

Study of Four Onion Varieties Drying Kinetics in an Oven and a Solar Greenhouse

Ngon éFall Beye^{1,2}, Nicolas Cyrille Ayessou¹, Cheikhou Kane¹, Mariame Niang Mbaye¹, Cheikh Talla³, Abdou Sene² & Codou Mar Diop¹

¹Polytechnic School, (ESP) / Center for Food Security and Functional Molecules Studies (CESAM-RESCIF), Cheikh Anta Diop University, Dakar, Senegal

²Laboratory for Biological Sciences, Agronomy and Complex Systems Modeling (LaBAM) / UGB, Saint-Louis, Senegal

³Pasteur Institute of Dakar, Epidemiology Unit for Infectious Diseases - 36, Avenue Pasteur, Dakar, Senegal

Correspondence: Ngon éFall Beye, Training and Research Unit of Agricultural Sciences, Aquaculture and Food Technologies (UFR S2ATA), Department of Food Technologies, Gaston Berger University, Senegal. Tel: 221-339-601-986. E-mail: ngone-fall.beye@ugb.edu.sn / fallbeye@gmail.com

Received: March 4, 2019

Accepted: March 22, 2019

Online Published: April 15, 2019

doi:10.5539/jfr.v8n3p59

URL: <https://doi.org/10.5539/jfr.v8n3p59>

Abstract

Onion production (*Allium cepa* L.) in Senegal reached 390 000 tons in 2016. Due to post-harvest losses, annual demand (150 000 and 250 000 tons) is being met through imports. This work consists in proposing a drying process at a lower cost to overcome this dependence and preserve the quality of the product. The optimization of local onion varieties drying in an oven and in solar greenhouse, as well as the physicochemical characterization of the products were carried out. The moisture of fresh onion bulb varies between 85.56 ± 0.60 and 89.13 ± 0.69 (%). To obtain a moisture $\leq 8.89 \pm 0.16$ (%) ensuring stability, the optimal drying conditions in the oven are $60^\circ\text{C} / 6\text{H}$ (Galmi Violet) and 7H (Safari, Gandiol F1 and Orient F1). Under these conditions, the content of polyphenols in g equivalent of gallic acid / 100 g db increases (0.111 ± 0.0040 to 0.312 ± 0.0041 before drying, $0.546 \text{ g} \pm 0.0117$ to 0.837 ± 0.0091 after drying). Optimum solar drying in a greenhouse is obtained between temperatures of 35 to $65^\circ\text{C} / 8\text{H}-9\text{H}$. From a perspective of sustainable development, the perspective is the modeling of drying kinetics in a solar greenhouse.

Keywords: *Allium cepa* L., Local varieties, drying, optimal conditions, moisture, water activity, polyphenols

1. Introduction

Senegalese agriculture, particularly rainy and seasonal agriculture, contributed about 18% of GDP in 2015 (National Agency for Statistics and Demography [ANSD]) and is one of the key levers for ensuring food security. Horticultural is the most dynamic sub-sector of this Senegalese agriculture, with a growth of between 5% and 10% since 2004.(ANSD, 2014; Direction de l'Horticulture [DH], 2015). This performance is mainly driven by the growth of the onion sub-sector which represents 60% of horticultural production (DH, 2016).

In fact, onion (*Allium cepa* L.), a very popular vegetable in Senegal, with an annual consumption of between 150,000 and 250,000 tons (ARM, 2016) represents 25% of household expenditure. The most common use of onion in households across the country is fragmenting the bulb into pieces that are incorporated into recipes for flavor development. However, despite a record production of 390,000 tons in 2016, meeting household demand over the year remains dependent on imports due to significant post-harvest losses due to the high *moisture* content of the onion. Thus, to reduce post-harvest losses, developing the dehydration process seems to be an excellent opportunity but the process requires a lot of energy.

Many studies on food products drying have shown that drying efficiency and kinetic characteristics depend on the drying conditions and the types of products (varieties and their degree of maturity, shape, thickness, composition), but also on the electric or solar drying mode. Among these studies can be mentioned those on the onion (Ahmed-Zaid, 1999; Albitar, Mounir, Besombes, & Allaf, 2011; Anwar & Tiwari, 2001; Kiranoudis, Maroulis, & Marinou-Kouris, 1992; Krokida, Karathanos, Maroulis, & Marinou-Kouris, 2003; Sarsavadia, Sawhney, Pangavhane, & Singh, 1999), the pepper (Anwar & Tiwari, 2001; Lhendup, 2005) and the beef

(Lhendup, 2005; Tom, 2015).

On the other hand, the use of solar drying, a major lever to overcome the energy constraint, preserves the quality of products despite the variability of climatic conditions (Boughali, 2010; Jannot, 2006; Mendez Lagunas, 2007). These findings and the absence of data in the literature on local varieties justify the initiation of this research.

The objective of this study is to optimize the drying of four onion varieties in an oven and in solar greenhouse and to compare solar drying, which reduces the energy bill, to electric convective drying. Optimal drying conditions are determined by studying the impact of this process on some major biochemical and physicochemical parameters.

2. Materials and Methods

2.1 Materials

2.1.1 Plant Material

The local onion is collected in the cooperative of the locality of RAO in Saint-Louis (Senegal). The varieties studied are Galmi violet, Safari, Gandiol F1 (Gandiolais) and Orient F1 (Orient) with a maturity of 85% of leaves falling at harvest.

2.1.2 Analysis Equipment

Analysis equipment: an oven with ventilation (Memmert brand), a solar greenhouse equipped with a ventilation system to regulate the ambient air temperature and humidity, sensors for temperature and humidity readings, capsules in pyrex, drying racks, a scale (Denver instrument brand with a reliability rate of 0.0001g), a thermohygrometer (Voltcraft brand with a precision of 1 °C and 3.5%), a water activity meter (Rotronic HP 23 brand), a pH meter (HI 23 brand), a burette, a spectrophotometer (Specord brand), a mineralizer, a distiller and laboratory glassware.

2.1.3 Graphical and Statistical Representation Tools

Data exploitation is carried out with both the R version 3.4.0 (Team R Core, 2017) software for the comparison test between the two methods of drying, the analysis of variance and the concordance of the measurements, and the Excel version 2016 software as a tool for scientific calculations for graphic representations.

2.2 Methods

The peeled onions are washed in chlorinated water 100 ppm (0.1 mg / L water), rinsed three times with clean water, dewatered and finely chopped with a chopper to neglect the deformation of the product during the drying process.

The thickness of the samples is in the range of 1.7 mm.

2.2.1 Kinetics Study

The tests are conducted in an oven in the temperature range of 50 °C to 70 °C with a step of 5 °C to determine the optimum temperature / time to obtain stable products.

Ten grams are taken from the chopped onions of three different bulbs, and spread in pyrex cups. The experiments are carried out with ventilation at a fixed air velocity of 2.4 m/s and a relative humidity between 10 and 15% (Babalís & Belessiotis, 2004; Clemente, Frías, Sanjuan, Benedito, & Mulet, 2011; Kiranoudis et al., 1992; Krokida et al., 2003; Sarsavadiya et al., 1999).

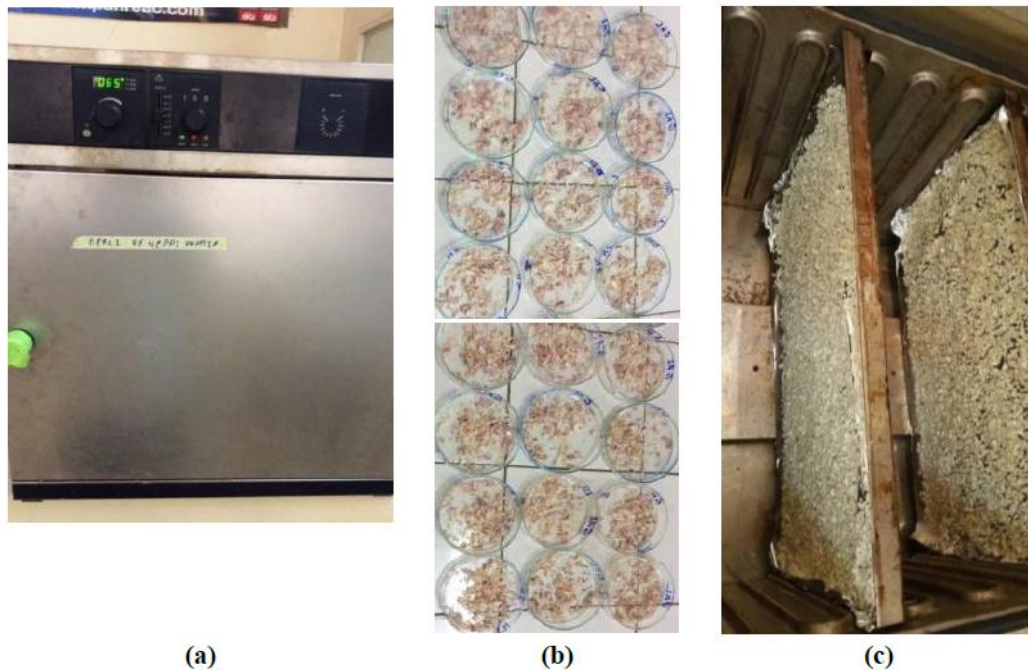


Figure 1. (a) Photo of the oven (b) cups for monitoring kinetics (c) trays for producing onion powder samples

Regarding solar greenhouse drying, the four varieties are dried simultaneously (one variety per drying rack). Each rack is squared in four parts of equal size (0.74 X 0.71 m) on which three kg of onion are spread in monolayer. Inside the solar greenhouse, removable room sensors make it possible to follow the evolution of the temperature and the relative humidity, two determining parameters for the drying. During solar greenhouse drying, the relative humidity varies between 10-60% and the temperature varies between 35 °C and 65 °C.

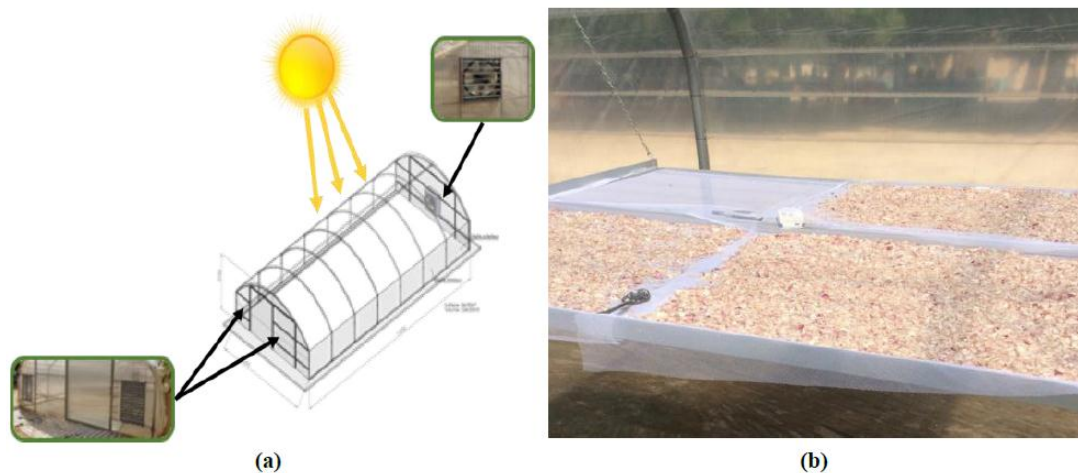


Figure 2. (a) Photo of the solar greenhouse from the outside with the ventilation and air extraction system and (b) photo of a drying rack with the onions distributed in a thin layer

Both in the oven and in the solar greenhouse, the experiments are performed in triplicate and the monitoring of the weight loss takes place every hour.

2.2.2 Physico-Chemical Analyses

The various biochemical and physicochemical analyses performed on raw materials as well as onion powders obtained by dehydration in an oven and in a solar greenhouse are the pH according to NF V76-122: 1994, NF

EN 1132, titratable acidity according to NF V 05-101 January 1974, European Standard EN 12147 December 1996), the moisture content with reference to standard NF ISO 712: 2009), the activity of water according to standard NF EN ISO 17025). In addition, the polyphenols, the most important functional elements to be preserved during the drying of the four onion varieties, are evaluated by the Folin-Ciocalteu reagent spectrophotometric assay method in a basic medium at 760 nm. The total polyphenol content is expressed in gallic acid equivalent.

All moisture measurements and characterization analyses are performed in triplicate to ensure repeatability.

2.2.3 Statistical Analyses

The evaluation of the reproducibility and the repeatability of the measurements is made by the numerical method which is the LIN coefficient (Lawrence & Lin, 1989).

The Lin's concordance coefficient varies between -1 and 1, where the values -1, 0 and +1 respectively mean perfect discordance, zero concordance and perfect match.

The Student's parametric test is used for the comparison of the:

- characteristics of onion varieties (water activity, titratable acidity, pH and polyphenol content) before drying;
- stability moisture of the oven-dried samples and those dried in a solar greenhouse.

All statistical analyses are performed with a significant threshold of $p < 0.05$.

3. Results and Discussion

3.1 Characteristics of Onion Varieties before Drying

The physical and chemical characteristics of the samples before drying are presented in table 1.

All varieties are marked by a high moisture content and A_w , pH and polyphenols values are almost identical. Only the acidity of the Safari variety seems to stand out (9.23 mEq / 100g db) from that of the other varieties (between 4 and 6 mEq / 100g db).

The two most important criteria for the stability of food products, namely the moisture content (%) and the water activity of fresh onions are respectively for:

- Galmi violet $85.56 \pm 0.60 / 0.945 \pm 0.01$;
- Safari $88.11 \pm 0.61 / 0.950 \pm 0.001$
- Gandiol F1 $86.99 \pm 0.10 / 0.940 \pm 0.001$;
- Orient F1 $89.13 \pm 0.69 / 0.947 \pm 0.009$.

Table 1. Major characteristics of onion samples before drying

Variety	Galmi Violet	Safari	Gandiol F1	Orient F1
Moisture (%wb)	85.56 ± 0.60	88.11 ± 0.61	86.99 ± 0.10	89.13 ± 0.69
Water Activity	0.945 ± 0.011	0.950 ± 0.001	0.940 ± 0.013	0.947 ± 0.009
Polyphenols (g EAG /100g db)	0.111 ± 0.0040	0.134 ± 0.0065	0.162 ± 0.0016	0.312 ± 0.0041
Titrable Acidity (mEq / 100g db)	6.12 ± 0.00	9.23 ± 0.00	4.51 ± 0.02	6.13 ± 0.38
pH at 10%	6.42 ± 0.03	6.29 ± 0.06	6.35 ± 0.03	6.37 ± 0.03

Legend: Equivalent Gallic Acid (EAG)

3.2 Optimal Drying Conditions

The Lin coefficients obtained for the measurement concordance test for all oven drying and solar greenhouse drying kinetics vary between 0.9993555 and 0.9999317 with a confidence interval of [0.9991869; 0.9999431]. This indicates that there is a perfect match between the three measurements made for each test.

The results of the statistical test for the comparison of the oven drying kinetic data to that in solar greenhouse are between [-0.44906 - 0.73362] for Student's parameter (t), [0.4697 - 0.9572] for the pvalue and [24 - 26] for the degree of freedom (df). Therefore, regardless of the oven drying temperature, $p > 5\%$ values show that there is no significant difference between oven drying and solar greenhouse drying kinetics.

The stability of dried fruits and vegetables is guaranteed with a moisture content of $8 \pm 2\%$ or less and an A_w between 0.5 and 0.6 to avoid any microbial activity (Bernard & Carlier, 1992; ESA, 2004; Faiveley, 2003; Le Meste & Chiotelli, 2002). These values serve as a reference to determine the optimal drying conditions taking

into account the evolution of the physicochemical characteristics after drying.

3.2.1 Optimal Drying Conditions in the Oven

Figure 3 shows the evolution of the moisture content of Galmi Violet, Safari, Gandiol F1 and Orient F1 varieties dried in an oven at different temperatures.

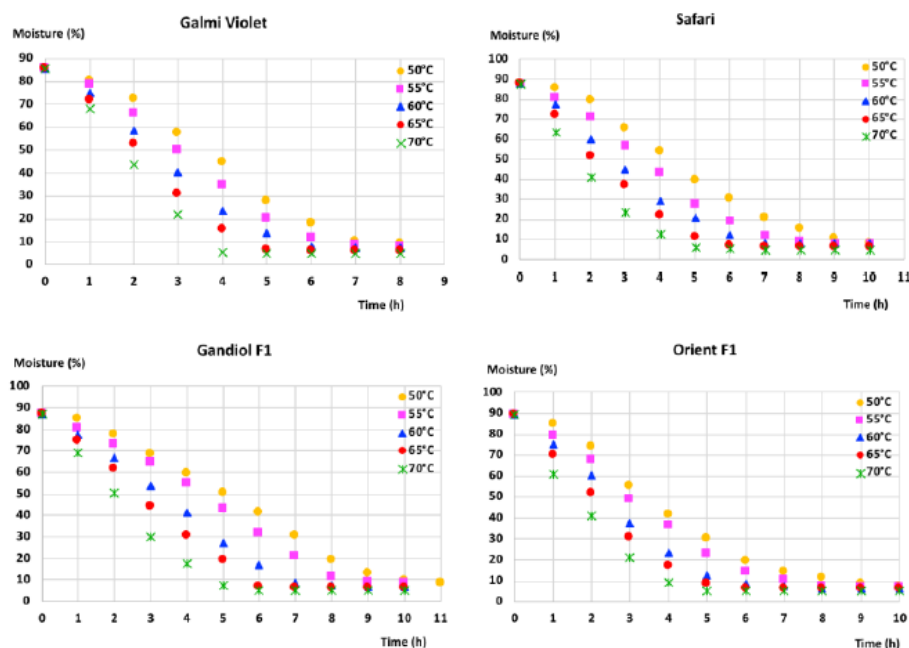


Figure 3. Evolution of moisture content of oven-dried onion varieties at different temperatures

The optimal drying time in the oven, which makes it possible to reach the stability moisture, changes inversely with the increase in temperature. Over the temperature range between 50 °C and 70 °C, the results (Figure 3) obtained for the four varieties are as follows:

- the initial moisture content of Galmi Violet ($85.56 \pm 0.60\%$) decreases to a moisture stability of between 8.89 ± 0.16 and 5.23 ± 0.34 (%) for an optimal time between 8H and 4H depending on the drying temperature. At each increase in temperature (+5 °C), the drying time decreases (-1H);
- with an initial moisture content of 88.11 ± 0.61 (%), the stability moisture of the Safari variety, between 8.14 ± 0.52 and 6.30 ± 0.26 (%) according to the drying temperature; is reached for an optimal time between 10h and 5h. The drying time decreases (-1H) at each increase in temperature (+ 5 °C) except from 55 °C to 60 °C where the time step is (-2H);
- the Gandiol F1 variety with an initial moisture content of 86.99 ± 0.10 (%) has a stability moisture of between 8.68 ± 0.33 and 7.70 ± 0.39 (%) depending on the drying temperature. The optimal drying time varies between 11H and 5H with a pitch of (-2H) for each increase of a step of 5 °C in the temperature range of 50 °C to 60 °C and (-1H) for that ranging from 60 °C to 70 °C;
- for the Orient F1 variety with an initial moisture content of 89.13 ± 0.69 (%), the stability moisture is between 8.54 ± 0.41 and 5.02 ± 0.24 (% db) depending on the drying temperature. The optimal drying time is between 9H and 5H with a variation of (-1H) for each temperature increase of a step of 5 °C in the range 50 °C to 60 °C, of (-2H) in the range of 60 °C to 65 °C and no variation in that of 65 °C to 70 °C.

For each variety, the optimal temperature and the optimal drying time are determined taking into account changes in moisture content and water activity

(Bonazzi, Dumoulin, & Bimbenet, 2008; Charreau & Cavaille, 1991; Jeantet, Croguennec, Schuck, & Brulé 2008; Jiménez Elizondo, 2011), as well as the impact of the process on polyphenols (Ali, Bordia, & Mustafa, 1999; Lombard, Peffley, Geoffriau, Thompson, & Herring, 2005; Yang, Meyers, van der Heide, & Liu, 2004). These are constituents of therapeutic interest (Ali, Thomson, & Afzal, 2000; Griffiths, Trueman, Crowther, Thomas, & Smith, 2002; Zohri, Abdel-Gawad, & Saber, 1995).

3.2.2 Optimal Drying Conditions in a Solar Greenhouse

Figure 4 shows the evolution of the moisture content of sun-dried onion varieties at varying temperatures during drying.

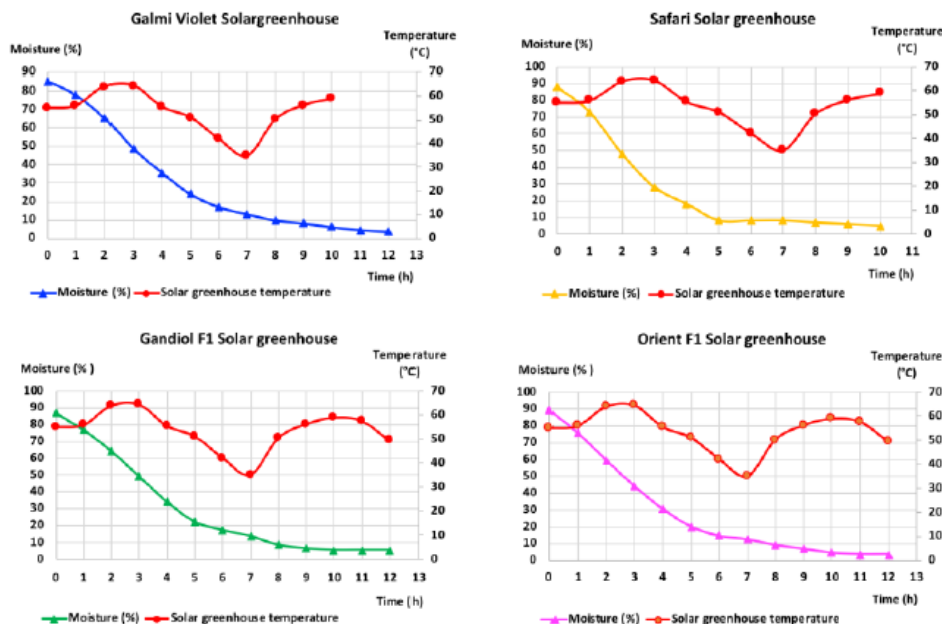


Figure 4. Evolution of the moisture content of the four sun-dried onion varieties at varying temperatures during drying

The drying of onions in a solar greenhouse unlike the oven depends on the sun. Thus during the tests the temperature and humidity in the solar greenhouse varied in the respective ranges of 35-65 °C and 10-60%. The drying kinetics of the four varieties are essentially identical.

Figure 4 shows that the stability moisture values are reached from 8H solar greenhouse drying and that from 10H the values are almost stable. Table 2 displays the different moisture contents for drying times from 8H to 10H.

Table 2. Drying time in the solar greenhouse and moisture content of dried samples

Variety	Moisture (% db)		
	Drying time		
	8H	9H	10H
Galmi Violet	9.89 ± 3.034	8.23 ± 2.004	6.23 ± 2.465
Safari	6.88 ± 2.107	5.88 ± 0.195	4.88 ± 0.088
Gandiol F1	8.54 ± 2.620	6.49 ± 2.253	5.45 ± 0.954
Orient F1	9.7 ± 4.18	6.89 ± 1.045	4.66 ± 1.193

The moisture content is inversely proportional to the drying time in the solar greenhouse and the elimination of water is different depending on the variety. These results are compared with Aw and polyphenol values to determine the optimal drying time.

3.3 Physico-chemical Characterization of the Samples after Drying

Water activity (Aw), titratable acidity, and pH are characteristics of the environment as important in the stabilization of food products as the moisture content. To avoid any microbial activity, an Aw between 0.5 and 0.6 is necessary. Moreover, the more acidic the medium (pH less than 4.5), the more it is unfavorable to chemical and biochemical degradation reactions (Bernard & Carlier, 1992; Charreau & Cavaille, 1991; Faiveley, 2012).

3.3.1 Characterization of Dried Samples in an Oven

3.3.1.1 Evolution of Water Activity

The evolution of water activity for the four varieties (Figure 5) shows that the initial Aw values between 0.940 ±

0.01 and 0.950 ± 0.001 decreases with increasing drying temperature. The initial A_w values are divided by a factor between 1.70 and 2.78 for each temperature step of $+ 5^\circ\text{C}$ in the oven. A_w reaches values between 0.362 ± 0.003 and 0.447 ± 0.069 at 60°C . On the other hand, the A_w values of the samples for the 65°C and 70°C temperatures remain relatively stable in this range, except for the Orient F1 variety at 65°C (0.497 ± 0.002).

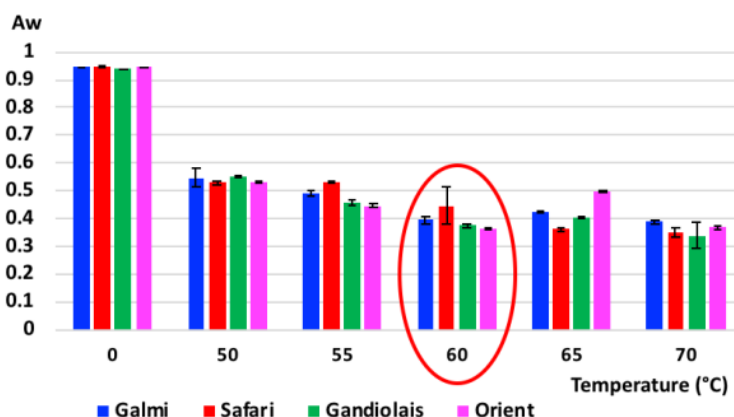


Figure 5. Water activity of the samples after optimal drying

3.3.1.2 Evolution of Titratable Acidity and pH

The monitoring of titratable acidity and pH at 10% of oven-dried samples (*Figure*) indicates that with increasing drying temperature, the initial values of titratable acidity and pH at 10% ranging respectively between 4.51 ± 0.02 and 9.23 ± 0.00 mEq / 100g (db) and 6.29 ± 0.06 and 6.42 ± 0.03 , change inversely for the four varieties. The multiplicative factor for titratable acidity is between 0.84 and 2.53 while the pH is divided by a factor in the range of 1.12 to 1.28. However, over the temperature range of 50°C to 70°C , the difference is not significant for both titratable acidity and pH (all p values for Student's test are greater than 0.05).

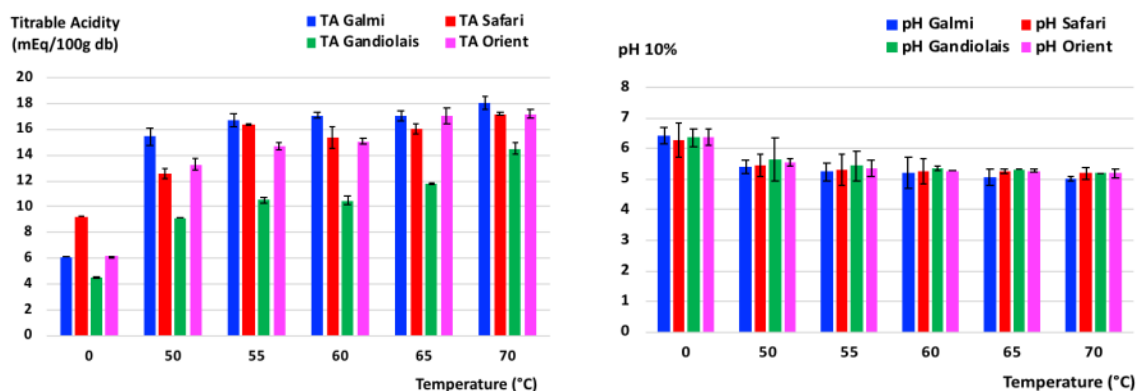


Figure 6. Titratable acidity and pH of the samples after drying in an oven at different temperatures

3.3.1.3 Evolution of the Polyphenol Content

The initial levels of total polyphenols (Table 1) of the four varieties, ranging from 0.111 ± 0.0040 to 0.312 ± 0.0041 g EAG / 100g (db), increase with drying temperature (Figure 7Figure). The increase in total polyphenol content is greatest at a temperature of 60°C with 0.546 ± 0.0117 g EAG / 100 g (db) for Galmi Violet; it is 0.837 ± 0.0091 g EAG / 100g (db) for Safari, 0.694 ± 0.0173 g EAG / 100 g (db) for Gandiol F1 and 0.691 ± 0.0162 g EAG / 100 g (db) for Orient F1. This effect of temperature on polyphenol content is similar to those found in the literature (Ali et al., 1999; Lombard et al., 2005; Yang et al., 2004).

Nevertheless, from 65°C , a decrease of about 0.3% to 37% is observed. This decrease is accentuated at 70°C , showing the negative impact of temperature on polyphenols.

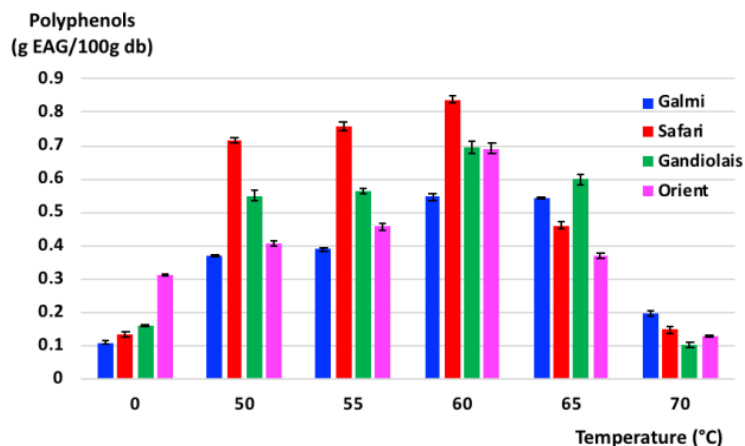


Figure 7. Polyphenol content after drying in an oven at different temperatures

The temperature range 50 °C to 65 °C with an optimal drying time between 6H and 11H makes it possible to obtain characteristics (A_w and moisture content) ensuring the stability of the product. However, the concern to maintain the functional properties of the polyphenols and to reduce the energy consumption makes it possible to determine the best drying time-optimal temperature pair.

Thus, the 60 °C temperature with an optimal time of 6H for Galmi Violet and 7H for the other three varieties, is the best time/temperature pair because the polyphenol content is at its maximum. The products dried under these optimal conditions in the oven have a water activity of about 0.4 and a moisture content respectively for Galmi Violet, Orient F1, Safari and Gandiol F1 of $7.96\% \pm 0.42$; 7.17 ± 0.63 ; $8.42\% \pm 0.05$ and $8.67 \pm 0.15\%$.

With these moisture and A_w values, the biochemical and physicochemical reactions and the development of the microorganisms responsible for the perishability of the products are then inhibited (Bernard & Carlier, 1992; Faiveley, 2003).

3.3.2 Characterization of Samples after Drying in a Solar Greenhouse

In the solar greenhouse drying conditions with the respective temperature and humidity ranges in the greenhouse of 35-65 °C and 10-60%, the initial water activity of the samples decreases after 8h drying (Table 1). The water activity values of the four dried onion varieties ranged from 0.577 ± 0.007 to 0.675 ± 0.041 (Table 3). These results are in the range to avoid any microbial activity (Bernard & Carlier, 1992; Charreau & Cavaille, 1991; Faiveley, 2012).

This decrease in the water activity of varieties continues with the increase in drying time in the solar greenhouse. Thus, for a drying time of 9H, the values of the water activity of the samples are between 0.505 ± 0.005 and 0.550 ± 0.018 while at the end of 10H of drying, they are between 0.415 ± 0.012 and 0.491 ± 0.006 .

Table 3. Water activity of solar greenhouse dried samples at different drying times to achieve stability moisture values

Variety	Water Activity (A_w)		
	Drying time		
	8H	9H	10H
Galmi Violet	0.577 ± 0.007	0.538 ± 0.003	0.469 ± 0.012
Safari	0.589 ± 0.003	0.505 ± 0.005	0.477 ± 0.000
Gandiol F1	0.675 ± 0.041	0.55 ± 0.018	0.415 ± 0.012
Orient F1	0.617 ± 0.008	0.536 ± 0.005	0.491 ± 0.006

The stability moisture of samples dried in a solar greenhouse at different times (Table 2) shows that the optimal drying time is 9H for Galmi Violet and Orient F1 varieties and 8H for Safari and Gandiol F1 varieties. At these optimal times, the values of the water activity (Table 3) between 0.536 ± 0.005 and 0.675 ± 0.041 ensure the absence of any microbial activity. The characteristics of the products dried under these optimal conditions are presented in Table 4.

Table 4. pH, titratable acidity and polyphenol content of solar greenhouse dried samples under optimal conditions

Variety	Optimal drying time (H)	pH (at 10%)	Titrable acidity (mEq / 100g db)	Polyphenols (g /100g db)
Galmi Violet	9	5.52 ±0.14	47.43 ±5.035	0.530 ±0.003
Safari	8	5.56 ±0.03	48.60 ±1.018	0.720 ±0.003
Gandioli F1	8	5.35 ±0.03	34.89 ±0.198	0.505 ±0.009
Orient F1	9	5.48 ±0.10	48.760 ±2.432	0.607 ±0.005

At these optimal times of 9H for the Galmi Violet and Orient F1 varieties and 8H for the Safari and Gandioli F1 varieties, the characteristics of the solar greenhouse dried products (Table 4), compared to the initial values (Table 1), reflect that:

- the titratable acidity increases with the drying temperature whereas the pH at 10% changes inversely for the four varieties. The titratable acidity of the varieties that are dried in solar greenhouse ranges from 34.89 ± 0.1 to 48.760 ± 2.322 mEq / 100g (db). As for pH, the values are in the range of 5.35 ± 0.03 to 5.56 ± 0.03 ;
- polyphenol contents also increase with drying. The initial values of polyphenols of Galmi Violet (0.111 ± 0.004 g EAG / 100g db), Safari (0.134 ± 0.0065 g EAG / 100g db) Gandioli F1 (0.162 ± 0.0016 g EAG / 100g db) and Orient F1 (0.312 ± 0.0041 g EAG / 100g db) varieties are respectively multiplied by a factor of 5.48; 5.37; 3.10 and 1.94 after drying in the optimal conditions of solar greenhouse.

Photos of onion powders obtained after drying in an oven at temperatures of 60 °C, 65 °C and 70 °C and those obtained after drying in a solar greenhouse in 8H, 9H and 10H time are shown in the Figure 8.

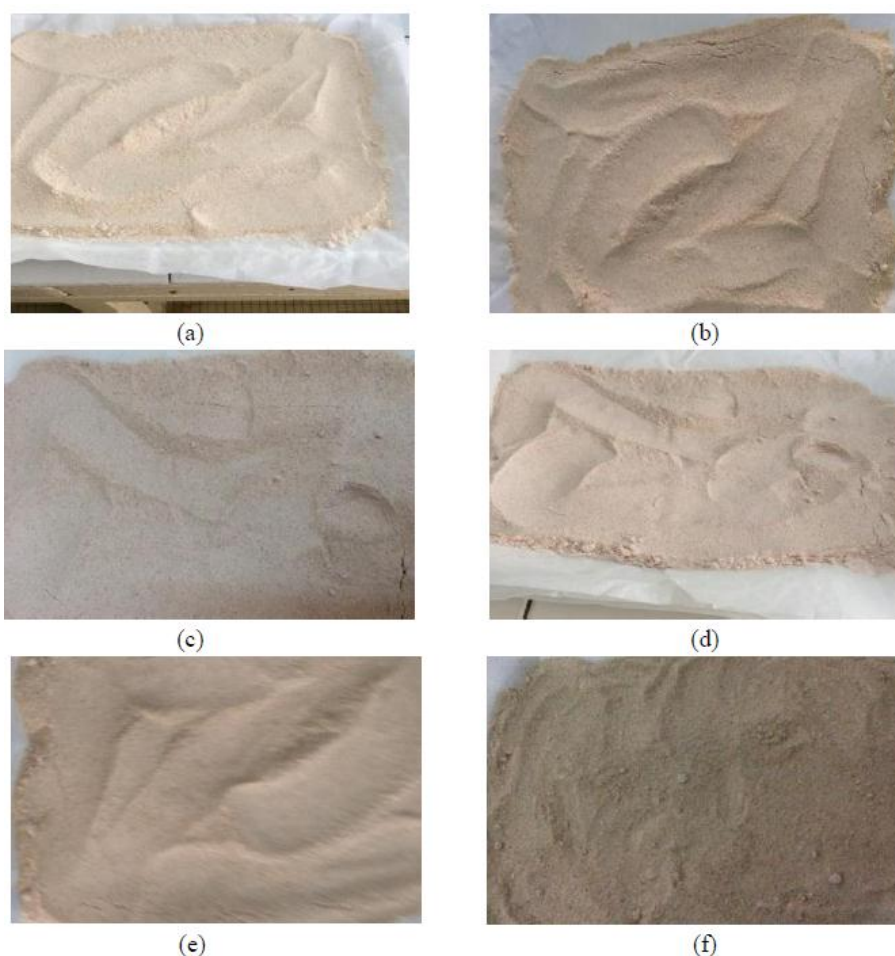


Figure 8. Onion powders obtained after drying in optimal conditions in an oven [(a) 60 °C, (b) 65 °C and (c) 70 °C] and solar greenhouse [(d) 8H, (e) 9H and (f) 10H]

The higher the temperature and the drying time increase, the darker the color of the powders obtained is.

The impact of temperature on polyphenols (Ali et al., 1999; Lombard et al., 2005; Yang et al., 2004), constituents of therapeutic interest (Ali et al., 2000; Griffiths et al., 2002; Zohri et al., 1995), associated with the phenomenon of crusting when the removal of water is done too quickly and browning dried products (Figure 8), allow to avoid temperatures above 65 °C and times greater than 10H for drying onions. On the other hand, too long exposure times consume not only a lot of energy, but can also affect the quality of the product. Therefore, the best temperature / time pairs are 55 to 65 °C / 6H to 8H with an optimum at 60 °C.

As for the results obtained by drying in the greenhouse presented in Table 2, Table 3 and Table 4, they show that moisture and Aw stability are obtained without browning the products after 8 hours to 9 hours of drying with a temperature in the greenhouse varying from 35 to 65 °C during the day. Moreover, in this solar greenhouse temperature range, the polyphenol contents of the four onion varieties increase after drying. These results are comparable to those obtained in the oven.

The results of the parametric test of Student confirm that there is no significant difference between oven drying and solar greenhouse drying kinetics under the study conditions because all p values are > 5%.

4. Conclusion

The research carried out in the framework of this study made it possible to optimize the dehydration process of onion bulbs using two different energy sources. The ideal drying ranges are 55 °C to 65 °C / 6H to 8H in an oven and 35 to 65 °C / 8H to 9H in a solar greenhouse to obtain products with low moisture content ($\leq 8\%$).

Reducing high moisture content and water activity in the onions by drying in the oven as well as in solar greenhouse thus ensures the stability of the dried products. In addition, although the drying time in solar greenhouse is greater than that in the oven, the impact of drying on the evolution of the polyphenol content is substantially identical regardless of the energy source used. These results guide the choice towards the solar source for the management of post-harvest losses through the dehydration of onions.

However, lack of control of solar greenhouse drying temperatures can affect the nutritional and organoleptic quality of dried onions. The Establishment of the desorption isotherms and the modeling of the drying kinetics is thus necessary to control the parameters and ensure the regularity of the quality of the finished product. A study of the stability of onion powders including the monitoring of the re-humidification and color changes during storage should be considered. The reconstitution of dried onions and the sensory analysis by the consumers will be the next stages to be explored for a possible vulgarization of the products.

Acknowledgments

This work was carried out at the Polytechnic school (ESP) and the Center for Food Security and Functional Molecules Studies (CESAM-RESCIF), Cheikh Anta Diop University of Dakar, Senegal. We thank them for supporting us financially and materially.

References

- Agence Nationale de Statistiques et de la Démographie (ANSD). (2014). *Situation Economique et Sociale du Sénégal (SES)*. Consulté le 2 mars 2018, à l'adresse. Retrieved from http://www.ansd.sn/index.php?option=com_sess&view=sess&Itemid=418
- Agence de Régulation des Marchés (ARM). (2016). *Rôles et Impacts des actions de l'Agence de Régulation des Marchés dans l'organisation de la sous-filière oignon au Sénégal*. Agence de Régulation des Marchés.
- Ahmed-Zaid, A. (1999). *Optimisation des capteurs solaires plans à air: application au séchage de produits agricoles et de la pêche* (PhD Thesis). Valenciennes.
- Albitar, N., Mounir, S., Besombes, C., & Allaf, K. (2011). Improving the Drying of Onion Using the Instant Controlled Pressure Drop Technology. *Drying Technology*, 29(9), 993-1001. <https://doi.org/10.1080/07373937.2010.507912>
- Ali, M., Bordia, T., & Mustafa, T. (1999). Effect of raw versus boiled aqueous extract of garlic and onion on platelet aggregation. *Prostaglandins, Leukotrienes and Essential Fatty Acids (PLEFA)*, 60(1), 43-47. <https://doi.org/10.1054/plef.1998.0006>
- Ali, M., Thomson, M., & Afzal, M. (2000). Garlic and onions: their effect on eicosanoid metabolism and its clinical relevance. *Prostaglandins, Leukotrienes and Essential Fatty Acids (PLEFA)*, 62(2), 55-73. <https://doi.org/10.1054/plef.1999.0124>
- Anwar, S. I., & Tiwari, G. N. (2001). Convective heat transfer coefficient of crops in forced convection

- drying—an experimental study. *Energy conversion and management*, 42(14), 1687-1698.
[https://doi.org/10.1016/S0196-8904\(00\)00160-6](https://doi.org/10.1016/S0196-8904(00)00160-6)
- Babalís, S. J., & Belessiotis, V. G. (2004). Influence of the drying conditions on the drying constants and moisture diffusivity during the thin-layer drying of figs. *Journal of Food Engineering*, 65(3), 449-458.
<https://doi.org/10.1016/j.jfoodeng.2004.02.005>
- Bernard, A., & Carlier, H. (1992). *Aspects nutritionnels des constituants des aliments. Influences des technologies*. In *Les Cahiers de l'ENS. BANA*. Lavoisier Tec & Doc
- Bonazzi, C., Dumoulin, E., & Bimbenet, J. J. (2008). Le séchage des produits alimentaires. *Industrie Alimentaire Agricole*, 125(03-04), 12-22
- Boughali, S. (2010). *Etude et optimisation du séchage solaire des Produits agro-alimentaires dans les zones Arides et désertiques* (PhD Thesis). Université Batna 2
- Charreau, A., & Cavaille, R. (1991). Séchage: I. Théorie et calculs. *Techniques de l'ingénieur. Génie des procédés*, 2, J24080-1
- Clemente, G., Frías, A., Sanjuan, N., Benedito, J., & Mulet, A. (2011). Influence of air velocity in dehydration of potato cubes. *III European Drying Conference (EuroDrying'2011)*, 26-28
- Direction de l'Horticulture (DH). (2015). *Direction de l'Horticulture: Statistiques horticoles*. Direction de l'Horticulture
- DH. (2016). *Direction de l'Horticulture : Statistiques horticoles*. Direction de l'Horticulture.
- ESA. (2004). European Spice Association (ESA) quality minima document. *Bonn, Germany*.
- Faiveley, M. (2003). L'eau et la conservation des aliments. Notions de biochimie alimentaire et alimentation humaine. *Techniques de l'Ingénieur F*, 1011
- Faiveley, M. (2012). L'eau et la conservation des aliments. *Techniques de l'Ingénieur F*, 1011(V2).
- Griffiths, G., Trueman, L., Crowther, T., Thomas, B., & Smith, B. (2002). Onions : A global benefit to health. *Phytotherapy Research*, 16(7), 603-615. <https://doi.org/10.1002/ptr.1222>
- Jannot, Y. (2006). *Habilitation à diriger des recherches: Du séchage des produits alimentaires tropicaux à la caractérisation thermophysique des solides*. Université Bordeaux I
- Jeantet, R., Croguennec, T., Schuck, P., & Brulé G. (2008). *Sciences des Aliments 1- Stabilisation biologique et physico-chimique*. Consulté à l'adresse <https://hal.archives-ouvertes.fr/hal-01454471>
- Jiménez Elizondo, N. (2011). *Impact des opérations thermiques agroalimentaires à hautes températures sur la dégradation des anthocyanes: Caractérisation et modélisation des cinétiques réactionnelles*. Montpellier SUPAGRO - Institut des Régions Chaudes
- Kiranoudis, C. T., Maroulis, Z. B., & Marinou-Kouris, D. (1992). Drying Kinetics Of Onion And Green Pepper. *Drying Technology*, 10(4), 995-1011. <https://doi.org/10.1080/07373939208916492>
- Krokida, M. K., Karathanos, V. T., Maroulis, Z. B., & Marinou-Kouris, D. (2003). Drying kinetics of some vegetables. *Journal of Food engineering*, 59(4), 391-403. [https://doi.org/10.1016/S0260-8774\(02\)00498-3](https://doi.org/10.1016/S0260-8774(02)00498-3)
- Lawrence, I., & Lin, K. (1989). A concordance correlation coefficient to evaluate reproducibility. *Biometrics*, 255-268
- Le Meste, M., & Chiotelli, E. (2002). Chapitre 2. Interactions entre l'eau et les autres constituants alimentaires-Rôle dans la conformation, l'état d'association, la stabilité et la fonctionnalité des molécules. In *L'eau dans les aliments (Le Meste, M., Lorient, D. & Simatos, D., eds.)*. Tec & Doc Lavoisier, Paris. Lavoisier - Tec & Doc
- Lhendup, T. (2005). Technical and financial feasibility of a solar dryer in Bhutan. *Energy for Sustainable Development*, 9(4), 17-24. [https://doi.org/10.1016/S0973-0826\(08\)60496-2](https://doi.org/10.1016/S0973-0826(08)60496-2)
- Lombard, K., Peffley, E., Geoffriau, E., Thompson, L., & Herring, A. (2005). Quercetin in onion (*Allium cepa* L.) after heat-treatment simulating home preparation. *Journal of Food Composition and Analysis*, 18(6), 571-581. <https://doi.org/10.1016/j.jfca.2004.03.027>
- Mendez Lagunas, L. (2007). *L'effet des conditions variables de séchage sur la cinétique de séchage et la qualité de l'ail* (PhD Thesis). Université de Laval, Québec
- Sarsavadia, P. N., Sawhney, R. L., Pangavhane, D. R., & Singh, S. P. (1999). Drying behaviour of brined onion

slices. *Journal of Food Engineering*, 40(3), 219-226. [https://doi.org/10.1016/S0260-8774\(99\)00058-8](https://doi.org/10.1016/S0260-8774(99)00058-8)

Tom, A. (2015). *Contribution au séchage solaire des produits carnés : Modélisation et réalisation d'un séchoir adapté aux pays tropicaux*. (PhD Thesis). ENSAM, Paris. Consulté à l'adresse. Retrieved from <http://www.theses.fr/2015ENAM0013>

Yang, J., Meyers, K. J., van der Heide, J., & Liu, R. H. (2004). Varietal Differences in Phenolic Content and Antioxidant and Antiproliferative Activities of Onions. *Journal of Agricultural and Food Chemistry*, 52(22), 6787-6793. <https://doi.org/10.1021/jf0307144>

Zohri, A.-N., Abdel-Gawad, K., & Saber, S. (1995). Antibacterial, antidermatophytic and antitoxigenic activities of onion (*Allium cepa* L.) oil. *Microbiological Research*, 150(2), 167-172. [https://doi.org/10.1016/S0944-5013\(11\)80052-2](https://doi.org/10.1016/S0944-5013(11)80052-2)

Copyrights

Copyright for this article is retained by the author(s), with first publication rights granted to the journal.

This is an open-access article distributed under the terms and conditions of the Creative Commons Attribution license (<http://creativecommons.org/licenses/by/4.0/>).