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PAPER

Use of a forced convection solar dryer for the reduction of post-harvest losses: case of the 'akikon' tomato variety in benin (West Africa)

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Abstract

The local variety tomato (Lycopercicum esculentum Mill) named 'akikon' is one of the most consumed and widely cultivated fruiting vegetables in Benin Republic. In this work, we designed and built a dryer usable for limiting the frequent losses of the massive produced tomatoes. This paper analyzes the first results, obtained from the different experiments carried out with the developed dryer, in a context of forced convection. The results showed that increasing the temperature from 55 to 70 °C resulted in a shorter drying time decreasing from 1266 to 672 min with a brighter colour of the dried tomatoes for 70 °C. However, the increase of temperature does not affect the smell of the dried tomatoes. After drying, 7 to 8 months were required before we notice a colour change (from red to red-brown) of the dried product , indicating that the storage method still needs to be improved.

1. Introduction

Tomato (Lycopercicum esculentum Mill) is a species of herbaceous plant in the Solanaceae family. It is one of the most widely consumed vegetables in the world due to its numerous properties, especially in terms of health [1–3]. It is readily available on the market and is used as an ingredient in the cooking of many dishes, mainly to give them flavour and colour [4, 5]. Its importance is reflected in the evolution of the quantity produced on a global, regional and even local scale. Indeed, the various reports of the Food and Agriculture Organization of the United Nations (FAO) have highlighted this evolutionary trend in tomato production for several years (figure 1). From these different reports, it is observed that from 1961 to 2020, tomato production increased from about 28 million tons to more than 180 million tons worldwide, from about 2 million tons to more than 22 million tons in Africa, and from about 3,300 tons to more than 260 thousand tons in Benin with a maximum of more than 400 thousand tons in 2014 [6]. This evolution in the production of this foodstuff indicates its place in the life of each family worldwide.

Several varieties of tomatoes are cultivated and also imported in Benin Republic. Among them, one can cite 'Tounvi', 'Akikon', 'Kekefo', 'Ouaga' as local varieties and 'Sonafel', 'Tezier', 'Pomme', 'Roma', 'Rossol' etc as the imported varieties [7, 8]. However, the high water content of fresh tomatoes (about 95%) and their soft outer coating cause their rapid microbial spoilage and short shelf life, resulting in high annual post-harvest losses (20%–50%) [9, 10]. Recently, several reports and scientific publications have highlighted the extent of agricultural post-harvest losses [11–14]. Among these losses, tomatoes lost occupy the first place (or a predominant one), due to their very high water content (90%–95%) [15]. Indeed, in tropical countries, losses have been estimated at 20%–50% from harvest to consumption [9, 16–18]. In Benin Republic, these losses are estimated to around 86%, with 28% occurring during transport/storage, 37% during production, 5% during

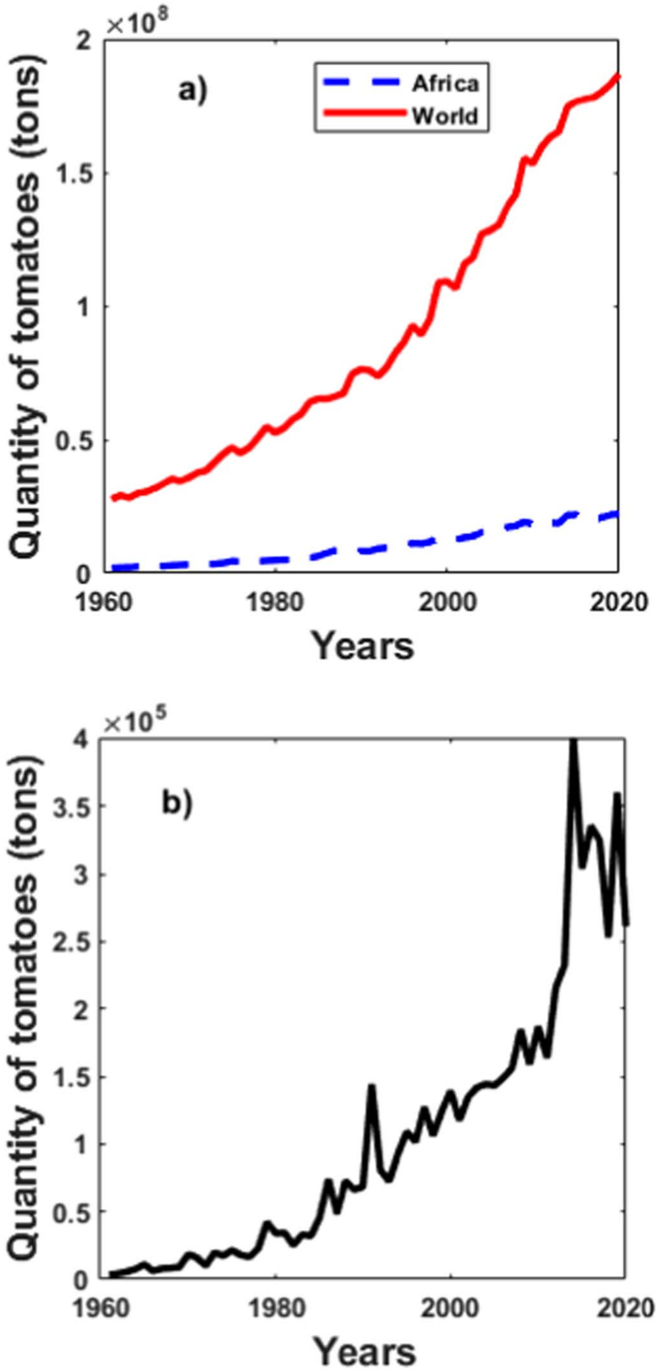

Figure 1. Evolution of tomato production in Africa and the world (a) and in Benin (b). Source: FAOSTAT, 2022 [6].

processing and 16% during marketing [19]. This creates significant economic losses among producers and considerable damage among the population. In addition to their economic and social implications, post-harvest losses also have a very negative impact on the environment. Indeed, agricultural inputs (land, water and energy), wasted and therefore not used, also lead to additional CO_2 emissions, which ultimately affects the environment [20]. The Food and Agriculture Organization of the United Nations (FAO) report, using the life cycle perspective, estimated emissions from food produced but not consumed to be around 3.3 Gtons of CO_2 equivalent. , without even taking into account land use change [21]. Moreover, the recent political troubles related to the Benin and Nigeria cross-border trade cause many losses to tomatoes exportations from Benin Republic to Nigeria [22]. This event have highlighted the urgent need to define a strong way of conserving this foodstuff in order to limit future losses. The conservation of this vegetable has been a main topic of several researches in recent decades [1, 23–27]. Drying is one of the most widely used preservation proposed solutions. But, the dried product is often subject to several types of degradation [28]. From open-air drying by the farmers

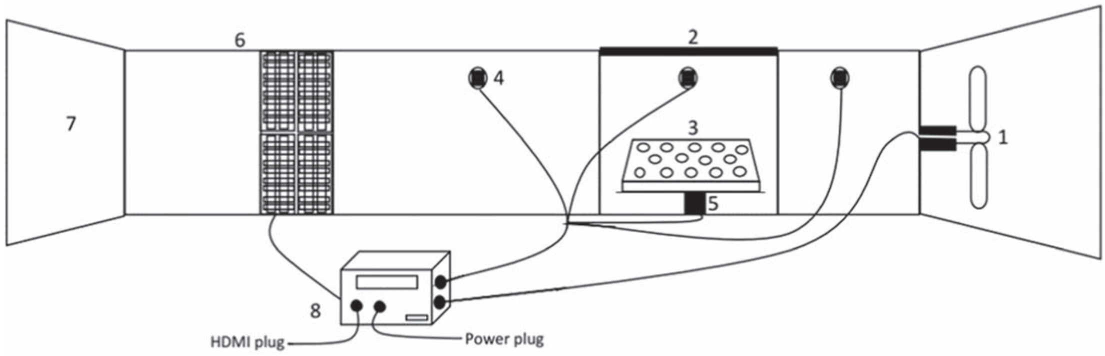

Figure 2. The drying device (realized drying vein) with its different compartments and the sensors used (pressure, temperature, humidity).

to modern drying facilities, through various transformations, several means have been put in place to preserve this product. Among the most common methods of drying tomatoes, one can cite: the foam mat technique [29], spray drying [30–32], sun drying [33] and convection drying [34–41]. In Africa, the first work carried out on the drying of tomato (Lycopersicon esculentum) was about the Zahra variety [42]. The drying of this tomato variety was done using several techniques (drying in the open air, solar with natural conversion, with forced conversion and finally under vacuum). In this study, it was noted that forced convection and vacuum drying techniques at a temperature of 50 °C and a pressure of 20 cmHg presented interesting results, from the point of view of nutritional quality and more precisely of lycopene. In 2020, further research was conducted on optimizing processing parameters for hot air drying of tomato slices [43]. The work used the Taguchi technique and, it was observed that the drying temperature is the most important to control the drying time. In 2022, further authors evaluated the effectiveness of a mixed-mode natural convection solar dryer for the transformation of fresh Roma variety tomatoes into dried tomato powder [44]. Their results were satisfactory in terms of consumer appreciation. In Benin, a study has been carried out on the conservation of the local variety Tounvi tomato (Lycopercicon esculentum Mill) by dehydrating tomato samples based on immersion impregnation (DII) in 2012 [45]. The study showed good preservation of the quality of the tomato as well as microbiological stability; but this period of microbiological stability was only observed for seven (07) weeks. The first drying studies carried on 'akikon' tomato variety in Bénin, was done in 2014 [46]. At the end of the drying carried out in an oven setted to 45 °C for a period of 16 h on pre-treated tomato slices, a significant difference was observed in the texture, color and taste of the different samples.To contribute in the reduction of post-harvest losses of tomatoes in Benin, we have set up a forced convection solar dryer within the framework of the 'FOOD Conservation by Utilizing Solar Energy for Drying '(FOCUSED-BENIN)' project. The objective of this work is to present the preliminary results obtained when drying tomato using our convective drying device.

2. Materials and methods

2.1. Solar drying device

The device used in this study is a drying vein manufactured at the 'Laboratoire de Physique du Rayonnement (LPR)' at Abomey-Calavi University (UAC) in Benin Republic. The walls are made of 0.8 cm thick Plexiglas (figure 2). It is essentially composed of three (03) compartments including a central drying chamber (2) of dimensions 16.6 cm × 36 cm × 16.6 cm. Each compartment is equipped with a temperature and relative humidity sensor (4) type DHT22 / AM2302 with good accuracy (Relative humidity: ±2% and ±5% at extremes; Temperature: −40 ~+150 °C; ±0.5 °C). An electronic scale (5) capable of measuring up to 10kg is placed inside the drying chamber. It is controlled by an Arduino type mass sensor. The balance supports a sample holder made of a perforated tray (3) measuring 14.90 cm × 30 cm. The heating compartment (6) contains four thermostats of 150W each. They can be powered by conventional electricity or photovoltaic solar panels. A fan (1) is used to provide forced convection within he dryer with an air velocity varying from 0.66 $m.s^{-1}$ to 4 $m.s^{-1}$. An orifice (7) is used to ensure that the air enters the vein. Finally, the vein is equipped with a black box (8) with a memory card that stores all the experimental data.

Figure 3. Sliced tomatoes ready to go into the dryer.

2.2. Experimental protocol

The 'akikon' variety of Tomatoes were purchased fresh at the local market in Abomey-Calavi in the south of Benin Republic. A sorting of the tomatoes which are intended for drying is carried out in order to separate those which are too ripe from those which are not in good condition. Next, the tomato is washed and rinsed well with clean water (without any other pre-treatment) and then cut into 4 thin slices with a knife (figure 3). Finally, the tomato is emptied of its seed content and left to drain in a sieve for a few minutes (about 10 min). To evaluate the effect of temperature on dried tomatoes, drying was done on samples in four different environments: 55 °C, 60 °C, 65 °C or 70 °C, as done in several previous works on drying tomato [1]. The mass of each sample is measured during the drying process. The slices were spread out on the rack within the drying chamber with a spacing that made the distribution of the heat flow on these tomato slices homogeneous. The speed of the drying air is set at 0.66 $m.s^{-1}$. The device is fully autonomous and runs under a computer application. The system stops when the mass of the sample no longer varies.

3. Results and discussions

After calibration of the different sensors used and the necessary adjustments of the device, the drying operation started and the data recorded during the drying process was collected at the end of the drying of each dried sample. The collected data are processed and the dried tomatoes are packed. The results of the analysis showed that the variety of tomato used contains 95.67% water (143.49g/150g tomato) and 4.33% dried matter (6.51g/150g tomato). A part from the water content which decreases from 95.67% to 7.99%, 7.56%, 7.20% and 1.56% respectively at 55 °C, 60 °C, 65 °C and 70 °C at the end of the drying process. This result is similar to those found in the literature. Indeed, during the drying process, we have observed a decrease in drying time with increasing drying temperature as mentioned in several works [1, 3, 28, 42, 47–50]; a decrease in the moisture content of the product over time, was also observed by these authors. Moreover, it would appear that the other nutrients have remained concentrated in the dried tomatoes. Indeed, all the dried products kept their red coloring, the main carotenoid responsible for which, lycopene, is a very powerful antioxidant [51]. We noted an improvement in tomato colour with increasing temperature and drying time as mentioned in several works [52–55]. Given that the lycopene is responsible for the red pigment in tomatoes [56], this improvement in its color is due to an increase in the lycopene content that these authors would have noticed with the increase in temperature and drying time. Similarly, it was observed during their work, that during drying for high temperatures, the level of certain elements (fat, vitamin C, β-carotene) decreased while that of many other elements such as carbohydrates, protein and lycopene increased the concentration of these nutrients as moisture was removed [55].

3.1. Influence of temperature

During the drying process, heat and mass are transferred simultaneously [57]. The various tests carried out in our study show that the temperature influences the drying kinetics. This influence is more important as the temperature increases, which leads to a decrease in the water content of the product. Similar observations have been obtained by [42, 57, 58]. For a constant drying air velocity equal to 0.66 $m.s^{-1}$, temperatures of 55 °C,

Figure 4. Samples of tomatoes dried during the different experiments at 55 °C (a), 60 °C (b), 65 °C (c) and 70 °C (d) respectively.

Table 1. Information on the initial product mass, drying temperatures, dry mass and drying time of each product.

Drying tempera ture (°C)	Initial mass (g)	Final mass (g)	Dry mass (g)	Drying water content (%)	Drying time
55 °C	150,53	18,537347	6,51	7,99	25 h
60 °C	150,64	17,898384		7,56	25 h
65 °C	150,40	17,3388		7,2	25 h
70 °C	150,06	8,850936		1,56	23h18min

60 °C, 65 °C and 70 °C were set respectively for different trials and the following drying times were observed 1266, 911, 838 and 672 min for reaching 11% moisture content in tomato. Thus, there is a decrease in drying time with an increase in temperature. Similar results were noted by [59]. The temperature does not seem to have any influence on the odour of the dried tomato. However, it influences the colour of the tomato Thus, figure 4 belows show the state of the untreated tomato dried at 55 °C, 60 °C, 65 °C and 70 °C respectively. Table 1 provides information on the initial mass, drying temperatures, dry mass and drying time of each product.

3.2. Influence of drying on colour of the dried tomato

From the analysis of the colour of the untreated tomato dried at these different temperatures, it appears that the colour of the tomato dried at 65 °C and 70 °C is the most vivid compared to the untreated tomatoes dried at 55 °C and 60 °C. The colour of untreated dried tomatoes obtained at temperatures of 65 °C and 70 °C, which could seem to be the best drying temperatures for red tomatoes [3, 49, 50], could be due to the conservation of nutrients, in this case lycopene, the red pigment that gives tomatoes their red colour [51] and which is known to prevent cancer, protect against premature ageing, and protect against ultraviolet rays, but does not protect against the sun's rays [2, 60, 61].

3.3. Analysis of the drying process

The data collected during the tomato drying were processed. Figure 5 shows the evolution of the water content of the tomato during the drying period of time.

The water content of the tomato during drying for various temperatures was analyzed. For the different temperature values, a decrease in water content of the tomato over time is observed. The analysis in figure 5 shows that the water content decreases more rapidly during the drying process as the temperature increases.

Thus, the drying time taken to reduce the tomato water content from 95.67% to 11% is 1266, 911, 838 and 672 min respectively for temperatures set at 55, 60, 65 and 70 °C. It is therefore clear that temperature influences the drying process (figure 6). The results of our experiments are in agreement with those mentioned

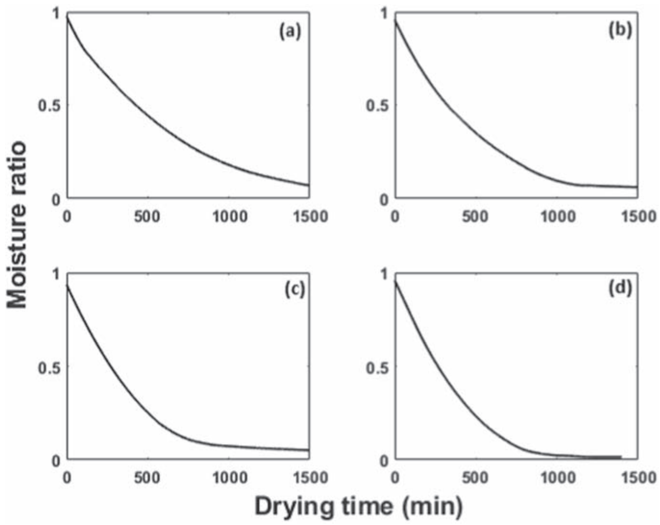

Figure 5. Evolution of water content during drying of tomatoes at 55 °C in (a), 60 °C in (b), 65 °C in (c) and 70 °C in (d).

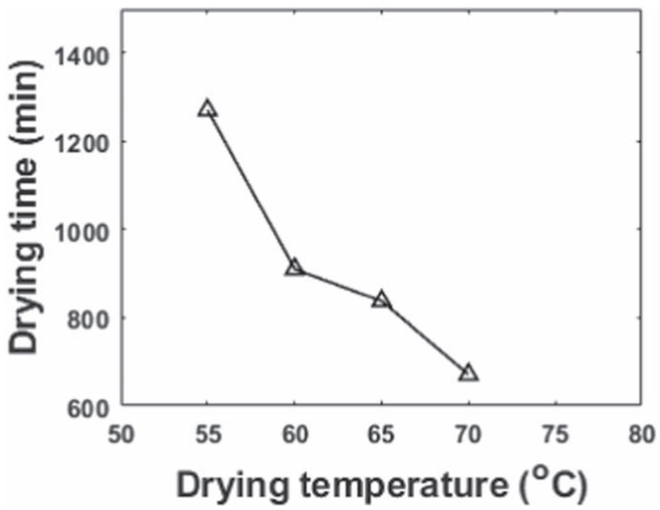

Figure 6. Influence of drying temperature on the drying time of tomatoes.

in several works in which the authors also observed a decrease in the water content profile during drying [1, 3, 42, 57–59, 62].

3.4. Discussion

This study is a first in forced convection drying for tomato variety 'Akikon' in Benin Republic. The major interest of the device, is that it can be used everywhere on the national territory and elsewhere, because operating on solar pholtovoltaic. The designed dryer is not without flaws. Possible adjustments will be made on the device to optimize the drying process in order to obtain well dried products at the end. This device at laboratory scale, which can dry up to 300g of tomato in 24 h, is of great importance for the conservation of tomato and will contribute significantly to the reduction of post-harvest losses of this foodstuff, to food security and consequently to poverty reduction in the country. Its scaling up will be of great benefit to agricultural promoters and can contribute to the achievement of the Sustainable Development Goals, in particular SDG 2 which states to End Hunger, Ensure Food Security, Improve Nutrition and Promote Sustainable Agriculture; SDG 1 which aims to Eradicate Every Form of Extreme Poverty Including the Lack of Food, Clean Drinking Water, and Sanitation; SDG 3 which aims to Ensure Healthy Lives and Promote Well-being for All at All Ages and SDG 6 which goal is to Ensure Availability and Sustainable Management of Water and Sanitation for All. In addition, there was a conservation problem with the dried products. Indeed, after about 7 to 8 months of conservation, the dried products lost their red colour in favour of a red-brown colour (figure 7). This could be due to the bottles

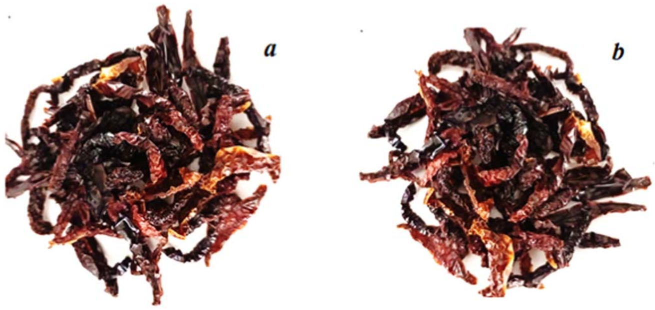

Figure 7. Colour change observed in dried tomatoes after about seven (7) to eight (8) months of drying. In (a), the tomato dried at 65 °C (conservation period: 08-12-2021 to 21-07-2022) and in (b), the tomato dried at 70 °C (conservation period: 30-10-2021 to 21-07 2022).

used for preservation. In view of this observation, new types of packaging will be used for the products to be dried to limit the colour change noted. Changes will be made to this device to make it more suitable for drying fruit and vegetables in general for the welfare of the population in Benin Republic.

4. Conclusion

In order to reduce post-harvest losses observed in tomatoes, a drying line was designed and built. The objective of this work is to analyze the first results from the different experiments carried out with the dryer. The study of the influence of the tomato drying temperature on the colour, odour and drying time of the tomato using the forced convection drying method was carried out. From the results obtained, it was observed that the increase in temperature not only affected the colour of the dried tomato but also the drying process and allowed for short drying times. The main finding of this study is that the developed device operating on solar photovoltaic, under the same or similar operating conditions (temperature, drying time) like in other studies, provided the products of the same quality, while at the same time it also offered advantages in regard to portability of devices and preservation of food at the farm level. This is particularly relevant for national and African context, as well as for other areas where different logistics problems and socio-economic conditions limit ability to reduce hunger, poverty and generation of food waste. Comparison of the results obtained in this study with the results of other studies also indicated that the Akikon tomato grown in Benin (West Africa) in regard to the drying performance is of similar quality like the same and other tomato varieties grown in other regions. However, it was noted that it had no influence on the smell of the dried tomato. The results of the forced convection solar drying used in this study are particularly interesting for temperatures of 65 °C and 70 °C with a drying time of about 24 h. It should be noted that it would also be interesting to study the packaging for the conservation of the dried tomato, the shelf life and the rehydration capacity of the dried tomato, in order to prevent change of colour which was noticed after 7 to 8 months after drying.

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Data availability statement

The data that support the findings of this study are openly available at the following URL/DOI: https://www.fao.org/faostat/en/#data/FBS.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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