Design and Fabrication of an Engineering Model of a Crop Dryer

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ABSTRACT. *Processing of agricultural produce often requires drying to improve storability by maintaining low moisture contents that are unfavourable for microbial growth. Lack of appropriate drying technology at farm level or for small-scale operations is a common problem in Sri Lankan Agriculture irrespective of the crop type. The main objective of this study was to develop an engineering model of a compact drying cabinet for small- scale processing of agricultural produce. Based on problems identified with the existing dryers, the functional requirement of the engineering model was to produce a uniform distribution of air through out the drying chamber. Among several alternative methodologies to obtain an even airflow distribution, a forced air circulation along with the diffusion method was selected.*

The drying chamber was designed to meet the capacity requirement of 50-100Kg of fresh produce with thin layer drying. A model of a cabinet type dryer was fabricated consisting three main components; airflow distribution unit, drying chamber and hot air supply unit. The fabricated dryer was evaluated according to the standard test procedures for dryers that include assessing of performance in air and temperature distributions, developing of drying curve and analysing the quality of the final product.

The model was successful having even airflow distribution with respect to fresh and heated air. Temperature distribution inside the drying chamber was almost even and the variation was within 3^0C. These two conditions satisfy the need for uniformity in drying. When pepper (Piper nigrum) was dried at the recommended temperature of 57^0C, it took nearly 23 h to reach the moisture constant to the equilibrium level. The tests on quality parameters indicated that the end product was having values comparable with the standard values.

The developed model of a dryer can be used successfully since it provides conditions required for even drying of produce while maintaining the product quality. With suitable adjustments in air velocity and temperature, it could be used for thin layer drying of other produce.

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INTRODUCTION

Problem identification and justification

Drying, a process of moisture removal in a controlled manner is practiced for preserving food products. The process removes moisture required for the growth of microorganisms and prevents from spoilage (Troller and Critian, 1978). The moisture is removed to a safe level that does not affect important qualities of a commodity. The temperature, relative humidity and velocity of drying air are important parameters, which govern the moisture removal process. In addition to them, quality and nature of the raw material, processing treatment, density of loading, and method of drying contribute to the quality of the final product. The levels at which these factors are maintained in drying process vary from product to product.

Sri Lankan farmers use the traditional "sun drying" method for most of the agricultural produce. There are many disadvantages and problems associated with the process of sun drying. It lacks controllability on the drying conditions. Often, the drying process is very slow and can be interrupted by unfavourable weather conditions. It also requires constant supervision of the process since the produce has to be protected from rain and predators. Moreover, the chances for contamination due to dust, dirt and insect infestation are high under open sun drying condition. As a result, the dried product is of poor quality. Therefore, it is necessary to introduce improved technology for drying to upgrade the quality and thereby overcome the problems of traditional sun drying (Herath, 2002).

Drying of produce by farmers or small-scale processors, as a mean of value addition has not been successful due to unavailability of appropriate technology. The various types of locally fabricated dryer designs are available for agricultural processing in farm level or in small industries. These locally fabricated dryers, run on various energy sources, are simple and inexpensive, but require improvements in some operational conditions. Uneven distribution of air temperature and velocity inside the drying chamber results in varying drying rates in different locations. Therefore, it requires additional attention and operation to prevent uneven drying patterns. A solution is required to obtain uniformity in air temperature and velocity throughout the chamber while accepting technical and economical feasibilities. Therefore, an important design consideration will be to facilitate even distribution of air throughout the drying chamber to ensure uniform moisture removal process.

The main objective of this research was to design and develop a compact drying cabinet for small-scale crop processing. The intended dryer has uniformity in distribution of air and flexibility in using different sources of heat energy.

MATERIALS AND METHODS

Design development

Based on the problems identified with existing dryers, the functional requirement of the engineering model was to produce a uniform distribution of air throughout the chamber. A forced air circulation along with a diffusion method was selected to obtain the uniformity in distribution of velocity and temperature. Therefore, the design requirements for the airflow distribution unit are to; (i) provide uniform distribution to all the trays inside the drying chamber, (ii) be compact in order to reduce the material costs.

There are several alternative methodologies to obtain even airflow and temperature distribution inside the drying chamber, as given below.

1. Forcing the hot air through a perforated plate. It gives resistance and high backpressure. Due to high fan power requirement, the fabrication and maintenance costs are higher. This method is usually used for high capacity dryers (William, 2005).

2. Forced air through a network of ducts. This method is also used in high capacity dryers (William, 2005). The fabrication and maintenance costs are higher.

3. Provision of barriers at the air inlet with guide ducts is another alternative for producing an even airflow distribution, which is more feasible with small-scale cabinet type dryers. With these barriers, high backpressure creating resistance against the airflow helps to convert the incoming laminar flow to turbulent.

The change in airflow pattern helps to distribute the air evenly. This method is feasible for tray dryers, because it takes comparatively low space to create an even airflow distribution (Charm, 1981). Figure 1 depicts a profile of the structure required to obtain airflow patterns in this manner. Due to the simplicity and comparatively low space required to create an even airflow distribution, this particular structure was selected as the design alternative.

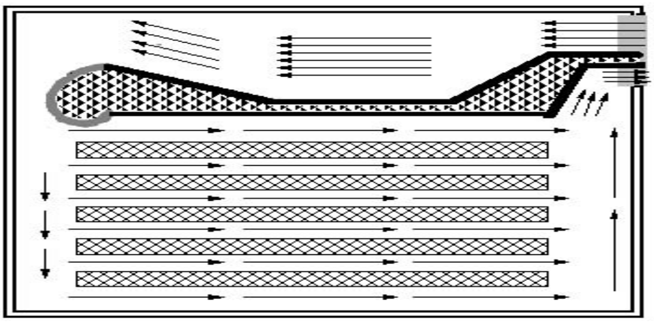

Fig. 1. Profile of the structure required to change the airflow pattern.

The selected design alternative for obtaining required flow pattern was scaled up by using a computer based graphic application to come up with different models with varying dimensions (Charm, 1981). These models can be fitted to dryers of different capacities. The dryer capacity, selected on the basis of small-scale agricultural processing applications, was 50-100 kg of raw material.

Design of the drying chamber

The drying chamber was designed to meet the capacity requirement with thin layer drying. Based on the material layer thickness in a tray and bulk density of the fresh produce, the tray area was determined. Adequate room was given to assure the cross flow pattern of air to achieve uniform and sufficient moisture removal. By considering the normal working height of a person, the model was constructed. The specification of the drying chamber and trays are given below. There were 19 drying trays inside the chamber.

Length of the drying chamber	=125 cm
Width of the drying chamber	= 92 cm
Length of a tray	= 73 cm
Width of a tray	= 60 cm
Height of a tray	= 2.5 cm
Distance between two trays	= 5.0 cm

Fabrication of the dryer

A model of a cabinet type tray dryer was fabricated according to the above specifications at the Department of Agricultural Engineering, Faculty of Agriculture, University of Peradeniya. The fabrication details are given below according to three major components; Airflow distribution unit, Drying chamber, and Hot air supply unit.

Airflow distribution unit

The profile of the airflow distribution unit is shown in Figure 2. A bank of tubes was arranged as a diffuser in the middle of the airflow path. This module is installed in the upper part of the dryer as shown in Figure 1. The heated air supply is fit at the inlet.

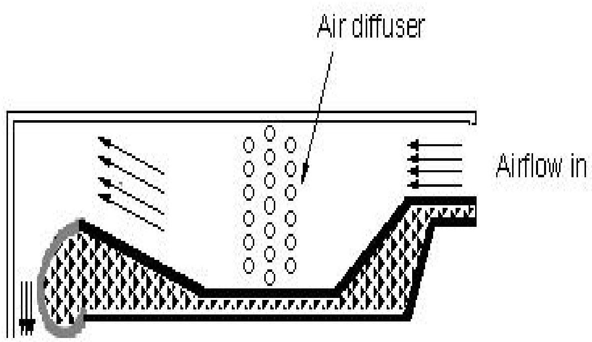

Fig. 2. Profile of the air distribution module.

Drying chamber

The drying chamber was fabricated using plywood sheets, aluminium sheets and perspex (flexi-glass). Provisions were available for measurement of air velocity and temperature at selected profiles in the chamber. Four caster wheels were fixed at the bottom of the drying chamber in order to move the system. A photograph of the whole drying system is shown in Plate 1.

Plate 1. A view of the dryer.

Hot air supply unit

For experimental purpose, two electric heaters of 2 kW and 1 kW (total of 3 kW) capacity with a control to regulate the heat supply were used. This heater capacity was adequate to provide heated air at the required airflow rate for drying when loaded fully with fresh produce. The heaters were installed inside the duct that supplies air to the chamber. The air duct, fabricated using thin gauge aluminium sheets, was insulated. An electric centrifugal type blower with a capacity of 0.5 hp was used to force the heated air to the drying chamber. A wire mesh was fixed inside the air inlet to obtain the uniformity in distribution on a horizontal axis.

Performance evaluation of the dryer

According to the standards of Regional Network of Agricultural Machinery (RNAM), temperature distribution, air flow distribution, drying curve, drying rate curves, drying time, drying efficiencies and quality of the dried products are important parameters to be assessed on performances evaluation of a dryer (Sitthiphong *et al.*, 1989). The developed model was mainly tested for airflow and temperature distributions.

Evaluation of the dryer for airflow distribution

Air velocities at selected locations were measured by using a probe type digital air velocity meter. These measurements were taken with fresh air (at room temperature) as well as with heated air under the loaded and unloaded conditions of the dryer. The velocity above each tray was measured across the direction of flow at three different distances of 6 cm, 30 cm and 55 cm from the right sidewall (when viewed from the door end). The data were plotted against the tray number to observe the air flow distribution pattern. Mean velocity inside the drying chamber as well as the standard deviation was calculated in order to get an idea about the velocity variation.

Evaluation of the drying chamber for temperature distribution

The temperature inside the drying chamber was measured using the same air velocity meter. These measurements were taken only with the heated air. The locations where readings were taken are identical to the velocity measurements. The data were plotted against the tray number to observe the temperature distribution.

Development of drying curve for evaluation of the dryer for performances

Drying curve, another parameter in dryer evaluation, was developed by using pepper (*Piper nigrum*) as the produce. Fresh pepper was blanched before drying in order to get better appearance in the final products as well as to increase the drying rate. The dryer temperature was maintained at 57^{0}C by using a thermostatic control. Samples were taken randomly from the dryer for moisture determination. Three representative samples of pepper were taken and kept in a mechanical convection type oven at 105^{0}C for 72 h to reach a constant weight. The drying curve was developed on the wet basis of moisture content.

Evaluation of the dried products for quality parameters

As a parameter in dryer evaluation, the dried pepper samples were analysed for quality parameters. These tests were carried out at the Post Harvest Technology Division, Research Station, Department of Export Agriculture, Matale.

RESULTS AND DISCUSSION

Performance evaluation of the dryer

The performance evaluation of the dryer was done according to the airflow distribution and temperature distribution.

Evaluation of the dryer for airflow distribution

Air velocity measurements taken for both fresh air and heated air above each tray were plotted to observe the flow patterns. The tray numbers were assigned from the top to bottom. Figure 3 depicts the resulting velocity curves for hot air at temperature of 57^{0}C temperature.

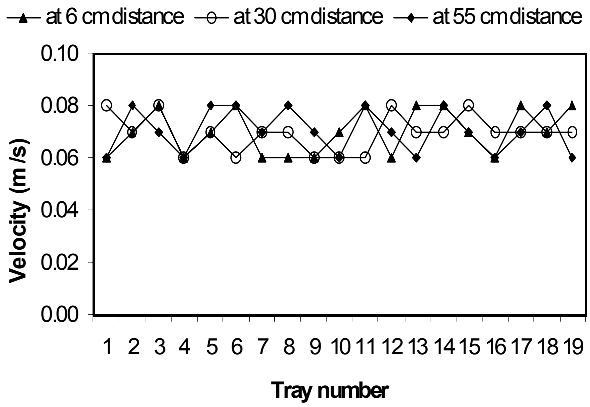

Fig. 3. Hot air velocity distribution inside the drying chamber.

The mean velocity inside the dryer for heated airflow was 0.073 m/s and the standard deviation of velocities observed for heated airflow was 0.003 m/s. Velocity measurements taken for fresh air were plotted and the resulting curves are shown in Figure 4. Mean velocity for fresh airflow inside the dryer was 0.70 m/s and the standard deviation was 0.03 m/s. The coefficients of variation for heated and fresh air were 4.01% and 4.29%, respectively. It implies that the air velocity within the dryer is uniform and this condition is maintained when temperature is adjusted.

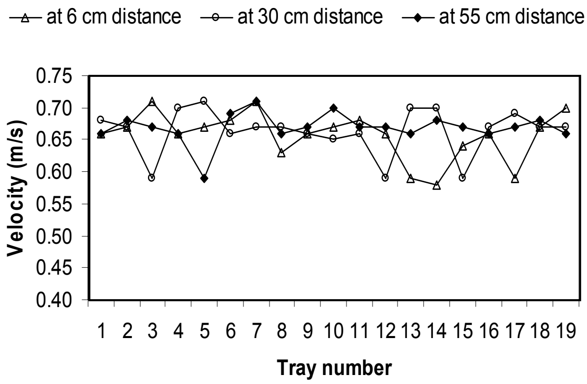

Fig. 4. Fresh air velocity distribution inside the drying chamber.

In this study, with the air velocity of 0.073 m/s and temperature of 57^{0}C, it requires 23 h to reach the equilibrium moisture condition. Although there is no research data stating the appropriate heated air velocity suitable for pepper drying, drying at high airflow rates is not advisable to prevent volatile compound losses. In case of maize drying, it is adequate to dry at 0.08-0.15 m/s of air velocity at around 40^0C to 45^0C temperature under thin layer drying (Singhagajen, 1981).

Evaluation of the dryer for temperature distribution

Figure 5 depicts the respective graphs for temperature distribution inside the dryer. According to the results obtained, it shows that temperature inside the drying chamber varied within the range of 54.0^0C to 56.8^0C. The temperature inside the dryer was set to 57^0C by using a calibrated thermostat. The drying temperature for pepper should not exceed 57^0C to prevent the volatile oil losses (Anon, 1998). Thin layer drying assures the uniformity in drying process as well as an efficient drying process.

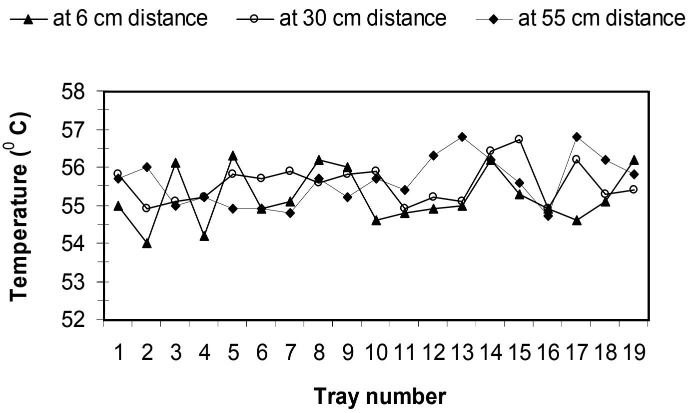

Fig. 5. Temperature distribution inside the drying chamber.

Performance on pepper

The drying behaviour of black pepper is given in Figure 6. According to the resulting curve, it took nearly 23 h to reach a constant weight. The initial moisture content of pepper was 70.6%. The final moisture content in the dried product was 10.17%. If the RH is below 60%, the product can be stored with longer shelf life without any deterioration. During the drying trial and especially at the moisture level of 10.17%, the inside RH was 58% and the outside the dryer (ambient RH) was 86.7%. It indicates that the set condition of the dryer is capable of providing suitable RH condition for longer shelf life of the finally dried product.

The pressure drop across the dryer for the hot air flow when loaded with pepper was 12 cm of water column. This is an important parameter in determining the fan brake power that is required in designing of the forced air mechanism. The blower generated a volumetric flow rate of 0.063 m^3/s at a velocity of 2.11 m/s at the inlet.

Quality parameters evaluation for dried pepper

The laboratory test results for dried pepper are shown in Table 1. The black pepper samples taken from the dryer indicate quality parameters that are comparable with standard values. Therefore, the drying process with the dryer was acceptable.

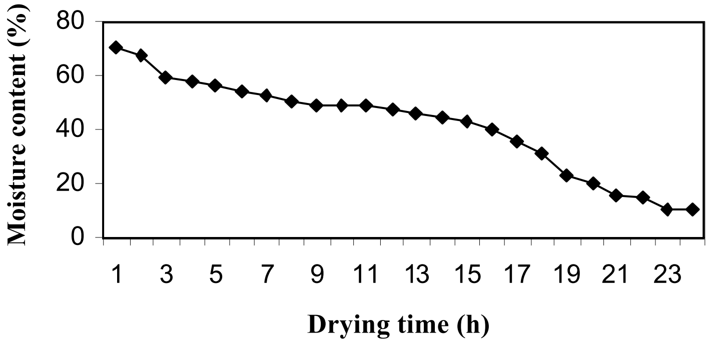

Fig. 6. Drying curve of pepper (*Piper nigrum*).
Note: Moisture content is on the wet basis.

Table 1. Laboratory tests results of quality parameters for black Pepper.

Parameter	Sample values	Acceptable values*
1. Bulk Density (g/l)	446.15	500.00
2. Moisture content (%)	12.00	12.00
3. Volatile oil content (%)	2.35	2.30
4. Oleoresine content (%)	13.60	9.60
5. Piperine content (%)	5.87	2.30

Note: * Premathilake (2001).

CONCLUSIONS

The following conclusions can be drawn on the basis of results obtained in the study.

The model developed is successful with even airflow distribution with respect to fresh and heated air. Temperature distribution varied within 3^0C; therefore it is almost even and encourages uniformity in drying.

Under the set dryer conditions for pepper, it takes nearly 23 h to reach the constant moisture content that is acceptable for storage. The pepper dried in the temperature range of 55 to 57^0C resulted quality parameters comparable with the standards.

According to above results, the developed model of a dryer can be used successfully in terms of duration for drying process, even air distribution condition in drying and physical qualities of the ultimate products. The dryer can be used for drying of other produce with minor adjustments. It may require evaluation of drying characteristics of selected produce to facilitate adjustment of the dryer temperature and velocity.

ACKNOWLEDGEMENTS

We express our sincere appreciation to Sri Lanka Council for Agricultural Research Policy (CARP) for granting funds for this study.

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