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The Effects of Shriveling up Waste Watermelons in Different Solar Drying Systems on Withering and Relevant Microbial Parameters

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HIGHLIGHTS

- Withering and silage of water-rich waste watermelons.
- Waste watermelon slices wilt in 444.38 and 583.13 minutes in two different systems.
- Making microbially safe silage for animals by wilting water-rich waste watermelons.
- Combined solar drying system is more advantageous in terms of withering parameters.

Abstract: This study aimed to examine the shriveling parameters and some aerobic microbial qualities of waste watermelons in a combined solar energy drying system (CDS) and an open sun drying system (OSDS). Results showed that the CDS was better than the OSDS in terms of the temperature, relative humidity, surface temperature, time, and speed of reaching the target humidity level of the air-shriveled watermelon slices. The number of mesophilic aerobic bacteria (log_{10} cfu/g) increased in the shriveled ($P>0.05$) silages compared to fresh watermelon slices in the CDS and OSDS groups and decreased in silages ($P<0.05$). Compared to fresh watermelon slices, yeast count (log_{10} cfu/g) decreased in the shriveled CDS group ($P>0.05$) and increased in the OSDS group ($P>0.05$) and was not detected in silages. No mold was determined in the fresh watermelon slices and silages in the CDS and OSDS groups. However, mold was found to be higher in the shriveled slices in the OSDS group than in the CDS group ($P<0.05$). Aflatoxin was not detected in the fresh, shriveled and silage watermelon slices. As a result, it was determined in this study that the CDS group was more advantageous in terms of slaking parameters compared to the OSDS group in the shriveling process of the waste watermelon slices, which had not been previously studied. It was observed that there was no significant difference between the two systems in terms of aerobic microbial quality determined during the wilting and ensiling process.

Keywords: Waste Watermelon; solar energy systems; wilting; silage; microbial quality.

INTRODUCTION

Today, livestock is one of the fastest-growing agricultural sectors. Many countries have a feed shortage problem. In the growing, processing, packaging, distribution, and consumption of fruits and vegetables, approximately 1.81, 6.53, 32.0, and 15.0 million tons of fruit and vegetable waste are generated in India, the Philippines, China, and the United States respectively. [1]. Economically, discarding edible materials means not only wasting food, but also losing important associated resources [2].

As of 2019, 100 million tons of watermelon were produced worldwide, 3.87 million of which were produced in Turkey [3]. In a study by Fish and coauthors [4], it was reported that the level of waste of watermelon produced in the field for any reason is 20%. In the light of this information, the amount of watermelon that is wasted annually is 786,000 tons in Turkey and 20 million tons worldwide, based on the 2019 production levels. The watermelons that are wasted contain significant levels of sugar, protein, fat, mineral substances, beta carotene, vitamin A, vitamin C, vitamin B, lycopene, citrulline, cryptoxanthin, lutein + zeaxanthin, betaine, and phenolic compounds [5-9]. Fresh watermelon puree produced by shredding the waste watermelon flesh, peel and seeds, contains 8.88% DM, 1.16% CP, 0.18% EE, 0.63% CA, 0.54% CF, 6.38% NFEM (nitrogen free extract matter) [10,11], 2.65% fructose, 1.26% glucose, 0.88% sucrose, and 0.03% maltose on wet matter. In addition, watermelon puree contains significant levels of vitamin C, carotene, and lycopene [10]. However, the most important aspect of waste watermelons is the high-water content. Water-rich plants such as waste watermelon continue to live and respire for some time after they are cut and chopped. In this process, losses due to oxidation and enzymes occur in silage feed [12]. The moisture of barley used in beer production was reduced from 74.2% to 6.30% with a natural convection solar dryer [13]. Fresh fodders are either dried to a moisture content of less than 150 g/kg and stored as hay in stable condition, or as silage in a low pH and anaerobic environment after shriveling to a moisture content between 500 to 650 g/kg. The prolongation of the drying time of hay and the wilting time of silage feed leads to the development of aerobic bacteria, yeast, and fungi in the feed. These microorganisms consume easily soluble carbohydrates and produce carbon dioxide, water, and heat in these feeds, as well as causing nutrient loss [12,14]. In addition, molds that reproduce in moist feeds also become harmful by secreting toxins [15].

There are not many studies on converting water-rich waste watermelon into durable feed and feed additives. However, watermelon is grown as a summer fruit between May and September in countries with a sunny and warm climate, such as Turkey, and can become waste [7, 16, 17]. In a study conducted in Osmaniye [18] between May and September, when watermelon can go to waste, as both radiation and temperature values are considered, it was found that solar energy constituted a good energy source for shriveling waste watermelon. Yet, in studies conducted on this subject [19, 20], disadvantages have been reported, including the mixing of foreign materials such as dust and soil into products dried using the open sun drying method, the difficulty of protecting products dried in adverse weather conditions (rain, wind), the difficulty of protecting products from damage in drying areas, and the growth of aerobic microorganisms such as fungi in the products. It has been asserted that solar dryers, which have been recently developed, are an alternative drying method that eliminates or minimizes the above-mentioned disadvantages. On the other hand, in another study [21], it was reported that some microorganisms in the product could be inactivated by heat and light UVA rays during open sun drying, but that this method could lead to an increase in microbial populations in the case of exposure to rain, wind, dust, insects and other animals. In the same study, it was stated that in greenhouse drying with direct solar energy, UVA rays partially pass through the transparent cover, and these rays cause the inactivation of some microorganisms, albeit only slightly. Information about how the sun-drying of feeds reduces the feeds' microbial load has also been presented in other studies [22, 23]. The temperature of the drying air affects the drying rate of the herbal product at a higher level than the relative humidity [24]. Similar results, conducted with a different approach, were obtained in another study [25]. The wilting process is needed to reduce the moisture concentration of the water-rich feeds to be preserved, to improve their silo storage properties, and to prevent leakage losses from the silo. The rapid wilting process in a short time reduces the dry matter and nutritive value losses of the silage feed [26].

According to the information obtained from reviewing the above literature, a significant quantity of watermelon, which has a feed or feed additive value, becomes waste in Turkey and worldwide. Studies in which watermelon peel is dried and turned into flour have been found in the literature [27]. However, there is no open-source literature on the use of waste watermelon fruit (skin, seeds, and flesh) for drying or silage. There is a good solar energy potential during the seasonal period when watermelon is wasted. This study aimed to determine the most effective solar energy drying system in reducing the water content of waste watermelons to the level of silage. In this context, drying in the open sun, which is the traditional drying

method was compared with the greenhouse-type combined dryer system with the support of a solar air heater. In the test, the effects of these two different drying systems on the temperature of the drying air, the relative humidity of the air, the time for the watermelon slices to reach the target shrivel level, the wilting rate, the mesophilic aerobic bacteria, yeast and mold growths and aflatoxin levels in the wilting process, and silage of the shriveled waste watermelon slices were revealed.

MATERIAL AND METHODS

Feed material

In the research, waste watermelons not sold at the sales points in Osmaniye (Turkey) were collected and brought to the laboratory and used as silage feed material. Watermelons that were left on the shelf in September-October and therefore could not be sold were used.

Selected solar drying systems

Two different systems, namely the solar combined drying system (CDS) and the open-air sun drying system (OSDS), were used in wilting. The roof of a three-story building was chosen as the trial site for both systems to prevent contamination and shading with dust and soil on the product, especially with the effect of the wind during the wilting process.

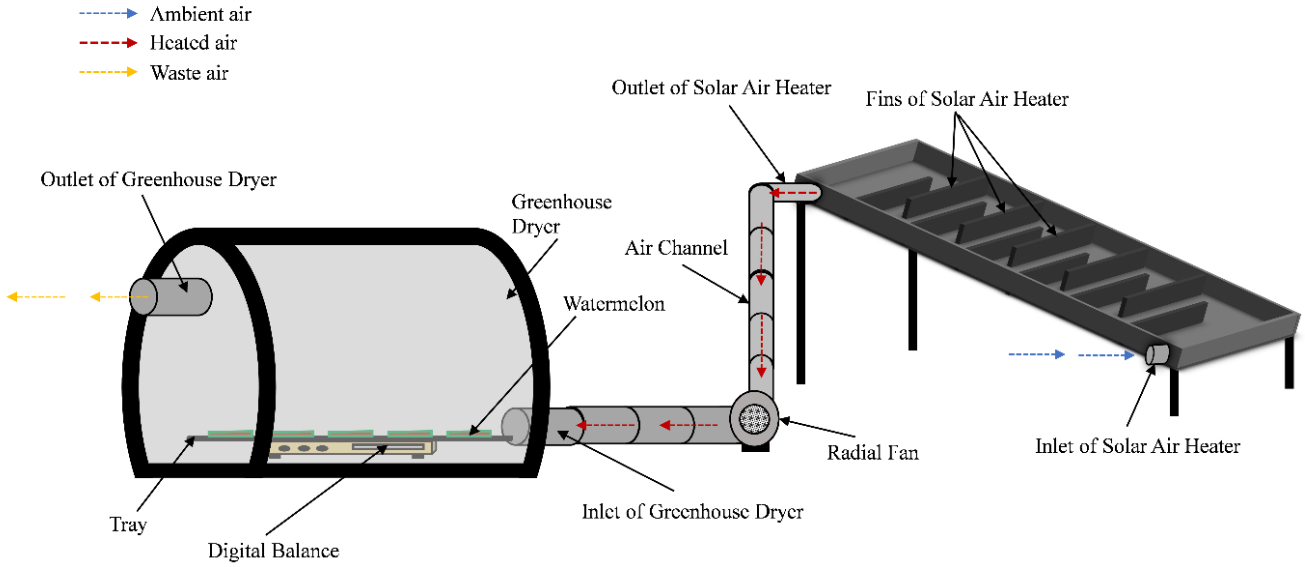

Figure 1. Schematic diagram of the solar combined drying system

Solar combined drying system

A CDS was used in this study, benefiting from studies on greenhouse-type [28] direct and indirect solar energy drying systems [29]. A schematic diagram of the solar CDS is shown in Figure 1. The system consists of two main units, a solar-powered air collector and a greenhouse. The dimensions of the air collector are 1.9 m x 0.9 m and 66 cm x 7 cm. Tempered glass is used in the solar collector, which is positioned with an inclination of 22°. The temperature of the air entering the solar collector through a speed-controlled radial type fan with a flow rate of 650 m^3 / h (max.) 170 W was increased in the collector, and its relative humidity was reduced. The dry and hot air was transferred to the greenhouse-type drying cabinet, which is heated by direct solar radiation and covered with an 8 mm transparent plastic sheet, through an insulated air duct. Then, the air heated by direct and indirect solar energy removed the relative humidity in the product and left the greenhouse through an 11 cm diameter circular chimney positioned 60 cm above the south wall and the ground.

Open sun drying system

In this traditional system, the wilting process of the watermelon slices occurred under natural convection conditions at the temperature and relative humidity of the outdoor environment, by exposing the slices to direct sunlight.

Wilting and siloing of waste watermelons

Watermelons that were not sold at the sales points were collected free-of-charge and brought to the laboratory. The watermelons were first washed by brushing them under tap water, and the water used for washing was filtered. These watermelons were sliced into pieces of 0.5 and 1.0 cm thickness and arranged on drying trays. Four different types of watermelon were taken randomly from the watermelons collected from the sales points, and the initial humidity level was determined as 91.5% in the drying cabinet at 105ºC. A humidity level of 65% was targeted as the moisture rate to end the shriveling. After adding 1% salt to the shriveled watermelon slices, the construction of the bale silos in the application was taken as an example and pressed into 1-1.5 kg cloth bags by wrist power. Then, the cloth bags were wrapped with a stretch plastic cover and bundled with duct tapes to make mini bale silos. The silos were opened approximately 90 days later.

Research Groups

The research groups were determined by the solar energy drying systems, which were defined above and used in the wilting of waste watermelons. Accordingly, the group wilted in the solar CDS was named the CDS Group, and the group wilted in the OSDS was called the OSDS group. Eight replications were used in the research.

Measurements made in drying systems

A computer-aided 16-bit IOTECH PD3001 Datalogger was used to measure temperature, relative humidity, weight, and solar radiation in both experimental groups and to record the data at 30-minute intervals. To measure the temperature of the drying air, COLE PARMER Thermo elements with a sensitivity of 0.1ºC were used on the surfaces of the watermelon slices in the open air, in the greenhouse, and both systems. In addition, EPLUSE air humidity meters with 2-3% sensitivity were used in the open air and greenhouse test. To measure solar radiation, FRONIUS irradiance meters with the same slope as the collector slope and accuracy of ± 5% were used. The weight change of shriveled watermelons in both systems was measured with DİKOMSAN electronic scales with a sensitivity of 0.1 g.

Wilting process in watermelon slices

In both systems, trays that were tared and the starting weight of which was recorded by putting watermelon slices inside were placed on DİKOMSAN Electronic Scales. Then, weight losses due to evaporating water were recorded every 30 minutes. When the moisture of the watermelon slices decreased from 91.5% to 65%, the wilting process was terminated.

Wilting duration (minutes)

This is the time it takes for the watermelon to drop from the initial humidity to the target humidity.

Wilting speed (gram/30 minutes)

"The change in the weight of the watermelon during a period of 30 minutes until it reaches the target moisture level." Its formula is the ratio of weight to grams at the end of 30 minutes.

Taking samples from feed materials and analyses made

In both systems, samples were taken from the fresh waste watermelons before wilting, the shriveled watermelons after wilting, and the watermelon silages in opened silos after ensiling, and placed in sterile bags. The samples were stored in a deep freezer at -20°C until the analysis. The TMABC (total mesophilic aerobic bacteria count) [30], mold count [31], yeast count [31], and aflatoxin level [32] of these samples were determined according to the methods discussed above.

Statistical analysis

The t-test was used to statistically evaluate the difference in wilting parameters between the two study groups [33]. One-way ANOVA was used to evaluate the microbial parameters and aflatoxin amounts [33].

RESULTS

Average solar radiation values measured at 30-minute intervals during the day over the study period are given in Figure 2. Temperature, relative humidity, and watermelon slice surface temperature values measured at 30-minute intervals during the wilting period are given in Figure 3; The values of the witheration rate and reaching the target humidity level are given in Figure 4, and the average temperature and relative humidity values are given in Figure 5. The parameters determined during wilting in the study groups are given in Table 1, the microorganism population (log_{10} cfu/g) and aflatoxin levels (ppb/g) in the wilting process and silage are given in Tables 2 and 3.

Table 1. Parameters determined during wilting in research groups

Wilting parameters	n-Value	CDS	OSDS	T	p Value
Wilting ambient temperature [°C]	8	49.12±1.10	30.77±0.84	13.258	0.000*
Wilting ambient relative humidity %	8	24.72±1.92	42.31±2.60	-5.435	0.000*
Surface temperature of shriveled watermelon [°C]	8	35.92±1.26	30.94±0.68	3.473	0.004**
Target humidity level %	8	63.77±1.84	64.98±2.13	-0.431	0.673****
Time to reach target humidity level (minutes)	8	444.38±20.63	583.13±39.02	-3.144	0.007**
Wilting Rate of Watermelon (grams/30 minutes)	8	59.66±3.60	47.06±2.95	2.709	0.017***
Amount of dried watermelon (grams)	8	1172.82±95.13	1216.74±98.18	-0.321	0.753****

CDS: Solar combined drying system- Group, OSDS: Open sun drying system- Group, *: P<0.001 is statistically significant.
**: p<0.01 is statistically significant., ***: p<0.05 is statistically significant., ****: p>0.05 is not statistically significant.

Table 2. Microorganism population in wilting process and silage of out-of-market watermelons in different drying systems. (log_{10} cfu/g)

Microorganisms (log_{10} cfu/g)	Sliced Watermelon						
	Fresh (n = 8)	Shriveled		Silage			
		CDS (n = 8)	OSDS (n = 8)	CDS (n = 8)	OSDS (n = 8)	SEM	p Value
Total Mesophilic Aerobic Bacteria Count	5.27±0.52a	6.18±0.19a	5.78±0.22a	3.69±0.17b	3.80±0.35b	0.144	0.000*
Yeast Count	3.59±0.20ab	3.50±0.08b	3.90±0.17a	0.00±0.00c	0.00±0.00c	0.055	0.000*
Mold Count	0.00±0.00b	1.63±0.49a	2.28±0.53a	0.00±0.00b	0.00±0.00b	0.143	0.000*

a, b, c: the difference between values with different letters on the same line is statistically significant., SEM: Mean of standard error
*: p<0.001 is statistically significant.

Table 3. Aflatoxin levels (ppb/g) in the wilting process and silage of out-of-market watermelons in different drying systems

Aflatoxins (ppb/g)	Sliced Watermelon						
	Fresh (n = 8)	Shriveled		Silage			
		CDS (n = 8)	OSDS (n = 8)	CDS (n = 8)	OSDS (n = 8)	SEM	p Value
B1	0.00±0.00	0.02±0.02a	0.01±0.01a	0.00±0.00a	0.00±0.00a	0.004	0.602**
B2	0.00±0.00b	0.00±0.00b	0.00±0.00b	0.01±0.00a	0.00±0.00b	0.002	0.058**
G1	0.00±0.00	0.01±0.01a	0.00±0.00a	0.00±0.00a	0.00±0.00a	0.003	0.421**
G2	0.00±0.00	0.02±0.01b	0.02±0.01b	0.13±0.04a	0.02±0.01b	0.009	0.000*

a, b: the difference between values with different letters on the same line is statistically significant., SEM: Mean of standard error
*: p<0.001 is statistically significant. **: p>0.05 is not statistically significant.

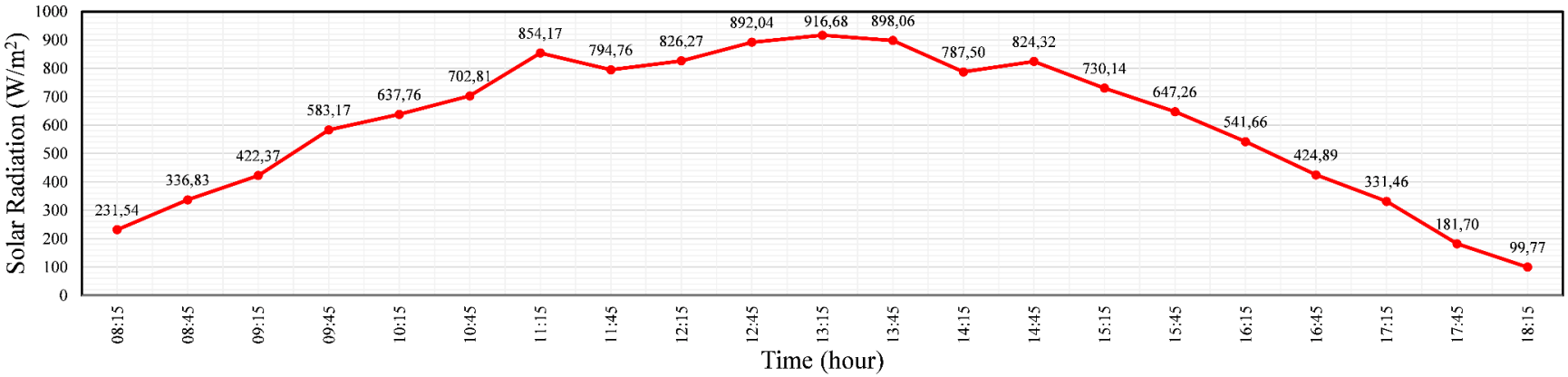

Figure 2. Average solar radiation values measured at 30-minute intervals during the study process.

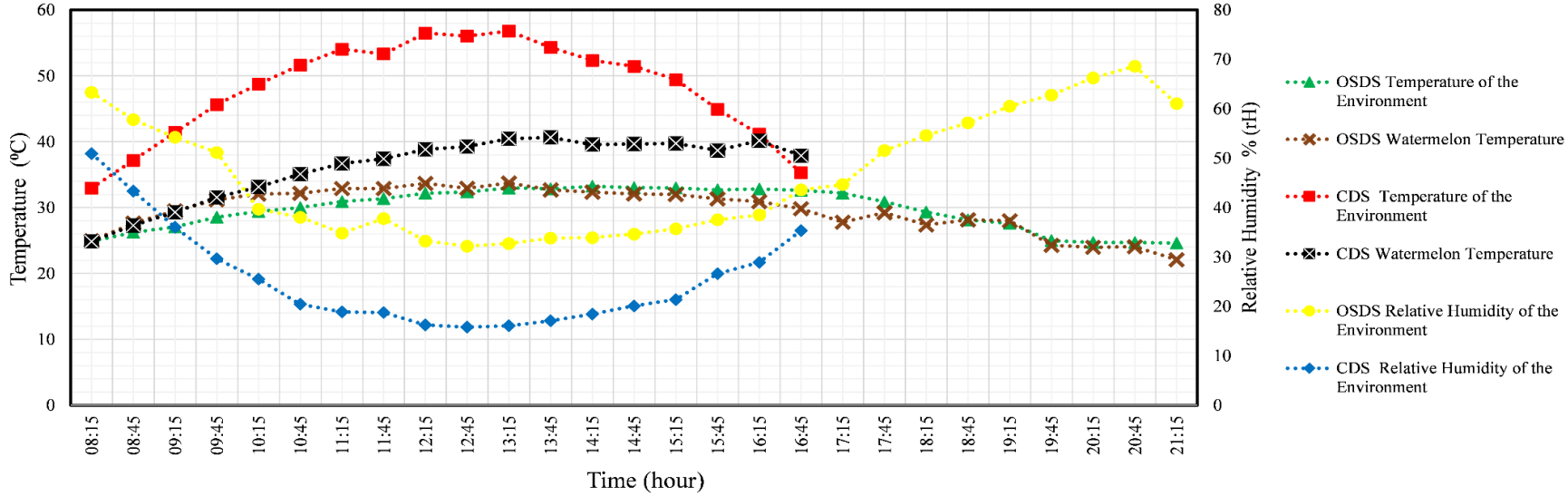

Figure 3. Temperature, relative humidity and watermelon slice surface temperature values measured at 30-minute intervals during the wilting process

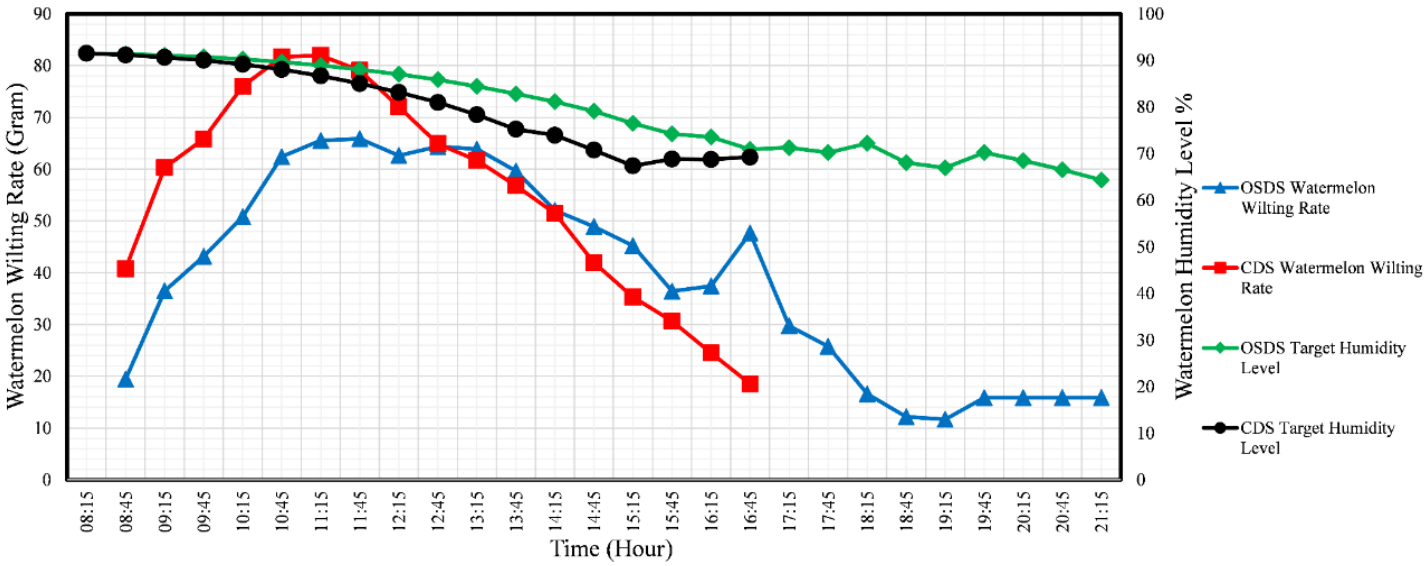

Figure 4. The values of witheration rate and reaching the target humidity level measured at 30-minute intervals

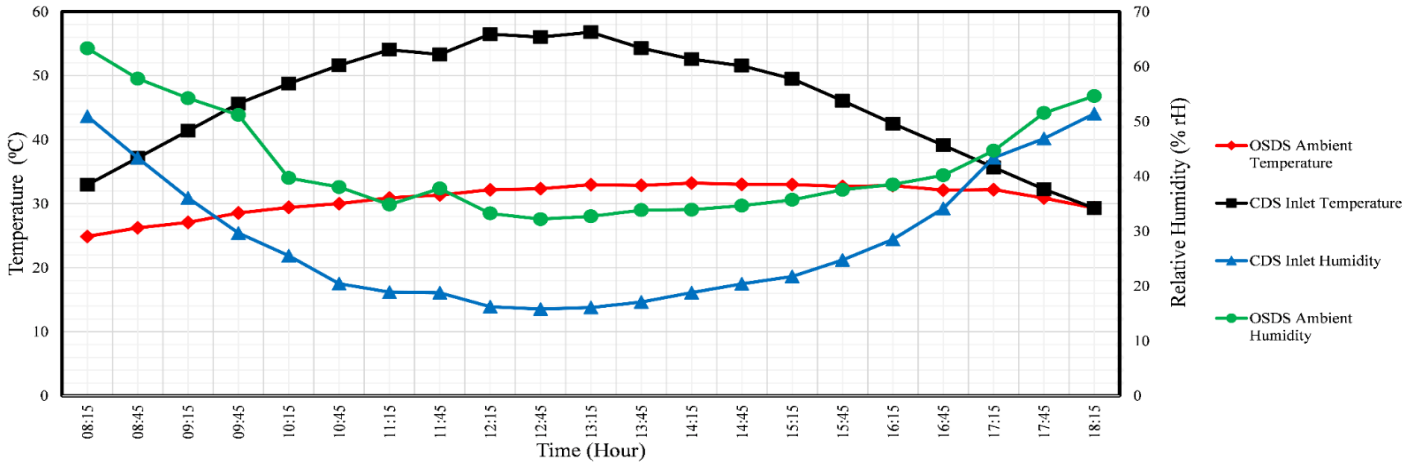

Figure 5. Average temperature and relative humidity values measured at 30-minute intervals during the day in CDS and OSDS Systems over the study process

DISCUSSION

The solar radiation intensity measured at 8:15 am when the waste watermelon started wilting was 231.54 W/m^2, at 9:15 it was 422.37 W/m^2, at 10:15 it was 637.76 W/m^2, at 11:15 it was 854.17 W/m^2, and it gradually increased to 916.68 W/m^2 at 13:15. This rise in radiation continued until 14:45 and then started to decrease, at 18:15 it fell under the radiation of 08:15, which was the starting time (Figure 2). When the radiation data obtained in this study are compared with those in a previous study [18], it is seen that they are in accordance with each other (Figure 2). On the other hand, in another study [34], the temperature of the environment in which the alfalfa silage plant shriveled outdoors under the sun was lower than the one in this study, and the relative humidity was higher (Figure 3). Unlike the previous study, the naturally existing solar energy potential in the CDS group of this study was intervened in with the greenhouse and collector technology, which collects the sun's rays and increases its effect, and forced convection, which accelerates dehydration [29, 35]. In the experiment conducted in this context, the open sun wilting system (OSDS group), realized with the effect of natural convection was compared with the wilting system (CDS group), set up with the combination of greenhouse + collector + forced convection. Accordingly, it was determined that the wilting air temperature was higher ($p < 0.001$) in the CDS group compared to the OSDS group, and the relative humidity was lower ($p < 0.001$) during the wilting process of the waste watermelon slices (Table 1 and Figure 3). It was observed that the wilting speed of the waste watermelon slices was higher in the CDS group than in the OSDS group. This increase was found to be statistically significant ($p < 0.05$). From another point of view, it was found that the wilting time (minutes) of watermelon slices was statistically shorter in the CDS group ($p < 0.01$) (Table 1). In a previous study on drying red pepper with similar systems, it was found that red pepper dried faster in solar drying systems compared to drying in the open sun [19]. Obtaining such a result may be due to the fact that the temperature of the air, which plays a role in drying or wilting, is higher in the combined system and its relative humidity is lower (Table 1, Figure 3). This is because the air temperature of the dryer has a more significant effect on the drying kinetics compared to the air relative humidity [24]. Again, while natural convection is not intervened with in the open air, intervening with forced convection in the combined system shows that more regular wilting can be achieved. As a matter of fact, in a previous study, in a dryer at 55-81°C at an airspeed of 1.3 m/s and 2.51 m/s, an average of 4.66 kg and 5.3 kg of water per day flew respectively [36]. It has been stated in a previous study that the increase in wilting rate and shortening of the duration is also crucial in terms of reducing the dry matter and nutrient losses of the silage produced [26]. Top and coauthors [20] reported that solar-assisted dryers shorten the drying time, reduce contamination, and are advantageous in many respects compared to open sun drying. Drying speed is crucial in dry feeds, and wilting speed in silage feeds. This is because, in order to make quality silage from water-rich forages, the silage material must be rapidly wilted, immediately filled into the silo and sealed, and its contact with oxygen must be kept short [37]. This opportunity is provided by the combined system used in this study. In other words, in this system, watermelon slices wilted faster in the CDS group than in the OSDS group (Table 1, Figure 4).

In the study, TMABC, mold and yeast count were determined in the samples taken during the wilting and silage process of waste watermelons in both drying systems. Accordingly, a low and non-statistical increase in TMABC was detected during the wilting of the fresh form of waste watermelon slices. This increase was observed to be higher in the CDS group than in the OSDS group (Table 2). This may have been due to the direct ultraviolet radiation effect of the sun's rays in the OSDS [21]. This is because aerobic microorganisms develop rapidly in wet silage materials with the presence of oxygen and an appropriate temperature [38]. The yeast count, which was 3.59 $\log_{10}$ cfu/g in the fresh watermelon slices, decreased to 3.50 $\log_{10}$ cfu/g in the CDS group during the withering process, while it increased to 3.90 $\log_{10}$ cfu/g in the OSDS group. The difference between the groups was statistically insignificant in the fresh watermelon slice in the CDS group, but significant in the OSDS group. Mold was not detected in the fresh samples; however, it was found to be 1.63 $\log_{10}$ cfu/g in the CDS group and 2.28 $\log_{10}$ cfu/g in the OSDS group in the shriveled watermelon slices. In other words, in contrast to aerobic mesophilic bacteria, both yeast and mold levels grew higher in the watermelon slices that were wilted in the open air. In previous studies, it was reported that the amount of mold and yeast increased during the wilting process of the silage material [38]. It has been reported that molds generally reproduce in wet feeds [15]. On the other hand, it has also been reported that during sun drying, some microorganisms can be inactivated by heat and light ultraviolet (UV) radiation, and an increase in microbial populations may occur due to exposure to rain, wind, dust, insects, and animals. For this reason, it has been stated that there are higher levels of microbial contamination during conventional sun drying [21]. However, in a study conducted under laboratory conditions, a significant difference was found in the amount of both yeast and mold in the sample dried with direct sunlight compared to the indirect ones ($p < 0.05$). No significant difference ($p > 0.05$) has been detected in aflatoxin-secreting fungi identified in both directly and

indirectly dried banana flour samples [23]. All these study results show that the increase in the number of yeast and mold in open sun drying is caused by environmental factors plus mold and yeast contamination. The absence of mold in fresh watermelon slices can also be attributed to the fact that the outer part of the watermelon was washed and dried before slicing, and the inner part first had contact with the external environment through slicing.

Considering the microbial load in the waste watermelon silages produced as the final durable product after wilting (Table 2), it was observed that the TMABC was statistically lower than both the fresh material and the shriveled watermelon slices ($p < 0.001$). Again, in the analyses made regarding yeast and mold, the amount of yeast and mold that had increased in the wilting process in both systems completely disappeared in the silages ($p < 0.001$). This was due to the inability of aerobic bacteria, yeast, and molds to survive with the consumption of oxygen in the feed mass when the appropriate moisture, physical form, airtight compression, and closure of the feeds are made in the silage [12, 37, 38]. Despite the decrease in the number of mesophilic aerobic bacteria, their presence in the silage mass can be attributed to the fact that a small amount of the selective anaerobic bacteria species in the silage survive in the silage during the storage period and start to multiply again when the silage is opened [39]. When the bacterial population reaches 10^7 -10^8 cfu/g and the mold population reaches 10^6 -10^7 cfu/g, the fermentation products are consumed by the microorganisms, resulting in an increase in temperature in the silage [40]. The heat generated in silages also causes yeast and mold growth and protein damage [41, 42]. However, the low number of aerobic bacteria reflecting the deterioration of the silages, and the absence of yeast and molds in the silages indicate that the waste watermelons are safe in terms of microbial quality in both wilting systems. It has been reported that when the mold level in the silage is greater than 5 $\log_{10}$ cfu/g, the DM losses exceed 20%, and when the mold number exceeds 6 $\log_{10}$ cfu/g silage, the DM losses exceed 40% [26].

In the analyses made for aflatoxin B1, B2, G1 and G2, very low and insignificant levels were found in fresh, shriveled, and silage watermelon slices. This can be attributed to the fact that the molds grown during the wilting process in both wilting systems shrivel in one day without sufficient time to produce aflatoxin, and the oxygen is cut off by making silage. On the other hand, the fact that there was no significant difference ($p > 0.05$) in aflatoxin-secreting fungi detected in the samples of banana flour dried under both direct and indirect sunlight [23] explains the finding obtained in this study (Table 3). Normally, aflatoxins are common contaminants in corn, peanuts, flaxseed and other plants with a high carbohydrate content (such as watermelon slices) [43]. Plants can be contaminated from the time they are cultivated in the field, as well as during growth, harvest, transportation and storage [44]. In a previous study, the total aflatoxin level in silages was found to be between 4.33-19.92 ppb, with an average of 8.65 ppb [45]. Briefly, in this study, it was determined that the silages obtained from the siloing of waste watermelon slices in both drying systems were found to be a safe feed in terms of aflatoxin level (Table 3).

CONCLUSION

This study found that the CDS is more advantageous in terms of withering parameters compared to the OSDS in the wilting of waste watermelon slices. When the waste watermelon slices were evaluated in terms of microbial quality during the wilting and siloing processes, it was observed that there was no significant difference between the two systems, and safe watermelon slice silages could be produced in terms of microbial quality. According to these results, it can be said that agricultural operators, especially small family businesses can process waste watermelons into durable silages that are safe in terms of microbial quality by shriveling and siloing in both solar-powered CDS (444 minutes) or OSDS (583 minutes) during the day. However, in the CDS, the waste watermelons shriveled 24% faster than under direct sunlight. Nevertheless, in cases where waste watermelons are formed in large quantities, there is still a need for new studies with alternative approaches in order to be able to perform the wilting and silage work with a serial industrial system.

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