Development of Turning Devices for Solar Drying of Paddy Rice in the Philippines

การพัฒนาเครื่องกลับกองสำหรับการตากแห้งข้าวเปลือกใน ฟิลิปปินส์

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บทคัดย่อ: เครื่องหมุนรูปแบบใหม่ที่พัฒนาขึ้นมาสำหรับการตากแห้งข้าวเปลือกในเครื่องอบแห้งพลังงานแสงอาทิตย์แบบอุโมงค์ ถูกนำมาติดตั้งและทดสอบภายใต้สภาพการตากแห้งจริงในประเทศฟิลิปปินส์ ในการทดสอบจะทำการประเมินเพื่อหาประสิทธิภาพที่เหมาะสมของการหมุนข้าวเปลือก จากเครื่องหมุน 7 รูปแบบ ที่มีการแปรผันจำนวนและขนาดของเดือยการสั่น และกลไกการขับเคลื่อน ทั้งนี้เมล็ดข้าวที่ใช้จะถูกนำมาย้อมสี และวางในเครื่องอบแห้งระหว่างการทดสอบ จากนั้นทำการวิเคราะห์การเคลื่อนที่ของเมล็ดข้าวย้อมสีหลังจากการหมุน ผลการศึกษาพบว่าเครื่องหมุนที่มีการสั่นแบบแนวตั้งจะให้ประสิทธิภาพดีที่สุด เครื่องหมุนที่มีการสั่นแบบแนวตั้งนี้มีความแตกต่างอย่างมีนัยสำคัญเมื่อเปรียบเทียบกับเครื่องหมุนรูปแบบอื่นที่ติดตั้งในเครื่องอบแห้งพลังงานแสงอาทิตย์แบบอุโมงค์ อย่างไรก็ตามเครื่องชนิดนี้มีประสิทธิภาพในการประยุกต์ใช้ไม่เพียงแต่เฉพาะในเครื่องอบแห้งแบบพลังงานแสงอาทิตย์ แต่ยังรวมถึงกระบวนการทำแห้งเมล็ดพืชอื่น ๆ ที่มีจำนวนมาก และมีการวางแบบชั้นบาง โดยเฉพาะการตากโดยตรงด้วยพลังงานแสงอาทิตย์

คำสำคัญ: นาข้าว อุปกรณ์สำหรับพลิก การลดความชื้น เมล็ดย้อมสี

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Abstract: A previously developed turning device for paddy rice in a solar tunnel dryer consisting of a pivoted metal bar that was pulled longitudinally underneath the basement of the dryer was optimized. New model designs were constructed and tested under field conditions in the Philippines. Seven new configurations of the original device were assessed, which in cluded the amount of bars used (single or double bar), different bar diameters (2.5 or 5 cm), oscillatory or non-oscillatory motion, and two different driving mechanisms: dolly or hand pulling. A method was proposed that was able to assess the efficiency of turning the product during drying. Homogenous layers of colored grains were placed in the dryer while turning procedures were applied. From this data, displacement of colored grains was evaluated for all seven devices. The turning device, which gave the most favorable results for turning efficiency, consisted of a hand-pulled single bar at diameter of 5 cm that induced vertical oscillatory motion. The device significantly improved grain movement in the bulk compared to the six alternative devices. The method proved to be successful for evaluation of turning efficiency of paddy rice in a solar tunnel dryer. The turning device has potential application not only for solar drying, but also any drying process where grains are dried in thin bulk layers, particularly sun drying.

Keywords: Paddy rice, turning devices, drying, colored grains

Introduction

Rice (*Oryza sativa* L.) is the most vital staple food for 80% of the Philippines and the country's most important agricultural crop (Cororaton, 2006). Currently, population growth is faster than the increase in production (Dawe *et al.,* 2006; Sikkema, 2012), which inevitably will lead to increasing difficulties to feed the Filipino population in the future. The University of Hohenheim, together with local partners, is currently researching an inexpensive, easy, and reliable way of drying paddy (rough rice) in the Philippines using a solar tunnel dryer. Drying is an essential process that ensures product durability and prepares grains for milling, yet losses of up to 5% can occure during drying operations (De Padua, 1999). In addition, effective drying practices decrease fungal damage, extend shelf life, and lower the risk of losses due to insects (Jittanit *et al.,* 2010; Proctor, 1994). Solar drying practices do not rely on bulk through-flow of hot air like in conventional flat-bed dryers, thus effective and regular turning of the paddy bulk is required. Ipsita Das and Bal (2003) conducted experiments with respect to turning effects on the drying behavior of paddy rice. Paddy grains were placed into laboratory dryers where amplitude and frequency of vibration of the dryer bed could be modulated. They found that turning of paddy was important in order to establish uniform drying behavior and better-quality products. For successful operation of the solar tunnel dryer, simple turning devices, preferably made from local materials, need to be designed and tested in order to ensure uniform drying of the paddy bulk during operation. Also, a suitable method for assessment of turning efficiency of the presented devices needs to be developed. Hence, the two research questions of this study encompassed (i) the design and field testing of enhanced turning devices for solar tunnel drying applications and (ii) the development of a simple and suitable method for assessment of turning efficiency.

Materials and Methods

At the Postharvest Institute at IRRI (Los Banos, Philippines), a prototype solar tunnel dryer (27 m^2) with a capacity of 600 kg of wet paddy (Figure 1) was developed that required a system for turning the paddy grains during operation without opening the dryer. A simple device consisting of a pivoted metal bar that was pulled longitudinally underneath the polyethylene foil which was used to construct the basement of the drye (seen in Figure 1, left) was implemented. However, this device was decidedly not efficient at turning the grains and furthermore disrupted the foil during turning operations.

A downscaled version (dimensions: 1 x 3.5 m) of the original dryer was built to conduct trials on improvement of turning devices. In order to reduce the amount of product needed for experiments. A total of seven turning devices were evaluated and compared. Their respective specifications are portrayed in Table 1.

Baseline data was acquired for the original turning device (TD1, see also Figure 2) and used for comparison to the new devices TD2 to TD7 (Figure 2). The original device was re-designed into a double bar device that used metal bars at the same and at a smaller diameter (TD2, TD3 and TD4). All double bar devices were operated using a conventional dolly. The dolly enabled the induction of horizontal oscillation, a back-and-forth-movement, which was implemented during operation of TD4 and TD5 by applying rhythmical forward and backward motion while pushing the device. However, this was a non-

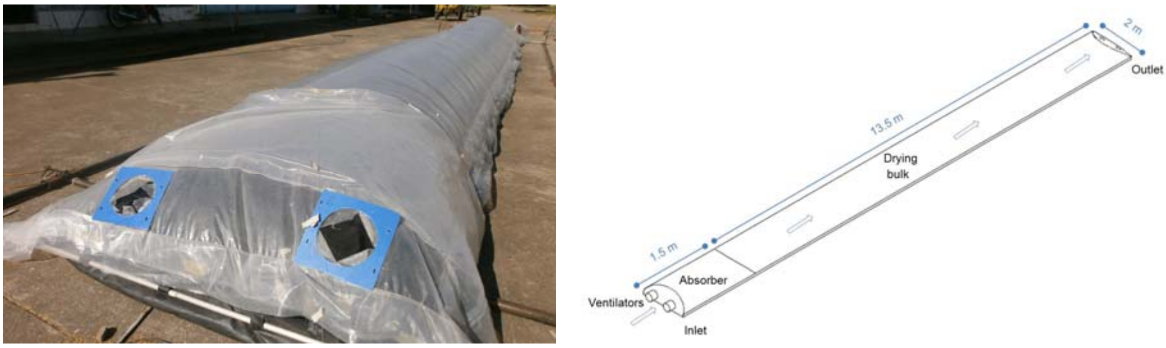

Figure 1 Description of the solar tunnel dryer when inflated (left) and sketch (right)

Table 1 Configuration and specifications of turning devices, which were designed, tested and evaluated for efficiency and ease of operation

Device	Bar	Diameter, cm	Oscillation	Operation
TD1	Single	5.0	No	Hand
TD2	Double	2.5	No	Dolly
TD3	Double	5.0	No	Dolly
TD4	Double	2.5	Horizontal	Dolly
TD5	Single	5.0	Horizontal	Dolly
TD6	Single	5.0	Vertical	Dolly
TD7	Single	5.0	Vertical	Hand

Figure 2 Turning Device 1 enabled paddy rice turning via hand pulling by two people. The device consisted of a single metal bar with a diameter of 5 cm. Turning devices 2, 3, 4, and 5 were operated via a dolly. TD2 incorporated a double bar at diameters of 2.5 cm each, whereas TD3 used two bars with 5 cm diameter. Both TD4 and TD5 induced horizontal oscillation and were operated with double bar (diameter = 2.5 cm) and single bar (diameter = 5 cm), respectively. Turning device 6 consisted of a single metal bar (diameter = 5 cm) operated via a dolly with the bar attached to the outer rim of the wheels in order to create up-and-down motion (vertical oscillation) in the bulk. Turning device 7 used a hand-pulled single bar (diameter = 5 cm) with C-shaped attachments welded to the bar in order to create vertical oscillation.

standardized technique and prone to inconsistent oscillation. Vertical oscillatory movement was believed to be much more desirable and was established by two methods. First, a single bar was attached to the outer rim of the wheel of the dolly, which created up-and-down-movements as the wheel rotated (TD6). Secondly, a C-shaped attachment was welded to the turning bar that created oscillation through the rotational movement of the bar (TD7). For assessing the turning efficiency of the devices, paddy grains were marked with different colors in order to be able to track grain movement between layers inside the bulk. Eight different options for grain coloring were evaluated. Water-based lacquer was found to coat grains effectively, dry quickly, not become sticky and produce strong contrasts, and thus, was ranked most useful. The colors blue, green and red were considered most distinguishable for the human eye. A section was created inside the dryer with a capacity of 24 kg of paddy to prevent mixture of edible grains with colored ones (Figure 2, TD1). Three layers (8 kg each) of colored grains were placed into the section: 8 kg of red grains in the bottom, green in the middle and blue in the top of the paddy bulk. The section had the same bulk height of 4 cm (1.3 cm each) of non-colored grains in other parts of the dryer. Fresh paddy was loaded into the other sections of the dryer and the product was dried in the open sun. Three replications were conducted for each turning device. Subsequently, the statistical test “one-way analysis of variance (ANOVA)” was used to show significant differences in turning efficiency of the different devices. The turning process was standardized, so that one turning event encompassed the longitudinal movement of the bar(s) from one end of the dryer to the other and back. Thus, 15 consecutive turning events were applied at 1-hour intervals until drying was complete, i.e. when bulk moisture content reached 14%, determined by resistance type moisture meter (G-WON, Grain Moisture Meter 8.3-40%).

For each turning device trial, three samples of colored paddy were drawn from the bulk after drying was completed. Extraction of colored paddy columns was performed by core sampling method according to Proctor (1994) using a plastic pipe (height: 4 cm, diameter: 12 cm) consisting of three rings each 1.3 cm that made it possible to sample top, middle, and bottom layer of the bulk individually. A fixed top and a removable bottom cap made it possible to seal the sample in order to avoid spillage of paddy. With the bottom cap removed, the cylindrical pipe was inserted into the bulk from the top until the rim of the pipe touched the bottom of the dryer and the cylinder was completely filled with paddy. The entire sample was then taken to the laboratory and separated into three subsamples each containing colored paddy from top, middle, and bottom layer, respectively. Each subsample was spread out on a white surface in order to isolate grains according to color. The paddy grains were counted and converted to percent of the total number of grains of the entire sample. Standard deviation (SD) was calculated from all samples of each turning device. Subsequently, one-way ANOVA was applied using SPSS software (ver. 21.0) to determine statistical significance between layers top, middle, and bottom. Significant difference between the percentages of colored paddy grains in the respective layers indicated whether the turning operation worked effectively.

Results and Discussion

Table 2 portrays mean distribution and standard deviation of colored grains for each turning device after 15 turning operations. The same letters in one row indicate a heterogeneous distribution of colored grains, i.e. a good turning is statistically proven. Similarly, low values for standard deviation also suggest high turning efficiency. Baseline data for TD1 showed standard deviation of 4.37 and statistically significant differences among the layers after turning, i.e. a significant part of the blue and red grains remained in their original positions: top and bottom layer, respectively. This indicates that the turning operations did not transpose the grains evenly inside the bulk (Figure 3). Double bar devices without any oscillation (TD2 and TD3) showed the highest standard deviation ranging 9.62-16.82 with TD4 also having higher standard deviation than the control. These treatments also showed the most significant differences of the mean distribution of colored grains. On the contrary, TD5, TD6, and TD7 did not show significant differences and had standard deviation values lower than the control device. TD7 revealed the lowest value for standard deviation (1.39) and thus implied to be the most efficient turning device.

Figure 7 portrays the results for TDs 2-7. For TD2, grains were not turned efficiently; hence, the majority of red grains remained in the original bottom layer, whereas the green grains remained in the middle and blue grains remained in the top layer, even after 15 turning operations. Results on the efficiency of TD3 and TD4 revealed significant differences in the distribution of colored grains after 15 turning operations. For TD3, red grains remained on bottom, while in TD4, blue grains remained on top. Thus, the devices did not improve turning, compared to the original device TD1. The results for TD5 showed that colored grains were distributed uniformly with low standard deviation after 15 turning operations. Hence, the portrayed results express that oscillatory movement of a turning device that uses one metal bar at 5 cm diameter was very effective in turning the paddy grains. Yet, it was operated by a non-standardized method of oscillation, i.e. horizontal oscillation was induced by “back-and-forth-movement” of the workers. This was a laborious and time-consuming task because the bar had a tendency to get stuck and needed extra care. Consequently, mechanically induced oscillation is preferred. Both TD6 and TD7 induced vertical oscillatory movement to the turning procedure that was efficient and could be standardized. Higher rate for turning, simple construction, inexpensive material used and ease of operation (hand-pulling) gave favor to TD7 with respect to practicability and efficiency for turning paddy rice in a solar tunnel dryer.

In summary, TDs 2-4 revealed significant differences between the shares of colored grains in the different layers of the bulk as well as high standard deviation, indicating they were not able to turn the grains sufficiently enough to distribute them uniformly between the layers. For TDs 5-7 efficient turning could be verified. TD5 used a non-standardized horizontal oscillation method that entailed difficulties in implementation in the field. From the standardized vertical oscillation methods applied with TD6 and TD7, TD7 revealed most uniform colored grain distribution in the respective layers of the paddy bulk and lowest values for standard deviation. Additionally, the ease of construction and operation is an advantage as compared to mechanical operation by dolly, and is thus favored.

Table 2 Evaluation of turning device efficiency based on mean distribution and standard deviation of colored grains for each turning device after 15 turning operations and three repetitions. Statistical significance was tested using one-way ANOVA (*P*<0.05)

Turning Device	SD		Blue (%)	Green (%)	Red (%)
TD1 single bar (5 cm)		Top[1/]	36.98^{a}	36.77^{a}	26.26^{b}
no oscillation	4.37	Middle*	36.65^{a}	34.35^{a}	29.00^{a}
operated by hand		Bottom*	30.78^{a}	29.31^{ab}	39.91^{b}
TD2 double bar (2.5 cm)		Top	49.09^{a}	27.76^{b}	23.15^{b}
no oscillation	16.82	Middle	18.55^{a}	49.39^{b}	32.06^{a}
operated by dolly		Bottom	6.91^{a}	28.68^{a}	64.41^{b}
TD3 double bar (5 cm)		Top	54.10^{a}	30.04^{b}	15.86^{b}
no oscillation	9.62	Middle	37.18^{a}	36.26^{b}	26.56^{ab}
operated by dolly		Bottom	30.61^{a}	33.06^{b}	36.33^{c}
TD4 double bar (2.5 cm)		Top	38.03^{a}	30.17^{b}	31.80^{c}
horizontal oscillation	6.07	Middle	30.60^{ab}	31.38^{a}	38.02^{b}
operated by dolly		Bottom	27.80^{a}	25.66^{ab}	46.54^{b}
TD5 single bar (5 cm)		Top	30.00^{a}	36.79^{a}	33.22^{a}
horizontal oscillation	2.32	Middle	30.90^{a}	35.53^{a}	33.57^{a}
operated by dolly		Bottom	30.59^{a}	36.01^{a}	33.40^{a}
TD6 single bar (5 cm)		Top	34.16^{a}	29.82^{a}	36.02^{a}
vertical oscillation	2.42	Middle	37.64^{a}	32.55^{a}	29.80^{a}
operated by dolly		Bottom	34.18^{a}	33.06^{a}	32.76^{a}
TD7 single bar (5 cm)		Top	34.09^{a}	32.77^{a}	33.14^{a}
vertical oscillation	1.39	Middle	33.90^{a}	32.75^{a}	33.35^{a}
operated by hand		Bottom	30.95^{a}	32.63^{a}	36.42^{a}

[1/] The results are portrayed in the same row using letters a, b and c. Identical letters for the mean values in the same row show that no significant difference of blue, green and red grains was detected, i.e. the bulk layer contained equal amounts of grains of each color, thus, they got properly turned. Different letters in one row signify that distribution of colored grains was not even and turning of paddy rice was insufficient, so that many grains of the same color remained in the initial layer from before turning processes were exercised

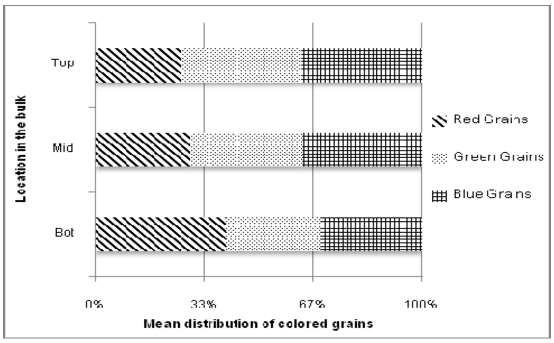

Figure 3 Mean distribution of colored grains (in %) in each bulk layer (Bot, Mid, Top) after 15 turning operations with turning device 1 (TD1)

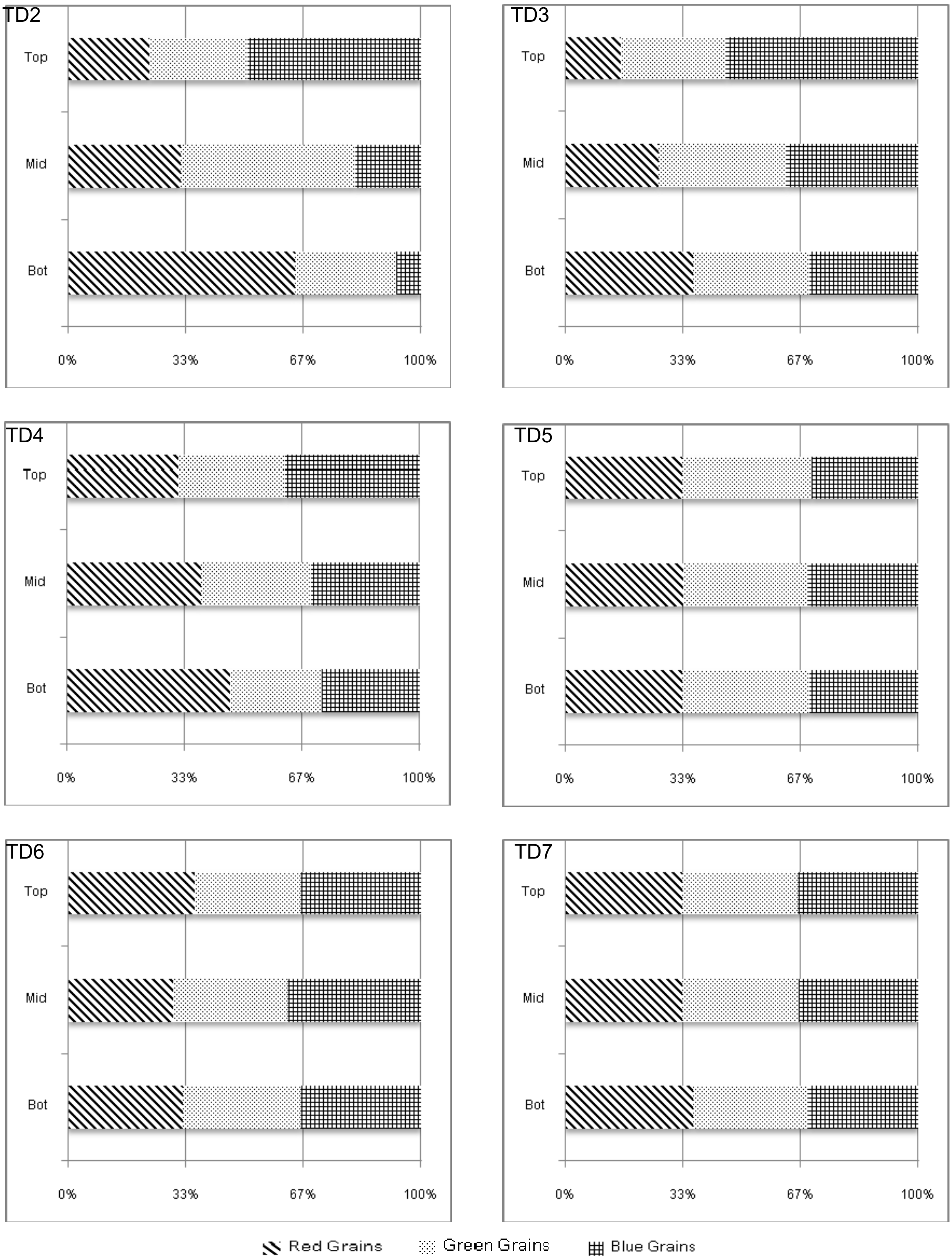

Figure 4 Mean distribution of colored grains (in %) in each bulk layer (Bot, Mid, Top) after 15 turning operations with turning devices 2-7

Conclusion

Various devices for turning paddy in a solar dryer were designed and tested. Based on a core sampling method found in literature, a method to assess grain turning of paddy rice in a tunnel dryer was developed successfully and could be used for comparing the efficiency of different turning devices. The most effective device consisted of ahand-operated single bar (diameter: 5 cm) with affixed C-shaped attachments that induced vertical oscillation of the paddy during turning events. The implications of this device for reducing postharvest losses are remarkable, since its simplicity reduces labor and maintains grain quality. Thus, this concept has potential application not only for solar drying, but also any drying process where grains are dried in thin bulk layers, particularly sun drying. Also, the established technique for evaluation of paddy turning efficiency will be able to serve future scientific purposes with respect to efficacy of grain turning during drying processes.

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