Article 13

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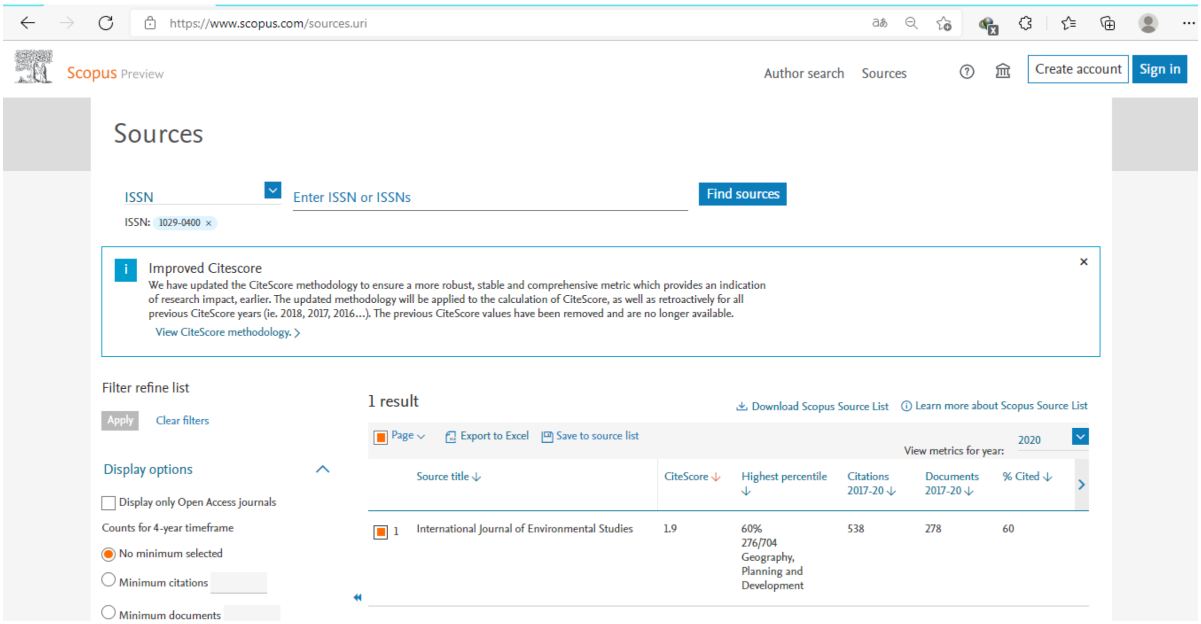
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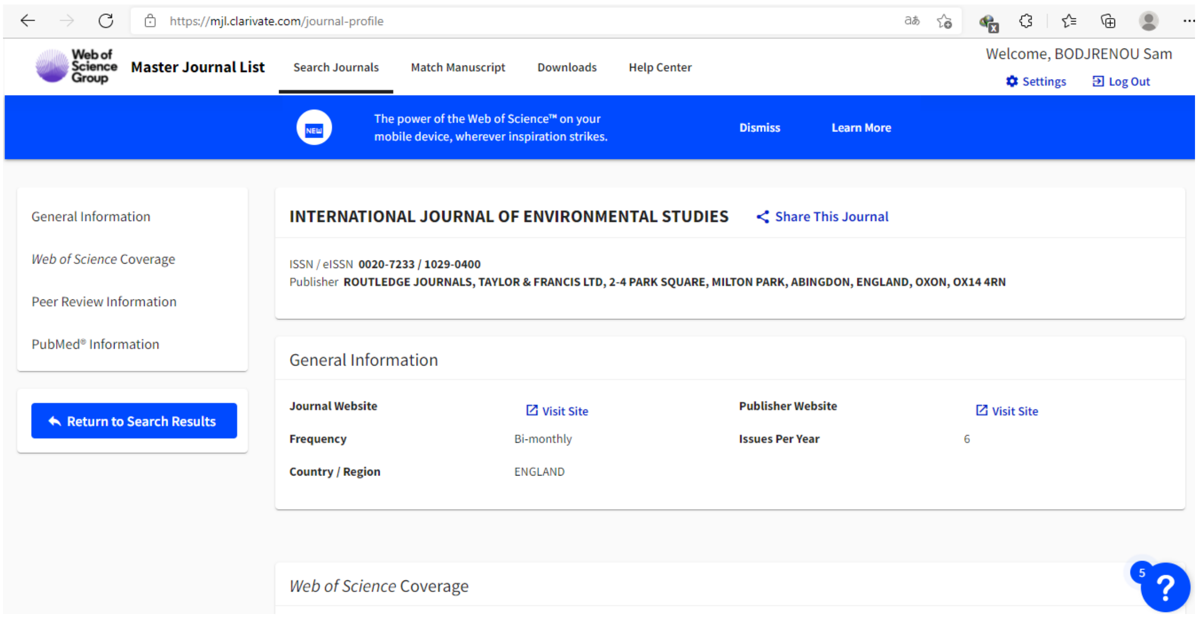
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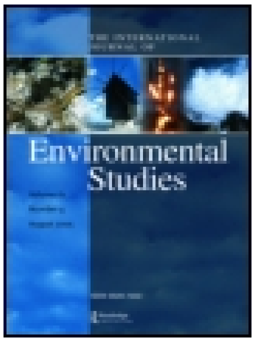

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Reduction of post-harvest losses through estimation of open air-drying period of agricultural products of mass consumption: case of Benin

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ARTICLE

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Reduction of post-harvest losses through estimation of open air-drying period of agricultural products of mass consumption: case of Benin

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ABSTRACT

Reducing the post-harvest losses of agricultural products is a current problem which deserves special attention, worldwide. In this work, agro-meteorological parameters collected at different weather stations of Benin Republic were analysed in order to highlight their seasonality, and to identify favourable air-drying periods for agricultural products. Periods from March to May and October to December have the peaks of global radiation and insolation; high temperatures values are concentrated between February and May, and rains sequences are observed from March to November. Cross-analysis of different parameters led to statistically identifying favourable drying periods for agricultural products in each region of the country. The period from November to February was shown to be favourable. It includes most post-harvest periods for most of the cultivated agricultural products and also has the best environmental and practical conditions for natural air-drying.

KEYWORDS

Agricultural products; post-harvest losses; Benin

Introduction

In Africa, agriculture provides jobs and businesses for the majority of Africans and most of their foodstuffs [1]. In Benin, the agriculture sector employs hundreds of thousands of people in peri-urban and rural areas [2]. It is one of the most important sectors of Beninese economy and also the second source of wealth in the country. In this country, large quantities of agricultural products are harvested each year. For example, Benin produced in 2018 in tonnes, 3.8 million cassava; 2.7 million yams; 1.5 million corn; 598,000 palm oil; 459,000 rice; 372,000 pineapples; 319,000 sorghum; 253,000 tomatoes; 225,000 peanuts; 221,000 soybeans; 215,000 cashew nuts; 13,000 of shea; 15,000 orange and 17,000 coconut [3]. Nevertheless, large post-harvest losses along the food chain threaten food security and purchasing power of African farmers. These losses, estimated at nearly 40% of cultivated

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agricultural products [4–7], are observed on almost all agricultural crops, vegetables, cereals and fruits.

Enormous quantities of products, both agricultural (cereals, vegetables, fruits, etc.) and livestock (meat, milk, etc.), are degraded in various ways because there is no system integrating conservation technologies and processing in the production chain. Benin is like many countries in Africa in regard to post-harvest losses. Indeed, significant amounts of post-harvest losses are recorded in Benin every year. Insufficient and inefficient processing, preservation and post-harvest storage facilities lead to a loss of 30–40% of each harvest [1].

In Benin, products of mass consumption (tomatoes, yams, sweet potatoes, pineapples, corn, etc.) are unfortunately those which suffer the big losses. This leads to severe food shortages at certain times of the year. To allow agriculture to feed all Beninese and increase farmers' incomes, a policy of reducing post-harvest losses is needed. Reducing these losses is becoming a general concern of the country. Yet despite these significant losses observed, the peasants have neither the technical nor financial means to afford the technological conditions necessary for the preservation of food [8]. And to overcome these post-harvest losses, they are turning to simple techniques such as solar drying [9].

This drying method is largely influenced by climatic conditions of production and storage sites. But there are significant difficulties. Rain, whole days without sunshine, lack of thermal heat during the night, display and collection of the products morning and evening, lack of suitable storage place for products, long drying time, absorption of moisture by products and formation of fungi, are major difficulties observed. Therefore, optimising solar drying could help increase food availability at all times, with food security, and contribute to sustainable development. To limit the difficulties encountered by populations, it would be necessary to help peasants in use of drying technologies especially solar dryers because sunshine is available throughout the country in general and in agricultural areas in particular. It is within this framework that the project called 'FOod Conservation by Utilising Solar Energy for Drying (FOCUSED-BENIN)' was initiated within the University of Abomey-Calavi. The goal of this project is the conservation of agricultural products from solar dryers and salt production from solar energy.

Several works have been carried out on the drying of agricultural products [10–19]. For example, Zanoni et al. [16] studied the drying of the samples of tomatoes, halved, in a conventional dryer. Their study was about the effect of drying conditions on the lycopene content of the tomato. El-Sebaii et al. [17] designed a solar dryer with indirect natural convection to dry tomato, onion, fig and grape. These researchers studied experimentally and theoretically the correlation between a constant K and the drying temperature of the product in a thin layer. Sacilik et al. [18] studied experimentally solar drying curves of tomato cut in half and distributed in a solar dryer under atmospheric conditions of Ankara (Turkey) and compared them to the way of drying in open air. Doymaz [20] studied the effect of treatment on drying kinetics of tomatoes cut in half and distributed on shelves of a forced convection dryer at temperatures of 55, 60, 65 and 70°C by using electrical resistors passing perpendicularly through the grids. Hasturk Sahin et al. [19] studied the effects of drying methods, such as hot-air drying (at 65, 75 and 85°C drying temperatures), sun drying, vacuum drying and freeze drying, and pre-treatments, namely dipping into 1% ascorbic acid +1% citric acid and dipping into 2% sodium metabisulphite after 2% ethyl oleate +4% potassium carbonate solution application on lycopene retention, and colour properties of dried tomato slices.

In the same way, several methods are often used to preserve agricultural products. Among these methods, drying is the most common process used for preservation [20]. This technique is used depending on the properties and needs of the products to be dried [21]. The objective of drying is the removal of water to the level at which microbial spoilage and deterioration reactions are greatly minimised [22]. In addition, sun drying is the most common method used to preserve agricultural products in tropical and subtropical countries [20]. Achieving success is complex. During the process, the phenomena of heat and humidity transport [23] occur simultaneously. Chemical and biochemical reactions that take place during drying process can significantly influence the quality of the dried product. And during sun drying, the organoleptic qualities of the final product may deteriorate owing to the lack of protection against rain, storms, dirt, dust and insect infestation [20]. The drying of agricultural products can be carried out in closed equipment to improve the quality of the final product [24,25]. Several studies have also proven the influence of temperature and air speed on the kinetics during the drying process [20,26]. It follows that the drying in the open air of agricultural products depends on the speed of the ambient air, the humidity, the temperature of the environment: in short, the meteorological conditions.

Therefore, the heat and mass transfer at the surface of the product to be dried depends mainly on the parameters of the dry air; among others: temperature, relative humidity, air speed, thermal conductivity, specific heat capacity, and density. The objective of this study is to analyse the agro-meteorological parameters of natural air-drying over Benin's territory in order to highlight their seasonality. This will make it possible for farmers to know the favourable periods for air-drying in open air of consumer agricultural products, especially during periods of important production. The results obtained in this work will provide important information on the suitable periods for open-air drying of agricultural products, using solar dryer technologies.

Data and methods

Study area

Benin is in the intertropical zone. It is located in West Africa between parallels 6′15 and 12°30′ of north latitude and meridians 1° and 3°40′ of east longitude [27] (Figure 1). The climate is subequatorial with two dry seasons and two altered rainy seasons [28].

Data

Agro-meteorological parameters of the agricultural air-drying products process have been analysed to study their seasonal variability. These parameters are: wind speed, relative humidity, air temperature, rainfall, solar radiation, insolation. Data used cover the period from 2008 to 2018 (eleven years). Agro-meteorological parameters analysed come from the six (06) weather stations of the National Directorate of Meteorology of Benin Republic (DNM-Benin) namely Cotonou station, a coastal town in the south, Bohicon station about 150 km from Cotonou, Savè station in the centre about 100 km from Bohicon, Parakou station about 100 km from Savè, Natitingou station, in the north-west and Kandi station in the north-east of the country. A correction was carried out on

Figure 1. Study area with Benin's weather station towns (Cotonou, Bohicon, Save, Parakou, Kandi, and Natitingou).

these data from in-situ measurements by the mobile station of the Laboratory of Radiation Physics (LPR/FAST/UAC). After treatments on the basis of available data, seasonal variability of the parameters mentioned above has been analysed. Extreme values of various parameters have been deduced from statistical analysis. Mean values were deduced using relation (1) and standard deviation (σ) using relation (2).

$$\bar{x} = \frac{1}{N}\sum_{i=1}^{N} x_i \tag{1}$$

$$\sigma = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N} |x_i - \bar{x}|^2} \tag{2}$$

where x_i is the parameter and, N number of records.

Results and discussion

Radiation analysis

Figure 2 illustrates the seasonal variability of global radiation at the level of each synoptic station. Monthly global solar radiation profiles appear to be identical at all stations; an increase is observed between January and April, then between August and November and a decrease between April and August and between November and December at these stations. At Cotonou, on the other hand, the first phase of decrease stops in July followed by a second phase of earlier increase (from July to November). Average values are

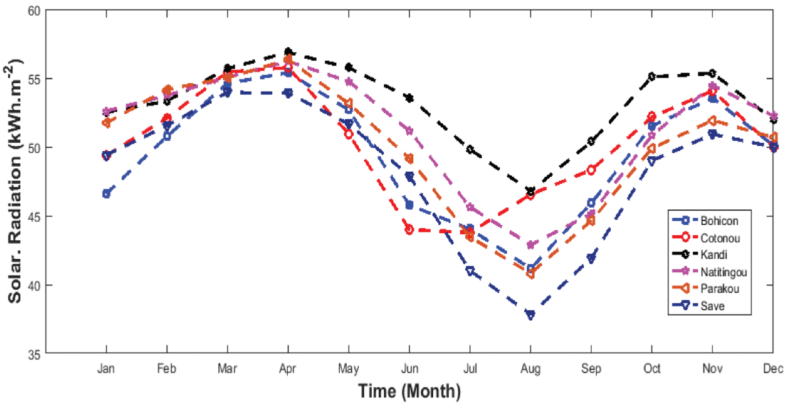

Figure 2. Seasonal variability of global radiation on Benin's weather synoptic stations.

Table 1. Summary of global radiation measured at Benin weather station sites on a seasonal scale.

Sites	Minimum value (kWh/m^2)	Mean value (kWh/m^2)	Maximum value (kWh/m^2)	Standard deviation (σ) (kWh/m^2)
Cotonou	43,78	50,21	55,76	4,03
Bohicon	41,16	49,34	55,39	4,55
Savè	37,83	48,25	53,96	5,22
Parakou	40,82	50,09	56,35	4,83
Kandi	46,79	53,09	56,87	2,96
Natitingou	42,89	51,23	56,22	4,37

between 48.25 (at Savè) and 53.09 kWh/m^2 observed at Kandi. From the figure's analysis, it appears that the period from January to May, and September to December is where large values of global solar radiation are observed; the period from mid-May to August produces the lowest values of global radiation. Three major seasons of solar radiation can therefore be observed at various sites. The first between January and May, the second between September and December where maximum solar radiation is observed with a peak in April for a value of 56.87 kWh/m^2 observed at Kandi. The third season is observed between the months of May and September where minima are noted (minimum radiation value 37.83 kWh/m^2) observed at Savè.

Average and extreme values of global solar radiation indicated in Table 1, are deduced from statistical analysis for the period from 2008 to 2018 at different sites. Standard deviation values for each site are also mentioned.

Average number of insolation days during the year

Sunshine or insolation refers to measurement of radiation on a given surface for a specified period of time. Sunshine's duration therefore varies from one station to another. Figure 3 indicates average number of hours of sunshine at each of Benin's weather measurement stations. This number increases from South to North, with a break in trend at Bohicon. Indeed, the number of sunny days is higher at Cotonou (2,345.1 h) than Bohicon (2,176.8 h). Values deduced from statistical analysis are in agreement with those mentioned in the agro-climatic Atlas on climate variability and change in Benin [29].

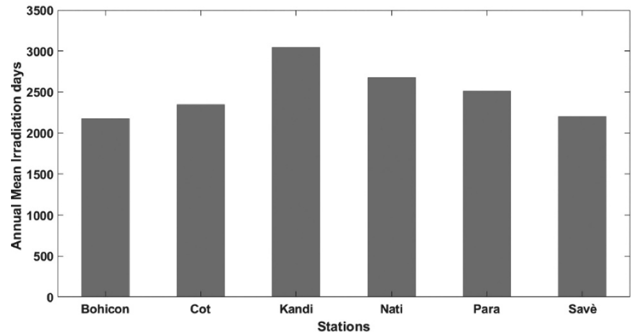

Figure 3. Average number of hours of insolation at each Benin weather station.

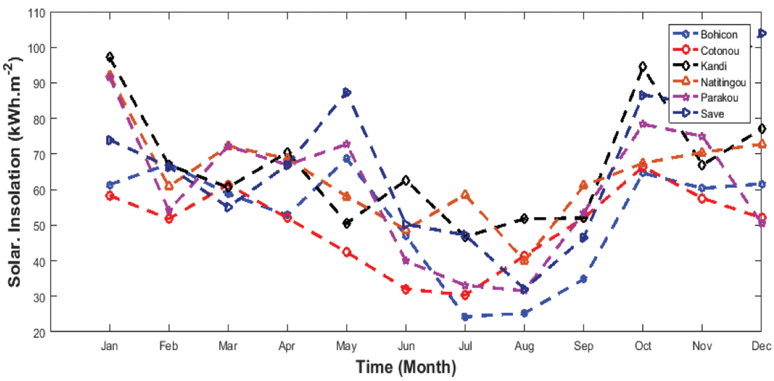

Figure 4. Seasonal variability of solar insolation at Benin's weather stations sites.

Seasonal insolation variability

Figure 4 shows seasonal variability in sunshine signal at Benin's synoptic stations. There are not many similarities in sunshine profiles in the regions where stations are located. There are minimums during the period from July to August at all stations with values between 1.5 and 4.7 kWh/m^2. Peaks are noted in January, May, October and December at most of the station sites with values between 5.85 and 10.5 kWh/m^2. On average, Cotonou and Bohicon are the regions that experience low amounts of insolation over different seasons of the year.

Different characteristics (average and extreme values) deduced from the analysis of the different curves are shown in Table 2 for the period from 2008 to 2018. Solar Insolation's standard deviation values for each site are also mentioned.

Temperature analysis

Temperature comparison at different sites

Comparison was made between temperature values recorded at different weather stations of Benin and the Laboratory of Radiation Physics (LPR) mobile station. Figure 5 shows the comparison between temperature data at two measuring stations at Bohicon. From

Table 2. Characteristics of insolation at Benin's weather station sites at annual scale.

Sites	Minimum value (kWh/m²)	Mean value (kWh/m²)	Maximum value (kWh/m²)	Standard deviation (σ) (kWh/m²)
Cotonou	3,038	4,98	6,64	1,12
Bohicon	2,42	5,22	6,87	1,59
Savè	3,21	6,67	10,40	2,12
Parakou	3,16	6,00	9,17	1,91
Kandi	4,47	6,64	9,72	1,64
Natitingou	3,99	6,42	9,22	1,32

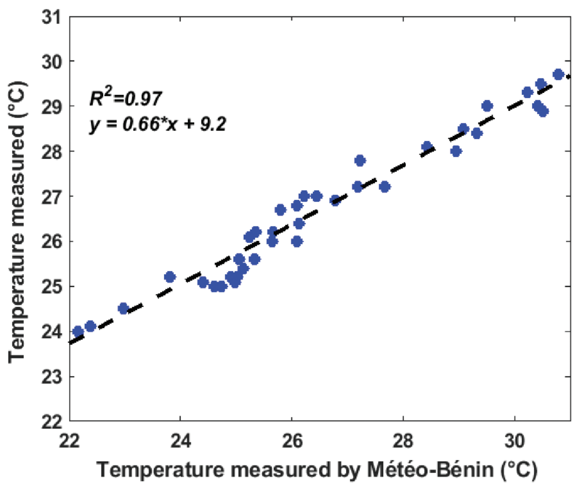

Figure 5. Linear regression between temperatures measured by LPR mobile station and that of Bohicon weather station.

the relation found, the temperature at any weather station in Benin can be deduced, knowing that measured by the mobile station. This made it possible to generate over the measurement period the various characteristics of the temperature measured at each station.

Intra-annual variability of the average indoor air temperature

Figure 6 below illustrates seasonal variability of temperature at different weather sites of Benin synoptic stations. Temperature variability indicates an increase between January to May and August to November and a decrease between March and August and then from November to December. From Figure 6, analysis, it appears that the periods from January to May and from November to December are the hottest periods of the year where large values of average temperatures of air under shelter are observed; the period from June to October is the coldest period of the year where lowest temperature values are observed in most of the sites. Three main seasons can therefore be observed at these sites with regard to temperature. The first between January and May, the second between November and May when maximum temperatures are observed, with a peak in March and April depending on the site. The third season is observed between May and October where

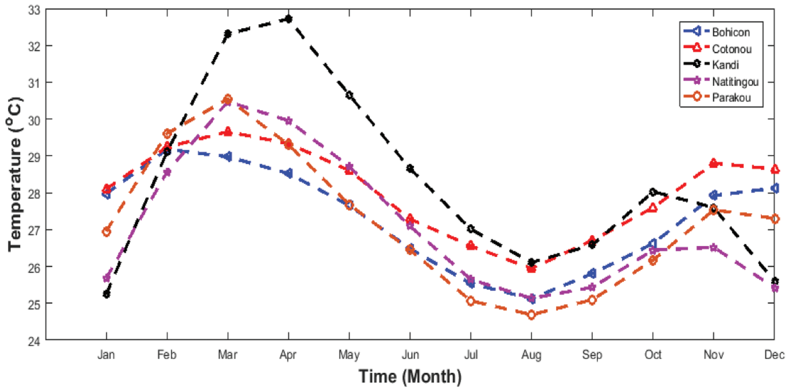

Figure 6. Seasonal variability of air temperature at five of Benin's weather synoptic stations.

Table 3. Summary of various air temperature values observed on Benin's weather synoptic station sites at interannual scale.

Sites	Minimum values (°C)	Mean value (°C)	Maximum value (°C)	Standard deviation (σ) in (°C)
Cotonou	25,94	28,04	29,66	01,21
Bohicon	25,13	27,33	29,18	01,37
Savè				
Parakou	24,69	27,20	30,55	01,88
Kandi	25,24	28,30	32,72	02,50
Natitingou	25,13	27,09	30,47	01,87

minimums are noted. The results found in this work are in agreement with those of Djohy et al. [30] and Oyédé [31]. Indeed, results of Djohy et al. [30] indicated similar variations at Kandi. In their work, taking into account air average temperatures from 1970 to 2010, two similar peaks were observed. Too many missing temperature data are observed in the dataset at Savè station. This is why the temperature analysis did not take this city into account.

From temperature's statistical analysis over the period from 2008 to 2018, different values were deduced for each site (Table 3). Again, because of missing air temperature data observed at Savè, that station is omitted in the Table.

Analysis of relative humidity at synoptic stations in Benin

Humidity comparison

Comparison is made between relative humidity values recorded at various weather stations of Benin and LPR mobile station. Figure 7 shows this comparison at Parakou station. Various characteristics are generated from this relationship found, over the measurement period of relative humidity measured at each weather synoptic station.

Intra-annual variability of relative humidity

Figure 8 shows seasonal variability of relative humidity at different weather synoptic station of Benin. Seasonal change in humidity presents almost homogeneous profiles at

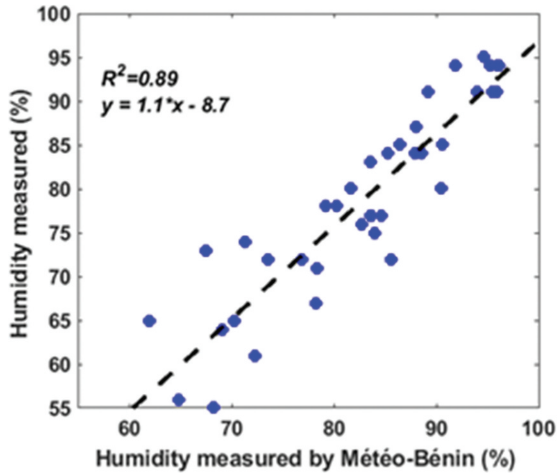

Figure 7. Linear regression between relative humidity measured by LPR mobile station and weather synoptic station of Benin (Case of site of Parakou).

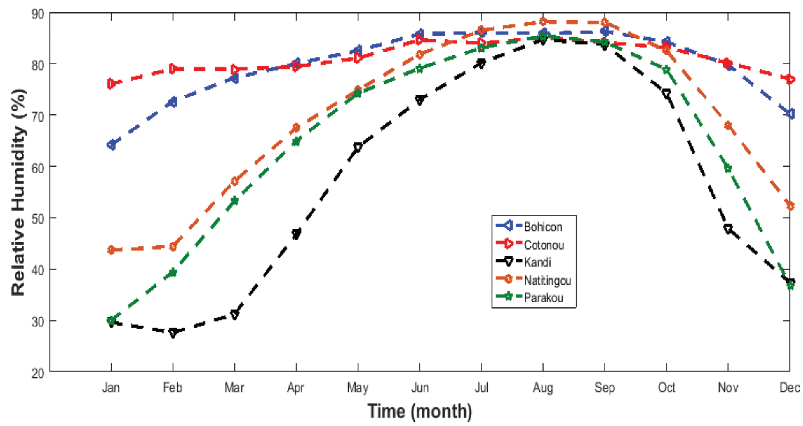

Figure 8. Seasonal variability of relative humidity at five of Benin's weather synoptic station.

different measurement sites. An increase in humidity dataset is observed from January to August followed by a decrease until December. Humidity minimums values are noted in January and peaks are recorded in August at all observation sites. It appears from the analysis of this figure that, the periods from January to August are relative humidity positive evolution periods. On the other hand, a decrease in relative humidity is observed during the period from August to December. Two main seasons can therefore be observed. The first between May and October and the second between November and April, when maximum values are observed. Again, too many missing humidity data are also noted in the dataset at Savè station.

Humidity characteristics deduced from analysis of different curves are mentioned in Table 4.

Table 4. Summary of different values of relative humidity observed on weather synoptic stations of Benin at seasonal scale (Humidity data are not consistent for Savè Station).

Sites	Minimum value (%)	Mean value (%)	Maximum value (%)	Standard deviation σ (%)
Cotonou	76,06	81,04	85,05	03,08
Bohicon	64,13	79,55	86,30	07,23
Savè				
Parakou	29,27	64,07	85,39	20,05
Kandi	27,63	56,66	84,70	22,29
Natitingou	43,67	69,57	88,17	16,74

Analysis of rain data at synoptic stations in Benin

Figure 9 illustrates seasonal variability of cumulative rainfall at different weather stations in Benin. Statistical analysis of this cumulative rainfall in Cotonou indicates values exceeding the cumulative average for the months from May to July (large rainy season) and from September to October (small rainy season). At Bohicon, the analysis indicates values exceeding the average for months from March to July (large rainy season) and from September to October (small rainy season). At Parakou, the same analysis shows values exceeding the average for the months from May to October and from May to September at Kandi. Seasonal variability found at Kandi is comparable to the findings of Saré et al. [32]. At Natitingou, the analysis indicates values exceeding the cumulative average for the months from June to October. Values found here are in perfect agreement with usual trends. In fact, the work of Toffi in 2008 [33] already indicated the same variability in southern Benin. They are reinforced by recent work by Lawin et al., 2019 [34]. Djohy et al., 2015 [30] indicated similar variations in cumulative rainfall at Kandi.

A monthly characterisation of the cumulative rainfall is deduced from the statistical analysis of the various curves and is shown in Table 5. Again, the station of Savè is omitted because data are lacking.

Figure 10 shows average annual number of rainy days at each of Benin's synoptic weather stations. This number decreases from Cotonou (78 days) to Savè (75 days) via

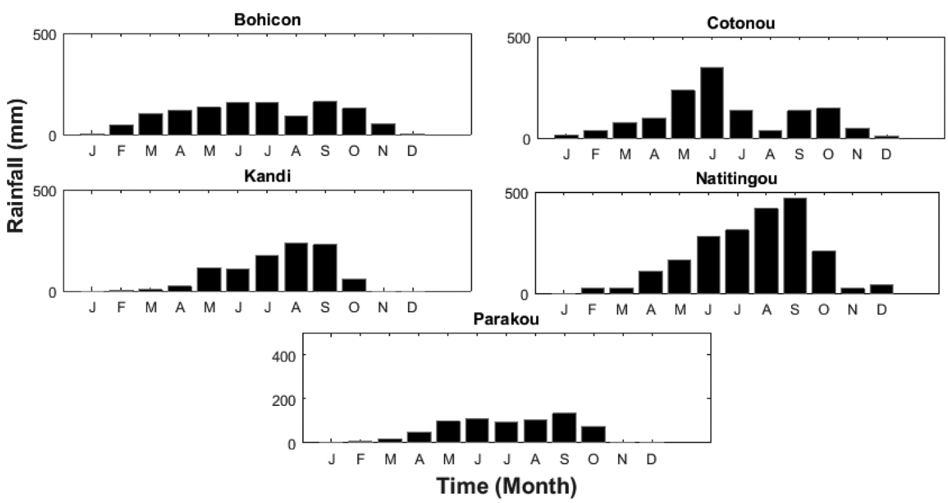

Figure 9. Seasonal variability of cumulative rainfall at five different weather stations in Benin.

Table 5. Summary of various air temperature values observed at five of Benin's weather stations at interannual scale.

Sites	Minimum value (mm)	Mean value (mm)	Maximum value (mm)	Standard deviation σ (mm)
Cotonou	09,87	108,86	345,20	99,62
Bohicon	04,78	97,30	161,41	56,80
Savè				
Parakou	0,65	58,26	133,77	49,51
Kandi	00	80,00	235,33	91,45
Natitingou	00	172,76	469,71	164,91

Bohicon (77 days) and increases from Savè (75 days) to Natitingou (89 days) via Parakou (87 days). On the other hand, it rains less at Kandi than other regions of the country (68 days). Values deduced from statistical analysis are in agreement with those mentioned in the agro-climatic Atlas on climate variability and change in Benin [29].

Wind data analysis

Figure 11 illustrates seasonal variability of wind speed at Benin's synoptic weather stations. The monthly wind speed profiles in Cotonou and Bohicon show a similar trend as do those of Parakou, Natitingou and Kandi. On the other hand, that of Savè presents a different picture. In Cotonou as in Bohicon, maximum winds are observed between February and April then between June and October with speeds exceeding 4 $m.s^{-1}$ in Cotonou and 1.5 $m.s^{-1}$ in Bohicon. At Parakou, Natitingou and Kandi these maxima are observed between March and June for speeds reaching 2.8 $m.s^{-1}$ at Parakou, 2 $m.s^{-1}$ at Kandi, Natitingou and Savè. Wind seasonal variability found here is comparable to those mentioned in Laïbi's work in 2011 [35] for Cotonou. Indeed, by analysis of winds data over the period from 1955 to 2005, peak speeds are obtained in March for values about 4.5 ms^{-1} and in August for values exceeding 5 ms^{-1}. Results found in this work are comparable to those mentioned in other studies. Mathos et al. [36], and Donnou et al. [37], obtained wind speed values between 1.44 and 3.58 $m.s^{-1}$; 2.5 and 5.35 $m.s^{-1}$ respectively.

A monthly characterisation of wind speed is deduced from statistical analysis of the various curves and is shown in Table 6.

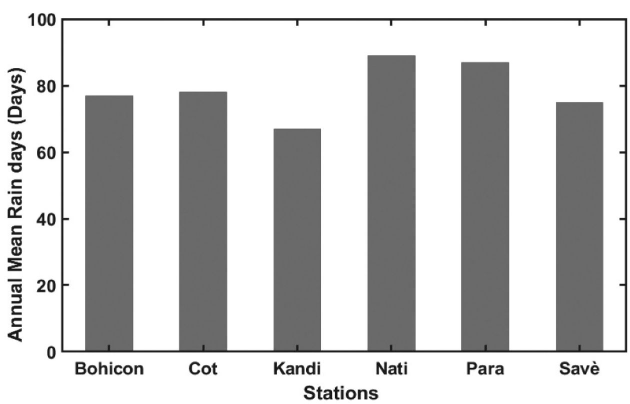

Figure 10. Average annual number of rainy days at each of Benin's synoptic weather stations.

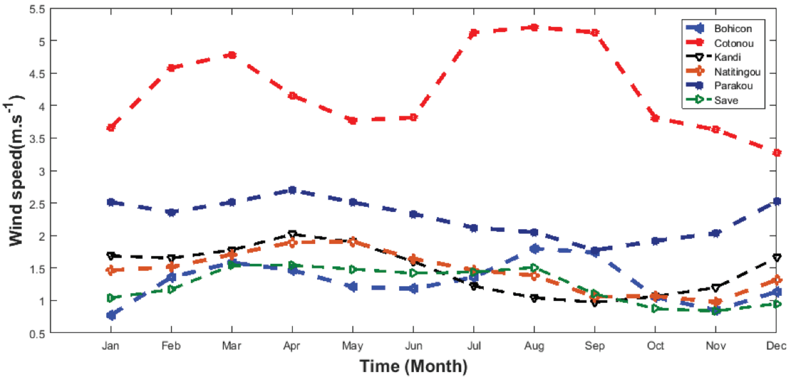

Figure 11. Seasonal variability of wind speed at Benin's six synoptic weather stations.

Table 6. Summary of different values of wind speed observed at each of Benin's synoptic weather stations at seasonal scale.

Sites	Minimum value ($m.s^{-1}$)	Mean value ($m.s^{-1}$)	Maximum value ($m.s^{-1}$)	Standard deviation σ ($m.s^{-1}$)
Cotonou	3,28	4,24	5,21	0,68
Bohicon	0,77	1,29	1,78	0,32
Savè	0,84	1,24	1,54	0,27
Parakou	1,77	2,28	2,70	0,29
Kandi	0,97	1,48	2,02	0,36
Natitingou	0,98	1,45	1,90	0,31

Agricultural products drying period in different regions of Benin

Seasonality cross-analysis of various parameters that can contribute to agricultural products air-drying as part of reduction of post-harvest losses, made it possible to identify drying periods in the various regions housing Benin's synoptic weather stations. Conservation of agricultural products should take place after the harvest: i.e. when weather conditions are the most favourable for open-air drying and other techniques. The rainy season obviously is not favourable. Periods of no rain found were from November to March for Kandi and Parakou regions; from December to January for Bohicon and Cotonou and the month of January for Natitingou. In terms of sunshine, the periods of strong global radiation rates are observed from February to May and October to December. A cross-analysis between these two parameters shows that rainy periods are those of high radiation. Relative humidity has the highest values during the months from April to October, and the lowest values between November and March. Results obtained in this work are the first and deserve to be deepened in order to allow agricultural producers to optimise the yield in terms of conservation by natural air drying, while waiting for implementation of appropriate technologies.

Conclusion

This research concerns the statistical estimation of the drying period of agricultural products of mass consumption in Benin Republic. The goal of the study was to characterise the seasonal variability of agro-meteorological parameters in the natural air-drying process in Benin Republic. Agro-meteorological parameters collected from the National

Directorate of Meteorology of Benin Republic (DNM-Benin) were analysed and led to a better understanding by region, of periods during which meteorological conditions favour natural air-drying of agricultural products. The period from November to March appears to be the ideal period for solar open air-drying of agricultural products in Benin Republic. As Benin is a developing country, air-drying of agricultural products is of great benefit to the populations of agricultural areas which produce concentrated volumes of products during short harvesting periods. Indeed, thanks to this process, the farmers can keep a part of the agricultural products resulting from the harvests and can sell them at the appropriate time and consequently increase their incomes. This will help improve their living conditions. On the other hand, solar open air-drying during the right season will allow a better conservation of harvested products, and therefore the availability of the products throughout the year. In short, dried products will contribute to reduction of losses and consequently to added-value for agricultural producers in various regions, to food security and ultimately to Sustainable Development Goals. Results obtained in this work showed the state of solar air-drying in Benin, its weaknesses and inadequacies, its impacts on agricultural products and producers. There are plans to design suitable solar dryers that will extend the air-drying period to reduce losses of agricultural products. This will increase and promote food self-sufficiency in different regions of the country.

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