Solar drying of olive oil by-products for the production of solid biofuels

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A B S T R A C T

Olive trees are usually native to the Mediterranean countries, but cultivation has spread globally during the past two decades due to healthy benefits attributed to olive oil consumption. An olive tree field is not only the source of olive oil, its main product, but also of a number of other by-products or residues including: biomass from pruning, pomace, leaves and wastewater. Biofuels are sustainable and renewable energy sources derived from biological materials wastes such as for example olive oil by-products. Among others, direct combustion and co-combustion of biomass with low rank coals is widely accepted as less risky, less expensive, time-saving options to utilize biomass energy [1]. Several experts indicated that direct combustion encounters various problems, such as hard to ignite, unsteady, unstable and incomplete combustion, and huge amount of gaseous pollutants due to the high moisture content [2, 3]. During this study the utilization of olive pomace, leaves and biomass from pruning for the production of solid biofuels were examined. Solar drying process was used in order to remove moisture. Three different substrates were tested including pomace (POM), pomace with leaves (PL) and pomace with leaves and biomass from pruning (PLP). Results showed that moisture content decreased from 47%, 52% and 45 % at the beginning to 37%, 43% and 33% after 10 days of solar drying for POM, PL and PLP, respectively. The total organic carbon (TOC) was 667 ± 6.4, 658 ± 28 and 634 ± 2 g/Kg for POM, PL and PLP, respectively.

Keywords: solar drying, greenhouse, agro-industrial waste, moisture, combustion.

1. Introduction

In the Mediterranean areas of European Southwest, agroindustrial activities are very important, and a great amount of residues are produced. This is the case of olive oil manufactures, which give rise to significant amounts of olive pomace. The management of these residues involves a problem for these industries due to their potential as pollutants in some cases and to the costs associated to the treatments needed for their proper removal. The high amount of residues derived from an olive oil tree and the olive oil production, together with its temporary and highly concentrated generation, causes a serious problem in all areas from which it originated. The olive pomace, once it has been subjected to a drying process, can be used as a fuel.

Olive pomace is a biomass by-product of olive oil production and is a very abundant agricultural waste in the Mediterranean area. It still contains significant oil content and important moisture content, depending on the olive oil extraction process. The olive pomace must be dried before its use as an animal feed or biofuels. It has been found for oil extraction, for instance, that the wet waste product must be fairly dry to give satisfactory yields (moisture content ranging between 5% and 10%) [4].

Applying free solar energy may well be an alternative solution for reduction of the cost of the drying process. However, contrary to drying with constant conditions, the obtained drying kinetics during solar drying present some variations, as the operating conditions continuously change with time.

Solar drying processes can be a very attractive technology for the treatment of olive oil mill residues in order to decrease the high energy consumption derived from the drying operations, thus decreasing the environmental impact of these residues [5, 6]. In literature, there are numerous studies on the solar drying of wastewater sludge in a greenhouse [7, 8]. Drying of the olive pomace has been investigated previously. Arjona et al. [9] studied in laboratory drying tunnel the drying process of olive pomace and the drying rate was determined with respect to operating conditions. Gogus amd Maskan [10] studied the effects of microwave power, thickness and temperature on the drying of olive pomace in microwave oven. Doymaz et al. [11] used cabinet dryer to studied drying of olive pomace by using mathematical models. However, to our knowledge, there is no information in the literature about the drying behaviour of olive pomace and olive by-products in a greenhouse solar drying unit.

In this work, the effect of greenhouse solar drying of the oil tree by-products, olive pomace (POM), pomace with leaves (PL) and pomace with leaves and biomass from pruning (PLP), is examined. The resulting by-products, once dried out, have a final application as fuel. Solar drying was applied as an economical and efficient further–dewatering and drying method. Therefore, the aim of this study is to study the effect of climatic conditions (solar energy) in three different substrates and the moisture removal on natural solar drying, thus allowing its actual use as a fuel.

2. Methodology – Materials and methods

2.1 Materials

Olive pomace (POM) was three-phase pomace originating from Olive oil mill of Peza Union of Heraklion, Crete, Greece. Also olive leaves used in the present study were collected from Olive oil mill of Peza Union and biomass from pruning was collected from farm of Technological Educational Institute of Crete. Biomass from pruning was homogenized using a mechanical wood crusher (approximately size 1.0-5.00 mm). Three different substrates were tested including a) pomace (POM), b) pomace (80%) with leaves (20%) (PL) and c) pomace (60%) with leaves (20%)

and biomass from pruning (PLP) (20%). Initially, the characteristics of experimental materials are summarized in Table 1.

Table 1 – Characteristics of experimental materials

Parameters	POM	PL	PLP
Moisture (%)	47.3 ± 0.2	52.1 ± 0.2	44.9 ± 2.7
Total Organic Carbon (g/kg)	667 ± 6.4	658 ± 28	634 ± 2.0

2.2 Experimental design

The experimental study was carried out at the pilot solar drying unit, a greenhouse with a roof height of 3.5m, located at the farm of Technological Educational Institute of Crete, in Heraklion Greece. The schematic view of the unit is shown in Fig.1. Aeration of the surface of the materials is effectuated by side windows. The greenhouse effect provides effective usage of the solar energy. Three different substrates were utilized: a) pomace (POM), b) pomace (80%) with leaves (20%) (PL) and c) pomace (60%) with leaves (20%) and biomass from pruning (PLP) (20%) in order to investigate the solar drying procedure of olive oil by-products. POM and PL was dried for 56 days and PLP for 67 days, in a 3.0x1.5x0.20m concrete tank and the thickness of the POM, PL and PLP stack was approximately 10 cm. The materials were mixed manually twice a day for materials renewal purposes. The experiments were continued till the moisture content of the samples was reduced to 10% (w/w).

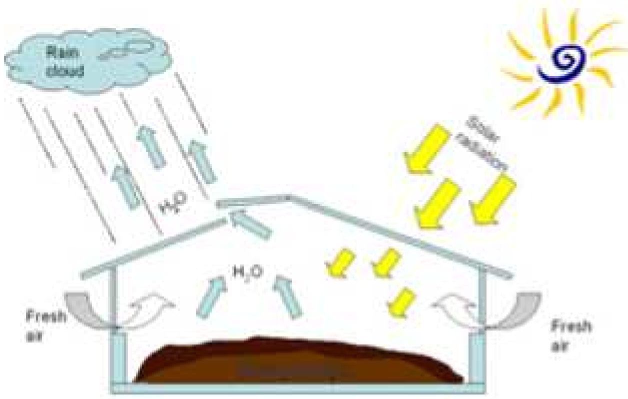


Fig. 1 Schematic view of the covered solar drying unit.

2.3 Analytical methods and equipment

The moisture content of the materials was measured after drying the samples at 105^{o}C for 24h. The total organic carbon (TOC) of the materials was analyzed using a TC/TN analyzer with a solid sample module (TOC-V, SSM-5000A, Shimadzu, Japan). During the experiments, changes in the temperature of samples and in the climatic conditions were constantly measured and documented in the solar drying unit and materials. Temperature of samples was measured using a Mini-K Thermocouple Thermometer (DTM Ni-Cr). Meteorological data were collected with a meteorological station. The results such as: every ten minutes data of solar radiation (Pyranometer CM11) and Relative Humidity (SKH 2011) were gathered from the Weather station in T.E.I. of Heraklion.

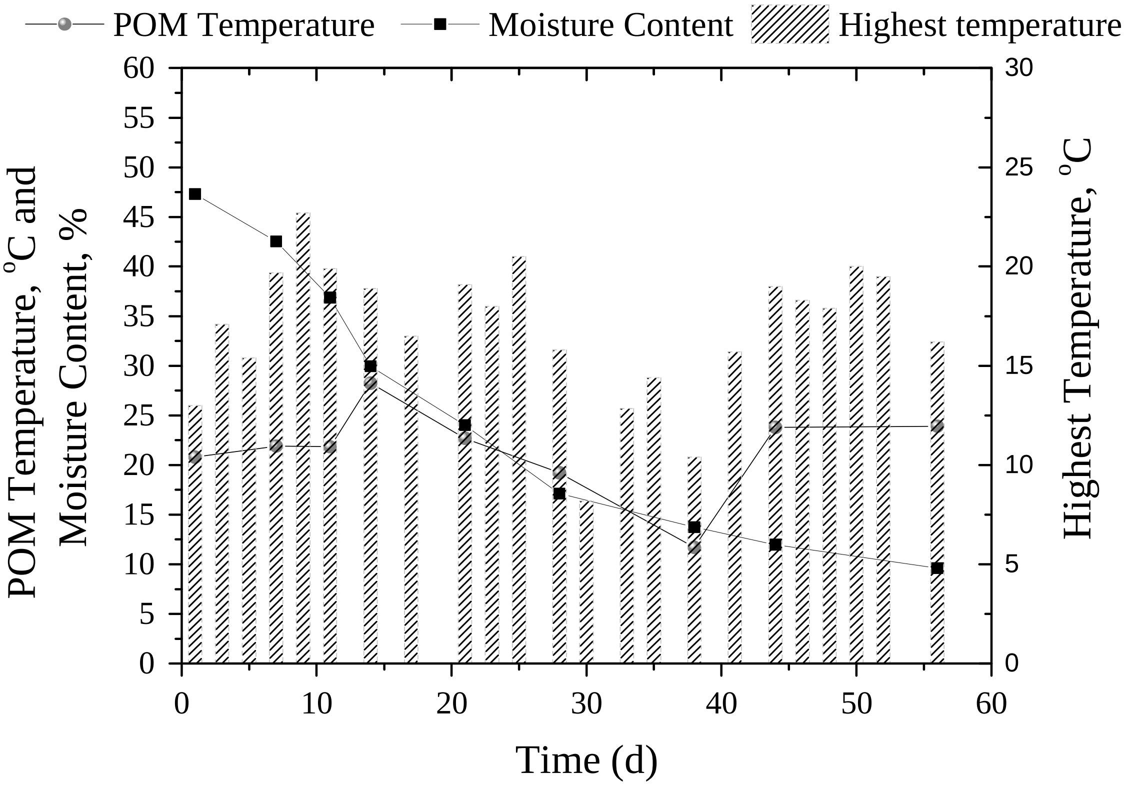
3. Results and Discussion

POM and PL was dried for 56 days using solar energy and PLP for 67 days respectively. The moisture content and temperature of the materials are shown in Fig. 2. Also highest ambient temperature measured during the natural solar drying of materials is presented in Fig.2. The climatic conditions (highest temperature, relative humidity and solar radiation) observed during the natural solar drying of POM, PL and PLP are presented in Fig. 2 and Fig. 3. The moisture content of POM gradually decreased from 47.27±0.22% on the initial day to 24.02±2.45% on the 21st day and finally to 9.61±1.88% on the 56th day. The maximum moisture removal was 6.92% on the 14th day with the highest POM temperature 27.7^{o}C, and the minimum moisture removal was 1.75% on the 44th day. The moisture content of PL gradually decreased from 52.06±0.17% on the initial day to 22.63±0.56% on the 28th day and finally to 8.52±1.52% on the 56th day. The maximum moisture removal was 7.96% on the 21th day with the highest PL temperature 24.8^{o}C, and the minimum moisture removal was 3.02% on the 56th day. The results show that the maximum moisture removal is related with the highest material temperature. Regarding POM and PL, the maximum highest ambient temperature was 22.7^{o}C on the 9th day, and the minimum highest temperature was 8.2^{o}C on the 30th day. The maximum average relative humidity, during the day, was 96.1% on the 41st day, and the minimum relative humidity, during the day, was 53.8% on the 21st day. The maximum average solar radiation, during the day, was 350Wm^{-2} on the 56th day and the minimum was 12Wm^{-2} on the 1st day. The results show that the maximum moisture removal is related with the minimum relative humidity and also with stable solar radiation values from 3rd day to 17th day.

Finally, PLP was dried for 67 days. The moisture content of PLP gradually decreased from 44.85±2.66% on the initial day to 24.6±0.70% on the 28th day and finally to 9.73±2.34% on the 67th day. The maximum moisture removal was 7.11% on the 25th day with the highest PLP temperature 25.1^{o}C, and the minimum moisture removal was 1.49% on the 18th day. Regarding PLP, the maximum highest ambient temperature was 23.6^{o}C on the 64th day, and the minimum highest temperature was 8.2^{o}C on the 20th day. The maximum average relative humidity, during the day, was 96.1% on the 31st day, and the minimum relative humidity, during the day, was 53.8% on the 11st day. The maximum average solar radiation, during the day, was 350Wm^{-2} on the 46th day and the minimum was 43Wm^{-2} on the 31st day.

Regarding total organic carbon (TOC) was initially 667 ± 6.4, 658 ± 28 and 634 ± 2 g/Kg for POM, PL and PLP, respectively. The TOC of POM gradually decreased from 667±6.4 g/kg on the initial day to 647.3±13.75% on the 11th day and finally gradually increased to 684±1.0 g/kg on the 56th day. TOC of PL gradually decreased from 658±28 g/kg on the initial day to 645.9±13.75% on the 11th day and finally gradually increased to 665±5.6 g/kg on the 56th day. Finally, TOC of PLP from 634±2 g/kg on the initial day to 637.9±1.5% on the 67th day. So, no correction was observed between TOC and moisture removal.

a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Moisture Content
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POM Temperature, oC and Moisture Content, %
Highest Temperature, oC
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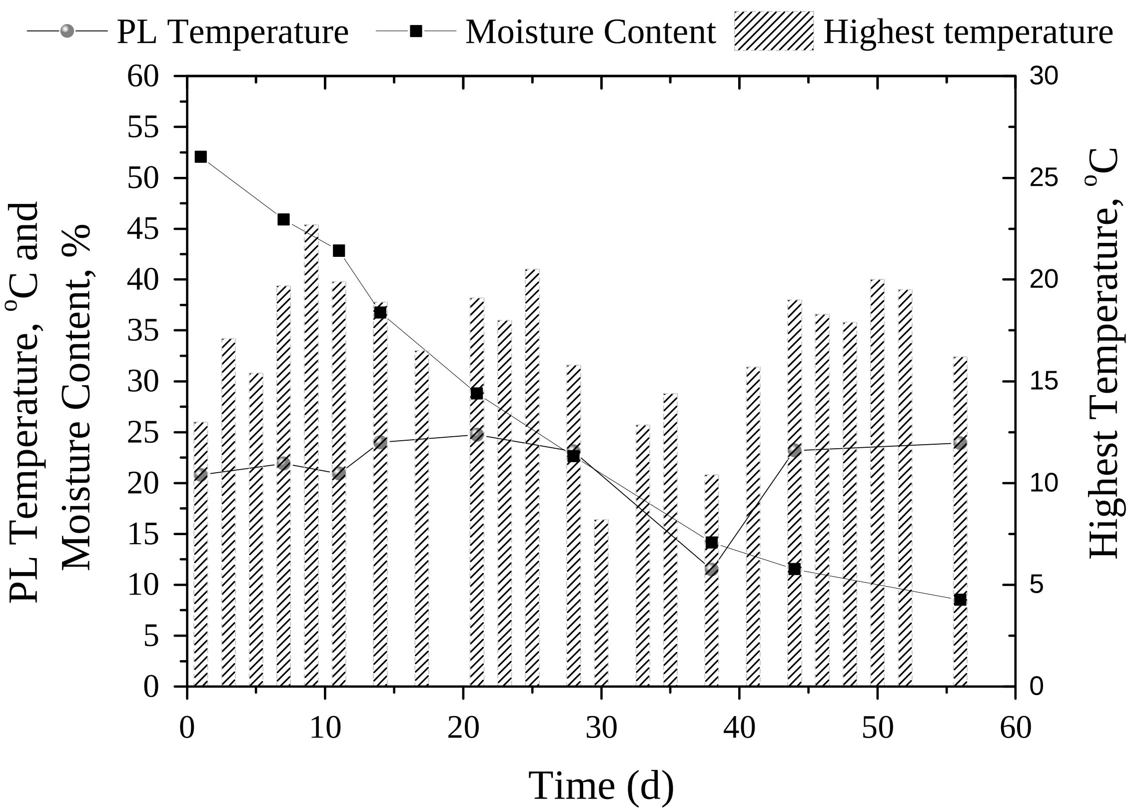
PL Temperature
Moisture Content
Highest temperature
PL Temperature, oC and Moisture Content, %
Highest Temperature, oC
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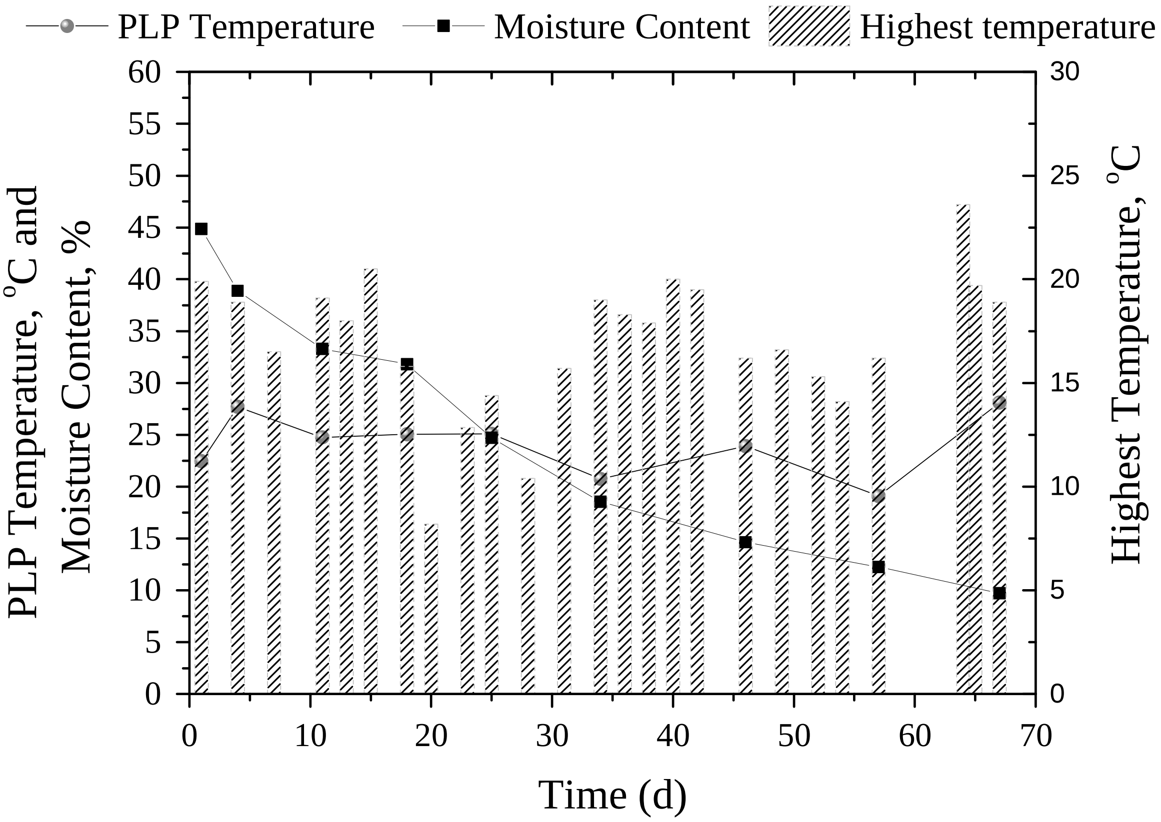
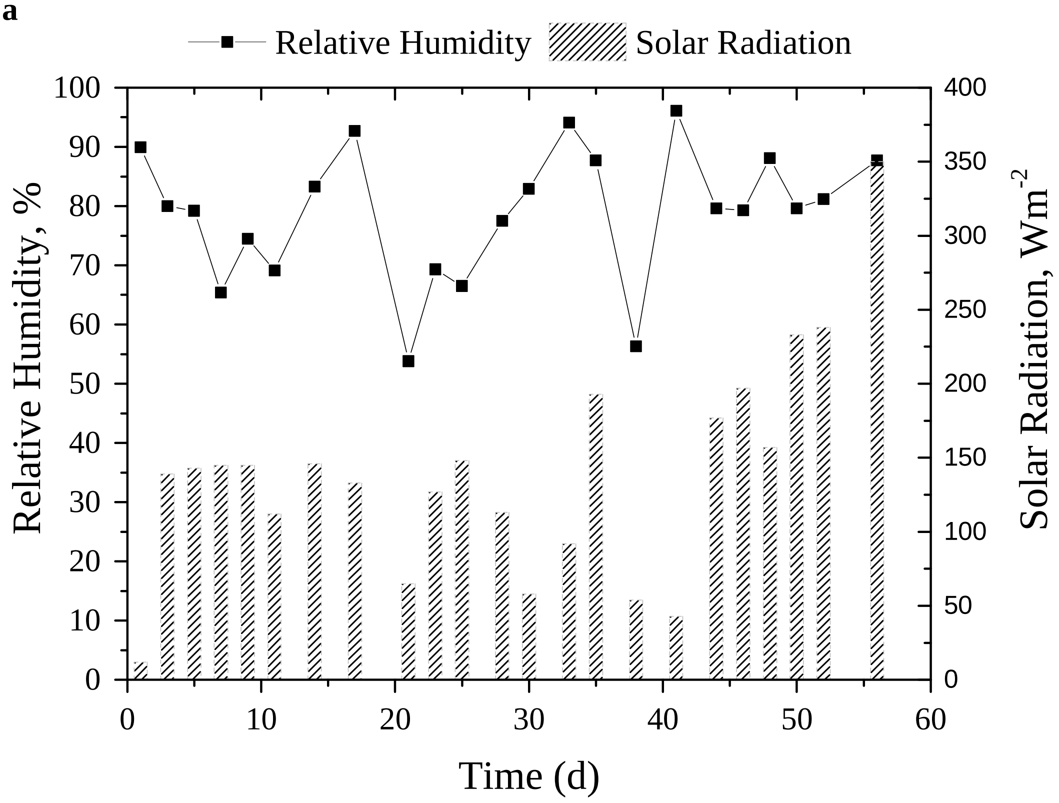


Fig. 2 Profile of (a) POM, (b) PL and (c) PLP Temperature and moisture during Solar drying.

a



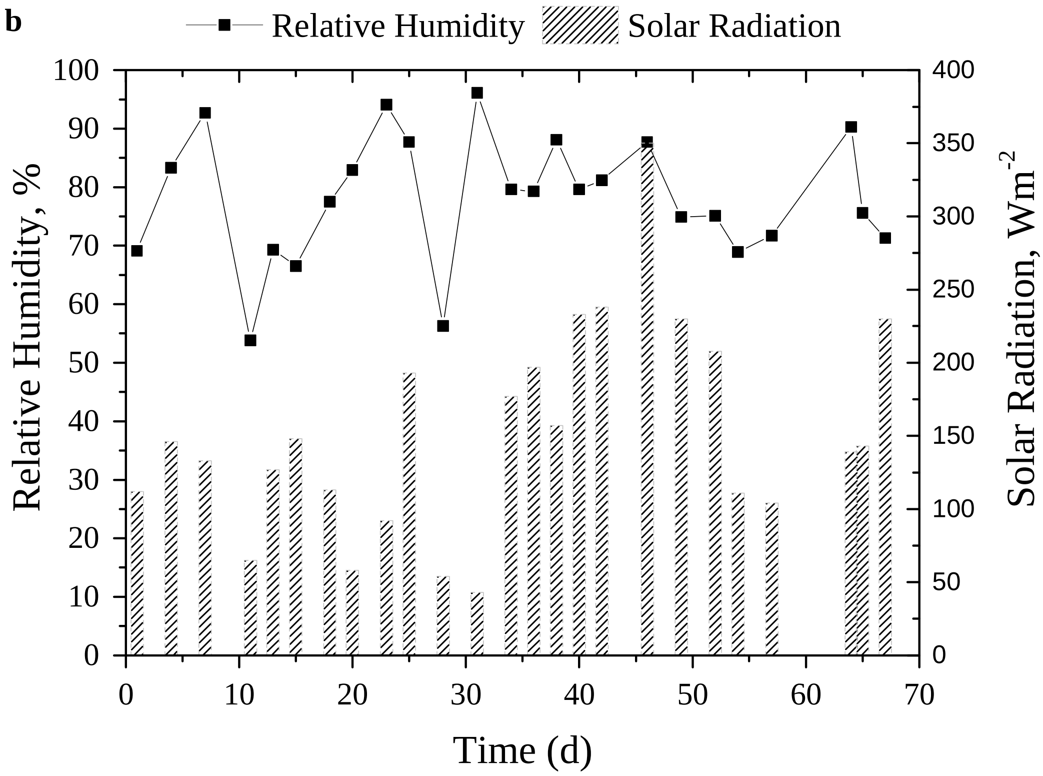


Fig. 3 Variations in the climatic conditions observed during the natural solar drying of (a) POM and PL (b) PLP.

4. Conclusions

In the present study, the utilization of olive pomace, leaves and biomass from pruning for the production of solid biofuels were examined. Solar drying process was used in order to remove moisture. Three different substrates were tested including pomace (POM), pomace with leaves (PL) and pomace with leaves and biomass from pruning (PLP). Results showed that moisture content decreased from 47%, 52% and 45 % at the beginning to 9.6%, 8.52% and 9.32% after 56 days of solar drying for POM and PL, respectively and after 64 days of solar drying for PLP. The total organic carbon (TOC) was initially 667 ± 6.4, 658 ± 28 and 634 ± 2 g/Kg for POM, PL and PLP, respectively and finally after solar drying to 684±1.0 g/kg, 665±5.6 g/kg and 637.9±1.5 g/kg, respectively. So, no correction was observed between TOC and moisture removal. Finally, the rate of moisture was positively related to minimum relative humidity and with the highest material temperature. Solar drying was applied as an economical and efficient further–dewatering and drying method in three different substrates thus allowing its actual use as a fuel.

ACKNOWLEDGMENTS

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