Iowa State University
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A Modelica Library for Thin-Layer Drying of Agricultural Products

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Outline

- Introduction and Motivation
- Methods and System Modeling
- Modeling Outcome and Simulation Results
- Model Validation
- Conclusion and Future Work

Introduction

2050
~9.7 billion people

2018
~7.4 billion people

- Water
- Energy
- Food
  - Cereals: 70% calories consumed

Kent J. Bradford, Peetambar Dahal, Johan Van Asbrouck, Keshavulu Kunusoth, Pedro Bello, James Thompson, Felicia Wu,
The dry chain: Reducing postharvest losses and improving food safety in humid climates,
Trends in Food Science & Technology, Volume 71, 2018, Pages 84-93,
https://doi.org/10.1016/j.tifs.2017.11.002.

Introduction

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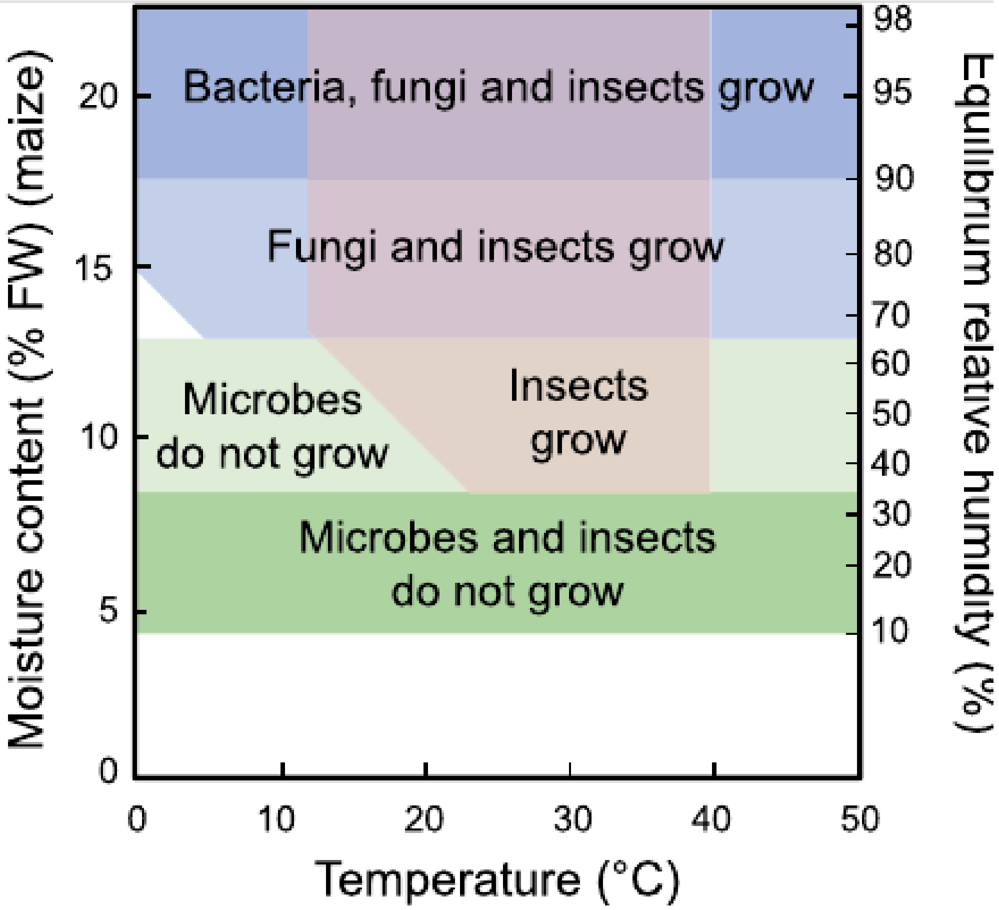
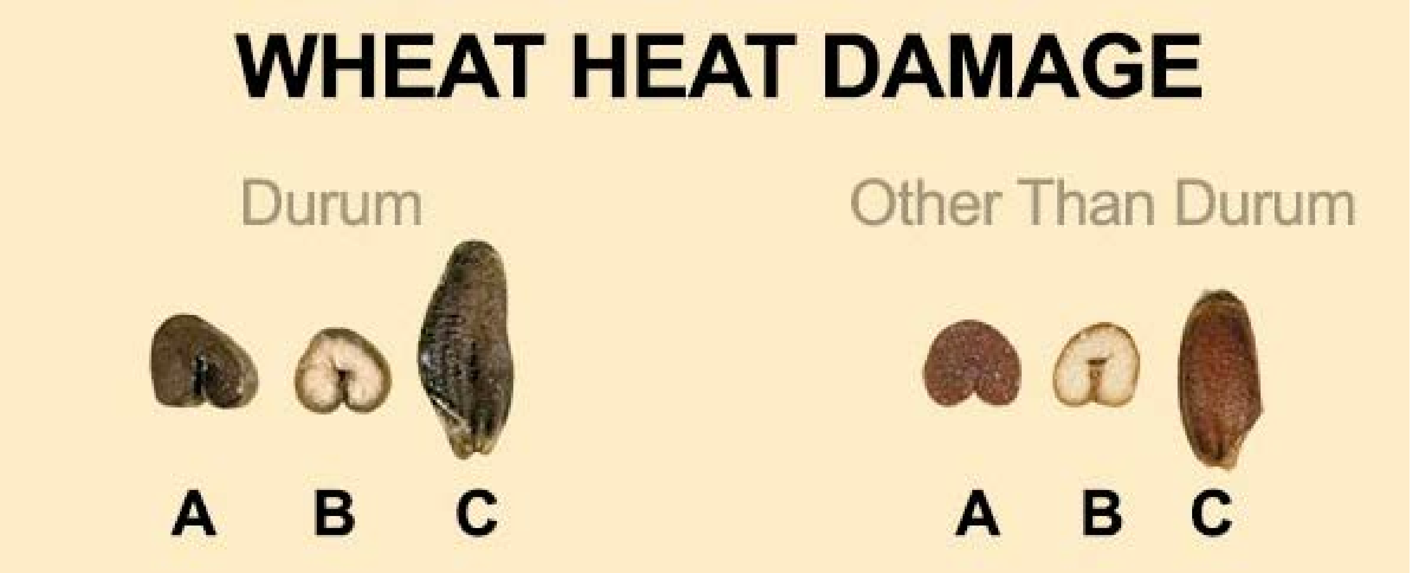
https://doi.org/10.1016/j.tifs.2017.11.002.

https://tgmsystem.com/key-topics/mold-growth/

High Moisture Content



Introduction



- More susceptible for physical damage
- Loss of nutrients
- Loss of market value

Low Moisture Content

Introduction

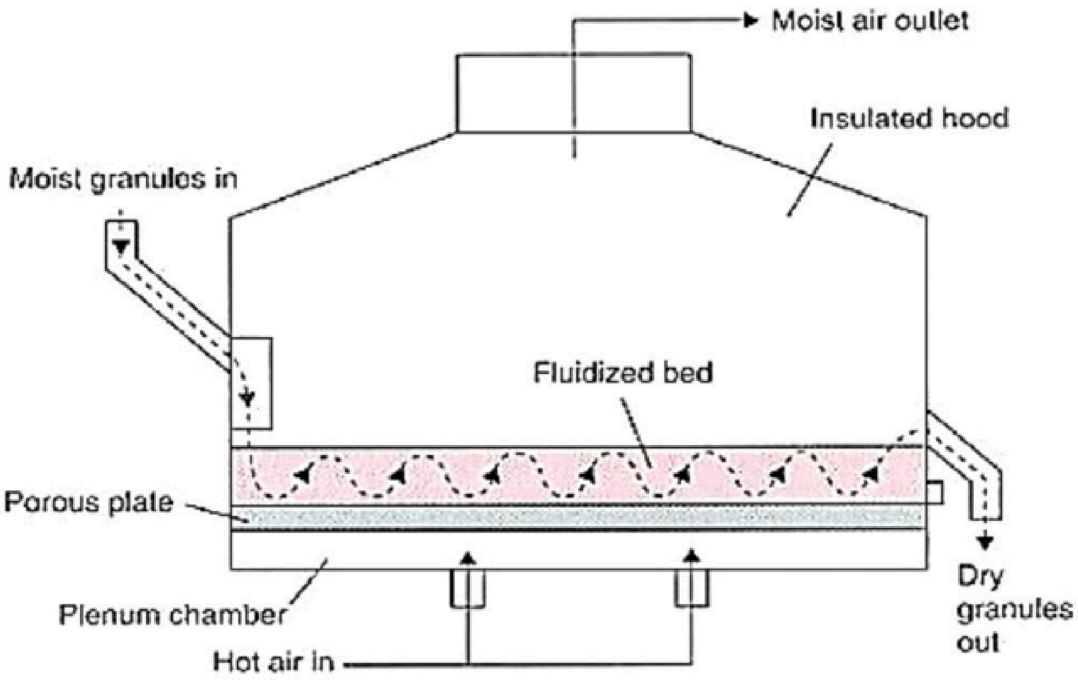


Fig. 1. Schematic diagram of a typical FBD dryer.

Sivakumar, Saravanan, Elaya Perumal, & Iniyan. (2016). Fluidized bed drying of some agro products – A review. *Renewable and Sustainable Energy Reviews, 61*, 280-301.

- Environmental factors
  - Air temperature
  - Relative humidity
  - Psychrometric factors
- Technical factors
  - Heat source
  - Dryer type
  - Material

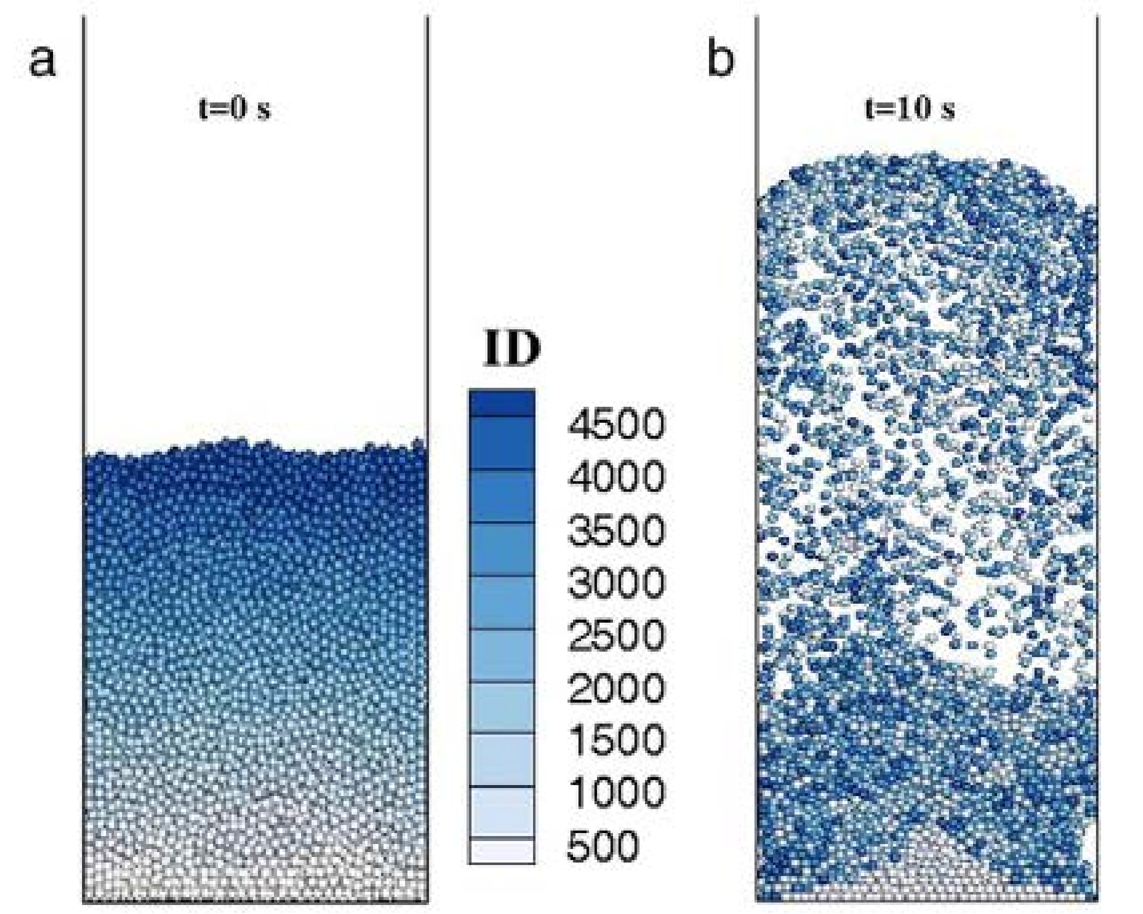


Fig. 2. (a) Particles before mixing with their identities (ID) indicated (0 s) and (b) particle mixing at 10 s for the inlet air velocity of 7 m/s.

Azmir, Hou, & Yu. (2018). Discrete particle simulation of food grain drying in a fluidised bed. Powder Technology, 323, 238-249.

Figure 2. The main window of the simulation software.

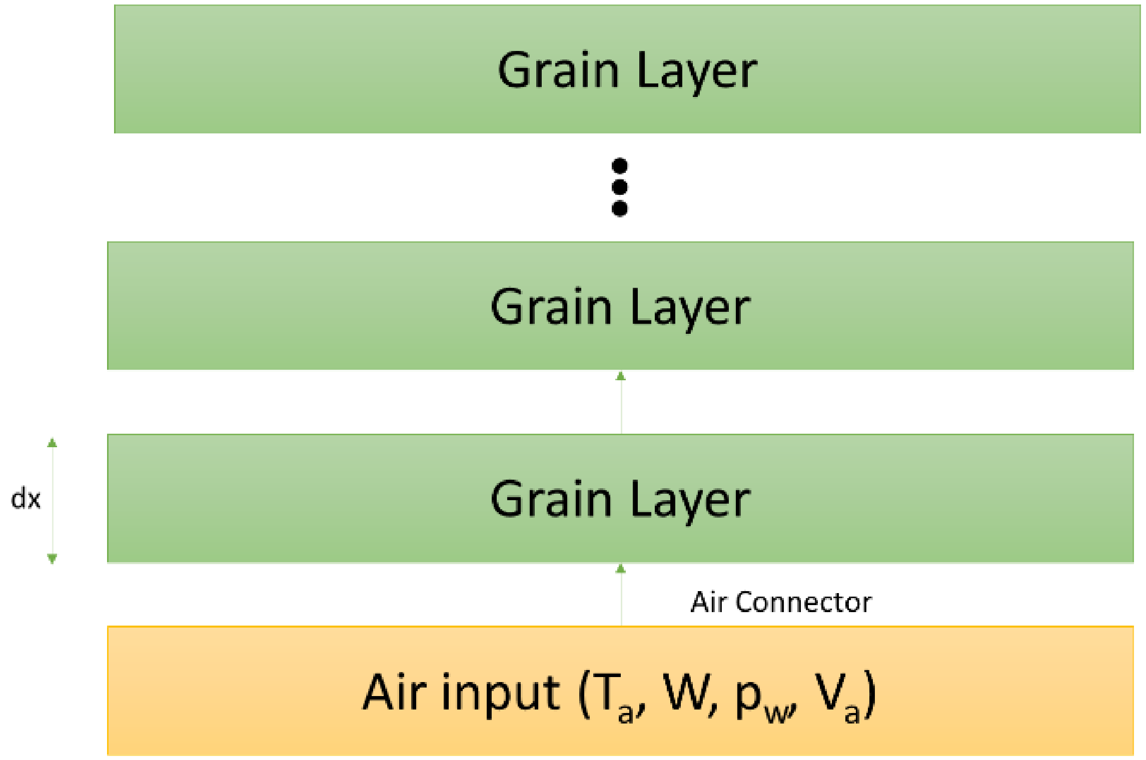
C.-C. Jia, W. Yang, T. J. Siebenmorgen, and A. G. Cnossen. Development of Computer Simulation Software for Single Grain Kernel Drying, Tempering, and Stress Analysis. Transactions of the ASAE, 45(5):1485–1492, 2002. ISSN 2151-0059. doi:10.13031/2013.11039.

Objectives

- Develop a grain drying process model for barley, corn, and soybean
- Simulate the model under different scenarios
- Compare the simulated with empirical data and calculate the difference between both

System Modeling – Static Bed Drying Model

- Thermodynamic and mass transfer process
- Static thin layers
  - Infinitesimal size (dx)
- Air flow from the bottom to the top



System Modeling – Static Bed Drying Model

Moisture Content →
$$\frac{dM}{dt} = -k \times (M - M_e) \quad (1)$$

Air Temperature →
$$\frac{dT_a}{dx} = \frac{-h'a}{G_a c_a + G_a c_v W} \times (T_a - T_p) \quad (2)$$

Product Temperature →
$$\frac{dT_p}{dt} = \frac{h'a}{\rho_p c_p + \rho_p c_w M} \times (T_a - T_p) + \frac{h_{fg} + c_v(T_a - T_p)}{\rho_p c_p + \rho_p c_w M} \times G_a \frac{dW}{dx} \quad (3)$$

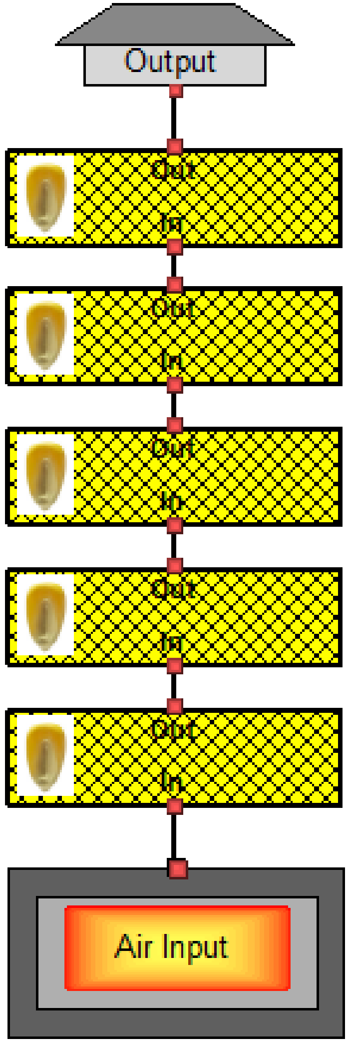
Humidity Ratio →
$$\frac{dW}{dx} = -\frac{\rho_p}{G_a} \times \frac{dM}{dt} \quad (4)$$

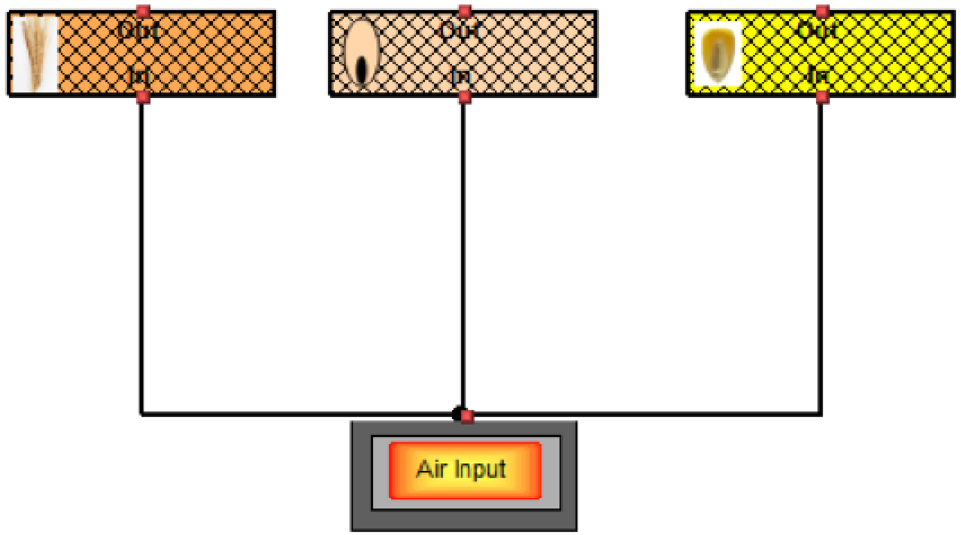
$$1 - \frac{P_v}{P_{vs}} = e^{[-K_{Me}(T_a + C_{Me})(100M_e)^{N_{Me}}]} \quad (6)$$

Brooker, D. B., Bakker-Arkema, F. W., & Hall, C. W. (1992). Drying and storage of grains and oilseeds. Van Nostrand Reinhold.

Model Development

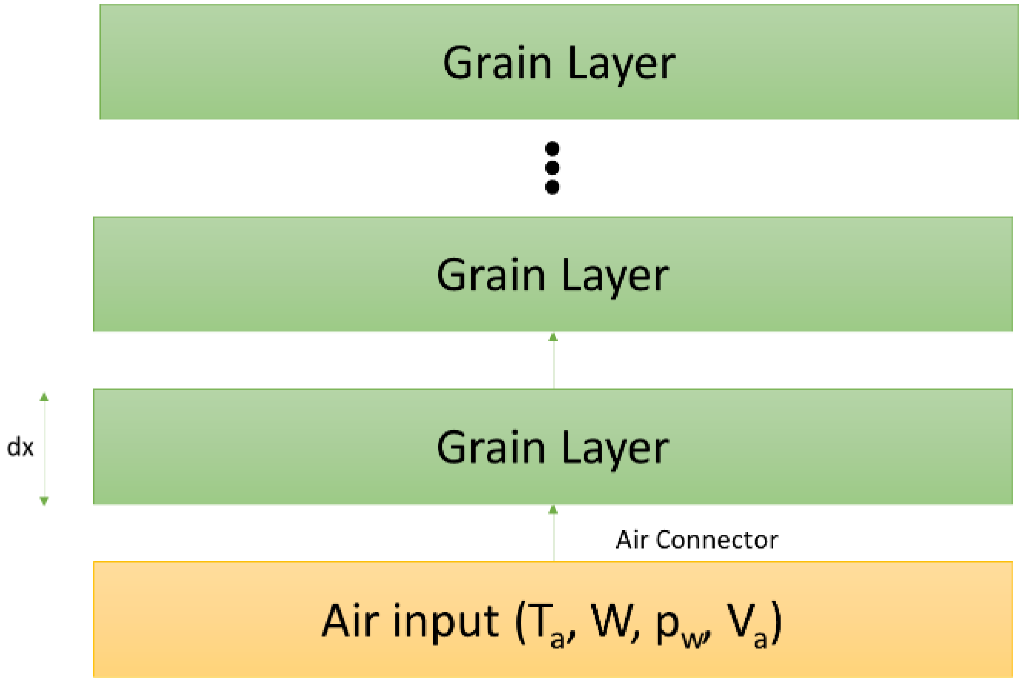
- Grain Library:
  - Barley
  - Corn
  - Soybean
- Dryer Package:
  - Dryer Input
  - Air Output
  - Air Connectors



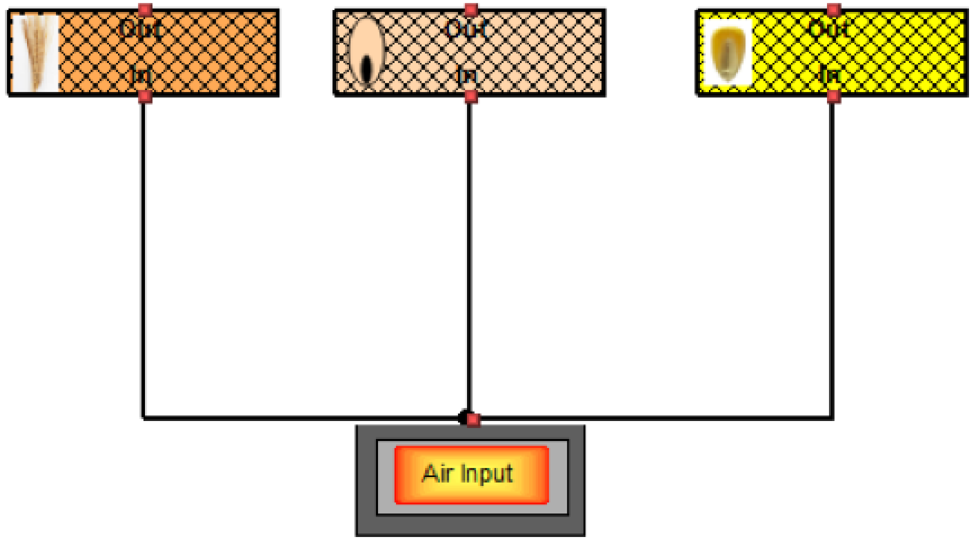


Model Development

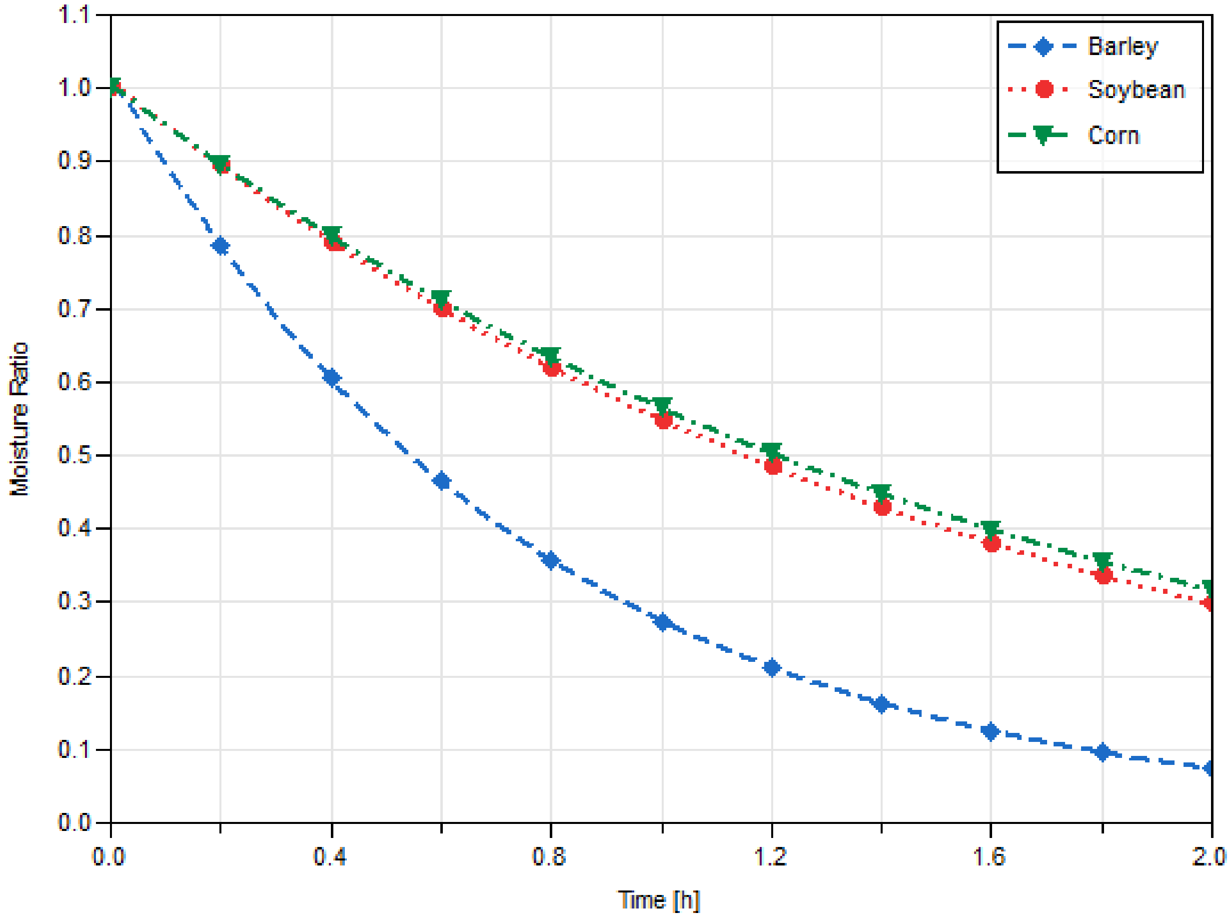
```
connector AirCon
import SI = Modelica.SIunits;
SI.Temperature Ta(displayUnit="Kelvin") "
    Air temperature (K)";
pw "partial pressure of water vapor in
                  air";

SI.MassFraction W(min=0) "air humidity
    ratio";
SI.Velocity Va(start=10, displayUnit="10"
    ) "Air velocity";
end AirCon;
```



Simulation Results – Grain Comparison

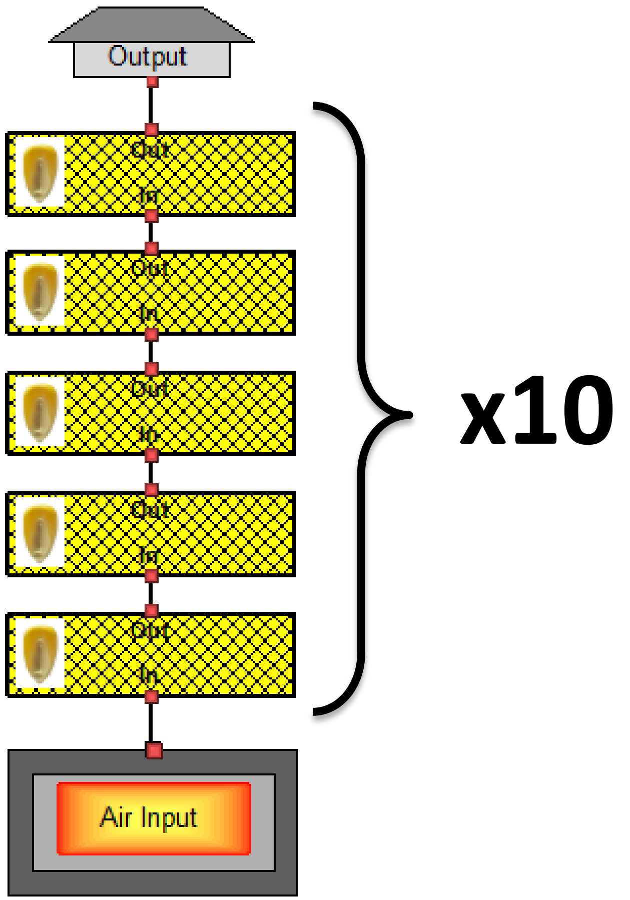


Initial Moisture Content = 35% (w.b.)
Layer Thickness = 25 cm
Initial Grain Temperature = 25 ^{0}C
Drying Temperature = 70 ^{0}C
R.H. = 50%



Simulation Results – 50 Corn Layers

- 50 x 0.25 m= 12.5 meters
- Initial Moisture Content = 35% (w.b.)
- Initial Grain Temperature = 30 ^{0}C
- Drying Temperature = 70 ^{0}C
- R.H. = 50%



Simulation Results – 50 Corn Layers

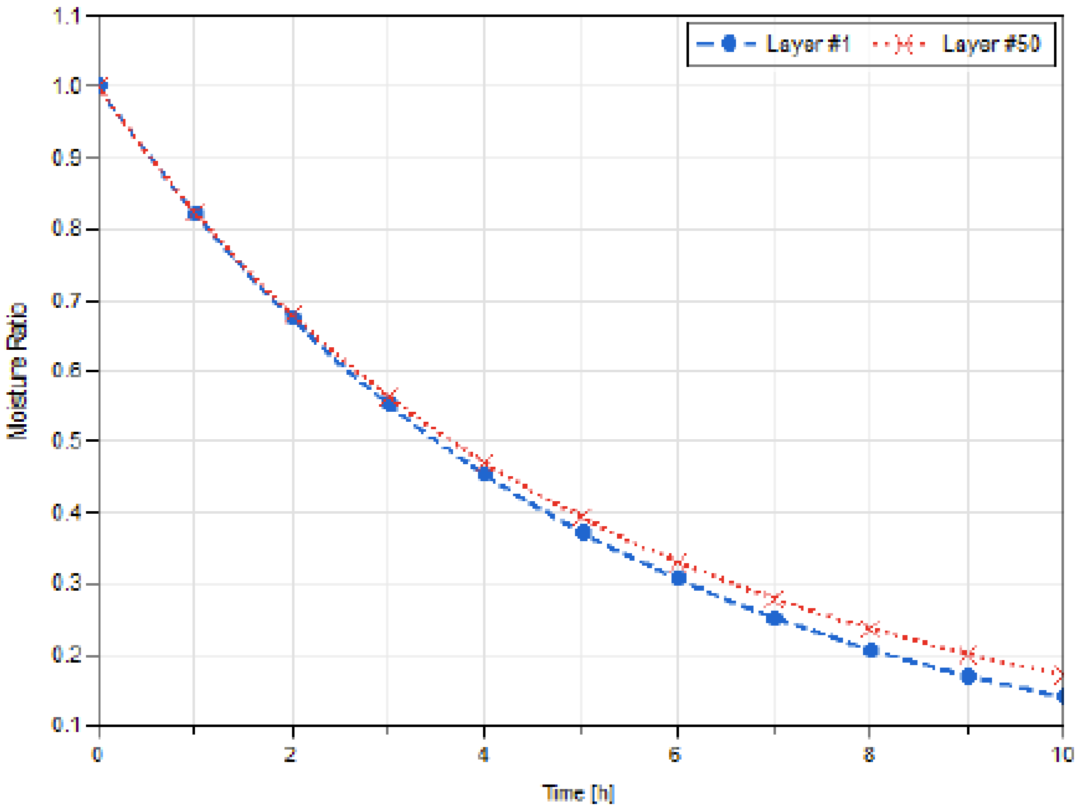


Figure 4. Moisture Ratio over time for the first and last layer of a deep bed simulation

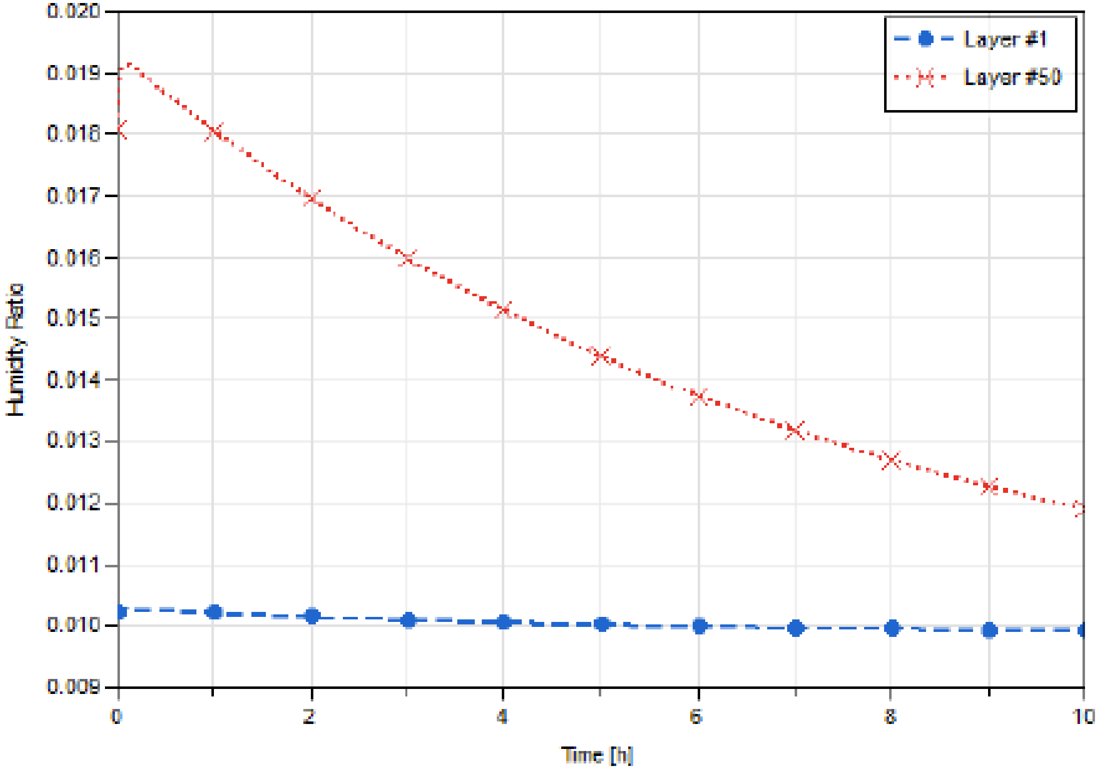


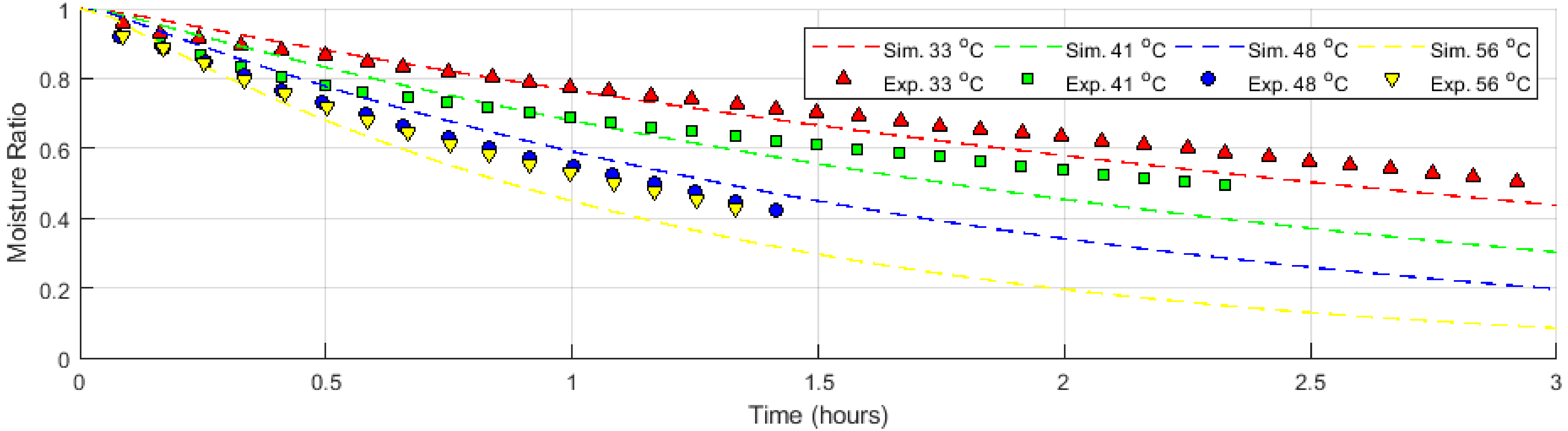
Figure 5. Humidity Ratio (m/m) at the exit of the first and last layer over time for the a deep bed simulation

Model Validation

Table 2. Experimental data collected for comparison

Parameters	Barley (Markowski et al., 2010)	Corn (Li and Morey, 1984)	Soybean (Freire et al., 2005)
Initial Moisture Content (%, w.b.)	17.5	26	Results in Moisture Ratio
Layer Thickness (mm)	333.0 ± 5.0	5.91	27.0
Air velocity (m/s)	30.1 ± 0.1	0.3	1.75
Initial Air Temperature (°C)	33, 41, 48, and 56 ± 2	27, 49, 71, 93, and 116	31.5, 45, and 58.5
Initial Product Temperature (°C)	Around 10	Room temperature	Close to air temperature
Drying duration (hours)	3	10	6.666
Initial RH (%)	±35	-	-

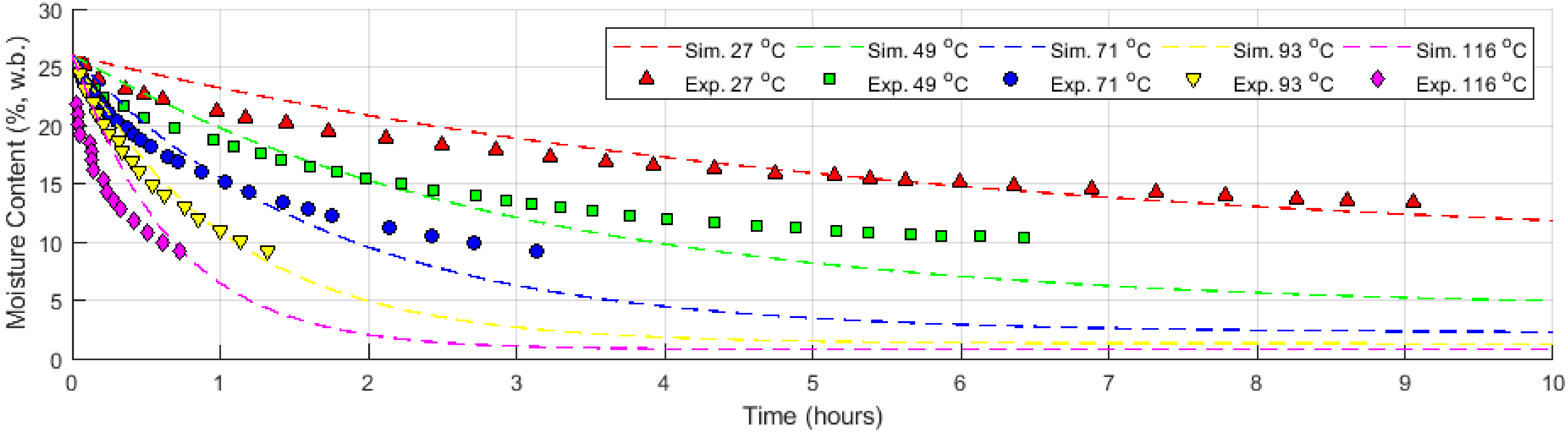
Model Validation



(a)

Barley

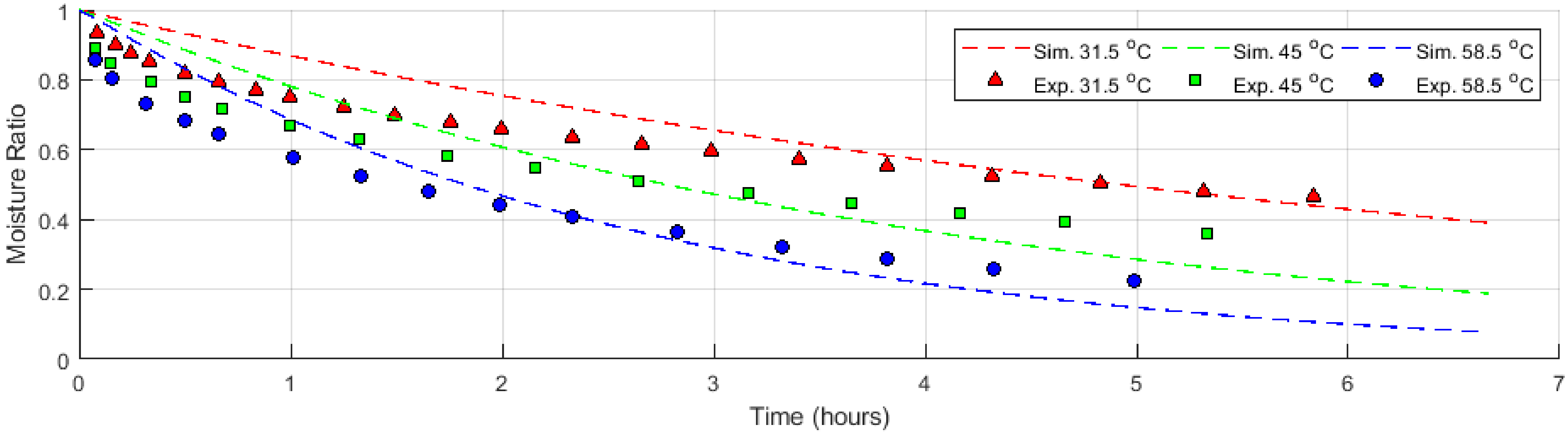
Model Validation



(b)

Corn

Model Validation



(c)

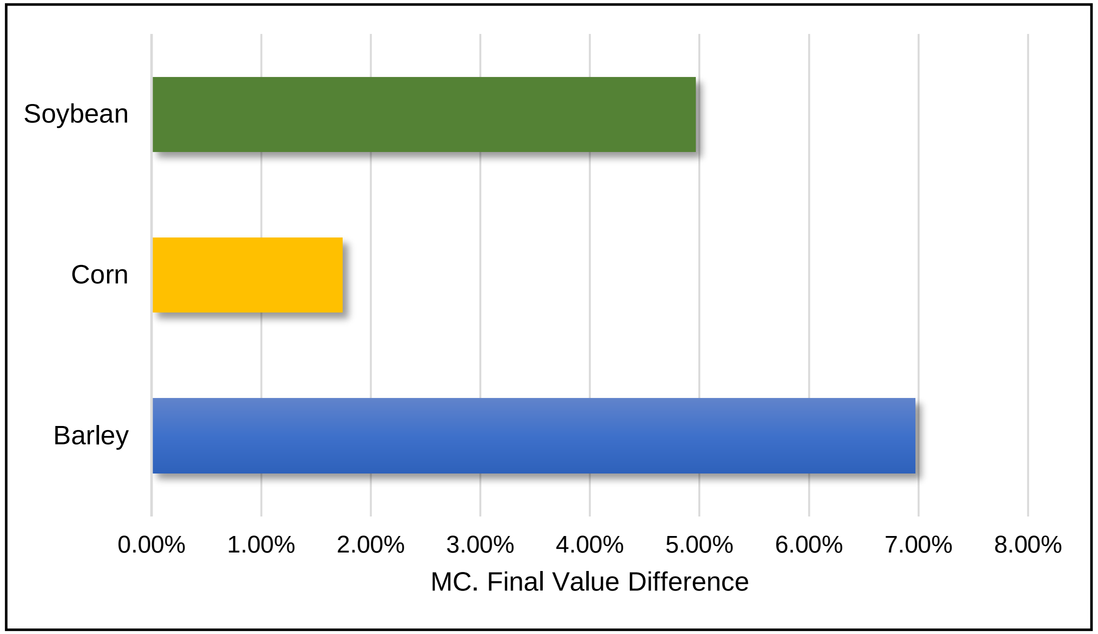
Soybean

Conclusion

- The simulations represented the expectations for different scenarios

- Drying trend was similar

- Difference were observed



Averages of the final Moisture Content Difference between the **Modelica** model and empirical data

Future Work

- Expand different aspects of the model
  - More types of grain
  - Fans and more detailed thermal systems
  - Different types of dryers
- Perform a sensitivity analysis for the variables influencing grain drying
- Apply to education and extension
  - ”Translate” to farmers and industry

Thank you!

Questions?

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EXTRA

System Modeling - Assumptions

1. The volume shrinkage of the kernels was negligible for the calculations.
2. The temperature gradients for an individual layer were constant.
3. The model did not take into consideration the conduction between kernels.
4. The dryer walls were considered adiabatic and with negligible heat capacity.
5. Empirical and theoretical equations were used for parameter calculation. All these equations were considered accurate.