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RESEARCH ON HEAT TRANSFER DURING THE DRYING PROCESS OF AGRICULTURAL SEEDS

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Abstract

Development of computers and software made possible CFD (Computational Fluid Dynamics) modeling of heat transfer phenomena in drying process of agricultural seeds. Validation of the mathematical model of the heat transfer process in a porous medium was achieved by measuring the seed temperature at several points of the seed layer in a dryer. The CFD simulation obtained the temperature profile in the seed layer on the three thicknesses studied. Simulation and experiment allow optimization of the drying process by increasing the quality of dried seeds with low energy consumption. The results of the simulation and experimental data give a dry layer optimum thickness of the 100 mm for all tested seeds.

Key words: numerical simulation, heat transfer, drying process, agricultural seeds

Drying of agricultural seeds is important in the long-term conservation of cereals. By the drying process the agricultural seeds lose a quantity of moisture until they reach the steady-state moisture to which they can be stored without suffering any loss of quality. Typically, this drying process takes place convectively by means of a heat transfer agent which penetrates the porous grain layer by taking up an amount of moisture which is eliminated in the atmosphere. If the heat required for drying is not recovered from the used drying agent, the energy consumption increases. In order to reduce energy consumption and reduce drying time it is necessary that the temperature distribution be as uniform as possible in the seed layer to be dried.

By determining the temperature distribution in the porous layer of dried seeds, it is possible to identify areas where superheating or underheating occurs in the layer. Knowing the temperature profile in the seed layer makes it possible to optimize the flow rate of drying agent and the thickness of the layer to be dried. Over time, many mathematical models have been developed to simulate heat and moisture transfer in loose and aerated cereal seeds. Many models have been obtained at relatively low temperature and humidity for cereals.

The partial differential equation models for wheat storage with aeration were developed by (Metzger, 1983; Wilson, 1988). The models simulated forced convective heat and moisture transfer in vertical direction, but the model was not validated. (Chang *et al*., 1993, 1994; Sinicio *et al*., 1997) developed a rigorous model to predict the temperature and moisture content of wheat during storage with aeration, and found that prediction result is in reasonable agreement with observed data. (Sun&Wood, 1997; Jia *et al*., 2001; Andrade, 2001; Devilla, 2002) simulated the temperature changes in a wheat storage bin respectively, and however, the moisture changes were not done. (Iguaz *et al*., 2004) developed a model for the storage of rough rice during periods with aeration. Two models of the phenomenon of mass and heat transfer in a bed of grains was developed and analyzed (Thorpe, 2007). In a subsequent paper (Thorpe, 2008) is calculated on CFD (*Computational Fluid Dynamics*) models to a software that simulates heat and moisture transfer in the bad grain. Based model and simulation of (Thorpe, 2008; Wang *et al*., 2010) developed and validated by experimental measurements of temperature transducers introduction the theoretical model at different points in a grain silo.

The paper aims to apply a mathematical model experimentally validated for the drying of

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malt (Cârlescu *et al*., 2012) for the drying of maize seeds on a three-layer experimental model, so that the optimal thickness of the grain layer for which the distribution temperature is optimal.

MATERIAL AND METHOD

In the drying process maize seeds from the hybrid DKC 4717 were used.

Experimentally, a three-layer concentric seed dryer was designed and developed to study temperature distribution in order to improve the qualitative indices of grain seeds subject to preservation (*figure 1*). The internal deflectors of the dryer have the role of uniformizing the drying agent on the height of the layer.

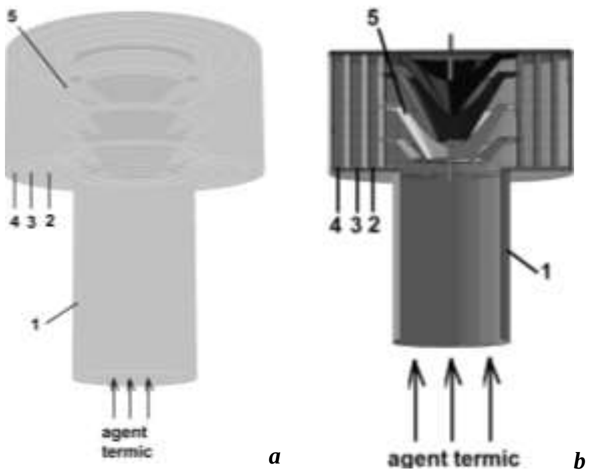

Figure 1 **Geometry of the three-layer dryer and deflectors: a- general view; b- section**

1– heat duct; 2– first seed layer; 3– second layer, 4– third layer, 5– deflectors.

The experimental drier for decide the optimal thickness of the seed bed to be dried is provided with a series of sensors for monitoring the temperature, humidity and velocity parameters of the thermal agent.

The temperature and humidity of the product are determined by K- type sensors (measuring range -40°C to +400°C, accuracy +/-0.3°C) located in each of the three layers. Additionally, the moisture and temperature of the drying agent prior to penetration into the grain seed layer and after, are monitored by means of some DLPTH1 moisture and temperature sensors (measuring range 0°C to +100°C, accuracy +/-0.1°C; 0 to 100% RH, accuracy +/-0.1% RH). Grain seed humidity is recorded at constant time intervals using a Grain Moisture Meter Tester MD-7822 (measuring range -10°C to +60°C, accuracy +/-2°C; 2 to 30% RH, accuracy +/-1%RH).

Determination of porosity in the seed layers was performed with the 3D SKYSCAN 1172 micro CT scanner and related software. The drying agent velocity at the inlet and outlet of the dryer was monitored using the TROTEC TA 300 hot wire anemometer (measuring range 0.1 m/s to 30 m/s, accuracy ± 0.1 m/s). Information obtained by the sensors is numerically transferred and graphically represented on a computer by means of a graphics card.

The experimental research on heat transfer to agricultural seed drying is preceded by the CFD simulation process because the simulation involves the use of physical parameters (porosity, volumetric mass, specific heat, conductivity) for both product and air used as a drying agent.

By CFD simulation of the grain drying process it is possible to graphically visualize the evolution of temperature and humidity fields at any point in the seed layer. CFD analyzes provide complex information on the drying phenomenon, which can not be obtained under experimental conditions. *Table 1* presents the capability and limits of the experiment and the CFD numerical simulation by comparative analysis.

CFD simulation, based on a complex mathematical model of heat and mass transfer, involves the pre-processing stages (dryer modeling), processing (dryer model calculation), postprocessing (graphical representation of the obtained solutions).

CFD simulation was performed with the Ansys FLUENT software using the TYAN workstation (2XCPU-Intel Xeon 3.33GHz; RAM-16GB DDR3 2600).

For both the drying and CFD simulation experiment the maize seeds with an initial humidity of 25% were used in the three layers and the porosity index determined experimentally by CT scan of a volume of 68.7 cm^3 with a number of 78 seeds of maize was 34.5%.

The drying speed used in both experiment and simulation was 2 m/s and the temperature was 40°C and 70°C, respectively.

The process of calculating the drying of the maize seeds for each of the two used temperatures was about 4 hours.

RESULTS AND DISCUSSIONS

The drying operation of agricultural seeds, depending on how it is conducted, can influence both positively and negatively their storage quality. Rapid drying of seeds with high humidity and high temperatures causes instant drying of the bean shell, welding of the outer ends of the capillary vessels, closing of the pores from the surface and preventing the outflow of the water from the grain. In such cases, by the accumulation of water vapours in the capillary vessels and the formation

Table 1

Comparative analysis between experiment and simulation

Types	Experiment	CFD simulation
	Quantitative description of the drying phenomenon using measurements	Quantitative prediction of the drying phenomenon using mathematical models and CFD simulation software
Number of parameters analyzed	1	>1
Number of points analyzed	1	>1
Model scale	low	real
Number of problems analyzed	limited	unlimited (depending on the software)
Conditions of deployment	laboratory	real condition
Sources of errors	measurement errors	modeling, meshing, deployment

of an overpressure inside the seeds, fracture and breakage occur (Thierer *et al*.,1971).

In maize seeds due to the horny layer of seed, drying of water is slower. If the grain is applied to too high a drying temperature, it cracks in one or more places, becomes very brittle, and the endosperm changes its cohesion and in the milling process it turns into fewer particles and more flour, which is totally undesirable in fodder technology. The grain embryo is the place where the highest moisture transfer takes place. For this reason, bursting stresses cause cracks when the elimination of water in the environment is accelerated by a high temperature gradient, because in this case the moisture in the neighbouring layers can no longer replace the removed water at the same rate.

By applying an appropriate drying process to an optimal thermal regime and moisture extraction that does not force the drying, it can substantially improve the proportion and nature of the seed substance as well as seed viability (germination).

The drying time of the grain mass of the three layers present in the drier depends to a large extent on the initial humidity and the shape in which the water in the grain is found. The influence of heat may be favourable only if the following three main factors are taken into account: the temperature and velocity of the drying agent, as well as the temperature of the grain mass.

The factors to be taken into account when determining the seed drying regime are the moisture of the grains at the entrance to the dryer, the maximum temperature of the heating of the grain and the temperature of the drying agent.

Moisture of grain seeds influences their porosity by altering the internal friction coefficient.

Settlement grain seed layer leads to a decrease in porosity. Experimentally, at the end of the drying process, the moisture in the three layers of corn seeds decreases unevenly in the radial direction as follows: layer I- 11.5%, layer II-11.7% and layer III - 14% and the porosity index varies on the three layers with seeds as follows: layer I - 38.5%, layer II - 38.0% and layer III - 37%. The porosity index was determined at the beginning of drying (maize seed humidity of 25%) and at the end of the drying process (maize seed humidity of 11.5%). The temperature variation in the three layers of corn seeds in the drier for the drying velocity of 2 m/s with a temperature of 40 °C at an initial moisture content of 25% maize seeds is shown (*figure 2*). By comparing the temperatures in the three layers one can see a detachment of the layer I compared to the layers II and III. This shows that the moisture in layer I passes into layers II and III, making their temperature rise more slowly. It is also noticed that, starting from the half-drying period, the temperatures in the seed layers begin to increase. The seed temperature in layer I stabilizes after 14 minutes at 35 °C with a uniform humidity of 11.5%. The total drying time is 20-30 minutes until all the seeds in the three layers reach the humidity of 11.5%. In layers II and III a non-uniformity of the humidity distribution was determined.

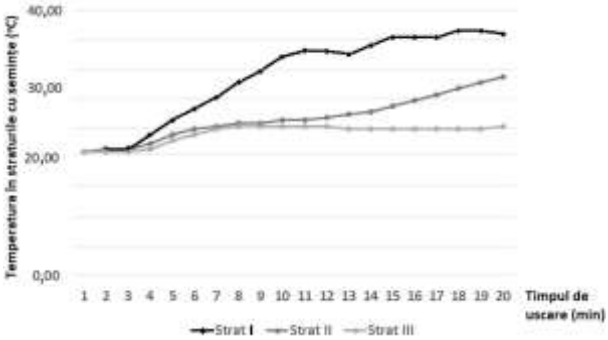

Figure 2 **The temperature variation in the maize seed layers**

The temperature variation in the three layers of corn seeds in the drier for the drying velocity of 2 m/s with a temperature of 70 °C at an initial moisture content of 25% maize seeds is shown (*figure 3*). By comparing the temperatures in the three layers one can see a detachment of the layer I compared to the layers II and III. This shows that the moisture in layer I passes into layers II and III, making their temperature rise more slowly. It is also noticed that, starting from the half-drying period, the temperatures in the seed layers begin to increase. The seed temperature in layer I stabilizes after 9 minutes at 40 °C with a uniform humidity of 11.5%. The total drying time is 15-20 minutes until all the seeds in the three layers reach the humidity of 11.5%. In layer III a non-uniformity of moisture distribution was determined.

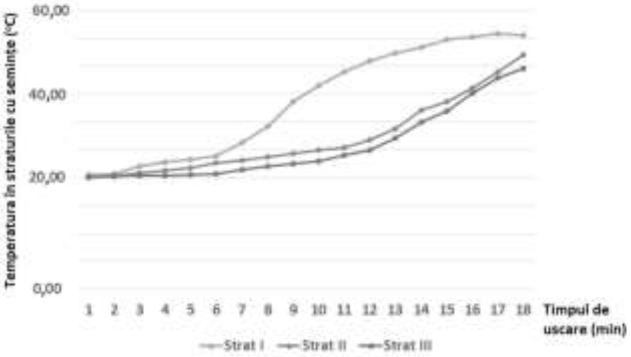

Figure 3 **The temperature variation in the maize seed layers**

CFD simulation postprocessing follows the presentation of the main parameters of interest in the color scheme of the maize seed drying process. Parameters are given, for each computation node, in the form of temperature fields, or by showing the flow of air through current lines depending on its velocity and temperature. The postprocessing was done for the three layers of maize seed following the temperature distribution in the seed layers.

The temperatures for the two simulated drying variants were 313 K (40 °C) and 343 K (70 °C). In the first variant, with a thermal agent entering the temperature of 313 K (40 °C) on the longitudinal section of the three-layer maize seed dryer, the average temperature of the heat agent decreases progressively from the layer I, which first contacts the thermal agent with 311 K (38 °C) at the second layer with 305 K (32 °C), reaching the third layer at an average temperature of 301 K (28 °C) until the end of the drying process *(figure 4)*.

In order to observe the degree of uniformity of temperature distribution in the three layers of corn seeds, a cross-section through the dryer was also made *(figure 5)*.

Inside the drier, the temperature of the drying agent is 313 K (40 °C).

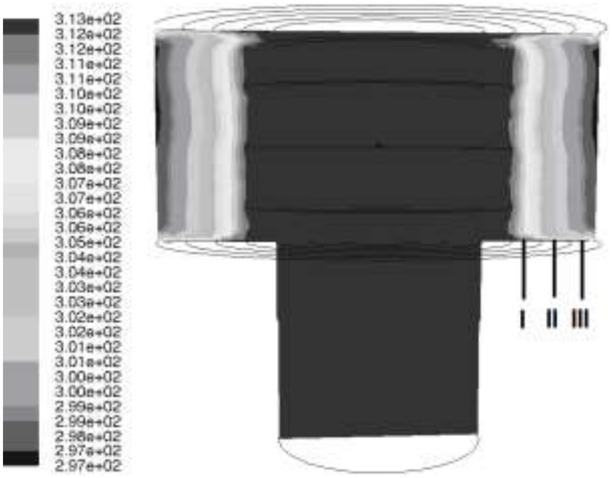

Figure 4 **The temperature variation in the maize seed layers - the longitudinal section of the dryer T(K)** (dryer temperature of 40 °C)
I– first seed layer; II– second layer, III– third layer

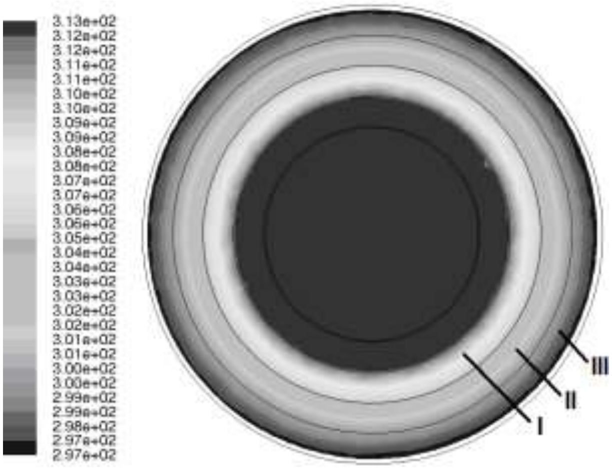

Figure 5 **The temperature variation in the maize seed layers – the cross section of the dryer T(K)** (dryer temperature of 40 °C)
I– first seed layer; II– second layer, III– third layer

In the second CFD simulation with a thermal agent entering 343 K (70 °C) on the longitudinal section of the drier and three layers of maize seed, the average temperature decreases progressively from the first layer by 338 K (65 °C) to the second layer with 318 K (45 °C), reaching the third layer at an average temperature of 308 K (35 °C) until the end of the drying process *(figure 6)*.

In order to observe the degree of uniformity of temperature distribution in the three layers of maize seeds, a cross section through the dryer was also made *(figure 7)*.

Within the drier, the temperature of the drying agent is 343 K (70 °C).

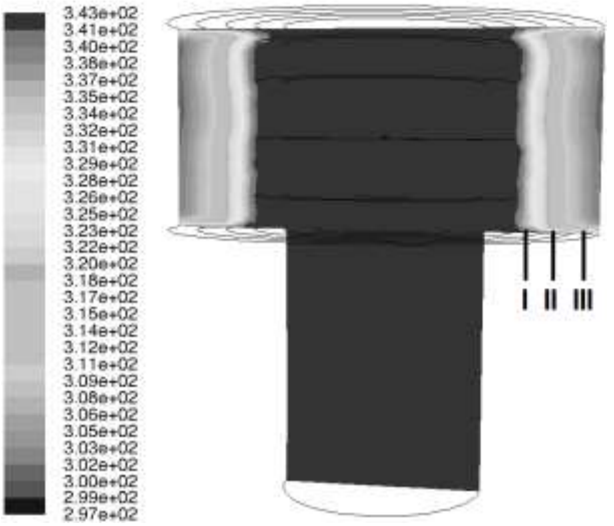

Figure 6 **The temperature variation in the maize seed layers - the longitudinal section of the dryer T(K)** (dryer temperature of 70 °C)
I– first seed layer; II– second layer, III– third layer

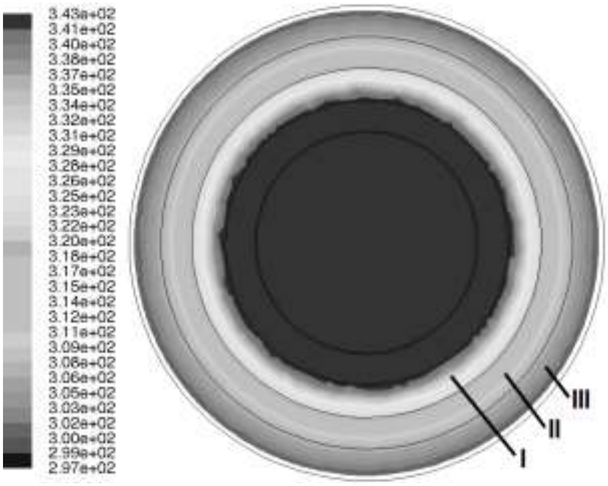

Figure 7 **The temperature variation in the maize seed layers – the cross section of the dryer T(K)** (dryer temperature of 70 °C)
I– first seed layer; II– second layer, III– third layer

The field of the pathlines obtained in the three-layer seed dryer has a laminar flow of the drying agent at the inlet to the dryer, and in the region of the baffles one can see a uniform distribution of the drying agent over the entire surface of the maize seeds to be dried.

In the first simulation model with a thermal velocity of 2 m/s and an inlet temperature of 313 K (40 °C), a velocity increase of up to almost 8 m/s is observed in the deflector region as a result of the reduction of the section, to reach uniformly again at 2 m/s on the surface of the first seed layer. Passing the three layers of maize seeds, the velocity of the pathlines drops to 0.3 m/s at the exit of the last layer *(figure 8)*.

In the second CFD simulation at an air velocity of 2 m/s and its inlet temperature of 343 K (70 °C), the same velocity increase is observed in the deflector region as a result of the reduction of the section, and it will become uniform again at 2 m/s on the surface of the first grain seed layer.

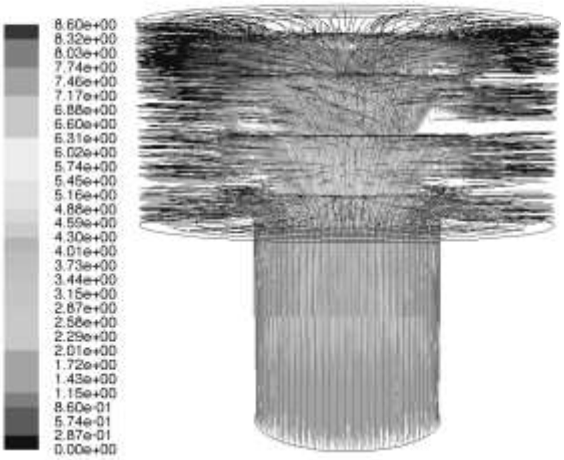

Figure 8 **The pathlines field inside the dryer with baffles and three layers v (m/s)**
(dryer temperature of 40 °C)

Passing the three layers of maize seeds, the pathlines velocity drops to 0.3 m/s at the exit of the last layer. The distribution of the velocity of the three-layer drying agent has small variations from the first variation because the geometry remains unchanged and the temperature does not substantially influence the flow of hot air *(figure 9)*.

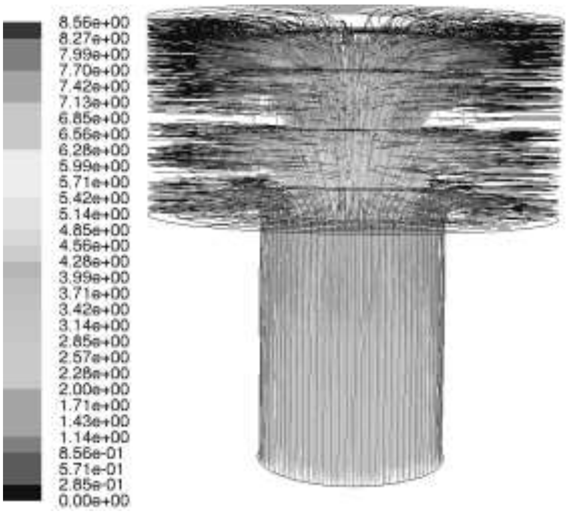

Figure 9 **The pathlines field inside the dryer with baffles and three layers v (m/s)**
(dryer temperature of 70 °C)

CONCLUSIONS

The experimental results on the maize seed drying process indicate an optimal drying in the first layer of seed with 100 mm thick.

The additional introduction of the second and third layers into the drier leads to an inadequate drying with moisture not corresponding to the grain conservation standard and an increase in drying time.

CFD simulation provides the possibility of viewing the temperature gradient in the layers of maize seeds to be dried.

The distribution of temperature obtained by CFD simulation is uniform in the first layer of seeds and correlates with the experimental results obtained for the temperature in this layer.

The temperature in the second and third layers remains lower as a result of the increase in moisture taken from the first layer and a slight ventilation by the decrease of the thermal agent velocity in these layers.

CFD simulation supports experimental research to optimize the drying process for grain seeds.

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REFERENCES

Andrade E.T., 2001. *Simulacao da variacao de temperatura em milho armazenado em silo metalico.* Minas Gerais: Imprensa Universitaria, Universidade Federal de Vicosa, Tese de doutorado em Engenharia Agricola, 174-178.

Cârlescu P., Dobre V., Țenu I., Roșca R., 2012. *Modeling on heat transfer during malt drying process.* Buletinul Institutului Politehnic Iaşi, Tomul LVIII (LXII), Fasc. 3, 203-209.

Chang C. S., Converse H. H., Steele J. L., 1993 *Modeling of Temperature of Grain During Storage with Aeration*. Trans. Am. Soc. Agric. Engrs., 36, 2, 509-519.

Chang C. S., Converse H. H., Steele J. L., 1994 *Modeling of Moisture Content of Grain During Storage with Aeration*. Trans. Am. Soc. Agric. Engrs., 37, *6*, 1891-1898.

Chung, D.S., Pfost, H.B., 1967 *Adsorption and Desorption of Water Vapor by Cereal Grains and their Products.* (I) *Heat and Free Energy Changes of Adsorption and Desorption.* Transactions of the American Society of Agricultural Engineers, 10, 549-555.

Devilla I.A., 2002, *Simulacao de deterioracao de distribuicao de temperatura umidade em uma massa de graos armazenados em silos com aeracao.* Minas Gerais: Imprensa Universitaria, Universidade Federal de Vicosa, Tese de doutorado em Engenharia Agricola, 84-90.

Hunter, A.J., 1987 *An Isostere Equation for Some Common Seeds*. Journal of Agricultural Engineering Research, 37, 93-107.

Hunter, A.J., 1989 *On the Heat of Sorption of Paddy Rice.* Journal of Agricultural Engineering Research, 44, 237-239.

Iguaz A., Arroqui1 C., Esnoz A., Virseda P., 2004 *Modeling and Simulation of Heat Transfer in Stored Rough Rice with Aeration*. Biosystems Engineering. 89, 1, 69-77.

Jia C. C., Sun D. W., Cao C. W., 2001 *Computer Simulation of Temperature Changes in a Wheat Storage Bin*. J. Stored Prod. Res., 37**,** 165-167.

Metzger J. F., Muir W. E., 1983 *Computer Model of Two Dimensional Conduction and Forced Convection in Stored Grain*. Canadian Agricultural Engineering, 25**,** *2*, 119-125.

Sinicio R., Muir W.E., Jayas D.S., 1997 *Sensitivity Analysis of a Mathematical Model to Simulate Aeration of Wheat Stored in Brazil*. Postharvest Biol. Technol., 11, 107-122.

Sun D.W., Woods J. L., 1997 *Simulation of the Heat and Moisture Transfer Process During Drying in Deep Grain Beds*. Drying Technology, 10**,** *15*, 99-107.

Thierer L., Volf 1971 - *Determinarea calității produselor agricole vegetale*. București. Editura CERES.

Thorpe G.R., 2007 *Heat and Moisture Transfer in Porous Hygroscopic Media: Two Contrasting Analyses.* Fifth International Conference on Heat Transfer, Fluid Mechanics and Thermodynamics, Sun City, South Africa.

Thorpe G.R., 2008 *The Application of Computational Fluid Dynamics Codes to Simulate Heat and Moisture Transfer in Stored Grains.* Journal of Stored Products Research, 44, 21-31.

Wilson S.G., 1988 *Simulation of Thermal and Moisture Boundary Layers During Aeration of Cereal Grain.* Mathematics Comp. Simul., 30, 181-188.