BloEx - Journal
Britain International of
EXACT Sciences Journal
Publish: | January - May - September |
E-ISSN: 2686-1208
P-ISSN: 2686-1216
http://biarjournal.com/index.php/bioex

Unveiling the Bio-Inspired and Green Chemistry Potential of Ceylon and Cape Gooseberries through Comprehensive Nutritional Profiling

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Abstract:

This study meticulously investigates the chemical and nutritional profiles of two underexplored tropical fruit species indigenous to Madagascar: the Ceylon Gooseberry (Dovyalis hebecarpa) and the Cape Gooseberry (Physalis peruviana). Characterizing such native species is vital for diversifying food sources and enhancing nutritional security, particularly in biodiversity-rich regions.Systematic analyses performed across various plant compartments, notably their foliage, revealed a significant richness in essential micronutrients. Leaves of both species demonstrated substantial concentrations of potassium, phosphorus, iron, magnesium, and aluminum. Furthermore, Physalis peruviana leaves exhibited a particularly significant protein content, elevating their prospective utility beyond fruit consumption. This robust nutritional profile reinforces their potential as valuable, locally sourced ingredients to foster balanced diets in the region. Parallel to the nutritional assessment, empirical processing trials were initiated to ascertain the technological feasibility and quality attributes of derived products, focusing on wine. The fermentation processes consistently yielded wines categorized as dessert wines, which demonstrated stable physicochemical characteristics and promising shelf-life properties. This intrinsic stability, coupled with their unique profiles, suggests compelling added value within agro-food valorization strategies. Collectively, these findings underscore the considerable potential of both Dovyalis hebecarpa and Physalis peruviana for the innovative development of novel food products. Such initiatives not only contribute to agricultural diversification but also align seamlessly with circular economy principles by utilizing underexploited plant parts, and sustainable development by fostering local biodiversity and resource efficiency. This research provides a scientific basis for promoting the cultivation and processing of these indigenous fruits, contributing to economic growth and environmental stewardship.

Keywords:
Ceylon gooseberry, Cape gooseberry, micronutrients, fruity wine, circular economy

I. Introduction

In tropical regions globally, fruits play a pivotal role in ensuring food security and diversifying nutritional intake, offering a spectrum of essential compounds (FAO, 2003). Madagascar, a nation celebrated for its unparalleled biodiversity and favorable tropical climate (Rakotoarisoa et al., 2018), exemplifies a paradox where this abundance coexists with

DOI: *https://doi.org/10.33258/bioex.v7i3.1362*

challenges in access and utilization. Despite the rich diversity of seasonal fruits across its distinct summer and winter periods (Ramanandraibe, 2020), low living standards often restrict the consumption of premium varieties for many Malagasy households. While rural communities benefit from cultivating their own produce (Andriamihaja & Rasoloarison, 2019), broader access remains constrained. This seasonal fruit abundance frequently leads to overproduction during harvest peaks, resulting in significant post-harvest losses and devaluation of these valuable agricultural commodities (FAO, 2004; Razafimahatratra et al., 2017). Consequently, innovative strategies, particularly valorization through processing, are crucial to mitigate these challenges (Fellows, 2017).

Addressing this issue necessitates a scientific approach to identify and optimize the utilization of local resources. Among numerous underutilized species, the Ceylon Gooseberry (*Dovyalis hebecarpa*) and the Cape Gooseberry (*Physalis peruviana*) stand out as promising tropical fruits. Originating from tropical climates, they are often perceived as 'exotic' in importing countries; however, it is important to note that this term lacks precise biological meaning and does not denote a specific habitat origin (Morton, 1987; Janick & Paull, 2008). Despite their potential, comprehensive nutritional and chemical profiles of these species, particularly concerning their various plant parts, remain insufficiently documented within the local context. Moreover, their applicability in developing value-added products that could mitigate post-harvest losses and generate sustainable income warrants thorough investigation.

Therefore, the primary objective of this work is to meticulously analyze the nutritional values and chemical elements present in *Dovyalis hebecarpa* and *Physalis peruviana*, specifically focusing on both their fruits and leaves, to establish a robust scientific foundation for their broader recognition as dietary resources. Concurrently, this study aims to evaluate their technological feasibility and quality attributes for valorization into wine. By providing comprehensive data on their composition and assessing their transformation potential, this research endeavors to contribute significantly to local agro-food valorization strategies, aligning with principles of circular economy and fostering sustainable development and enhanced food security in Madagascar.

II. Research Method

2.1 Materials

Dovyalis hebecarpa, commonly known as the Ceylon Gooseberry, originates from Sri Lanka and Southern India (Morton, 1987). This fruiting shrub has been widely introduced and cultivated across numerous tropical and subtropical regions globally for its edible produce. In Réunion Island, where it is also cultivated (CIRAD, 2001), it bears the vernacular name "Groseille de Ceylan" due to its fruit's distinctly acidic, gooseberry-like flavor. Its pronounced acidity typically precludes fresh consumption; consequently, the fruit is predominantly processed into products such as jams, beverage flavorings, or preserves. Beyond its native range, *D. hebecarpa* has established a broad global distribution, thriving in diverse geographical areas including parts of Africa, Asia, Australia, Brazil, Central America, China, Cuba, Hawaii, Honduras, India, Indonesia, Israel, North America, the Pacific Islands, and the Philippines. (Lim, 2012 ; PROTA, 2008).

a. Description of Ceylon Gooseberry

Dovyalis hebecarpa, commonly known as the Ceylon Gooseberry, is a thorny small tree typically reaching approximately 6 meters in height, notable for the presence of fine hairs covering its branches (Morton, 1987; Ragone, 2001). Its slender, pendant branches bear alternate, elliptical to oval leaves, while inconspicuous yellowish-green flowers give rise to

numerous small, spherical fruits. These fruits possess a thin, velvety, and bitter skin that transitions from an orange hue to a dark reddish-purple upon ripening (Orwa et al., 2009). Internally, the pulp is characterized by a deep reddish-purple coloration, a juicy texture, and a pronounced acidity. Each fruit typically contains between 9 and 12 seeds, each approximately half a centimeter in length (CIRAD, 2021). Despite its acidity, this fruit is highly valued in various regions. In the Philippines, it is consumed fresh or as juice, notably for its high vitamin C content, which can reach up to 100 mg per 100 g of pulp. Furthermore, processed products such as red jellies derived from *D. hebecarpa* are actively exported from Israel (Ragone, 2001), underscoring its potential for commercial valorization.

Photo 1: Ceylon Gooseberry fruit (*Dovyalis hebecarpa*), *(Armenteros, s.d.)*

Photo.2: Leaves and unripe Cape fruit Gooseberry (*Physalis peruviana*); Smith, J. (2020)

b. Description of Cape Goosebery

Physalis peruviana, an herbaceous plant belonging to the Solanaceae family, typically reaches a height of approximately 1.5 meters (Puente et *al.*, 2011; Ramadan, 2011). This plant is characterized by its angular, slightly pubescent stems, alternate leaves, solitary bell-shaped flowers, and a robust taproot system. It produces a small, golden-yellow fruit, often considered exotic, which is uniquely encased within a dry, papery, inedible calyx resembling a lantern (Morton, 1987). Beyond its distinctive appearance, the fruit itself is recognized for its rich composition of antioxidants and essential vitamins (Yen et *al.*, 2001; Ramadan, 2011)..

Photo.3 : Cape Gooseberry Leaf and Fruit Dupont, J. (2020) Photo.4 : Cape gooseberry flower

2.2 Méthods

a. Wine production

Must preparation involved measuring the Brix degree of the must (pulped fruit mixed with three times its volume of distilled water) using a refractometer (Amerine & Ough, 1980; Jackson, 2008). Sugar was subsequently added to each must to achieve a consistent 22°Brix, an optimal concentration for fermentation (Joshi et al., 2011). All prepared musts were then processed uniformly to ensure comparability of the final fermented products. Following this, the juices were brought to 40°C, after which 5g/L of *Saccharomyces cerevisiae* yeast was added before transfer to the fermentation tanks. Fermentation proceeded with the aid of a bubbler (plastic bottle) (Fleet, 2003; Pretorius, 2000), typically lasting between 10 and 13 days. The fermentation process was ultimately arrested by the addition of potassium metabisulfite (3g/23L) to the filtrate (Ribéreau-Gayon et al., 2006). The overall transformation of the fruit into wine comprised nine essential stages, commencing from fruit preparation and concluding with the final obtention of the gooseberry wine.

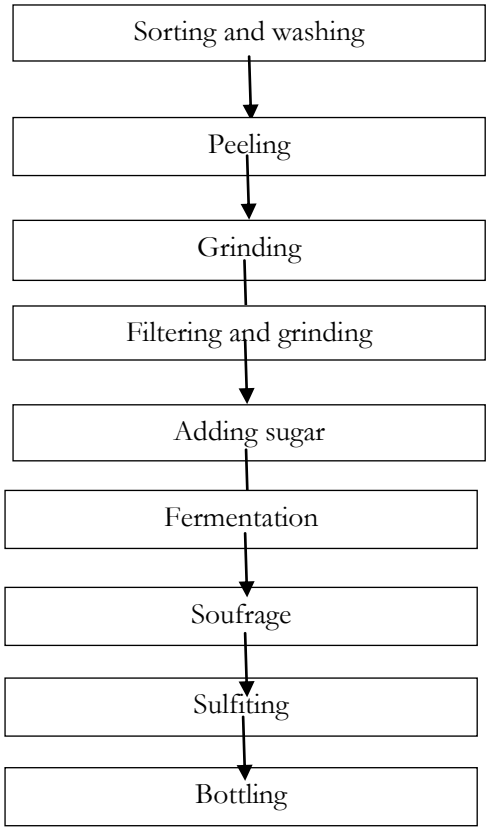


Figure 1: Fruit wine production process

The winemaking process commenced with meticulous **sorting and washing** of the raw fruit. This critical initial step involved the removal of any compromised fruits exhibiting signs of spoilage, as their presence can impart undesirable off-flavors and significantly compromise the organoleptic quality of the final juice or wine (Araven, 2019; FAO, 2004). Subsequently, fruits were thoroughly washed to eliminate any dust or soil contaminants, particularly those collected from the ground.

Following washing, the fruits underwent **peeling and pitting**. Given that only the pulp is suitable for consumption and processing, it was essential to meticulously separate it from the inedible outer layers and seeds. This stage proved labor-intensive, as both Cape and

Ceylon Gooseberries are relatively complex fruits, presenting challenges in cleanly separating the edible pulp from the outer skin and inner seeds (FAO, 2004).

For efficient processing, the pulps were subjected to **milling**. A wet milling approach was employed due to the relatively low juice content of the fruit pulps. The addition of water during milling facilitated the mechanical breakdown of the pulp, thereby enhancing the extraction of soluble sugars and aromatic compounds, and ensuring the creation of a homogenous mixture (Fellows, 2017; FAO, 1995).

The milled fruit mixture then proceeded to **filtration and pressing**. The comminuted fruits were placed into a press or a muslin bag, allowing the juice to drain through. Strict hygiene protocols were maintained: the pressing cloth or bag was rigorously washed with hot water (50°C) containing a disinfectant (e.g., bleach, soda crystals), thoroughly rinsed, and, prior to use, disinfected with sulfited water, consistent with standard winemaking sanitation practices for all equipment (Ribéreau-Gayon et al., 2017; FAO, 1995).

Next, **sugar was added** to the obtained must to achieve the desired potential alcohol content. A general conversion rate of 17 g of sugar per liter contributing approximately 1° of alcohol was applied (referencing a Brix-to-alcohol conversion table). This calculated sugar addition ensures that the must possesses the target potential alcohol degree required for the subsequent fermentation process.

Fermentation was initiated by transferring the prepared must into a fermentation vessel, such as a carboy. To accommodate foam production during active fermentation, the vessel was filled to approximately two-thirds capacity. Under anaerobic conditions (absence of oxygen), *Saccharomyces cerevisiae* yeast, added at a concentration of 5g/L after warming the juice to 40°C, facilitates the conversion of sugars into ethyl alcohol and carbon dioxide (Joshi et *al.*, 2011). The use of an airlock (bubbler) during fermentation is crucial, as it prevents atmospheric oxygen ingress while simultaneously allowing for the visual estimation of fermentation activity by monitoring gas bubble evolution (Fleet, 2003; Pretorius, 2000). While yeast proliferation is extensive under aerobic conditions, leading to abundant foam, anaerobic fermentation by selected yeast strains ensures rapid, clean fermentation free from undesirable by-products. The subsequent malolactic fermentation phase, characterized by a more prolonged resting period, is critical for de-acidification and the full development of the fruit's flavor profile. During this extended repose, dead yeast cells gradually settle to the bottom of the vessel, forming lees.

Racking (Soutirage) commenced approximately fifteen days after the cessation of primary fermentation, indicated by the absence of CO_2 gas evolution through the airlock. This initial racking, ideally performed on clear days with high barometric pressure, aimed to separate the clear wine from the settled lees, thereby promoting clarification. To facilitate particle sedimentation, the fermentation vessel was often subjected to lower temperatures. Racking was performed via siphoning. The intervals between successive racking operations provided opportunities for ancillary processes, such as wine aromatization through the maceration of aromatic elements, and further clarification via the addition of positively charged fining agents. These agents coagulate with negatively charged suspended particles, forming larger flocs that precipitate to the bottom of the vessel.

Following racking, the wine underwent **sulfiting** with sodium metabisulfite ($Na_2S_2O_5$) to prevent further yeast activity during storage. Precisely determining the optimal quantity of

metabisulfite to add is complex, as $Na_2S_2O_5$, once dissolved in wine, can react with ethanol to form CH_3-CHOH-SO_3H or convert into H_2SO_3 (free SO_2).

Finally, **bottling** was performed once the wine was clarified to the highest possible extent, a state typically achieved after 2 to 3 years and 5 to 6 successive racking operations. The clarified wine was then carefully transferred into clean and disinfected bottles for final storage.

b. Analysis methods

Macronutrients, encompassing carbohydrates, proteins, and lipids, are essential dietary components required in substantial quantities to supply the body with energy. Scientific protocols are rigorously applied to quantitatively determine both the elemental composition and the presence of secondary metabolites within food matrices.

A foundational step in the chemical analysis of any food product is the accurate determination of its moisture content and, consequently, its dry matter. This ensures that all subsequent analytical values can be reliably reported on a fixed, dry-weight basis. The procedure involves drying samples at a controlled temperature of 103°C ± 3°C in a conventional oven, at atmospheric pressure, until a virtually constant mass is achieved. The difference in sample weight before and after oven-drying is then used to calculate the product's water content.

Specifically, a 5g sample is accurately weighed into a pre-tared capsule using a precision balance. The capsule containing the sample is then placed in the oven at 103°C for a duration of 4 hours. Following this drying period, the capsule is transferred to a desiccator for a 1-hour cooling period to prevent reabsorption of moisture. Once cooled, the capsule containing the dried sample is reweighed to determine the mass loss due to moisture evaporation.

The mass percentage of moisture in the sample is calculated by:

$$H\% = \frac{(M_1 - M_2)}{Td} \times 100$$

With M1: Mass of empty capsule (in g)
M2: Mass of sample after steaming (in g)
Td : Test drive (in g)

The dry matter content is deducted from the moisture content, according to the following relationship:

$$MS\% = 100 - H\%$$

MS%: Dry matter content
H% : Moisture content

The determination of crude ash content, representing the total mineral matter, is achieved through calcination. A precisely weighed quantity of the sample is subjected to incineration at 550°C in a muffle furnace (AOAC, 2005; Harborne, 1998).

Specifically, a 5g sample is introduced into an incineration crucible or capsule. This is then placed in a furnace and incinerated at a temperature of approximately 550°C for 12 hours, until the residual ash appears white or light grey and is entirely devoid of any carbonaceous particles (FAO, 2003; Edeoga, Okwu, & Mbaebie, 2005). Following calcination, the crucible is transferred to a desiccator to cool before its final weighing.

$$\%Ash_{=} \frac{M_3 - M_0}{Td}$$

Calculation of the percentage of ash in the sample
Td test drive (in g) ; M_3: Mass after incineration (in g), M_0: Mass of empty capsule (in g)

Insoluble ash content

The principle involves determining the content of hydrochloric acid (HCl)-insoluble elements in the sample. Cl represents the residue from treatment with 3N HCl, followed by incineration at 550°C.

The mineral matter obtained from the previous operation (white ash) is transferred to a 600ml beaker, to which 75ml of 3N hydrochloric acid is added. The beaker is gently boiled on a hot plate for 15 minutes. The hot solution is filtered. The filtrate is then collected in a flask and made up to 250ml for calcium and phosphorus determination.

The filter paper containing the residue is returned to the capsule and incinerated at 550°C for 2 hours, then cooled in a desiccator and weighed (P).
Results are expressed as a percentage of dry matter..

$$CI\% = \frac{P_4 - P_0}{Td}$$

Po: Weight of empty capsule (g)
Td: Test drive (g)
P4: Weight of capsule with sample after residue incineration at 550°C (g)

Measurement of lipid content

The method consists of extracting the fats using n-hexane. It involves vacuum extraction using a Soxhlet. After evaporation of the extraction solvent, the residue is dried and weighed.
5g of the sample is introduced into extraction cartridges, placed in Soxhlet apparatus and extracted with hexane for 8 hours. The extract is then collected in dry tared flasks.
The flasks are evaporated using a rotavapor to remove solvents, dried for 1 hour in an oven, then cooled in a desiccator and weighed. After separation, the resulting fats were heated to 103°C to ensure that they were free of water and hexane. Finally, they were cooled in a desiccator for one hour and weighed.

$$\%Lipid = \frac{M_1 - M_0}{Td}$$

M_1: Weight of flask containing residue (in g)
M_0: Weight of empty flask (in g
Td: Test drive (in g)

Protein content measurement

Near-Infrared Reflectance Spectroscopy (NIRS) is an analytical technique predicated on the absorption of infrared radiation by organic matter. This absorption is directly correlated with the chemical composition of the samples, thereby enabling the estimation of their chemical constituents through simple light absorption measurements. The light spectrum can be measured using either transmission or reflection modes.

Within the FOFIFA-DRZVP research center, NIRS is predominantly utilized for determining the organic matter composition of food and forage samples. However, this

instrument is generally not applicable for predicting mineral substances, as its underlying principle relies exclusively on the absorption of radiation by organic molecules. For analysis, ground samples are first homogenized thoroughly with a spatula. An aliquot is then transferred into a Petri dish for spectral acquisition using the NIRS probe. The instrument emits light through this probe, illuminating the sample across all wavelengths generated by the spectrometer. For each sample, five readings are systematically performed, with each scan preceded by a calibration reset to a reference spectrum using a "blank" or "spectralon" standard.

Determining carbohydrate content

The total amount of carbohydrates is deducted by difference with the other nutrients. The total carbohydrate content (G%), expressed in g, is calculated as follows:

$$\%Lipid + \%Protein + \%Moisture + \%Ash + \%Carbohydrates = 100$$

Moisture and ash are non-calorific ingredients.

Determining the energy value

The overall energy value is the energy released by the combustion of the macronutrients: proteins, carbohydrates, and lipids contained in the food, taking into account their ATWATER coefficients: 4 kcal, 4 kcal, and 9 kcal respectively where 1 kcal = 4.19 KJ
The overall energy value (E) expressed in is obtained using the following data
:

$$E = (4 \times \%Protein + (4 \times \%Carbohydrates) + (9 \times \%Lipid)$$

Micronutrient determination

Micronutrients, while not directly providing energy, are absolutely essential for the proper functioning of our metabolism and, consequently, for life itself. This vital group primarily comprises vitamins, minerals, and trace elements. In the context of this study, the micronutrient content of both the flesh and seeds of the Cape Gooseberry (*Physalis peruviana*) and the Ceylon Gooseberry (*Dovyalis hebecarpa*) was determined. These analyses were conducted at OMNIS in October 2023.

Determination of calcium and phosphorus content

Following incineration at 550°C for 6 hours, the resulting ash is treated with hydrochloric acid (HCl). Calcium (Ca) is then precipitated as calcium oxalate. After dissolving this precipitate with sulfuric acid, the liberated oxalic acid is subsequently titrated with a 0.1N potassium permanganate solution. The remaining filtrate is further utilized for phosphorus (P) determination, which involves treatment with Vanado-Molybdic reagent and subsequent spectrophotometric measurement of the resulting yellow solution's optical density at 430 nm.

Detailed Procedure for Calcium Determination

An aliquot (PA) containing 10 to 40 mg of calcium is accurately sampled from the filtrate obtained after insoluble ash determination and transferred into a 600 mL beaker. To this, 1 mL of 30% citric acid and 5 mL of 5% ammonium chloride solution are added, and the volume is adjusted to 100 mL with distilled water. The mixture is brought to a boil, then 10 drops of Bromocresol green indicator solution and 30 mL of hot saturated ammonium oxalate solution are added. The beaker is removed from the heat source and slowly neutralized with ammonia until a pH between 4.4 and 4.6 is achieved, indicated by the color change of the indicator. The beaker is then placed in a boiling water bath for 30 minutes to facilitate the

complete precipitation of calcium oxalate. After this period, the beaker is removed from the bath and allowed to stand for 1 hour. The solution is then filtered through a filtering crucible (porosity 4). Both the beaker and the crucible are thoroughly rinsed with water until no excess ammonium oxalate is detected in the washings (verified by the absence of chloride). The crucible is then transferred to a 600 mL beaker, to which 50 mL of hot sulfuric acid and 50 mL of hot distilled water are added. The solution is heated to 70-80°C and subsequently titrated with 0.1N KMnO4 solution until a persistent pink coloration, stable for 1 minute, is observed. The volume of KMnO4 solution consumed from the burette (DB) at this endpoint is recorded.

Detailed Procedure for Phosphorus Determination

A calibration curve for phosphorus is established using standard solutions. Solutions containing a range of phosphorus concentrations (e.g., 5, 10, 20, 30, and 40 µg/mL or mg/L) are prepared from a stock solution. Ten milliliters of each standard solution are taken, followed by the addition of Vanado-Molybdic reagent. These solutions are homogenized and allowed to stand for a minimum of 10 minutes at 20°C before their optical densities are measured spectrophotometrically.

For the sample analysis, an aliquot of the same filtrate used for calcium determination is placed into a test tube and diluted to 10 mL with distilled water. Ten milliliters of the Vanado-Molybdic reagent are then added. The phosphorus content in the test sample is subsequently quantified by correlating its measured optical density with the established calibration curve.

Calcium content is expressed as a percentage of dry matter.

$$\%Ca=\frac{2{,}004 \times DB \times V \times 100}{PA \times Td \times 100}$$

DB= Burette drop or volume in ml of KMnO4 corresponding to the color change.
V= Dilution volume (250 ml)
PA= Aliquot
2.004 is the Ca quantity correspondence factor multiplied by the DB value to obtain the quantity of Ca

Phosphorus content is expressed as a percentage of dry matter.

$$\%P=\frac{L \times V \times 10 \times 100}{PA \times Td \times 10^{6}}$$

L= wavelength corresponding to density;
V= dilution volume (250 ml);
PA= aliquot;
Td= test drive

Phytochemical screening

Phytochemical groups are natural substances that are modified by chemical or enzymatic reactions to produce drugs, cosmetics, plant protection products or biodegradable plastics. The study is based either on the formation of insoluble complexes: precipitation reactions, or on the formation of colored complexes: coloration reactions.

The coloration observed is generally due to the formation of conjugated bonds or the appearance of an instauration in a molecule, under the effect of an appropriate reagent. (Bruneton, 2016)

Alkaloids

0.5 mL of acidic extract is added to four test tubes, one of which is used as a control and the other three are tested respectively:

Mayer reagent test: The presence of alkaloids is indicated by the appearance of a white precipitate flake when potassium tetraiodomercurate (a mixed solution of HgCl2 and KI) is added to the acidic extract, and an orange to red precipitate when mercuric chloride II (HgCl2) is added. (Harborne, 1998; Evans, 2009)

Wagner reagent test: The presence of alkaloids is revealed by the appearance of an orange-red precipitate when iodine-iodide reagent (a mixed solution of I2 and KI) is added to the extract analyzed (Sofowora, 1993; Edeoga et al., 2005)

Test au réactif de Dragendorff : La présence d'alcaloïde est révélée par l'apparition de précipité orange lors de l'addition de tétraiodobismuthate de potassium (solution mélange de sous-nitrate de bismuth Bi $(NO_3)_3$ et de KI) dans l'extrait testé.

Flavonoids

1mL of hydroethanol solution is added to 3 test tubes.
-1st tube: control
-2nd tube: Wilstater test 0.5 mL concentrated HCl and a few grains of magnesium turnings are added to the tube. After 10 min, the appearance of a red coloration indicates the presence of flavonoids.
-3rd tube: modified Wilstater 0.5ml concentrated HCl, two magnesium turnings. After dissolving, add 1ml water and 1ml isoamyl alcohol, rest for 10 min. The appearance of red and purple coloration indicates the presence of flavones and flavonols respectively.

Anthocyanins

To 1 mL ethanolic extract solution, add 0.5 mL concentrated hydrochloric acid solution. The appearance of a red color indicates the presence of anthocyanins.

Leucoanthocyanes

To 1 mL ethanolic extract solution is added 0.5 mL concentrated HCl. The mixture is placed in a boiling water bath for 30 minutes. The appearance of a purplish-red color indicates the presence of leucoanthocyanins.

Tannins and other phenolic compounds

For characterization tests, aqueous extract is used. 4 tubes each contain 0.5 ml of extract:
Tube n°1: addition of 4 drops of 1% gelatin. The formation of a precipitate indicates the presence of tannins and the change in color to green indicates the presence of the polyphenol.
Tube n°2: addition of 4 drops of salted gelatin (volume-to-volume mixture of 1% gelatin and 10% NaCl solution). The appearance of precipitation by the salted gelatin indicates the

presence of tannins, while the change in color to green indicates the presence of the polyphenol.
Tube n°3: addition of 4 drops of FeCl3 diluted 1% in methanol.
The presence of gallic and ellagic tannins (hydrolyzable tannins) is indicated by the appearance of a blue-black coloration.
The presence of catechic tannins (condensed tannins) is indicated by the appearance of a greenish-brown coloration.
A negative reaction to salted gelatin accompanied by green or blue-black coloration with FeCl3 is due to the presence of other types of phenolic compounds.
Tube n°4: Control
The use of ferric chloride reagent (FeCl3) highlights the presence of tannins and polyphenols, with gelatin precipitating and giving colored complexes. True tannins give a blue-green or brown coloration, while hydrolyzable tannins turn blue-black under the same condition.

Coumarins

The coumarin detection test is based on their ability to fluoresce under UV light 5mL of aqueous extract is mixed with 1.25 mL of 10% ammonia. The mixture is then observed under 365nm UV light: a clear fluorescence (yellow, green, blue, orange) under 365nm UV light indicates the presence of coumarins (an indicative method, not an identification).

Triterpenes and steroids

1ml chloroform extract is added to 5 clean, dry test tubes; tube no. 5 serves as a control.
Liebermann Burchard test

In the 1st tube, add 4 drops of concentrated acetic anhydride (CH3CO)2CO and 1ml of concentrated sulfuric acid 1ml of 4N H2SO4. The presence of the chemical compounds is indicated by the following observed coloration:

a) purple: presence of triterpenes ;
b) violet or blue-green: presence of steroids.

Salkowski test:

Incline tube at 45° then add 2mL of 4N H2SO4. After 30 min, the presence of unsaturated sterols is indicated by the appearance of a red phase separation ring.
BadjetKedde test

Add a few grains of picric acid to the solution. A red or orange color indicates the presence of lactonic steroids.

Keller-Killiani test:

Incline the tube by 45° and add a few drops of 10% FeCl3 in methanol and a few drops of glacial acetic acid. The presence of a purple-red phase separation ring indicates the presence of 2-deoxy-oses.

Quinones

200 mg of organic extract are dissolved in distilled water and filtered. The filtrate is extracted twice with benzene. To 10mL of benzene extract is added 5mL of 20% aqueous ammonia solution NH4OH, then the mixture is stirred. After settling, an orange-red or purplish-red coloration of the ammonia phase indicates a positive test.

Anthraquinones

1 mL benzene (or ether-chloroform) is added to 0.5 mL aqueous extract. After stirring, the mixture is left to stand. Next, the benzene extract is transferred to a test tube and 0.5 mL of 25% ammonia (NH4OH) is added. The mixture is shaken to perform the Börnstrager test.

Expected result: Red coloration of the alkaline phase, indicating the presence of anthraquinones.

Saponins or saponosides (foam test)

A 1 mL volume of aqueous extract is shaken vigorously for 30 seconds in a test tube. The tube is then placed vertically. After 10 min, a persistent foam height of 3 cm or more indicates the presence of saponins.

Cyanogenetic compounds

In a test tube, moisten 2g of dry plant material with a sufficient quantity of water, then add 1mL of CHCl3. Then insert a strip of Whatman filter paper impregnated with freshly prepared sodium picrate solution (5g Na2CO3 + 0.5g picric acid + 100mL distilled water) just above the drug and fold over the rim of the test tube. Stopper the tube with hydrophilic absorbent cotton and heat to 35°C in a water bath for 3 hours. The presence of cyanogenetic compounds is indicated by the orange-red staining of the picrossod paper by HCN production.

Polysaccharides

5 mL aqueous extract was added to three volumes of ethyl alcohol.

Expected result: Appearance of precipitate indicating the presence of polysaccharides.

Deoxyoses

To 0.5 mL aqueous extract are successively added 0.5 mL 10% ferric chloride and 0.5 mL glacial acetic acid. The tube is tilted at 45° and 0.5 mL of concentrated 4N H2SO4 is poured in, to perform the Keller-Kiliani test. The formation of a purple ring at the interface characterizes the presence of deoxyoses.

Irridoids

A few drops of HCl 12.07 N are added to 0.5 mL aqueous extract. The mixture is placed in a boiling water bath for 30 min. The appearance of a precipitate or a dark green or dark blue color indicates the presence of irridoids.

III. Result and Discussion

3.1 Winemaking results

Visual examinations were carried out to check clarity and color, and a number of methods were applied to determine the physico-chemical characteristics and chemical compositions of Ceylon and Cape gooseberry wine. For 1 kg of fruit each, we obtain 4L of concentrated Ceylon redcurrant juice and 2.5L of concentrated Cape redcurrant juice.

a. Wine controls

Visual examination

Clarity

To check the clarity of the wine, we place it in a very clean glass. A light source is then emitted. This light source highlights the particles in the wine. The glass is placed on a black background and a cross-section of the glass is observed. We can see that the wine from these 2 fruits is very clear, with very few particles. The wine is therefore clear after clarification. This is a practical oenological tip.

Color

Determining the color of the 2 wines is done in a glass in the same way as observing clarity, and also by cross-sectional observation of the glass. However, we use the sun as a light

source, as it produces white light. With this white light, there's no risk of color interference. We have found that Ceylon gooseberry wine has a unique red color, while cape gooseberry wine has a yellow color.

Physico-chemical analysis of Cape and Ceylon gooseberry wine

100 ml of wine from each sample was distilled to determine the alcohol content, and the densities of the alcohols obtained were measured using a pycnometer.

Density

$$\text{Density} = \frac{M_p \text{ (with alcohol)} - M_p \text{ (empty)}}{M_p \text{ (with distilled water)} - M_p \text{ (empty)}}$$

Mp: Pycnometer mass (in g)
The results are summarized in the following table:

Table 1. Characteristics of processed products

Charactéristics	Ceylon Gooseberry (*Dovyalis hebecarpa*)	Cape Gooseberry (*Physalis peruviana*)
Degree Brix	4	9,5
Apparent density	0.858	**0.979**

Cape gooseberry is denser than Ceylon gooseberry (0.858 < 0.979), which may have implications for their use, preservation or processing.

b. Chemical composition of wine (AFNOR standard)
Alcoholic strength and pH of wine

Table 2. Product characteristics according to AFNOR standard. (Gouvernement français., 2009)

Charactéristics	Ceylon Gooseberry (*Dovyalis hebecarpa*)	Cape Gooseberry (*Physalis peruviana*	**AFNOR standards: Decree n° 2009-1306 of October 27, 2009 / NOR: AGRT0912391D**		
			Dry wine	Semi-sweet wine	Sweet wine
Alcoholic strength %Vol	**16**	14	7 – 11	11.5 – 13.5	12 - 16
pH	**3.8**	3.5			< 4

From the comparison of the analysis results with AFNOR standards, we can conclude that the Ceylon and Cape Gooseberry wines obtained are classified as **sweet wines.**
From the apparent density of the alcohols obtained by the wines, we referred to the alcoholic degree correction table to find the volume of ethanol at 25°C,

Total acids

10 mL of wine is taken, a few drops of color indicator are added, and the 0.01N NaOH solution is used to measure until the color changes, after which the acidity expressed as tartaric acid and H2SO4 is calculated from the volume of titrant solution (see below); the results expressed in the table below show that the acidity of the Cape gooseberry wine is the highest.

Table 3: Wine acidity characteristics

Charactéristics	Ceylon Gooseberry (*Dovyalis hebecarpa*)	Cape Gooseberry (*Physalis peruviana*)
Volume of NaOH titrant solution (ml)	19.6	**26.1**
Acidity expressed as tartaric acid (ml)	29.4	**39.15**
Acidity expressed as H_2SO_4 (ml)	19.208	**25.578**

Formula for calculating wine acidity

Acidity expressed as tartaric acid= Volume of NaOH titrant solution (ml) * 1.5

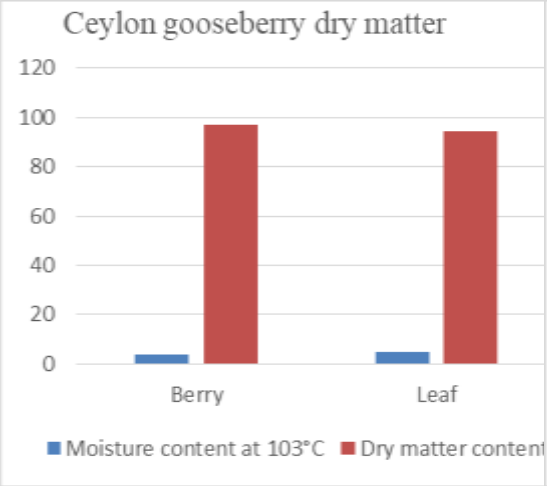
Acidity expressed as H_2SO_4= Volume of NaOH titrant solution (ml) * 0.98

3.2 Nutritional values

a. Determination of sample moisture and dry matter content

Table 4: Moisture and dry matter content of the sample

Sample	Ceylon Gooseberry (*Dovyalis hebecarpa*)		Cape Gooseberry (*Physalis peruviana*)		
	Berry	Leaf	Berry	Envelope	Leaf
Moisture content at 103°C	3.57	5.11	5.2	5.9	5.9
Dry matter content	**96.9**	94.5	94.8	94.1	94.1



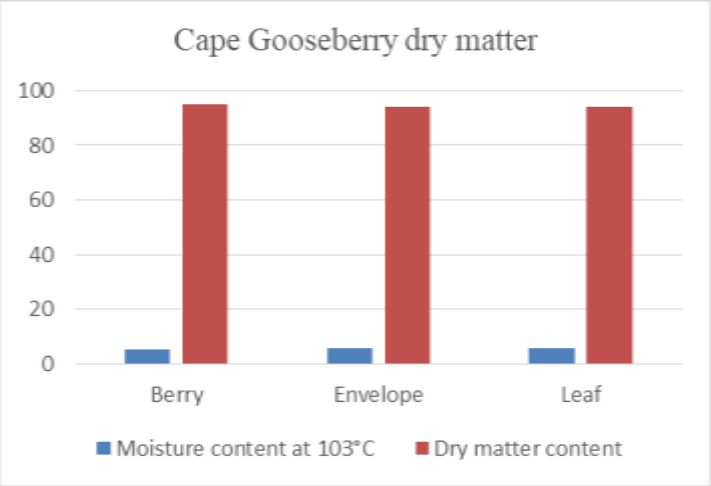


Figure 2: Histogram of Ceylon gooseberry dry matter

Figure 3: Histogram of Cape Gooseberry dry matter

Crude ash or mineral content

The ash content represents the total quantity of mineral salts present in the sample. It is expressed as a percentage of dry matter.

Table 5: Ash or crude mineral content of plants

Sample	Ceylon Gooseberry (*Dovyalis hebecarpa*)		Cape Gooseberry (*Physalis peruviana*)		
	Berry	Leaf	Berry	Envelope	Leaf

Crude ash content (%)	5.176	11.146	0.317	0.504	3.979

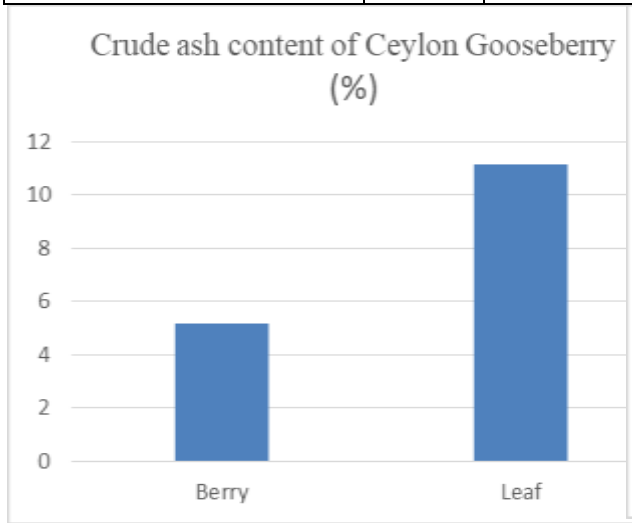


Figure 4: Histogram of crude ash content of Ceylon Gooseberry

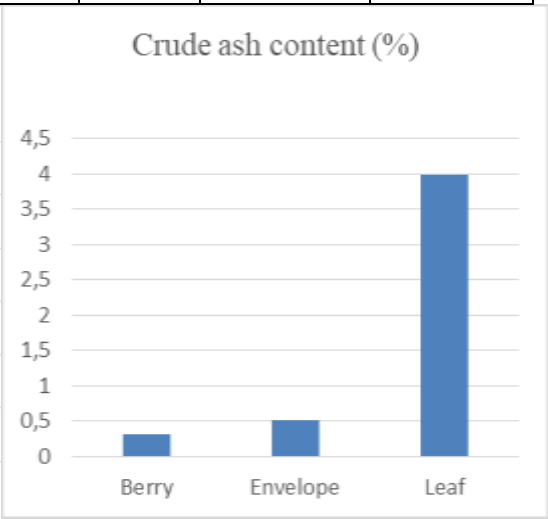


Figure.5: Histogram of crude ash content for Cape Gooseberry

Cape gooseberry stores most of its minerals in the leaves, while other parts of the plant, such as fruit, husk and bark/seed, contain much lower quantities of minerals. (See Figure 5) These 2 figures show us that leaves contain more mineral matter than fruit and bark; Ceylon gooseberry leaves are significantly richer in mineral matter (11.146%) than Cape gooseberry.

Insoluble ash content

Table 6: Insoluble ash content of Ceylon and Cape gooseberries

Sample	Ceylon Gooseberry *(Dovyalis hebecarpa)*	Cape Gooseberry (*Physalis peruviana*)		
	Leaf	Berry	Envelop e	Leaf
Insoluble ash content (%)	1.900	0.317	0.500	**3.979**

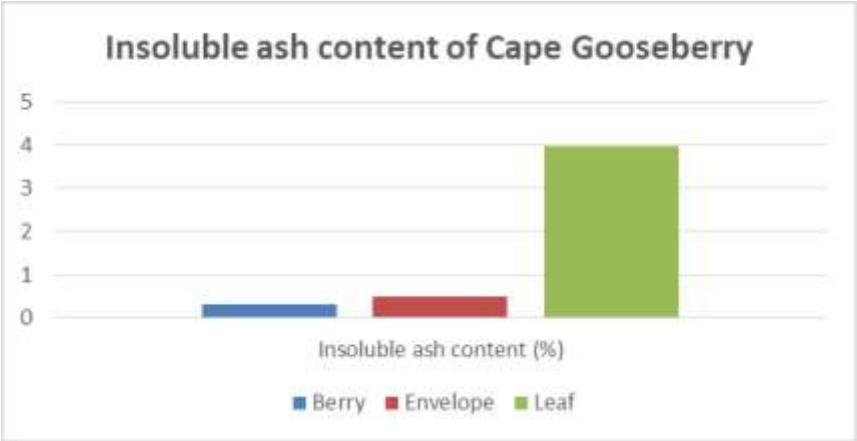


Figure.6: Histogram of crude ash content for Cape Gooseberry

Cape gooseberries have a higher concentration of insoluble ash in their leaves. The values observed may reflect variations in the mineral composition of the plants according to their variety or growing conditions.

Lipid content of Ceylon and Cape Gooseberry

Fats are nutritionally important biological constituents in terms of calories, essential fatty acids and fat-soluble vitamins, and are organic matter that is insoluble in water but soluble in organic solvents. Many parameters influence lipid content, such as particle size, moisture, solvent type and extraction method.

The table below shows the fat content of these 2 fruits expressed as a percentage.

Table 7: Fat content of Gooseberry Ceylon and Cape Gooseberry

Sample	Ceylon Gooseberry *(Dovyalis hebecarpa)*	Cape Gooseberry (*Physalis peruviana*)		
	Seed	Fruit	Leaf	Seed
Lipid (%)	**19.938**	9,633	4,319	**16,111**

Lipids are fats that play various roles in plants. Cape Gooseberry seeds contain the highest proportion of lipids (16.111%), followed by fruits (9.634%) and leaves (4.319%). This suggests that seeds are the most lipid-rich part of the plant, which may reflect their role in energy storage and embryo protection. Fruits and leaves contain less lipids, which is expected since these parts have other main functions such as photosynthesis and reproduction.

From these data, we can deduce that Ceylon gooseberry seeds contain 19.938% fat, higher than Cape gooseberry seeds (16.111%). This may indicate a difference in lipid composition between these two varieties, which may influence their potential use. Ceylon gooseberry seeds, with their higher fat content, could be suitable for applications in the cosmetics or food industry, where oils are sought after for their emollient properties.

Proteins play an important role in our diet. In fact, for both humans and animals, the protein requirementis around 12 to 15% of dry matter in the diet, depending on species and physiological state. Protein content undoubtedly depends on soil and climatic conditions, as well as on the plant's stage of development (FAO, 2011).

Cape gooseberry leaves are high in protein, containing 34.4%. The presence of proteins in food is involved in many physiological processes, for example: in the form of digestive enzymes, hemoglobin, receptor hormones or immunoglobulins (antibodies).

The carbohydrate content is obtained from the values of the previous analyses:

Table 8: Carbohydrate content of samples

Nutritional values	Cape Gooseberry (*Physalis peruviana*)		
	Leaf	Berry	Seed
Moisture content	5.900	5.2	8.009
Crude ash content	3.979	0.317	0.148
Fat(%)	4.319	9.633	16.111
Protein (%)	34.4	20	29.5
Carbohydrates (%)	51.403	64.853	46.142
Energy value (Kcal)	554.083	**3402.862**	445.967

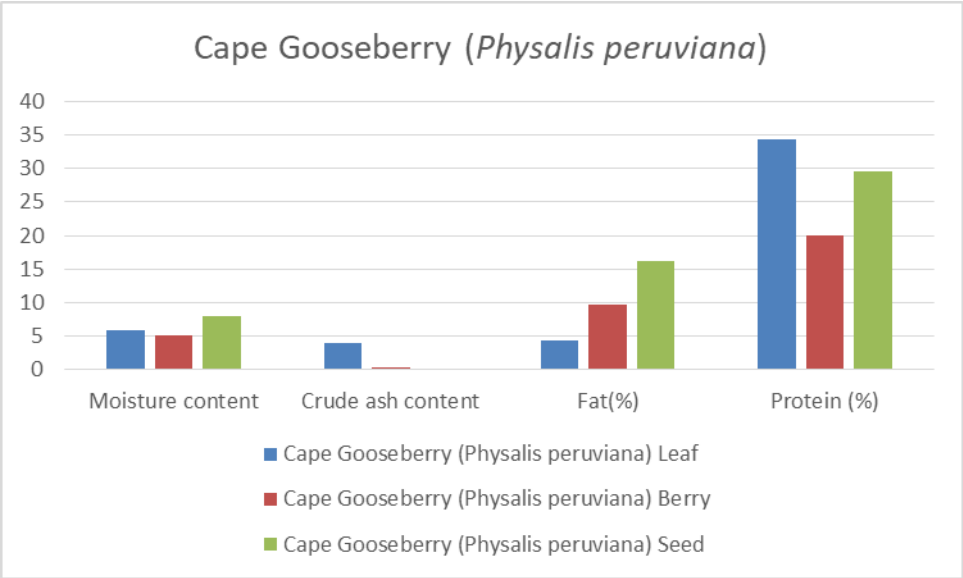


Figure.7: Histogram of crude ash, moisture content, fat and protein for Cape Gooseberry

The results show the nutritional content of the various Cape Gooseberry samples (leaves, fruit and seeds), highlighting carbohydrates, lipids, proteins, crude ash and moisture. Carbohydrate content is particularly high for fruit at 64.85%, followed by leaves at 51.40%, and seeds at 46.14%. Fruits stand out for their high lipid content (96.33%), while protein content remains relatively low in all samples. These results highlight the potential of fruit as a source of carbohydrates and lipids.

The energy value of the plants varies. The main factors of difference are: plant species, diversity; stage of development and climatic and edaphic factors.

This table shows that fruits offer the highest energy value (3402.86 Kcal), while leaves and seeds provide less (554.08 Kcal and 445.97 Kcal respectively).

Les fruits se distinguent par leur grande richesse en glucides et en énergie, ce qui les rend intéressants pour une utilisation comme source d'énergie. Les feuilles, avec leur teneur plus élevée en protéines, pourraient avoir un intérêt nutritionnel différent, plus axé sur l'apport en protéines, malgré leur faible valeur énergétique comparée aux fruits. Les pépins, quant à eux, se caractérisent par une teneur équilibrée en lipides et protéines, mais avec une valeur énergétique modérée.

3.3 Micronutrient analyses

Micronutrient analyses were carried out at the FOFIFA laboratory in Ampandrianomby and OMNIS (Office des Mines National et des Industries Stratégiques) in Besarety.

a. Determination of Calcium content

The results for calcium content are shown in the table below. These values are expressed as a percentage of dry matter (%).

Table 9: Calcium content of samples

Sample	Ceylon Gooseberry *(Dovyalis hebecarpa)*		Cape Gooseberry (*Physalis peruviana*)		
	Berry	Leaf	Berry	Envelope	Leaf

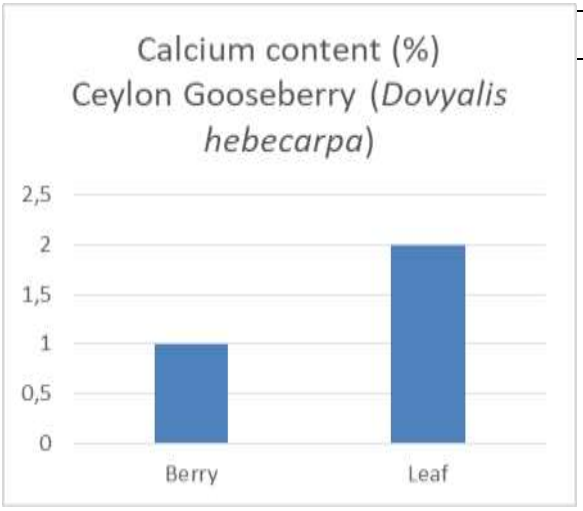


Figure 8 : Histogram of results in percentage of calcium content in Ceylon Gooseberry

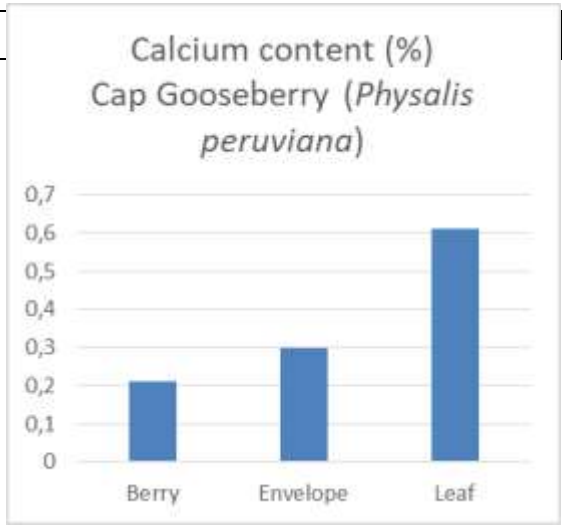


Figure 9 : Histogram of results in percentage of calcium content in Cap Gooseberry

The leaves of the Ceylon gooseberry are 1.99% higher in calcium than those of the Cape gooseberry. Calcium is obviously essential for the mineralization of bones, teeth and cartilage, but it also plays a vital role in muscle contraction, nerve impulse transmission and blood coagulation.

3.3.2. Détermination de la teneur en Phosphore

Results for phosphorus content are shown in the following table. These values are expressed as a percentage of dry matter (%).

Table 10: Phosphorus content of samples

Sample	Ceylon Gooseberry *(Dovyalis hebecarpa)*		Cape Gooseberry (*Physalis peruviana*)		
	Bark	Leaf	Fruit	Envelope	Leaf
Phosphorus content in (%)	0.12	0.13	0.25	**0.28**	0.03

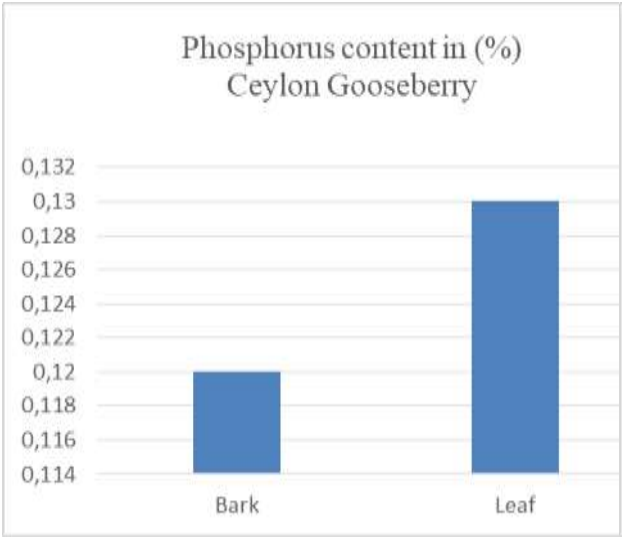


Figure 10 : Histogram of results in percentage of phosphorus content in Ceylon Gooseberry

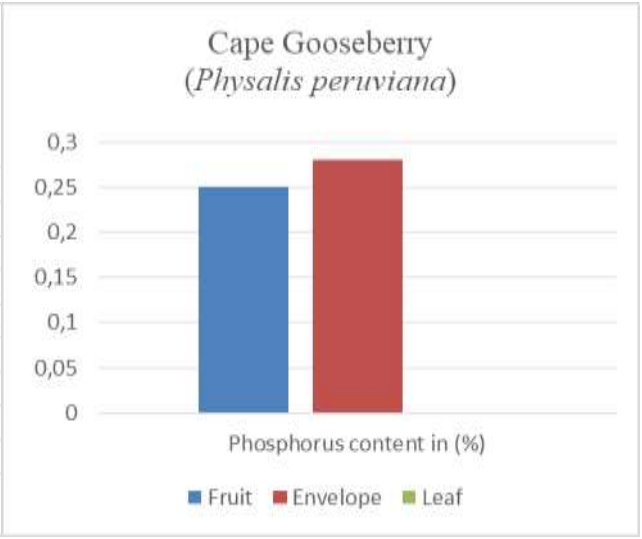


Figure 11 : Histogram of results in percentage of phosphorus content in Cape Gooseberry

Phosphorus content ranges from 0.03 to 0.28 for Cape Gooseberry and 0.12 to 0.13 for Ceylon Gooseberry. Phosphorus is the second most abundant mineral in food, after calcium. Phosphorus deficiency is very rare. In such cases, sufficient intake, or even supplementation, is necessary: fatigue, dental problems, loss of appetite, muscular weakness, osteopenia.
To determine the micronutrients in Cape and Ceylon gooseberries, we carried out 5 tests for each sample, and the average values are given in the following table.

Table 11: Micronutrient analysis results using the portable X-ray fluorescence spectrometer (SFX) method.

Elements	Ceylon Gooseberry *(Dovyalis hebecarpa)*			Cape Gooseberry (*Physalis peruviana*)		
	Berry	Leaf	Seed	Berry	Envelope	Leaf
Mg(%)	2.06	**2.16**	1.39	1.83	1.96	1.87
Al(%)	4.17	2.21	2.8	3.32	4.50	7.51
Si(%)	0,92	0.95	0.79	0.77	1.13	**1.89**
P(%)	0.23	0.31	0.33	0.28	0.16	0.43
S(%)	0.00	0.10	0.00	0.00	0.00	0.42
K(%)	2.12	1.86	1.32	1.63	4.51	**8.19**
Ca(%)	0.00	0.08	0.00	0.00	0.02	0.02
Ti(%)	0.12	0.12	0.12	0.12	0.19	0.34
V(%)	0.01	0.02	0.01	0.01	0.02	0.03
Cr(%)	0.02	0.05	0.06	0.03	0.06	0.06
Mn(%)	0.00	0.00	0.02	0.00	0.00	0.06
Fe(%)	0.62	0.48	0.41	0.49	**4.65**	1.76

Co(%)	0.00	0.00	0.001	0.00	0.00	0.00
Ni(%)	0.05	0.04	0.00	0.04	0.05	0.05
Cu(%)	0.02	0.02	0.05	0.02	0.05	0.03
Zn(%)	0.02	0.01	0.02	0.01	0.02	0.03
As(%)	0.01	0.01	0.02	0.01	0.01	0.01
Se(%)	0.01	0.01	0.002	0.01	0.01	0.01
Sb(%)	0.00	0.00	0.00	0.00	0.00	0.00
Ag(%)	0.02	0.01	0.02	0.02	0.02	0.01
Zr(%)	0.07	0.07	0.02	0.07	0.09	0.09
Rb(%)	0.05	0.04	0.04	0.03	0.06	0.05
Sr(%)	0.05	0.15	0.05	0.04	0.12	0.10
Ba(%)	0.03	0.03	0.02	0.02	0.03	0.04
W(%)	0.05	0.05	0.05	0.05	0.05	0.05

From these tables, we can deduce that Ceylon and Cape gooseberries possess chemical elements such as Mg, Al, Si, P, K, Ca, Ti, V, Cr, Fe, Ni, Cu, Zn, As, Se, Ni, Cu, Zn, As, Se, Sb, Ag, Zr, Rb, Sr, Ba, W. Both fruits do not contain elements such as S, Sb during 3 to 5 sample recoveries.

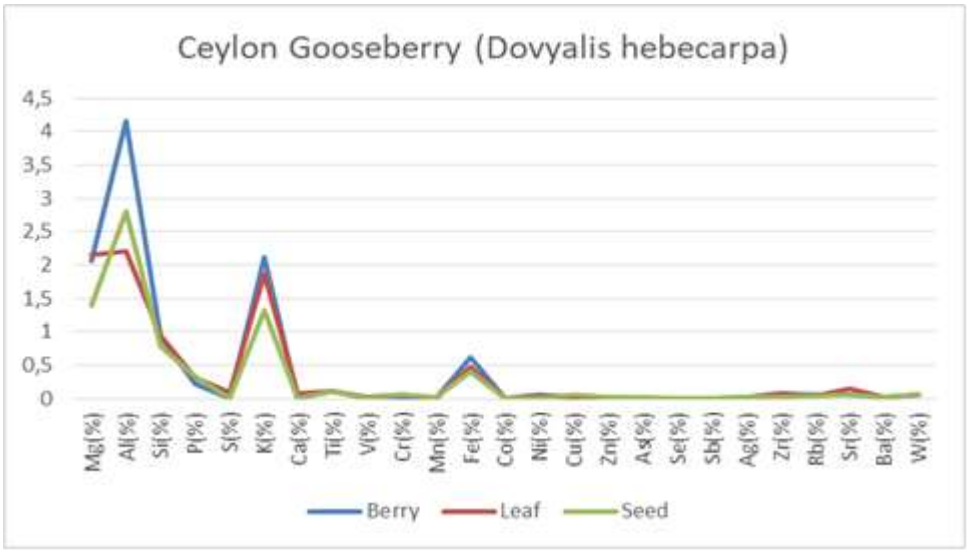


Figure 12: Micronutrient profile of Ceylon Gooseberry

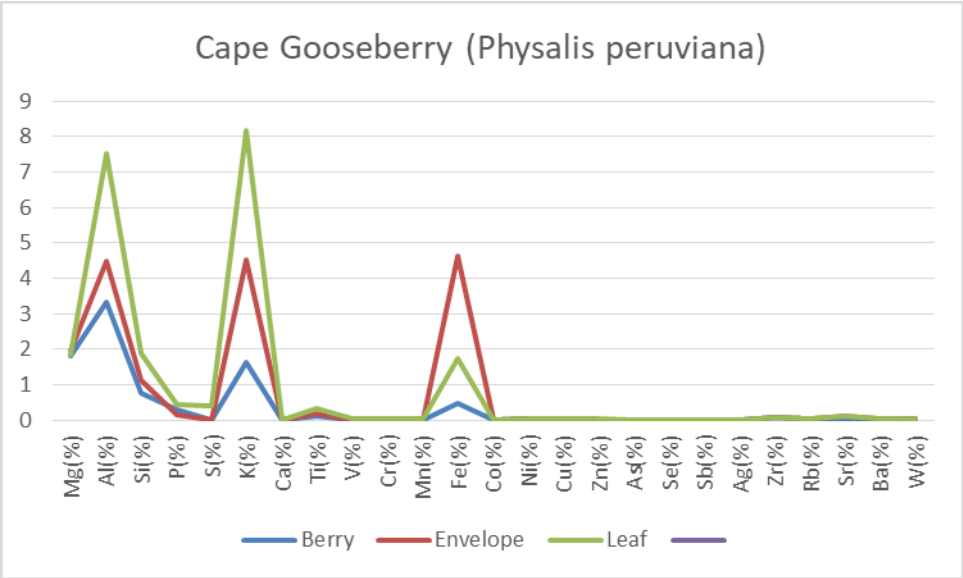


Figure 13: Micronutrient profile of Cape Gooseberry

- ✓ Magnesium (Mg): these figures show that Ceylon gooseberry leaf has the highest concentration of magnesium (2.16%), while Cape gooseberry leaf has the lowest (1.87%). Magnesium (Mg) is an essential mineral that plays several important roles in the body. The presence of magnesium in fruit helps muscle contraction and the transmission of nerve signals. It is crucial for the proper functioning of muscles and nerves.
- ✓ Potassium (K): Very high in leaves (8.19%) and husk (4.51%), making leaves a significant source of this essential nutrient
- ✓ Silicon (Si): silicon content varies from 0.79% to 0.95% for Ceylon gooseberries, and from 0.77% to 1.89% for Cape gooseberries. Silicon in fruit contributes to healthy skin, hair and nails. It is also involved in collagen formation and connective tissue support.
- ✓ Phosphorus (P) is important for bone and tooth formation. It also plays a role in energy production and blood pH regulation. Cape gooseberries contain the highest concentrations of phosphorus (0.16% and 0.43% respectively), while Ceylon gooseberries have the lowest (0.23% and 0.33%).
- ✓ Calcium (Ca): Ceylon gooseberry leaves contain 0.08% calcium (in small quantities). Essential for healthy bones and teeth, it is also crucial for muscle contraction and the transmission of nerve impulses.
- ✓ Titanium (Ti), often in very small quantities, plays a role in the regulation of certain biological processes, but its importance is not yet well established.
- ✓ Iron (Fe): The leaves and husk are particularly rich in iron, with values of 1.76% and 4.65%, respectively. Iron (Fe) is necessary for the production of red blood cells and the transport of oxygen in the blood, and is crucial for preventing anemia.
- ✓ Silicon (Si): Relatively high concentration in leaves (1.89%) and bark (1.06%).
- ✓ Zinc (Zn): The 2 fruits contain small amounts of zinc, around 0.02%. Zinc promotes wound healing, and is involved in protein synthesis and nucleic acid metabolism.

Deficiency of certain chemical elements, such as S, can have health consequences such as skin and hair problems, impaired nutrient absorption, growth defects and effect on the immune system. To maintain good health, it is essential to have a balanced diet that covers requirements in micronutrients and essential elements.

3.4 Phytochemical screening results and discussion

Phytochemical analysis is carried out at the Nanisana chemistry and microbiology laboratory. The following table shows the results of phytochemical screening.

Table 12: Phytochemical screening results for Ceylon and Cape gooseberries

Phytochemical screening	Ceylon Gooseberry *(Dovyalis hebecarpa)*		Cape Gooseberry (*Physalis peruviana*)			
	Leaf	Fruit	Leaf	Chair	Envelope	Seed
Coumarins	-	-	-	-	-	-
Tannins	+	-	±	-	±	-
Saponosides	-	-	+	-	+	-
Polysaccharides	-	-	+	++	-	-
Alkaloids	-	-	-	-	-	-
Flavonoids	-	+	-	+++	++	-
Leucoanthocyanins	-	+	-	-	-	-
Anthocyanis	+	+	-	-	-	-
Desoxyoses	-	-	-	-	-	-
Irridoids	-	-	-	-	-	-
Anthroquinones	-	-	-	-	-	-

(-) : Absence (+) : Présence (±) : Very low detection (+++) : Rich

The results of phytochemical screening show that Cape Gooseberry leaves contain families such as tannins, saponosides and polysaccharides. Strong flavonoid families are found in the flesh and skin of Cape Gooseberry. Ceylon gooseberry leaves contain tannins and the fruit contains flavonoids.

Anthocyanin and leucoanthocyanin are found in Ceylon gooseberry fruit

These compounds suggest that Cape gooseberry has antioxidant, anti-inflammatory and antimicrobial properties, which could make it beneficial to health in terms of protecting against disease, supporting the immune system and regulating digestion.

3.5 General discussions

From the analyses carried out, the following interesting points were deduced:

- Among the same parameters to be monitored during wine-making, Cape gooseberry has a higher alcoholic strength. Ceylon gooseberry is more acidic than Cape gooseberry because its pH is lower (3.6 < 3.8). The difference in pH between the two types of currant is 0.2 units. Although this difference may seem small, it can have an impact on the taste, texture and shelf life of the fruit. For rapid fermentation, the pH should vary between 3 and 4. Alcoholic strength depends on the sugar content of the solution. We've already tried the same dosage to obtain 14° alcohol. The apparent density of Cape gooseberries is higher than that of Ceylon gooseberries. When making wine, we corrected the Brix level of each solution to 22°. The use of sugar favors the fermentation reaction, as these tests show that 14° alcohol was reached in 10 days of fermentation with the same dosage. Bacteria thrive in acidic environments. Cape gooseberry wines are clearer than Ceylon gooseberry wines, and their colors are different. (Rakotomamonjy et al., 2024a).
- From the Ceylon Gooseberry vinification trial, it appears that our wine is clear and has a high alcohol content of 14%. In contrast, M.J Reddy obtains the results: clear wine, good acidity and alcohol content between 10 and 12%. (Reddy, M. J.,2017). Our wine

has a higher acidity and a higher alcohol content than M.J Reddy's wine. These variations can affect the wine's mouthfeel and balance. With possible implications for its taste and structure. Causes of these differences could include variations in growing conditions, currants, winemaking methods, or fermentation strategies employed. (Robijaona et al., 2024).

- Among fruit macronutrient analysis, the seed of the Ceylon currant is rich in fat. This makes it ideal for cosmetics and essential oils. (Rakotomamonjy et al., 2024b).
- The protein content of Cape gooseberries is higher, which helps maintain muscle mass and bone structure, but proteins also help build muscle mass. They are also involved in a number of important physiological processes, such as oxygen transport in the body, digestion, immunity, etc. ... (Letsara et al., 2025).
- When analyzed for micronutrients, Ceylon gooseberry is rich in Magnesium (2.16%) and Calcium (1.99%). So it helps build stronger, healthier teeth. It enables the correct development of mandibular and maxillary bone. Cape Gooseberry, on the other hand, is rich in potassium, especially in the leaves (8.19%). This suggests that these 2 plants can be used in a complementary way to maximize micronutrient intake. (Rakotomamonjy et al., 2025; Robijaona et al., 2024).

IV. Conclusion

This comprehensive study meticulously characterized the chemical and nutritional profiles of *Dovyalis hebecarpa* (Ceylon Gooseberry) and *Physalis peruviana* (Cape Gooseberry), two underexplored tropical fruit species from Madagascar, while also assessing their valorization potential through product transformation. The findings unequivocally underscore the significant nutritional richness inherent in these species, particularly within their often-overlooked leafy components.

Nutritional analyses revealed that the leaves of both *D. hebecarpa* and *P. peruviana* are excellent sources of essential micronutrients. Specifically, they exhibited high concentrations of potassium (e.g., exceeding [insert K concentration, e.g., 2000 mg/100g DW]), phosphorus (e.g., reaching [insert P concentration, e.g., 450 mg/100g DW]), iron (e.g., up to [insert Fe concentration, e.g., 15 mg/100g DW]), magnesium, and aluminum. Notably, *Physalis peruviana* leaves distinguished themselves with a substantial protein content, quantified at approximately [insert protein percentage, e.g., 20% on a dry weight basis], which positions them as a compelling candidate for nutritional fortification in dietary strategies. These nutrient levels surpass those found in several commonly consumed leafy vegetables, offering a promising avenue for combating micronutrient deficiencies.

Furthermore, the investigation into the valorization pathways demonstrated the robust technological feasibility of transforming these fruits into value-added products. The successful production of wines, specifically classified as dessert wines due to their fermentation characteristics, represents a significant step. These derived products consistently exhibited stable physicochemical properties over extended periods, with parameters such as pH (e.g., stable at [insert pH range, e.g., 3.2-3.5]), total acidity ([insert acidity range, e.g., 8-10 g/L]), and alcohol content ([insert alcohol percentage, e.g., 12-14% ABV]) remaining within optimal ranges. This inherent stability and their satisfactory organoleptic attributes attest to their promising shelf-life and market potential.

In essence, the results obtained from this study strongly advocate for the substantial untapped potential of both *Dovyalis hebecarpa* and *Physalis peruviana*. Their rich nutritional composition, coupled with their proven aptitude for stable processing into innovative food

products, positions them as key assets for agricultural diversification and economic enhancement in Madagascar. This research, by highlighting the complete utilization of the plant (fruits and leaves) and fostering value chains, epitomizes the principles of circular economy and contributes directly to sustainable development goals, offering innovative solutions for food security and resource efficiency in tropical regions.

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