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Artisanal solar dryer adapted to the climate of the highlands of Madagascar

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Abstract *— Madagascar has vast cultivable land and great seasonal variation in agricultural production. At market levels, it encounters a period of overproduction which leads to a large drop in product prices. Thanks to the climatic conditions of this large island which has the advantage of sunshine throughout the year, we have studied and created in this article an Artisanal solar dryer adapted to the climate of the highlands of Madagascar. We are interested in studying a solar ginger dryer because this spice takes on important roles in terms of nutrients. Our dryer is made from locally available materials. According to our studies followed by experiments, we have observed the effectiveness of our homemade solar dryer. The maximum internal temperature of our dryer reaches a value of 50°C after 50 minutes of operation. The nutritional values of dried ginger are preserved, which proves the effectiveness of our dryer.*

Keyword*— *solar dryer, dried ginger, absorbent plate

I. INTRODUCTION

Madagascar is a country with fertile soils. Various vegetables and fruits are produced in different seasons. Growers as well as consumers encounter problems when storing fruits and vegetables. The promotion of local products from Madagascar is very important given its abundance in a short period. Farmers use traditional methods to dry fruits and vegetables. To have more output and efficiency, we will present in this article studies, simulations as well as a design of an artisanal dryer adapted to the Malagasy climate. Our device is made from local raw materials available from farmers. The drying speed depends on several parameters including air temperature, ventilation speed and the intensity of solar radiation as well as air humidity.

Physical characteristic of a ginger [1] [2]

Ginger is a plant recently gaining attention in the food and pharmaceutical industries because of its spice and medicinal importance. Major post-harvest processing of ginger is being carried out locally in West Africa and Nigeria due to the unavailability of information on the engineering properties including physical, mechanical, thermal and optical properties which are the main considerations in the design of machines for post-harvest handling of crops. The research looked at some physical properties of ginger (Zingiber officinale) rhizomes such as major, minor and intermediate diameters, geometric mean, sphere city, bulk volume, bulk density, surface area, angle of repose and the coefficient of friction which are essential in the design and construction of the processing and handling equipment of Zingiber officinale. The properties were determined using ASAE standards. The average value obtained for major diameter, minor diameter, intermediate diameter, geometric mean, sphere city, bulk volume, surface area, bulk density and angle of repose within the moisture content range of 10.9 % and 51.6 % dry basis are 112 mm, 38.3 mm, 72.3 mm, 67.6 mm, 0.61, 832.5 cm^3 , 147 cm2 , 0.92 g/cm3 , 480 respectively. The coefficient of friction was obtained on three different structural materials, the values obtained are: 0.40 on glass, 0.49 on stainless steel and 0.55 on wood. All the physical properties measured showed some deviations from the average values which is typical of biomaterials. The physical properties increase with an increase in the moisture content except the sphere city and bulk density which decrease as the moisture content increases.

Table 1: Summary of Physical Properties of Ginger

Property	Number of Samples	Range	Mean Value	Standard Deviation
Major Diameter(mm)	41	761-133	112	25,5
Intermediate Diameter(mm)	41	60-82,0	72,3	9,8
Minor Diameter(mm)	41	28-44,0	38,3	7,1
Geometric Mean(mm)	41	50,4-78,3	67,6	12,4
Sphericity(dec)	41	0,66-0,59	0,61	0,03
Surface Area(cm2)	41	79,8-192,6	147	49,8
Bulk Volume(cm3)	41	660-112,0	832,5	201,2
Bulk Density (g/cm3)	41	0,96-0,87	0,92	0,048

Chemical properties of ginger

The chemical composition and antioxidant activity (in aqueous and solvent extracts) of Ginger root (Zingiber officinale) were determined. The antioxidant components analysed were polyphenols, vitamin C, β carotene, flavonoids and tannins. Antioxidant assays such as free radical scavenging activity, reducing power and total antioxidant activity were carried out for ethanol, methanol, acetone, 80% methanol and 80% ethanolic extracts. Protein and fat of sample were 5.08 and 3.72 g/100 g respectively. Ash, minerals namely iron, calcium, phosphorous, zinc, copper, chromium and manganese) and vitamin C were 3.85 (g), 8.0 (mg), 88.4 (mg), 174 (mg), 0.92 (mg), 0.545 (mg), 70 (μg), 9.13 (mg) and 9.33 (mg) per 100 g of sample, respectively. Antioxidant components (polyphenols, flavonoids and total tannin) were higher in hot water (100°C) extract than other solvent extracts and 30°C water extract. Antioxidant activity by 3 different methods showed higher activity in solvent extract than water extract. Order of antioxidant activity by reducing power and free radical scavenging activity by DPPH was as follows, 80% methanolic > 80%ethanolic > methanolic > ethanolic > 30°C water >100°C water > acetonic extract. [4]

The obtained results recorded that hot water extract of ginger peels was the promising extract exhibiting promising antioxidant activity. Fractionation of this promising extract was achieved by silica gel column chromatography with petroleum ether/ethyl acetate as mobile phase. Six fractions were produced. Thin layer chromatography ($TLCF_{254}$) was used for separation of active compounds and bioautography confirmed their antioxidant efficiency. Higher antioxidant activity and cytotoxicity against HepG2 cell line was recorded by fraction No. 4. Cold water extract of ginger peels exhibited comparatively higher antioxidant efficiency while both aqueous peel extracts showed antibacterial efficiency against four Gram-positive and Gram-negative bacterial strains using well diffusion assay.[5]

Ginger root (Zingiber officinal Rose) was analyzed to identify its nutritional and anti- nutritional contents. The results showed that Ginger has 34.13% crude protein, 4.07% Ether Extract, 4.02% crude fiber content, 13.75% moisture content, 7.64% Ash content and 1.036% vitamin C. Furthermore, ginger contains major minerals like: Zn 64.0 mg/l, Mn 5.90 mg/l, Fe 279.7 mg/l, Cu 8.80 mg/l, Ca 280.0 mg/l and P 8068.0 mg/l. The result obtained confirmed the usefulness of ginger root as a potential functional food and could be explored further in new product and formulation. I. Introduction Ginger (Zingiber officinal rose) is an underground stem or rhizome of the plant Zingiber officinate. It has been used as traditional medicine in China, India, Malaysia and Arabic countries since ancient times. Ginger has been used to treat stomach upset, nausea, diarrhea, colic, arthritis, heart conditions, flu- like symptoms and painful menstrual periods 1. It was found that Ginger extracts have antimicrobial properties against E.Coli, sslmonella typhi and bacillus substilis that are common cause of gastro intestinal tract infections 2 . The important active component of ginger root is the volatile oil and pungent phenol compound such as gingerol, which is a very potent anti-inflammatory compound. Modern scientific research has revealed that ginger possesses numerous therapeutic like anti-oxidant effects, an ability to inhibit the formation of inflammatory compounds and direct anti-inflammatory effects 3. Ginger has also been found to reduce all symptoms associated with motion sickness like dizziness, cold sweating, nausea and vomiting 4.[5]

Table 2*: Nutritional composition of ginger (per 100g)*

Constituent	**Value**	**Constituent**	**Value**
Moisture	$15{,}02 \pm 0{,}04$	Ash(g)	$3{,}85 \pm 0{,}61(4{,}53)$
Protein(g)	$5{,}087 \pm 0{,}09(5{,}98)$	Calcium(mg)	$88{,}4 \pm 0{,}97(104{,}02)$
Fat(g)	$3{,}72 \pm 0{,}03(4{,}37)$	Phosphorous(mg)	$174 \pm 1{,}2(204{,}75)$
Insoluble fiber (%)	$23{,}5 \pm 0{,}01(27{,}65)$	Iron(mg)	$8{,}0 \pm 0{,}2(9{,}41)$
Soluble fiber (%)	$25{,}5 \pm 0{,}04(30{,}0)$	Zing(mg)	$0{,}92 \pm 0(1{,}08)$
Carbohydrate(g)	$38{,}35 \pm 0{,}61(4{,}53)$	Copper(mg)	$0{,}545 \pm 0{,}002(0{,}641)$
Vitamin C(mg)	$9{,}33 \pm 0{,}08(4{,}53)$	Manganese(mg)	$9{,}13 \pm 0{,}01(10{,}74)$
Total carotenoids	$79 \pm 0{,}2(9296)$	Chromium(µg)	$70 \pm 0(83{,}37)$

All value in this table represents the mean $\pm SD(n = 4)$. Figures in the parenthesis represent the dry weight values.

Table 3: Antioxidant components and total antioxidant activity of ginger in different solvent extracts.

Antioxidant components	**Water**		**Methanol**	**Ethanol**	**Methanol (80%)**	**Ethanol (80%)**	**Acetone**
	(0,060)	(0,010)					
Total Polyphenols mg/100g	$840 \pm 2{,}1$	$838 \pm 3{,}0$	$510{,}22 \pm 2{,}2$	$565 \pm 4{,}1$	780 ± 5	$800 \pm 4{,}3$	$325 \pm 1{,}9$
Tannin g/100g	$15{,}1 \pm 0{,}05$	$1{,}34 \pm 0{,}08$	$1{,}12 \pm 0{,}05$	$0{,}98 \pm 0{,}03$	$1{,}28 \pm 0{,}01$	$1{,}15 \pm 0{,}1$	$0{,}67 \pm 0{,}08$
Flavonoids g/100g	$2{,}98 \pm 0{,}06$	$1{,}371 \pm 0{,}01$	$0{,}685 \pm 0{,}005$	$0{,}278 \pm 0{,}003$	$0{,}404 \pm 0{,}002$	$0{,}352 \pm 0{,}002$	$2{,}249 \pm 0{,}002$
Total antioxidant activity $\mu mol/g$ of sample	$73529{,}4 \pm 121$	$73529{,}4 \pm 0{,}04$	$98822{,}5 \pm 66$	$91176{,}25 \pm 66$	85295 ± 47	80000 ± 38	32056 ± 27

Table 4: Correlation between antioxidant activity and antioxidant component of sample in different solvent extracts.

Corrélation (R^2 values)	**Water extract**			**Solvent extract**		
Antioxydant components	Method of assay			Method of assay		
	DPPH	Reducing power	Total antioxydant	DPPH	Reducing power	Total antioxydant
Flavonoids	-1	-1	-1	0,493	0,505	0,613
Polyphenols	1	1	1	0,901	0,847	0,579
Total Tannin	-1	-1	-1	0,985	0,887	0,885

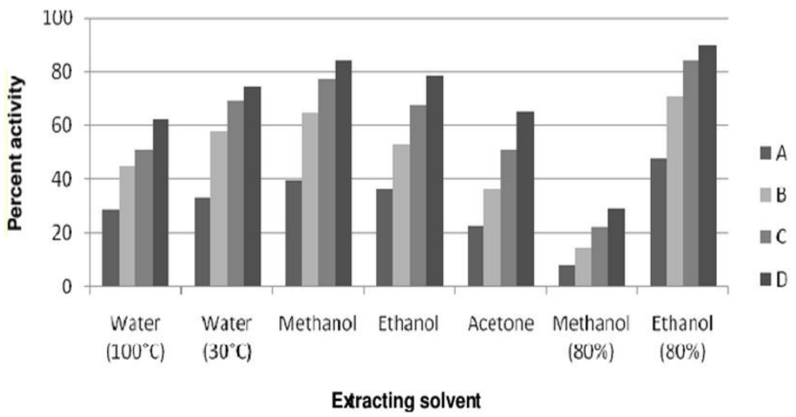

Fig.1 Free Radical Scavenging Activity of ginger in different solvent extracts. Concentration of sample (in mg): In 80% methanolic extract, A: 0.4, B: 0.6, C: 0.8 and D: 1.0. For all other extracts, A: 2.5, B: 5.0, C: 7.5, D: 10.

For solvent extract in DPPH method, methanolic extract was not included for statistical analysis since the concentration did not match with other extracts

It has been reported that the reducing power of bioactive compounds is associated with antioxidant activity (Yen et al., 1993; Siddhuraju et al., 2002). Hence, it is essential to determine the reducing power of phenolic constituents to explain the relationship between their antioxidant effect and their reducing power. The reducing power of different solvent extracts of ginger was estimated. Highest reducing power was also in 80% methanolic extract followed by 80% ethanolic extract (Figure 2). As reported by Chen et al. (2008), the reducing power of methanolic extract of 18 different species of ginger ranged from 0.34 to 1.6 nm in 100 mg of sample. In our study, methanolic extract of sample showed much higher activity of 0.208, 0.393, 0.558, 0.681 nm for 2.0, 4.0, 6.0 and 8.0 mg of sample. Antioxidant components and activity are highly dependent on extracting solvent and concentration of solvent (Turkmen et al., 2006), but they also vary within the samples. Many researchers have reported the relationship between phenolic content and antioxidant activity. In some studies, they found a correlation between the phenolic content and antioxidant activity (Velioglu et al., 1998), whereas others found no relationship (Kahkonen et al., 1999). As it is shown in **Table 4**, in this study we also found high correlation between polyphenol content and antioxidant activity in both water extract (R2 = 1) and solvent extract (DPPH, R2 = 0.901, reducing power, R2 = 0.847 and total antioxidant activity R2 = 0.579). Total tannin and flavonoids did not show any correlation with antioxidant activity in aqueous extract. In solvent extract, total tannin showed high correlation with reducing activity (R2 = 0.887), total antioxidant activity (R2 = 0.885) and free radical scavenging activity (R2 = 0.985). Flavonoids showed correlation with reducing power (R2 = 0.505), total antioxidant (R2 = 0.613) and DPPH (R2 = 0.493). Since the antioxidant activity was higher in alcoholic extract than aqueous extract, it is advisable to use the extracting media capable of extracting the lipophilic antioxidant compounds from ginger.

USES OF DRY GINGER [6]

Dried ginger is known for its health benefits and is utilised as a health supplement worldwide. They have been used extensively in respiratory, digestive, and cardiac conditions, boosting overall health.

Dry ginger powder is known for its digestive benefits. Adding it with buttermilk or vegetables can ease aches and discomforts associated with long-term digestion issues. Grabbing a pinch of dry ginger powder before meals kindles the digestive fire. It is renowned for its Grahi (absorbent or binding nature), making it suitable for constipation and IBS. It relieves bloating, intestinal gas, indigestion, and other discomforts.

Dried ginger is rich in gingerol and shogaol, contributing to its analgesic and anti-inflammatory properties. It can inhibit the release of inflammatory molecules and flush out toxins in arthritic conditions, including rheumatoid arthritis, osteoarthritis, etc. Traditional formulations include dried ginger as an active ingredient in herbal formulations for pain and swelling.

Consuming dried ginger can support the immune system. The anti-microbial properties help fight bacterial, viral, and fungal infections, strengthen the body's innate immunity, and improve overall health. The tradition of ginger tea or ginger kwath during winter has deep roots in enhancing the body's strength.

Whether it is a cough or a cold, ginger combinations always win the hearts of millions as the quickest remedy. Gingerol, the active constituent in dried ginger, contains anti-microbial compounds that help fight respiratory conditions. A pinch of dry ginger powder with honey or turmeric helps address dry cough and cold.

The increased cholesterol levels in the body may increase the risk of heart attack and other conditions. Incorporating dried ginger in meals can significantly reduce harmful cholesterol levels and improve good cholesterol levels.

Dry ginger powder can create wonders on the skin. Dried ginger's antioxidant and anti-inflammatory properties boost skin hydration, increase skin elasticity, reduce acne and wrinkles, improve skin tone, and prevent ageing.

Gingerols and Shogaols in ginger can stimulate various biological reactions, including burning belly fat and body weight. They can indirectly act on weight management by stabilizing blood sugar and improving digestion, absorption, and elimination of food we consume.

Ginger-based hair products, including oil, paste, or hair mask, can adapted according to your choice. They benefit from enhanced blood circulation to the scalp, improved hair growth, hair loss and premature greying, and prevention of scalp infections.

Dried Ginger Powder can be an ideal remedy for period-related issues such as muscle cramps, body aches, nausea, bloating, etc. Natural compounds in ginger can relax uterine muscles and reduce muscular contractions' intensity. Furthermore, they improve blood circulation, regulate hormones, and alleviate periods.

SOLAR DRYER

Solar dryers are devices that use solar energy to dry substances, especially food.

Traditional methods of food drying are to place the foodstuffs in the sun in the open air. This method, called sun drying, is effective for small amounts of food. The area needed for sun drying expands with food quantity and since the food is placed in the open air, it is easily contaminated. Therefore, one major reason why sun drying is not easily performed with larger quantities of food is that the monitoring and overview becomes increasingly more difficult with increasing food quantities. In contrast to sun drying, where the food is exposed directly to the sun, the solar drying method uses indirect solar radiation. The principle of the solar drying technique is to collect solar energy by heating-up the air volume in solar collectors and conduct the hot air from the collector to an attached enclosure, the meat drying chamber. Here the products to be dried are laid out. [7]

In this closed system, consisting of a solar collector and a meat drying chamber, without direct exposure of the meat to the environment, meat drying is more hygienic as there is no secondary contamination of the products through rain, dust, insects, rodents or birds. The products are dried by hot air only. There is no direct impact of solar radiation (sunshine) on the product. The solar energy produces hot air in the solar collectors. Increasing the temperature in a given volume of air decreases the relative air humidity and increases the water absorption capacity of the air. A steady stream of hot air into the drying chamber circulating through and over the meat pieces results in continuous and efficient dehydration. [8]

Solar dryers require a certain investment for the set-up of the appliance, but no expenditures for the fuel. The basic function of a solar dryer is to heat air to a constant temperature with solar energy, which facilitates extraction of humidity from crops inside a drying chamber. Ventilation is enabled at a constant rate through defined air inlets and outlets, small solar ventilators or temperature difference, either due to exposition or vertical height. In direct sun driers the food is put in boxes with a transparent lid. Additionally, the temperature in the drier is raised due to the greenhouse effect and the air exchange is regulated by vents. The food is not exposed to direct sunlight in indirect sun driers as the fresh air is heated separately from the food chamber. This method is preferable for drying foods which lose nutritional value when exposed to direct sunlight. Hybrid driers combine solar energy with a fossil fuel or biomass fuel (Green and Schwarz, 2001a).

A first step when considering solar drying is to compare the different drying options available. Solar drying will only be successful, when it shows tangible benefits in comparison to existing drying methods. In comparison to the traditional way of drying outside in an open field, solar dryers prevent contamination of produce by dust, insects, etc., thereby ensuring quality. They allow small-scale farmers to transform their harvest into storable and tradable goods, which they can sell off-season at higher prices. The constant temperature and ventilation allow a consistent drying process which results in better product quality and higher prices. However, the investments costs of solar dryers vary highly depending on the size of the solar dryer, locally available materials and environmental conditions, such as slope and exposition of the side, rainy seasons. [9][10]

Different types of solar dryers

- direct drying (solar box dryer),
- indirect drying (solar cabinet dryer),
- mixed mode drying (solar tunnel dryer) or
- hybrid drying (hybrid solar/biomass cabinet dryer).

Benefits of Solar Dryers [11]

The technology provides several socio-economic benefits. One of the main issues facing developing countries today is the issue of food security. The solar food dryer can improve food security through allowing the longer storage of food after drying compared to food that hasn't been dried.

The solar dryer can save fuel and electricity when it replaces dryer variations that require an external energy source in the form of electricity or fossil fuel. In addition, solar food dryers cut drying times in comparison to sun drying. While fossil fuel or electrically powered dryers might provide certain benefits (more consistent air flow and higher temperatures), the financial barriers that these technologies provide might be too high for marginal farmers. For instance, electricity might be not available or too expensive and fossil fuel powered drying might pose large initial and running costs.

Fruits, vegetables and meat dried in a solar dryer are better in quality and hygiene compared to fruits, vegetables and meat dried in sun drying conditions. As mentioned, due to the closed system design, contamination of food is prevented or minimized. In addition, the food is not vulnerable to rain and dust, compared to the open system design of sun drying.

In rural areas where farmers grow fruits and vegetables without proper food drying facilities, the farmers need to sell the food in the market shortly after harvesting. When food production is high, the farmers have to sell the food at low price to prevent the food from losing value through decomposition. Therefore, the solar food dryer might be able to prevent the financial losses farmers in these situations face. Dried food can be stored longer and retain quality longer. Moreover, dried fruits and vegetables might be sold as differentiated products which possibly enhances their market value. For example, dried meat can be processed into a variety of different products.

Drying food reduces its volume. Therefore, in combination to longer storage times, the food is also more easily transported after drying which potentially opens up additional markets to the producer of the food.

II. METHOD AND MATERIALS

One cm thick plywood was used to make the entire dryer.

The air sensor is made up of:

- an insulated wooden board (plywood)
- two layers of polystyrene used as insulation
- a blackened aluminum sheet covering the insulation
- glazing covering everything a few centimeters above the sheet metal

The layers of polystyrene are placed on the wooden planks. Between the insulation and the black sheet, there is an empty part where air can circulate to the drying chamber. The black plate allows maximum irradiation to be captured, this is what we call the absorber. The air enters the dryer from the bottom, it is heated thanks to its contact with the black metal plate. For the glazing, which serves to increase the greenhouse effect of the sensor, we used 2.5 mm glass, leaving 2.5 cm of space between the glass and the sheet metal.

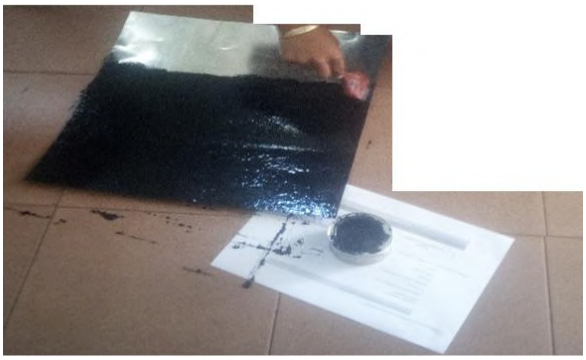

Fig.2: Painting the sheet metal

To assemble the plywood, we use wood glue, nails and vices so that everything holds together well.

Fig.3: Assembly of plywood

Steps for drying ginger

To dry gingers, first ensure that they are clean. Then we sort them and peel them. Then, we cut them with thicknesses of approximately 2 mm. The gingers are ready to be dried, finally, we place them in the dryer on the rack. We install the temperature probe to see the internal and external temperatures of the dryer.

Fig.4: Steps for drying ginger

To collect temperature varieties during drying, we used a thermistor called a "temperature sensor". and an Arduino board connected with the temperature sensor to transfer the values into the computer.

Fig.5: Temperature sensor

III. RESULT AND DISCUSSION

All the equipment is well installed, it remains to take the temperatures every 5 minutes. The measurements are carried out from 12 p.m. on January 18, 2024 and the data obtained are presented in the table below.

Table 5: outside and inside temperatures measured

Time in minutes	External temperature in °C	Internal temperature in °C
0	44.00	40.75
5	44.50	43.38
10	43.50	44.69
15	43.50	45.63
20	45.50	46.44
25	41.50	45.63
30	41.00	45.31
35	41.50	46.19
40	43.50	47.38
45	45.00	48.50
50	45.50	49.81
55	42.00	48.88
60	42.50	48.60
65	41.50	47.38
70	42.00	48.25
75	36.50	45.63
80	37.00	45.56
85	38.50	46.13
90	40.50	46.75
95	44.50	47.33
100	42.00	45.44
105	41.50	42.88
110	40.00	41.13
115	38.00	38.00
120	36.00	37.00
125	35.00	36.19
130	35.50	37.06
135	36.00	37.56
140	35.00	35.50
145	35.50	37.31
150	36.00	37.94

The internal and external temperature variation is represented by the figure.

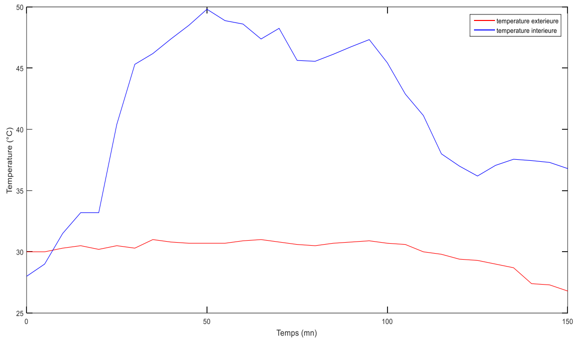

Fig.6: Internal and external temperature variation

At the beginning, the internal temperature is a little lower than that of the external. After a few minutes, equality between these two temperatures is reached. Then, we observe a gradual increase in the external temperature until reaching the maximum after about an hour thanks to the absorber and the greenhouse effect. The internal temperature begins to drop after two hours and the temperature gain is worth 10°C. A temperature reduction of up to 25°C can be achieved during a period under open air.

The test of Nutritional value of ginger before end after the drying is show in the **Table**. In the 10g, of raw and dried ginger, the quantity of nutritional value is kept.

Table 6: Nutritional value of ginger

Nutrient	Raw ginger (root) 10g	Dried ginger (ground) (10g)
calories	3,3	3,4
Proteins	0,1	0,9
Carbohydrates	0,3	0,4
Lipids	0,1	0,4
Dietary fiber	0,2	1,4
Vitamin	Antioxidants, B, C, Iron, Manganese, Potassium	Antioxidants, B, C, Iron, Manganese, Potassium

IV. CONCLUSION

We proposed a small capacity solar dryer, simple and easy to make with local materials which will be well suited for the Malagasy population. This is one of the possible means of preserving agricultural products given that Madagascar is a country rich in fruit and vegetable production. Ginger, which is a very common spice in all regions, requires an artisanal drying technique so that its conservation is profitable in terms of specific nutrients.

We found an increase in the internal temperature of the solar dryer while that of the external remains almost constant. This increase in internal temperature shows that the homemade dryer is functional. In this article, we presented the principle of artisanal manufacturing of the solar dryer adapted to the climate of Madagascar.

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