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Drying Faba Bean Seeds in a Silo with a Vertical Air Circulation System

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Summary. Legume seeds harvested by combine harvesters in the fall are characterized by a high moisture content. In this study, faba bean seeds were dried at low temperatures in a silo with a vertical air circulation system. Low temperature and long drying time of 90 hours minimized thermal stress in seeds. The objective of the study was to describe the drying process of faba bean seeds in a silo with vertical air flow, slightly heated by a 13.5 kW electric heater. The results of the study have indicated that the amount of air pumped into the silo by a WP-25 fan ranges from 723 $m^3 \cdot Mg^{-1} \cdot h^{-1}$ to 150 $m^3 \cdot Mg^{-1} \cdot h^{-1}$, subject to the degree of silo filling with faba bean seeds. A vertical air circulation system with a ventilation cone facilitates the process of drying faba bean seeds. Faba bean seeds are dried most rapidly along the silo's axis of symmetry, whereas the drying rate is lowest along the silo's outer walls. Seeds are dried faster in the lower part of the silo, therefore, a two-phase drying process is recommended in planes W1, W2 and W3. Seeds dried in the lower part of the silo should be removed upon the achievement of the optimal moisture content for storage. The remaining seeds should be dried in the second stage of the process.

Key words: silos, drying, storage, faba beans.

INTRODUCTION

New low-tannin faba bean varieties with a determinate growth habit, containing a minimal amount of tannins (0.014 mg per g DM), could contribute to the popularity of faba beans grown for fodder, in particular, if imports of genetically modified soybean meals are limited. The faba bean is a legume plant of great environmental significance that plays an important role in crop rotation schemes with a predominance of cereals. Legume seeds harvested by combine harvesters in the fall are characterized by a high moisture content. Intensive drying of faba bean seeds in roof dryers leads to thermal stress, which damages the embryo and causes seeds to develop microcracks [8, 9]. Roof dryers are not suitable for drying crop seeds. Several attempts have been made to dry faba bean seeds at low temperatures in silos with radial or vertical air flow [2, 3, 4]. Low temperature and long drying time of 90 hours minimized thermal stress in seeds [12, 10]. The positive results of experiments where cereal seeds were dried in silos [2] prompted the current attempt to dry faba bean seeds in a silo with a vertical air circulation system. The objective of this study was to describe the drying process of faba bean seeds in a silo with vertical air flow, slightly heated by a 13.5 kW electric heater. The silo's ventilation efficiency and the amount of air supplied to the silo, subject to the height of the seed layer inside the silo, were determined to evaluate the drying process.

MATERIALS AND METHODS

A drying silo with a vertical air circulation system was designed at the former Department of Process Devices (presently the Department of Agricultural Process Engineering) of the University of Warmia and Mazury in Olsztyn. A patent application was submitted to the Polish Patent Office, which issued copyright No. 74982 for the silo [1, 5]. The device was designed for drying and storing cereal grain. A diagram of the silo used in this experiment is presented in Figure 1.

The silo is a steel structure. The cylindrical section with a diameter of 3 m is made of galvanized steel coated with plastic on both sides. Air is pumped into the silo by a fan (7). The ventilation cone (5) with a base diameter of 1.63 m is made of perforated steel with vent openings. The slant height of the cone is parallel to the slant height of the discharge tube. The cone is separated from the discharge tube by a distance of 0.7 m. Research results indicate that the designed ventilation system permits air movement throughout the entire bulk [2]. For the needs of this experiment, inspection openings, marked W1, W2, W3 and

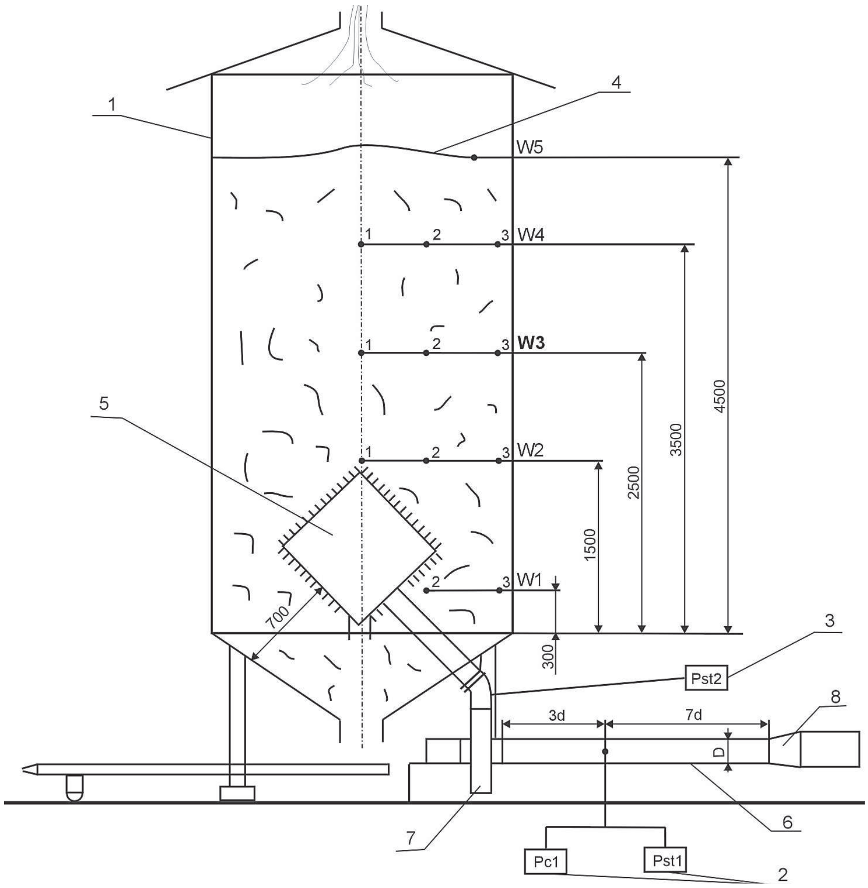

Fig. 1. A diagram of the experimental silo with a vertical air circulation system and a ventilation cone: 1 – silo, 2 – micro pressure gauge for measuring pressure inside the suction pipeline, 3 – pressure gauge, 4 – top surface of the seed layer, 5 – ventilation cone, 6 – suction pipeline, 7 – fan, 8 – electric heater, W_1, W_2, W_3, W_4 – sampling planes (1 – the silo's axis of symmetry, 2 – at mid-radius, 3 – by the wall), W_{31}, W_{32}, W_{33} – sampling points where seed temperature was measured continuously.

W4, were drilled along the silo's four longitudinal planes at the distances given in Figure 1. The silo was equipped with a 13.5 kW heater (8), WP-25 fan and micro gauges (2) for measuring the total pressure and static pressure of pumped air. Pressure was measured to the nearest Pa. Inspection openings were used to collect samples from various locations in the bulk. Total airstream pressure and static pressure were measured to calculate fan efficiency and the amount of air pumped into the silo. The first measurement was performed for an empty silo (H=0), and successive measurements were performed when seeds were added in layers of 0.5 m until the height of the seed bed inside the silo reached 4.5 m. The thickness of the seed layer should not exceed 4.5 m due to the risk of seed damage under the exerted load [11]. The measurements were used to calculate ventilation efficiency and the amount of air supplied to the silo in line with the presented method [2, 3]. Faba bean seeds were harvested from the same field in five batches. Seed purity ranged from 87.52 to 92.12%, with 7.08 to 11.12% content of usable impurities and 0.52 to 1.36% content of non-usable impurities. Total seed weight was determined at 25.4 Mg. Samples for the determination of seed moisture content were collected at various points along four sampling planes: the silo's axis of symmetry (W21, W31, W41), at the distance of 0.75 m from the axis of symmetry (W12, W22, W32, W42) and along the silo wall (W13, W23, W33, W43). The moisture content of seeds was determined by the drying method with the accuracy of 0.01%. Seeds were dried for 90 hours by circulating heated air throughout the silo. The parameters of circulating air are given in Figure 4. Samples for evaluating seed moisture content were collected eight times, approximately every 10 hours. The temperature and moisture content of drying air were determined upon sample collection.

RESULTS

The results of calculations revealed that the total area of vents in the ventilation cone is larger that cross-sectional area of the pipeline connecting the fan with the silo. Therefore, air flow was not throttled inside the silo. Changes in ventilation efficiency as a function of the height of the seed layer are presented in Figure 2. Initially, at H=0, air was pumped by the fan into the silo at a rate of 4270 $m^3 \cdot h^{-1}$. Ventilation efficiency was reduced to 4090 $m^3 \cdot h^{-1}$ when the thickness of the seed layer reached 1 m. Faba bean seeds were added in successive layers of 0.5 m until the height of the seed bed inside the silo reached 4.5 m. The fan was active and pressure was measured every time a new batch of seeds was added to the silo. The results of ventilation efficiency calculations are presented in Figure 2. The curve indicates that fan efficiency reached 3950 $m^3 \cdot h^{-1}$ when the silo was full. This is a constant value at which faba been seeds were dried for 90 hours. The correlation between ventilation efficiency and the height of the seed layer was described by a regression equation (Fig. 2). Changes in the amount of air pumped into the silo as the height of the seed layer increased from 1 to 4.5 m are presented in Figure 3. The seed layer with the height of 1 m was aired at 723 $m^3 \cdot Mg^{-1} \cdot h^{-1}$. When the height of the seed layer increased to 4.5 m, the amount of air pumped into the silo was reduced to 155 $m^3 \cdot Mg^{-1} \cdot h^{-1}$, and the drying process was conducted at this air flow rate for 90 hours. Changes in the amount of air supplied to the silo as the thickness of the seed layer increased from 1 to 4.5 m were described with a regression equation (Fig. 3). Regression equations can be used to calculate ventilation efficiency and the amount of air supplied at any thickness of the seed layer (Figs. 2 and 3). Seed drying inside a silo is determined by ventilation efficiency, air temperature and relative moisture content [2, 4, 6]. In this study, drying air had stable parameters with temperature of 18 to 21° and relative moisture content of 46 to 57%. Changes in air parameters as a function of time are presented in Figure 4.

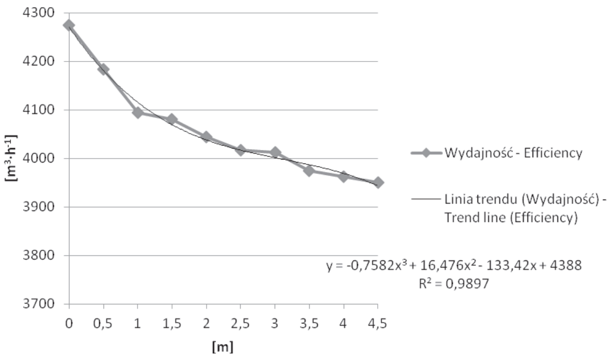

Fig. 2. Changes in ventilation efficiency, subject to the height of the seed layer in the silo.

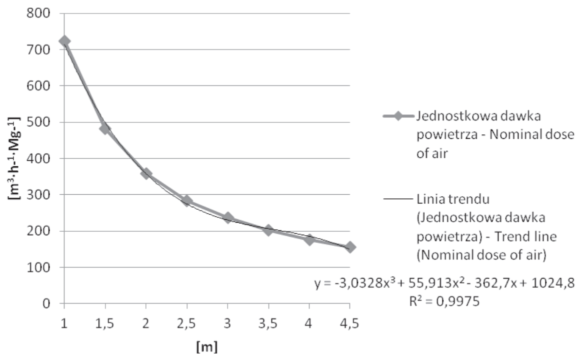

Fig. 3. Changes in the amount of air supplied to faba bean seeds in the silo.

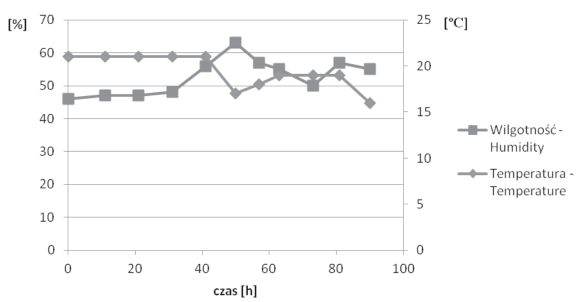

Fig. 4. Temperature and relative moisture content of air as a function of drying time.

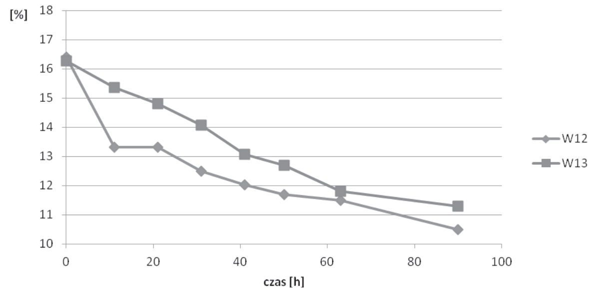

Fig. 5. Actual drying process in the silo in sampling plane W1.

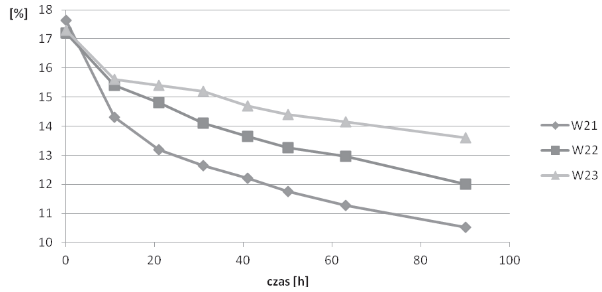

Fig. 6. Actual drying process in the silo in sampling plane W2.

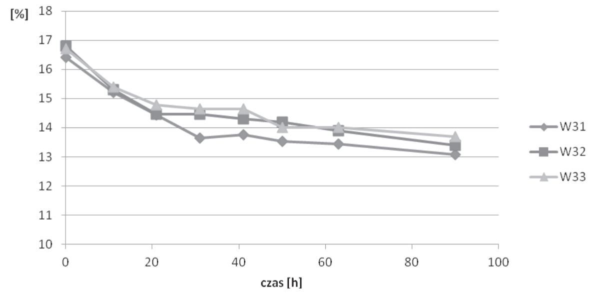

Fig. 7. Actual drying process in the silo in sampling plane W3.

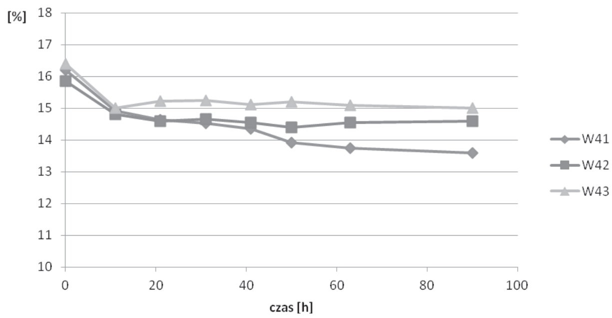

Fig. 8. Actual drying process in the silo in sampling plane W4.

In plane W1, samples were collected at two points, W12 and W13, between the discharge tube and the ventilation cone (Fig. 5). Ventilation efficiency curves indicate that drying in plane W1 proceeded at the highest rate after 90 hours, and relative moisture content was determined at 10.5% and 11.3%, respectively. The drying rate at points W12 and W13 was very high because seeds were dried by air with the lowest moisture content.

The initial moisture content of seeds in plane W2 was 17.5% (Fig. 6). At the end of drying, the highest drop in moisture content to 10.5% was noted along the axis of symmetry, whereas the lowest drop to 13.6% was observed by the silo wall. The above results can be attributed to increased air flow resistance due to seed segregation along the silo wall [2, 7].

The drying process was most stable in plane W3, and changes in air moisture content were similar at all points. The drying process was slowest in plane W4 (Fig. 8). After 90 hours of drying, moisture content was determined at 13.6% in point W41, 14.6% in W42 and 15% in W43. Air passing through the thickest seed layer is more moist than at the beginning of the process (planes W1 and W2). Ventilation curves indicate that seeds were dried most rapidly along the silo's axis of symmetry. The seed bulk was characterized by the highest porosity along the axis of symmetry, which minimized air flow resistance inside the silo [2].

CONCLUSIONS

1. The amount of air supplied to the silo by the WP-25 fan ranges from 723 $m^3 \cdot Mg^{-1} \cdot h^{-1}$ to 150 $m^3 \cdot Mg^{-1} \cdot h^{-1}$, subject to the degree of silo filling with faba bean seeds.
2. A vertical air circulation system with a ventilation cone facilitates the process of drying faba bean seeds.
3. Faba bean seeds are dried most rapidly along the axis of symmetry, whereas the drying rate is lowest by the silo's outer wall.
4. Faba beans are dried faster in the lower part of the silo, therefore, a two-phase drying process is recommended in planes W1, W2 and W3. Seeds dried in the lower part of the silo should be removed upon the achievement of the optimal moisture content for storage. The remaining seeds should be dried in the second stage of the process.

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PROCESS SUSZENIA NASION BOBIKU W SILOSIE Z PIONOWYM PRZEPŁYWEM POWIETRZA

Streszczenie. Nasiona roślin strączkowych zebrine przy użyciu kombajnu jesienią charakteryzują się wysoką zawartością wilgoci. W tym badaniu, nasiona bobiku suszono w niskich temperaturach w silosie z pionowym przepływem powietrza. Niska temperatura i długi czas suszenia wynoszący 90 godzin zminimalizowały stres cieplny w nasionach. Celem badania było opisanie procesu suszenia nasion bobiku w silosie z pionowym przepływem powietrza, lekko ogrzewanym przez 13,5 kW grzejnik elektryczny Wyniki tego badania wskazują, że ilość powietrza pompowanego do silosu przez wentylator WP-25 wynosi od 723 $m^3 \cdot Mg^{-1} \cdot h^{-1}$ do 150 $m^3 \cdot Mg^{-1} \cdot h^{-1}$, zależnie od stopnia wypełnienia silosu nasionami bobiku. Pionowy obieg powietrza ze stożkiem wentylacyjnym ułatwia proces suszenia nasion bobiku. Bobik suszy się najszybciej wzdłuż osi symetrii silosu, natomiast szybkość suszenia jest najniższa wzdłuż zewnętrznych ścian silosu. Nasiona suszą sie szybciej w dolnej części silosu, zatem zaleca się dwufazowy proces suszenia w płaszczyznach W1, W2 i W3.

Nasiona suszone w dolnej części silosu należy usuwać po osiągnięciu optymalnej zawartości wilgoci w celu przechowywania. Pozostałe nasiona powinny być suszone w drugim etapie procesu.

Słowa kluczowe: silosy, suszenie, przechowywanie, bobik.