INFLUENCE OF FIRING ON THE PROPERTIES OF CLAYS: A SUBSTRATE FOR SOILLESS CULTIVATION

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ABSTRACT

Faced with global population growth requiring increased food production, urban agriculture is one of the innovative solutions. The article focuses on the production and use of calcined clay balls, a growing medium made from clay sourced from rice fields in the Urban Commune of Antananarivo, Madagascar. The manufacturing stages, such as mixing, extrusion, shaping and firing, influence the physical and chemical characteristics of the balls, in particular their porosity, water retention capacity, pH and cation exchange capacity. Firing improves intragranular and intergranular porosity by removing organic matter and reducing bound water. Agronomic trials carried out on the soilless cultivation of Mentha spicata show that the use of calcined clay balls substrate is more effective than that on arable land. Although the study focused on potassium, it is suggested that its interaction with phosphorus should also be explored and that the water retention capacity of the substrate should be improved by adding water retainers.

Keyword *: calcined clay balls, water retention capacity, porosity, Agronomic trials*

1. INTRODUCTION

Faced with global population growth requiring increased food production, urban agriculture is emerging as an innovative solution to strengthen food security by bringing production sources closer to consumers and reducing transport distances, as well as the associated carbon footprint [1]. It is well known that increasing urbanization puts considerable pressure on agricultural land, thus reducing the availability of space for food production [2]. Between 2017 and 2022, 55% of new buildings constructed in the metropolitan area of Antananarivo were built on land previously used for cultivation [3]. Within this context, soilless cultivation, an approach that uses substrates other than arable soil, appears as a promising alternative for meeting the food needs of urban populations while optimizing the use of available resources. It is practiced on millions of hectares worldwide, particularly in Europe, where many vegetables, herbs, and cut flowers are grown in greenhouses [4]. Among the substrates used in these cultivation systems, calcined clay balls stand out for their physicochemical properties that are favorable to plant growth. This article aims to explore the production and use of calcined clay balls as a soilless cultivation substrate in the Urban Commune of Antananarivo. Clay, a natural rock mainly composed of silicates and a major component of irrigated rice-growing soils in the Malagasy highlands, was selected as the raw material. The clay was shaped into small balls and fired at around 600 °C. Agronomic tests were then carried out to evaluate the effectiveness of the resulting product. Agronomic tests were then carried out to evaluate the effectiveness of the resulting product.

2. MATERIALS AND METHODS

The trial of substrate production using calcined clay balls is followed by physicochemical characterizations and agronomic trials, those aimed at evaluating its use in soilless cultivation [5].
The production of the substrates comprises three main phases :
- Extraction of raw materials ;
- Preparation of clay balls ;
- Firing.

2.1 Materials used

2.1.1 Raw materials extractions

- Spade ;
- 50 liters polypropylene bag for transport.

2.1.2 Raw materials characterization

-Transparent glass bottle with a wide enough neck to be sealed by hand for the sedimentation test.

2.1.3 Shaping the clay balls

- Mixer/Extruder : This is a metal meat grinder with modified teeth and outlet holes. The materials are abrasive and require improved surface resistance of the mechanical parts in contact with the material.
- Workbench ;
- Electric pre-firing oven at 200°C.

Firing Equipment

- Vertical intermittent charcoal kiln with a capacity of 17 L ;
- Probe thermocouple

2.1.4 Raw Materials

- Clay

Clays, from the Latin "Argilla," are sedimentary rocks composed primarily of phyllosilicates, more or less hydrated, with a grain size of less than 2µm in pedology and less than 4µm in geology. It is a natural, plastic material with appropriate water content, and hardens after drying or firing. Clay is very sensitive and easily altered and can be considered an evolving structure. Structurally, they consist of an arrangement of silicic tetrahedra and aluminic and/or magnesian octahedra. These tetrahedra and octahedra result from the superposition of three types of parallel anionic planes containing oxygen anions and hydroxyl groups.
The raw material for the production of calcined clay pellet substrates comes from the Betsimitatatra rice paddies, located in Ampasika at geographic coordinates (18°7'60"S and 47°46'60"E). Irrigated rice cultivation substrates are primarily composed of montmorillonite and kaolinite, two varieties widely distributed across the globe. It is likely that the raw material contains these two types of clay.

- Charcoal

The charcoal used as fuel is that available on the local market and used by households for cooking.

2.1.5 Mesuring equipments for determination of the physical, chemical and bacteriological characteristics of the substrates obtained

- Precision balance ;
- Beaker ;
- Mercury porosimeter ;
- Flame photometer ;
- pH meter.

2.1.6 Agronomic testing

- Container

The containers are 30 brown plastic pots, truncated cone-shaped, 9.5 cm high, with a bottom diameter of 7 cm and a top diameter of 10 cm.

- Plant materials.

Common name : Mentha spicata
Phylum : Spermatophyta
Class : Dicotyledons
Order : Lamiales
Family : Labiaceae (Menthaceae).
Genus : Mentha
Species : Mentha spicata L., synonym Mentha viridis L.
Characteristics

Category : perennial with creeping rhizomes.
Habit : erect.
Foliage : aromatic evergreen (smell reminiscent of chewing gum), light green to dark green. On tetragonal stems, leaves (8 cm) are lanceolate, toothed and heavily veined.
Colour : pink to pale mauve.
Seeds : brown
Growth : rapid.
Height : 0.30–0.60 cm.

- Nutrient solution

Major minerals such as N-P-K-Ca-Mg-S-Na-Cl and trace elements are essential for the plant. They are taken from the substrate solution, also known as the nutrient solution. The latter is based on natural liquid manure with added farm manure.

- Topsoil

It is used as a control.

2.2 Methods

2.2.1 Clay extraction methods.

In situ characterisation of clays is the preliminary stage of extraction, providing an initial assessment of the sample's texture and guiding the choice and selection of suitable raw materials. The results obtained are refined in the laboratory by means of a sedimentation test to evaluate the particle size fractions. This approach is based on the rapid identification tests commonly used by manufacturers of traditional fired bricks to evaluate certain characteristics of the material and confirm the suitability of the raw material for use. It comprises five (5) steps :
- Visual examination with the naked eye to assess the proportion of sandy and fine fractions in the sample, i.e. those with a diameter of less than 0.08 mm. Samples containing large stones, gravel or coarse sand should be avoided ;
- Splinter test : a slightly damp pellet of the sample is cut in half ; a shiny appearance indicates the presence of clay ;
- Washing test : the sample is wet and used to wash the hands ; a soapy feel and difficulty rinsing indicate that it is rich in clay ;
- The olfactory test, which focuses on raw materials with a smell reminiscent of 'mouldiness' accentuated by heating or humidification. It is a characteristic indicator of the presence of organic matter. The latter is necessary in the composition of raw materials because during firing, it burns away while creating voids in the substrate, thus improving its porosity ;
- The sedimentation test distinguishes between silt and clay and assesses the presence of organic matter. The procedure consists of filling a bottle with raw material up to a quarter of its height, filling the remaining three quarters with water and sealing the opening. The bottle is then shaken vigorously, left on a horizontal surface until the mixture settles, and this operation is repeated twice. At the end, a layer of sand settles at the bottom of the bottle, topped by a layer of silt and water, as well as organic and other elements.

The selected raw materials are taken from the ground using a spade. They are then placed in polypropylene bags and transported to the site where the calcined clay balls are manufactured, the Materials and Civil Engineering Laboratory of the CNRIT.

2.2.2 Mixing and shaping the balls

The raw material is moistened and reduced to a malleable paste. The amount of water required varies depending on the initial water content. At this stage, a preliminary test of the clay pellet shaping is necessary to ensure product homogeneity. The following clay ball mixing and shaping process is carried out. The mixer/extruder, which combines a horizontal axis mixer and a die, is optimised for improved efficiency. The water content is adjusted according to the consistency of the paste for better shaping at optimal speed. This results in a more consistent texture, facilitating extrusion. A constant and controlled feed reduces variations in the size and shape of the extrudates. It is also advisable to have an extrudate diameter between 5 mm and 7 mm to allow for better shaping of the balls. The extrudates are then rolled on a workbench to form balls approximately 8 mm in diameter.

2.2.3 Cooking method

A preliminary cooking test at up to 600°C is carried out to determine the behaviour of the raw material. Mass loss is measured as a function of temperature to assess, among other things, dehydration and decarbonation. For the

presentation of the results, each value is reported to the constant mass at 105°C and the whole is presented in a curve developed using EXCEL software.
After drying in the open air, the balls undergo pre-drying at a controlled temperature between 40°C and 60°C to minimise the risk of cracking. For firing, drying at 200°C is recommended to remove residual moisture. The clay balls and charcoal are then arranged in alternating layers of 3 cm and 5 cm thickness in the kiln. The arrangement of the clay balls and charcoal allows for better air circulation and more uniform firing by using grids or spacers between the layers. As a guide, the amount of charcoal required for firing is 700 g of eucalyptus charcoal for 2500 g of dried clay balls. This value is optimised according to the calorific value of the charcoal used. They are then heated to a temperature of 600°C and maintained for five hours. As this is an intermittent firing process, the calcined clay balls are removed after they have cooled completely. A gradual heating cycle is used to prevent thermal shock. Monitoring the temperature inside the furnace using thermocouples allows for better control of the firing process.

2.2.4 Determination of the physical, chemical and bacteriological characteristics of the substrates obtained

Knowledge of the culture substrate makes it possible to explain and predict the transfer of mineral elements between the solid phase and the nutrient solution to the plants, particularly when the medium is 'physically and chemically active. Hence the importance of determining the physical, chemical and bacteriological characteristics of the substrate obtained. The actual and apparent densities, intragranular and intergranular porosities, maximum water content of the substrate and cation exchange capacity are the characteristics to be determined.

The physical characteristics

The physical characteristics of calcined clay bead substrates to be determined are bulk and true density, true and apparent porosity, intergranular and intragranular porosity, and water content.
Substrate densities
-The « apparent density » Mva is the mass of the solid phase relative to the apparent volume. The substrate is placed in a glass beaker and filled to a known level of capacity determined as Va, also called the « apparent volume ». It is then weighed. If P0 is the mass of the empty beaker and P1 is the mass of the beaker with the substrate.

$$\mathrm{Mva} = \frac{(\mathrm{P1} - \mathrm{P0})}{\mathrm{Va}} \qquad \text{(Formula n°1)}$$

The « real density » (Mvr) is the mass of the solid phase relative to the volume of solid (Vs). The beaker containing the substrate is then filled with distilled water up to a known volume level V. Let Vv be the quantity of water poured in. The voids in the substrate are saturated by the liquid if no more bubbles are released at the surface.
The volume of the solid phase Vs is then equal to :

$$\mathrm{Vs} = \mathrm{V} - \mathrm{Vv} \qquad \text{(Formula n°2)}$$

$$M\mathrm{vr} = \frac{\mathrm{P1} - \mathrm{P0}}{\mathrm{Vs}} \qquad \text{(Formula n°3)}$$

Water content

This section concerns the study of substrate behaviour in the presence of the liquid phase. To interpret the moisture results required for crop monitoring, only the volumetric expression is used, as it represents the water available to the roots, that retained in the substrate.
The same sample we used previously, soaked in water, is weighed after complete drying.
Let P2 be the weight of this substrate sample. The mass of water retained in the substrate Mo is :
$M\mathrm{O} = \mathrm{P2} - \mathrm{P1}$(Formula n°4)

The water content Hv is then :

$$\mathrm{Hv} = \frac{\mathrm{P2} - P1}{\mathrm{V}} \qquad \text{(Formula n°5)}$$

V being the volume marked on the beaker's level line.

Characteristics of pore space

A solid material occupies a container with a given volume called the « apparent volume » (Va). During cultivation, this volume Va is occupied by the solid phase, which has its own volume (Vs), and by fluids (liquid phase and gas phase) occupying the pore space or « void volume » (Vv). The « total porosity » Pt of such a medium is defined by the ratio between the void volume and the apparent volume :

$$Pt = \frac{\mathrm{Vv}}{\mathrm{Va}}$$ (Formula n°6)

$$Pt = \frac{(\mathrm{Va} - \mathrm{Vs})}{\mathrm{Va}}$$ (Formula n°7)

Parfois, il est plus commode de considérer le rapport Vv/Vs appelé : « void index » Iv

$$Iv = \frac{\mathrm{Vv}}{Vs}$$ (Formula n°8)

There are two types of porosity one relating to the average value of voids inside each balls, known as « intragranular porosity », and the other relating to voids outside each balls but retained in the container, known as « intergranular porosity ».
Pintra « intragranular porosity » refers to the pores found inside the individual grains of the balls. These pores can be of different sizes and shapes. It is calculated by measuring the volume of the pores inside the balls and relating it to the total volume of the balls. The général formula is :

$$Pintra = \frac{\mathrm{Vig}}{\mathrm{Vtg}}$$ (Formula n° 9)

Where Vig is the volume of pores inside a clay balls and Vtg is the total volume of the clay bead.
The pores inside the clay ball are first determined by collecting representative samples of all the balls, which have been dried beforehand. Each ball is then characterised by dry weighing and placed in a mercury porosimeter. Mercury is injected under pressure and gradually into the pores. Vig is the average value of the measured volumes of mercury injected into the balls. Vtg is the average volume value of each ball in the representative sample.
The « intergranular porosity » Pinter is calculated using formula n°10.

$$Pinter = Pt - Pintra$$ (Formula n°10)

Chemical characteristics

The chemical characteristics define the reactivity of the substrate. For calcined clay balls substrate, the pH and cation exchange capacity must be determined.

- *pH(H_2O)*

The value of the pH is necessary for fertilisation and to meet the requirements of the plants. In any liquid medium, the presence of H^+ ions determines the acid-base reaction of that medium. This is the pH of the solution in which the substrate is immersed. To measure the pH, distilled water is added to the substrate in a volume ratio of 1:5, it is then measured using a pH meter. The value obtained is defined as the pH (H_2O).

- *Cation exchange capacity*

Dissolution is the ability to dissolve more or less easily by dissociating into several electrically charged particles called ions. The liquid phase retained in the substrate, from which the plant will extract nutrients, is an aqueous solution containing mainly charged particles. The major elements are represented by cations and anions. In the absence of plants, contact between the solution and the substrate usually changes the composition of the latter, due to exchange phenomena resulting from the exchange capacity of the substrate, the process of insolubilisation or dissolution, and the biological instability of the substrate, which results in the production or use of mineral elements from certain solid materials used to make the substrate. This property is called 'cation exchange capacity', often abbreviated to CEC. It is usually expressed in milliequivalents per kg of material. It is most often expressed in milliequivalents per litre of substrate (meq/L of substrate).
The protocol used is that used by the CNRIT chemistry laboratory, analysis by photometry of K^+ in the liquid phase.
The reagents are freshly prepared distilled water and K_2CO_3.
Samples of the substrate are each mixed with K_2CO_3 solution. The potassium content of the solution is depleted in K. The liquid phases are then analysed by flame photometry to determine the non-adsorbed K+ in the liquid phase.
Samples of 60 ml of the substrate are each mixed with 300 ml of K_2CO_3 solution in increasing doses. After two hours, the potassium content of the solution is depleted of K. The liquid phases are then analysed by flame photometry to determine the amount of unadsorbed K^+ in the liquid phase. The values are plotted on a previously

established calibration curve. This curve gives the values in ppm of the concentrations of non-adsorbed K^+. The quantity adsorbed by the solid phase (substrate) is obtained by calculating the difference between the quantity of K^+ ions in the initial liquid phase and the liquid phase after mixing with the substrate.

2.2.5 Methods for agronomic testing on calcined clay pellet substrate

Soilless cultivation, a technique using substrates other than arable soil, is employed. The plants are placed in pots filled with the substrate and are regularly exposed to a solution that provides essential minerals and nutrients. After washing and disinfecting the pots, they are filled with a substrate of clay balls previously soaked in water or topsoil. They were then placed on a support covered with sterilised plastic sheeting. They were positioned facing east, one metre from a bay window. The young plants were stolons taken from clumps. These were immersed in a solution of two parts per thousand bleach for two minutes, followed by rinsing with distilled water.
Twenty (20) pots are filled with calcined clay balls and ten (10) others with topsoil to serve as controls. Two (2) stolons are planted in each pot.
To facilitate the maintenance of plant health, cultivation is carried out in an open system where drainage water is collected and discharged directly into the drains.
To water the calcined clay pellet substrates, the pots are immersed in a basin filled with nutrient solution, or simply in water, for three minutes, five or six times a day, starting one hour before sunrise and ending one hour before sunset.
For the control group, the pots are not immersed in water but watered directly at the same frequency. The pH of the substrate is controlled by adjusting the proportion of water and nutrient solution.

3. RESULTS

The results of the tests on the production of substrates made from calcined clay beads are presented below, along with their physical and chemical characteristics and the associated agronomic tests.

3.1 Production of calcined clay beads growing media

The production of growing media involves three main phases :
- Extraction of raw materials, which required testing to select suitable raw materials with a high clay content but containing organic matter that will be burned during firing, thereby improving the pore space ;
- Preparation of the clay balls ;
- Firing, preceded by tests to determine mass loss as a function of temperature.

3.2 Results of tests on the choice of raw materials : clay

The results of the four preliminary tests in the table provide information on the composition of the selected raw material.

Table 1 : Results of preliminary tests on the raw material sample

Designation of tests	Observations	Meaning
Visual inspection with the naked eye	Free of large stones, gravel and coarse sand, most grains not visible to the naked eye	High clay content
Shine test	Shiny appearance at the cut mark	Presence of clay
Washing test	Soapy feeling on hands washed with the sample	High clay content
Smell test	Musty smell accentuated by heating or humidification	Presence of organic matter

These preliminary tests show that the raw material has a high clay and organic matter content. These results are confirmed by the sedimentation test results in Figure 1.

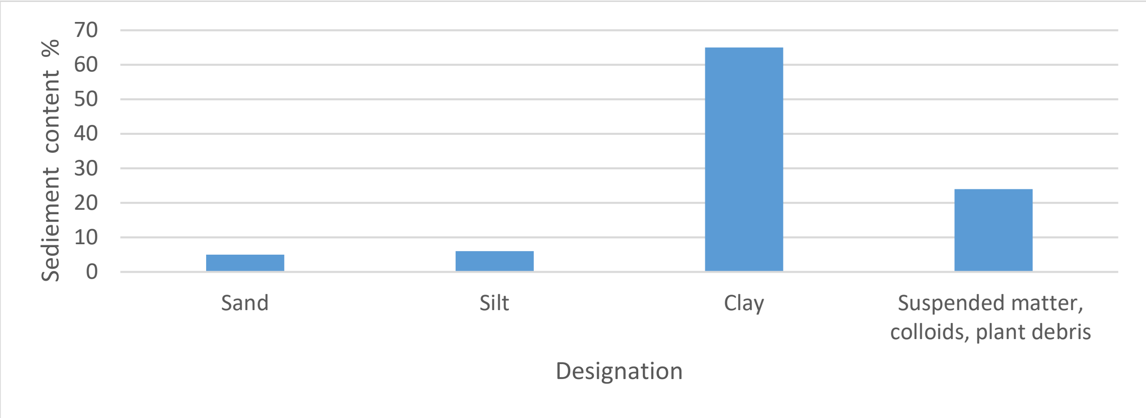

Figure-1 : Results of sedimentation tests

The sedimentation test provides details on the proportion of textural fractions : the clay phase represents 60% of the volume of the raw material sample, while the other components (suspended matter, colloids, debris and others) correspond to 25% of the total sample.

3.3 Preparation of clay balls

The curve showing the variation in mass loss as a function of temperature is shown in Figure 2.

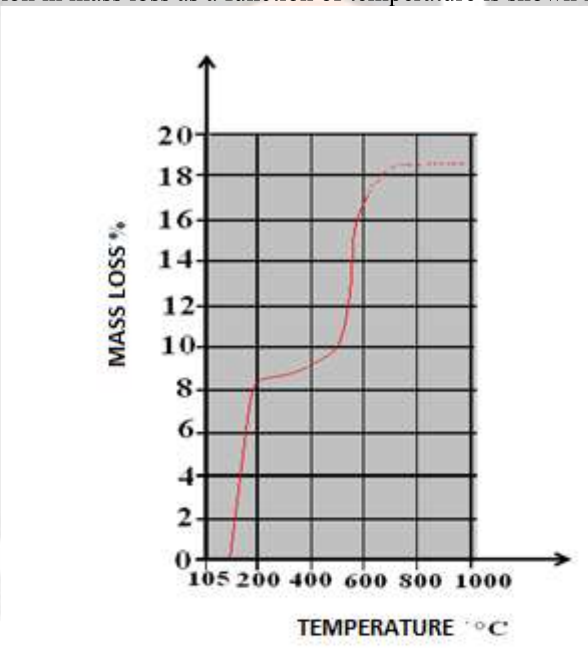

Figure-2 : Mass loss curve as a function of temperature relative to the constant mass corresponding to 105°C

From the mass loss curve as a function of temperature in Figure 2, three slopes can be observed : two sharp slopes before 200°C and between 450°C and 600°C, separated by an almost flat section between 200°C and 450°C. After firing and cooling, the calcined clay beads are beige to light brown in colour and between 6 and 8 mm in diameter, as shown in the photo of the beads in Figure 3.

Figure-3 : Photo of clay balls calcined after firing

3.4 Physical and chemical characteristics of the calcined clay balls substrate

The results of the physical and chemical characterisation of the calcined clay balls obtained are summarised in Table 2**.**

Table 2 : Physical and chemical characteristics of calcined clay balls

Designation	Symblol	Unit	Value
Physical characteristics			
Apparent density	M_{va}	kg/m3	546
Real density	Mvr	kg/m3	1832
Pore space characteristics			
Void ratio	Iv	-	2,36
Total porosity	P_t	%	70,20
Intragranular porosity	P_{intra}	%	36,20
Intergranular porosity	P_{inter}	%	34,00
Water content	H_v	kg/m3	304
Chemical characteristics			
Hydrogen potential	pH (H_2O)	-	7,8

The results in Table 2 are supplemented by the curve in Figure 4, which highlights the cation exchange capacity of the substrate.

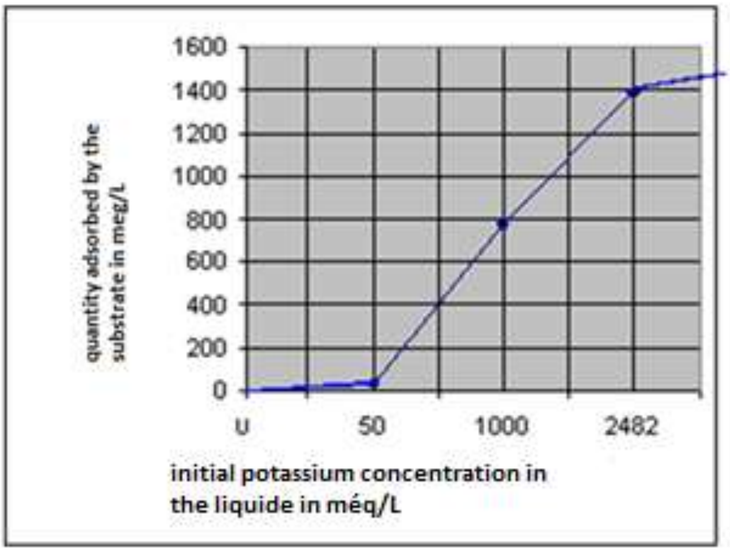

Figure-4 : Variation curve of cation exchange capacity, adsorption of potassium by the substrate

3.5 Results of agronomic trials in soilless cultivation on calcined clay substrate of *Mentha spicata*

After seven days, the stems of plants grown in clay pellet substrates are longer than those grown in topsoil. This difference in length can reach 15 cm after 45 days.

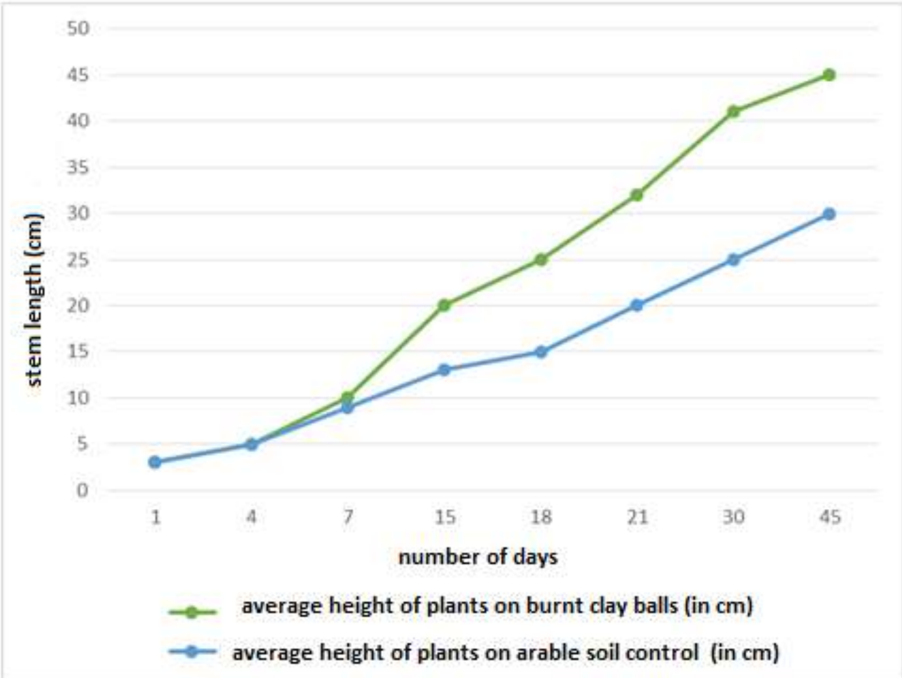

Figure 5 : Curve showing the change in stem length over time

As *Mentha spicata* are perishable foodstuffs, the fresher they are, the more they are appreciated for their flavour and aroma

Figure-6 : Photos of agronomic trials, end of cultivation

4. DISCUSSIONS

4.1 Method for producing calcined clay beads substrate

Calcined clay beads substrate is produced using the same technologies as those used to produce terracotta materials for construction. The major contribution of our work lies in adapting these methods for use in another industry. Compared to expanded clay, which is fired at temperatures above 1000°C [6], calcined clay is fired at 600°C, resulting in energy savings. This production temperature is sufficient to sanitise the substrate, which becomes free of all bacteriological activity inside, a favourable condition given that it is in direct contact with aromatic herbs that are eaten raw when used in soilless cultivation [7]. In addition, it gives it adequate mechanical strength, as it does not settle.
From the curve in graph No. 2 representing mass loss as a function of temperature, a weight loss corresponding to the loss of hydration water and part of the hygroscopic water between 20°C and 200°C can be observed. A very slight slope, almost flat, is observed between 200°C and 450°C, followed by a sharp slope between 450°C and 600°C. The latter corresponds, on the one hand, to the partial loss of water of constitution, one of the characteristics of hydrated phyllosilicates during firing and, on the other hand, to that of organic matter [8]. These results confirm those of the raw material sedimentation test in graph No.1, showing the presence of clay and organic matter in the initial raw material.

4.2 Physical characteristics of calcined clay beads : air and water content of the substrate

The presence of a gas phase is necessary in a growing medium. Root system development occurs in the pore space, to the detriment of the gas phase. However, this decrease in air content may be quite small, as the roots also tend to have a structuring effect on the substrate [9]. One of the determining parameters is intergranular porosity. In this study, its value is 34%, which gives a volume proportion occupied by the grains of 66%. By adopting a hard sphere model and considering the grains as non-deformable balls that are in contact, it is known that for a body-centred cubic (bcc) structure, also known as a face-centred cubic structure, the proportion of space occupied by the spheres, also known as compactness, is around 0.68 [10]. By comparing the value of the proportion of volume occupied by the clay balls to that of the compactness of the 14 Bravais lattices, the arrangement of the clay balls is close to a body-centred cubic lattice configuration. This structure is not compact in the strict sense, unlike the face-centred cubic or compact hexagonal structure with a compactness of 0.74 [11]. According to the results of agronomic trials presented in Figure 6, from the seventh day after planting, the length of the stems of plants grown on clay pellet substrates is greater than that of plants grown in arable soil. This difference in length can reach 15 cm after 45 days. This situation can be attributed, among other things, to the compaction of the topsoil during cultivation, leading to a decrease in intergranular porosity and affecting oxygen availability at the root level [12]. On the other hand, calcined clay pellets, with their 'non-compact' structure, are conducive to gas exchange, which has the effect of preventing the risk of root asphyxia. One of the characteristics of the growing medium is the volume of water available to the plant, known as water content. This represents the amount of water retained in the container. Based on the results of the sedimentation test of the raw material used to manufacture the substrate (Table 2), we have a percentage of suspended matter and colloids, organic debris of 25%. During firing, these were calcined, leaving voids inside the substrate granules. These voids contribute to the high intragranular porosity value of 39.80% and are partly responsible for water retention [13]. These voids improve the texture of the final product by increasing its water content. It should be noted that in this study, it has a value of Hv = 304 g/litre. As a result, it has been found that cultivation on calcined clay substrates is more effective than cultivation on arable land, especially at the end of the growing season. This situation is likely due to soil compaction during cultivation in the case of arable land, leading to a decrease in porosity and thus affecting the availability of air and water for plants [14].

4.3 Chemical characteristics : cation exchange capacity

Cation exchange capacity originates from the substitution of a valence ion (N-1) by a valence ion N within the structure, either in the octahedral cavities or in the tetrahedral cavities, thus leading to an electrical imbalance. Electrical neutrality per layer is due to cations adsorbed on its surface, which are responsible for cation exchange. For fired clays, the nature of the product is determined by that of the pre-existing clay minerals and their structural substitutions. During firing, the mineral undergoes dehydroxylation, passing through intermediate stages formed by chemically equivalent oxides. According to the results of potassium adsorption tests on the substrate in Figure 3, the substrate is chemically active with a cation exchange capacity of up to 1400 m.e.g./litre, equivalent to 76.41 m.e.g. per 100 g. When used in soilless cultivation, this characteristic allows for alternating watering with water and nutrient solution.

4.4 Use of calcined clay substrate in pot cultivation

Soilless cultivation of Mentha spicata shows us that calcined clay balls can be used very effectively as a substrate. This is based on the basic principles of hydroponics, as the substrate is regularly irrigated by immersion in a solution that provides the plant with essential minerals and nutrients [15]. Under equal conditions, it is better than arable land and does not require ploughing. As the calcined clay balls are free of any form of organic life, the young plants are sterilised before planting, and the cultivation is carried out without chemical fertilisers or insecticides, the aromatic herbs obtained can be considered healthy[16]. In Figure 6, as an ornamental plant, the greenish tufts of Mentha spicata are very decorative against the beige and light brown background of the substrate, which matches the brown pots. Placed on a glassed-in balcony or in a room, its scent perfumes the space and provides a feeling of freshness.

5. CONCLUSION

The study on the production of calcined clay balls substrate highlighted that clays traditionally used in conventional cultivation can be transformed into a substrate suitable for soilless cultivation. Beyond the selection of raw materials, the different stages of the manufacturing process, mixing, extrusion, shaping into balls, and firing, are decisive in determining the physical and chemical characteristics of the final product, such as porosity, water-holding capacity, pH, and cation-exchange capacity. From the curve of mass loss as a function of temperature, relative to the constant mass at 105 °C of the raw material, the firing improves the intragranular porosity of the clay balls by eliminating organic matter and partially removing structural water from hydrated phyllosilicates between 200 °C and 450 °C. Given the polluted state of urban soils, such as in the Urban Commune of Antananarivo, the use of calcined clay balls as a soilless substrate could offer a practical solution for herb farmers. Since these are perishable food products, the fresher they are, the more appreciated they are for their flavor and aroma. Effective water management is important for irrigation, and regulating the substrate through soilless cultivation is one possibility in industrial farming. This approach is no longer dependent on weather conditions, allowing for safe, organized production activity aligned with expected results. The concept of integrating an herb garden into living spaces may also appeal to urban residents seeking to reconnect with nature. The study of chemical properties was limited to potassium, which is insufficient, as its interaction with phosphorus is also of interest. It is additionally necessary to improve the water-holding capacity of the substrate to better control irrigation frequency, potentially by combining it with hydro-retentive materials.

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