Effect of Different Drying Methods on Quality Characteristics of Wheat Grains

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Wheat is one of the main staple cereals used worldwide, providing 50% of food energy and protein consumed globally. Drying, the oldest preservation technique used for agricultural products, is the removal of moisture to its certain desired requirement. The drying process aims to reduce the grain's moisture content for safe storage. The present study was carried out at the Department of Farm Structures and Postharvest Engineering, Sindh Agriculture University, Tandojam, Pakistan. Freshly harvested wheat grain varieties TD-1, Imdaad-2005 and Sindhu were collected from the Latif Experimental Farm, Sindh Agriculture University, Tandojam. The wheat grain samples were subjected to three different drying methods i.e. sun drying, convective drying and intermittent drying. Data in terms of quality for wheat grain was observed initially, and then after being subjected to different drying methods. The results revealed that moisture content, length, width, thickness, thousand kernel weight, weight loss, bulk density, germination and drying rate for all wheat varieties decreased with respect to time in all drying methods. The results in terms of quality after drying was observed to be better for intermittent drying, followed by convective and sun drying. The farmers and grain processing industries are suggested to adopt the intermittent drying method, which enhances grain quality and reduces energy consumption.

Keywords: Grain; Drying; Convective; Intermittent; Quality; Processing; Storage.

Introduction:

Wheat *(Triticum aestivum L.)* is among the most important staple cereals consumed worldwide [1]. It contributes approximately 50% of the total dietary energy and protein intake globally. With the global population projected to reach 9.1 billion by 2050, the significance of wheat as a primary food source is expected to increase further. To meet the rising demand, food production will need to increase by 70%, which in turn requires a 60% boost in the overall food supply [2]. Globally, approximately 1.8 billion tons of food is wasted each year. This significant loss occurs due to various biotic factors (such as pests and diseases) and abiotic factors (including heat, drought, natural ripening processes, and improper handling). Collectively, these factors lead to considerable postharvest losses and a decline in food quality [3]. In 2020, Pakistan's wheat production reached 24,946 thousand tonnes, reflecting a substantial rise from 6,476 thousand tonnes in 1971. This growth corresponds to an average annual increase of 3.11% [4]. In Sindh province, wheat is cultivated on approximately 0.9 million hectares, contributing an average of around 3.0 million tons annually to the region's total production [5]. Major commercial varieties grown in Sindh are TD1, Kiran-95 and Imdad-2005, and major growing districts in Sindh are Hyderabad, Khairpur Mirs, Mirpurkhas, Shaheed Benazirabad, Naushahro Feroze and Dadu [6].

Drying, one of the most traditional method for preserving agricultural products involves reducing the moisture content to a desired level that maintains the product's quality and extends its shelf life [7]. Reducing the moisture content of food to safe levels effectively inhibits the activity of enzymes, bacteria, yeasts and molds, thereby extending shelf life and preserving quality [8]. Artificial drying efficiently eliminates excess moisture from agricultural products; however, precise control of the process is essential to preserve their nutritional content, texture and overall quality [9]. Improved product quality and reduction of losses can only be achieved by introducing suitable drying technologies [10] However, the increase in purchasing power of the farmers of the dryers, and the reflection of the quality in the price of quality dried products are the important prerequisites for acceptance of the dryers by the farmers [11].

Sun drying is widely practiced in the tropical and sub-tropical regions. However, this method is highly dependent on weather conditions and is often associated with contamination from dirt, dust and insect infestation, as well as losses caused by birds and animals [12]. During sun drying, agricultural products are typically spread on surfaces such as beaten earth, mats, concrete or floors. However, drying grains directly on the ground and prolonged drying durations elevate the risk of aflatoxin contamination in cereal crops [13]. The drying rate of agricultural products is influenced by different factors, including solar radiation, ambient temperature, wind velocity, relative humidity, and the initial moisture content [14]. Intermittent drying is an alternative method that improves drying kinetics, enhances product quality, and reduces energy consumption per unit of moisture removed. This method has been widely used in both experimental studies and modelling, demonstrating its potential for efficient and sustainable drying processes [15]. Intermittent drying accelerates drying kinetics by introducing pauses in the drying cycle. This approach mitigates moisture gradients within the product, facilitating faster and more efficient moisture removal. Consequently, it enhances production efficiency by reducing both drying time and costs. Through precise regulation of drying conditions, intermittent drying helps minimize the adverse impacts of heat and moisture on grains [16]. It provides high-quality end products, characterized by better retention of taste, color and nutritional content. The intermittence period serves as a resting time for the grain mass, allowing the moisture in both liquid and vapour form to migrate from the grain's interior to its surface. This process enhances the efficiency of heat and mass transfer when the grain is again exposed to heated air in the drying chamber [17].

Novelty Statement:

Various drying methods have been employed for drying grains; however, limited research has been conducted on intermittent drying, specifically for wheat grains in the study area. Therefore, this research was conducted to address and fill the existing knowledge gap.

Objectives:

The study was carried out to assess the effect of different drying methods i.e. sun drying, convective drying and intermittent drying on quality characteristics and drying rate of different wheat grains.

Material and Methods:

Study Area:

The study was conducted at the Laboratory of Farm Structures and Postharvest Engineering, Faculty of Agricultural Engineering and Technology, Sindh Agriculture University, Tandojam, Pakistan. Freshly harvested wheat grain varieties TD-1, Imdaad-2005, and Sindhu were collected from the Latif Experimental Farm, Sindh Agriculture University, Tandojam, Pakistan. The collected samples were properly sealed and brought to the Laboratory of Farm Structures and Postharvest Engineering for further experimentation. The wheat grains were subjected to three different drying methods i.e. sun drying, convective drying and intermittent drying. Data from grain samples were observed initially, and then after being subjected to different drying methods.

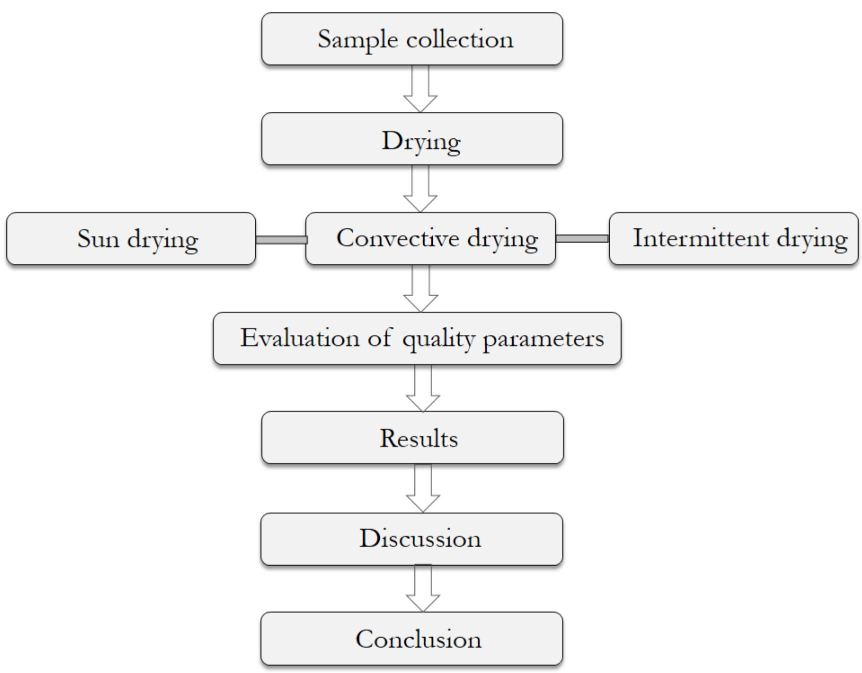

Figure 1. Flowchart of methodology

Sun Drying:

The grains were evenly spread on black polythene sheets under direct sunlight. As solar energy strikes the uneven surface of the grains, the absorbed radiation converts into thermal energy, leading to an increase in the grain temperature. This results in long-wavelength radiation loss from the surface of the product to the ambient air, through moist air. In addition to long-wavelength radiation lost, there is convective heat loss too, which occurs by blowing wind through moist air over the surface.

Convective Drying:

In this process, heated air was used to remove moisture from the grains. The grains were spread in a thin, uniform layer to ensure even drying. As heated air passed over grains, it absorbed moisture from their surfaces, causing the internal moisture to evaporate into the air, which was subsequently vented out. The process involved controlling parameters such as temperature (50 ℃), airflow rate and humidity to ensure efficient drying without damaging the grain's quality [18].

Intermittent Drying:

Intermittent drying involved alternating periods of active drying with rest phases (tempering). During the active drying phase, heated air was applied to evaporate surface moisture. This was then followed by a tempering phase, where the heated source was removed, allowing internal moisture to migrate naturally toward the surface. The cycles were repeated until the desired moisture content was achieved [19].

Ambient Temperature and Relative Humidity:

The ambient temperature and relative humidity were recorded during the drying period. The ambient temperature was directly calculated from the dry bulb, whereas relative humidity was determined by the Psychrometric chart using dry and wet bulb data.

Moisture Content:

Oven-dried method was used for determining the moisture content of wheat [20]. The samples from each treatment were kept in an oven at a temperature of 105 °C for 24 hours, the moisture content was calculated using the following formula.

$$\text{Moisture content} = \frac{\text{Initial weight - Final weight}}{\text{Initial weight}} \times 100$$

Length, Width and Thickness:

A Vernier caliper was used for determining the length, width and thickness of wheat grains. Three grain samples were randomly selected, reporting its average values.

Thousand Kernel Weight:

One hundred randomly selected grains were measured on an electronic weight balance with an accuracy of 0.001 g, which was then multiplied by 10 for a 1000-grain mass [21].

Weight Loss:

The weight loss after drying was calculated using the following equation.

$$\text{Weight loss (Wf)} = \text{Wi} \times \frac{100 - \text{MCi}}{100 - \text{MCf}}$$

Bulk Density:

Bulk density was calculated by the ratio of the mass of the sample to the total volume. The grain samples were filled into a known volume container, where the mass added was weighed using an electronic balance [22].

$$\beta = \frac{m}{V_c}$$

Germination:

For the determination of germination, the samples were kept in petri dishes lined with soft paper and soaked with water. The petri dishes were stored at room temperature accordingly. The germination was calculated using the following formula [23].

$$\text{Germination (\%)} = \frac{\text{Number of seeds germinated}}{\text{Total number of seeds}} \times 100$$

Drying Rate:

It is the change in moisture content (w.b.) divided by drying time, and expressed as percentage per hour. The average drying time was encountered for drying efficiency. The relationship shown in the equation below was used to calculate the drying rate.

$$R = \frac{\text{Mi - Mf}}{t}$$

Where; R = Rate of drying (%/h); Mi = Initial moisture content; Mf = Final moisture content; t = Drying time

Results:

The ambient temperature and relative humidity were recorded inside and outside the building during the drying period (Figure 2). The maximum and minimum temperatures inside the building on the first and second day one was recorded to be 21 °C and 14.5 °C, and 23.4 °C and 13.5 °C respectively. The maximum and minimum relative humidity inside the building on the first and second day was recorded to be 71 % and 50.9 %, and 70 % and 60 % respectively.

The maximum and minimum temperatures outside the building on the first and second day one was recorded to be 30 °C and 13 °C, and 27.5 °C and 12 °C respectively. The maximum and minimum relative humidity outside the building on the first and second day was recorded to be 69 % and 35 %, and 78 % and 42 % respectively.

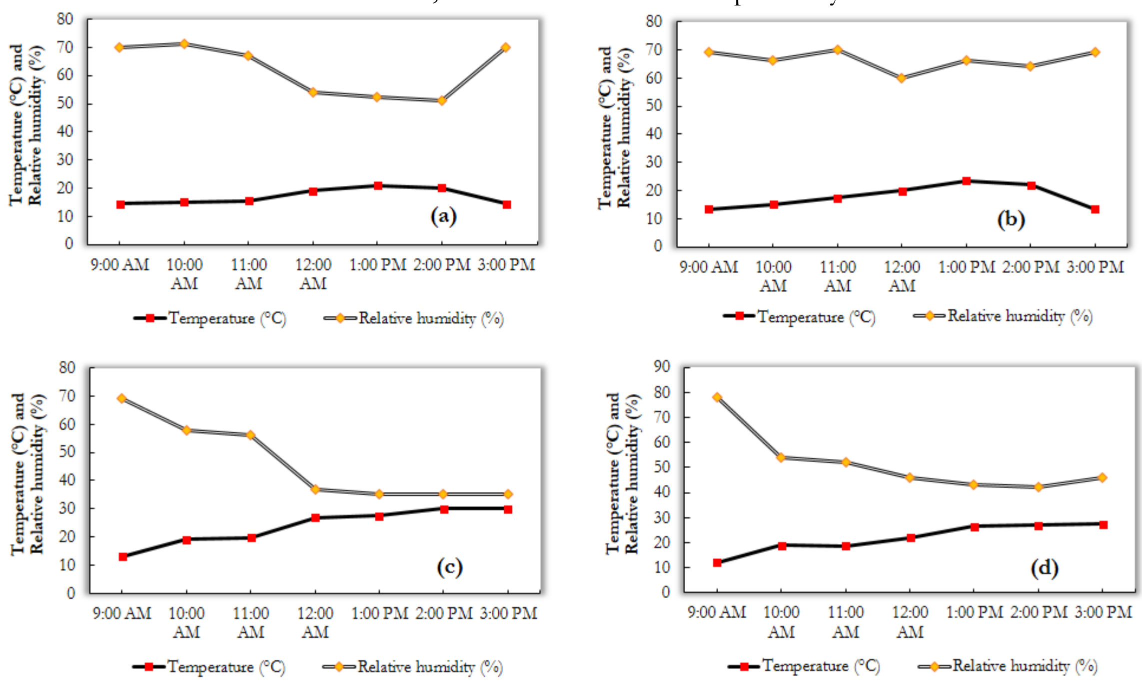

Figure 2. Ambient temperature (℃) and relative humidity (%) inside building on 1st day (a), inside building on 2nd day (b), outside building on 1st day (c) and outside building on 2nd day (d).

Moisture content of different wheat varieties under different drying methods is shown in Figure 3(a-c). The initial moisture content of wheat grain varieties was recorded to be 20 %. After drying, the moisture content of the TD-1 wheat variety for sun drying, convective drying and intermittent drying was observed to be 11.04, 11.02 and 11.02 %. After drying, the moisture content of Imdaad-2005 wheat variety for sun drying, convective drying and intermittent drying was observed to be 11.07, 11.05 and 11.06 %. After drying, the moisture content of the Sindhu wheat variety for sun drying, convective drying and intermittent drying was observed to be 11.06, 11.07 and 11.05 %.

The length of different wheat varieties under different drying methods is shown in Figure 4(a-c). The length of TD–1 in sun drying, convective drying and intermittent drying decreased from 7.50 mm at 20% to 7.464, 7.467 and 7.466 mm at 11%. The length of Imdaad-2005 in sun drying, convective drying and intermittent drying decreased from 6.10 mm at 20% to 6.068, 6.067 and 6.066 mm at 11%. The length of Sindhu in sun drying, convective drying and intermittent drying decreased from 7.20 mm at 20% to 7.145, 7.146 and 7.147 mm at 11%.

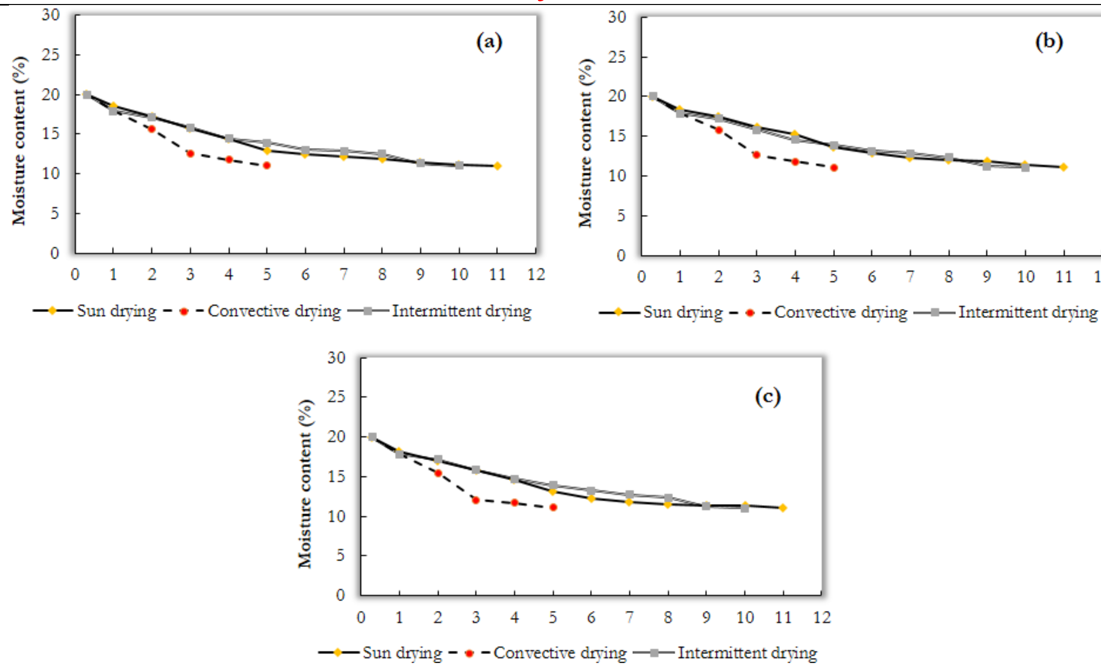

Figure 3. Variation in moisture content (%) of varieties TD-1 (a), Imdaad-2005 (b) and Sindhu (c) with respect to time (hours) under different drying methods.

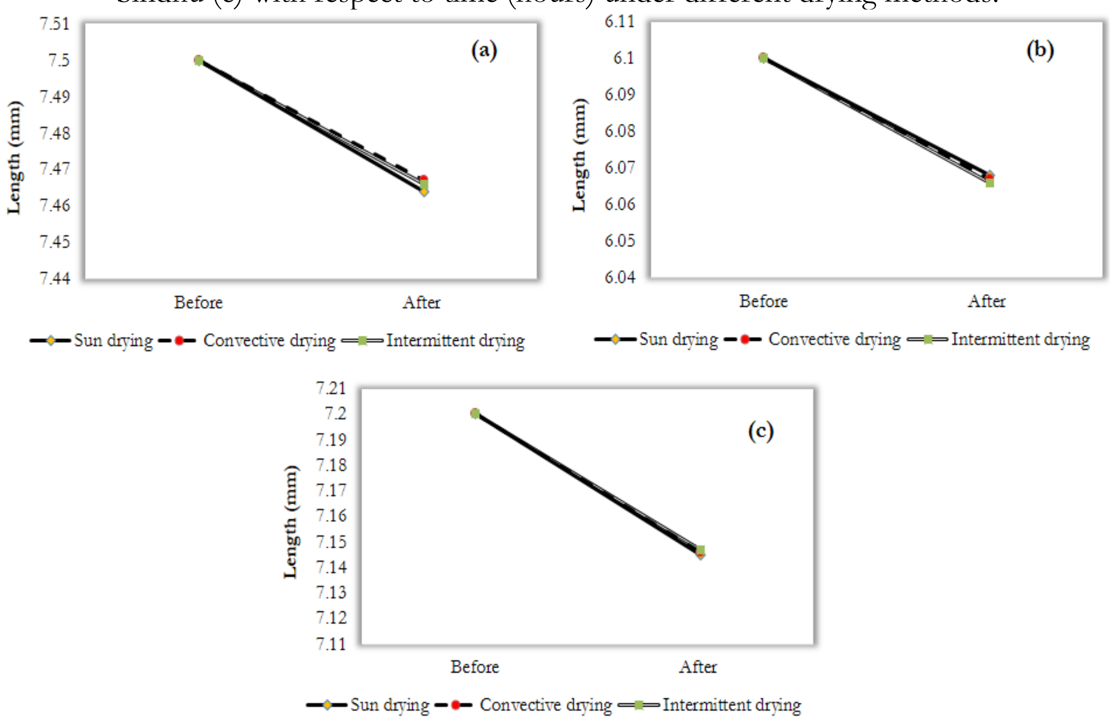

Figure 4. Variation in length (mm) of varieties TD-1 (a), Imdaad-2005 (b) and Sindhu (c) under different drying methods.

Figure 5(a–c) illustrates the width variations of different wheat varieties when subjected to various drying methods. The width of the TD-1 grain variety decreased from 3.30 mm at 20% moisture content to 3.280 mm, 3.278 mm and 3.276 mm after sun drying, convective drying and intermittent drying respectively at 11% moisture content. The width of Imdaad-2005 in sun drying, convective drying and intermittent drying decreased from 3.80 mm at 20% to 3.780, 3.770 and 3.775 mm at 11%. The width of Sindhu in sun drying, convective drying and intermittent drying decreased from 3.10 mm at 20% to 3.075, 3.080 and 3.070 mm at 11% moisture content.

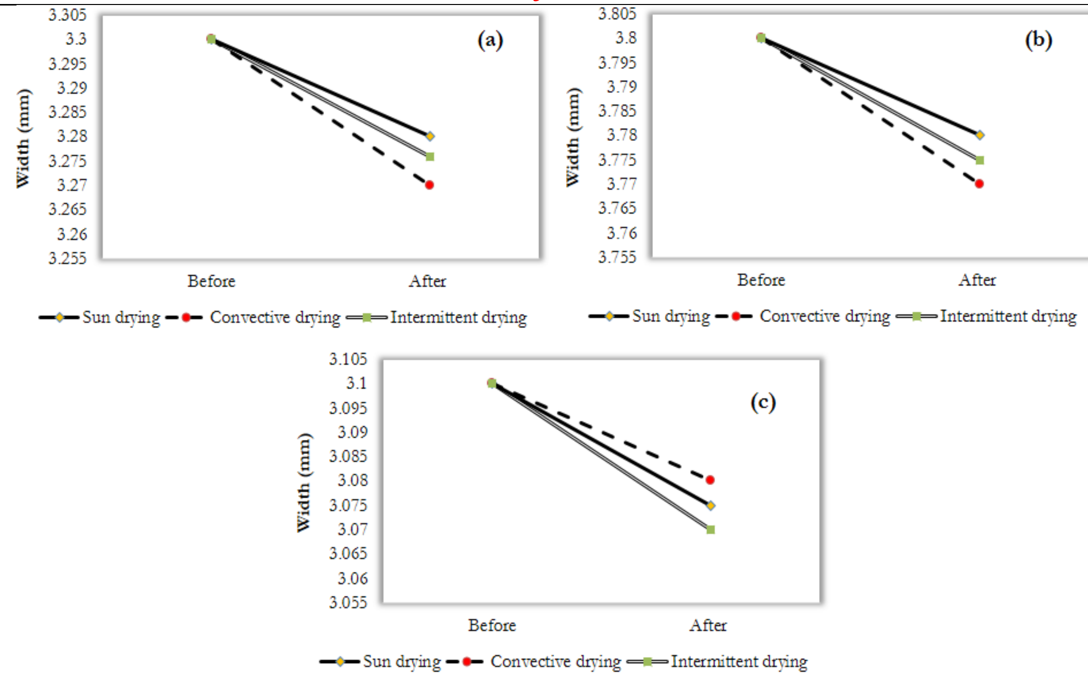

Figure 5. Variation in width (mm) of varieties TD-1 (a), Imdaad-2005 (b) and Sindhu (c) under different drying methods.

Figure 6(a–c) presents the thickness variations of different wheat varieties under various drying methods. The thickness of the TD-1 variety decreased from 2.50 mm at 20% moisture content to 2.475 mm, 2.476 mm and 2.478 mm after sun drying, convective drying and intermittent drying respectively at 11% moisture content. Similarly, the thickness of the Imdaad-2005 variety decreased from 2.60 mm at 20% to 2.574 mm, 2.575 mm and 2.576 mm at 11% moisture content, while the Sindhu variety showed a reduction from 2.30 mm at 20% to 2.260 mm, 2.261 mm and 2.264 mm at 11% moisture content.

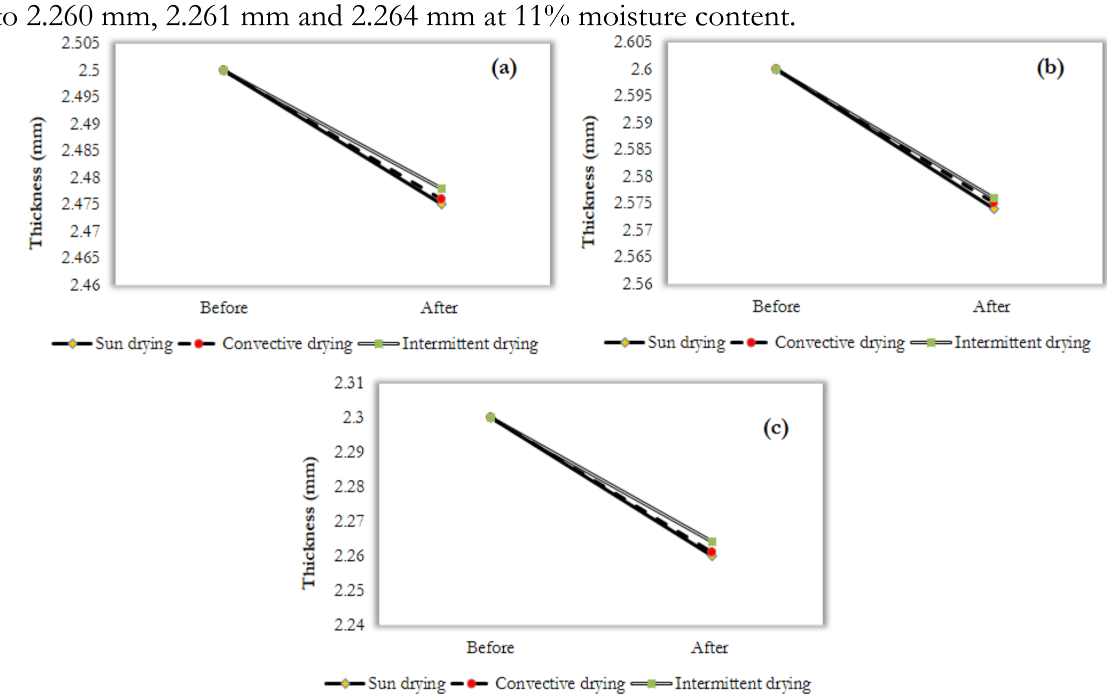

Figure 6. Variation in thickness (mm) of varieties TD-1 (a), Imdaad-2005 (b) and Sindhu (c) under different drying methods.

Figure 7(a–c) illustrates the variation in thousand kernel weight for different wheat varieties when subjected to various drying methods. The thousand kernel weight of TD–1 in sun drying, convective drying and intermittent drying decreased from 39.66 g at 20% to 33.05, 33.20 and 33.37 g at 11%. The thousand kernel weight of Imdaad-2005 in sun drying, convective drying and intermittent drying decreased from 42.43 g at 20% to 36.13, 36.07 and 36.39 g at 11%. The thousand kernel weight of Sindhu in sun drying, convective drying and intermittent drying decreased from 35.26 g at 20% to 30.02, 30.13 and 30.41g at 11%.

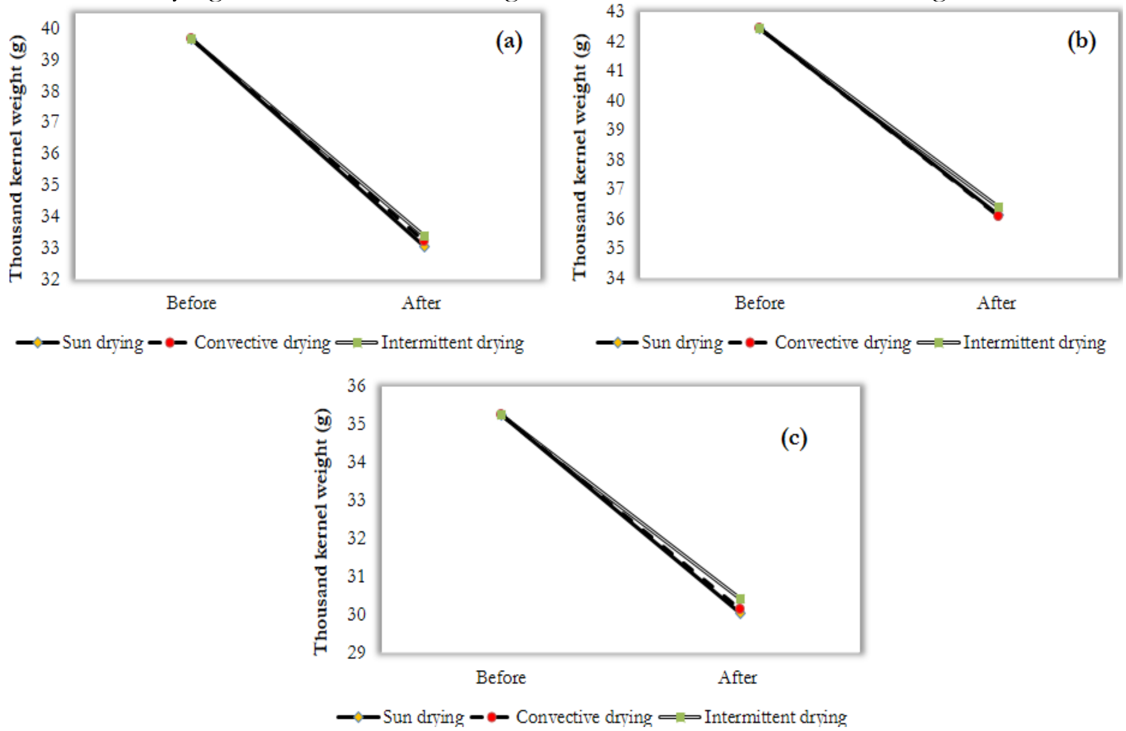

Figure 7. Variation in thousand kernel weight (g) of varieties TD-1 (a), Imdaad-2005 (b) and Sindhu (c) under different drying methods.

Weight loss of different wheat varieties under different drying methods is shown in Figure 8(a-c). A sample of 500g was kept for drying in all three methods. After drying, the weight loss of the TD-1 wheat variety for sun drying, convective drying and intermittent drying was observed to be 409.73, 409.18 and 409.19 g at 11% moisture content. After drying, the weight loss of the Imdaad-2005 wheat variety was recorded to be 409.62 g, 409.44 g and 409.43 g under sun drying, convective drying and intermittent drying respectively at 11% moisture content. Similarly, the Sindhu variety showed weight loss of 409.27 g, 409.62 g, and 409.63 g under the same respective drying methods at 11% moisture content.

The bulk density of different wheat varieties under different drying methods is shown in Figure 9(a-c). The bulk density of TD–1 in sun drying, convective drying and intermittent drying decreased from 0.97 g/cm^3 at 20% to 0.956, 0.957 and 0.955 g/cm^3 at 11%. The bulk density of Imdaad-2005 in sun drying, convective drying and intermittent drying decreased from 1.02 g/cm^3 at 20% to 0.986, 0.984 and 0.987 g/cm^3 at 11%. For the Sindhu variety, bulk density decreased from 0.97 g/cm^3 at 20% moisture content to 0.951 g/cm^3 in sun drying, 0.953 g/cm^3 in convective drying, and 0.952 g/cm^3 in intermittent drying at 11% moisture content.

The germination of different wheat varieties under different drying methods is shown in Figure 10(a-d). The germination percentage in the TD-1 variety decreased from 95% at 20% moisture content to 70% under sun drying, 60% under convective drying, and 80% under intermittent drying at 11% moisture content. The germination of Imdaad-2005 in sun drying, convective drying and intermittent drying decreased from 70% at 20% to 50, 60 and 70 % at 11%. For the Sindhu variety, the germination percentage decreased from 80% at 20% moisture content to 70% in sun drying, 60% in convective drying, and 80% in intermittent drying at 11% moisture content.

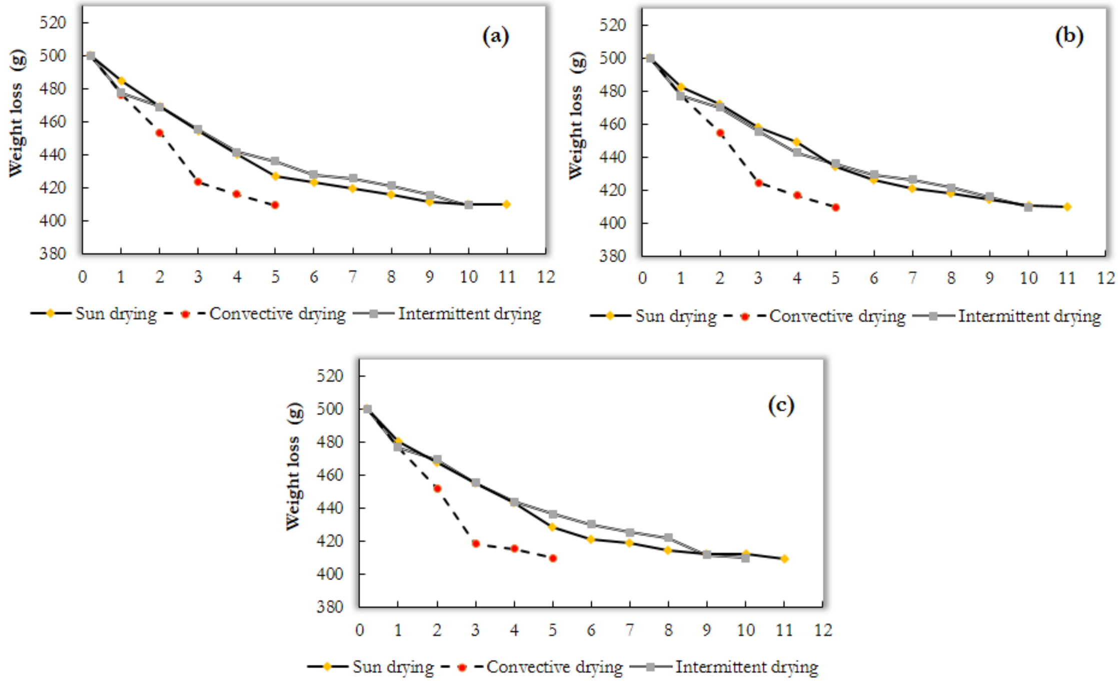

Figure 8. Variation in weight loss (g) of varieties TD-1 (a), Imdaad-2005 (b) and Sindhu (c) with respect to time (hours) under different drying methods.

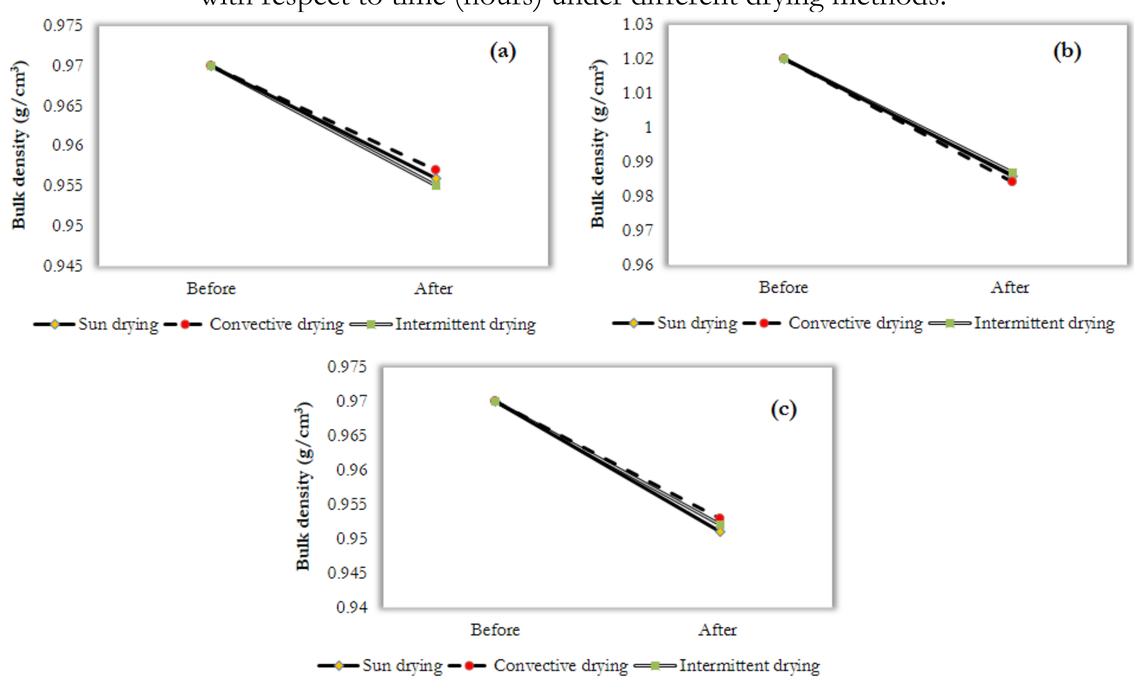

Figure 9. Variation in bulk density (g/cm^3) of varieties TD-1 (a), Imdaad-2005 (b) and Sindhu (c) under different drying methods.

The drying rate of different wheat varieties under different drying methods is shown in Figure 11(a-c). The drying rate of TD–1 in sun drying, convective drying and intermittent drying decreased from 1.92, 1.72 and 1.99 g/hr at 20% to 0.03, 0.05 and 0.02 g/hr at 11%. The drying rate of Imdaad-2005 in sun drying, convective drying and intermittent drying decreased from 1.99, 1.69 and 2.09 g/hr at 20% to 0.02, 0.04 and 0.04 g/hr at 11%. The drying rate of Sindhu in sun drying, convective drying and intermittent drying decreased from 2.06, 1.8 and 2.14 g/hr at 20% to 0.01, 0.03 and 0.02 g/hr at 11%.

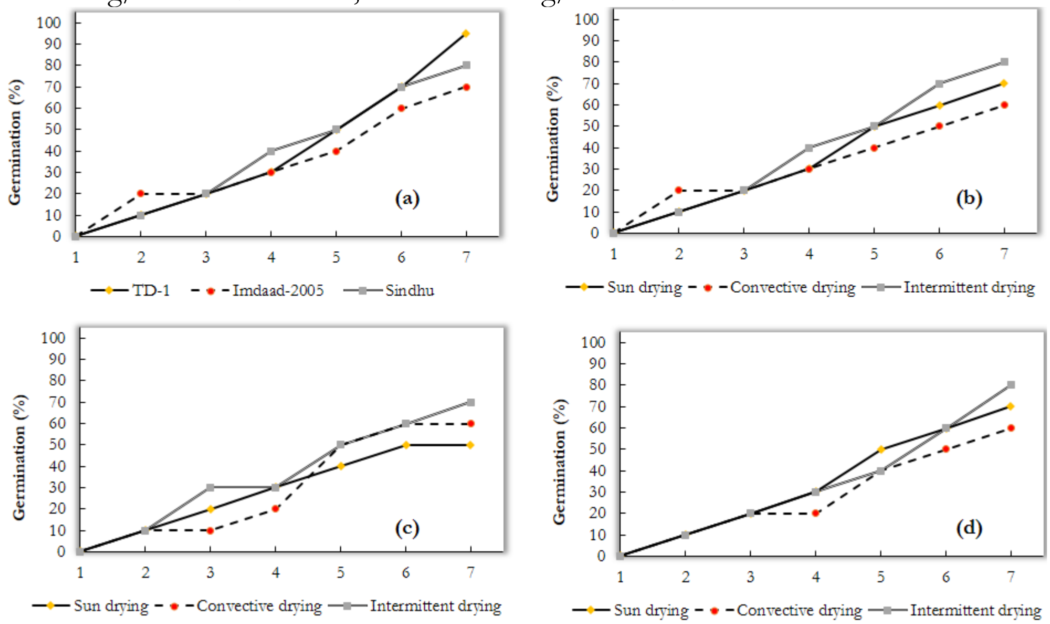

Figure 10. Variation in germination (%) of the initial sample (a), and of varieties TD-1 (b), Imdaad-2005 (c) and Sindhu (d) with respect to days under different drying methods..

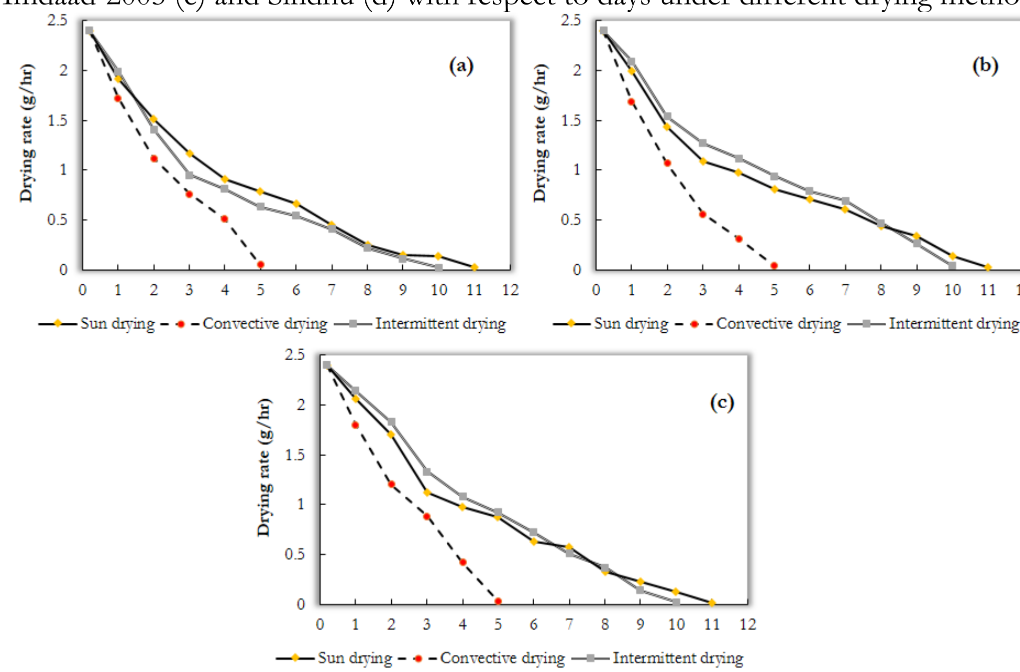

Figure 11. Variation in drying rate (g/hr) of varieties TD-1 (a), Imdaad-2005 (b) and Sindhu (c) with respect to time (hours) under different drying methods.

Discussion:

The drying process is driven by the heat and mass transfer between the grain and its surrounding environment. Incomplete, improper and over-drying can significantly alter grain quality and reduce consumer acceptance. The desired moisture content of dried grain is therefore a key parameter in designing effective drying systems and selecting optimal performance [24]. The results for this study revealed that the moisture content decreased with increasing drying time, under all drying methods i.e. sun drying, convective drying and intermittent drying (Figure 3). The results are in line with the study conducted by Mabasso et al. [25]. The length of wheat grains decreased with increasing drying time (Figure 4) under all drying methods. The length of TD – 1 in sun drying, convective drying and intermittent drying decreased from 7.50 mm at 20% moisture content to 7.464, 7.467 and 7.466 mm at 11%, for Imdaad-2005 variety it decreased from 6.10 mm at 20% to 6.068, 6.067 and 6.066 mm at 11%, and for Sindhu variety it decreased from 7.20 mm at 20% to 7.145, 7.146 and 7.147 mm at 11% respectively. These findings align with those reported by Sahoo et al. [26], who observed a reduction in seed length from 4.80 mm to 4.54 mm as the moisture content decreased from 25% to 10%. Similar results for the impact of drying time and intermittence for polished and brown rice using various analytical techniques have also been reported by Martens et al. [17]. The width and thickness of wheat grains for all varieties decreased with decreasing moisture content from 20% to 11% (Figures 5 & 6), and increasing drying time. These results are consistent with the findings of Jamali et al. [27], who reported that the width of different wheat grain varieties decreased with a decrease in moisture proportion. The average seed width of TD-1 decreased from 4mm at 20% moisture content to 3.83mm at 10%. Similarly, the length of the TJ-83 variety decreased from 3.17 mm at 20% moisture content to 3.00 mm at 10%. These findings are further supported by Amin et al. [28], who reported that the seed thickness of lentils varied linearly with changes in moisture content.

The thousand-kernel weight of wheat grains for all varieties decreased with increasing drying time (Figure 7). The thousand kernel weight of TD – 1 in sun drying, convective drying and intermittent drying decreased from 39.66 g at 20% moisture content to 33.05, 33.20 and 33.37 g at 11%, for Imdaad-2005 variety it decreased from 42.43 g at 20% to 36.13, 36.07 and 36.39 g at 11%, and for Sindhu variety it decreased from 35.26 g at 20% to 30.02, 30.13 and 30.41g at 11% respectively. These results are in line with the findings of Ganjloo et al. [29], who reported that the mass of one thousand green pea seeds decreased linearly from 547.46 to 188.89 g as the moisture content decreased from 75.15 to 15.21%. Soliman et al. [30] reported a decrease in thousand kernel weight from 39.7g to 23.2g. The weight loss of wheat grains for all varieties decreased with increasing drying time (Figure 8). A sample of 500g was kept for drying in all three methods. The weight loss of TD-1 wheat variety after drying for sun drying, convective drying and intermittent drying was observed to be 409.73, 409.18 and 409.19 g at 11% moisture content, for Imdaad-2005 variety it was observed to be 409.62, 409.44 and 409.43 g at 11 %, and for Sindhu variety it was observed to be 409.27, 409.62 and 409.63 g at 11%. The results are in line with the study conducted by Likhayo et al. [31] and Mahmood et al. [32]. The bulk density of wheat grains decreased with increasing drying time (Figure 9). These findings are consistent with those of Soliman et al. [30], who reported that the bulk density of wheat at 11.9% moisture content was 715.29 kg/m³, which was lower with 767 kg/m³ when recorded at 18% moisture content. The results also support the findings of Paziuk et al. [33], who conducted a study on improving the energy efficiency of grain seed drying processes while preserving seed quality. The germination of wheat grain varieties decreased with increasing drying time (Figure 10). These results are in line with the findings of Paliwal & Sharma [34], who reported that germination of the seed decreased with increasing drying process. The drying rate of wheat grains for the all varieties decreased with increasing drying time (Figure 11). The drying rate of TD – 1 in sun drying, convective drying and intermittent drying decreased from 1.92, 1.72 and 1.99 g/hr at 20% moisture content to 0.03, 0.05 and 0.02 g/hr at 11%, for Imdaad-2005 it decreased from 1.99, 1.69 and 2.09 g/hr at 20% to 0.02, 0.04 and 0.04 g/hr at 11%, and for Sindhu it decreased from 2.06, 1.8 and 2.14 g/hr at 20% to 0.01, 0.03 and 0.02 g/hr at 11%. These results are in line with the findings of Shalini et al. [35], who reported that the drying rate of wheat grain varied with a decrease in the moisture content. The drying rate initially decreased rapidly, which, with time, became slow. Franco et al. [36] also had also concluded with similar results while conducting a study on the intermittent drying of rice grains to improve the drying process.

Conclusion:

The moisture content, length, width, thickness, thousand kernel weight, weight loss, bulk density, germination and drying rate for all wheat varieties i.e. TD-1, Imdaad-2005 and Sindhu decreased with respect to time in all drying methods i.e. sun drying, convective drying and intermittent drying. The results in terms of quality after drying were observed to be better for intermittent drying, followed by convective and sun drying for all wheat varieties. Based on the findings of this study, the farmers and grain processing industries are suggested to adopt the intermittent drying method, which results in better grain quality and energy saving.

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