

Effect of Drying Method and Hydrothermal Treatment on Physicomechanical Properties of Parboiled Rice

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Abstract

Rice grain was obtained from milled paddy, in which the husk and bran are removed. During the milling process, rice varieties having inherent poor milling quality or those have been processed under unfavorable conditions, break and so their head rice yield (HRY) decrease. Parboiling is one of the hydrothermal postharvest treatment before drying and milling processes. After parboiling, the grains become stronger and breakage of rice is very much reduced during milling, leading to often a remarkable increase in the HRY. In this study the paddy was soaked in hot water (70 °C) for 1 h and drained, then steaming was done at four periods (0, 5, 10 and 15 minutes) at atmospheric pressure. Drying process was carried out using two driers techniques, solar and continuous, at three inlet air temperature to the chamber dryer of 35, 40 and 45°C. Results revealed that the effects of drying air temperature and steaming time showed a significant effect on HRY and broken kernels for Hashemi rough rice cultivar ($p < 0.05$) in continuous dryer. In both drying techniques the higher HRY performance was appeared at 35°C drying air temperature and 10 min steaming time. It was observed that dried kernels in continuous dryer were stronger (more bending strength) than those dried in the solar dryer and had a higher rate of HRY during subsequent processing operations. It was proved that increasing the steaming time to a safe level caused a reduction in broken kernels which was associated with higher HRY.

1. Introduction

Rice is one of the most important cereals in human nutrition, consumed by about 75% of the global population. Among the cereals, rice share equal importance as leading food sources for humankind. Rice is a staple food for nearly one-half of the world's population and provides 60% of the food intake in Southeast Asia (Muthayya et al., 2014). During the processing operation of rice, prevention of fractures in rice kernels is uncontrollable even with the care and precision in treatment in order to obtain the maximum HRY. It has been found that there is still a considerable breakage in milled rice for some varieties of paddy. In such cases the inherent poor milling quality is the main cause of breakage. Such a breakage may be eliminated by gelatinizing the starch which will fill the voids and cement the fissures and cracks (Ituen Ukpakha, 2011). According to the three-point bending test, the researchers concluded a significant relationship between the mechanical properties of paddy and HRY and also a strong relationship between HRY and the percentage of paddy rice that could withstand the certain breakage force (Wani et al., 2012). In order to determine the quality properties of rice grain, checking the starch varieties is important as one of the key parameters in determining of cooking quality (Wani et al., 2012). Endosperm of cereals is largely starch grains made of Gonal. The spaces between grains are filled with air and moisture. The seeds are so opaque appearance. During the seeds production, it may arise fractures or cracks in the grains (Danbaba et al., 2011). Parboiled rice is prepared from paddy processed with thermal energy and water before drying and milling process (Bhattacharya, 2011). In fact, the parboiled rice is nothing but rice precooked in paddy form and then dried back before being milled (Bhattacharya, 2011). Rice is included starch granules that are gelatinized during parboiling and open molecules of starch and protein fill the empty space between the grains in the endosperm. The color of

rice grain becomes fainter and more rigid mode which can reduce percent of the broken kernels of rice during processing due to prevent rice crunch (Agrawal et al., 2014). The hydrogel of starch is subjected to wet heat, which get a product having greater rigidity (Chun et al., 2015). As a result of gelatinized starch, several important physical changes occur in rice which play an important role in the next processing operations of rice. For example, it would be effective storage, milling, and cooking quality (Bhattacharya, 2011; Hu et al., 2017; Roy et al., 2011; Siriphollakul et al., 2015; Yu et al., 2017). Depending on the variety of rice, water temperature and duration of soaking, steaming time, temperature and pressure, drying time and temperature and other factors related to the rice parboiling, show different physical properties and so several quality. It takes the longer time to cook at the same temperature for parboiled rice than raw rice (no parboiling) at the same variety. As well as, the loss of protein and starch in the parboiled rice is less during cooking (Agrawal et al., 2014). Parboiling of paddy is carried out in three steps. Soaking, steaming and drying. In the soaking process void spaces in the hull and rice kernel are filled with water. Starch granules absorb water and swell causing an increasing in the volume of paddy. This makes the starch granules swell enough to gelatinization and those fill the empty spaces of kernel (Bello et al., 2015). Soaking in water is a result of molecular absorption, capillary absorption and hydration. At the beginning of soaking, the water enters into the grain due to capillary force and fills the spaces between the granules in the grain. Then, some water molecules absorbed by starch molecules enter into its molecular networks, and so remain as hydrated water (Mohsenin, 1996). Steaming process is done to enhance the moisture content of paddy. During steaming process, paddy is already soaked to be exposed to hot steam for a period of time (Ituen Ukpakha, 2011). Steaming is completed gelatinization of starch and it is the most important part of parboiling process. Steaming process depends on factors such as: steaming conditions, the pressure of the steam and steaming time (Bhattacharya, 1985; Yu et al., 2017). After two rounds, the rice becomes dry. Paddy must be harvested at high-moisture content, ranging from 20 to 28%. This high moisture content is conducive to rapid deterioration in quality such as discoloration, yellowing, germination and damage to milling quality. Drying method is a key factor affecting the milling quality of parboiled rice (Bhattacharya, 2011). Parboiled paddy may be dried in shade, sun or with hot air. Drying of high moisture paddy is important to prevent the grain quality deterioration. The conventional method for drying process as sun drying, is inadequate to guarantee the quality and quantity of the produce, so there is a high demand for mechanical drying facilities. Several methods have been used for drying of parboiled rice, such as sun drying, hot air drying, vacuum drying and superheated steam drying (Bhattacharya, 2011; Soponronnarit et al., 2006; Taechapairoj et al., 2004). Rice, including products that depending on the variety and relative humidity is picked with a humidity of 16 to 28 (% w.b.). The thermal drying systems was used for drying the product, especially in areas with high relative humidity. For this purpose, a warm air stream is passed in the bed in order to more quickly reach the desired level of humidity. In the drying, air transport is used to displace the evaporate moisture as well as the heat to evaporate the moisture content. In the continuous drying, breakage of kernels started in the humidity of approximately 18% and it increases with the gradual reduction of humidity. Therefore, it is recommended that this is done at about 20% moisture content (Bello et al., 2006). Drying, should be done as continuous and multistage and also includes a tempering step in the process. After that, seeds can be dried easily and with the lowest percentage of breakage. Many studies have been done in order to optimize the drying

and tempering conditions to reduce waste and improve the HRY during the conversion of rice (Aquerreta et al., 2007; Dong et al., 2010; Ghasemi et al., 2018; Siebenmorgen et al., 2004; Wang et al., 2017). Grain varieties those are long and thin were used more for parboiling, because of the amount of fragmentation on them, more than short or medium grain. In addition, some varieties of rice that are more likely crunch, are preferred (Bello et al., 2006). The aim of this study was to investigate the effects of drying methods and steaming time on some physical and mechanical properties such as HRY, crack percentage and breakage resistance in parboiled rice of long grain of Hashemi variety which dried by two drying methods of mixed- mode solar dryer and continuous dryer.

2. Materials And Methods

2.1 Material

A local variety of long rice paddy, Hashemi, abundantly grown in agricultural farms of Bandar-Anzali, Iran with an initial moisture content of about 28 ± 1 (% w.b.) was used. During transport and storage process, the grains were kept in the seal plastic bag and all samples were stored at 4 ± 1 °C in a refrigerator until the experiments were carried out.

2.2 Moisture Content Determination

Grains were then cleaned, weighed and dried in an oven at 105 ± 1 °C for 24 h and the loss in weight was reported as moisture content dry basis (Sun et al., 2014). Before starting the experiment, paddy samples were taken out and layered on a plain surface and left at room temperature for 12 h to reach thermal equilibrium (Obi et al., 2016). The samples were finally conditioned at a moisture content as low as $11.5 \pm 1\%$ w.b. then stored at ambient conditions in vacuum sealed plastic bags for at least 48 h before any measurement. The moisture content of the sample was determined at the beginning and end of each set of experiments.

2.3 Sample Preparation

2.3.1 Parboiling Process

Parboiling process on rice grains was performed in three stages: soaking, steaming and drying.

2.3.1.1 Soaking

The absorption of water by nutrients normally regarded as the soaking is done based on the diffusion mechanism. As a result of the absorption of moisture, rough rice is swelled. This process continues until the balance is established between the amount of water absorbed by the grains and that water vapor exists in the space among grains granules (Mohsenin, 1996). Paddy rice with initial moisture content of $11.5 \pm 1\%$ w.b. was soaked in hot water at temperature of 70 °C for 1 h for all the different treatments. Then, the samples were taken out and drained over a mesh for eliminating the superficial water. Soaked rice was tempered for 2 h to penetrate the water in rice and weighted. Soaking rice for a period of time

less than 1 h and longer than 2 h can cause to reduce the HRY and white belly in grains, respectively (Soponronnarit et al., 2006). The moisture content after soaking was approximately $29.5 \pm 1\%$ w.b.

2.3.1.2 Steaming

Steaming was conducted at atmospheric pressure after soaking the drained grains. The steaming method of open steaming (without pressure) in a laboratory cooking chamber was considered. Soaked rice is placed in a special perforated plates for thin layer (layer thickness of 2.5 cm), were exposed to uniformly saturate steam from all directions. Four steaming duration treatments, zero (soaking without steaming), 5, 10 and 15 min were applied. Steaming used to complete gelatinization, doesn't reduce the moisture content of grain by increasing the amount of moisture available in the form of compressed vapor. During steaming, spread of water-soluble material in the grain is continued and increased since soaking time was began (Bello et al., 2006).

2.3.1.3 Drying Process

In each method of drying, changes take place during the drying process. These properties vary during drying due to moisture removal, structural shrinkage and internal collapse. Previous studies have shown that several factors have a decisive role in the performance of drying grain and output variables. The most important of these factors include: deep bed of rice (d.b.), ambient air temperature (T_a), relative humidity of the ambient air ($R.H_a$), the inlet air temperature to the dryer chamber (T_{in}), the initial moisture content of grain ($M.C_{in}$), the final moisture content of grain ($M.C_f$) and air velocity (V_{in}) (Allameh Alizadeh, 2013; Grigg Siebenmorgen, 2015; Kumar et al., 2017). Performance of the dryers in two terms of inlet air temperature to dryer and drying method (under constant other conditions such as air velocity and bed depth which were identical in both type dryer) were evaluated to examine the effects of drying on the properties of parboiled rice. After steaming, the rice samples were transferred to the laboratory dryers. Two methods of solar and continues drying were used to carry out all experiments. The rice samples were dried at inlet air temperatures to the dryer chamber of 35, 40 and 45 °C using two-stage drying with intermediate tempering in both drying method.

2.3.1.3.1 Solar Dryer System

A mixed mode passive solar dryer was employed. In this pilot solar dryer, hot air is provided by natural convection through an air solar collector. The drying section of experimental dryer was a chamber, with a tray capacity of 2.8 kg paddy in batch. In order to create uniform conditions during the drying, the rice grains was used as thin layer drying (bed height of 2.5 cm) (Nassiri Etesami, 2016). Seed bed consists of a metal mesh that is flat to the horizon and perpendicular to the flow of hot air blown. This dryer also includes a flat solar collector to get hot air. The dimensions of the solar collector were $55 \times 150 \text{ cm}^2$ (Fig. 1). One of the most important parameters affecting the efficiency of a solar collector is angle relative to the horizon. It is positioned to south with angle of 45 degrees which is the most suitable for the conditions of solar irradiation in Shiraz, Iran. Inlet air to the dryer was provided by an air blower (Type Vn-25), for drying of samples. The samples are dried in a bed exposed to direct sunlight and hot air blown

from the blower at the same time. The utilization of solar energy and hot air (which indirectly used the sun's energy to heat) will be greatly saved energy and reduced drying time. Changes in the temperature of the inlet air to the dryer were done with the ability to change the level of the absorber plate that was placed in the sun (reduction the temperature by covering part of the absorber and an increasing at temperature by removing the cover).

2.3.1.3.2 Continuous Method

Continues dryer consists of a centrifugal fan to supply the necessary air blown for drying with hot air. Intake air from the blower after passing through an electric heater with an electronic proportional controller (thermostat) that regulates the temperature, was blown on the bed which was placed on the main chassis with a slope of 45 degrees to the horizontal. The air was blown through a vertical duct at the end of which the sample holder was placed. Continuity of seedbed was provided by output rotary valve driven by a 5 W engine (Model AL–KIA). The valve includes a product mass flow controller hub that was formed of a teflon cylinder with 8 plastic blade around it. Hub blades were perpendicular to the direction of flow. The motor was mounted on the main chassis, drive the hub with a steady pace (1.8 rpm) as counter clockwise and make the product out of the steep bed of dryer (Fig. 2). In each treatment, 280 g of samples were used. For thin layer drying process, two metal mesh were used from both above and below the product flow with a distance of 2.5 cm to control the bed height. While samples were crossing the space between the two mesh, exposed to hot air blown from vent underneath in the direction perpendicular to the product flow and were dried slowly. The difference in weight of samples before and after running a pass was regularly recorded.

2.3.2 Tempering

In the drying process, removal of paddy moisture content is done from external surfaces. It occurs a difference between internal and external humidity levels so that the outer surface of grain has a lower moisture content than the inner levels. Such differences at temperature and humidity levels between the different parts of a grain rice cause the gradient in moisture content and temperature within the rice. This is ultimately lead to the formation of differential stress (Ghasemi et al., 2018). Today, in the rice production industry (especially parboiled rice) used a multi-stage drying method to reduce moisture content of grains to suitable levels for storage and conversion operations (Nasrnia et al., 2012). In the first stage, samples were dried until the moisture content reached to $18-20 \pm 1\%$ w.b. and the dried samples were then tempered to ambient temperature. For tempering tests, the grains were placed in small plastic containers and sealed to prevent moisture loss. Then, by applying a drying process, the second stage was completed until the grain final moisture content was reached to $11.5 \pm 1\%$ w.b. The tempering time for each treatment was considered 7 times the amount of drying time in the first stage (Aquerreta et al., 2007). Finally, after drying process the samples were kept in the sealed plastic bag before their qualities were investigated.

2.3.3 Dehusking and Polishing

After drying, samples were stored for one week at room temperature before all physical and mechanical properties of raw and parboiled paddy were determined. The dried paddy rice was then dehusked in a testing rubber roll huller (Satake THU-35A, Japan). Raw and Parboiled dehusked rice was weighed and followed by milling. 10 g of the brown rice were milled for 30 seconds to yield white rice (polished) by using a laboratory polisher (Kett, Japan). The dehusked kernels were graded and then separated in two fractions using a grain sorter: a whole fraction and a broken one. A kernel is considered broken if its length is smaller than 75% of a whole kernel (Yu et al., 2017).

2.4 Physical and Mechanical Properties

2.4.1 Breakage Ratio and Crack Percentage

The percentages of dehusked and broken kernels were estimated by hand-sorting of broken kernels. This procedure was applied for measuring the breakage ratio of 50 g parboiled rice samples. A kernel being 75% or more intact was considered as whole kernel (Buggenhout et al., 2014). Crack percentage of kernels was estimated using a device to observe cracks of 50 dehusked rice grains which are randomly selected from samples hand-sorting of whole. The device contains a fluorescent lamp that was placed under a page grid. When the light to be emitted grains on grid, the number of cracked grains was identified and recorded.

2.4.2 Breakage Resistance

According to research on the mechanical properties, bending and tensile strength are criterion for measuring the performance of rice (Sarker et al., 2017). On the other hand, due to difficulty of tensile strength tests for rice, the best option for testing is bending test (Abdollahzadeh *et al.*, 2017; Pruengam et al., 2016). The Instron device (STM-20 SANTAM, Iran) was used for three-point bending test. In order to measure the rice breakage resistance in bending, 100 g of raw and parboiled dehusked rice grains were randomly selected and loaded by Instron jaw blades with loading speed of 10 mm/s (Fig. 3). Recording of the data was performed by software installed on the computer connected to the machine. The maximum breakage resistance due to force-deformation diagram displayed on a computer screen, was determined. The bending stress was then calculated as follows (Siebenmorgen et al., 2004):

$$\sigma = F.L.C / 4.I (1)$$

Where, σ is bending stress (N/m²l), F is maximum bending force (N), L is distance between supports (m), C is distance of neutral axis of the outer layer of grain that is half the thickness of the seed (m) and I is moment of inertia (m⁴).

2.4.3 Head Rice Yield (HRV)

Head rice yield is an estimate of the quantity of head rice which can be produced from a unit of paddy. The head rice yield was calculated with respect to the paddy weight and it was expressed as a percentage. The result is expressed in terms of rice processing yield, which is the ratio of the weight of

white (husked) kernels to the total weight and in terms of head rice yield, which is the ratio of the weight of whole kernels to the total weight of white rice (Purhagen et al., 2018). After dehusking and polishing process the samples were placed into sealed polyethylene bags to prevent further moisture loss.

2.5 Statistical Analysis

Analysis of variance (ANOVA) was carried out to detect the differences of three dependent variables of breakage ratio, breakage resistance and HRY in raw and parboiled rice. Independent variables were considered as drying method, inlet air temperature to the dryer chamber and steaming time. Significant differences between means by Duncan's multiple range test at a significance level of 0.05 ($p < 0.05$) were performed using SPSS 18. Experiments were conducted on 100 kernels for each combination of independent variables. All the experiments were carried out in triplicate and mean values were reported.

3. Results And Discussion

3.1 Drying process

It was showed that by increasing in time, the moisture contents decreased for different treatments of steaming time and control at the inlet air temperature to the dryer chamber of 35 °C in the continuous dryer (Fig. 4) and mixed mode passive solar dryer (Fig. 5). This duration was determined by intermittent sampling of the paddy and oven dry measuring of the moisture content. The control treatment had more time for loss the moisture content. During drying of most agricultural products, initial moisture is quickly removed, then is followed by progressively slower drying rates (Perrot et al., 2007).

It clearly shows that drying rate, which is slope of the drying curve, becomes smaller with progress of drying. Such drying is referred as falling rate drying. The results showed that in all different inlet air temperature to the dryer chamber, by increasing the steaming time of zero (just soaking and no steaming) to 10 min, the slope of the drying curve increased and the drying rate was associated with an increasing trend in both continuous and solar dryer. But at steaming time of 15 min, the slope of the curve suddenly fell.

It seems that the effect of increased steaming time on the uniform distribution of interstitial water among the starch granules after soaking and gelatinization processes, accelerates the evaporation of moisture from the grain texture. In fact, the dependence of the drying rate and duration of steaming can be attributed to the Bakker's moisture diffusion model (Yousaf et al., 2018). But strange behavior change of curve at steaming time of 15 min, can be linked to sudden decay texture of grain. In this diagrams, the flat horizontal line between the two stage of drying curves is known as tempering period. Tempering can cause thermal and moisture balance between surface and texture of the grains and thus largely prevents the creation of bending stress (Aquerreta et al., 2007). Tempering time is dependent on the duration of the first period of drying, so with increasing of steaming time, as well as decreasing of drying time in the first round, tempering time was reduced.

A comparison of moisture sorption rate versus time, at different inlet air temperatures to the dryer chamber of 35, 40 and 45 °C was also performed (Fig. 6). Drying process is shown in circumstances that paddy after 5 min of steaming were dried in the continuous dryer. The results showed that the slope was increased with increasing temperature and drying process at each stage of drying and tempering, was done in less time. High potential of grain for moisture disposal at higher temperatures lead to reduce drying time. Variation of moisture content changes versus time were showed in both continuous and mixed mode passive solar dryer in the same conditions of the steaming time of 10 min and the inlet air temperature to the dryer chamber of 35 °C (Fig. 7).

It was observed that the process of drying in both stages (before and after tempering) in the continuous dryer compared to solar dryer was significantly done in less time. This may be the result of short-term tempering effect, occurring at each pass of dryer, on paddy grains in this way. Tempering increases HRV and provides the possibility of drying the product more because of drying in a continuous method, all product at the same time is not aerated but some of the product, moving through the dryer, is aerated and the rest is tempered (Nassiri Etesami, 2011). Another reason for the increased rate of drying can be attributed to the crop rotation on continuous bed of this dryer. In addition to their local movement, orbital motion of the grains on the seedbed, increases their chances to aerate from all directions. Continuous bed provides the possibility of accelerating the drying rate to fixed bed in solar dry.

3.2 Physical and Mechanical Properties

3.2.1 Breakage Ratio and Crack Percentage

The physicochemical properties of raw and parboiled rice varieties were analyzed. Results showed that all effects of main factors as well as the interactions between of drying method and inlet air temperatures to the chamber on the percentage of broken kernels of parboiled rice in both dryers, were significant ($P < 0.05$). Variation of percentage of cracked kernels (Fig. 8) and breakage ratio (Fig. 9) showed for two types of solar and continuous dryers in terms of the inlet air temperature to the dryer. It was observed a direct correlation between breakage ratio and percentage of cracked kernels with inlet air temperature to the dryer. By reducing at the inlet air temperature, both of them decreased favorably. High drying temperature facilitated faster moisture removal that caused a relatively steep moisture gradient inside the kernel, inducing high residual stress that narrowed the difference of strength. Also, lower ultimate strength could cause cracks and fractures in the kernels during milling. When the rice is placed under high temperature, cracking occurs inside of the kernel and extends vertically along the axis of the rice grain. It also seems that the rapid transfer of moisture from the core of kernels and the effect of temperature on the grain, will cause a high stress and breakage in the grain (Odek et al., 2017; Srisang et al., 2016). In fact, cracking in the grains occurs by creation of stress. By increasing the drying temperature, stress caused by changes in grain moisture exceeds of its tensile strength (Chung et al., 2012). If the surface moisture decreases rapidly due to the rapid transfer of water from the inner parts of the grain to the surface, the outer layer is wrinkled and shrunk. The usage of high temperature for drying operation causes internal pressure (Billiris et al., 2016).

In addition, the results of the comparison of drying method showed that continuous drying method compared to solar drying significantly improved both of the breakage ratio and percentage of cracked kernels. In the fixed-bed seed like the one that exists in the solar dryer, distribution of rice in depth is not uniform. As the grain layer height in the seedbed increases, the difference in moisture content in different layers will be more and different levels of moisture content occur (Abasi Minaei, 2014). Excretion or absorption of moisture at different depths are not the same. Most of the moisture content in the grain can be seen in the lower layers of seedbed (Atungulu et al., 2018). Most of breakage occurs in seeds are placed in the floor of the seed bed and the lowest observed in the surface. It could be because of the more thermal stress caused in the grains of paddy near the bottom of the seedbed due to longer contact with hot air and accelerate the excretion of moisture in the lower layers and so it increases the chance of cracking in this grains (Firouzi Alizadeh, 2013; Ondier et al., 2012). But since in the continues method the grains were more evenly heated, so moisture is more uniform removed from the grain and so opportunity of Grain to reduce the moisture and thermal gradient was more and thus adverse effects of internal stress on the percentage of cracked kernels and breakage ratio, was reduced.

The results showed that the main and interaction effects of steaming time and drying method on percentage of broken kernels were significant. In Fig. 10, it can be seen that with increasing duration of steam from zero (Soaking and no steaming) to 15 minutes percentage of cracked kernels regularly declined. This reduction in cracks happens because during steaming, spread of water-soluble rice in the paddy that was started at soaking time, continues and Granular endosperm tissue during gelatinization takes viscous state and prevents cracks in next operation of rice processing (Bello et al., 2006). But can be seen in Fig. 11 that Steaming period of 15 minutes, the breakage ratio suddenly reduced. This sudden change in behavior can be attributed to destructive effect on the grain texture. Because with the increase of steam duration more than 10 minutes, starch structure of grain will decay and it is created small cracks in grain that is not visible by the device used in this experiment to see cracks.

3.2.2 Breakage Resistance

Analysis of variance showed a statistical significant difference between the means of Breakage Resistance with respect to the inlet air temperature to dryer and drying method ($p < 0.05$).

Figure 12 shows that by increasing the drying temperature resistance decreased rice and the higher breakage strength was in the inlet air temperature of 35 °C. In other words, inlet air temperature had a negative impact on rice grain yield point while according to Fig. 13, increasing steaming time as much as 10 minutes on breakage resistance had a positive impact. Then with increasing duration of steam up to 15 minutes, breakage resistance suddenly felt. Results showed that all main effects and interaction of steaming time and drying method on breakage resistance was significant ($p < 0.05$).

The reason for this fall of the breakage resistance in the duration of 15 minutes steam can be attributed to the adverse impact of excessive steaming time on the internal structure of parboiled rice. In this case it seems that excessive gelatinization of rice suddenly eroded the Granular tissue adhesion of endosperm. However, in period of steaming of 15 min was observed higher breakage strength in the grain compared

to zero minutes (soaking and no steaming). Increase steaming time must be applied in accordance with the major characteristics of the desired final product. In accordance with the results of previous research, it was found that the percentage of cracked grain in a sample is inversely proportional to the measured breakage strength so as to increase the percentage of cracks in a sample, breakage resistance force is reduced. The investigation revealed that increasing the steaming time and reduction in the drying temperature due to lower moisture and thermal stress applied to the samples during the drying process, increase the breakage resistance of rice (Aquerreta et al., 2007). Comparison between two different methods of drying in Figs. 12 and 13 indicates that a more breakage resistance for samples dried in continues system in all the treatments. One reason is that the mechanical properties of the grain were affected by weakened tissue of grain which was exposed to direct sunlight. Another reason is justified due to the uniform heating of samples dried in the continuous dryer which causes frequent temperature and moisture balance in the grains and thereby accelerating the drying process.

3.2.3 Head Rice Yield (HRY)

It was observed from the split plot analyses of variance for the HRY data were significantly ($P < 0.05$) affected by the main effects of inlet air temperature to dryer and drying method. The correlations (Fig. 14) of HRY between the inlet air temperatures to dryer showed a negative significant correlation. Reported that a lower temperature could result in a higher Head Rice Yield.

As previously mentioned, in accordance with the results of the research, the breakage ratio in a sample is inversely related with the HRY and so with the increase in the broken kernels, Head Rice Yield will be reduced.

Comparison of treatment means presented in Fig. 15 indicates that the HRY difference with respect to steaming time in both the solar and continues drying methods were significant ($p < 0.05$). It was found that increase in the steaming time to safe level (10 min) resulted in an increased HRY. But a decrease of head yield was observed for long steaming periods of 15 min or above. This fact shows that is recommended to limit steaming time for both drying methods. Figure 15 also shows that the HRY values were always greater in continues drying method than in Solar drying method ($P < 0.05$).

4. Conclusions

This study has focused on the effect of different method of drying and different hydrothermal processing treatments on the physical and mechanical properties of the parboiled rice. The results showed that all the effects of drying method, the inlet air temperature to chamber dryer and steam duration on the breakage resistance, percentage of cracked kernels, breakage ratio and HRY was significant ($P < 0.05$). In both of drying method The HRY efficiency and the lowest percentage of cracks was observed in the rice grains that after soaking steamed for 10 minutes and dried at 35 °C. Severe hydrothermal processing (steaming periods of 15 min or above) causes thermal degradation of starch. In general it can be said that the increase in inlet air temperature to dryer has a negative effect on rice yield, while steaming time, had a desired effect on the HRY and Rice yield point. Drying rice by using a continues dryer system

resulted in reasonable head rice yield, breakage resistance, breakage ratio and percentage of cracked kernels in comparison with that obtained when using solar drying.

Declarations

- **Ethics approval and consent to participate**

Not applicable.

- **Consent for publication**

Not applicable.

- **Availability of data and material**

The data supporting findings can be found.

- **Competing interests**

The authors don't have competing interests.

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- **Authors' contributions**

Mandana Mahfeli: Research, Writing.

Aliasghar Zomorodian: Cooperation and data evaluation.

Mohammad Zarein: Writing, Evaluation, Analysis.

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Figures

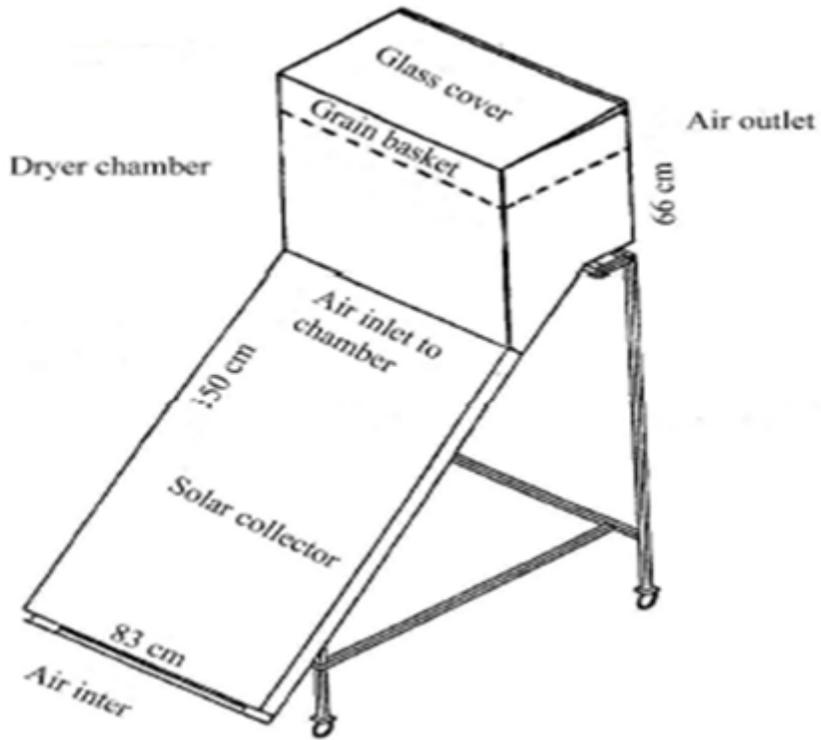


Figure 1

Schematic of mixed mode passive solar dryer

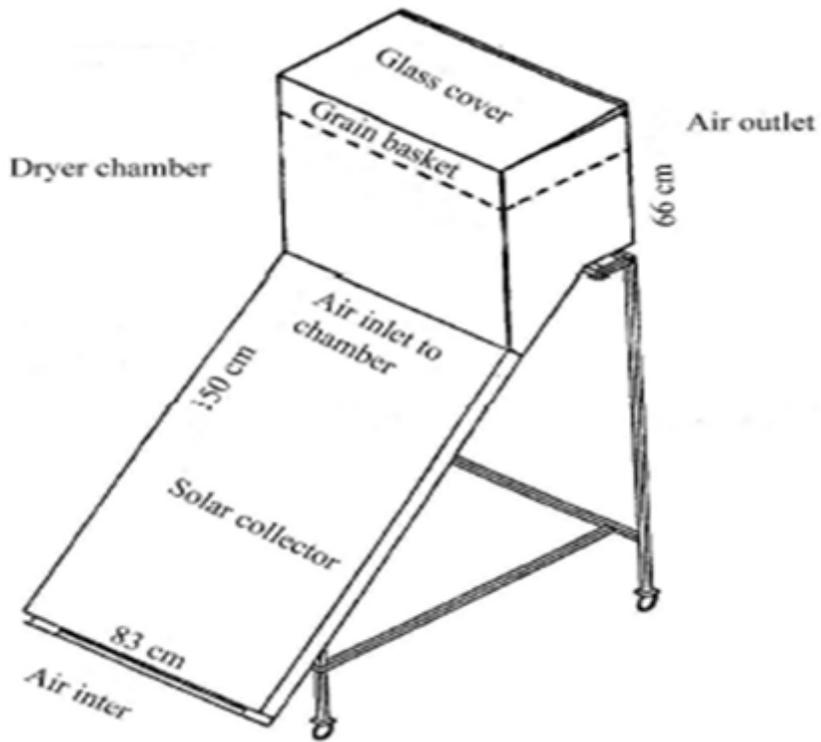


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Schematic of mixed mode passive solar dryer

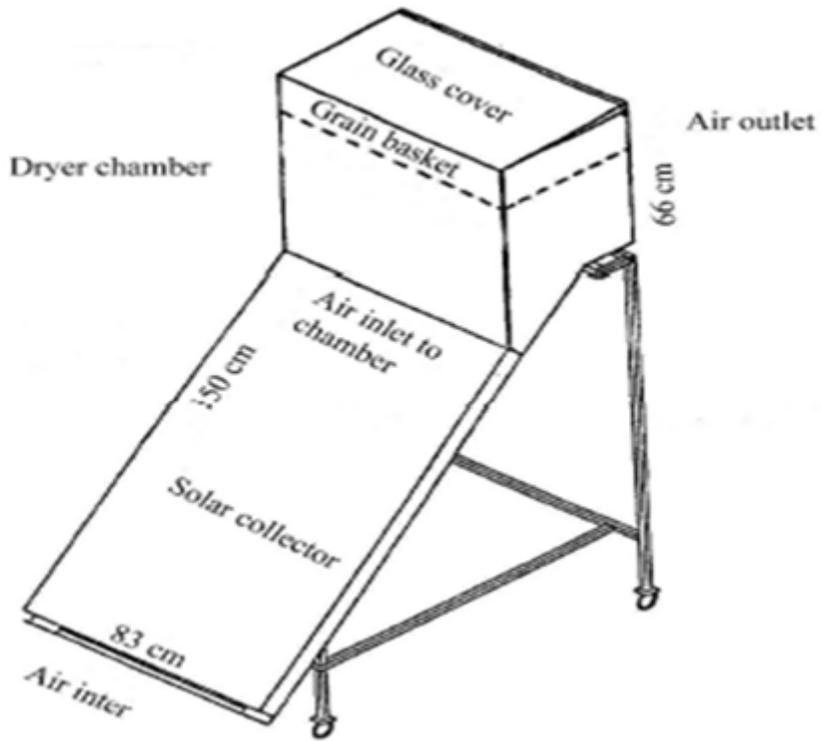


Figure 1

Schematic of mixed mode passive solar dryer

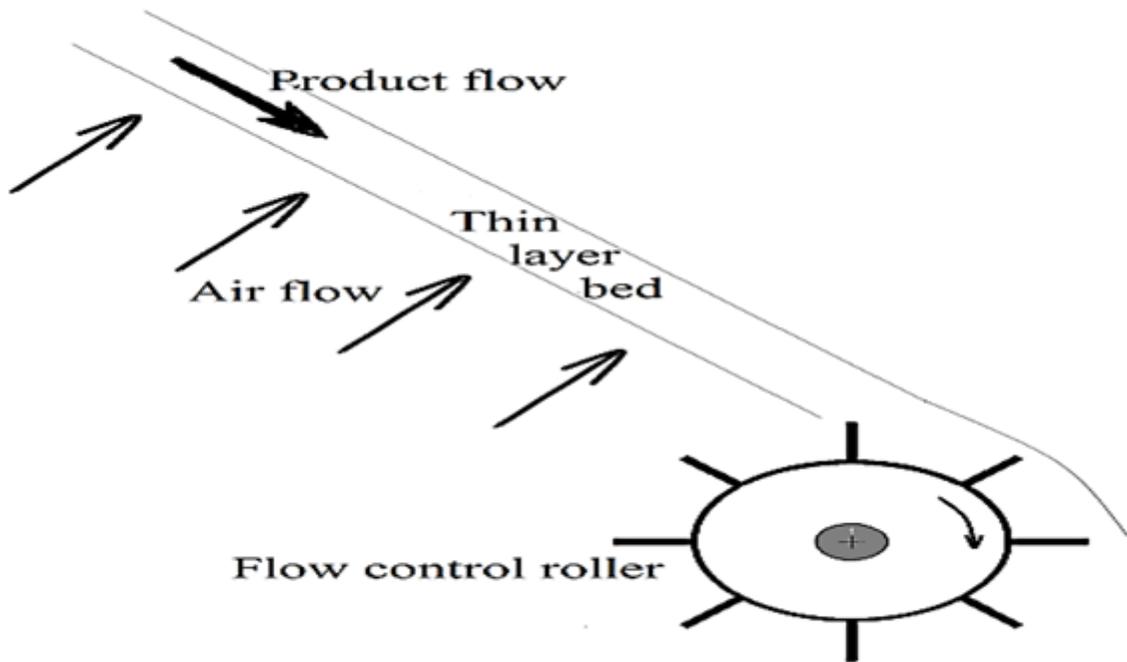


Figure 2

Schematic of air flow, product flow and seed bed in continuous dryer

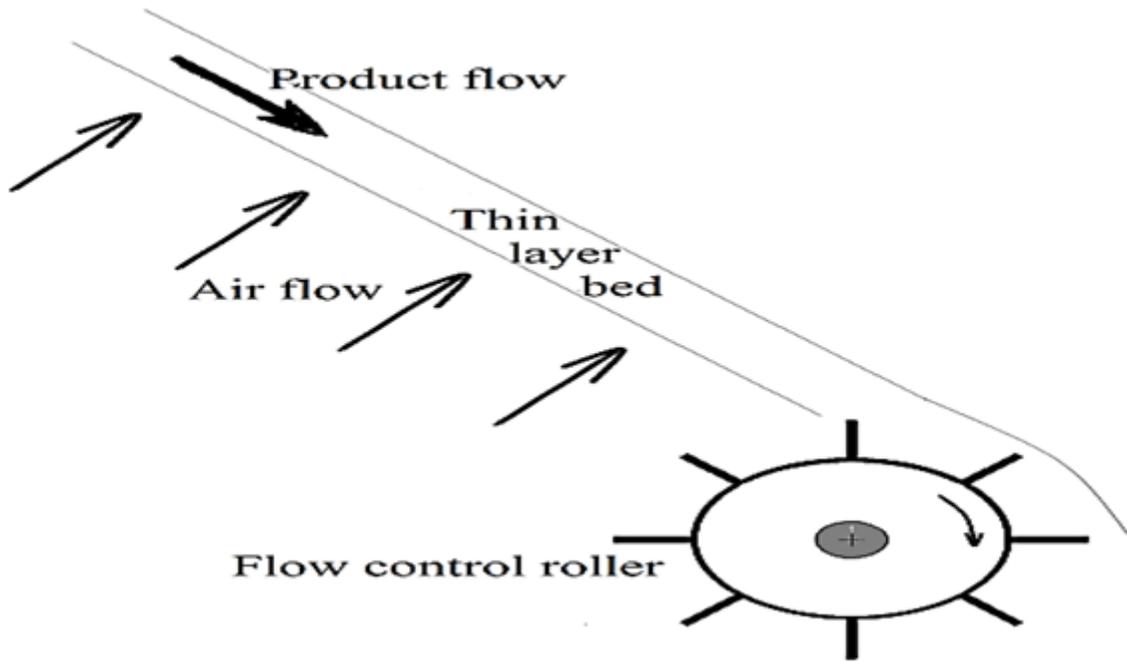


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Schematic of air flow, product flow and seed bed in continuous dryer

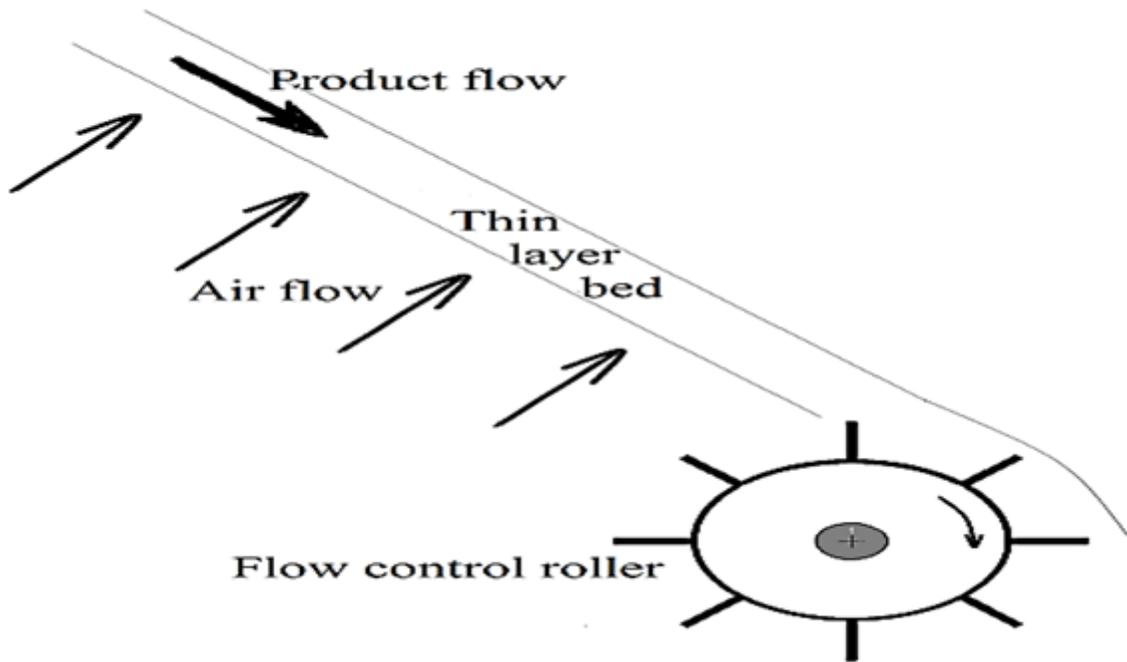


Figure 2

Schematic of air flow, product flow and seed bed in continuous dryer



Figure 3

Instron machine to measure the breakage resistance of rice in three-point bending test



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Instron machine to measure the breakage resistance of rice in three-point bending test



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Instron machine to measure the breakage resistance of rice in three-point bending test

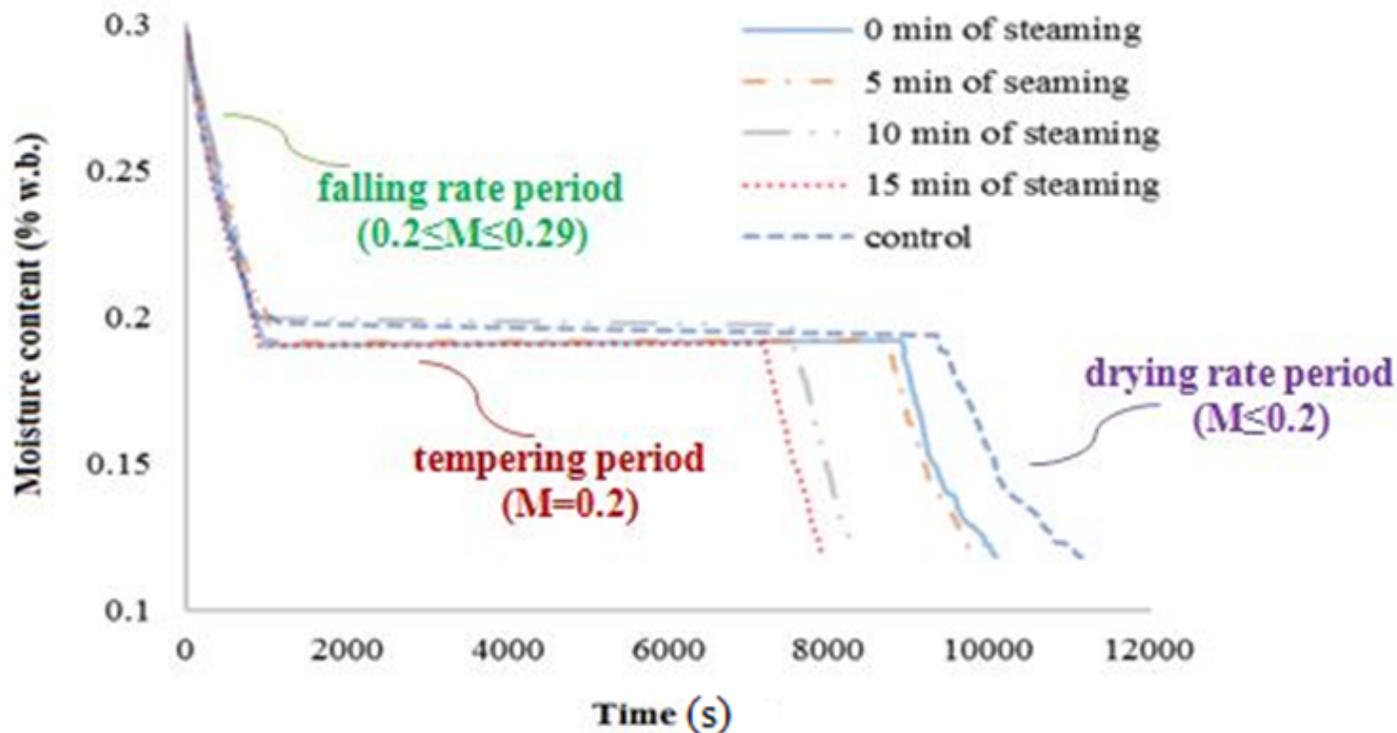


Figure 4

Variation of moisture content in the continuous dryer at temperature of 35 °C

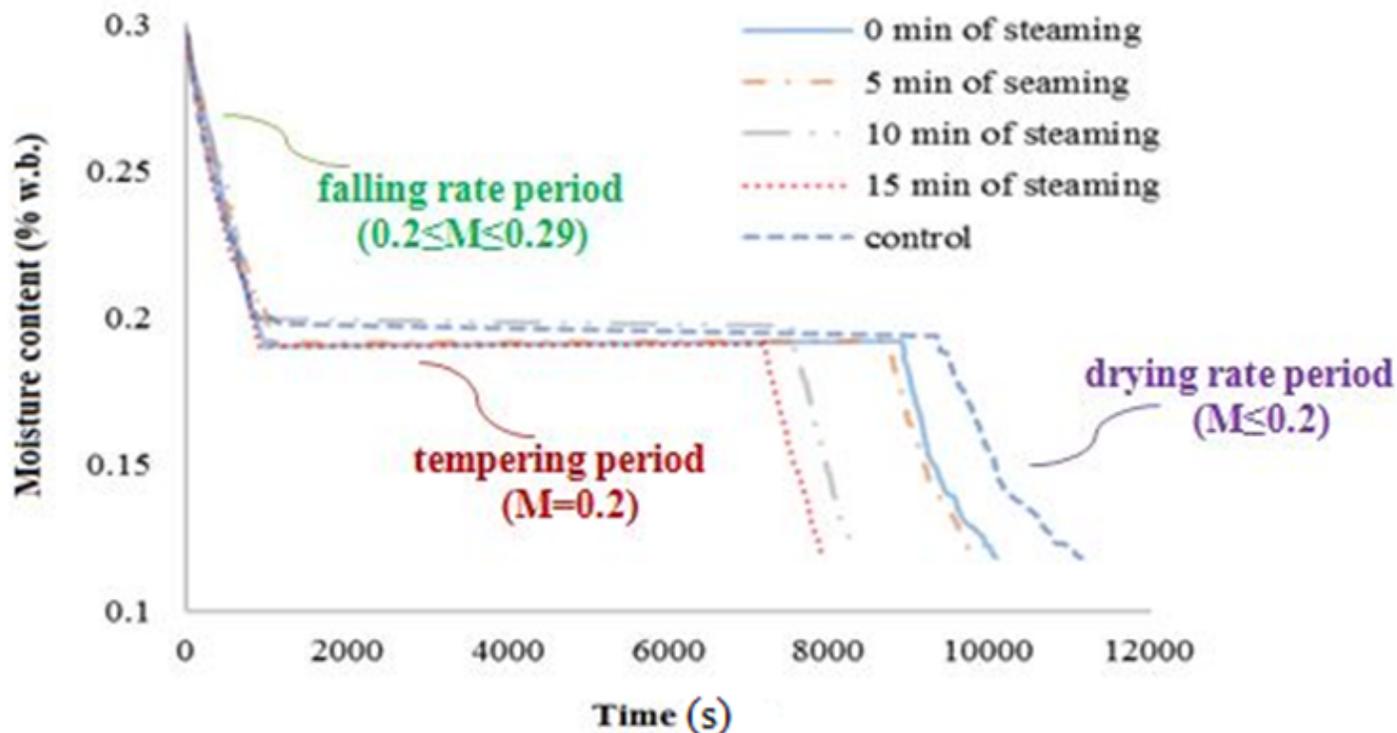


Figure 4

Variation of moisture content in the continuous dryer at temperature of 35 °C

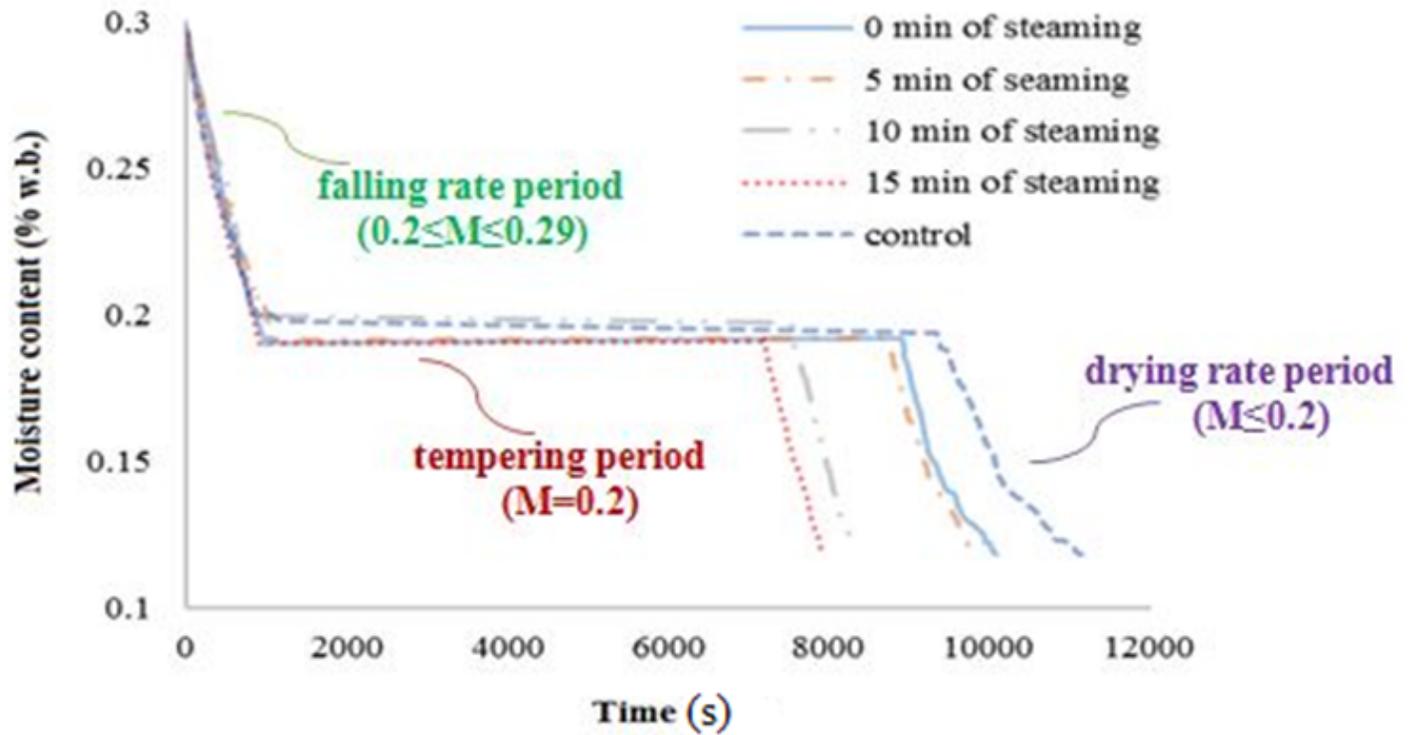


Figure 4

Variation of moisture content in the continuous dryer at temperature of 35 °C

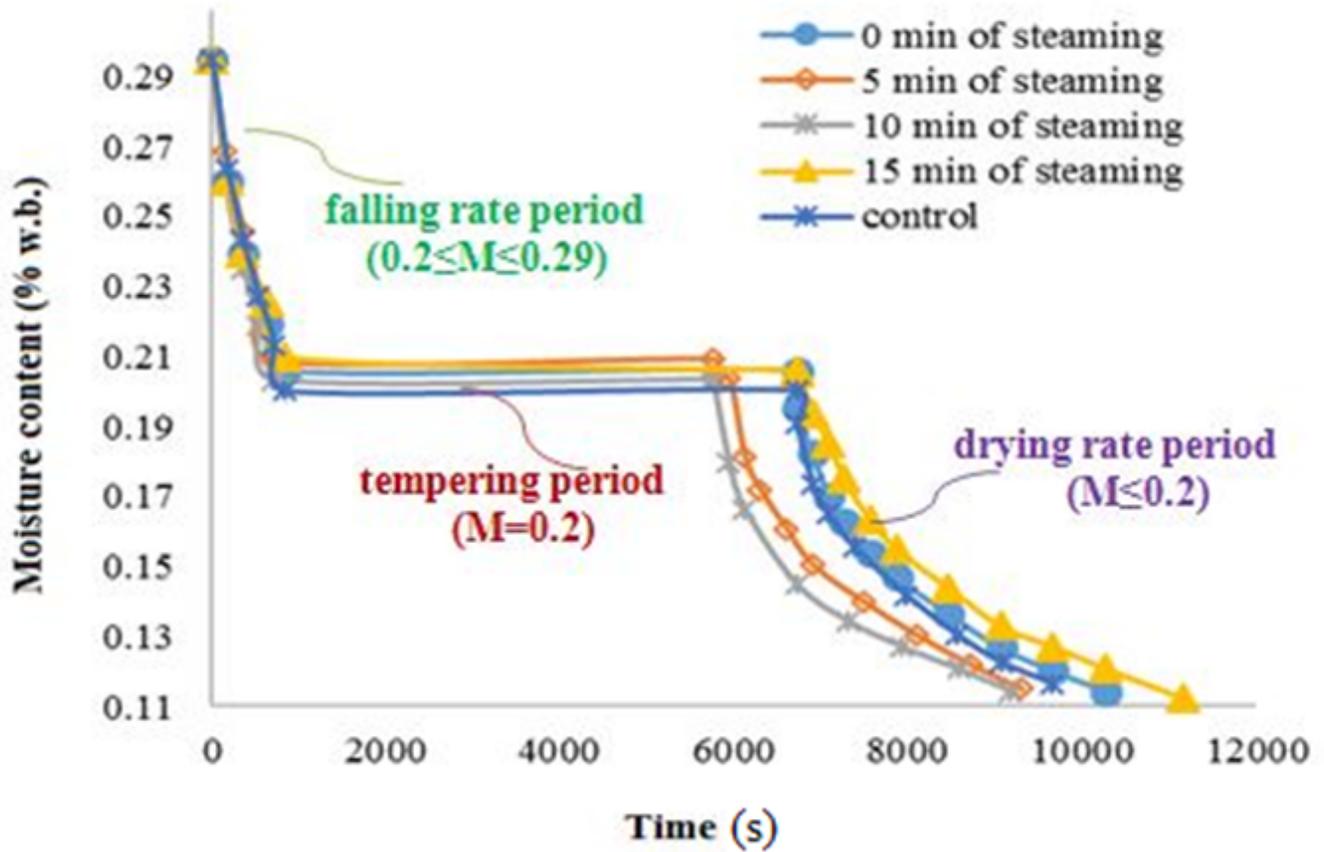


Figure 5

Variation of moisture content in the mixed mode solar dryer at temperature 35 °C

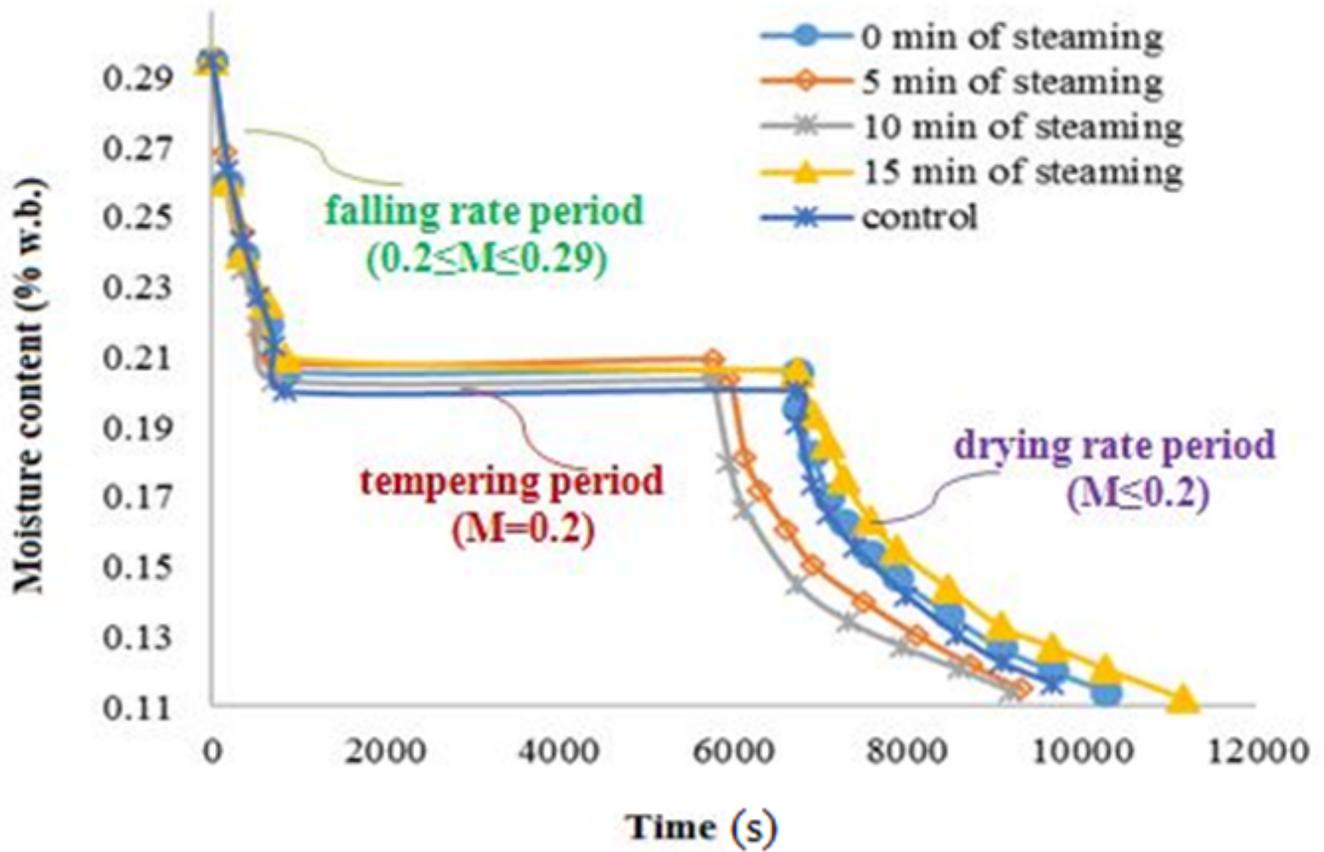


Figure 5

Variation of moisture content in the mixed mode solar dryer at temperature 35 °C

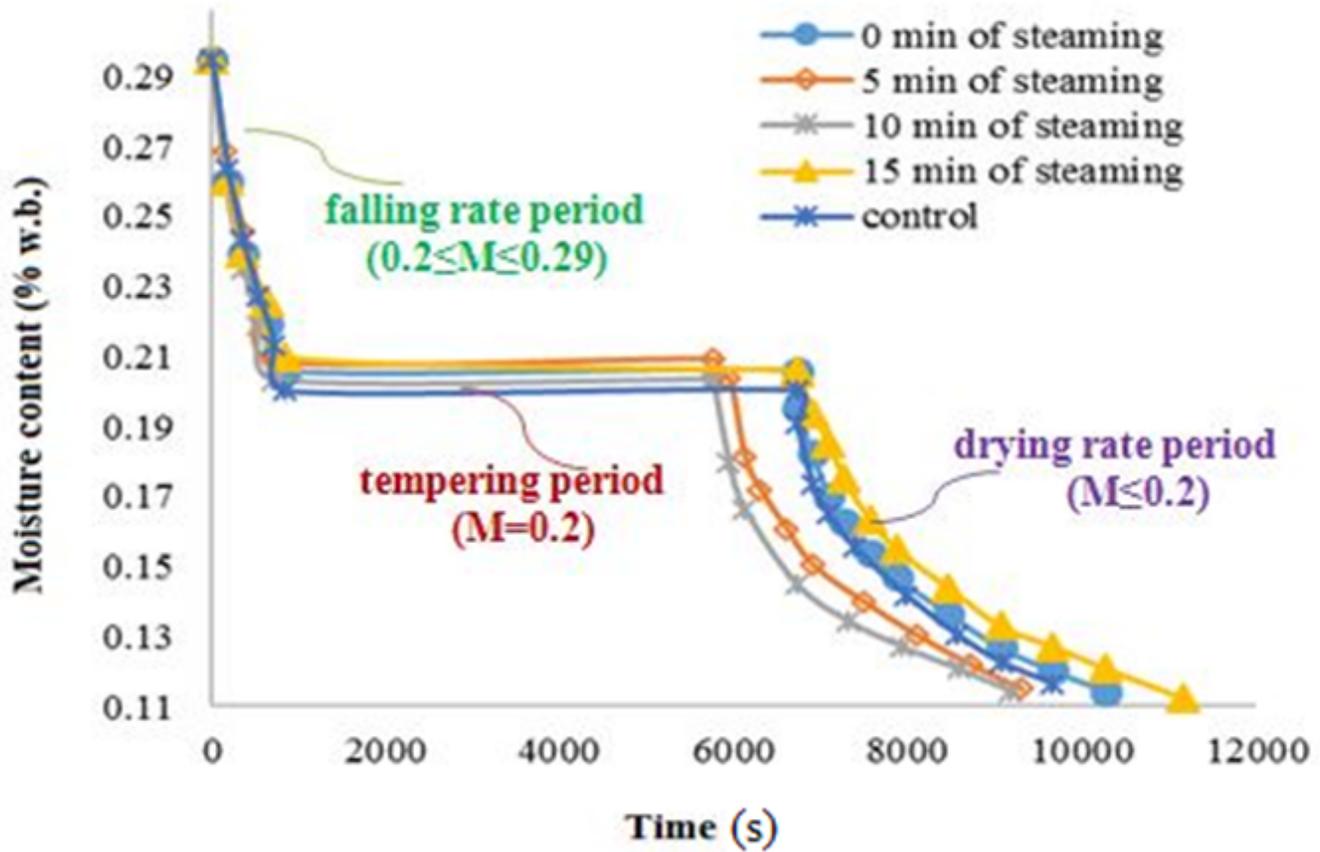


Figure 5

Variation of moisture content in the mixed mode solar dryer at temperature 35 °C

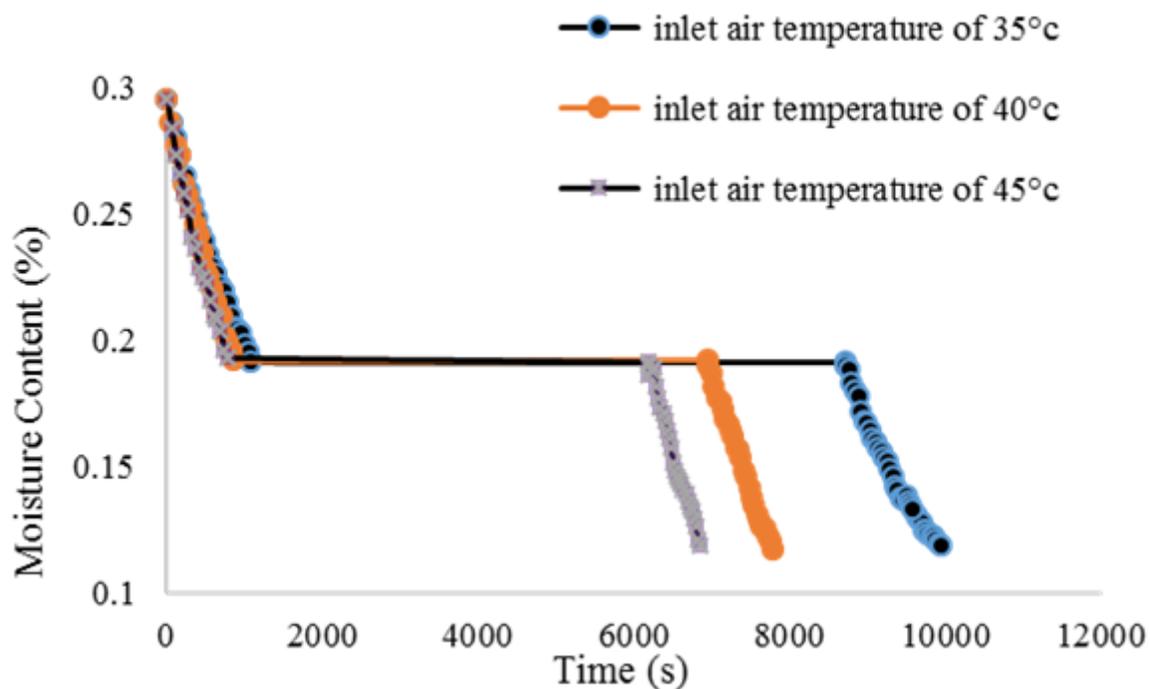


Figure 6

Variation of moisture content at different temperatures in the continuous dryer

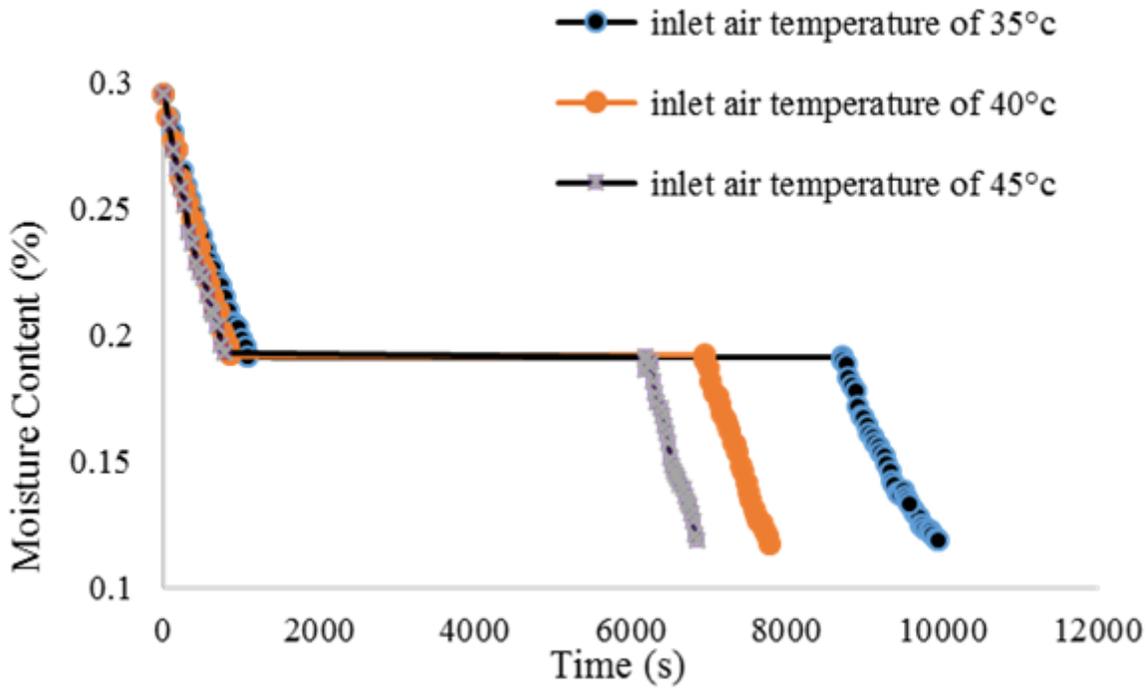


Figure 6

Variation of moisture content at different temperatures in the continuous dryer

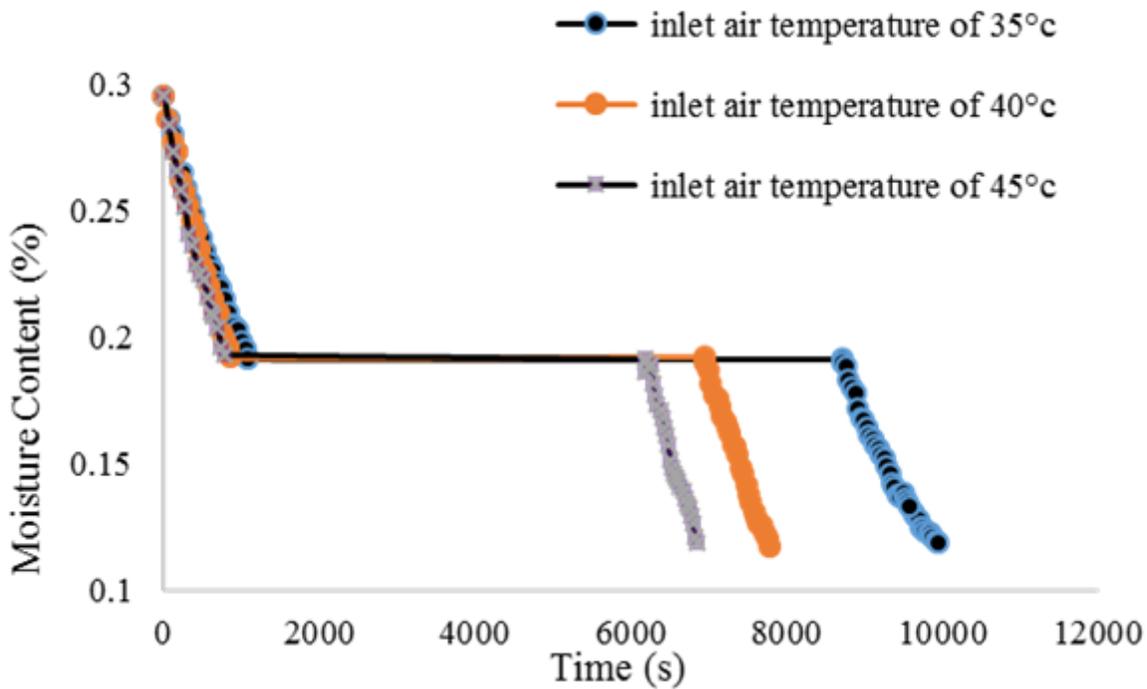


Figure 6

Variation of moisture content at different temperatures in the continuous dryer

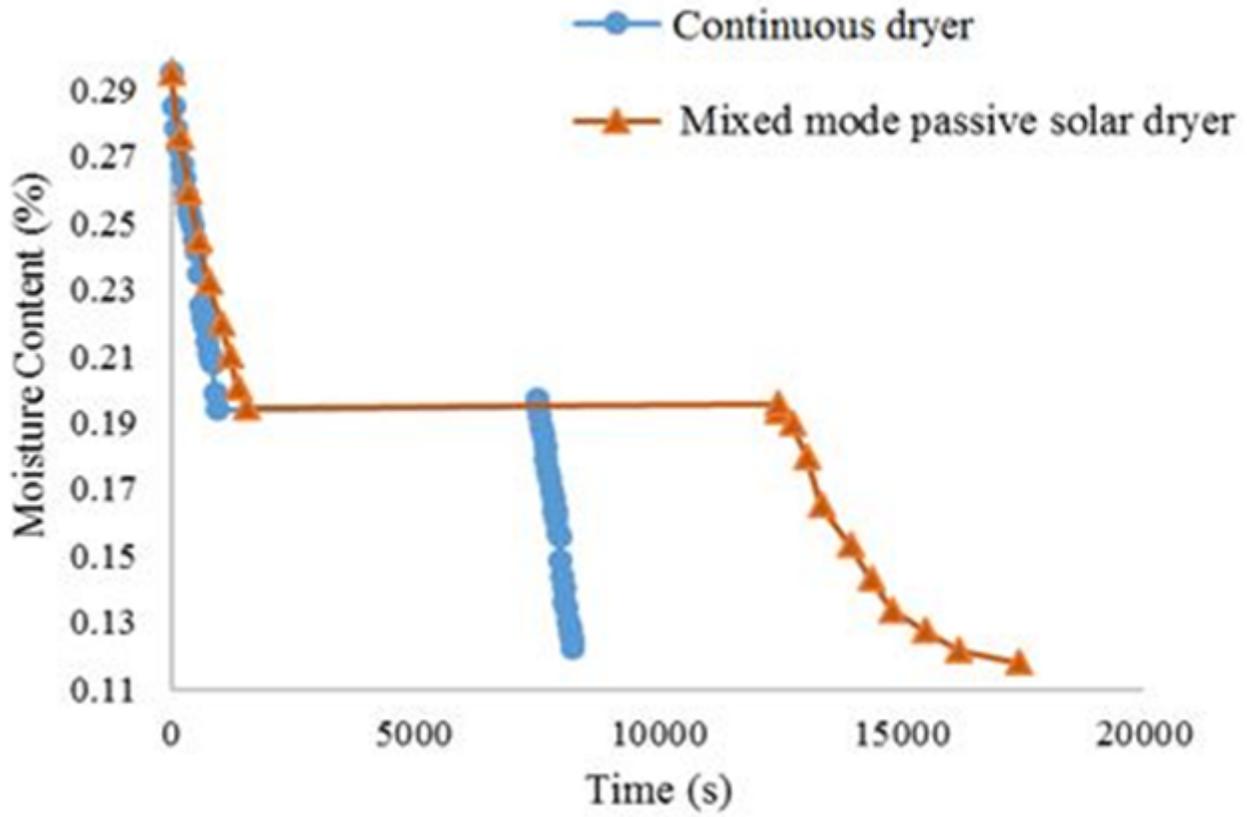


Figure 7

Variation of moisture content in two drying methods

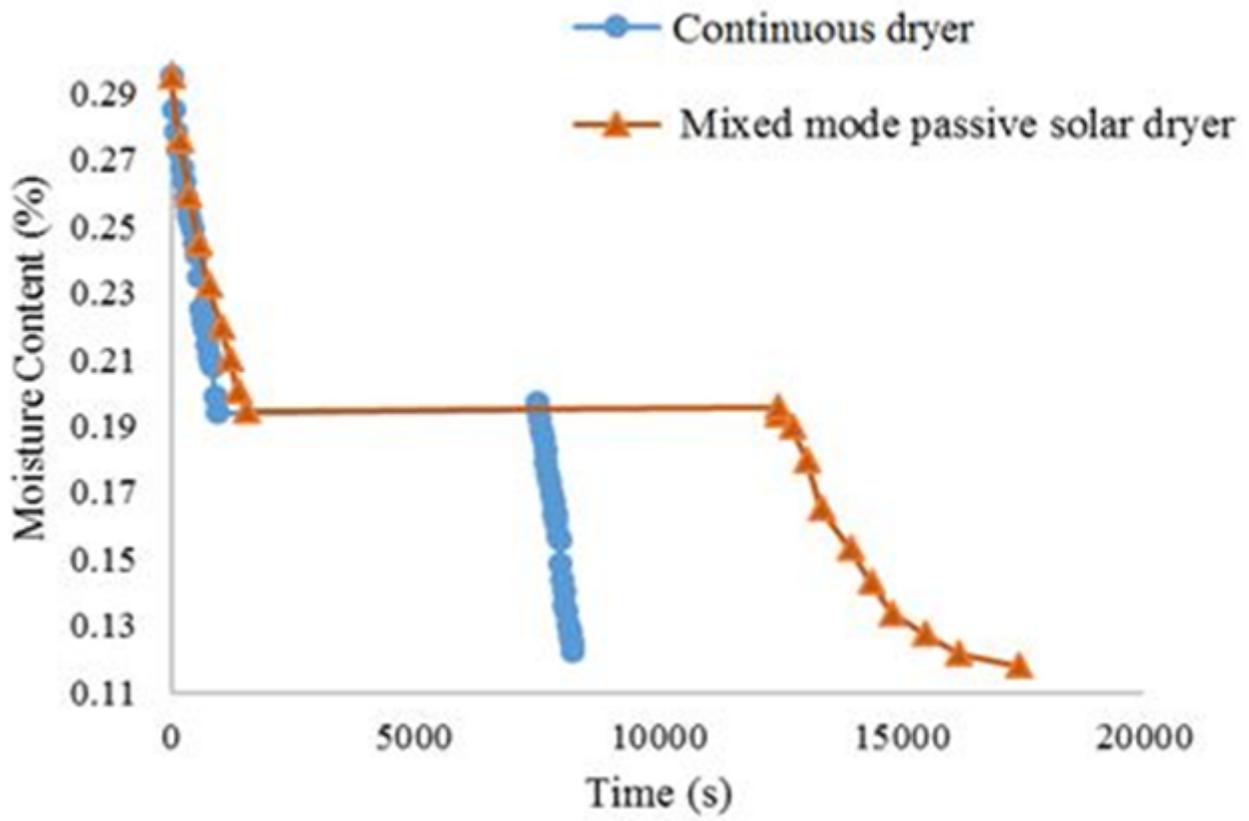


Figure 7

Variation of moisture content in two drying methods

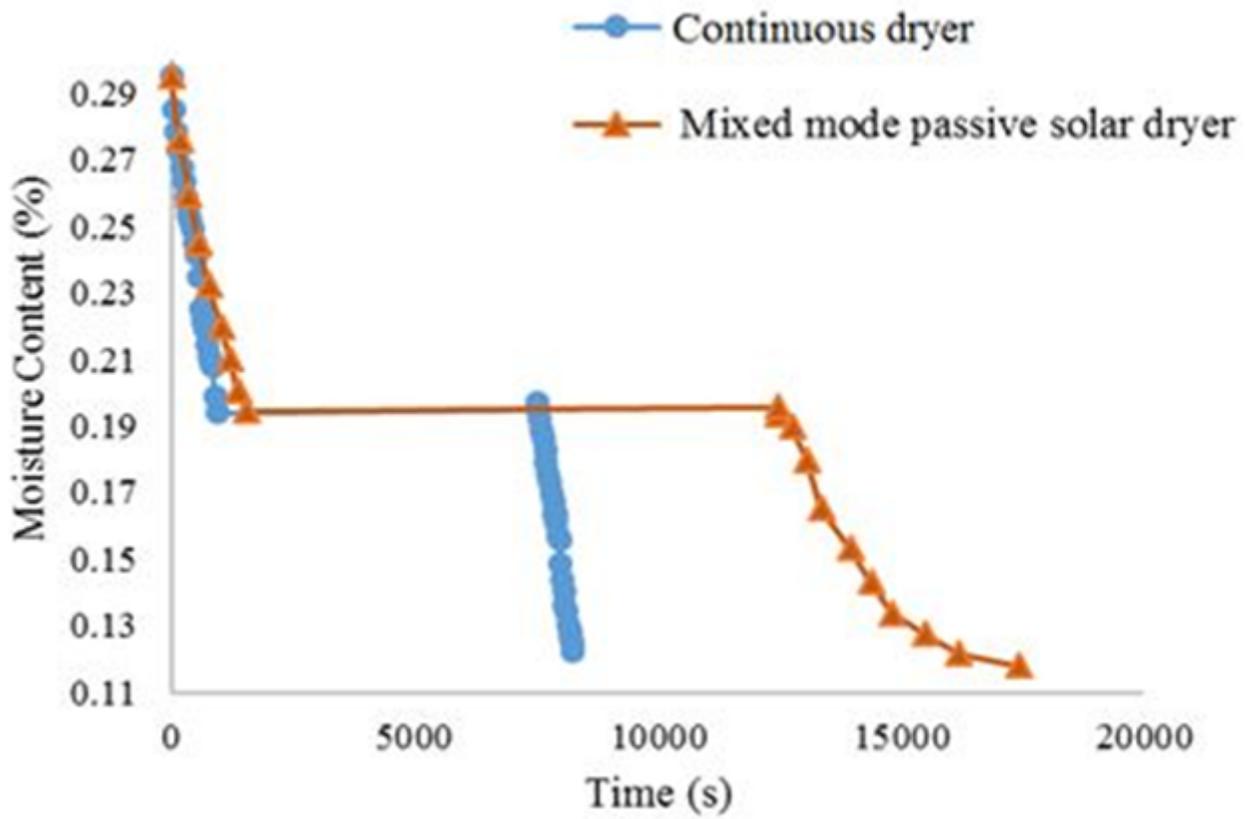


Figure 7

Variation of moisture content in two drying methods

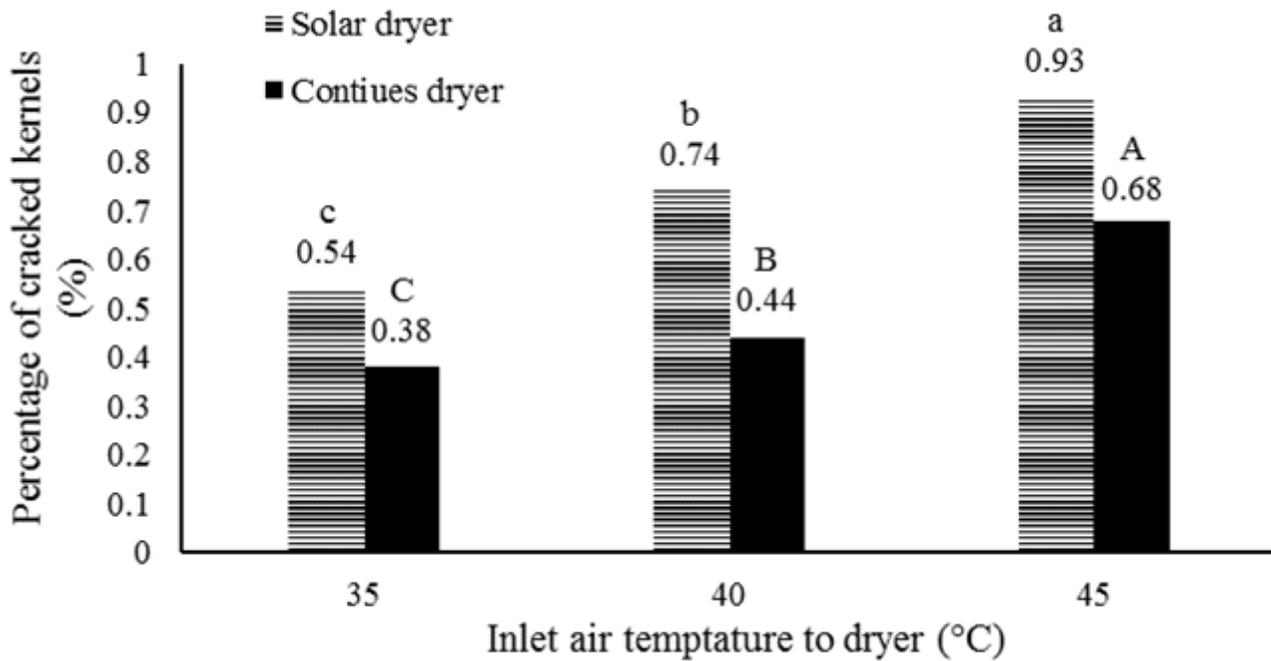


Figure 8

Variation of percentage of cracked kernels at different inlet air temperature

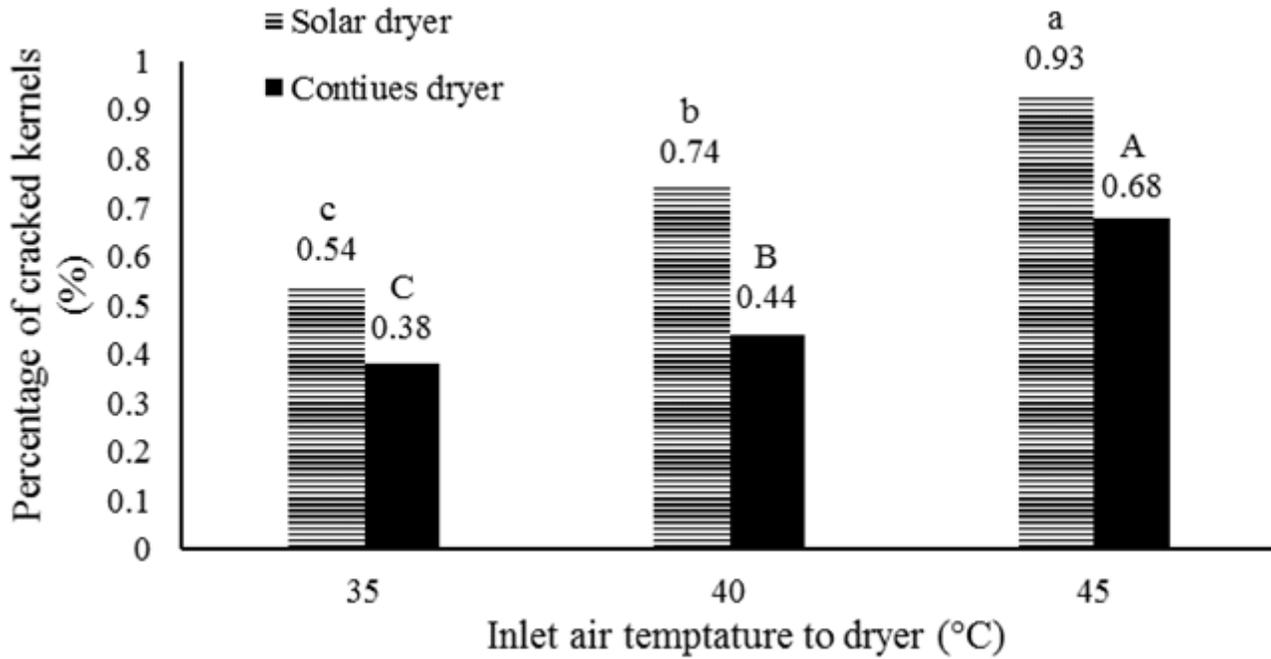


Figure 8

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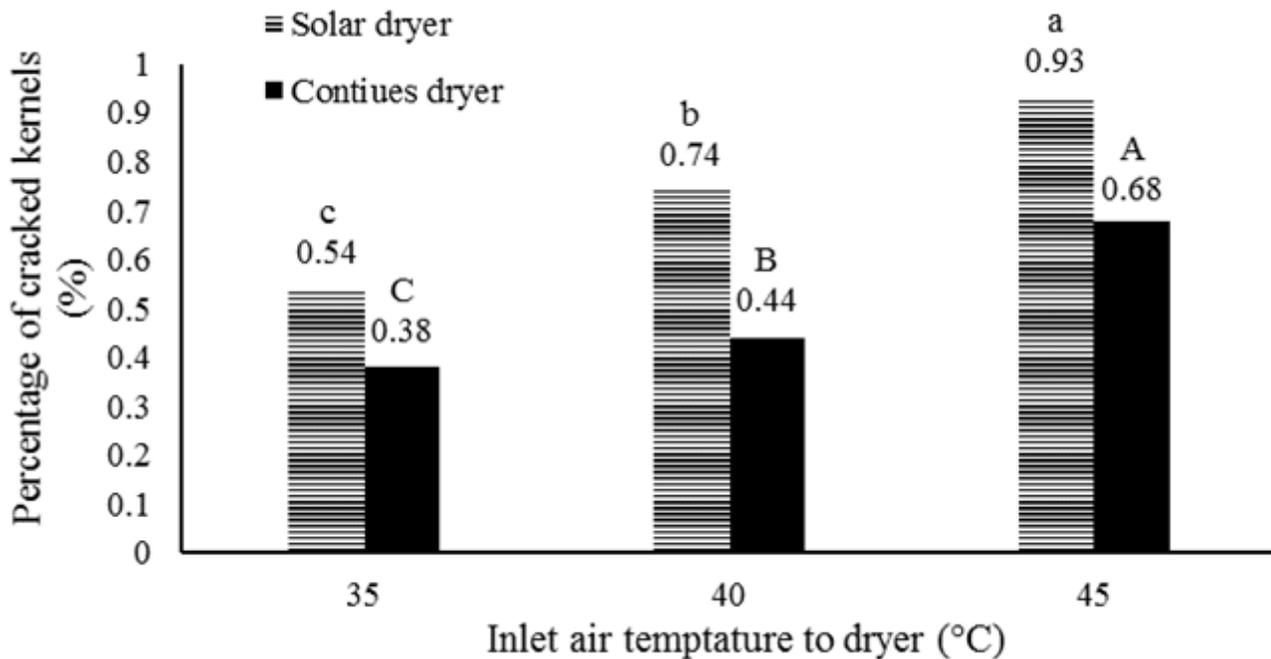


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Variation of percentage of cracked kernels at different inlet air temperature

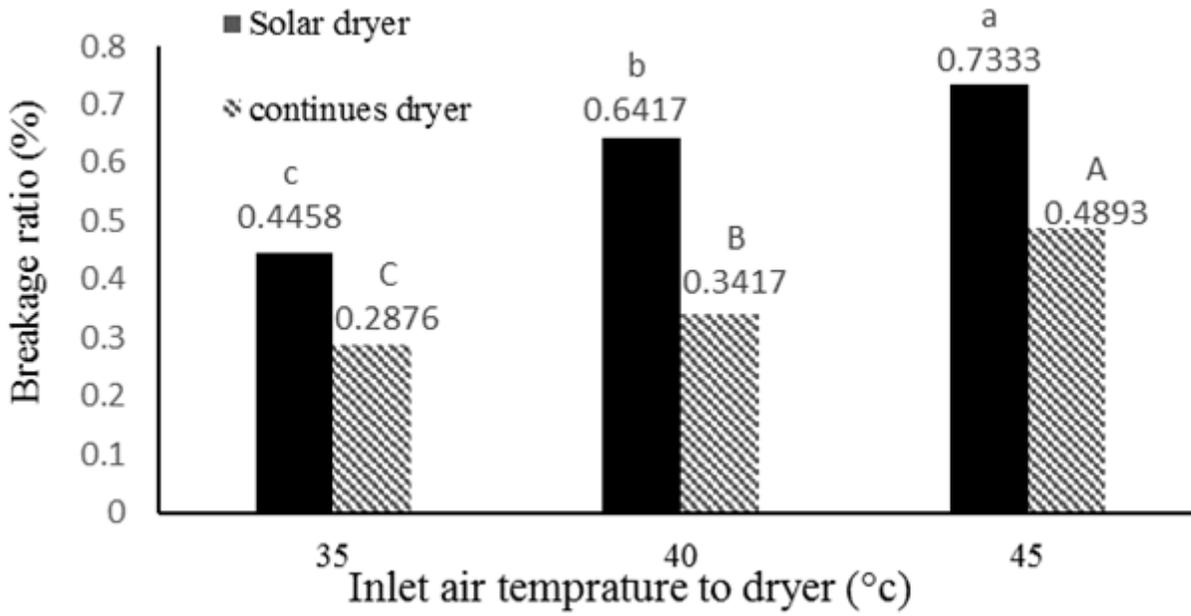


Figure 9

Variation of breakage ratio at different inlet air temperature

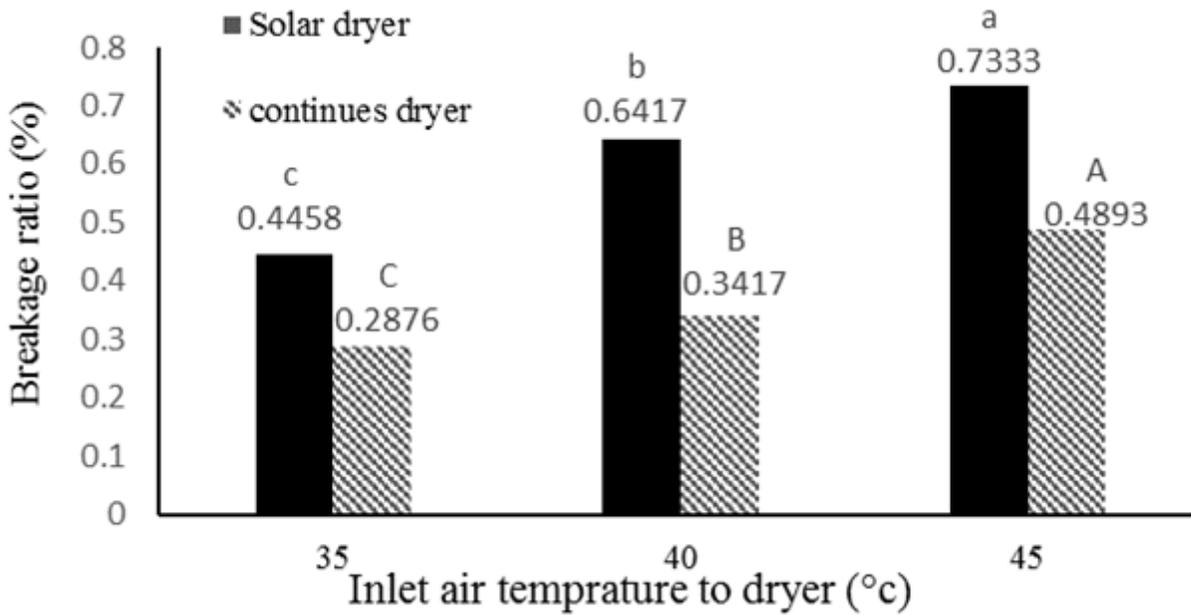


Figure 9

Variation of breakage ratio at different inlet air temperature

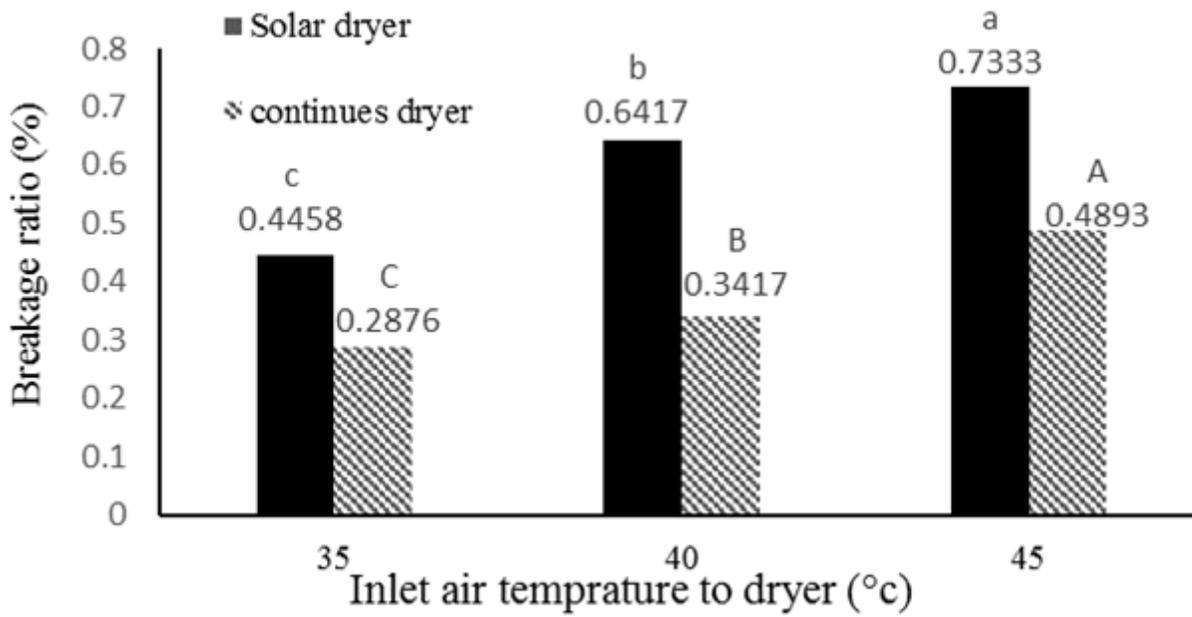


Figure 9

Variation of breakage ratio at different inlet air temperature

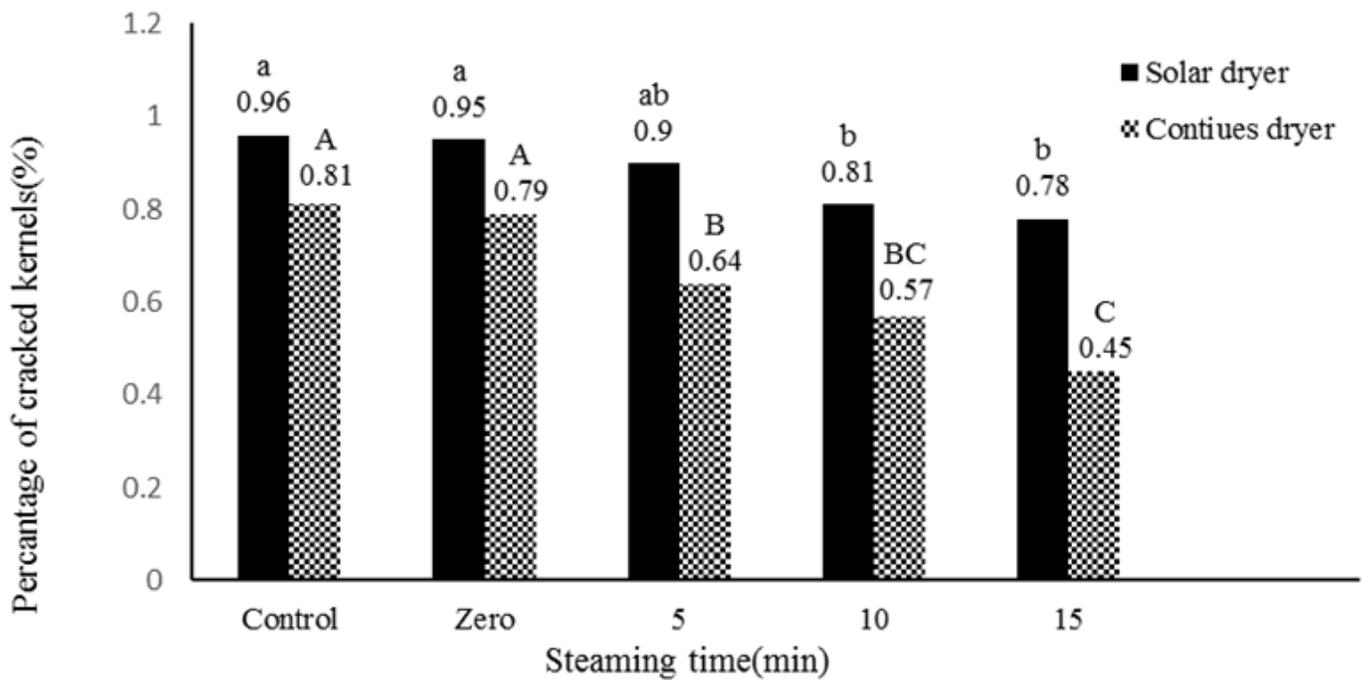


Figure 10

Percentage of cracked kernels with respect to steaming time

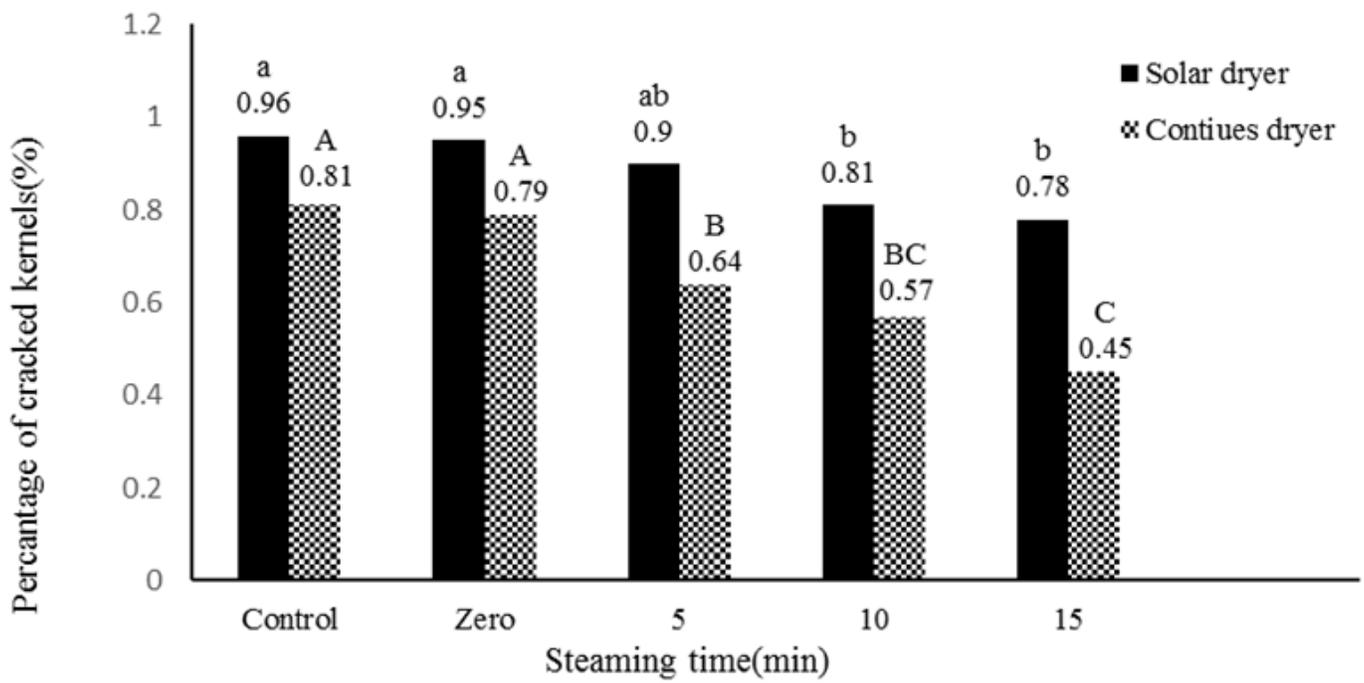


Figure 10

Percentage of cracked kernels with respect to steaming time

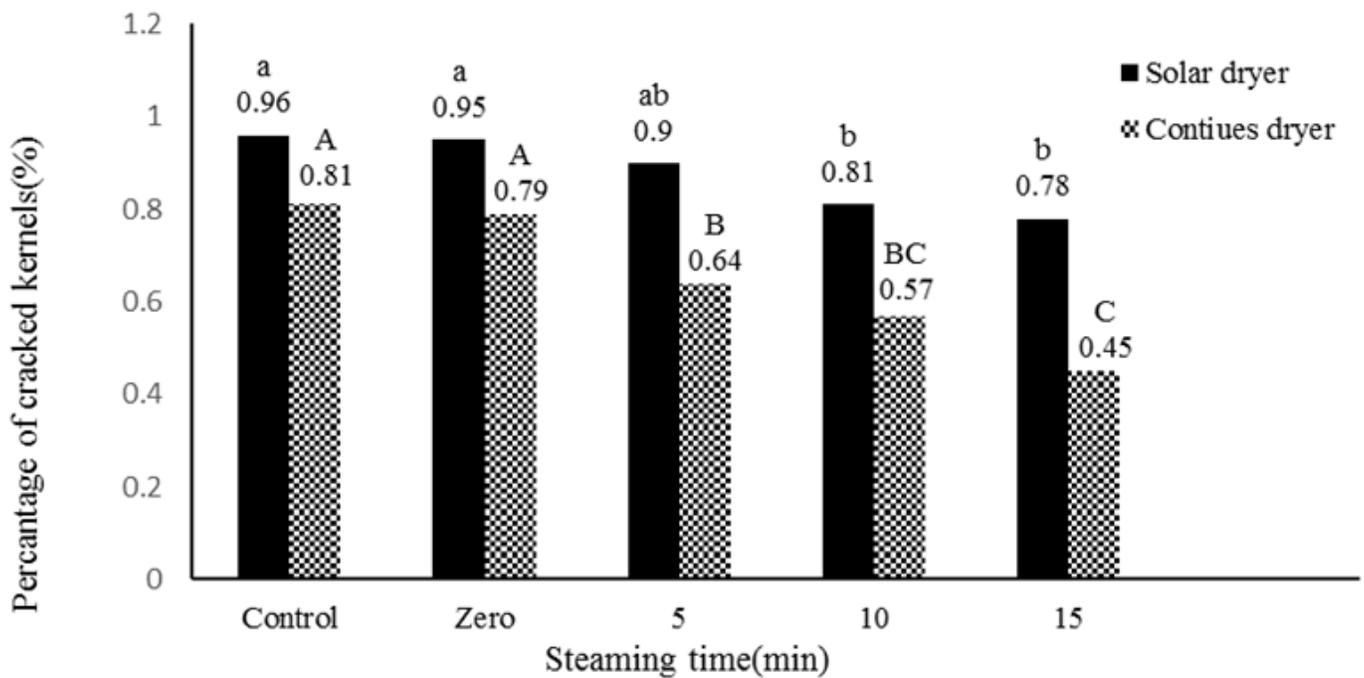


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Percentage of cracked kernels with respect to steaming time

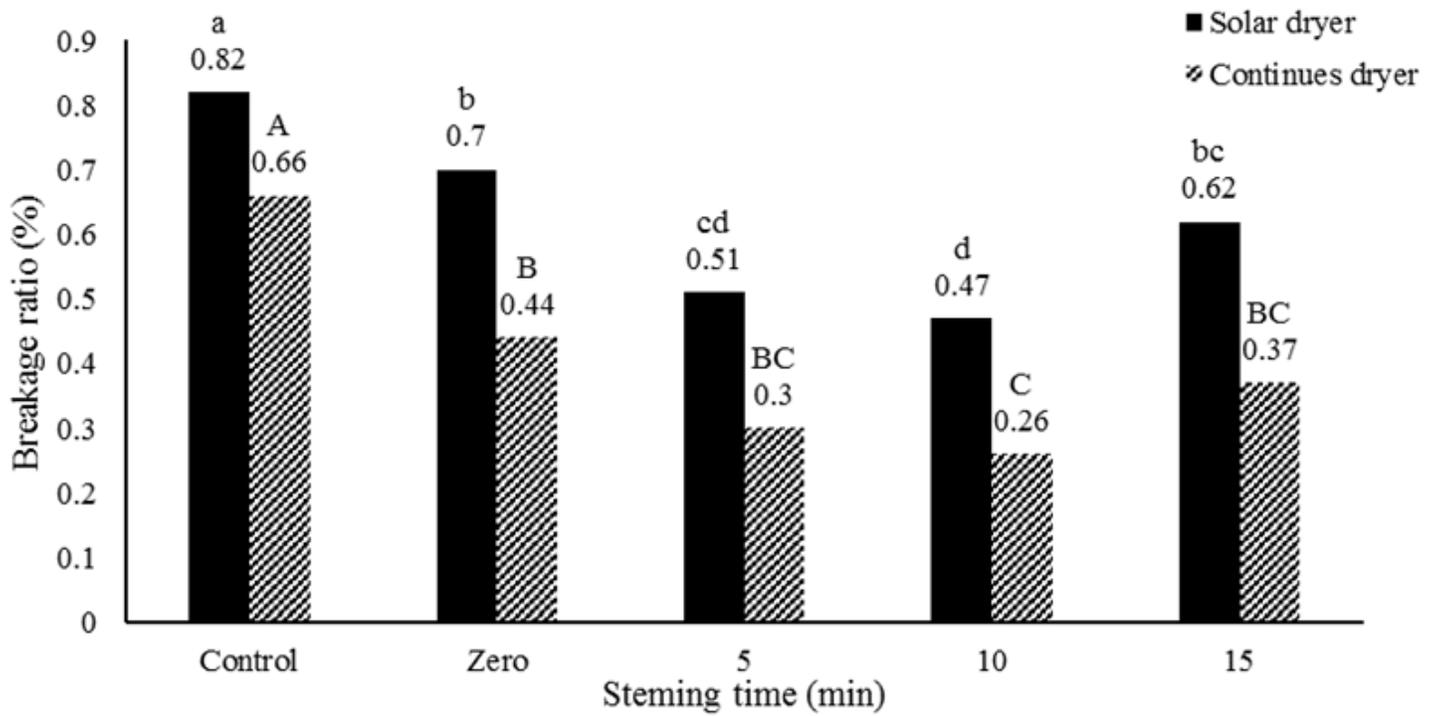


Figure 11

Comparison of the breakage ratio with respect to steaming time

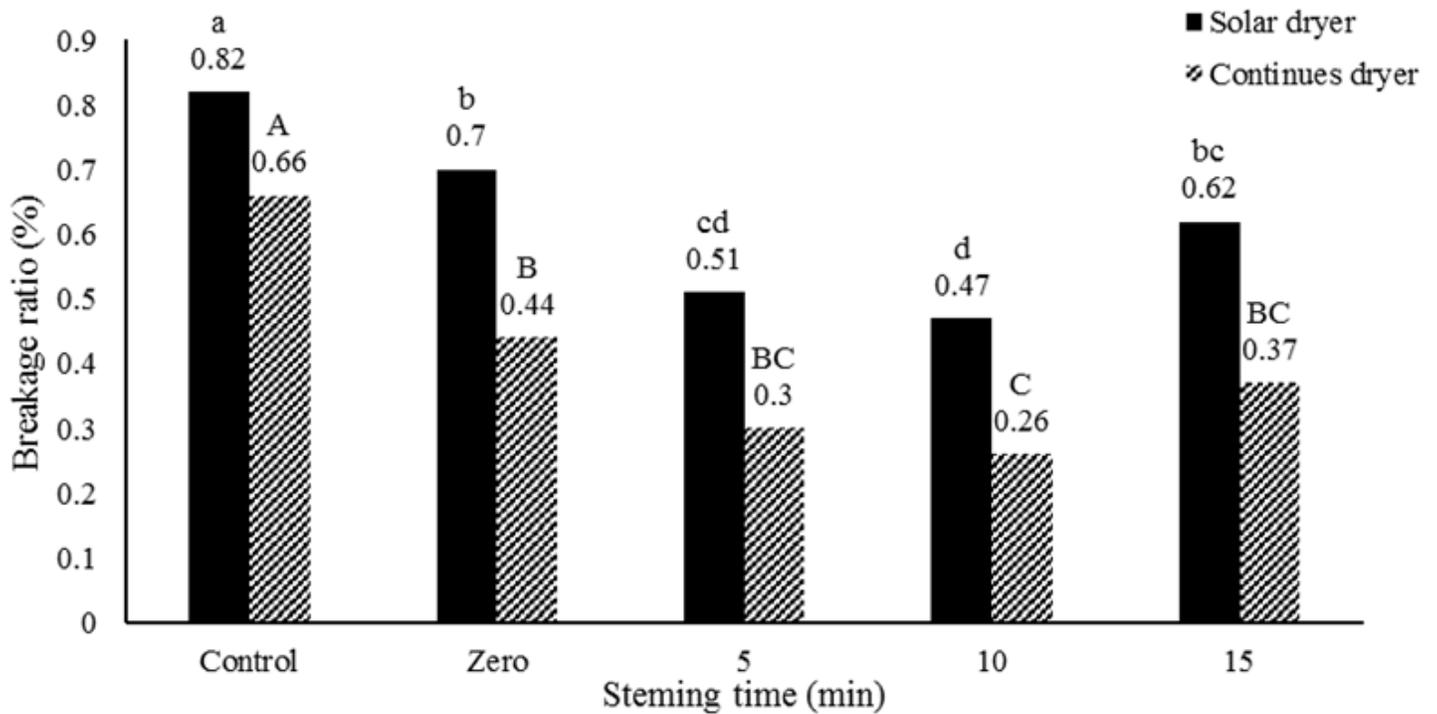


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Comparison of the breakage ratio with respect to steaming time

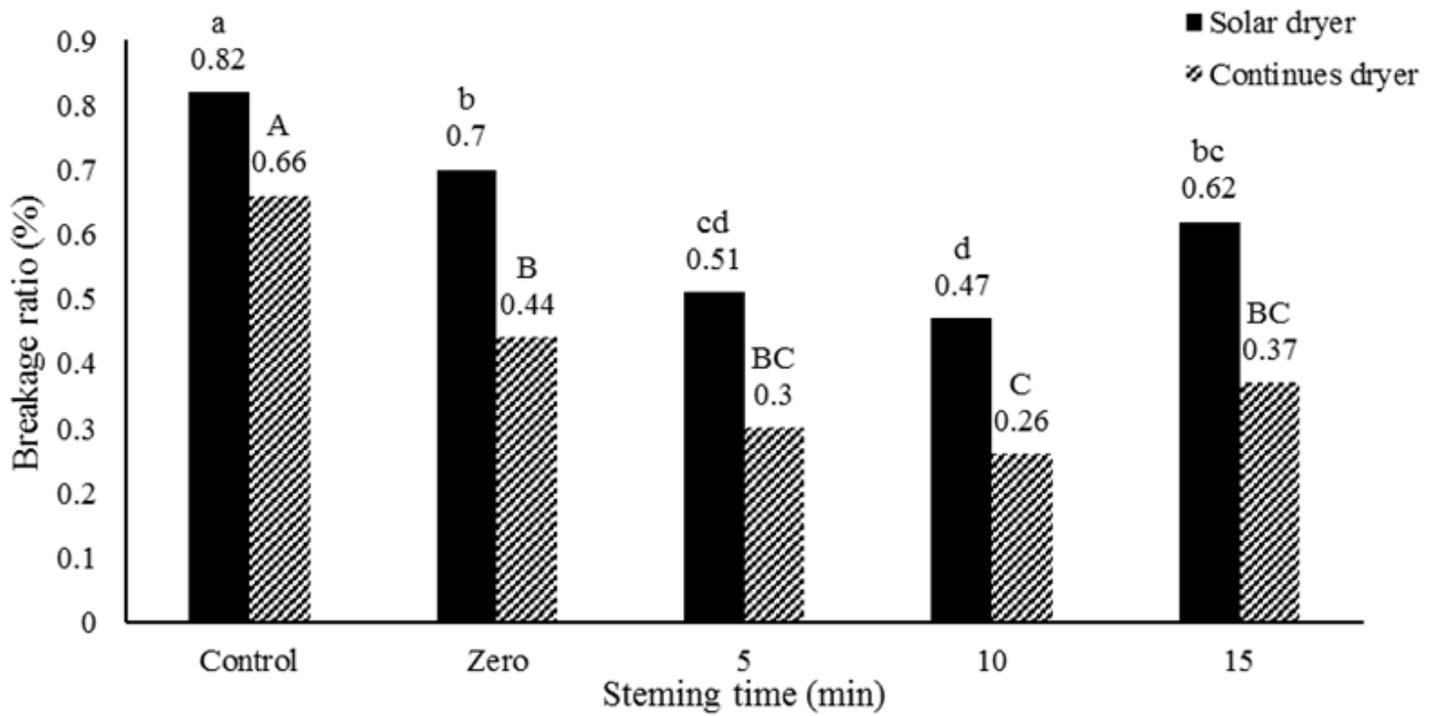


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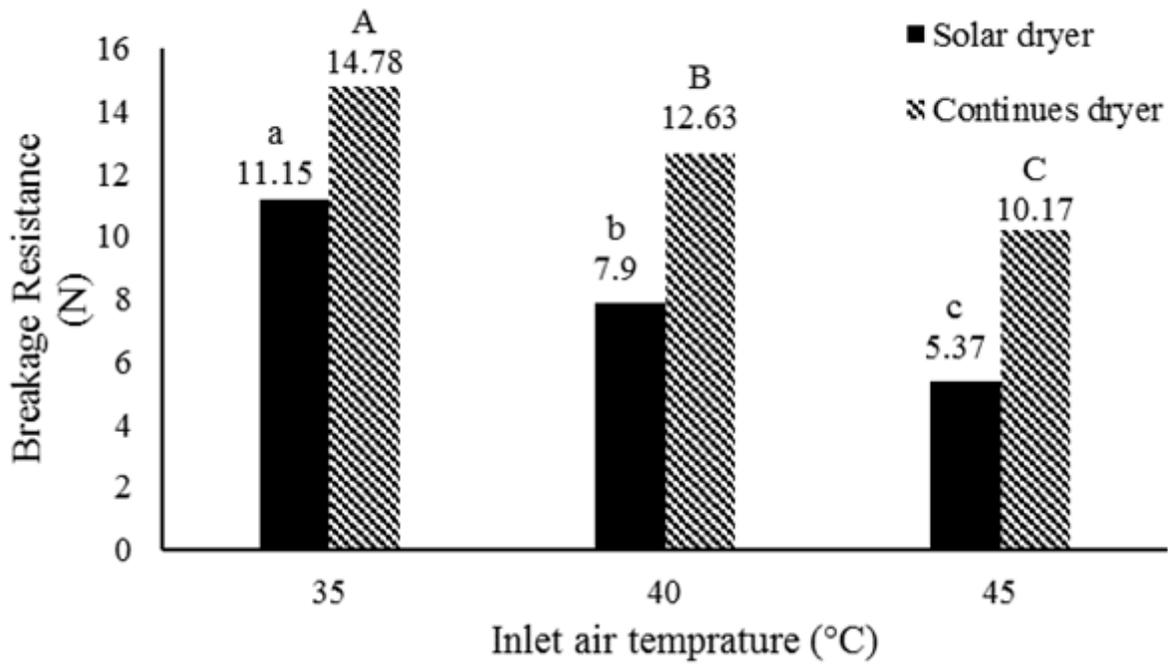


Figure 12

Comparison of the breakage ratio with respect to the inlet air temperature

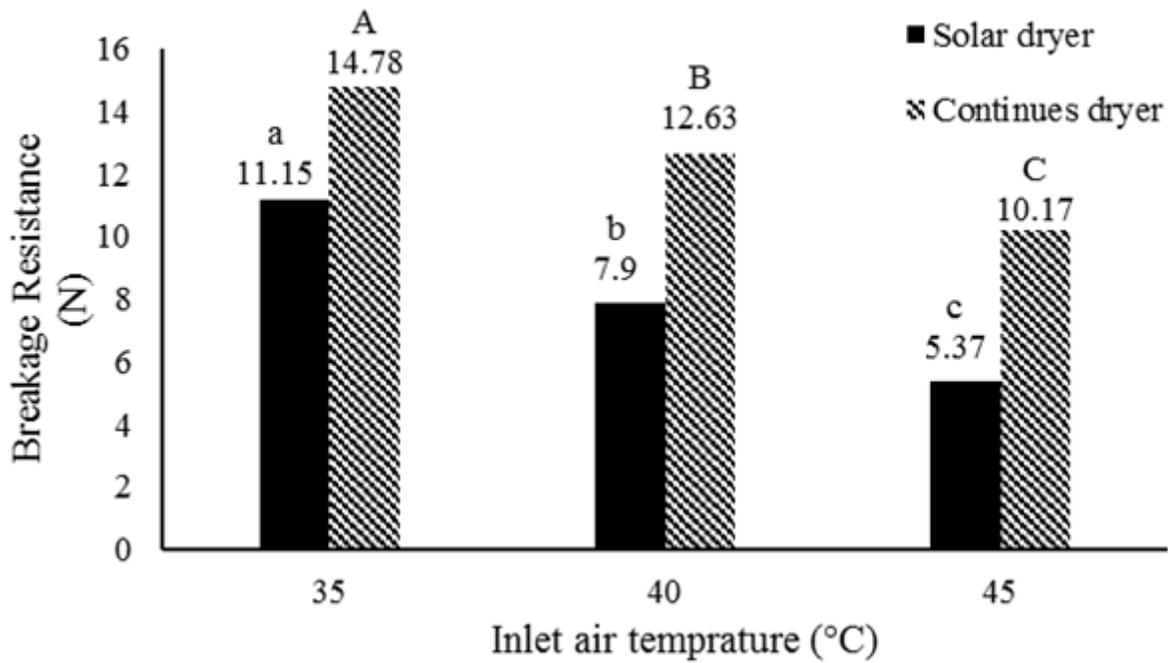


Figure 12

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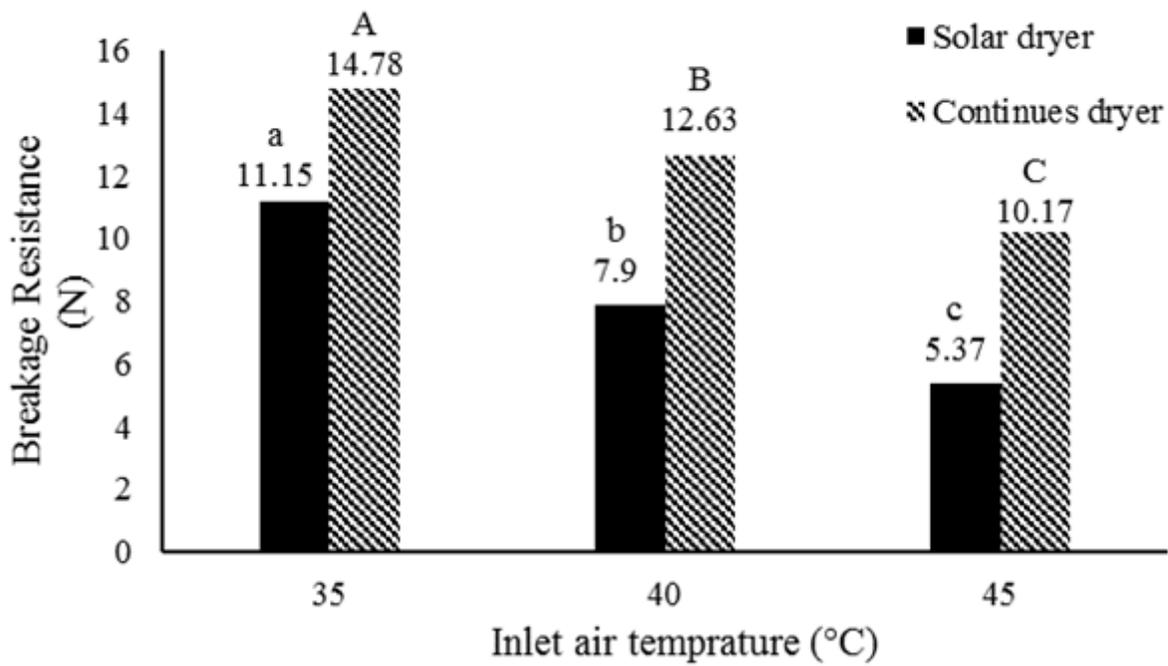


Figure 12

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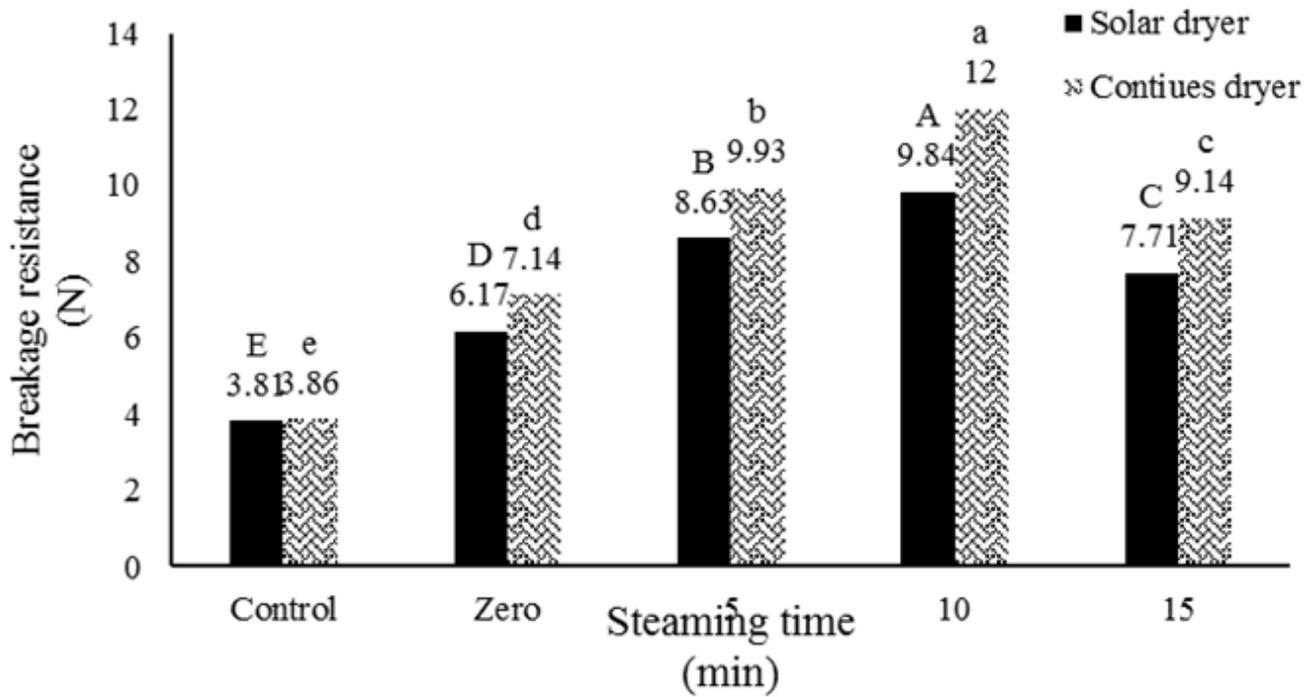


Figure 13

Comparison of the breakage resistance with respect to steaming time

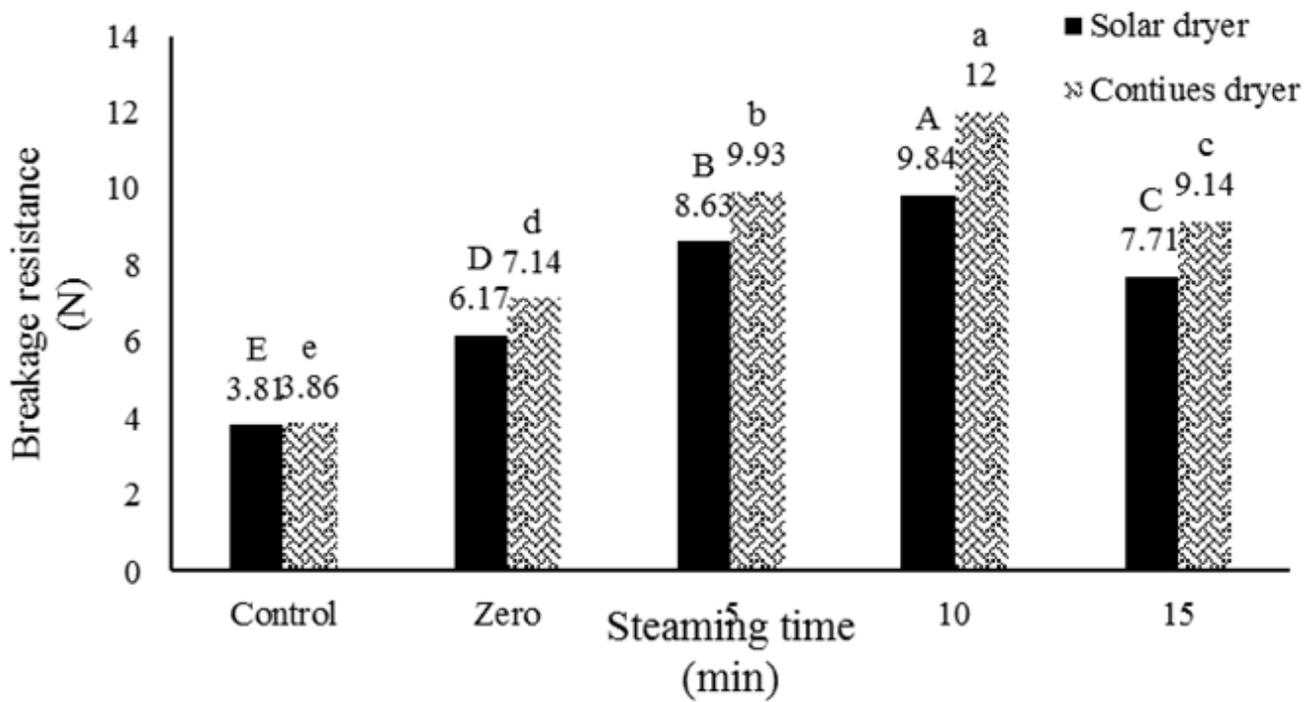


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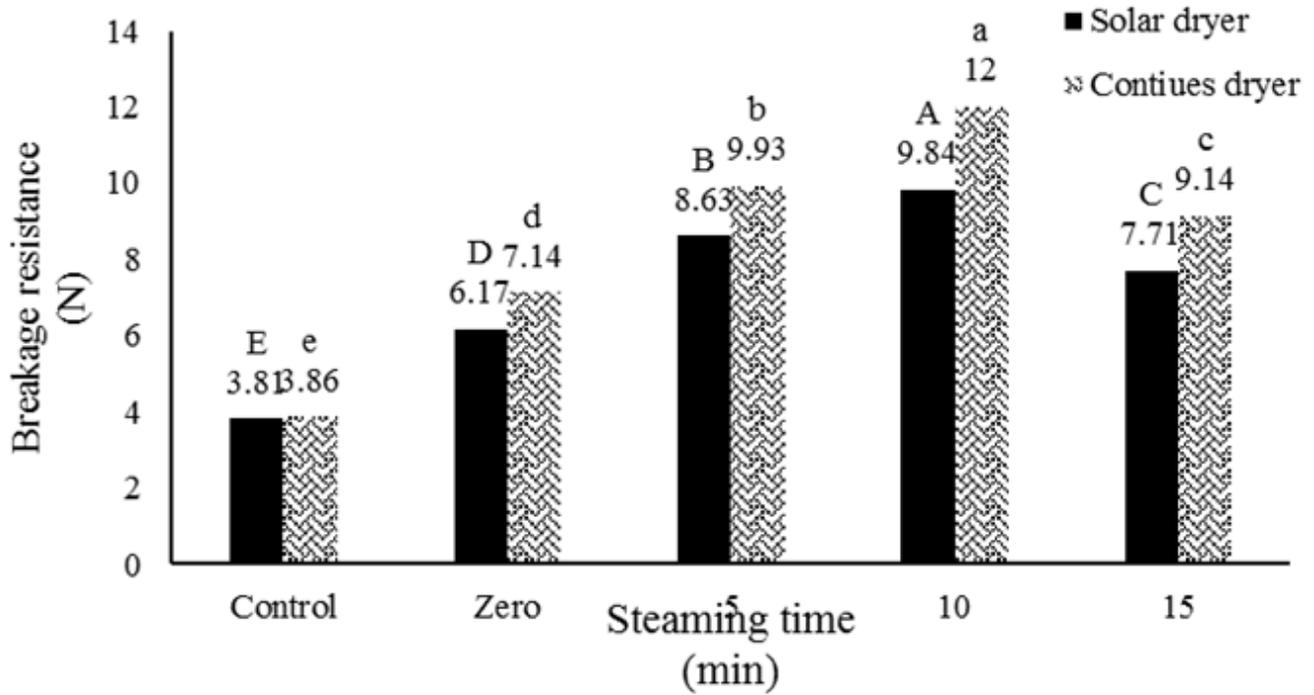


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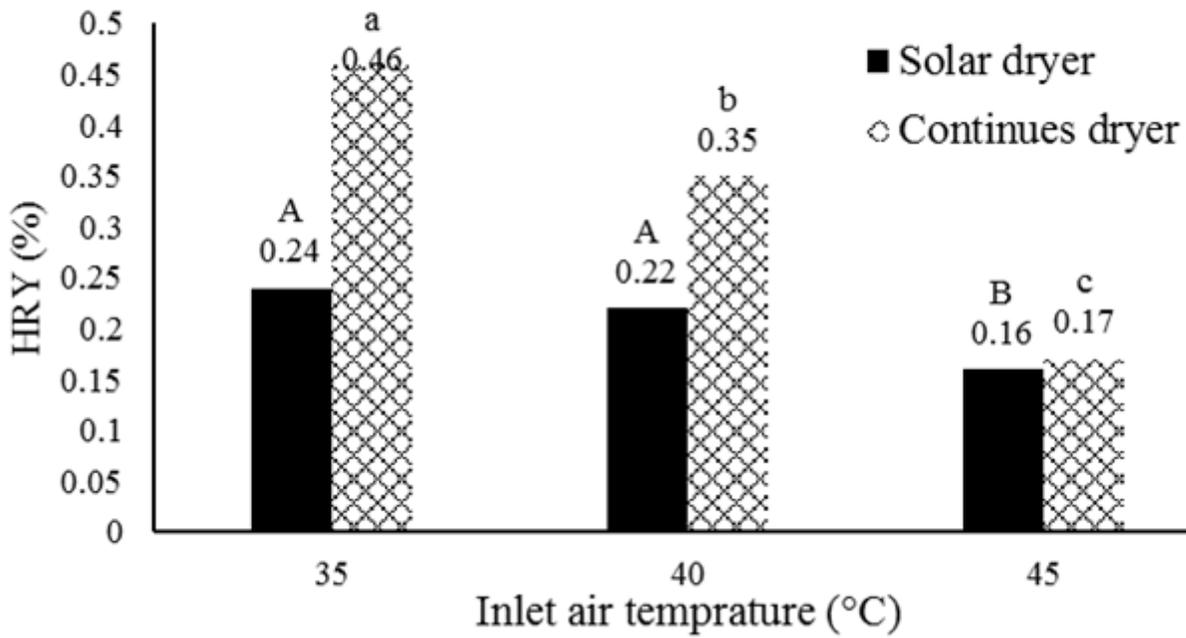


Figure 14

Comparison of the HRY with respect to the inlet air temperature

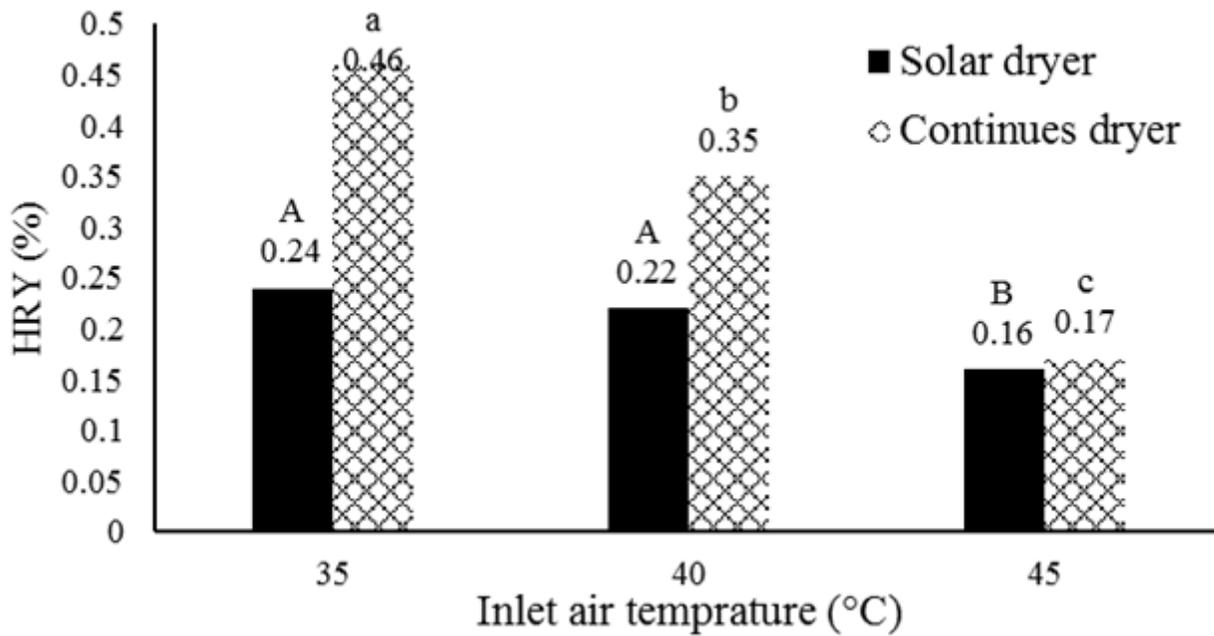


Figure 14

Comparison of the HRY with respect to the inlet air temperature

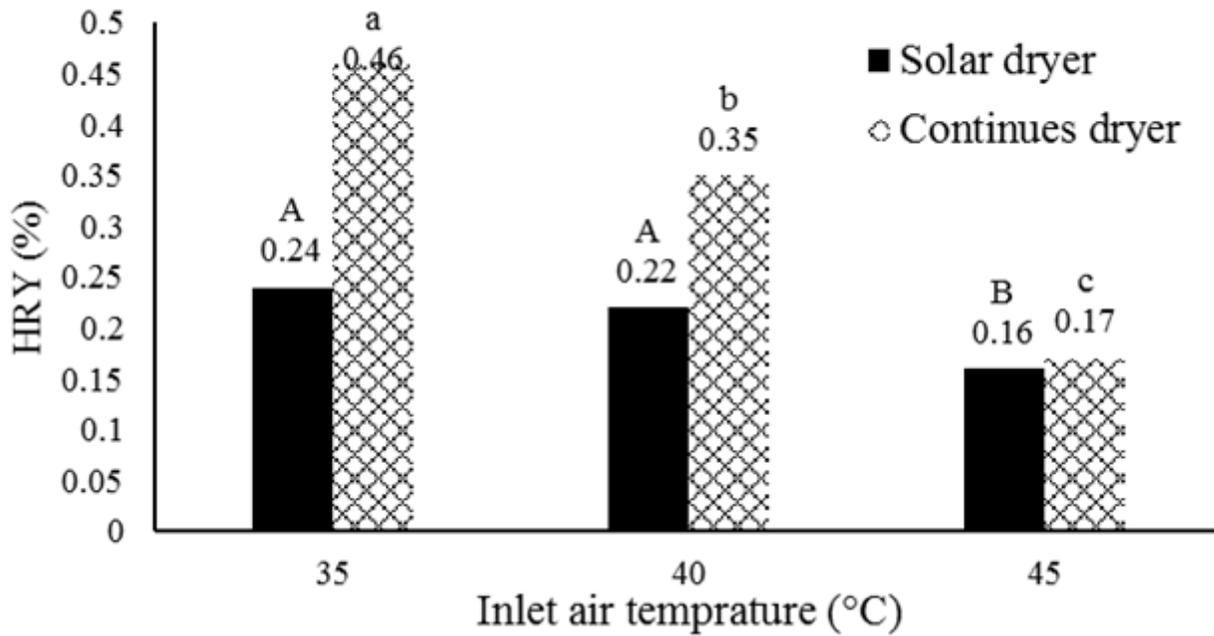


Figure 14

Comparison of the HRY with respect to the inlet air temperature

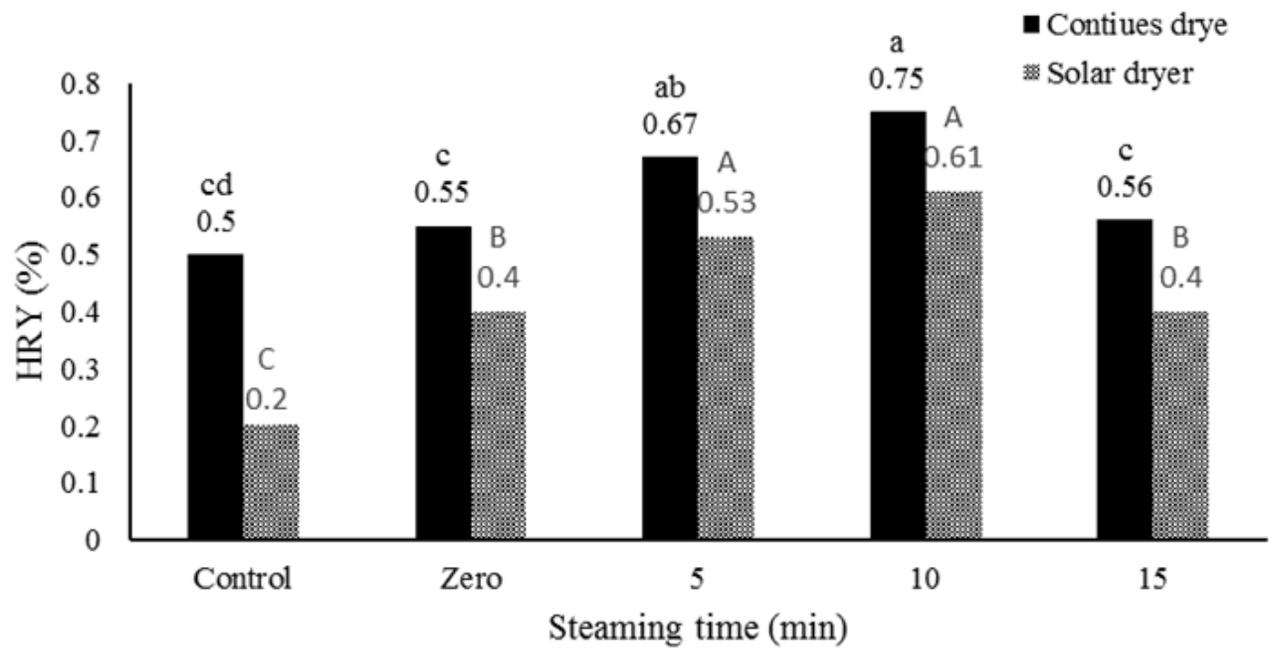


Figure 15

Comparison of the HRV with respect to steaming time

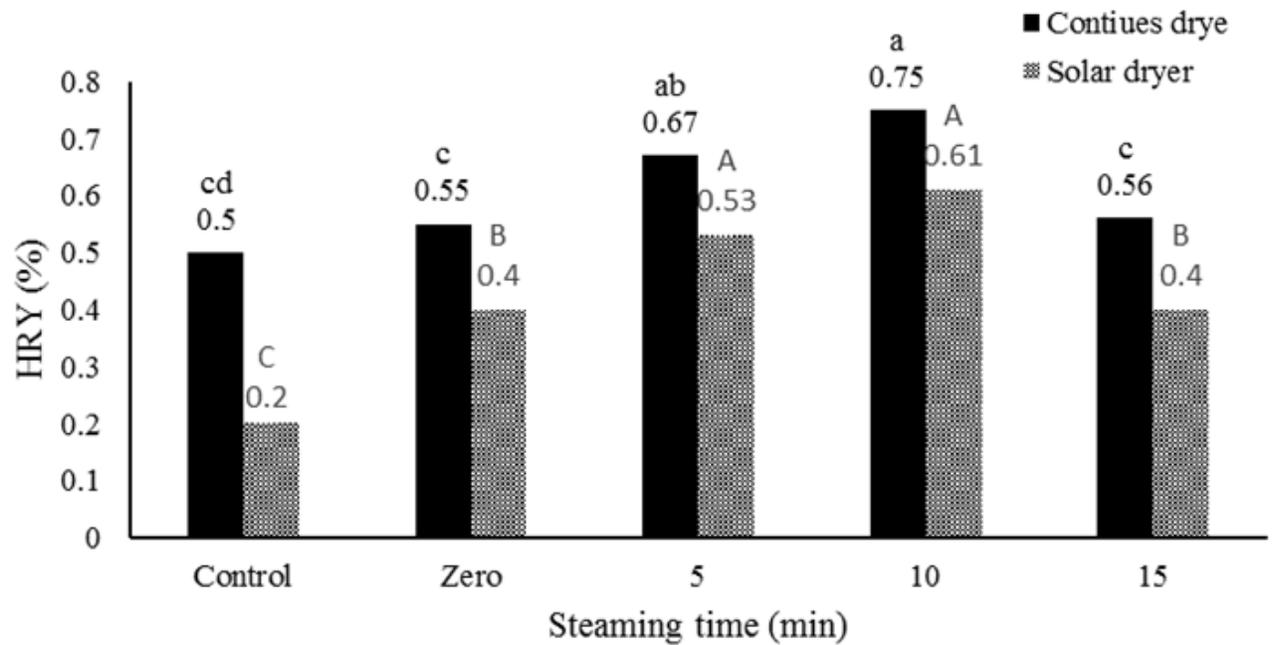


Figure 15

Comparison of the HRV with respect to steaming time

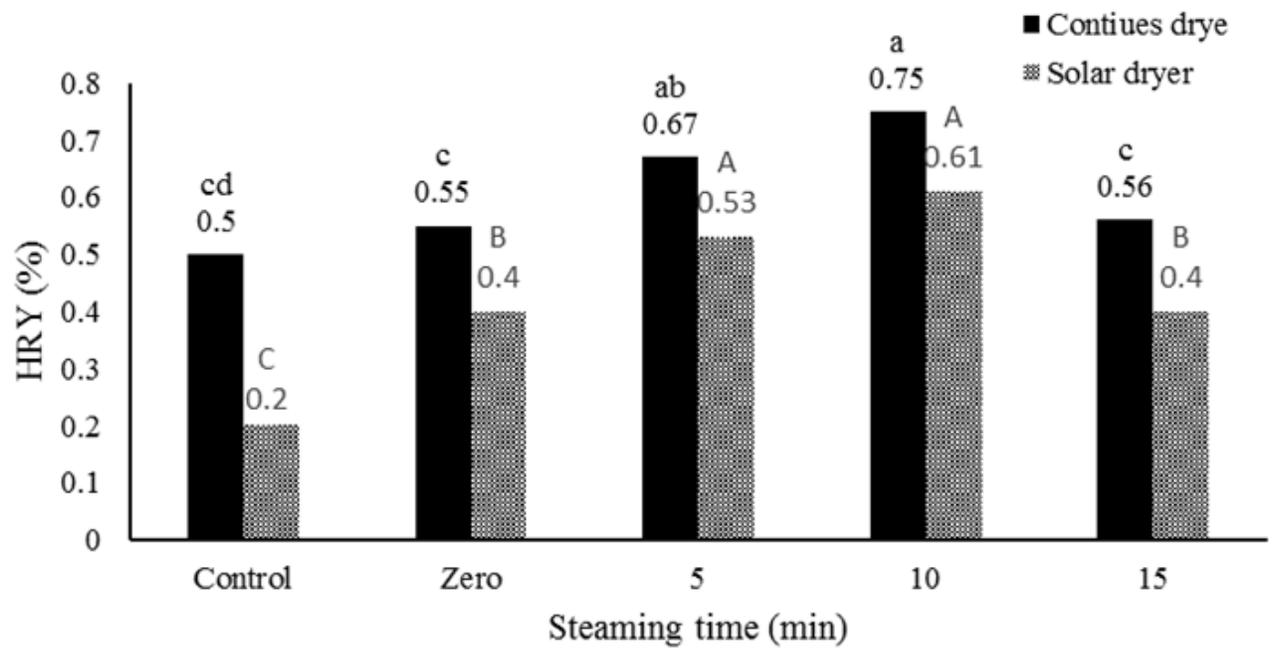


Figure 15

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