International Journal of Agriculture and Agricultural Sciences ISSN 1712-3496 Vol. 4 (3), pp. 103-109 October, 2017. Available online at www.advancedscholarsjournals.org © Advanced Scholars Journals

Full length Research Paper

Variation of static pressure along a column of grains of crambe subjected to airflow

***Eduardo Baccarin, Garrincha K. O. and Philippe Massa**

Departament of Rural Engineering, Faculty of Agricultural Sciences (FCA), São Paulo State University (UNESP), Fazenda Experimental Lageado, CEP 18603970 - Botucatu, SP, Brazil.

Accepted 19 September, 2017

The crambe has emerged as an option for the production of biodiesel, constituting itself as an alternative for off-season grain in Brazil. To obtain the best performance in the post-harvest product processing, knowledge of physical characteristics of the grains to as well as of the design of machines and structure storage is necessary. After pre-cleaning, the crambe (*Crambe abyssinica* Hochst) with a water content of 8% (wb) was placed into a silo prototype, provided a fan and plenum, and subjected to five airflow densities that were pre-determined in a total of four repetitions for each tested airflow. The static pressure was measured through the column in five layers. The results show that there is a significant effect of air flow on the static air pressure in the crambe column, which increased linearly with depth. The experimental data fitted with good accuracy the models of Hunter and Shedd, thus enabling their use for the crambe column as well. The objectives of this study were to evaluate the variation of static pressure along a column of grains of crambe that were subjected to five airflow densities and check the fit of this variation following mathematical models suggested by Sheed and Hunter.

Key words: *Crambe abyssinica*, resistance to airflow, Sheed, Hunter.

INTRODUCTION

The crambe is a species native from the Mediterranean region belonging to the Brassicaceae family, of annual cycle, with seeds presenting an oil content ranging from 28 to 60%. Thus, the crambe becomes a promising crop for biodiesel production (Carneiro et al., 2009; Silva et al., 2013, 2014). In Brazil, the crambe have been noted as a great option for the intercrop, because it is a winter crop that is characterized by both frost tolerance and drought resistance (Oliva et al., 2012).

The introduction of crambe in the country is recent. The first experiments indicated the year 1995 as the year that

*Corresponding Authors. Email: dr.edbaccarin@gmail.com

crambe was introduced. Therefore, there is a lack of information about the culture in Brazilian conditions, particularly technical issues related to post-harvest and for instance, their physical characteristics.

For the consolidation of crops in the country, the information about the drying and storage of the product becomes important, thus enabling post-harvesting structures to be built with technical parameters that are suitable for the crambe (Biaggioni et al., 2005).

The knowledge of the resistance to airflow in the grain bed is essential to design grain-drying and ventilation systems (Chun et al., 2011). This knowledge is also vital to select a ventilator that adequately provides the airflow that can overcome the pressure gradient supplied by grain (Abou-el-Hana and Younis, 2008).

The distribution of airflow in the grain mass depends on several factors, including the method of filling the grain, porosity, depth of grain yield, grain morphology and configuration, the air velocity, and impurity (Khatchatourian et al., 2009).

One can make some inferences about the static pressure. The greater the thickness of the grain mass, the higher the static pressure will be. Small grains offer more static pressure than big grains; lower water content in grains can increase the pressure to the passage of air. Therefore, experiments with low water levels have a higher safety margin in the formulation of projects.

In a mass of grains or seeds, the decrease of static pressure exhibited when traversed by airflow can be estimated by empirical curves, in which the static pressure is related to the airflow (Biaggioni et al., 2005). A frequently used model is a graph in logarithmic scale proposed by Shedd (1953) with a ratio to 22 types of grains. Another model used is proposed by Hunter (1983), who studied the static pressure difference through a mass of grains representing the Ergun model (1952) by the following equation:

$$\Delta P = MV + NV^2 \qquad 1$$

Where M and N represent the parameters of the fluid and the granular mass required for Ergun's formulation (1952).

A large number of studies exist with regard to airflow resistance of cereals, oilseeds, and vegetables, but no information about the crambe that exhibits resistance to an airflow of 33 crops exists in the literature or is even compiled (ASAE, 2011).

This study aimed at evaluating the variation of the static pressure along a column of grains of crambe with 8% water content that was submitted to five airflow densities; it also aimed at checking the fit of this variation by following the mathematical models suggested by Sheed and Hunter.

MATERIALS AND METHODS

This study was conducted at the Universidade Estadual Paulista (UNESP), Faculty of Agricultural Sciences, Campus of Botucatu/São Paulo. Crambe grains with 8% water content after pre-cleaning were placed into a silo prototype characterized by a galvanized steel column (with five taken for measuring the static pressure), plenum, and fan (Figure 1).

Crambe grains were placed in free fall within the prototype, reaching a height of 1 m. The test consisted of static pressure measurements by using an inclined tube differential pressure gauge (18°), Dwyer brand; 0.5 mm precision of water column, at different depths, for each of the four repetitions, totaling twenty measures of depth in the column.

The densities of airflows used were as follows: 4.76, 6.41, 8.51, 9.90, and 10.47 $m^3 min^{-1} m^{-2}$. The experimental design was completely randomized, with five lots of crambe and four replications. After obtaining the results, the averages were submitted to an analysis of variance and means were compared by the "t" test ($p \leq 0.05$).

For adjusting the equations proposed by Sheed (1953) and Hunter (1983), the parameters *a* and *b* were used in Equation 1 and M and N were used in Equation 2. These parameters emerge from the specific physiological characteristics of each type of grain, and it is necessary to obtain these parameters by using simple linear regression analysis.

In the determination of the best adjustment, the coefficient of determination (R^2) and the average percentage deviation (P) were used.

$$P = \frac{100}{n} \sum_{i=1} \left| \frac{\Delta P_{exp} - \Delta P_{calc}}{\Delta P_{exp}} \right|$$

where P is the average deviation in percentage,%; n is the amount of experimental data; Ap exp is the pressure gradient values obtained experimentally, Pa m^{-1}; and Ap calc is the pressure gradient values predicted by the model, Pa m^{-1}.

RESULTS AND DISCUSSION

The results show that there was a significant effect of all air flow densities, suggesting the influence of this variable in the resistance to airflow. The pressure drop is related to the increase in bulk density as well as reduction of the porosity of the mass of grains is promoted by raising the water content in the product (Amanlou and Zomorodian, 2011).

In the physical characterization of crambe, it was found out that the density of 347.36 kg m^{-3} corroborates with that of Silva et al. (2013) and Gonçalves et al. (2014). The porosity of crambe vary from 43 to 48% depending on the temperature and water content, corroborating the average for other grains, around 35 to 50% voids, this fact is due to the physical characteristics of the tegument crambe (Gonçalves et al., 2014).

The results of the variation of the static pressure gradient in function of air flux density are shown in Table 1. For the densities of airflow used (4.76 to 10.47 $m^3 min^{-1} m^{-2}$), the gradient of precision statics ranged from 165.0 to 427.5 m Pa^{-1}. The values showed that there was a significant effect between all densities of the airflow, which suggests the influence of this variable in the resistance to airflow.

The increase of the pressure drop from rising air flow can be attributed to the increase of kinetic dissipation as

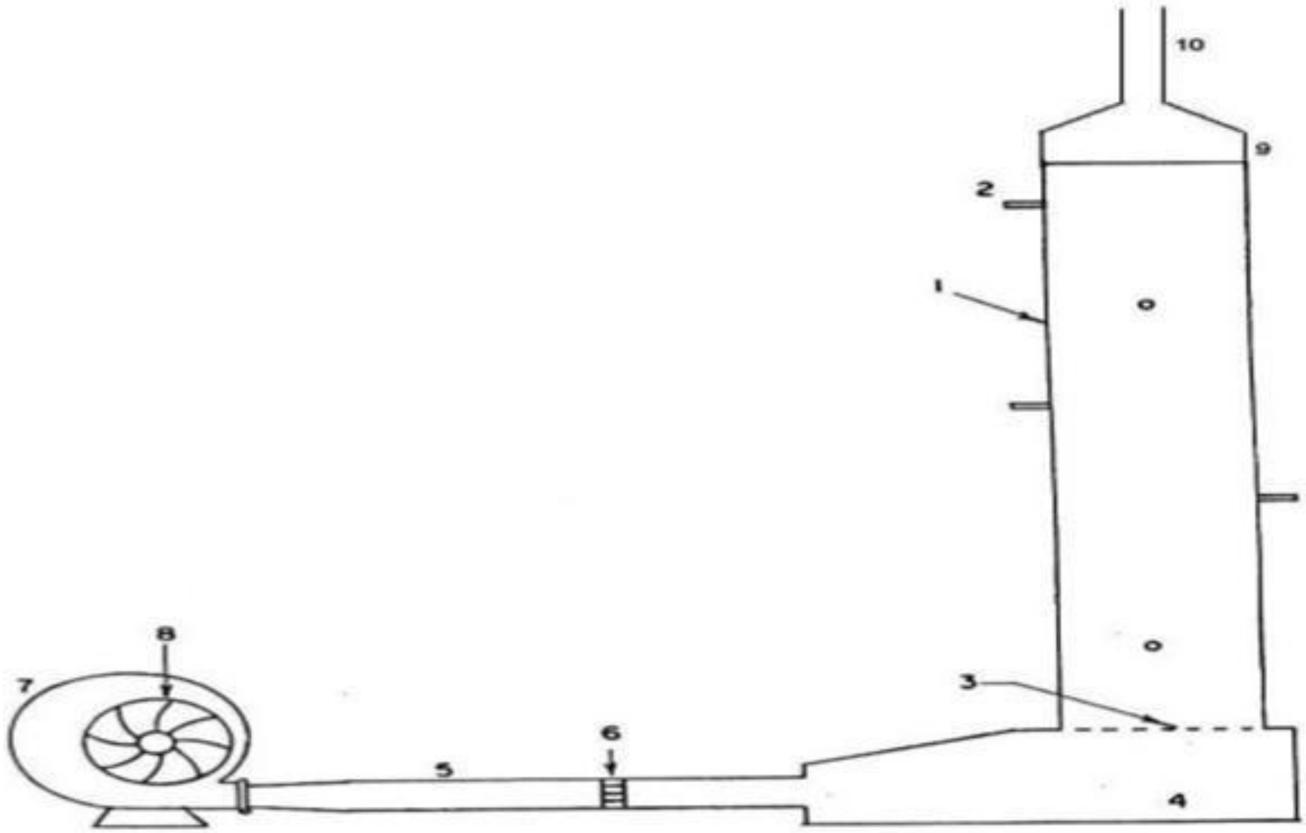

Figure 1. Scheme of the prototype used in determining the static pressure gradient of crambe. 1) Galvanized column, 1.20 m tall; circular section, 0.50 m in diameter; 2) Measuring the static pressure taps: copper pipes (5 mm in diameter) spaced 0.20 m vertically along the column; 3) Base perforated in metal with circular openings; 4) Chamber plenum: square section (0.55 × 0.55 m), 0.33 m high; 5) Tube with galvanized sheet metal connecting the fan to the plenum: 1.20 m long and 0.12 m in diameter; 6) Homogenizer airflow; 7) Centrifugal fan with straight blades: driven by an electric motor of 1/3 CV; 8) Diaphragm of air intake: allows one to control and vary the intake of airflow; 9). Cone air exit reducer; 10) Measuring to speed.

Table 1. Average values of static pressure gradient from crambe grains, in function on the airflow density.

Density of airflow (m^3 min^{-1} m^{-2})	Static pressure gradient (Pa m^{-1})
4.76	165.0^{a}
6.41	242.5^{b}
8.51	327.5^{c}
9.9	400.0^{d}
10.47	427.5^{e}
LSD	0.016
CV (%)	3.43

LSD: Least significant difference; CV: coefficient of variation. Means followed by the same letter do not differ, the "t" test ($p \leq 0.05$).

air speed increases (Agullo and Marenya, 2005).

However, the relationship between the air flow velocity and pressure gradient are different for each type of grain. This is due to factors such as, geometric shape of the grains, porosity, water content, compaction factor as others that provide differences in the roughness of the particle surface and thus alter the static pressure of the grains (Khatchatourian and Binello, 2008).

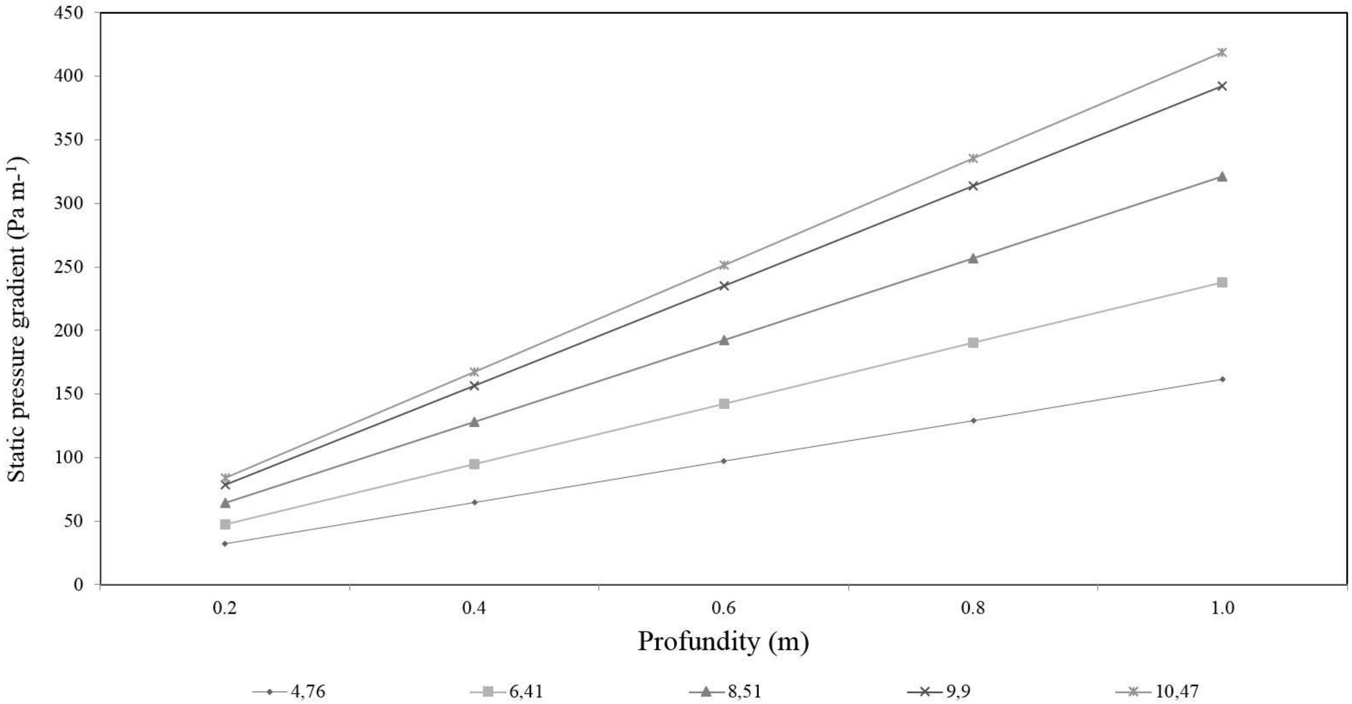

Figure 2. Effect from depth (m) and the density of the airflow (m^3 min^{-1} m^{-2}) on the static pressure gradient (Pa m^{-1}) in a column of crambe grains.

Table 2. Average percentage deviation (P) and coefficents of determination (R^2) from Shedd and Hunter models obtained by regression to the crambe grains.

Shedd	Hunter
P = 2.37%	P = 2.7%
R^2 = 98.0%	R^2 = 99.0%
a = 0.06876	M = 35.16
b = 0.82955	N = 0.6785
-	K = - 15.77

The variation in static pressure gradient measured in five layers and five airflow densities is as shown in Figure 2. Figure 2 establishes a dependency between the air flow velocity and static air pressure in the grain mass to varying depths of the storage layer. It is possible to look at a linear behavior of the static pressure curve with respect to depth from the crambe grain layer depicted. The increase in the static pressure of the gradient with the highest airflows is noted. These results corroborate those obtained in other experiments, such as quinoa (Gratão et al., 2013), peanut pods (Figueiredo et al., 2012), macadamia nut (Biaggioni et al., 2005), canola (Santos et al., 1999), white (Lukaszuk et al., 2008), grains, and cereals in general (ASAE, 2011).

According to Neethirajan et al. (2006) who have a seed compaction at the bottom of the silo. Possivelmete is one of the factors that causes signficant differences in static pressure drop at different depths, however, for Khatchatourian et al. (2009), simply increasing the depth of the grain mass can promote the increase of resistance to air flow, not necessarily being the increase in the degree of compaction in the deeper layers solely responsible for the increased resistance to air passage. The coefficients *a* and *b*, from Shedd model, and M and N, from Hunter model, are shown in Table 2. The coefficients of determination (R^2), 98% (Shedd) and 99% (Hunter), near 1 indicate a good adjustment and suggest good applicability of the two models for crambe culture. For the Hunter model, it is proposed to insert the constant K in the following equation:

$$\Delta P = K\ MV + NV^2$$

where K is a constant.

The model that has the best description of resistance to the air passage is one that has the highest coefficient of determination, and the lowest average percentage deviation (P) is recommended to be less than 5% (Kashaninejad and Tabil, 2009). The two settings used were below this recommendation in evaluating this parameter. The Shedd model was more suitable, because

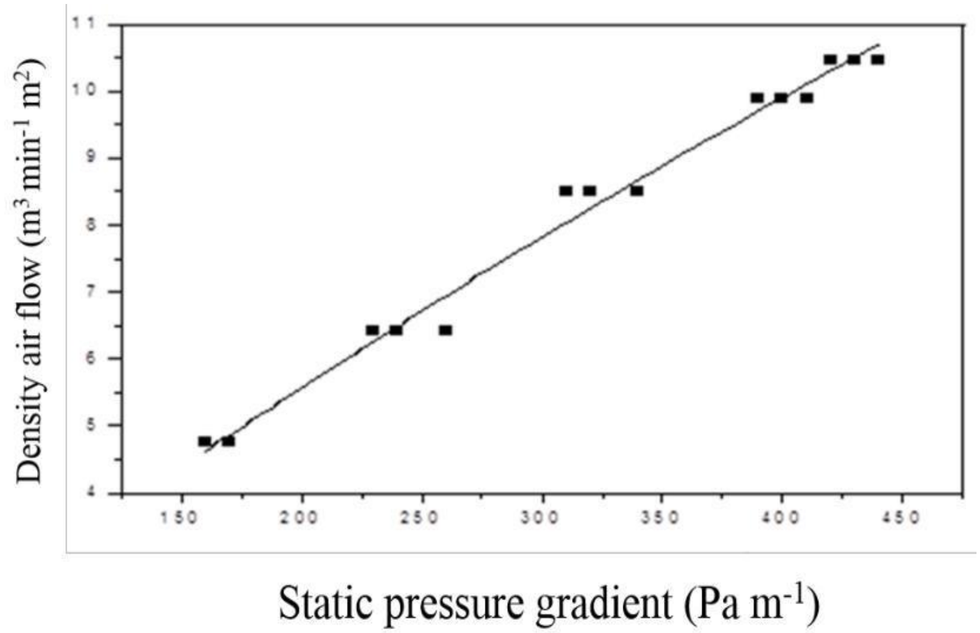

Figure 3. Comparison between the curves of the static pressure variation in the crambe grains column experimentally obtained by Shedd model.

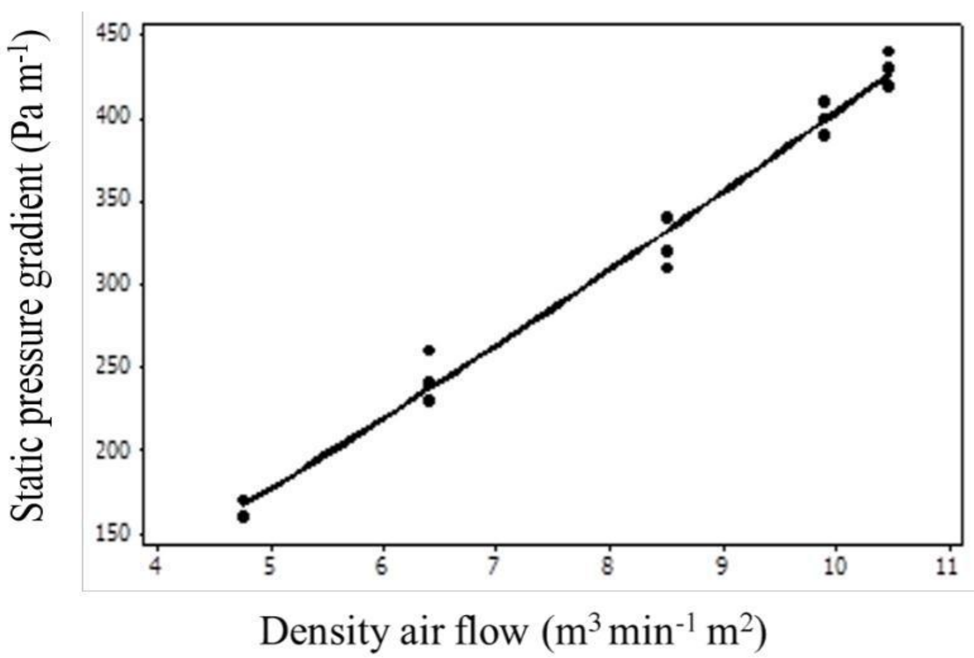

Figure 4. Comparison between the curves of the static pressure variation in the crambe grains column experimentally obtained by Hunter model.

it presented a lower value than the Hunter model.

The results corroborate research with other agricultural products such as canola (Andrade et al., 2001), quinoa (Gratão et al., 2013), and chickpeas (Shahbazi, 2011).

In Figures 3 and 4, the experimental data are shown as comparing the static pressure drop of the crambe grains column by using the Shedd and Hunter model. The results corroborate research with other agricultural products such as quinoa (Gratão et al., 2013), chickpeas (Shahbazi, 2011), and pistachio (Kashaninejad and Tabil,

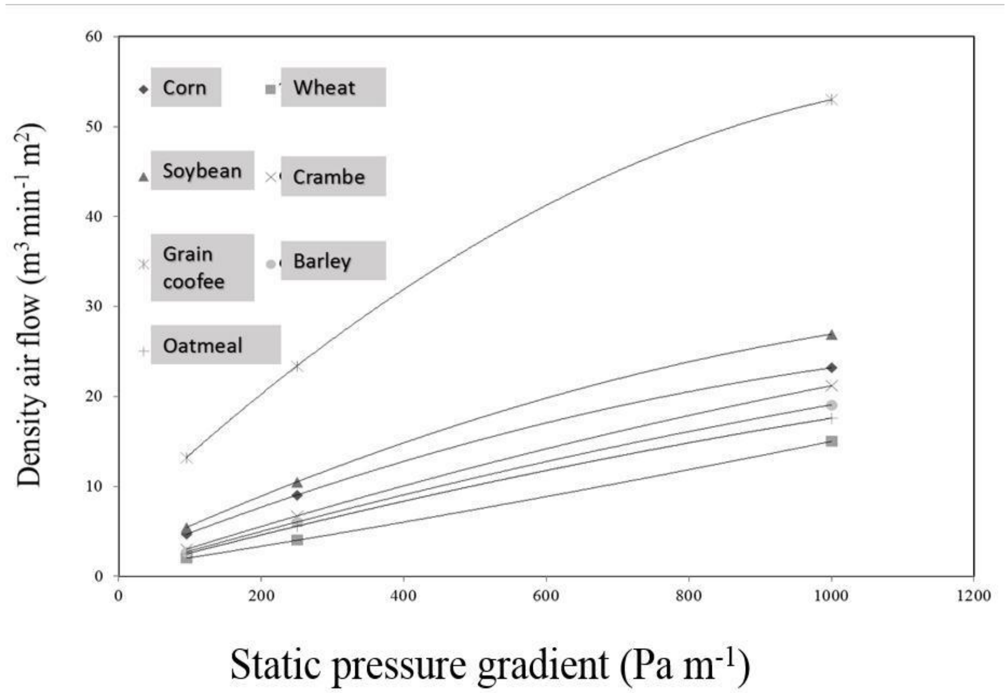

Figure 5. Pressure drop as a function of airflow for crambe grains with 8% water content compared with other grains.

2009), which point to the Shedd model as being the most suitable for determining the static pressure due to the higher coefficient of determination (R^2) compared with the Hunter model.

The Figure 5 shows the pressure loss in the function of air flux density with different grains in comparison to the crambe. It can be seen from Figure 5 that the static pressure exerted by crambe is greater than that of other grains like soy, corn, and coffee, and approximates to the resistance offered by small grains such as barley and oats; this fact is due to the size and shape of the crambe grains with characteristics that are very similar to these small grains (ASAE, 2011).

Conclusions

The static pressure increased linearly with an increase in air density and flow with an increase in depth of the vertical column of crambe. The variation of the static pressure provided by crambe, approaches from oat and barley. The Shedd and Hunter models adjusted satisfactorily to the experimental data in the airflow range investigated for crambe.

ACKNOWLEDGEMENTS

The São Paulo State University, to CAPES and CNPq are thanked for their financial support.

Conflict of Interests

The authors have not declared any conflict of interests.

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