

ISSN : 0973 - 8355

www.ijmmsa.com



INTERNATIONAL JOURNAL OF
MATHEMATICAL, MODELLING, SIMULATIONS AND APPLICATIONS

E-MAIL

editor.ijmmsa@gmail.com
editor@ijmmsa.com



Experimental Investigation of Moisture Reduction In Soybean Grains Using A Low-Power Recirculating Hot-Air Dryer

¹Yogesh Patil, ²Chetansingh Rajput, ³Abhaysinh Rathod, ⁴Manish Langote, ⁵Nandal Saurabh

¹Assistant Professor, Mechanical Engineering Department

Nagesh Karajagi Orchid College of Engineering & Technology, Solapur, India. yogeshpatil@orchidengg.ac.in

^{2,3,4,5}Students, Mechanical Engineering Department

Nagesh Karajagi Orchid College of Engineering & Technology, Solapur, India.

ABSTRACT

Post-harvest moisture reduction is essential for safe storage of soybean grains because excessive moisture can promote spoilage and deterioration. This study experimentally investigates a low-power recirculating hot-air dryer developed for small-batch soybean processing. The fabricated system has a $2 \times 3 \times 4$ ft cabinet, three perforated drying trays, a 300 W blower, two 200 W electrical heaters, and a 35 mm air-distribution manifold. An 8 kg soybean batch was distributed over the three trays in thin layers of approximately 6–7 mm and dried at an air temperature of about 45 °C. Moisture content was recorded at 10-min intervals up to 90 min for the upper, middle and lower trays. The measured average moisture content decreased from an initial 18% to 11.8% at 90 min, corresponding to a reduction of 6.2 percentage points or 34.4% relative to the initial moisture content. At 90 min, moisture contents were 12.2%, 11.8% and 11.4% for the upper, middle and lower trays, respectively, giving a tray-to-tray spread of 0.8 percentage points. The results indicate that the thin-layer, recirculating configuration provided progressive and relatively uniform moisture reduction without reported seed cracking or visible damage. The study demonstrates the feasibility of a compact low-power dryer for small-batch soybean processing; further trials should quantify specific energy consumption, drying kinetics and seed-quality parameters.

Keywords — Soybean drying; moisture reduction; recirculating hot air; thin-layer drying; low-power dryer; agricultural machinery.

1. INTRODUCTION

Soybean is an important agricultural commodity used for food, feed and industrial applications. Immediately after harvest, soybean grains may contain moisture at

levels that are unsuitable for safe storage. The project report identifies an initial moisture content of approximately 18% (wet basis) and a target of 12% for the developed drying

system. Excessive moisture can contribute to fungal and microbial growth, spoilage and deterioration of seed quality. Mechanical drying can provide controlled heat and airflow and can reduce the dependence of post-harvest processing on weather conditions.

Conventional sun drying is inexpensive but is weather-dependent and can be time-consuming and inconsistent. For small farms and laboratory-scale processing, there is therefore a need for compact drying systems that can provide controlled moisture reduction with modest power requirements. The present project addresses this need through a small-scale hot-air dryer designed for an 8 kg batch of soybeans.

Previous studies have investigated the heat and mass transfer behavior of soybean beds, continuous and intermittent drying, drying-temperature effects on quality, and energy-efficient dryer configurations. Thin-layer drying studies established the dependence of soybean drying behavior on air conditions and drying time [5], [18]. Fixed-bed and fluidized-bed investigations further examined heat and mass transfer, drying kinetics, energy use and product quality [3], [7], [13]. Studies on drying temperature and mode have also reported effects on moisture

reduction, cracking and seed quality [1], [3], [9]. These studies emphasize the importance of controlled temperature, airflow and drying conditions.

The present study differs in its emphasis on a compact, low-power, recirculating hot-air configuration intended for small batches. The system combines thin-layer trays, a blower-driven airflow path, electrical heating and recirculation. The objective of the experimental investigation was to evaluate the temporal reduction of soybean moisture and the uniformity of moisture reduction among three tray levels under a nominal drying-air temperature of 45 °C.

2. MATERIALS AND METHODS

2.1 Dryer Configuration

The fabricated dryer consists of a mild-steel frame and insulated cabinet with an internal footprint of approximately 2 × 3 ft and a height of 4 ft. Three removable perforated trays are arranged vertically. Each tray carries approximately 2.67 kg of soybeans, giving a total test load of 8 kg. The grain layer thickness is approximately 6–7 mm. A 300 W blower circulates air through the system, while two 200 W resistive heaters provide the hot-air input. A 35 mm hollow pipe manifold

distributes air below the trays. The arrangement is intended to recirculate heated

air while allowing moisture-laden air to escape through a vent.

Table 1. Main specifications of the experimental soybean dryer

Parameter	Specification
Cabinet	2 × 3 × 4 ft
Soybean load	8 kg per batch
Number of trays	3 perforated trays
Approx. load per tray	2.67 kg
Grain-layer thickness	6–7 mm
Blower	300 W, 220 V AC
Heaters	2 × 200 W resistive heaters
Nominal drying-air temperature	45 °C
Air-distribution manifold	35 mm hollow/perforated pipe
Initial moisture content	18%
Target moisture content	12%

2.2 Drying Principle and Airflow Arrangement

Soybeans were spread in thin layers on perforated trays. The blower circulated air through the heater section and manifold and across the grain layers. The heated air promoted moisture evaporation from the grain surface, while recirculation reduced the need to heat a continuously renewed air stream. The design calculations in the project report used an air velocity of approximately 0.2 m/s across the grain bed, corresponding to about 0.1115 m³/s or 401 m³/h (approximately 236 CFM).

2.3 Experimental Procedure

An 8 kg batch of soybeans was cleaned and distributed approximately equally over the three perforated trays. The initial moisture content was taken as 18%. The grain layer on each tray was approximately 6–7 mm thick. The blower and two electrical heaters were operated with the drying-air temperature maintained at approximately 45 °C. Moisture content was measured at 10-min intervals for the upper, middle and lower trays. The experiment was continued to 90 min and the recorded moisture values were compared among the three tray levels. Drying uniformity was evaluated from the difference

between the maximum and minimum tray moisture contents at each observation time.

2.4 Design Calculations

For an 8 kg batch with moisture reduced from 18% to 12%, the project calculations estimate approximately 0.48 kg of water removal. The corresponding latent heat requirement was estimated as approximately 1,083 kJ. At an assumed effective thermal efficiency of 50%, the design-stage drying time was estimated at approximately 90 min. The calculation therefore provided the basis for selecting a low-power recirculating arrangement.

The rated electrical power used in the reported test configuration was 300 W for the blower plus 400 W for the two heaters, giving a connected rated power of 700 W. If all components operated continuously at rated

power for 90 min, the corresponding upper-bound electrical energy input would be approximately 1.05 kWh. This is a calculated rated-energy value, not a measured energy-consumption result.

3.RESULTS AND DISCUSSION

3.1 Moisture Reduction

The measured moisture content decreased continuously throughout the 90-min test. The average moisture content across the three trays was 17.6% at 10 min, 14.3% at 50 min, 12.93% at 70 min, 12.20% at 80 min and 11.80% at 90 min. Thus, the average moisture reduction from the initial 18% was 6.2 percentage points, equivalent to a 34.4% reduction relative to the initial moisture content.

Table 2. Experimental moisture-content observations during drying

Time (min)	Upper tray (%)	Middle tray (%)	Lower tray (%)	Average (%)	Tray spread (percentage points)
10	17.7	17.6	17.5	17.60	0.2
20	17.4	17.3	16.9	17.20	0.5
30	16.8	16.4	16.3	16.50	0.5
40	15.9	15.6	15.5	15.67	0.4
50	14.7	14.1	14.1	14.30	0.6
60	13.9	13.5	13.4	13.60	0.5
70	13.1	12.9	12.8	12.93	0.3
80	12.4	12.2	12.0	12.20	0.4
90	12.2	11.8	11.4	11.80	0.8

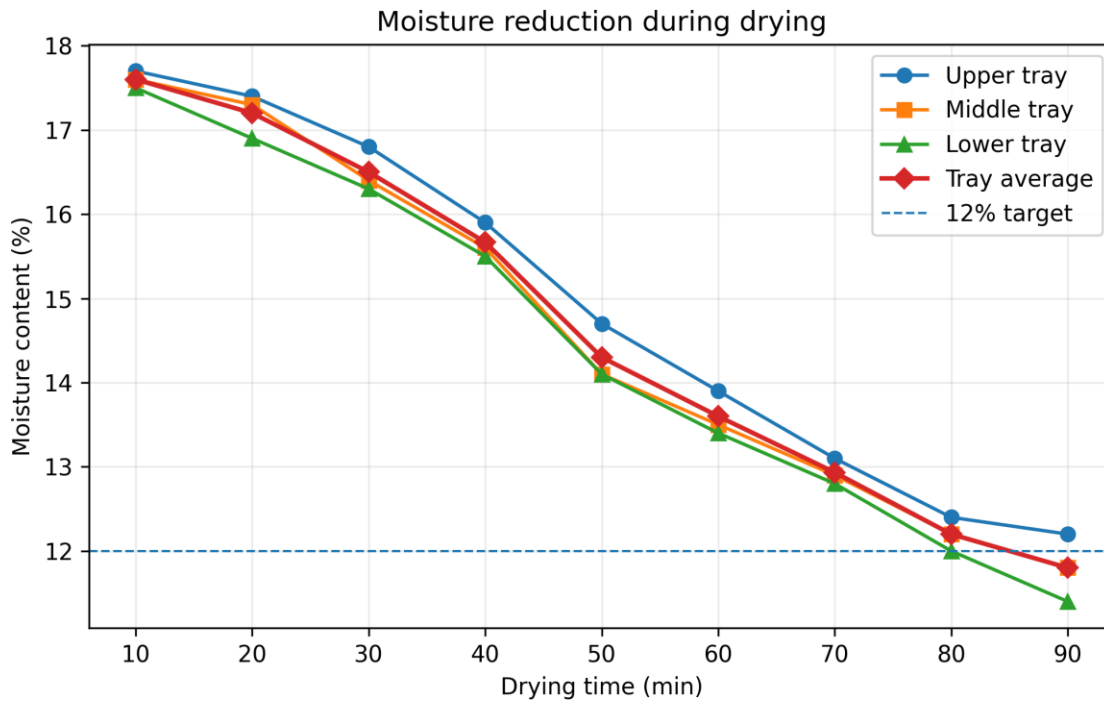


Figure 1. Moisture-content reduction with drying time for the three tray levels and the tray average.

3.2 Drying Uniformity

The three trays exhibited relatively close moisture values throughout the experiment. At 90 min, the upper, middle and lower trays contained 12.2%, 11.8% and 11.4% moisture, respectively. The maximum

difference among trays was therefore 0.8 percentage points. The tray spread remained below 0.6 percentage points up to 60 min and increased to 0.8 percentage points at 90 min. This indicates generally uniform moisture reduction, although a small vertical moisture gradient remained at the end of the test.

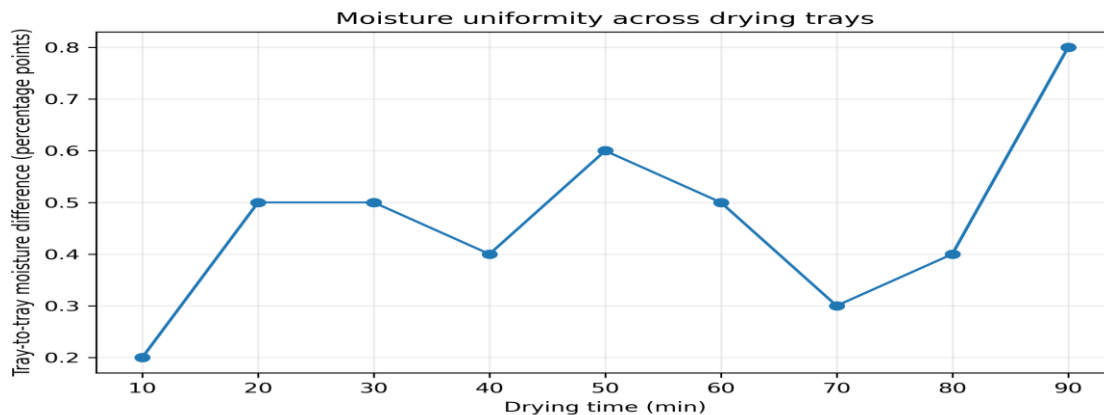


Figure 2. Tray-to-tray moisture difference during the drying experiment.

3.3 Achievement of the Target Moisture Level

The design target was approximately 12% moisture. At 80 min, the three tray values were 12.4%, 12.2% and 12.0%, respectively, giving an average of 12.2%. At 90 min, the average moisture was 11.8%; the middle and lower trays were below 12%, while the upper tray remained at 12.2%. Therefore, the experiment demonstrates achievement of approximately 12% moisture on an average basis by 90 min, but not strict attainment of $\leq 12\%$ in every tray at the final observation.

3.4 Drying Rate

Using the initial 18% moisture and the 90-min average value of 11.8%, the average moisture reduction rate over the complete test period was approximately 0.0689 percentage points per minute. This is an overall average rate and should not be interpreted as a constant drying rate because drying kinetics generally change with moisture content.

3.5 Energy Considerations

The experimental configuration used a 300 W blower and two 200 W heaters. The system was designed around recirculation because the design calculation indicated that heating the entire calculated fresh-air flow from 25 °C to 45 °C in a single pass would

require approximately 2.7 kW, which is substantially greater than the installed heater capacity. Recirculation therefore allows the system to reuse already heated air and limit the amount of fresh air that must be heated. A measured electrical-energy audit was not reported in the project data; accordingly, energy efficiency is discussed here as a design feature rather than as a quantified experimental efficiency.

3.6 Comparison with Previous Research

The present results are consistent with the broader literature emphasis on controlling airflow, temperature and moisture movement in soybean drying. Previous fixed-bed studies have shown that heat and mass transfer can vary within the drying bed and can be represented using coupled models [6], [13], while thin-layer studies have characterized soybean drying kinetics over a range of air temperatures [5], [18]. Intermittent-drying studies have examined opportunities to reduce energy use while maintaining product quality [3], [1]. Other work has examined mathematical modeling of soybean drying kinetics, including fractional-order, shrinkage and thermodynamic approaches [17], [20], [14]. The present work uses a simpler fixed-bed, thin-layer arrangement

intended for small batches and demonstrates progressive moisture reduction under a nominal 45 °C drying condition.

3.7 Seed Condition and Experimental Limitations

The project report states that no seed cracking or visible damage was observed during the test. However, seed-quality measurements such as germination, protein quality, oil quality, bulk density or mechanical damage were not quantitatively reported. Similarly, specific electrical energy consumption, relative humidity, exhaust humidity, actual airflow rate and replicate experimental runs were not reported. These limitations should be addressed before making generalized claims about energy efficiency or grain quality preservation.

4. CONCLUSION

A low-power recirculating hot-air dryer was experimentally evaluated for an 8 kg batch of soybean grains using three thin-layer perforated trays and a nominal drying-air temperature of 45 °C.

The average moisture content decreased from 18% initially to 11.8% after 90 min. The corresponding average reduction was 6.2 percentage points, or 34.4% relative to the initial moisture content.

At 90 min, moisture contents of the upper, middle and lower trays were 12.2%, 11.8% and 11.4%, respectively. The 0.8 percentage-point tray spread indicates reasonably uniform moisture reduction, although the upper tray remained slightly above the 12% target.

The recirculating configuration allowed a 300 W blower and 400 W total heater rating to be used for the small-batch dryer. The design-stage calculations indicate that recirculation is important because single-pass heating of the full calculated airflow would require substantially greater heating power.

The fabricated system therefore demonstrates the feasibility of compact, low-power hot-air drying for small-batch soybean processing. Further experimental work should include measured electrical energy consumption, controlled airflow and humidity measurements, drying-kinetic modeling, repeated trials and quantitative assessment of seed quality.

REFERENCES

- [1] C. A. Bissaro, R. O. Defendi, L. C. Pereira, A. L. Braccini, D. F. Rossoni, and L. M. M. Jorge, "Effect of intermittent drying on the energy consumption and physiological quality of soybean seeds," *Journal of Food*

Processing and Preservation, vol. 45, no. 3, Art. no. e15188, 2021, doi: 10.1111/jfpp.15188.

[2] P. C. Coradi, C. H. P. Fernandes, J. C. Helmich, and A. L. D. Goneli, "Effects of drying air temperature and grain initial moisture content on soybean quality (*Glycine max* (L.) Merrill)," *Engenharia Agrícola*, vol. 36, no. 5, pp. 866–876, 2016, doi: 10.1590/1809-4430-Eng.Agric.v36n5p866-876/2016.

[3] R. O. Defendi, P. R. Paraíso, and L. M. M. Jorge, "Optimization study of soybean intermittent drying in fixed-bed drying technology," *Drying Technology*, vol. 35, no. 1, pp. 125–137, 2017, doi: 10.1080/07373937.2016.1162171.

[4] R. L. Gianini, P. R. Paraíso, L. M. M. Jorge, and C. M. G. Andrade, "Modeling and energetic analysis of soybean meal drying in the indirect rotary dryer," *Chemical Product and Process Modeling*, vol. 4, no. 1, 2009, doi: 10.2202/1934-2659.1285.

[5] D. Hutchinson and L. Otten, "Thin-layer air drying of soybeans and white beans," *International Journal of Food Science & Technology*, vol. 18, no. 4, pp. 507–522, 1983, doi: 10.1111/j.1365-2621.1983.tb00292.x.

[6] M. Pfeifer, V. V. Murata, and M. A. S. Barrozo, "Modelling of soybean seed drying in concurrent sliding bed dryers: Effect of the number of stages on the seed quality and drying performance," *Biosystems Engineering*, vol. 107, no. 4, pp. 341–348, 2010, doi: 10.1016/j.biosystemseng.2010.09.008.

[7] S. Soponronnarit, T. Swasdisevi, S. Wetchacama, and W. Wutiwiwatchai, "Fluidised bed drying of soybeans," *Journal of Stored Products Research*, vol. 37, no. 2, pp. 133–151, 2001, doi: 10.1016/S0022-474X(00)00015-1.

[8] G. F. M. V. Souza, P. S. Avendaño, F. R. C. Ferreira, C. R. Duarte, and M. A. S. Barrozo, "A study on a novel system for soybean seeds drying: Performance and seed quality," *Drying Technology*, vol. 40, no. 14, pp. 2872–2879, 2022, doi: 10.1080/07373937.2021.1970579.

[9] H. W. Park, W. Y. Han, and W. B. Yoon, "Drying characteristics of soybean (*Glycine max*) using continuous drying and intermittent drying," *International Journal of Food Engineering*, vol. 14, no. 9–10, 2018, doi: 10.1515/ijfe-2018-0057.

[10] D. Zare and M. Ranjbaran, "Simulation and validation of microwave-assisted fluidized bed drying of soybeans," *Drying*

Technology, vol. 30, no. 3, pp. 236–247, 2012, doi: 10.1080/07373937.2011.630765.

[11] M. A. S. Barrozo, A. Mujumdar, and J. T. Freire, “Air-drying of seeds: A review,” *Drying Technology*, vol. 32, no. 10, pp. 1127–1141, 2014, doi: 10.1080/07373937.2014.915220.

[12] R. M. Torrez Irigoyen, S. M. Goñi, and S. A. Giner, “Drying–toasting kinetics of presoaked soybean: A mathematical model considering variable diffusivity, shrinkage and coupled heat transfer,” *Journal of Food Engineering*, vol. 142, pp. 70–79, 2014, doi: 10.1016/j.jfoodeng.2014.06.002.

[13] G. F. M. V. Souza, R. F. Miranda, F. S. Lobato, and M. A. S. Barrozo, “Simultaneous heat and mass transfer in a fixed bed dryer,” *Applied Thermal Engineering*, vol. 90, pp. 38–44, 2015, doi: 10.1016/j.applthermaleng.2015.06.088.

[14] D. E. C. de Oliveira, O. Resende, J. F. V. Bessa, A. N. Kester, and T. A. S. Smaniotto, “Mathematical modeling and thermodynamic properties for drying soybean grains,” *African Journal of Agricultural Research*, vol. 10, no. 1, pp. 31–38, 2015, doi: 10.5897/AJAR2014.8711.

[15] M. H. Khoshtaghaza, H. Darvishi, and S. Minaei, “Effects of microwave-fluidized bed drying on quality, energy consumption and

drying kinetics of soybean kernels,” *Journal of Food Science and Technology*, vol. 52, no. 8, pp. 4749–4760, 2015, doi: 10.1007/s13197-014-1557-6.

[16] H. Darvishi, “Quality, performance analysis, mass transfer parameters and modeling of drying kinetics of soybean,” *Brazilian Journal of Chemical Engineering*, vol. 34, no. 1, pp. 143–158, 2017, doi: 10.1590/0104-6632.20170341s20150509.

[17] D. J. Nicolin, D. F. Rossoni, and L. M. M. Jorge, “Mathematical modeling of soybean drying by a fractional-order kinetic model,” *Journal of Food Process Engineering*, vol. 41, no. 2, Art. no. e12655, 2018, doi: 10.1111/jfpe.12655.

[18] S. Rafiee, A. Keyhani, M. Sharifi, A. Jafari, H. Mobli, and A. Tabatabaefar, “Thin layer drying properties of soybean (Viliamz cultivar),” *Journal of Agricultural Science and Technology*, vol. 11, pp. 289–300, 2009.

[19] L. P. Silva, S. G. F. dos Santos, J. S. Queiroz, R. S. Rodvalho, and W. H. D. Buso, “Drying kinetics of soybean grains,” *Científica*, vol. 48, no. 2, pp. 99–106, 2020, doi: 10.15361/1984-5529.2020v48n2p99-106.

[20] G. L. Guilherme and D. J. Nicolin, “Soybean drying as a moving boundary problem: Shrinkage and moisture kinetics

prediction,” Journal of Food Process Engineering, vol. 43, no. 10, Art. no. e13497, 2020, doi: 10.1111/jfpe.13497.

[21] A. Anand, Y. Gariépy, and V. Raghavan, “Fluidized bed and microwave-assisted fluidized bed drying of seed grade soybean,” Drying Technology, vol. 39, no. 4, pp. 507–527, 2021, doi: 10.1080/07373937.2019.1709495.

[22] R. E. Lima, P. C. Coradi, M. T. Nunes, S. D. C. Bellochio, N. da S. Timm, C. F. Nunes, L. de O. Carneiro, P. E. Teodoro, and C. Campabadal, “Mathematical modeling and multivariate analysis applied earliest soybean harvest associated drying and storage conditions and influences on physicochemical grain quality,” Scientific Reports, vol. 11, Art. no. 23287, 2021, doi: 10.1038/s41598-021-02724-y.

[23] P. C. Coradi, M. B. Oliveira, L. O. Carneiro, G. A. C. Souza, and M. E. Cardoso, “Technological and sustainable strategies for reducing losses and maintaining the quality of soybean grains in real production scale storage units,” Journal of Stored Products Research, vol. 87, Art. no. 101624, 2020, doi: 10.1016/j.jspr.2020.101624.