DEVELOPMENT OF A DIRECT ACTIVE SOLAR DRYER AND ITS USE IN DRYING CHESTER LEAVES (*HEINSIA CRINITA*)

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ABSTRACT

A direct active solar dryer was designed and fabricated to dry Chester leaves (*Heinsia Crinita*) within one day but with features that will enhance its efficiency such as fans, battery, photovoltaic module, storage unit. Thus, it achieved solar drying utilizing forced convection to enhance the drying operation. Temperatures of the dryer were monitored on hourly basis while the moisture content analysis was done on a two (2) hourly basis. Test results showed that under no – load conditions, the dryer achieved a maximum temperature of 68.7℃ under sunshine. *Heinsia Crinita* weighing 1000 g of initial moisture content of 66.4% (w.b) was reduced to a final moisture content of 11.5% (w.b) under eight (8) hours. The Vitamin C content of *Heinsia Crinita* leaves was also determined by Redox titration at the beginning and end of the drying operation. The Vitamin C content of the solar dried leaves was compared with that of Sun dried leaves. Vitamin C was found to decrease as the Drying took place from 14.3 mg/100 g to 6.23 mg/100 g at the end of the solar drying whereas the Vitamin C content was found to be 2.67 mg/100 g at the end of sun-drying. Solar drying preserved color to a great extent as compared to sun dried leaves. There was also significant reduction in drying time as compared to sun drying. Equipment tests showed that there was a significant retention of product quality at least when compared to sundrying. The dryer performed satisfactorily and is recommended to be used in drying other high moisture crops to achieve product stability.

KEYWORDS: Direct active, *heinsia crinita*, solar dryer, sun drying, vitamin C.

1. INTRODUCTION

Drying of vegetables have achieved so much attention because farmers grow vegetables which have to be sold in the market immediately after harvesting, when the production is high, the farmers have to sell the products at very low prices, thereby incurring great economic losses (Babagana *et al,* 2012).

Chester Leaves (*Heinsia Crinita)* popularly known locally as Atama in Efik and Tonoposho in Yoruba is also an edible green vegetable especially found in the Southern part of Nigeria. It is also used for various purposes such as making of soup, leaf extract used in the treatment of skin rashes, treatment of umbilical hernia and other medicinal purposes (Alobi *et al*, 2012). However, freshly picked leaves of *Heinsia Crinita* cannot store for a long time as it will begin to decay. This is due to its high moisture content of 67.8% (Udousoro and Ekanem, 2013). In order to prevent this, the leaves are processed to more stable forms but still suitable for intended use. It has been reported that processed forms of the leaves are exported for various medicinal applications and also for foreign hotels offering intercontinental dishes. One major way of achieving product stability for *Heinsia Crinita* leaves is by reducing its moisture content. This process is even carried out locally by sun drying (Abo *et al*, 2011).

An important strategy for achieving product stability for *Heinsia Crinita* is by drying. Drying is the removal of water from a product through the application of some energy source which can be in the form of direct solar energy or energy from burning fuel or electrical heating (Alonge, 1997). The main purpose of drying in preserving foods is to remove moisture, so that the water activity of the dried product is low enough (e.g a_w <0.6) to stop spoilage and the growth of pathogenic microorganisms and to reduce other deterioration processes [Ajav and Fakayode, 2011]. Generally, it has been accepted that safe moisture levels for vegetables and fruits are within the range of 7% - 15% and temperature ranges of 35^0C to 63^0C are quite recommended for drying vegetables and fruits.

Admittedly, drying *Heinsia Crinita* could be done naturally as in open air sun drying, drying in chimneys or other means of drying. But with these drying methods are associated problems such as low product quality, questionable product safety, reduced market value, vulnerability to natural elements such as rain, insects, rodents or other animals, wasted time among others. In view of these, there is need to develop a system that can significantly minimize these problems. Solar dryers have been found to be an effective means to reduce associated problems that comes with achieving product stability. It is essential to mention that solar dryers are very economical and efficient, one reason for such owing to its availability and low cost implication. Solar drying is a process of using solar energy to heat air/or the products so as to achieve drying of agricultural products (Ajay *et al*, 2009).

Babagana *et al* (2012) designed and constructed a forced/ natural convection solar vegetable dryer with heat storage. Using this system, it was found out that the drying time of tomato, onion, pepper and spinach were greatly reduced as compared to open sun drying. Alonge and Adeboye (2012) evaluated the drying rates of some fruits vegetables with passive solar dryers. The passive solar dryers which were direct and indirect types were tested with pepper, okro and vegetables. The crops dried faster with the direct passive solar dryer than with the indirect passive solar dryer.

Alonge and Eke (2011) developed and evaluated a medium scale direct mode passive solar Tomato dryer. The dryer achieved over 50% in drying time when compared with the time taken in open sun drying. Moisture of tomato sample was reduced from 93.5% wet basis to 4.5% wet basis within 58 hours while the open sun drying took 124 hours. The problem is to design a solar drying system that will be able to dry *Heinsia Crinita* leaves to acceptable moisture levels preferably 12% or less required to obtain product stability under a period of one day .It is important that the products be dried under one day as intermittent drying could lead to spoilage due to bacterial infestation. Besides, if the product stays for too long in the drying unit, quality deterioration will occur.

Hence, to achieve drying in one day, the solar drying unit will be a forced convection dryer since natural convection dryers may not achieve desired drying within one day. Also, since mass production of the products for increased commercialization is of essence, drying has to take place faster, hence the need for an active solar dryer. The means used in achieving forced convection in the system will be through a fan which will be powered by a photovoltaic module which also charges a battery to supplement power for the fans. To further complement the fan, the solar dryer will incorporate a heat storage unit which will serve as a supplement during off sunshine hours.

The aim of this project is to design, construct, and test a direct active solar dryer with storage unit for *Heinsia Crinita* leaves which will achieve drying under a period of one day and also find out the effect of direct active solar drying on Ascorbic acid (Vitamin C) content of the leaves as compared to conventional sun drying. The results of No – load dryer test, Loaded dryer performance test, Solar drying test, Sun drying test as well as Ascorbic Acid determination are discussed.

2. MATERIALS AND METHODS

2.1 Materials

Fresh *Heinsia Crinita* were obtained from a local market in Uyo, Akwa Ibom State, Nigeria. It was directly transported to the drying site. The moisture content was determined using AOAC (2000) methods and the initial moisture contents for both first and second replications were 69.4% and 66.4% wet basis respectively.

2.2 Direct Active Solar Dryer

A sectional view of the Direct Active Solar Dryer is shown in Fig.1 while Fig.2 shows the actual picture of the dryer. The Dryer was designed designed and built in the Department of Agricultural and Food Engineering, University of Uyo. Features of the dryer include: solar collector, storage unit, photovoltaic module, battery, axial flow inlet and outlet fans, mesh tray, drying chamber, glass cover, switch.

The design of the dryer was based on the following considerations:

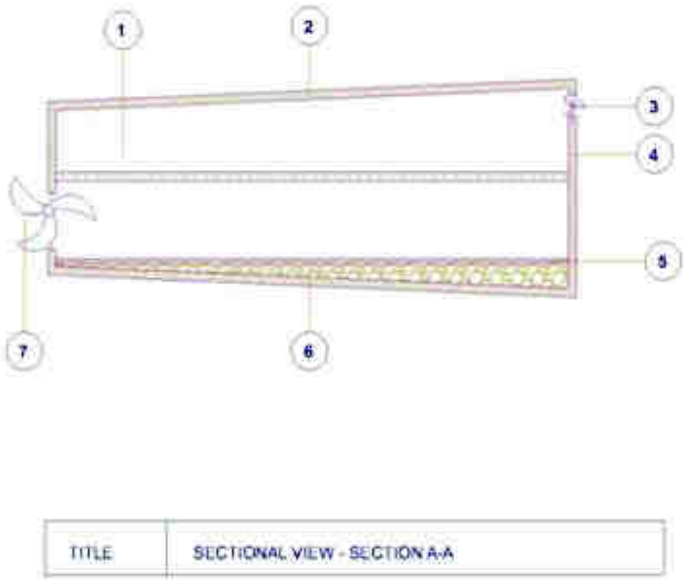
i. Meteorological Data collection.
ii. Amount of moisture to be removed from a given quantity of wet crop to bring it to safe storage level in a specific time.
iii. Physical features of the dryer
iv. Dryer area and dimension
v. Amount of heat stored in storage unit
vi. Fan capacity
vii. To reduce heat loss due to convection and radiation.
viii. Construction materials.
ix. Quantity of air needed for drying.

Sanitary considerations as well as Economic considerations were made in the course of constructing the dryer.

Basically, the equipment is a structure with frames made of wood. It has a short frame at the front which contains the suction inlet fan and a tall frame at the back which contains the door and the exhaust fan. The side frames constitute the length of the dryer and attached to one side of it are the battery ports and photovoltaic attachment. It incorporates a glass cover at the top for the greenhouse effect and thus the heat needed for drying operation. The dryer has a storage unit which is underneath the absorber plate at the bottom of the dryer. It is designed to absorb heat during sunshine hours and release the stored heat during off sunshine hours . The dryer is painted grey on the outside to prevent heat loss. The equipment has no external insulation as the thickness of the frame material is considered to provide reasonable insulation.

The solar drying equipment works on the principle of forced convection. The dryer has a suction inlet fan which delivers ambient air over the absorber plate, thereby causing convective heat transfer to take place from the absorber plate to the air. The heated air then rises and in the process comes in contact with the product on the mesh trays. There is convective heat transfer to the product resulting in the vaporization of water in the product. Thus, it is a simultaneous heat and mass transfer process. The mass (water) is then transferred to the hot dry air thereby causing it to be humid. At this point, the exhaust fan at the outlet exhausts the humid air to the environment.

The glass cover at the top also provides heat via the greenhouse effect. This heat is also absorbed by the collector and also used for the drying process. Thus, the principle of forced convection delivers more heated air to speed up the drying process and also exhausts more humid air to enhance the drying process. Moreover, as the name of the equipment implies, the products in the dryer are directly exposed to the sun during drying operation. This further enhances the drying operation. The Technical Specifications for major items of the Dryer is presented in Table 1.



1	TRAY
2	GLASS COVER
3	EXHAUST FAN
4	FRAME
5	ABSORBER PLATE
6	GRANITE PEBBLES
7	SUCTION INLET FAN

Figure 1. Sectional View of the Director Solar Dryer


Figure 2. Front View of Dryer

Some of the important design calculations made were as follows:

a) Design Basis: 1kg of *Heinsia Crinita* leaves

b) Amount of water to be removed from products

$$M_W = {M_P(M_i - M_f)}\Big/{(100 - M_f)} \qquad (1)$$

Where M_W = amount of water to be removed (kg)

M_p = mass of product (kg)

M_i = initial moisture content (%)

M_f = final moisture content (%)

c) Average drying rate

$$\mathbf{d_r = {}^{m_r}/_{t_d}} \qquad (2)$$

Where M_r = amount of moisture removed (kg)

t_d = drying time(hrs)

d) Mass of air required for evaporation

This shall be gotten from the energy equation for the evaporation of water.

$$M_W L_V = m_a C_p (T_1 - T_2) \qquad (3)$$

Where M_W = mass of water (kg)

L_V = latent heat of vaporization (kJ/kg)

m_a = mass of air (kg)

C_p = specific heat capacity of air (kJ/kg°C)

T_1 = final temperature (expected dryer temperature) (^{0}C)

T_2 = initial temperature (ambient temperature) (°C)

e) Collector useful thermal energy gain

$$Q = \left[C_P W_P (T_C - T_A) + \quad L_V \left(MC_i W_P - MC_f (W_P - MC_i W_P)\right)\right] \qquad (4)$$

Where Q = collector useful thermal energy gain (kJ)

C_p = specific heat capacity of product (kJ/kg°C)

T_c = collector temperature (°C)

T_a = ambient temperature (°C)

L_v = latent heat of evaporation (kJ/kg)

MC_i = initial moisture content (%)

Wp = weight of product (kg)

MC_f = final moisture content (%)

f) Mass/Volume flowrate of air

$$m_{a1} = {}^{M_a}/_{t_d} \qquad (5)$$

Where $m_{a1} = mass\ flowrate\ of\ air$

$$v_a = {}^{m_{a1}}/_{\rho} \qquad (6)$$

Where $v_a = volume\ flowrate\ (m^3/hr)$
$\rho = density\ of\ air\ (kg/m^3)$

g) Area of Collector: Neglecting heat losses, the rate of heat absorption by a solar collector can be estimated as:

$$Q/_A = (\tau\alpha I_0) \qquad (7)$$

Where Q = heat absorbed by solar collector (kJ)

A = area of solar collector (m^2)

$\tau\alpha =$ transmittance - absorptivity index of collector

I_0 = incident solar radiation (W/m^2)

Table 1: Technical Specification of Major Components in the Dryer.

Item	Specification
External dryer dimensions	1.29m(length) × 0.51m(width) × 0.52(height of long frame) × 0.37m(height of short frame).
Area of solar collector	0.6m^2
Fans	Inlet fan: axial flow, 10cfm, 12VDC Outlet fan: axial flow, 5cfm, 12VDC
Photovoltaic module	Crystalline carbon, 15WP, 17VMP
Battery	18V, < 5.1A initial current
Heat storage material	Black Granite
Temperature range of dryer	58°C - 63°C

2.3 Experimental Methods

2.3.1 No – Load Dryer Test

As the name implies, this was done with no product inside the dryer for eleven hours. The values for the following parameters were recorded on an hourly basis: time, collector temperature, cabinet temperature, outlet temperature, ambient temperature.

2.3.2 Drying Tests

This was carried out with two replications each for the *Heinsia Crinita*. The leaves (1kg) were loaded onto the drying tray and then placed inside the dryer. The door of the dryer was shut, then the switch was switched on for the drying process to begin. The parameters used to characterize the drying tests include: collector temperature, ambient temperature, cabinet temperature, outlet temperature which were used to derive the dryer performance curves under each loaded test.

Moisture content analysis in triplicates for both replicates was done on a two (2) hourly basis for the crop dried. For sun drying, 1kg of *Heinsia Crinita* leaves were spread out in the sun on a clean suface and away from contaminating influences.

2.3.3 Vitamin C Determination

Vitamin C concentration in *Heinsia Crinita* was determined by Redox Titration as reported by the Outreach College of Science, University of Cantebury. This method determines the vitamin C concentration in a solution by Redox titration using iodine. As the iodine is added during the titration, the ascorbic acid is oxidised to dehydroascorbic acid, while the iodine is reduced to iodide ions. The determination was carried out for fresh, solar dried and sun dried *Heinsia Crinita* leaves. The determination was divided into:

a) Sample Preparation: 100g of sample was cut into small pieces and grinded in a mortar and pestle. 10ml of distilled water was added several times while grinding the sample, each time decanting off the liquid extract into a 100ml volumetric flask. Thereafter, the ground vegetable pulp was strained through a cheese cloth, rinsing the pulp with a few 10ml portions of water and collecting all filtrate and washings in the volumetric flask. The extracted solution was made up to 100ml with distilled water.

b) Titration

i) 20ml aliquot of the sample solution was pipetted into into a 250ml conical flask and 150ml of distilled water and 1ml of starch indicator solution was added.

ii) The sample was titrated with a 0.005molL^{-1} iodine solution. The endpoint of the titration was identified as the first permanent trace of a dark blue-black colour due to the starch-iodine complex.

iii) The titration was repeated two more times with further aliquots of sample solution until concordant results were obtained.

3. RESULTS AND DISCUSSION

3.1 Result of No – Load Dryer Test

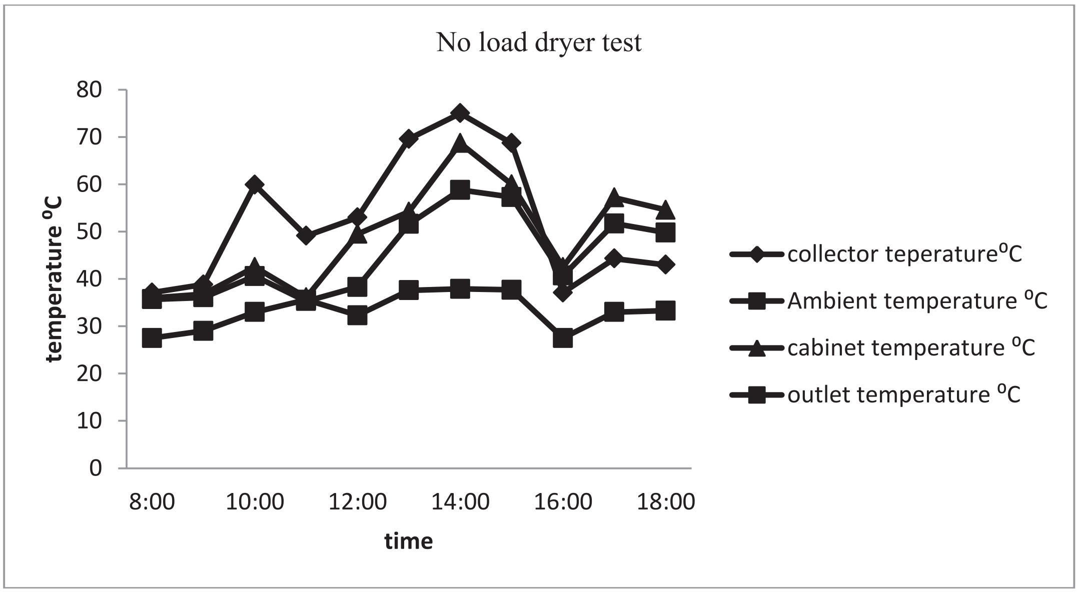


Figure 3: Curves of Collector, Ambient, Cabinet and Outlet Temperatures versus drying Time at No - Load

The result from Figure 3 showed a steady increase in temperature as the solar insolation increased. The collector reached the greatest temperature at 75°C during the day at 14:00 hours. However, due to the fluctuations in weather conditions, the collector surface experienced a series of temperature drops. The collector temperature started decreasing as the day went by and as the solar insolation decreased. The collector minimum temperature was 37.1℃.

The ambient temperature oscillated about the mean temperature for Uyo metropolis - 32℃. It reached its peak of 37.9℃ at 14:00 hours. The minimum ambient temperature for that day was 27.5℃ at 8:00 hours.

The cabinet temperature steadily increased as the insolation increased. It reached a peak of 68.7℃ at 14:00 hours. It had a minimum temperature of 36℃ at 8:00 hours.

As the graph above clearly shows, the temperature at the outlet closely followed the cabinet temperature but differed only with some minor differences in temperature. However, it generally takes the shape of the cabinet temperature. Thus, it can be inferred that at no – load, the dryer achieved its objective drying temperature of 59℃ for which it was designed for and even exceeded it by 9.7℃. However, it should be noted that the dryer was tested during the rainy season when solar insolation is highly unstable. But, even with that, the dryer showed good results and has a better potential if tested during the dry season.

3.2 Loaded Dryer Performance Curve for *Heinsia Crinita* Leaves (1st and 2nd Replications)

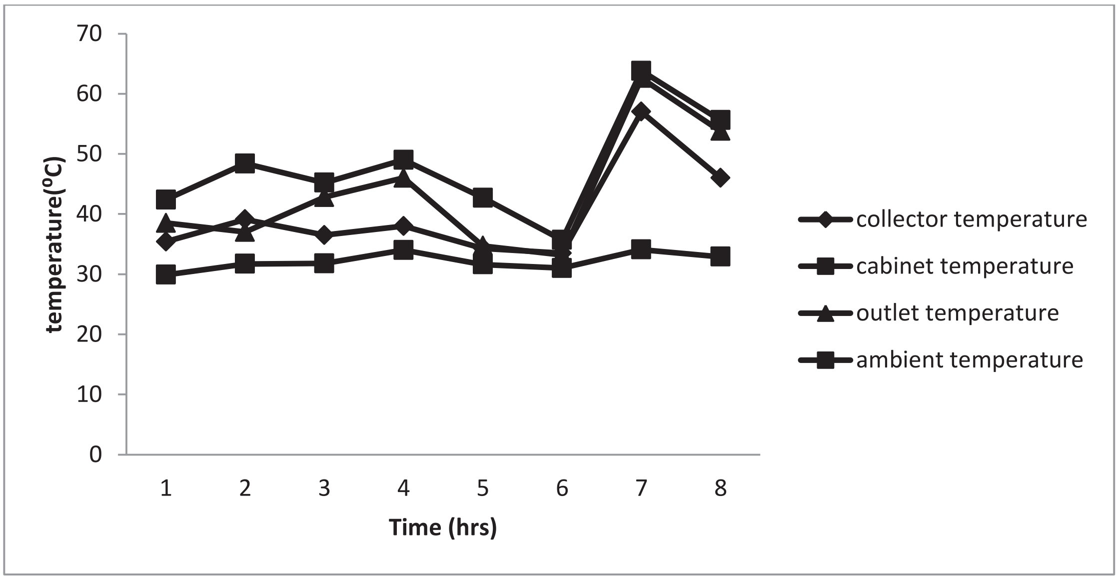


Figure 4: Curves of collector, Ambient, Cabinet and outlet Temperatures versus Drying time for Dryer Loaded with *Heinsia Crinita* – 1st Replication

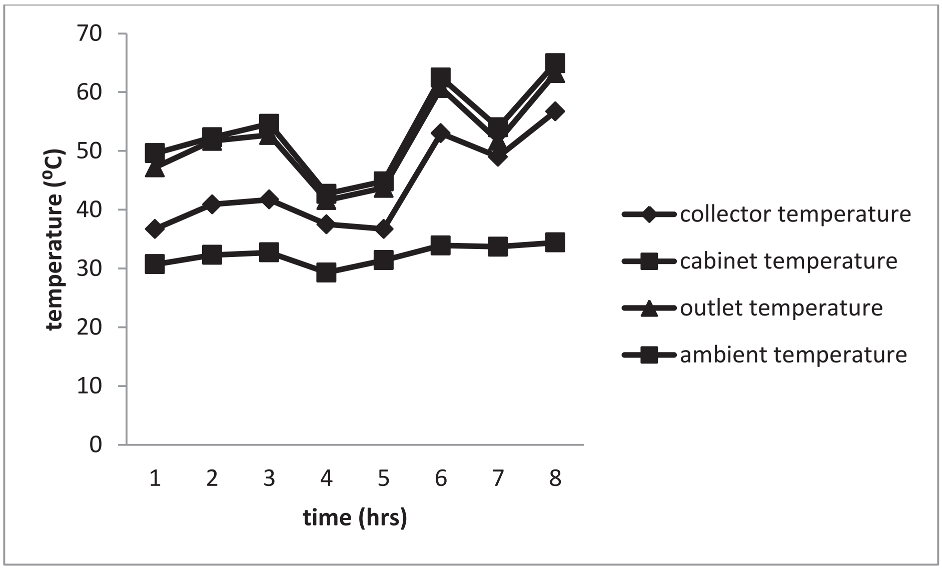


Figure 5. Curves of Collector, ambient, Cabinet and Outlet Temperatures versus Drying Time for Dryer Loaded with *Heinsia Crinita* – 2ne Replication

Both graphs (Figs. 4 & 5) show difference in performance mainly due to the weather patterns on the days of the first and second replication. The graph for the first replication showed wide fluctuations in the collector, cabinet and outlet temperatures. However, the graph for the second replication showed better results as the collector, cabinet, outlet and ambient temperatures followed a regular pattern of steady increase and drops.

3.3 Drying Curve for *Heinsia Crinita* (1st And 2nd Replication)

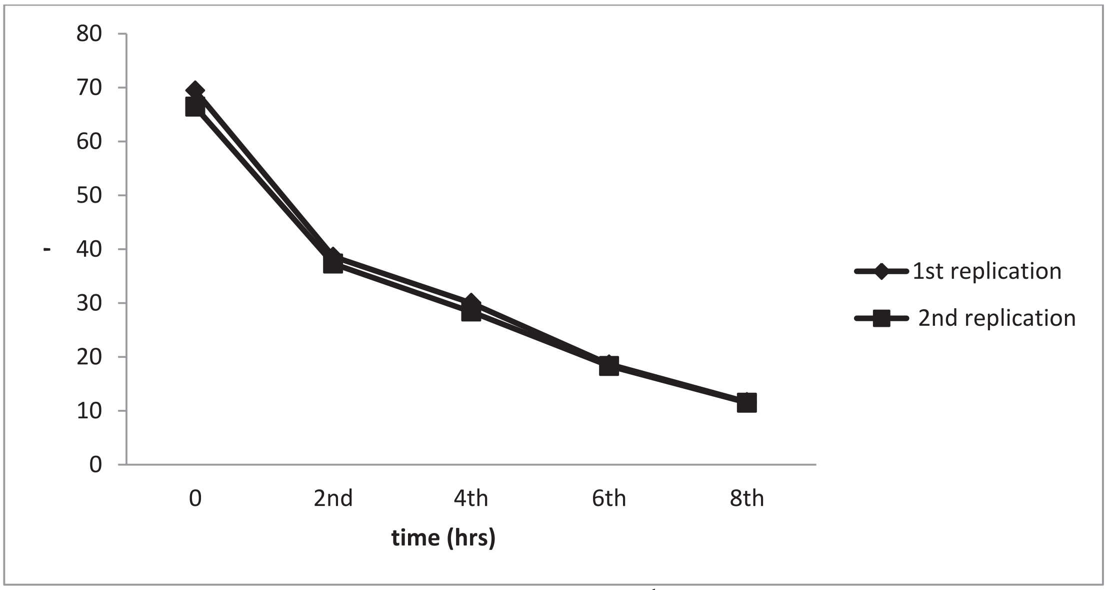


Figure 6. Drying Curves for *Heinsia Crinita* - (1st and 2nd Replications)

As seen from the graph (Figure 6), the drying curves for both the first and second replications seem to coincide with each other except at some points where the curves are seen as two distinct curves. This shows that the drying of *Heinsia Crinita* for both replications follow the same pattern. The first replication drying curve shows that there was a steady decrease in moisture content from its initial moisture content of 69.4% until the end of the drying time at which a moisture content of 11.6% was achieved.

The curve for the second replication showed a decrease in moisture content from its initial moisture content of 66.4% till a final moisture content of 11.5% was achieved at the end of the drying period. Both replications showed a good result and agrees with the objective of the design which is to reduce the moisture content of the leaves to a safe level of 12% moisture content.

3.4 Result of Sun Drying Test

It took more than one day to achieve product stability for Sun dried samples as compared to solar dried samples which took eight (8) hours. Sun dried samples also showed the least colour retention as compared to the solar dried leaves which preserved colour significantly.

3.5 Result of Vitamin C Determination

The Ascorbic acid (Vitamin C) content of the fresh *Heinsia Crinita* was 14.3mg/100g and the Ascorbic acid (Vitamin C) content of the Solar dried leaves was 6.23mg/100g while the Ascorbic acid (Vitamin C) content of the Sun dried *Heinsia Crinita* was 2.67mg/100g.

The results show that the vitamin C content the leaves decreased as the drying operation took place. Sun dried *Heinsia Crinita* especially showed a marked reduction in Vitamin C content. This declination is due to the fact that ascorbic acid is destroyed by heat and atmospheric oxygen. Thus, it can be concluded that the drying operation reduced the vitamin C content of the *Heinsia Crinita* leaves markedly.

4. CONCLUSIONS

The design and fabrication of a direct active solar dryer was done for drying *Heinsia Crinita* under a period of one (1) day. The performance of the dryer under test conditions showed that it is technically and economically feasible and easy to operate and maintain. This was especially because of the enhanced air flowrates inside the dryer. Evaluation of the test results have clearly shown that the direct active solar dryer performed satisfactorily and reduced drying time considerably when compared to sun drying for the same kind of crop. Results conclusively showed that Solar Drying preserved certain quality attributes of the leaves such as Vitamin C and colour. Thus it can be seen that considerable reduction in drying time for the leaves will result in economies of scale for mass production of the dried leaves.

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