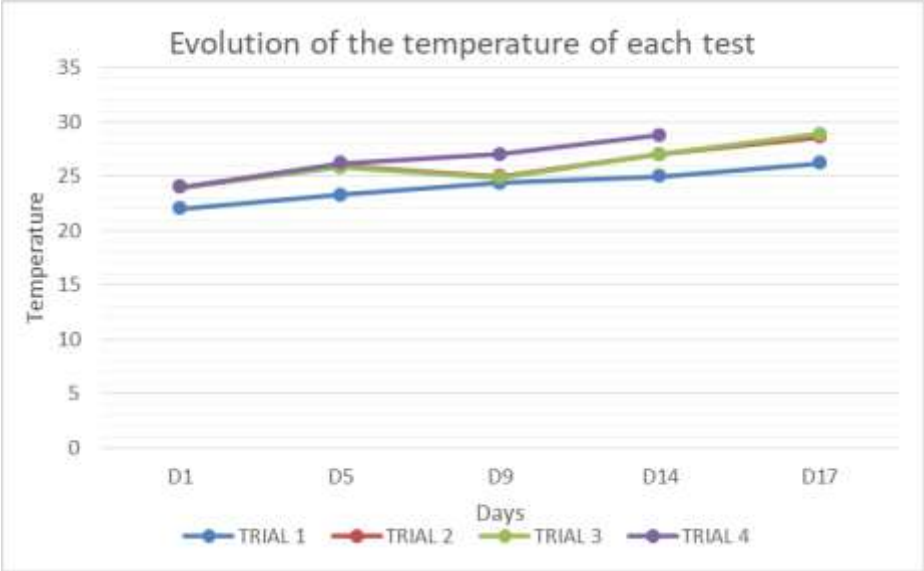

Figure 2. Evolution of the temperature of each test

From these evolution curves, the temperature observed in each trial is well within the temperature range for red winemaking (20°C-30°C).

The variation noted is between 22.0 and 28.9°C. Temperature monitoring is a very important parameter during alcoholic fermentation. This exothermic reaction releases a great deal of heat and occurs under certain conditions. If the temperature is too cold (10°C), the process slows down or even becomes incomplete, as yeast development becomes very difficult. If the temperature is too hot (over 40°C), yeast dies, as the environment becomes unsuitable for its survival. The key to successful alcoholic fermentation is therefore to maintain the right temperature throughout the process.

b. pH evolution

The pH monitoring of each trial is reported in the following table.

Table 6. Evolution of pH in each test

	pH of the must			
DAYS	TRIAL 1	TRIAL 2	TRIAL 3	TRIAL 4
D_1	4.12	3.54	3.42	3.18
D_5	3.58	3.52	3.41	3.16
D_9	3.55	3.46	3.39	3.16
D_{14}	3.54	3.44	3.38	3.15
D_{17}	3.51	3.43	3.36	-

From these results, the pH decreases as a function of fermentation time, due to ethanol production and the consumption of part of the malic acid by the yeasts.

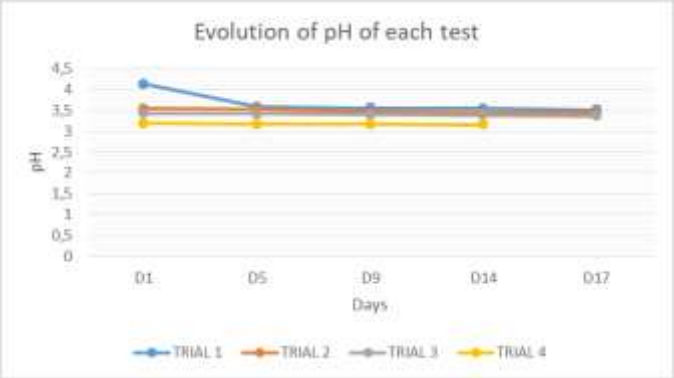

Figure 3. Evolution of the pH of each test

For all tests, the value at each measurement is between 3 and 4 except for test 1, which has a pH equal to 4.12 at the first measurement, but it gradually decreases after day 5. Acidity in trial 3 is almost stable until day 14, while acidity in trial 2 decreases until day 14. In Trial 4, acidity decreased until day 5, and became becomes almost stable from day 9.

In oenology, hydrogen potential is one of the variables used to characterize the properties of the reaction medium. The pH of musts and wines is generally between 3 and 4. Its influence on a number of aspects is well known:

- Contamination of musts and wines by undesirable microorganisms (bacteria, Brettanomyces yeasts) is facilitated by high pH values (above pH = 4).
- The effectiveness of sulfiting in preventing contamination also depends on the pH level. The lower the pH, the more effective the action of added sulfur dioxide
- Wine acidity is one of its basic characteristics, both analytically and sensorially. It conditions malolactic fermentation (MLF), wine conservation, the antiseptic power of sulfur dioxide, and wine clarification.

c. Sugar Content Evolution

The sugar content is monitored with a refractometer and is represented in the following table.

Table 7. Measurement results for sugar content (in % Brix)

	TESTS			
DAYS	TRIAL 1	TRIAL 2	TRIAL 3	TRIAL 4
D_1	17.2	20.4	22.2	20.3
D_5	12.0	15.3	16.1	15.0
D_9	5.1	8.5	8.7	8.9
D_{14}	4.5	5.3	5.5	4.4
D_{17}	4.5	5.1	5.5	-

The conversion is not total for all the trials but we can say that the fermentation is accelerating.

The following figure shows the curves representing these results

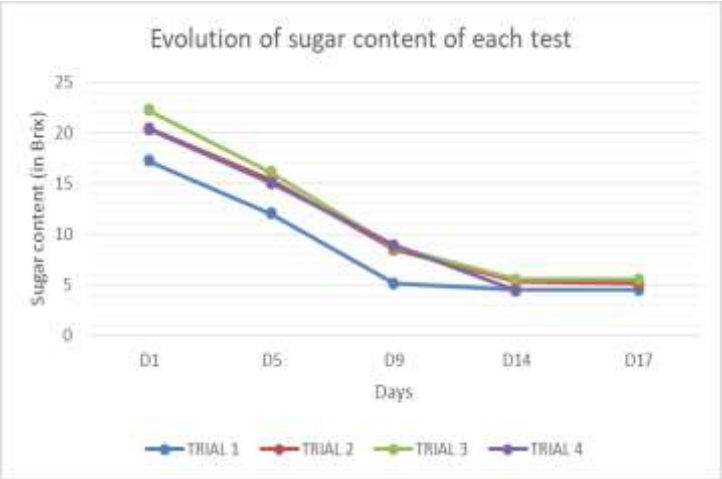

Figure 4. Evolution of the sugar content of each test

The results shown in the table and figure above show that for trials 1, 3 and 4, the Brix scale variation ends on day 14. Whereas for trial 2, there is still a small sugar-to-alcohol conversion scale equal to 0,2 %.

Conversion is not complete in all trials, but that fermentation is accelerating. With the refractometer, you can also measure the density of the must in Brix scale. However, measuring the density of a fermented must is less practical, as the presence of alcohol modifies the refractive index and needs to be corrected. In this case, this scale is used to measure the sugar conversion rate into alcohol.

3.3 Physico-Chemical Analysis of the Wine

a. Density and alcoholic degree of wine

The alcohol content of each wine is obtained after determining its density at 20°C. The result is then referred to the table of correspondence of the density with the alcoholic strength.

The density is calculated as follows:

$$d = \frac{Mwi - Mp}{Mwa - Mp}$$

Where:

d: density of the wine
Mwi: mass of wine
Mwa: mass of distilled water
Mp: mass of the vacuum pycnometer

The following table summarizes the results after the calculation.

Table 8. Results of the alcoholic degree of the 4 experimental trials

TRIALS	Density at 20°C	Alcohol content (%vol)
TRIAL 1	0.99458	3.8
TRIAL 2	0.98655	10.0
TRIAL 3	0.98362	12.4
TRIAL 4	0.98359	12.0

The results show that alcoholic strength depends on the type of hydrolysis used and the rate of glucose release.

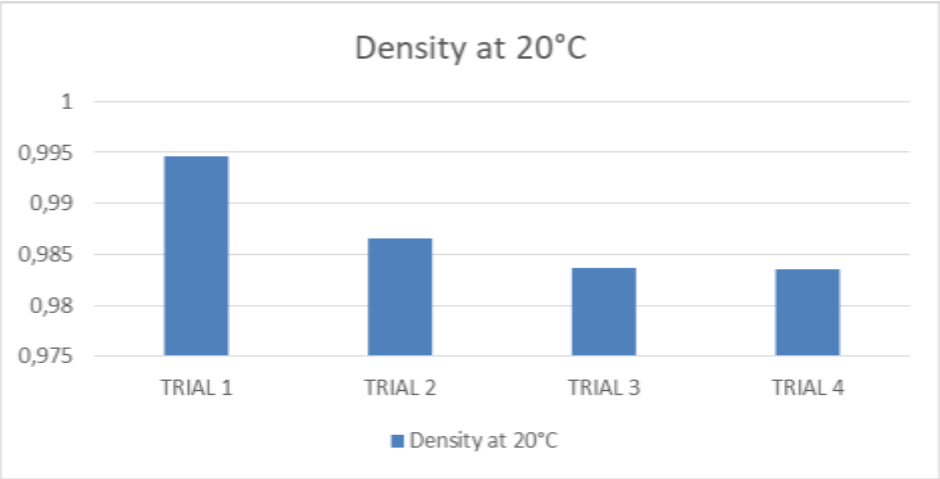

Figure 5. Density of each sample at 20°C

Trial 1 has the highest density, which decreases as hydrolysis progresses.

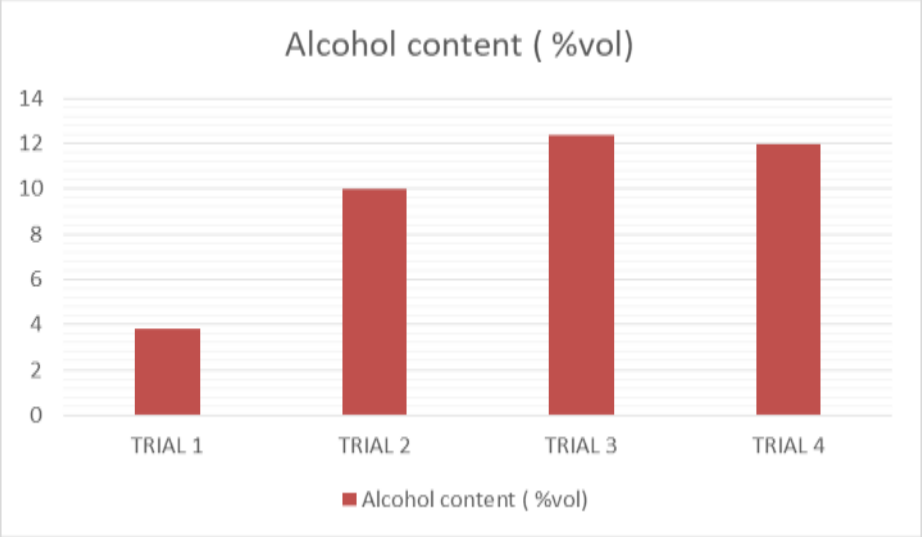

Figure 6. Alcohol content of individual samples

The alcohol content achieved in Trial 1 is very low. This can be explained by the lack of glucose in the must, and only the sugar added during chaptalization, which turns into alcohol. The wine from trial 2 failed to reach the desired alcohol content. Trial 3, on the other hand, which underwent successive addition of raisins and acid hydrolysis, achieved the desired degree.

A comparison of these two figures clearly shows that alcoholic strength varies inversely with density, depending on the evolution of hydrolysis.

b. Total acidity of the wine

These two parameters (sugar content and pH) are determined by direct reading on a refractometer and pH meter. The %Brix indicates the level of residual sugar (sugar not transformed into alcohol) in the wine, and the pH indicates the actual acidity, which affects the wine's stability.

Table 9. Direct reading results for %Brix and pH

TRIALS	% BRIX	pH
TRIAL 1	4,0	3,53
TRIAL 2	5,0	3,44
TRIAL 3	4,5	3,40
TRIAL 4	5,0	3,18

The total acidity represents the totality of all the acids of the wine and which translates especially to its gustatory characteristics. The quantity in g of H_2SO_4 per liter of wine is obtained according to the following calculation.

Total acidity = V x 0.98

V: volume of the soda solution (0,1 N) poured until the color change to violet is obtained during the titration of 10 ml of wine.

The results after calculation are shown in the next table.

Table 10. Results of calculation of the total acidity in H_2SO_4

TRIAL	Total acidity in H_2SO_4 (g/l of wine)
TRIAL 1	4.586
TRIAL 2	4.481
TRIAL 3	4.338
TRIAL 4	3.867

The values were found to range from 3.867 to 4.586.
According to the results of the analyses carried out, the physico-chemical characteristics of the beet wine comply with European regulations.

3.4 Results of in-vessel composting

a. Compost analysis

1. Compost physical characteristics

After 35 days of composting, the physical characteristics of the resulting compost are summarized in the table below.

Table 11. Compost physical characteristics

Quantity	1,51kg
Color	Black
Odor	None
Texture	Dry mud

2. Compost chamical characteristics

The chemical characteristics of beet vinasse compost compared with a commercial compost and a reference synthetic compost are shown in the table below.

Table 12. Chemical characteristics of beet vinasse compost

Elements	Compost from	Commercial compost	Reference synthesis
DR (%)	58,40	62,00	50-60
pH	7,19	6,51	7-8
C (%)	21,53	37,98	20-22

MO (%)	37,03	65,33	23-63
N (%)	1,42	1,51	1,5-3,0
C/N	15,16	25,15	10-20
P (%)	0,9539	0,3697	-
K (%)	5,16	1,36	-
Ca (%)	3,05	0,245	-
Mg (%)	2,25	0,55	-
Na (%)	0,235	-	-

DM: dry material

According to this table, all the nutrients essential for plant development (N, P, K, Ca, Mg, Na) are found in vinasse compost.

Primary elements (N, P, K) form the foundation of young plants and contribute to their growth, quality and general health. Secondary elements (Ca, Mg, Na) ensure plant nutrition. From the comparison of chemical compositions and reference results extracted from the "Reference synthesis: quality, maturity and agronomic efficiency of green waste composts", we can conclude that beet vinasse compost is exactly right.

However, as the organic matter content is quite low compared with commercial compost B, we obtained a satisfactory result:

- The high dry matter content (58.4%) is between 50 and 60% in the reference synthesis. This also means that vinasse compost is more concentrated. It is therefore rich in fertilizing elements
- The pH of 7.19 indicates that the product's acidity is fairly stable
- The C/N ratio of 15.16 is well within the norm of 10-20
- The phosphorus content of 0.9539% is much higher than that found in the other two commercial composts
- Potassium, at 5.16%, is very interesting
- Calcium, magnesium and sodium all have significant levels.

b. Zero waste circular economy application

Beet seeds are sown in three different vats. The amount of compost mixed with the soil before sowing the seeds in each tank is shown in table 13:

Table 13. Quantity of vinasse compost added in each nursery test

N °Tank	Tank 1	Tank 2	Tank 3
Quantity of vinasse compost (g)	0	100	200
Watering	1 time/day		

Figure 7. Tank 1

Figure 8. Tank 2

Figure 9. Tank 3

The two-week-old seedlings in tank 2 are the best and planted in four pots.
The amount of compost added to the soil before planting each test is shown in table 14.

Table 14. Quantity of compost type used in each test

N° pots	P1	P2	P3	P4
Type of compost	Vinasse	-	Vinasse	Commercial
Quantity of compost	50	0	100	100
Watering	1 time/day			

La comparaison des tests sur la plantation des jeunes plantes de betterave est présentée dans le tableau 15.

Table 15. Comparison table of tests on the planting of young beet plants

N° test	P1	P2	P3	P4
Planting time	15 days			
Growth	Medium	Very slow	Normal	Slow
Leaf condition	Green leaf	Green leaf	Dark green leaf	Green leaf

The successful use of vinasse compost can be seen in the difference in growth and leaf color of the cultivated plants. Plant P3 is the only one with good characteristics compared with plants P1, P2 and P4.

Figure 10. Plant P1

Figure 11. Plant P2

Figure 12. Plant P3

Figure 13. Plant P4

All these tests on the application of compost from beet vinasse lead us to the conclusion that it has a positive effect on growth speed and grain sprouting. It also contributes to the health and development of young plants.

IV. Conclusion

This study investigates the potential of utilizing beet (Beta vulgaris L.), traditionally known as a vegetable, in winemaking due to its distinctive sweet taste. Through thorough analysis employing Total X-ray Fluorescence (TXRF) and phytochemical screening, the examination of micronutrient and chemical compositions of both pulp and peel substantiates the integration of whole beet into the winemaking process.

The fermentation trials exhibit temperatures within the optimal range for red winemaking (22.0°C-28.8°C). Concurrently, the pH declines over fermentation time, attributed to ethanol production and yeast-mediated malic acid consumption, with musts and wines generally maintaining a pH between 3 and 4.

The activity of saccharomyces yeast, which converts sugar into alcohol, is effective for each test. While not achieving complete sugar-to-alcohol conversion in all trials, fermentation efficiency is notably accelerated, with a residual sugar-to-alcohol conversion scale of 0.2%. Alcoholic strength during fermentation is contingent on hydrolysis type and glucose release rate.

Total acidity values, measured in H2SO4, range from 3.867 to 4.586. Physico-chemical analyses affirm that the beet wine aligns with European regulations. According to the AFNOR standard, the wine obtained is considered sweet.

The recycling of vinasse, followed by composting, is employed in a sustainable approach. The resulting compost, characterized by a C/N ratio of 15.16, along with notable contents of P (0.95%), Ca (3.05%), Mg (2.25%), K (5.16%), and Na (0.24%), is utilized for beet nursery preparation. Subsequently, the compost supports the cultivation of young beet plants, exemplifying an innovative practice within a zero-waste circular economy framework.

This study underscores the feasibility of beet-based winemaking while demonstrating the potential for sustainable agricultural practices in a circular economy paradigm.

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