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Effect of two stage drying on milling performance: The case of parboiled paddy

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Abstract: *Paddy drying is an important global issues both for producer and the millers. This study aimed at evaluating the effect of two stage drying techniques on the milling performance of parboiled paddy. For this, BRRI Dhan 28 was used in this study, which become parboiled by traditional method. The parboiled paddy was then dried by two options of two stage drying: (i) Fluidized Bed Drying (FBD) at the first stage and tempering followed by again fluidized bed drying at low temperature (FBD+FBD) (ii)FBD at high temperature at the first stage and tempering followed by sun drying (FBD+SUN), and (iii) Sun drying (at ~32^{o}C) as the control. The first stage drying in fluidized bed dryer was carried out using three temperatures viz. 150, 160 and 170^{o}C for 3.0, 2.5, and 2.0 min, respectively at three different bed thickness viz. 8, 9, and 10 cm. After first stage drying, tempering was done for 45 minutes. For the first option, the second stage drying was carried by the same fluidized bed dryer at 50^{o}C for 60 min and bed thickness of 16 cm,andunder natural sun light as the second stage drying for the second option. Results revealed that uniform moisture content was observed during the first stage drying by fluidized bed dryer, which reduced from initial 35.25% (wet basis, wb) to intermediate moisture content of ~18.50% (wb). However, significant difference (P<0.05) was existent among the sample dried by the fluidized bed dryer and sun drying method as the second stage in reducing the moisture from intermediate (~18.50%, wb) to final (~13%, wb). Results of milling performance of two stage drying options demonstrated a considerable amount of milling recovery (78.33-80.93% for FBD+FBD, 79.13-80.95% for FBD+SUN, and 84.45% for the control), head rice (62.34-64.95% for FBD+FBD, 62.25-65.25% for FBD+SUN, and 73.15% for the control) and broken yield (13.98~15.88% for FBD+FBD, 11.48~12.98% for FBD+SUN, and 11.79% for the control) for the parboiled paddy, which were slightly lower than the control drying method (sun drying).Overall, the drying performance of the two stage drying techniques in case of parboiled paddy is acceptable considering the milling performance and could be used as alternative drying technique.*

Keywords: *Paddy drying, two-stage drying, fluidized bed drying, parboiled rice, milling performance*

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I. Introduction

Rice is one of the most important cereal crops and consumed as a staple food in many countries in the world, because of its significance inproviding basic nutrition (Deepa et al., 2010). About 500 million tons of milled rice are produced inthe world annually (Ricestat, 2017). Postharvest processes, including the operations from harvesting tomilling cause losses both in quantity and quality inthe range of 20–30% of rice grain produced (FAO,2013). Postharvest management of rough rice (paddy) plays a crucial role inmaintaining rice quality.In all paddy producing countries, paddy drying and management are the great concern of the millers and processors (Ibrahim et al. 2014). Moisture content of rough rice varies between 20-25% (wet basis, wb) during the harvesting time (Sarker et al., 2014). At these stages, humid condition accelerates the growth of molds and yellowing of the grains (Soponronnarit et al., 1998; Tirawanichakul et al., 2004). Therefore, removal of excess moisture from the paddy grain is necessary to increase the storability as well as to improve the milling recovery. Drying is one of the simplest but crucial food preservation methods that improve the stability of agroproducts for longer time by reduction of moisture to a safe level for storage and preventing the growth of microorganisms (Kamal et al., 2020; RKB, 2017). Delayed drying,incomplete drying, or inefficient drying leads to reduction in rice quality and increase in postharvest losses(RKB, 2017; Xiao & Gao, 2008).Parboiling or partial boiling is a hydrothermal process applied as a pretreatment prior to the drying and normal milling stage(Bhattacharya, 2011), which is nothing but rice precooked in paddy form and then dried back before being milled. During parboiling, starch granules become gelatinized,and open molecules of starch and protein fill the empty space between the grains in the endosperm. Also, the hydrogel of starch is subjected towet heat, which get a product having greater rigidity (Chun et al., 2015). As a result of gelatinized starch,several important physical changes occur in parboiled rice which play an important role in the next processingoperations of rice such as, 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).Besides, the color of parboiled rice grain becomes fainter and more rigid mode which can reduce percent of the broken kernels of riceduring processing due to prevent rice crunch (Agrawal et al., 2014). Parboiling of paddy is carried out in three steps: soaking, steamingand drying. In the soaking process void spaces in the hull and rice kernel are filled with water while steaming enhance the moisture content of paddy(Ituen and Ukpakha, 2011). The next step is the drying, which may be carried out in shade, sun or with hot air.Drying ofhigh moisture paddy is important to prevent the grain quality deterioration. The traditional drying process such as sun drying, is inadequate to guarantee the quality and quantity of the dried products (Kamal et al., 2019), so thereis a high demand for mechanical drying facilities. Several methods have been used for drying ofparboiled rice, such as sun drying, hot air drying (e.g. fluidized bed drying, Luciana State University (LSU) drying, fixed and inclined bed drying, etc.), vacuum drying and superheated steam drying(Bhattacharya, 2011; Soponronnarit et al., 2006; Taechapairoj et al., 2004).These drying techniques have several advantages e.g. reduced drying time, high milling yield, minimum broken rice with quality dried rice. In the recent years, two stage drying technique has gained popularity in many countries of the world for drying of cereal grains e.g. paddy, maize etc. (Akhtaruzzaman et al., 2021; Mondal et al. Mondal et al., 2019; Inprasit& Noomhorm, 2001). In this technique, grains are dried at high temperature (usually 80-200^oC) in the first stage (Inprasit& Noomhorm, 2001), which reduces the moisture level to 18~20% (wb) followed by low temperature drying (usually 40-60^oC) to reduce the moisture to a safe level of 12~14% (wb.) for longer storage (Sarker et al., 2013). The specific feature of such drying technique is the use of high velocity hot air at elevated temperature in the first stage of drying, resulting in reduced drying time and specific energy consumption with the maintenance of the quality of dried grains (Sarker et al., 2015). In the past few decades, a number of studies have been conducted on ordinary grain drying, most of which covered a wide range of topics including the drying kinetics and modeling of grain drying behaviour, physical properties, milling recovery, and cooking quality of the dried grains (Borompichaichartkul et al., 2007; Jaiboon et al., 2009; Nimmol & Devahastin, 2010; Zheng et al., 2011; Sarker et al., 2013, 2014, 2015; Mondal et al., 2019). However, studies related to drying of parboiled paddy using two stage drying techniques and its effect on the milling performance was not available elsewhere. Therefore, this study was aimed to investigate the drying and milling performance of parboiled paddy dried by two stage drying schemes employing fluidized bed dryer in the first stage followed by different preferences of second stage drying (fluidized bed dryer, and sun drying).

II. Materials and Methods

Collection of sample

In the present study, the most popular, commonly cultivated and high yield variety BRRI Dhan 28 was used for the experimental purpose. The paddy was collected from the local market of Dinajpur (one of the most paddy growing region), Bangladesh.

Parboiling process

In this study, the traditional parboiling method was used. For this, the paddy sample collected were first cleaned to remove impurities such as leaves, broken stalks, chaffs, immature seeds and unfilled seeds in order to obtain well filled samples for the experiment. Thereafter, the paddy was soaked into water at room temperature for 10 hr. (Khanali et al. 2012) and then the water was removed. The soaked paddy sample were kept in a aluminium pot and steam was produced by using a charcoal used kiln. The steaming process was continued until the vapor visible at the top.

Drying experiment

A laboratory scale batch type fluidized bed dryer designed and fabricated in the Department of Food Engineering and Technology, HSTU, Dinajpur was used for the first stage and second stage (in case of two stage drying operation) drying of the paddy samples. The dryer was made up of stainless steel and consisted a cylindrical fluidized bed column (75 cm height and 20 cm wide), 18 KW electric heater unit and 2.2 kW backward-curved blade centrifugal blower motor air inlet and recycling option of exhaust air. The schematic diagram the dryer is shown in **Fig. 1.**In this study, two options of two-stage drying were accomplished. First option of drying was carried out by Fluidized Bed drying at the first stage and tempering followed by again fluidized bed drying at low temperaturewhile the second option was conducted using fluidized bed drying at high temperature at the first stage and tempering followed by sun drying at the second stage. Paddy dried under natural sunlight (at ~32^{o}C) was used as the control. The first stage drying in fluidized bed dryer was carried out using three temperatures viz. 150, 160 and 170^{o}C for 3.0, 2.5, and 2.0 min, respectively at three different bed thickness viz. 8, 9, and 10 cm. After first stage drying, all dried samples were immediately tempered for 45 minutes by keeping in a plastic container (diameter and height were 10 cm and 12 cm, respectively).

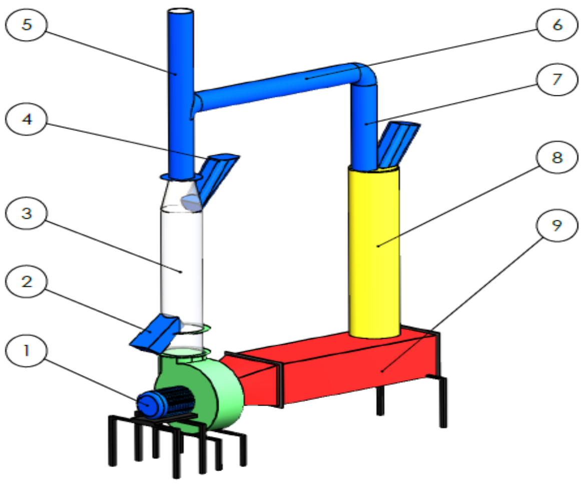

Fig. 1 The lab scale fluidized bed dryer used in this study. [1. Blower motor, 2. Outlet, 3. Drying chamber, 4. Inlet, 5. Air exhaust, 6. Recycling of exhaust Air, 7. Air inlet, 8. Mixing chamber, 9. Electric heater unit]

For the first option of two stage drying, the tempered samples were dried in second stage by the same fluidized bed dryer at 50^{o}Cfor 60 min and bed thickness of 16 cm (based on the preliminary experiments). For the second option, the fluidized bed dried sample at the first stage were used and again dried under natural sun light as the second stage drying. The corresponding time required to reach intermediate moisture content about ≤18% (wb) during first stage drying and final moisture content about ≤13% (wb) during second stage drying were recorded. During the drying operations, moisture content of dried paddy sample at different time interval was determined by digital grain moisture meter (GMK-303RS, Korea) with an accuracy of ± 0.5%, which was calibrated with oven drying method. The drying experiments were performed three times and corresponding data were recorded. The dried samples were stored in high density polyethylene bags at room temperature for assessment of milling performance.

Evaluation of milling performance

Evaluation of milling quality is an important criterion to identify the effect of drying techniques applied for removing the moisture. Thus, to know the effect of two stage drying technique on milling quality in terms of milling recovery,head rice yield and broken were analyzed in this study. For this, first the milling operation of the dried parboiled paddy samples were done using the Satake Dehusking Machine (Model: THU35B (3)-T, Japan) and Polisher (TMO5C(2)-T, Japan). Thereafter, the milling recovery,head rice yield and brokenwere determined according to the following equations (Sarker et al.,2013) and expressed as the percentage.

$$\%\ \text{Milling Recovery} = \frac{\text{Weight of milled rice}}{\text{Weight of dried paddy taken for milling}} \times 100$$

$$\%\ \text{Head Rice Yield} = \frac{\text{Weight of head rice}}{\text{Weight of dried paddy taken for milling}} \times 100$$

$$\%\ \text{Broken Yield} = \frac{\text{Weight of broken rice}}{\text{Weight of dried paddy taken for milling}} \times 100$$

Statistical analysis

The data obtained for drying time, milling recovery and head rice were analyzed using IBM SPSS (Version 22.0, SPSS Inc., Chicago, IL) statistical software and the results were expressed as the mean value ± standard deviation of three replicates. Statistically significant differences among the mean values of the analyzed parameters were evaluated by Duncan's Multiple Range Test (DMRT) at 95% confidence level.

III. Results and Discussion

Effect of two stage drying on the drying performance of parboiled rice

Moisture content plays significant role in the shelf life of dried paddy as it is associated with the growth of microorganisms and quality of the milled rice. Therefore, drying is an important option to reduce the moisture to a safe level for efficient storage of paddy or rice. Table 1 shows the effect of fluidized bed drying temperature during the first stage on the moisture content of parboiled paddy dried at different bed thickness (8-10 cm) and using the drying temperature of 150, 160 and 170°C for 3, 2.5 and 2 min, respectively based on the preliminary study. Prior to drying experiment, the parboiled paddy had the initial moisture content of 35.26% (weight basis, wb). It can be seen in case of bed thickness of 8 cm, the moisture content varied between 18.31-18.78% (wb) when dried at 150-170°C and no significant variation was observed among the samples (Table 1).

Table 1. Performance evaluation of first stage drying of parboiled rice using fluidized bed dryer (FBD) at higher temperatures

Drying temperature	Bed thickness	Initial paddy moisture	Intermediate moisture (%)
150°C	8 cm	35.26%	18.31±0.81a
160°C			18.78±0.18a
170°C			18.42±0.27a
150°C	9 cm		18.53±0.50a
160°C			18.23±0.31a
170°C			18.61±0.51a
150°C	10 cm		17.44±0.46b
160°C			18.15±0.39a
170°C			17.65±0.50b

Values are mean ± standard deviation of three replicates. Different lowercase letters in the column were differed significantly among the samples

Similar trend was observed for bed thickness 9 cm where the moisture content varied between 18.23-18.61% (wb), however, samples dried at 10 cm bed thickness and 150-170°C varied significantly ($P<0.05$) and ranged from 17.44 to 18.15% (wb) (Table 1). It can be noticed that the higher temperatures resulted in a rapid decease in moisture of the parboiled paddy from initial 35.25% to intermediate moisture content of ~18.50%, which might be due to the fact that themoisture is present near the surface of the parboiled paddy, thus allowing that moisture to be removed more easily in thefluidized bed since the high air flow was used. In addition, thetransfer rate of heat was rapid and this effect resulted in thehigh evaporation rate of moisture (Bootkote et al. 2016).

Table 2. Performance evaluation of two stage drying of parboiled rice: FBD at higher temperature followed by FBD at 50°C

First stage drying using FBD at higher temperature			Second stage drying using FBD at 50°C	
Drying temperature	Bed thickness	Intermediate moisture (%)	Bed thickness	Final moisture (%)
150°C	8 cm	18.31±0.81a	16 cm	13.47±0.09a
160°C		18.78±0.18a		12.78±0.07b
170°C		18.42±0.27a		12.23±0.10b
150°C	9 cm	18.53±0.50a		13.36±0.20a

160°C		18.23±0.31a	13.32±0.13a
170°C		18.61±0.51a	12.95±0.03ab
150°C		17.44±0.46b	12.35±0.02b
160°C	10 cm	18.15±0.39a	12.67±0.07b
170°C		17.65±0.50b	13.12±0.04a
Sun drying (control)			13.89±0.71a

Values are mean ± standard deviation of three replicates. Different lowercase letters in the column were differed significantly among the samples; FBD- Fluidized Bed Drying

Again in case of second stage drying using fluidized bed dryer at 50°C for 60 min for removing moisture from the intermediate (~18.5%, wb) to final (~13%, wb), significant difference ($P<0.05$) had existent among the samples irrespective of initial dried samples obtained at high temperature and different bed thickness (Table 2). Almost similar trend was observed for second stage drying using sun drying method expect those samples obtained at 10 cm bed thickness and different first stage drying temperatures (Table 3). It can be concluded from Table 2 and Table 3that both option of two stage drying techniques, i.e. fluidized bed drying at high temperature in the first stage followed by fluidized bed drying at low temperature and sun drying at the second stage produced dried paddy of uniform moisture content with some exceptional cases, which was comparatively similar with the sun dried paddy. Previous study evidenced that two stage drying techniques using fluidized bed following some other drying options such as LSU and sun drying have resulted uniform drying of different cereal grains such as paddy, maize and wheat (Akhtaruzzaman et al. 2021; Sarker et al. 2013; Inprasit& Noomhorm, 2001).

Table 3. Performance evaluation of two stage drying of parboiled rice: FBD at higher temperature followed by sun drying at 32°C

FBD at higher temperature at the first stage drying			Sun drying at the second stage
Drying temperature	**Bed thickness**	**Intermediate moisture (%)**	**Final moisture (%)**
150°C		18.31±0.81a	13.87±0.19a
160°C	8 cm	18.78±0.18a	13.65±0.49a
170°C		18.42±0.27a	13.95±0.87a
150°C		18.53±0.50a	13.83±0.19a
160°C	9 cm	18.23±0.31a	13.69±0.21a
170°C		18.61±0.51a	13.78±0.21a
150°C		17.44±0.46b	13.30±0.67b
160°C	10 cm	18.15±0.39a	13.13±0.56b
170°C		17.65±0.50b	13.55±0.12ab
Sun drying (control)			13.89±0.71a

Values are mean ± standard deviation of three replicates. Different lowercase letters in the column were differed significantly among the samples; FBD- Fluidized Bed Drying

Effect of two stage drying on the milling performance of parboiled rice

Milling recovery

The milling recovery of parboiled rice dried using two stage drying options are presented in Table 4. It can be seen that the milling recovery of parboiled paddy was ranged between 78.33-80.93% for FBD+FBD, 79.13-80.95% for FBD+SUN while it was 84.45% for the sun dried paddy (Table 4). Parboiled paddy dried by fluidized drying in both stages at 10 cm bed thickness had the highest milling recovery (80.20-80.93%) irrespective of drying temperature in first stage and were not differed significantly.Furthermore, it can be observed from Table 4 that milling recovery decreased with the lowering of bed thickness. As in case of 8 cm bed thickness the milling recovery was 78.33-78.83% while it was 79.18-79.68% for 9 cm bed thickness. On the other hand, Table 4 also depicts that comparatively higher milling recovery was observed for paddy dried with fluidized bed dryer followed by sun drying methods for the bed thickness of 8 cm (79.60-80.50%) and 9 cm (80.63-80.95%) than the FBD+FBD (78.33-78.83% and 79.18-79.68% for 8 cm and 9 cm, respectively). However, in this case, the milling recovery significantly increased with bed thickness from 8-9 cm then decreased. Although significant amount of milling yield was recovered, however, these values are much lower than that of sun dried paddy (84.45%). The variation in the milling recovery of parboiled rice/paddy might be bed thickness along with higher temperature in the fluidized bed dryer during the first stage drying. Also, the extend of milling might contributed to the recovery of milling yield of the parboiled paddy.

Head rice and Broken yield

Head rice yield is one of the crucial parameters of dried paddy. The head rice yield of parboiled rice dried using two stage drying techniques are summarized in Table 4. In case of first option of two stage drying i.e., FBD+FBD, the head rice yield of parboiled rice was ranged between 62.34-64.95% irrespective of the drying temperatures in the first stage and the bed thickness while these values were fluctuated within 62.25-65.25% for second option of two stage drying i.e., FBD+SUN.Also, it can be observed in Table 4 that the head rice yield was not varied significantly (regardless some exception) among the two stage dried parboiled paddy, when the paddy was dried to be almost the same final moisture content. Similar observation was reported by Bootkote et al. (2016).However, the control sample (paddy dried by sun drying method) yielded 76.15% head rice, which is quite higher than the two stage dried samples. Comparatively, similar results were found in different literatures, for instance, Bootkote et al. (2016) reported 60-71% head rice yield for parboiled paddy dried using fluidized bed dryer at different temperature; Mitsiri et al. (2020) stated 59-66% for parboiled rice dried by fluidized bed drying, Tirawanichakul et al. (2012) mentioned 58-72% for parboiled rice dried using convective and infrared irradiation techniques.Table 4 also showed that with the elevation of temperature of fluidized bed drying in the first stage, the head rice yield become decreased irrespective of the bed thickness used. Furthermore, head rice yield of parboiled paddy was the highest when used FBD+FBD techniques than the FBD+SUN in case of bed thickness 8 and 10 cm with some exceptional cases as for 9 cm. On the other hand, the broken rice yield was increased from 13.98% to 15.88% for FBD+FBD techniques while those values were ranged between 11.48% to 12.98% for FBD+SUN techniques, and the control sample yielded 11.79% broken rice (Table 4).

Table 4.Evaluation of milling recovery of two stage dried parboiled rice.

Firststage drying		Milling recovery (%)		Head rice yield (%)		Broken yield (%)	
Drying temperature	**Bed thickness**	**FBD+FBD***	**FBD+SUN**	**FBD+FBD***	**FBD+SUN**	**FBD+FBD***	**FBD+SUN**
150°C		78.83±0.38bc	80.08±0.27ab	64.27±0.82a	62.43±0.28c	14.48±0.28b	12.03±0.08ab
160°C	8 cm	78.48±0.13c	79.60±0.05b	63.42±0.37b	62.25±0.40c	15.53±0.18a	12.48±0.13a
170°C		78.33±0.23c	80.50±0.10a	62.34±0.53c	62.98±0.23bc	15.88±0.23a	12.05±0.15ab
150°C		79.28±0.07b	80.70±0.45a	64.55±0.76a	65.25±0.15a	13.98±0.18bc	11.48±0.33b
160°C	9 cm	79.68±0.38b	80.63±0.13a	64.22±1.06a	65.10±0.15a	14.28±0.03b	11.48±0.08b
170°C		79.18±0.08b	80.95±0.15a	63.67±0.45b	64.95±0.10ab	14.01±0.05b	12.08±0.02a
150°C		80.20±0.10a	79.13±0.17b	64.95±0.28a	64.48±0.18b	15.48±0.33a	12.85±0.35a
160°C	10 cm	80.93±0.23a	79.60±0.25b	64.45±0.50a	63.63±0.08bc	15.58±0.13a	12.50±0.15a
170°C		80.38±0.13a	79.88±0.17b	64.07±0.76ab	64.55±0.20ab	15.10±0.20a	12.98±0.18a
Sun Drying (control)		84.45±0.69		73.15±0.91		11.79±0.73	

Values are mean ± standard deviation of three replicates. Different lowercase letters in the column were differed significantly among the samples; FBD- Fluidized Bed Drying; FBD*- Fluidized Bed Drying in second stage at 50°C; SUN- Sun Drying

It is clearly seen in Table 4 that broken percentage was minimum in case of FBD+SUN techniquesFBD+FBD and elevated temperature produced higher broken percentage and lower head rice yield. Previous study evidenced that milling recovery i.e., head rice yield and broken yield depends on several factors like, moisture content of the paddy, drying temperature used, bed thickness, airflow rate, tempering time in case of two or multistage drying, and many others (Thakur and Gupta, 2006; Bootkote et al. 2016).Bootkote et al. (2016) reported that the drying temperature has astrong effect on the head rice yield asthe higher dryingtemperature provided the lower head rice yield. Because, higher drying temperature during fluidized bed drying (at the first stage) results in higher moisturedifferences between the center and the surface of the kerneland subsequently produceshigher tensile stress, which is larger than the failure tensilestrength of the parboiled paddy. Hence, the decrease of headrice yield was larger at higher drying temperature. According to Elbert et al. (2001), found that the head rice yield of theparboiled paddy was largely decreased as the drying temperature was increased, which is probably dueto the fact that higher kernels fissuring occurred at elevated temperature. However, the loss of head rice yield of parboiled paddy obtained in this study using two stage drying techniques is minimum, which might be the tempering effect after first stage drying. Previous study demonstrated that the improvement of head rice yield after tempering is due to the fact thatthe moisture gradient and stresses that had occurred duringdrying has been relaxed during tempering (Soponronnaritet al. 1999; Poomsa-ad et al. 2002; Cnossen et al. 2003). Furthermore, the damage or fissure in the parboiled paddy at intermediate stage i.e., between first and second stage drying, the moisture contents may recover after temperingsince the starch molecules can move and seal the cracks (Bootkote et al. 2016; Poomsa-ad et al. 2005).

IV. Conclusions

In this study, the effect of two stage drying techniques such as fluidized bed drying at higher temperature in first stage followed by different options of second stage drying e.g. fluidized bed drying at lower temperature and sun drying has been employed to evaluate the milling performance of parboiled paddy. Based on the findings of the study, it was observed that the performance of two stage drying techniques was considerable and can satisfactorily dry parboiled paddy with significant amount of milling recovery along with head rice yield and lower broken percentage. However, this study suggested to conduct further researches on the application of various two stage drying techniques such as fluidized bed drying followed by LSU and fixed bed drying to identify the suitable operating parameters such as temperature, bed thickness, tempering time, grain temperature along with energy efficiency and nutritional quality.

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