Turkish Journal of Range and Forage Science, 2023, 4(2): 93-100
doi: 10.51801/turkjrfs.1393543

Research

Turkish Journal of Range and Forage Science
https://dergipark.org.tr/tr/pub/turkjrfs

Solar Drying of Agrobiomass for Biopellets Production

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ARTICLE INFO

Received *21/11/2023*
Accepted *30/11/2023*

Keywords:

Agrobiomass
Biofuels
Biopellets
Open Sun Drying
Solar Energy

ABSTRACT

The paper presents the results of a study on solar drying of agrobiomass waste for the production of biopellets. The tests were conducted under open sun drying conditions during the summer in a Mediterranean climate, specifically in the Aydin province of Turkey. Drying tests were performed for two types of mixtures, i.e., sewage sludge and olive mill waste (OMW30), and sewage sludge and animal waste (DMC30). To ascertain the optimal conditions for the process the mixtures were dried under different thicknesses: 5, 10, and 20 cm and varied mixing intensities: no mixing and 6 times a day. It was observed that mixing of biowaste reduces time of drying, and the tests indicated a preference for drying the mixture with a thickness of 10 cm. The dried mixtures can be utilized in the production of pellets for energy applications.

1. Introduction

Solar drying is widely recognized as a sustainable and environmentally friendly alternative to conventional drying techniques, and it has become a well-established practice in agriculture. In agricultural sector drying process, is applied to remove moisture from crops, fruits, and vegetables, preserving their quality. A high level of moisture can promote the growth of microorganisms, bacterial activity, and mold proliferation, ultimately leading to material spoilage (Lingayat et al., 2021; Udomkun et al., 2020). The reduction of moisture can be achieved using solar or thermal energy in the drying process. This reduction is necessary to prolong the lifespan of the product and has a positive impact on transportation and storage. Solar drying is a method that can be particularly useful in areas with high sun radiation. It is stated that using solar drying can reduce the consumption of non-renewable sources for this process by up to 27% to 80% (Prakash et al., 2016).

The drying rate depends on several factors, including solar radiation intensity, the temperature and relative humidity of the air, the air circulation and thickness of the drying material layer (Wzorek, 2021). During the drying process, where heat and mass transfer occur simultaneously, moisture evaporates near the surface through various mechanisms, including liquid and vapor diffusion, capillary and gravity flows, as well as flow driven by shrinkage and pressure gradients (Ortiz-Rodríguez et al., 2022).

Solar dryers can be divided into two main types: direct and indirect solar dryers (Lingayat et al., 2021). Direct solar dryers expose the products to be dried directly to sunlight in an open field (a method known as open sun drying), and it is the most common and oldest method used in rural areas of developing countries.

Solar dryers can be categorized also according to their system design and the method of utilizing solar energy. For example, they can be classified such as passive, active, and hybrid solar dryers, which are distinguished by their approach to air

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*Correspondence author: e.yilmaz@adu.edu.tr circulation (natural or forced convection) and heat transfer mode (direct or indirect) (Lingayat et al., 2021; Udomkun et al., 2020).

Instead of main products the agricultural sector produces a substantial volume of by-products i.e., sludge, fibrous waste, crop residues, animal, and food processing waste.

The main problem with their reuse is high moisture content. Solar drying can be beneficial in transforming these by-products into valuable resources for various purposes, such as animal feed, energy production, composting, and other value-added products.

Agbede et al. (2023) investigated among others open sun drying of banana stalk chips which were untreated in 5, 10 and 15 mm thick. Solar drying of oil palm empty fruit bunches (EFB), a solid waste product from the palm oil industry, was studied in a hybrid solar dryer integrated with a thermal backup unit. It was determined that the time required to dry 2.5 kg of EFB is 4.21 days under open sun drying conditions. This can be reduced to 1.33 days by using the thermal backup (Al-Kayiem and Yunus, 2013). Maragkaki et al. (2016) examined the effect of greenhouse solar drying of various olive oil by-products among others three-phase and two-phase pomace as well as pomace with leaves and biomass from pruning. The study was conducted from January to April in Crete, Greece and wastes are dried in 10 cm layer. Results showed that for example moisture content for three-phase pomace decreased from 47 to 9.6% after 64 days and for two-phase pomace from 59 to 7.2 after 75 days of solar drying.

Wzorek (2021) conducted tests on drying biofuels made from sewage sludge and other waste in a solar greenhouse dryer equipped with a specially designed mixing system during the Polish summer and autumn conditions. The performed experiments demonstrated that it is beneficial to dry biofuels in 10 cm thick layer.

Türkiye has significant solar energy potential, making it one of the key renewable energy sources. The yearly average solar radiation is 1,311 kWh/m^2 per year and 3.6 kWh/m^2 per day. The total yearly insulation period is approximately 2,460 hours per year and 7.2 hours per day. Turkey was among the top markets for solar air heating and drying in 2021, along with countries like Canada, Spain, the USA, and Austria (Solar Thermal Energy, 2021).

The use of solar energy can be the initial step in biomass processing, either before or after pelletization, depending on the properties of agricultural materials. This preparation is essential for their application in energy processes (Kumar et al., 2022). Pelletization are frequently employed with various types of biomasses to enhance factors such as handling properties, increase its volumetric calorific value, and lower transportation costs (Whittaker and Shield, 2017; Yilmaz et al., 2018).

Therefore, it is crucial to research the solar drying of agricultural materials in regions with high solar radiation to optimize the solar drying processes.

2. Material and Methods

2.1. Materials

Agricultural biowastes: olive mill waste and animal waste as well as sewage sludge from municipal wastewater treatment were used in this study. The selection of biowastes was primarily based on their availability and, notably, the challenge of their utilization within the same region.

Samples of solid olive mill waste (OMW) were gathered from small-scale olive plants situated in the Aydin region. This region is known for its traditional cultivation of Olea europaea L olive tree, used for both oil and table olive production. The OMW material originated from the three-phase decanting method, which involved a combination of olive fruit kernels and pulp and water.

Cow manure originated from a local dairy farm (DCM) that manages 112 cows. The manure is stored there in an open space in the form of a midden.

Sewage sludge (MSS) originated from a mechanical-biological wastewater treatment plant serving 115,000 PE. The sludge had undergone a mechanical dewatering process.

Mixtures with various proportions were prepared using these biowastes, including a mixture with 70% sewage sludge and 30% olive mill waste (OMW30), as well as a mixture of sewage sludge and cow manure with 30% moisture (DCM30). The properties of biofuel components are detailed in Table 1.

The biofuel compositions OMW30 and DCM30 were subjected to solar drying.

Table 1. Parameters of components of biofuels

Materials	Moisture, % w.b.	Ash, % d.b	Volatile Matter,% d.b	HHV kJ/kg
OWM	84.24	22.29	48.65	18 860
AW	79.90	20.16	24.84	9 960
MSS	85.10	41.02	32.19	15 180

w.b. – wet basis; d.m. - dry basis

2.2. Methods

Solar drying test was conducted in the summer in August in Aydin, city at the Aegean province in Turkey (geographic coordinates of 37°50′53″ N latitude and 27°50′43″E longitude). The climate in this region is categorized as a Mediterranean climate, exhibiting characteristics of warm and arid summers alongside cool and wet winters.

In Fig. 1 is presented the total annual solar irradiance for the city of Aydın.

During the test, a meteorological station situated near the test stand continuously monitored ambient temperature, relative humidity, precipitation, and total global solar radiation.

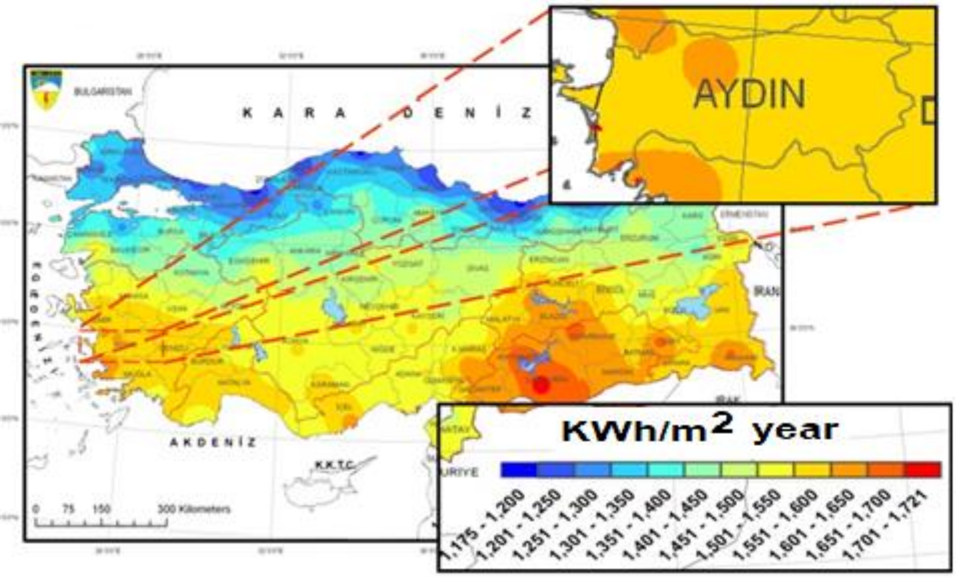

Figure 1. Total annual solar irradiance of Aydın (Anonymous, 2017).

Procedure of solar drying

The study was conducted in the research application area of the Biosystems Engineering Department, Faculty of Agriculture at Aydın Adnan Menderes University.

Biowaste was tested in an open sun drying system and exposed to the entire spectrum of outdoor environmental conditions. Biowaste, mixed in appropriate proportions, was placed in polypropylene containers, which were positioned on a wooden platform in the field to prevent stray radiation and heat transfer from the ground.

To enhance the process, screw-shaped vertical mixers, which moved along containers at a rational frequency ranging from 120 to 360 1/min, were also used for material mixing.

In order to determine the optimal process conditions and conduct a kinetic analysis of solar biowaste drying, a comprehensive set of tests was performed with variable parameters. These parameters encompassed different materials thicknesses (5, 15, and 20 cm) and various mixing intensities (no mixing and 6 times a day).

In the biowaste, the initial moisture content was determined, and then the daily moisture loss in the material samples was measured using the oven-dry method in accordance with the EN 12880:2000 standard.

The moisture content (MC) was calculated using the following equation:

$$MC\ (\%) = (m_1 - m_2 / m_1) \times 100 \qquad (1)$$

where: m_1 is the initial weight of sample and m_2 is the weight of the dry sample.

Pellets production

After the drying process, biomass materials with moisture levels below 20% were subjected to a pelletizing process using a pressure pellet mill equipped with two movable rollers and a variable flat die with Ø6 mm and Ø8 mm holes. Pellets with diameters 6 and 8 mm were produced.

Properties of pellets

In the produced pellets, energy properties were determined:

- Higher calorific value (HHV) was measured by using Oxygen Bomb Calorimeter, model 1341 according to EN 14918:2010 and ISO 1928 standards,
- Ash content was tested according to EN ISO 18122 standard,
- Voltaire matter was carried out according to EN ISO 18123 standard,
- Fixed carbon (FC) content was calculated by difference using following equation:

$$FC = 100 - VM - A \qquad (2)$$

where: VM is Voltaire matter, % and A is Ash content %.

3. Results and Discussion

The test was conducted under summer conditions. The average daily temperature during the testing period was 29.3°C, with an average maximum temperature of 33.2°C and an average minimum temperature of 26.5 °C. The average air humidity for this period was 55.65%, while the average total global solar radiation was 1.48 kWh/m².

Fig. 2 shows the temperature and relative humidity of the air during the test, while Fig. 3 illustrates the global solar radiation.

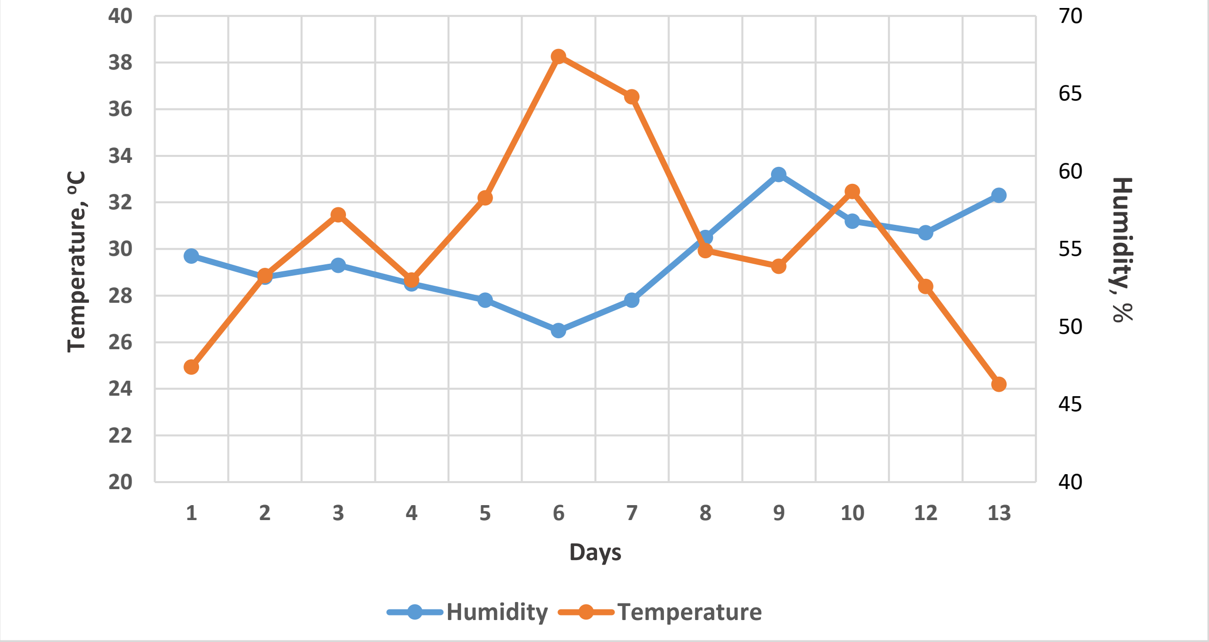

Figure 2. Air temperature and humidity during the test.

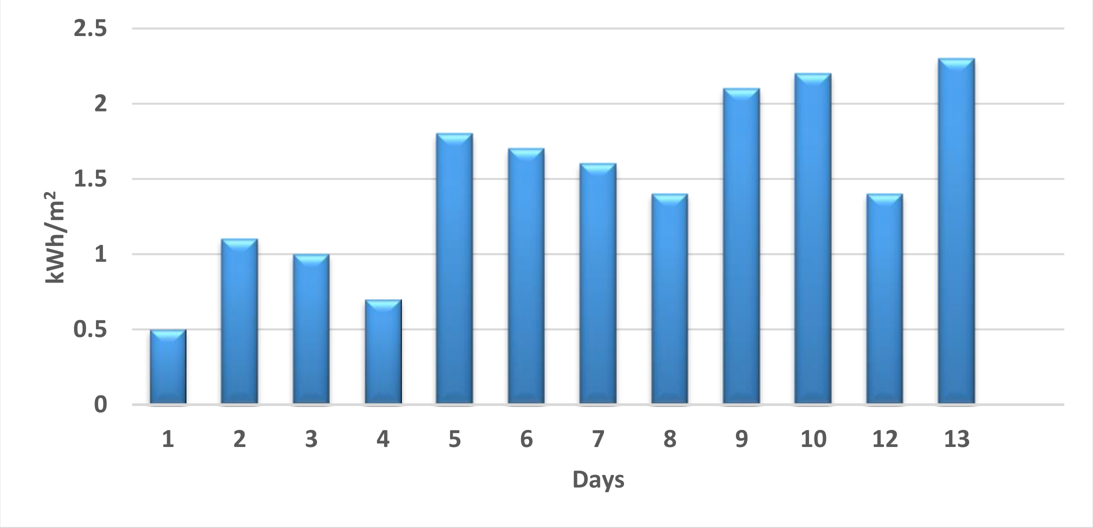

Figure 3. Solar radiation during the test.

In Figs 4 - 6 changes in moisture content in function of time for the tested mixtures of biowaste under open sun drying conditions are presented.

Based on the obtained research results, it can be concluded that mixing has an impact on the drying rate. In the case of drying without mixing, a slower moisture loss is observed compared to the variant with mixing, which is due to the transport of moisture from the interior of the dried material layer. Mixing led to the elevation of the material from the interior to the surface of the layer, facilitating contact with the drying agent. By drying biowaste mixtures in a layer with a thickness of 5 cm and applying mixing, a moisture content of 20% was achieved after 5 days. For solar drying in a 10 cm layer, the time extended by 3 days, and for drying in a 20 cm layer, it increased by 6 days compared to drying in a 5 cm layer. A slight difference in drying rate can be observed among the investigated mixtures, with DCM30 exhibiting a superior drying rate.

Similar results were observed by Yilmaz and Wzorek (2015) in the same climate conditions achieved for solar drying pure sewage sludge. Other authors, for example, Wzorek (2021) obtained a reduction below 10% in moisture content for a mixture of sewage sludge and sawdust after 15 days, and for the mixture of sewage sludge and meat and bone meal, after 8 days in Polish climatic conditions using a greenhouse solar dryer. According to Velis et al. (2009), 20% moisture content in the sludge is achieved during biological drying within 7 to 15 days.

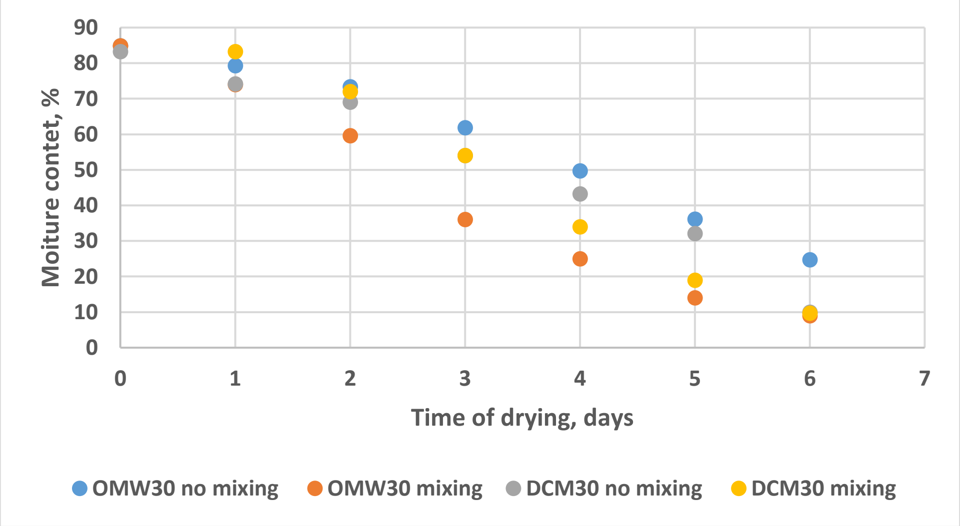

Figure 4. Changes in moisture content of biomaterials in function of time in open sun drying conditions; solar drying in 5 cm layer.

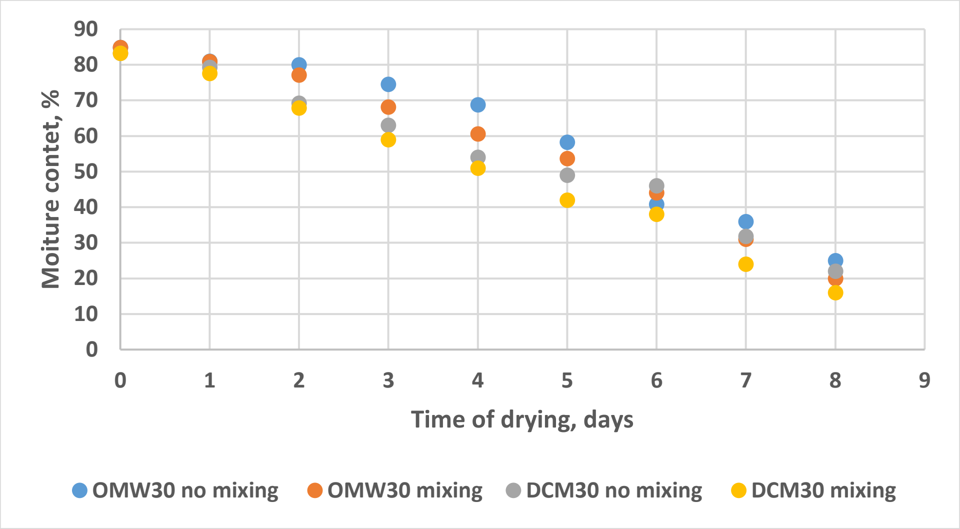

Figure 5. Changes in moisture content of biomaterials in function of time in open sun drying conditions; solar drying in 10 cm layer.

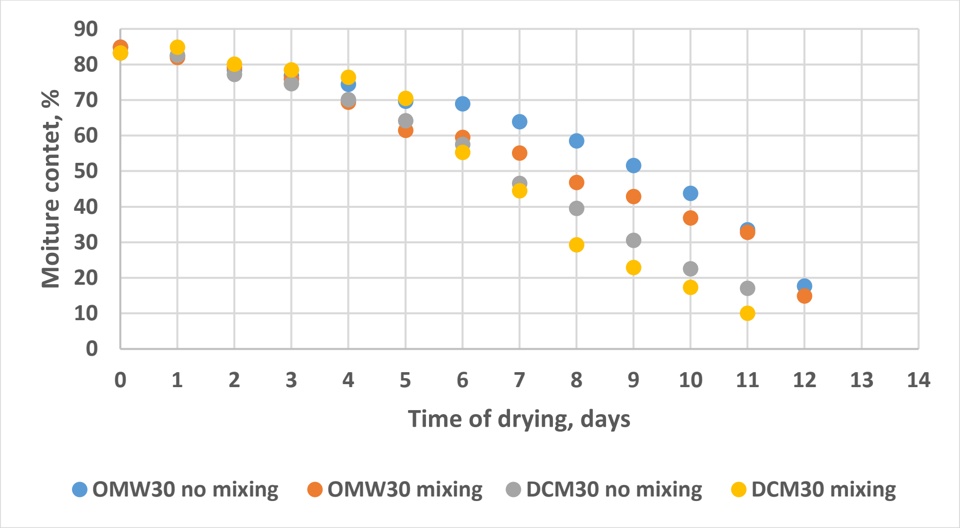

Figure 6. Changes in moisture content of biomaterials in function of time in open sun drying conditions; solar drying in 20 cm layer.

The dried mixtures of biofuel components underwent the pelletization process. In the study (Yilmaz et al., 2018), the pellets were produced using a specially designed system, which initially involved mixing the components and then forming them in special devices equipped with sieves and knives. In this arrangement, the mixtures were expected to have a moisture content in the range of 30-40%. However, in this experiment was decided to pelletize the biomaterials using a pressure pellet mill at lower moisture levels in the material.

The energy properties of the produced biopellets are presented in Table 2.

The addition of sewage sludge raised the Higher Heating Value of the DCM30 biopellets, which initially stood at 16.5 MJ/kg. HHV of DCM30 biopellets are significantly higher, with a value of 18.6 MJ/kg, and are highly recommended for energy generation. The calorific values of the produced bio-pellets fall within the range typical of plant and agrobiomass (Dinesha et al., 2019).

Table 2. Energy parameters of biopellets.

Biopellets	**Proximate Analysis (wt %)**				**HHV kJ/kg**
	Analytical moisture w.b.	**Ash d.b.**	**Volatile Matter d.b.**	**Fixed Carbon d.b.**	
OMW30	6.56	30.40	33.28	39.61	16 491
DCM30	5.57	39.61	29.74	30.64	18 633

w.b. – wet basis; d.m. - dry basis

4. Conclusion

The experiments yielded insights into the open air drying of biowaste in the summer conditions of the Aydin province. The study identified the key factors influencing the drying process, including the layer thickness, and mixing intensity, which have a positive impact on process. It was observed that the rate of solar drying is primarily contingent on the mixing of biowaste during the process, aside from weather conditions. Tests revealed a preference for drying the mixture in a 10 cm layer thickness.

It was observed a subtle disparity in drying rates between the OMW30 and DCM30 mixtures, with DCM30 demonstrating a more efficient drying rate.

The method involving solar drying followed by pelletization, can also find broader applications for agrobiomass utilization, such as for agricultural purposes like fertilizers. Pelletizing waste materials makes it easier to transport and store them.

The use solar energy for drying and application of agrobiomass for energy purpose can contribute to achieving sustainable development goals, reducing greenhouse gas emissions, and enhancing energy independence, provided that it is done responsibly and in an environmentally friendly manner.

Funding Statement

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

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