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Evaluation of the Performance of the ATESTA Forced Convection Dryer when Drying Pineapples

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Abstract

Objective: Evaluating the performance of the ATESTA [Solar Energy and Appropriate Technology Workshop] forced convection dryer, developed at the Albert Schweitzer Ecological Center of Burkina [CEAS Burkina], on the drying of pineapple slices in Togo. **Method:** For this purpose, two ATESTA dryers were setup in a company in Lomé, Togo, one operating in forced convection and the other, the witness, in natural convection mode. Drying tests of pineapple slices were carried out with these two dryers. Data were collected on water loss, organoleptic parameters and energy consumption during the drying process **Findings:** The results showed that the water loss rate increased by 11.4% as well as the first choice dry matter content by 36% and an energy saving of 21% percent of natural convection to forced convection. This performance of the ATESTA forced convection dryer increases the economic profit of USD [United States Dollar] 2.68/kg or USD 45.52/drying cycle and USD 2678.40/t of dried pineapples. The results of microbiological analyses revealed that the total flora [1.2.102 CFU/g] [Colony-Forming Unit per gram] yeast and mold [6.4.101 CFU/g] content of pineapple slices dried by the ATESTA forced convection dryer were in line with the limit values of the Directive 2000/13/EC [European Parliament and the Council]. **Novelty:** Performance tests on the forced convection dryer have made a more efficient dryer available to pineapple processors. Forced convection can also be adapted to existing dryers.

Keywords: Performance; ATESTA dryer; Togo; Forced convection; Dried prineapple

1 Introduction

Pineapple is one of the most consumed fruits in the world due to its physicochemical and sensory characteristics [1]. Togo is one of West Africa leading producers of organic pineapple. It exports most of its production to European Union (EU) countries, according to the Africa-EU Trade Report (2018-2019). In 2022, Togo produced over

44,391 tonnes of pineapple, 76% of which were organic and 24% conventional, according to the pineapple industry investment action plan 2024-2028. Pineapple is a seasonal fruit and is processed into juice, jam, dried strips or slices for preservation [2]. There are around fifty (50) micro, small and medium-sized agri-food businesses that produce about one [1] million liters of pineapple juice and 467t (ton) of dried pineapple according to the European Commission report (2019). This low rate of pineapple processing in Togo and in the southern countries in general, is due to limited access to drying technologies adapted to the needs of agribusiness stakeholders. In northern countries, there are several technological and technical solutions for preserving pineapple by drying [3,4]. But most of these techniques and technologies are not often accessible and adapted to the needs of users in developing countries. In these countries, dryers are developed according to products and energy sources available [5]. In order to remove energy barriers in southern countries, a number of projects have developed energy-saving solutions for solar dryers [6–8]. In West Africa, solar dryers are generally used for drying legumes and cereals [9]. Fruits such as pineapple and mango are dried by dryers using butane gas as heat energy source. The ATESTA gas dryer is the most widely drying technology used in the West African sub-region for drying fruit (mango and pineapple) [10]. It was developed by the NGO Albert Schweitzer Ecological Center (CEAS) in 1995 in Burkina Faso for drying mango and other fruits (pineapple, etc.) [10]. It is classified as a natural convection dryer, fully running on gas [5].

Today, the requirements of the European market and the growing demand for dried products have led to the introduction of other types of semi-industrial dryers imported from South Africa in the sub-region, according to the report of the World Bank study on improving the performance of the mango-based processed product chains in Mali and Burkina Faso 2009.

These dryers have not been widely used as they require a high level consumption and constant availability of electric power during operation [5].

In response to the difficulties associated with the availability of the imported dryer and the shortcomings related to the operation of the ATESTA gas dryer with natural convection (long drying cycles of more than 20 hours, high number of permutations, low rate of first choice dried product, high butane gas consumption, etc.), works conducted by [5] made it possible to integrate a forced convection device into the operation of the ATESTA dryer with natural convection.

Compared with those of the ATESTA dryer with natural convection, the performances of the ATESTA dryer with integrated forced convection show a net improvement of 68 to 100% in the quality of 1st choice dried mangoes, a reduction of 40% in drying time, 34% in butane gas consumption and a saving of 40% in energy costs [5].

These results obtained in Burkina Faso have enabled the country mango dryers to convert their ATESTA dryers to forced convection in order to increase their yields. However, pineapple dryers in Togo are facing the same problems with the natural convection ATESTA dryer.

In light of the above-mentioned mango drying results, this work seeks to provide solutions to the constraints faced by pineapple drying stakeholders in Togo and in the West African sub-region.

2 Methodology

2.1 Measuring Instruments

The devices used in this study are listed in Table 1 below. It summarizes the characteristics and use of each instrument.

Table 1. Characteristics of Study Instruments

N°	Designation	Use
		Instrument
1	Adjustable low-pressure propane regulator 4kg/h-50 to 200 mbar- cylinder inlet-outlet M20x150-Gurtner	Regulates the pressure at the outlet of the gas cylinder, thus ensuring optimal flow when connecting to burners using gas. It is installed at the outlet of the gas cylinder and connected to the gas pipe connection to the burners installed in the dryer combustion chamber.
2	63 mm axial stainless-steel thermometer with dial Ø100, maximum temperature 120°C. EN13190.	Measures the drying temperature inside the dryer. install in the dryer's drying chamber.
3	Thermo hygrometer EL-USD-2-LCD RH/TEMP Data logger LASCAR 100% HR [±2.25%] +80°C [±0.5°C]	Measures temperature, humidity and curve and graph tracking. It is installed on the middle racks during drying.
4	Electronic column scale, 150kg capacity - 20g accuracy	Weighs pineapple quantities before and after drying. It is used to weigh fresh and dried pineapple.
5	Anemometer Brand : Voltraft, PL-130AN	Measures air velocity s/m. It is used to measure air speed.
6	Stroke Stopwatch-Accuracy-Lithium Battery	Measures the duration of the drying cycle different stages.

Continued on next page

Table 1 continued

7	Food Technology Laboratory Department of the Institute for Research in Applied Sciences and Technologies Burkina Faso	Physicochemical nutrient analysis and microbiological characteristics of dried pineapple slices. Dried pineapple was analyzed in this laboratory

2.2 Drying Equipment: ATTESTA Forced and Natural Convection Dryer

The ATESTA dryer consists of:

1. A combustion chamber, called the soleplate, for heating the air. This serves as the support for the dryer. It is made of cement bricks and contains the ambient air inlet port and the gas burners. Each dryer has two combustion chambers measuring 1780*1780*700 mm.
2. The drying chamber or box consists of the rails on which the trays are introduced into the dryer. It is made of double-walled wood measuring 1230*1720*1720 mm, padded with glass wool for insulation.
3. The part where the air extractors are installed is called the helmet. Made of wood, it measures 800*1720*1720 mm. It evacuates moisture-laden air to the outside of the dryer through the chimneys.
4. The moisture-laden air from the products is discharged from the dryer through the chimney. The chimney is made of rolled sheet metal in a cylindrical shape with a diameter of 400mm and a length of 2000mm.

The ATESTA forced convection dryer has the same configuration as the solar dryer integrated with a thermal energy storage system for drying agricultural products[6]. They operate in forced convection mode with forced air circulation from bottom to top. The difference lies the air heating energy sources.

Figure 1 shows the operating principles of the ATESTA natural convection dryer, the forced convection dryer and a picture of the ATESTA dryer and dried pineapple. Both types of dryers were setup at the SETRAPAL tropical processing plant in Lomé.

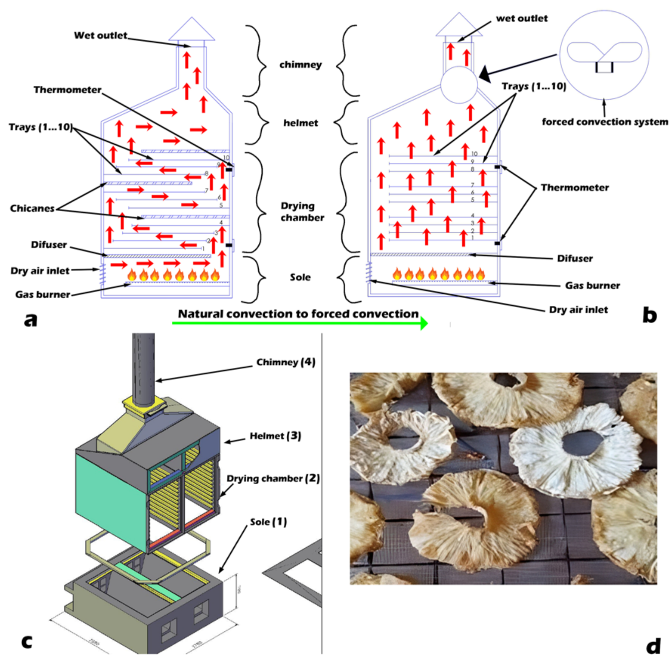

Fig 1. [a] Natural convection [b] Forced convection [c] ATTESTA dryer [d] Dried pineapple

Figure 1 shows that the air flow in Figure 1 **[a]** is channelled and irregular. In Figure 1 **[b]**, on the other hand, the air flows homogeneously from bottom to top. This change is explained by the effects of forced convection[5]. The ATESTA dryer works on the principle of heating the air to lower its relative humidity and increase its evaporation capacity, before circulating it over the products. The ambient air entering the combustion chamber is heated by the combustion of butane gas. The heated air passes through the pineapple slices spread out on trays and absorbs their moisture. The air loaded with moisture from the pineapple slices [5 kg per tray] is exhausted through the dryer chimney. Air circulation can be by forced convection [Figure 1**b**] or natural convection [Figure 1 **a**] [6]. The drying method of the ATESTA forced convection dyer is similar to that of the heat pump dryer for drying agricultural products of[7].

2.3 Plant material and raw material processing

The plant material or raw material used for drying is pineapple of the cayenne lisse variety. This variety is grown in the coastal countries of West Africa, as it is much in demand on the international market[11]. The ripe pineapples were prepared in three[3] stages: (i) washing, and weighting pineapples samples, (ii) Peeling, which consists of removing the skin from the washed pineapples using stainless steel knives, and weighing the pineapple pulp obtained after peeling, (iii) Cutting, which consists in cutting the peeled pineapples using a multi-cage stainless steel cutter to obtain pineapple slices of the same thickness (1.5 cm). The 1.5 cm-thick pineapple slices are then cut into rounds using another stainless-steel cutter. The sliced pineapples are spread out on trays, at a rate of 5kg/tray, for drying. This method of preparing pineapple samples is consistent with the one used by[12] for drying pineapples by indirect convection, as part of a circular economy strategy.

2.4 Testing of the ATESTA forced convention dryer

A pineapple drying test protocol with data collection tools was developed on based on the ATESTA forced convection dryer specifications and datasheets. Drying parameters (temperature, moisture content, water loss from pineapple slices) were defined as data to be collected during drying. The ATESTA forced and natural convection dryers were set up and adjusted (drying temperature, extractor rotation speed). After these adjustments, the prepared pineapple slices were weighed (110 kg of fresh pineapple slices per dryer) and put into the two dryers. Drying began in both dryers, following the operating principle of ATESTA forced and natural convection dryers (the trays were swapped every 2 hours). Temperature and humidity were recorded by a Thermo hygrometer EL-USD-2-LCD. This method of experimental drying of pineapple samples is comparable to the methods of[7,12] in pineapple, tomato and carrot drying experiments.

2.5 Quality of pineapple dried in the ATESTA forced convection dryer

The quality performance of the ATESTA forced convection dryer is assessed on the basis of the first choice rate dried pineapple. The first choice criteria are set by the customer [buyer] of dried pineapple. These quality criteria are mainly organoleptic (color, enzymatic browning or not, aroma). In addition to these criteria, we have integrated physicochemical and microbiological analyses to compare nutrients with existing standards. This method is comparable to the one used by[2] to assess the quality of pineapples, from five technical production routes in the Municipality of Allada in Benin.

2.6 Performance indicator results

Table 2 defines the formulas used to calculate the performance indicators based on the data collected during the drying tests.

Table 2. Formulas used to calculate performance indicators

N°	Definition of the formula	Computational elements	Formulae
01	Calculating gas consumption	Q1 : Total quantity of gas consumed Q2 : Quantity of dried product Q3: Amount of gas consumed/kg of dried product	$Q3 = \frac{Q1}{Q2}$
02	Power consumption	Qe : Dryer power consumption H : Number of hours of use J : Number of days of use P : Wattage unit	$Qe = H * J * P$
03	Cost of power energy consumed	Qe : Dryer power consumption Pe : Power prices in Burkina Faso Ce : Cost of power energy consumed	$Ce = Qe * Pe$
04	Cost of gas consumed	Q1 : Total quantity of gas consumed Pe : Gas prices in Burkina Faso Cg : Cost of gas consumed	$Cg = Q1 * Pe$
05	Total cost of energy consumed by the dryer	Ce : Cost of electrical energy consumed Cg : Cost of gas consumed Ct : Total energy consumed by the dryer	$Ct = Ce + Cg$

Continued on next page

Table 2 continued

06	Water loss	Ve : Water loss rate Q3 : Amont of water extracted T : Setting time Be k0 : Amount of pineapple slice before drying K1 : Amount of dried pineapple slice	$Ve = \frac{Q3}{T} Q3 = K0 - K1$
07	Calculation of % of 1st choice dried pineapple	Qf : Quantity of 1st choice pineapple SCF Qn : Quantity of 1st choice pineapple SCN Qfn : Total quantity of 1st choice SCF : Forced Convection Dryer SCN : Natural Convection Dryer	$\%Qf = \frac{Qf}{Qfn} \%Qn = \frac{Qn}{Qfn}$
08	Economic Gain Calculation	C : Price per kg of dried pineapple Pf : Total amount of the sale of Qf Pn : Total amount of the sale of Qn G : Economic gain	$Pf = C * QfPn = C * QnG = Pf - Pn$

These formulas will calculate the gas consumption and water loss rate.

2.6.1 ***Determining the cost of gas consumed***

The cost of gas consumption was used to assess the energy consumption of the two dryers. Formulas 1 and 4 in Table 2 were used for this purpose. We applied the method for calculating the heating power (P) of an ATESTA dryer burner [13] to calculate the quantity of gas consumed. Under this method, the amount of heat (Q) supplied by a burner to the dryer is measured by weighing the gas cylinder. Q = gas weight difference in kg × 46,000, with Q in kJ= Q1*46000 and P = Q/(3600 × time between weighing in h), with P in kW. We stuck to the quantity of gas consumed Q3, to determine the cost of gas consumption, on the basis of butane gas price in Togo, which justifies formula 4.

2.6.2 ***Determining the cost of electrical power***

The cost of electrical power consumed by the air extractors is used to calculate the total cost of energy consumed by the forced convection dryer. The formulas 2 and 3 are taken respectively from the International System of Units (SI) for calculating Kwh and Togo electricity price list in Table 3.

2.6.3 ***Determining the total cost of energy consumption***

This is the sum of the costs of butane gas and electricity consumed. This cost will be used to define energy savings. Formula 5 was used for calculations.

1. **Water Loss**

This gives the quantity of water extracted per hour from the products during drying operations. Formula 6 was used for the calculations. It was developed using the method for calculating the moisture content of mangoes in [13].

- **First choice rate of dried pineapple quality**

This rate is a valuable indicator of the performance of agricultural product dryers in West Africa. It represents the superior quality of dried products. It also allows us to witness the contribution of forced convection to the quality of dried pineapple. The formula 7 used for its calculation is the same one used to calculate the first choice rate for dried mango of [5].

- **Economic profit**

Represents the financial surplus on sales of first choice dried pineapple induced by forced convection. Formula 8 was used to make the calculations on the basis of the SETRAPAL first choice dried pineapple price list in Table 3.

- **Analysis of measurement errors and uncertainties**

Measuring instruments have ranges of accuracy in data measurements [6]. The accuracy ranges of measuring devices 3 and 4 in Table 1 are very close to the data used to calculate measurement errors in the work of [6,8]. They are below the accepted precision values [6].

2.7 Energy and dried pineapple costs in Togo

The costs of the various energy sources and dried pineapple in Togo are summarized in Table 3

Table 3. Energy and dried pineapple costs in Togo

Designation	Pricing and pricing sources
Gas	A 12.5 kg gas cylinder costs 10.76 US dollar, May 10, 2022 order, applicable sales rate by CEET.
Electricity	The price of a kilowatt hour is 0.20 US dollar for all [BT+MT], power price list in force set by the interministerial decree n°19/MME/MCDAT/MPR-PDAT/MCPSP of 26 November 2010 and its supplementary decree n°080/MME/CAB/2020 of 25 September 2020.
	1kg of 1st choice dried pineapple costs 9.93 US dollar/kg. Sale price of dried pineapple by SETRAPAL company of Togo.

The data in the table are used to calculate the cost of the energy consumed and the economic benefit of the dryers. They will be used to define the technical and economic parameters of the improved ATESTA dryer. This calculation method was used by[5] during the tests on the ATESTA forced convection dryer for mango.

2.8 Physicochemical characteristics of dried pineapples

Water content was determined by drying samples at 105°C ± 2°C for 24 h according to NF V03-707: 2000; ash content was determined by incineration at 650°C overnight according to international standard ISO 2171: 2007; crude protein content (N×6.25) was determined by the Kjeldahl method[14] after acid digestion according to NF V03 50: 1970; crude fat content was determined by soxhlet extraction using n-hexane according to ISO 659: 1998 and[15]. Total carbohydrates content was determined by spectrophotometric method at 510 nm using orcinol as reagent[16]. The energy value was calculated according to the Atwater method[17].

2.9 Microbiological analyses of pineapples samples

Total flora was enumerated by pour plate on Plate Count Agar (PCA) (Liofilchem, Spain) incubated aerobically at 30 °C for 72 h according to ISO 4833 (2003). Yeast and mold were enumerated by pour plate on Sabouraud agar (Liofilchem, Spain) incubated at 25 °C for 3-5 days according to ISO 7954 (1988).

3 Results and Discussion

3.1 Pineapple drying curves with the ATESTA witness dryers (natural convection)

Figure 2 shows the temperature evolution as a function of drying time, representing data collected during the drying of pineapple slices with the ATESTA forced convection dryer.

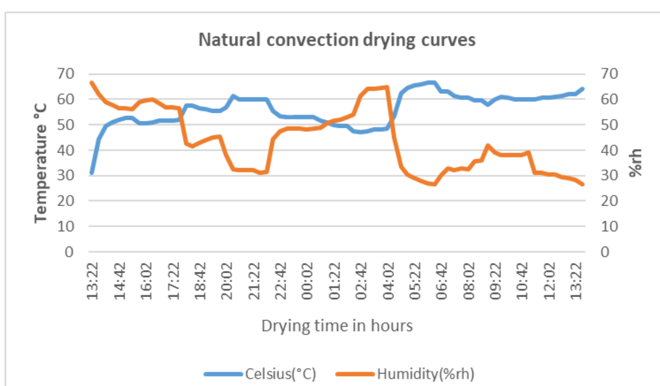

Fig 2. Natural convection drying curve

The drying curves of the ATESTA natural convection dryer show the evolution of the drying of pineapple slices introduced in the dryer. It was found that, during the first 8 hours of drying, the water content of pineapple slices varied from 68% to 45% with a temperature increase of 30 to 60°C inside the dryer. The drop-in humidity is due to the effect of heat, which is characterized by an increase in temperature. These results are in line with those of[6] who evaluated the performance of a new solar dryer integrated with a thermal energy storage system for drying agricultural products. The reduction in water content of pineapple slices is similar to the pineapple drying kinetic data reported in studies[12]. The variations of the humidity curve (decreasing during the first 8 hours and increasing during 5 hours of drying time and decreasing thereafter) showed the low circulation of hot air in the dryer linked to the natural convection and permutations of the trays. These results are in line with the work of[18] who have shown that the non-uniform air flow inside the drying chamber is the main drawback of natural convection dryers.

3.2 Pineapple drying curves with the ATESTA forced convection dryer

Figure 3 shows the evolution of temperature and humidity during drying using ATESTA forced convection. The data were collected during the drying tests of pineapple slices in the ATESTA forced convection dryer.

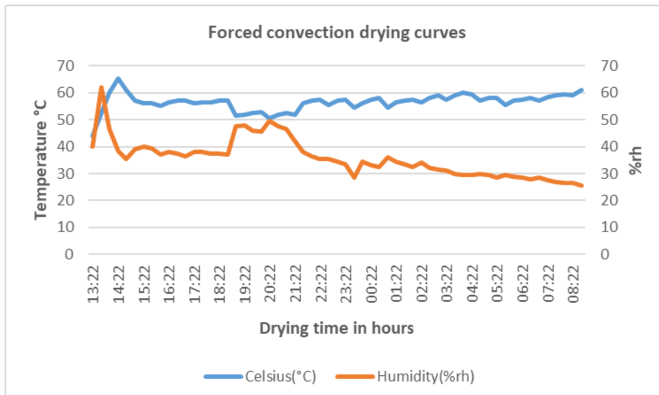

Fig 3. Evolution of temperature and humidity during drying using ATESTA forced convection

The drying curves (humidity and temperature) show a homogeneous drying of pineapple slices. During the first 2 hours, the water content varied from 61% to 40% and temperature evolved increasingly from 40°C to 60°C. This evolution of the drying parameters is related to the effect of the forced convection of the improved ATESTA dryer that allows a homogeneous drying of the products. These results are in line with those of[19] who demonstrated the same effects of forced convection in a solar dryer during tomato drying. After the 2 hours of drying, it was found that the temperature curve varied between 50 and 60°C. On the other hand, that of the humidity remained constant [40% rh] for 4 hours, then increasing from 40%rh to 50% rh for 2 hours and finally decreasing from 50%rh to 20%rh until the end of the drying which lasted 19 hours. These results, in relation to the evolution of drying temperatures, are in agreement with those of[7] who have confirmed that drying fruits and vegetables at a temperature range of 45 to 60°C guarantees the quality of the dried products. With regard to the irregular variations in humidity level in the drying chamber, linked to the ATESTA dryer operating mode (trays swapped every 2 hours), the same irregularities were observed when drying mangoes with the ATESTA forced convection dryer[5].

3.3 Water Loss

Figures 2 and 3 show that the drying speed of the forced convection dryer is faster than that of the natural convection dryer. In fact, water loss during drying increased from 3.9 kg/hour to 4.9 kg/hour, from natural convection to forced convection. We also note that for the same weight of fresh pineapple (110kg per dryer), drying by natural convection took 24 hours with 16.48kg of dried pineapple, while drying by forced convection took 19 hours with 17kg of dried pineapple. The difference in dried pineapple weight is linked to the convection mode. As natural convection does not allow for uniform air circulation, the products do not dry at the same time. These results are in line with those of[20] when drying red bananas in a single-slope direct solar dryer based on natural and forced convection.

3.4 Impact of drying on Physicochemical properties of products

The physicochemical characteristics of the dried pineapple samples from both types of dryers are presented in Table 4.

Table 4. Impact of drying on products

Characteristics	Acceptability test CEE-ONU DDP [2013]	D ried pineapple with ATESTA natural convection	Conformity decision	Dried pineapple with ATESTA forced convection	Conformity decision
Heat damage	5 percent	0 percent	Consistent	0.81 percent	Consistent
Moldy pineapple	0 percent	0 percent	Consistent	0 percent	Consistent
Fermented pineapples	0.5 percent	0 percent	Consistent	0 percent	Consistent
Pineapple with rot	0 percent	0 percent	Consistent	0 percent	Consistent
Pest attacks	2 percent	0 percent	Consistent	0 percent	Consistent
Foreign mineral	25 percent	0 percent	Consistent	0 percent	Consistent

The results of the analysis of the dried pineapples showed that the water content of the samples varied by 17.61% and 20.81% respectively for the pineapple dried with the two ATESTA forced convection and natural convection dryers. These values are in line with those recommended by UNECE DDP relating to the marketing and commercial quality control of dried pineapples[(21)] which sets the maximum moisture content of dried pineapples at 20% with an accepted tolerance of 5% for untreated dried pineapples.

3.5 Macronutrient composition of dried pineapple slices

The physicochemical characteristics of the dried pineapple samples of the two types of dryers are recorded in Table 5.

Table 5. Physicochemical characteristics of dried pineapple

Composition	Values found by R. HUET	Dried pineapple with ATESTA natural convection	Conformity decision	Dried pineapple with ATESTA forced convection	Conformity decision
Lipids	0.7 %	0.38 %	lower	0.38 %	lower
Carbohydrate	77.4 %	63.68 %	lower	64.28 %	lower
Proteins	2.4 %	1.8 %	lower	1.74 %	lower
Energy	342 Kcal	265.40 Kcal	lower	267.58 Kcal	lower

The fat, carbohydrate, protein and energy contents of dried pineapple samples with the two types of dryers recorded in Table 5 were lower than those reported by[(22)] on the chemical composition of pineapples. These differences may be explained by the varietal differences of the pineapples used.

3.6 Microbiological characteristics of dried pineapple slices

Table 6. Microbiological characteristics of dried pineapple slices

Microbiological criteria	ATESTA natural convection dried pineapple	ATESTA dried pineapple with forced convection	Limit value standard directive 2000/13/CE [CFU/g]	Conformity decision
Total flora **[CFU/g]**	$4.5.10^3$	$1.2.10^2$	$\leq 5.\ 10^3$	Conform
The yeasts and molds **[CFU/g]**	$3.5.10^2$	$6.4.10^1$	5.10^3	Not Conform

The microbiological criteria measured corroborate with the European standard[(21)], on microbiological criteria for foodstuffs except for the yeast and mold load in forced convection. The lipid, carbohydrate and protein contents and microbiological characteristics of pineapple samples dried with the two types of dryers presented are comparable with the results of pineapple quality assessment from the work of[(2)]. The differences may be explained by varietal differences of the pineapples used.

3.7 Energy consumption and economic profitability

Table 7 shows the energy consumption and economic efficiency of the ATESTA forced convection dryer. Formulas 01 to11 in Table 2 have been used for the calculations.

Table 7. Energy consumption and economic profitability

Designation	SCN	SCF
Butane gas consumption		
$Q1\ [kg]$	14.5	12
$Q2\ [kg]$	16.48	17
$Q\ [kg]$	0,85	0,70
Electricity consumption of Air Extractors		
$H\ [hours]$	24	19
$P\ [W]$	0	160
$Ce\ [kWh]$	0	3.04
$Q2\ [kg]$	16.48	17
$Ce/kg\ \ of\ dried\ \ pineapples$	0	0.18
Cost of energy consumption of dryers		
Q	0.85	0.70
$Cost\ of\ Q/kg\ of\ dried\ pineapple\ [USD]$	0.73	0.60
$KWh/kg\ \ of\ dried\ pineapple$	0	0.18
$Cost\ per\ kWh/kg\ of\ dried\ pineapple\ \ (USD)$	0	0.036
$Total\ energy\ cost\ \ (gas + power)\ per\ kg\ of\ dried\ pineapple\ [USD]$	0.73	0.64

The results show that the ATESTA forced convection dryer consumes less gas than the natural convection one. Drying 1 kg of fresh pineapple slices consumes 0.85 kg of gas in natural convection mode and 0.7 kg in forced convection mode, with an energy saving of 0.15 kg, accounting for 21% of the consumption in forced mode. This energy saving is due to the reduction of the pineapple slice drying cycle by 5 hours as a result of forced convection. The impact of forced convection on energy consumption is in line with the findings of[23] who demonstrated that consumption of energy during solar drying depends on the temperature and speed of the drying air. Regarding power consumption, Table 5 shows that forced convection drying consumes power energy, unlike natural convection. Forced convection is actuated by air extractors or air pumps, which require electrical power. Although natural convection drying does not consume power energy, we note that the cost of energy consumed by the ATESTA natural convection dryer is higher (0.73 > 0.64 US dollars) than that of the forced convection one, with a saving of 0.094 US dollars. This represents a financial gain of 15% on the energy consumption of 1 kg of pineapple dried by the ATESTA forced convection dryer. The results are in line with those of[24], who obtained an energy saving of 45.5% by using a heat pump (forced convection) in a solar dryer to dry kelp (***Laminariale Japonica***).

3.8 Quality of dried pineapple and economic profitability

Table 8 shows the rates of first choice mass quantities of dried pineapple.

Table 8. Rates of first choice mass quantities of dried pineapple

Dryer	Quantity 1st choice Compartment A Kg	Quantity 1st choice Compartment B Kg	Total quantity of 1st choice in Kg per dryer	% of first choice
Forced convection	3.92	4	7.92	68
Natural convection	2.14	1.55	3.69	32

The ATESTA forced convection dryer produces more than 36% of first choice dried pineapple compared to the natural convection one.

This result is due to the effect of forced convection that allows homogenization of dried products compared to natural convection. These results are in agreement with those of[18], who improved the drying process by increasing the homogeneity of the drying air distribution to 0.015m/s when drying injera. The increase in the quantity of first choice dried pineapple yields an economic profit on dried pineapple sales of 2.68 USD/kg, i.e. 2678.40 USD/t of dried pineapple. These results are in line with those of[7], who found an economic return on the heat pump dryer of $23,828.8 and $27,553.1 respectively for tomatoes and carrots, over 15 years of operation, with an investment cost of $5,221.8.

3.9 Performance of the ATESTA dryer when drying pineapple

The performance of the improved ATESTA dryer when drying pineapple is recorded in Table 9.

Table 9. ATESTA forced convection dryer performance

Parameters	Specifications
Air extractor by compartment	220V/ 160W, 1400 max/min, max air flow 60 m^3/min
Consumption of butane gas	0.7kg of gas /kg dried pineapple, 21% of energy saving compared to natural convection
External congestion	5190 x 1780 x 1780
Drying temperature	50 at 60 °c
Loading capacity	110 kg of fresh mango slices
Drying efficiency	36 percent first choice dried pineapple
Time of a drying cycle	19 hours, a reduction of 40% compared to natural convection
Number of permutations	10 times/Drying cycle is a reduction of 20% compared to natural convection

The performance of the ATESTA forced convection dryer, compared with that of the natural convection one, shows the impact of forced convection on pineapple drying. Table 2 clearly shows an improvement in the performance of the ATESTA dryer. Forced convection improves hot air circulation, increases drying speed and improves dryer efficiency. The performance results recorded in Table 9 are in agreement with the work of[24], who used forced convection to solve kelp drying problems similar to those of the ATESTA dryer with natural convection, including long drying time, high energy consumption, low drying efficiency and poor dried kelp quality. In addition to Kang's works[24],[19] improved by 30.9%, 15.2% and 8.7%, respectively, the average daily efficiencies of the collector, dryer and photovoltaic panel of the solar drying system when drying tomatoes in forced convection mode.

4 Conclusion

In this work, we have evaluated the performance of the ATESTA forced convection dryer when drying pineapple. It enabled us to carry out a South-South technology transfer. The ATESTA forced convection dryer was transferred from Burkina Faso to Togo with the involvement of local dryer manufacturers. The results of the pineapple slice drying tests showed an increase of 38% in first choice quality, an energy saving of 21%, i.e. a financial gain of 2.68 USD/kg or 45.52 USD/drying cycle and 2678.40 USD/t of dried pineapple. If local manufacturers adopt the technique of integrating forced convection on ATESTA dryers, this will facilitate its dissemination in the processing of tropical products in the West African sub-region. To meet the energy challenges facing agri-food drying units, it would be important to integrate renewable energies [biogas for heat production and photovoltaic solar energy for air extractor operation] into ATESTA dryer operation.

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