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9673204
Drying and Storage

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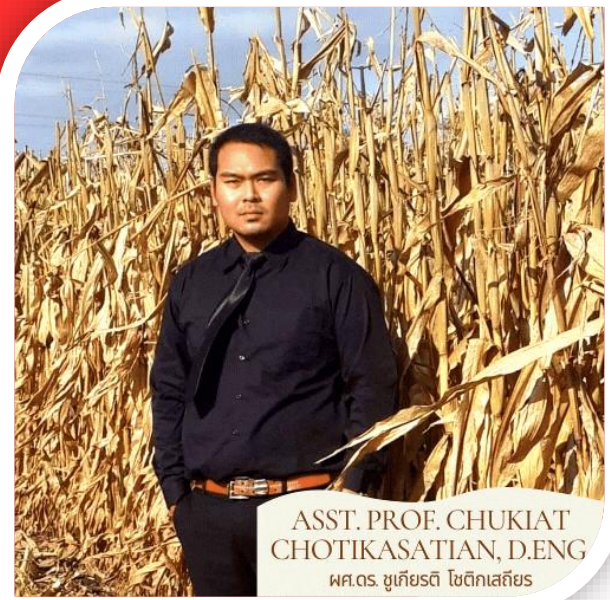
Course Description

Theory of drying, sun drying, principles of air flow, drying of agricultural products by heated air, moisture content determination, relationship of moisture and temperature, equilibrium moisture content, design of dryers storage

Professional Interest Statement:

- Monitoring CO_2/O_2 concentrations to assess biological activity and reduce post-harvest losses
- Establishing verification criteria for unacceptable insect infestation levels
- Supporting fumigation and grain storage management decisions
- Developing agricultural product drying and intelligent drying systems



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Lecture 9 – Principles of Agricultural Product Storage

Study Questions – Lecture 9

1. *Why is drying alone insufficient to ensure long-term storage stability of cereal grains?*
2. *How do temperature and relative humidity influence safe grain moisture content during storage?*
3. *Why is CO_2 concentration considered an important indicator of grain quality during storage?*

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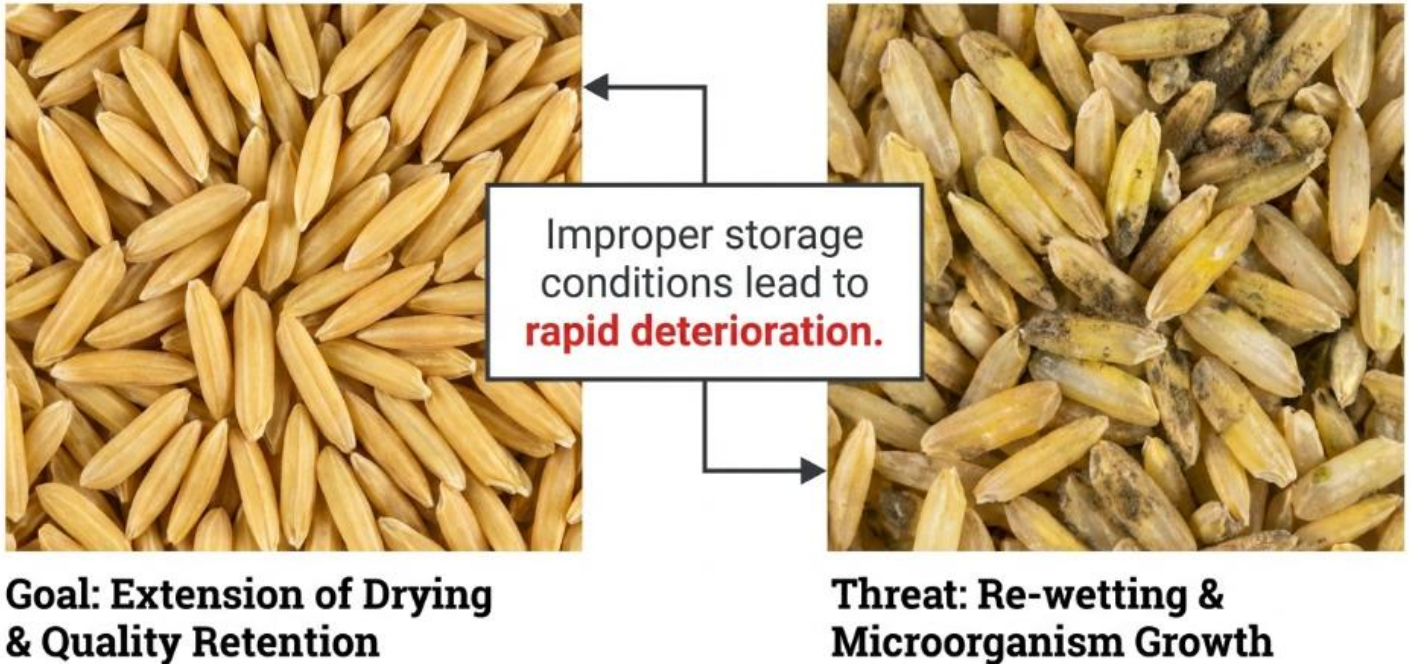
Lecture 9 – Principles of Agricultural Product Storage

Outline – Lecture 9

1. *Importance of Storage for Cereal Grains*
2. *Factors Affecting Grain Storage*
3. *Storage Methods and Structures*
4. *Monitoring Systems During Storage*

Importance of Agricultural Product Storage



The main objective of storage is to:

- Extend shelf life while maintaining quality
- Reduce quantitative and qualitative losses
- Prevent microbial, insect, and biochemical deterioration

Even after drying, improper storage may lead to:

- Moisture reabsorption
- Mold growth
- Discoloration
- Dry matter loss

Reference: Singh & Dixit, 2014, P.3

Storage Methods and Structures

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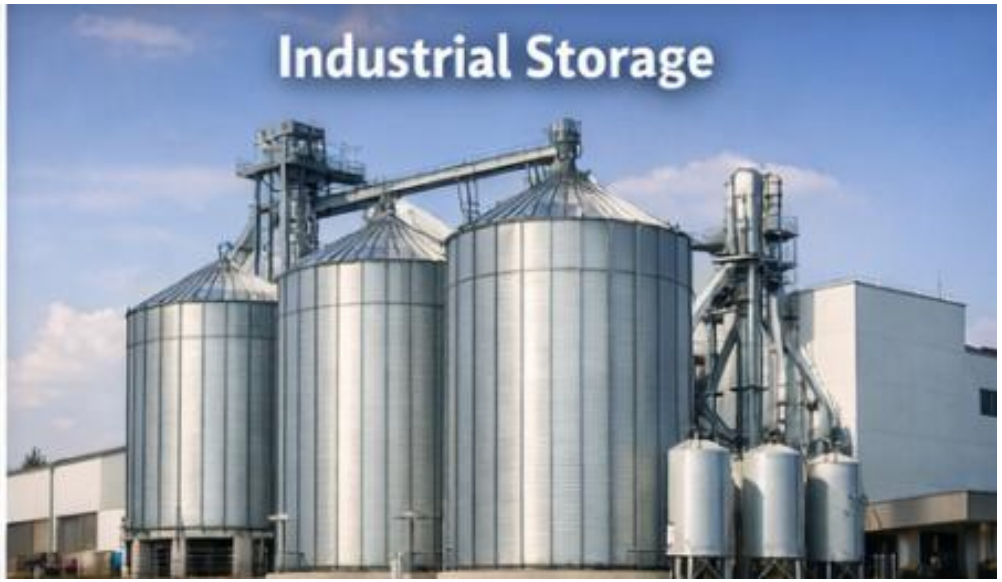

Method 1: Bag Storage

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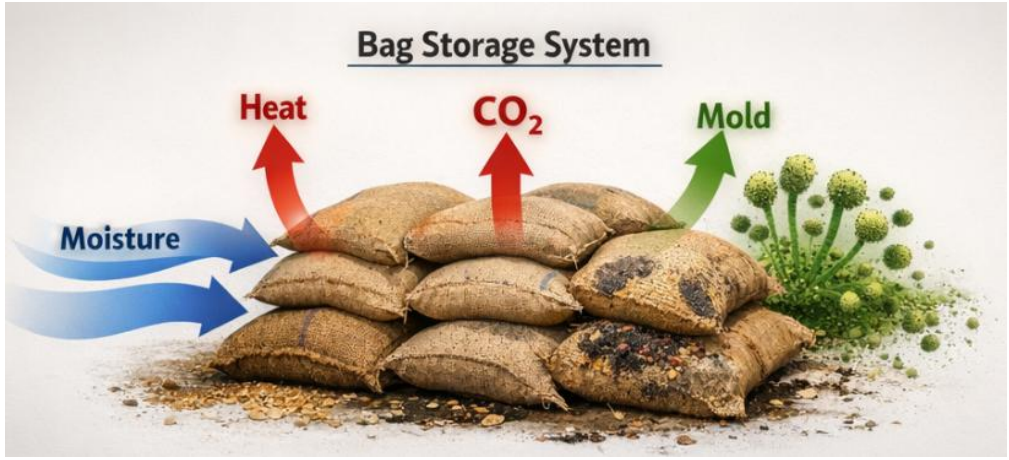
- **Usage:** Small scale, short duration.
- **The Problem:** Zero atmospheric control.
- **Mechanism:** Bags absorb moisture at night (High RH) and release it during the day (Low RH).

- **Result:** Sprouting and fungal growth.



The Respiration Equation

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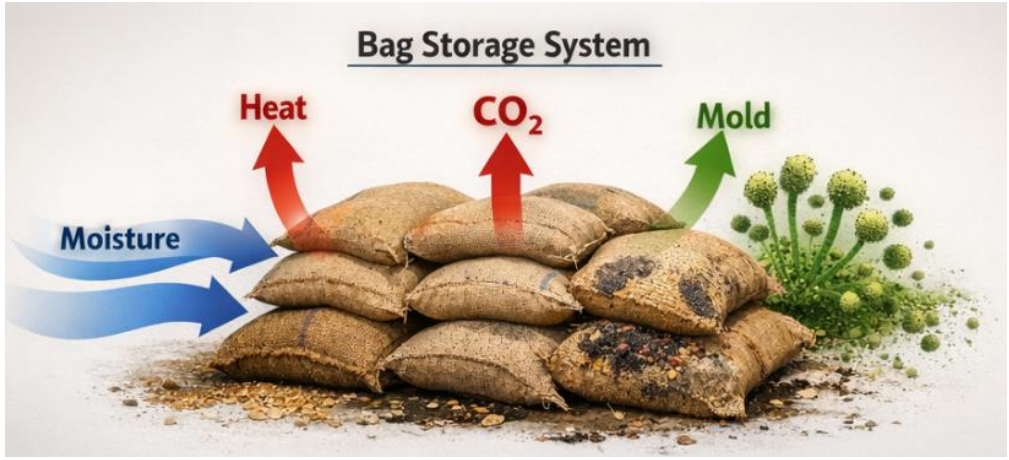
$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + Heat$$

Grain is a living organism. In a sealed environment, **self-generated heat and water create a feedback loop that accelerates mold growth and dry weight loss.**



Method 2: Bulk Storage

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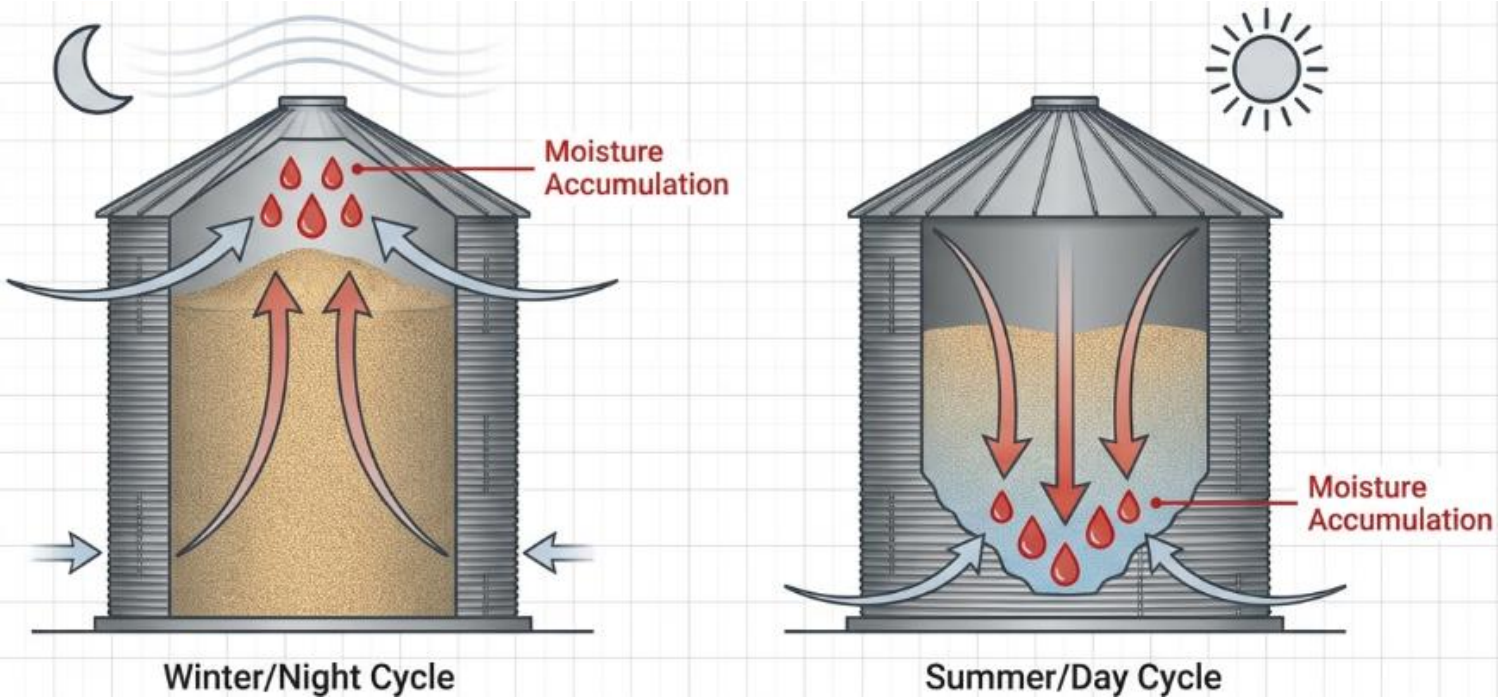
- Typically made of fiberglass with air inlets and outlets
- Equipped with ventilation fans and perforated pipes to distribute air throughout the grain mass

Method 3: Silo Storage



- **Industrial-scale storage (> 5 tons)** using galvanized steel structures
- **Moisture Condensation:** Temperature differences between day and night cause moisture to condense at the top (night) or bottom (day) of the silo
- **Night:** internal warm air → condensation at top
- **Day:** external warm air → condensation at bottom

Environmental Factors in Storage

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Safe Grain Moisture Content
(% w.b.)
in Equilibrium with Air at 65% Rh

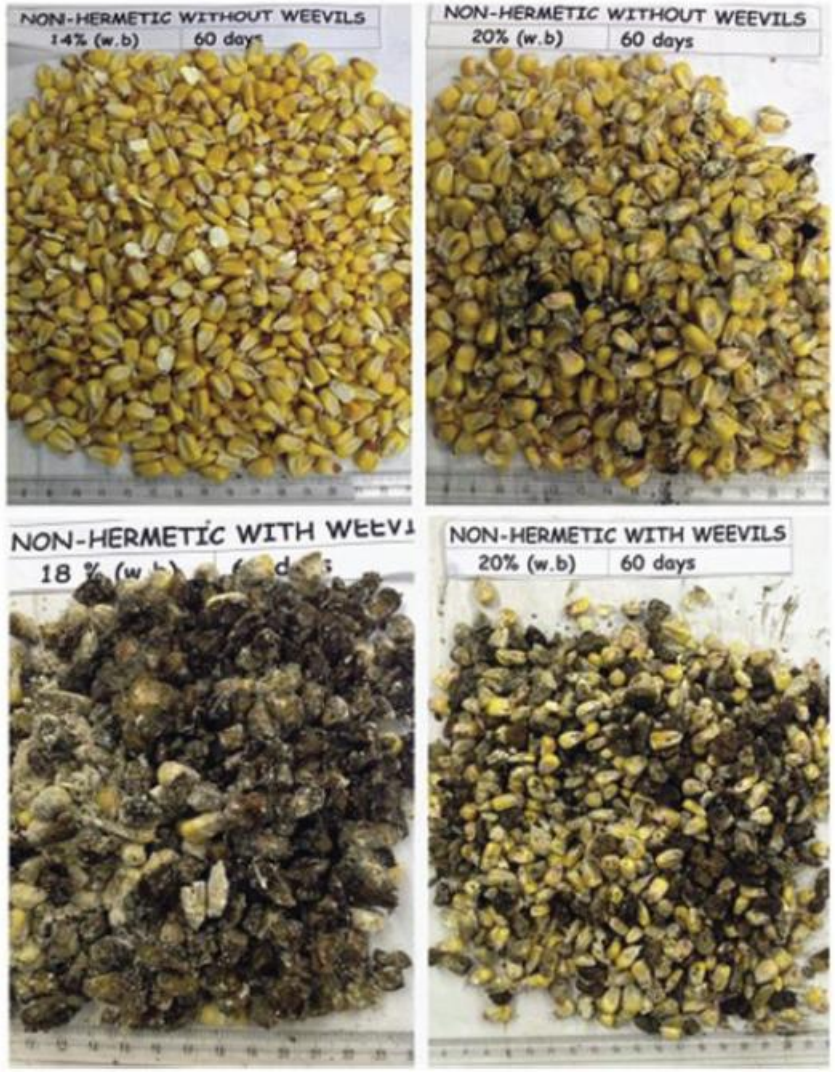
Temperature (°F)	Barley	Corn (yd)	Rice (Rough)	Sorghum	Soybeans	Wheat (Duram)	Wheat (Hard)	Wheat (Soft)
30	13.1	16.2	14.9	14.4	12.7	15.2	15.9	14.4
35	13.0	15.8	14.6	14.3	12.5	15.0	15.7	14.2
40	13.0	15.4	14.4	14.2	12.3	14.7	15.4	14.0
45	12.9	15.1	14.1	14.1	12.1	14.5	15.1	13.8
50	12.8	14.8	13.9	14.0	12.0	14.3	14.9	13.6
55	12.7	14.2	13.7	13.9	11.8	14.2	14.7	13.4
60	12.7	14.2	13.5	13.8	11.6	14.0	14.5	13.3
65	12.6	13.9	13.3	13.7	11.5	13.8	14.2	13.1
70	12.5	13.6	13.1	13.6	11.3	13.6	14.1	13.0
75	12.5	13.4	12.9	13.5	11.2	13.5	13.9	12.8
80	12.4	13.2	12.7	13.4	11.0	13.3	13.7	12.7
85	12.3	13.0	12.6	13.3	10.9	13.2	13.5	12.6
90	12.3	12.7	12.4	13.2	10.8	13.0	13.4	12.5
95	12.2	12.6	12.3	13.1	10.6	12.9	13.2	12.3
100	12.1	12.4.	12.2	13.0	10.5	12.8	13.0	12.2

Reference: Loewer et al., 1994, p. 217

Storage stability depends on:

- Grain properties
- Air temperature
- Relative humidity
- Storage structure

Environmental Factors in Storage (Cont.)



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Corn kernels stored for 60 days at different initial moisture contents demonstrate that prolonged storage under high-moisture conditions leads to fungal infestation

The results clearly confirm that elevated moisture levels during extended storage significantly increase the risk of mold development

Reference: Suleiman et al., 2018, p. 6

Environmental Factors in Storage (Cont.)

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Bag Storage

- Short term storage.
- Vulnerable to Rodents.

Silo Storage

- Long term storage.
- Resistant to Rodents.
- Vulnerable to Insects & Mold (Invisible Threats).

Storage stability depends on:

- Grain properties
- Air temperature
- Relative humidity
- **Storage structure**

Reference: Muthukumar et al., 2022, P.6

Monitoring Systems: Bag Storage (IoT)

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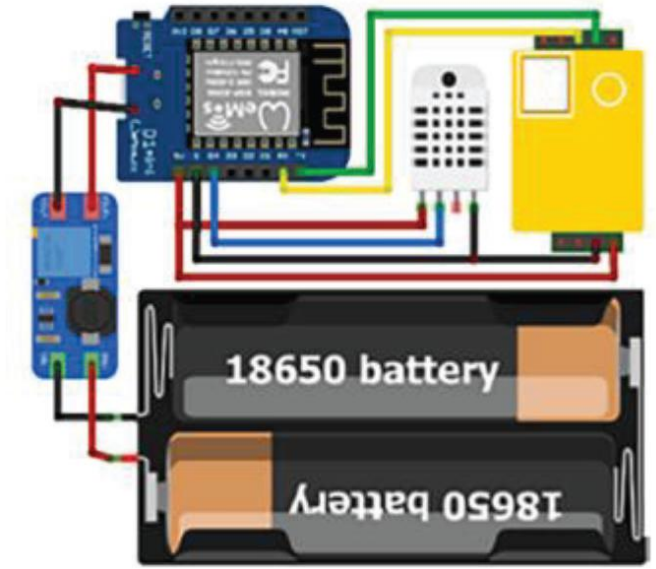
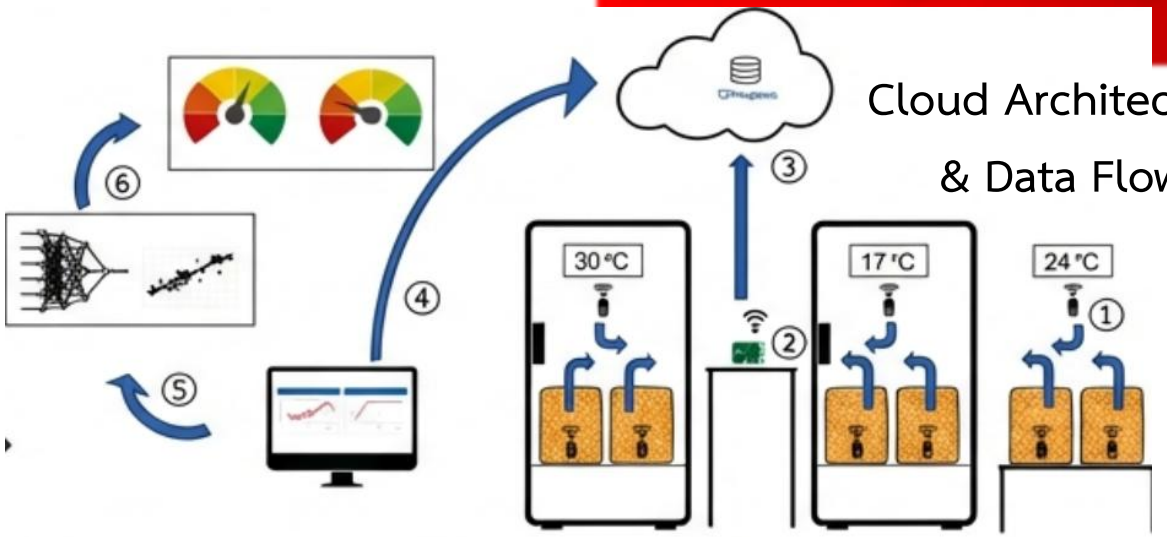


Hardware Setup
(ESP8266 & DHT22)



Cloud Architecture
& Data Flow

① Iot prototype sends data from temperature and RH data sensors to edge server
② Edge server stores sensor data and forwards it to cloud IoT platform
③ Cloud IoT platform (Thingspeak) stores data and provides real-time access
④ Requesting data to the IoT server
⑤ Statistical analysis of collected data
⑥ Estimated quality prediction

Bag Storage

Reference: Coradi et al., 2022, pp. 2-3

The Data: Equilibrium Moisture Content (EMC)

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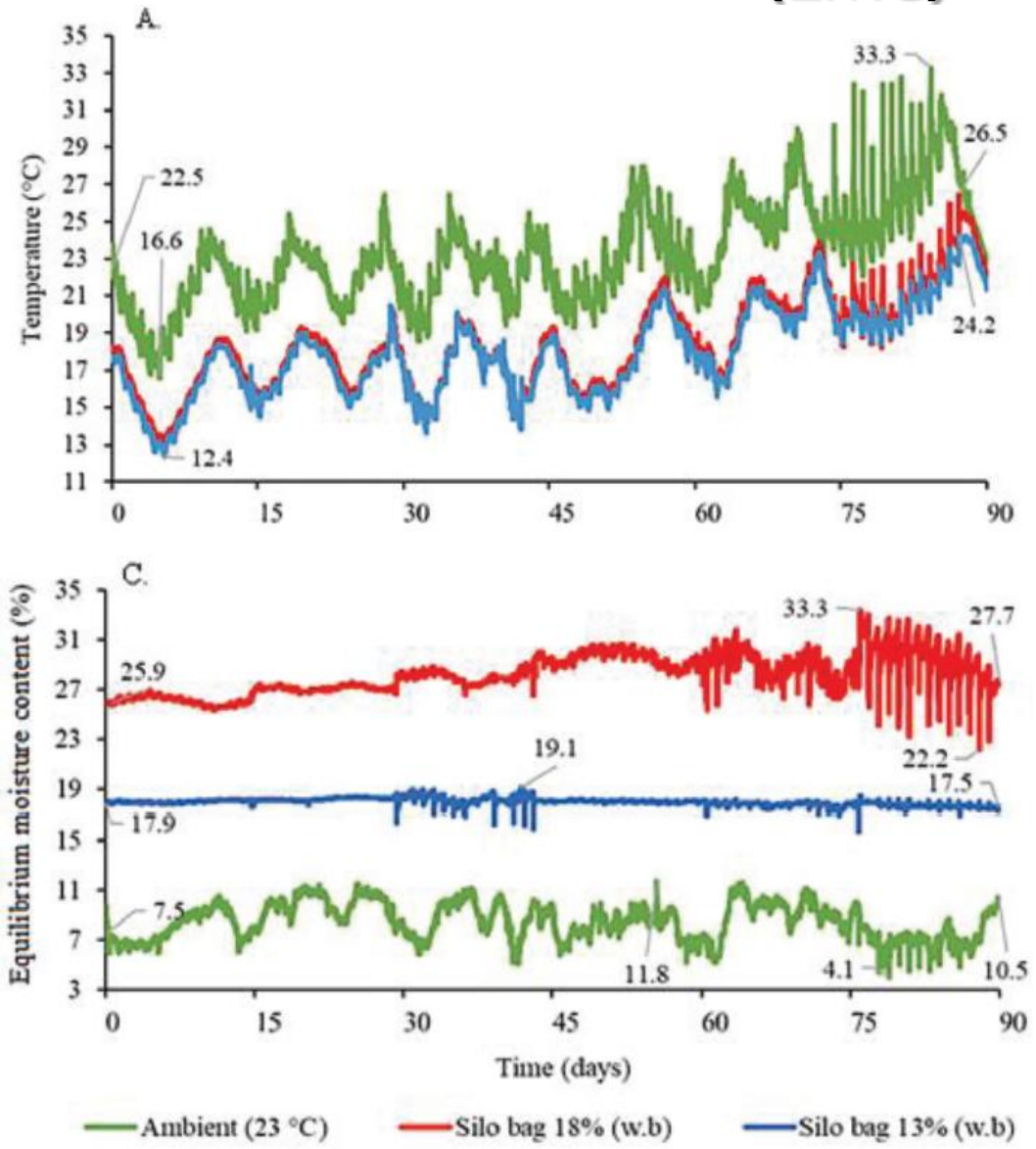
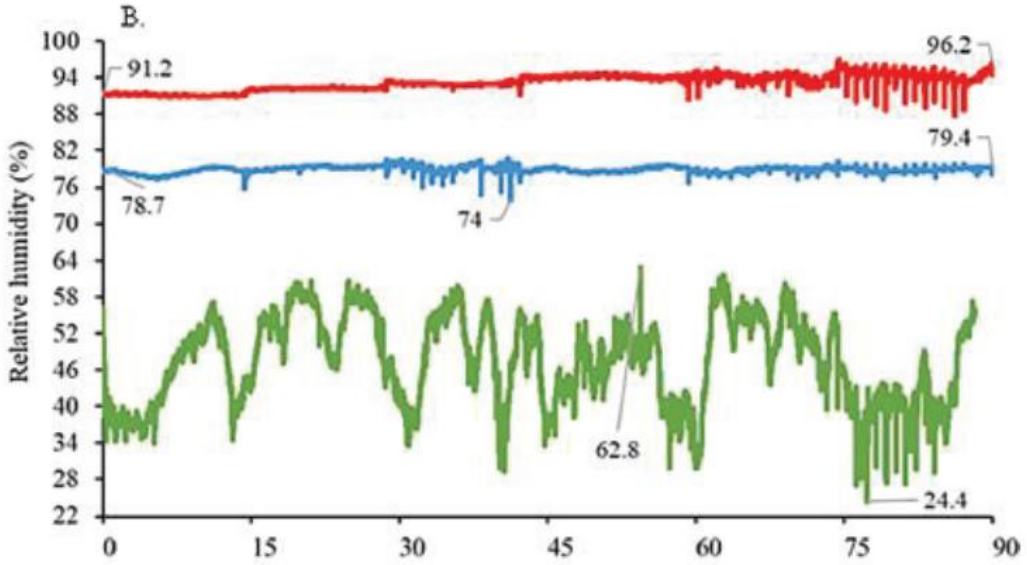


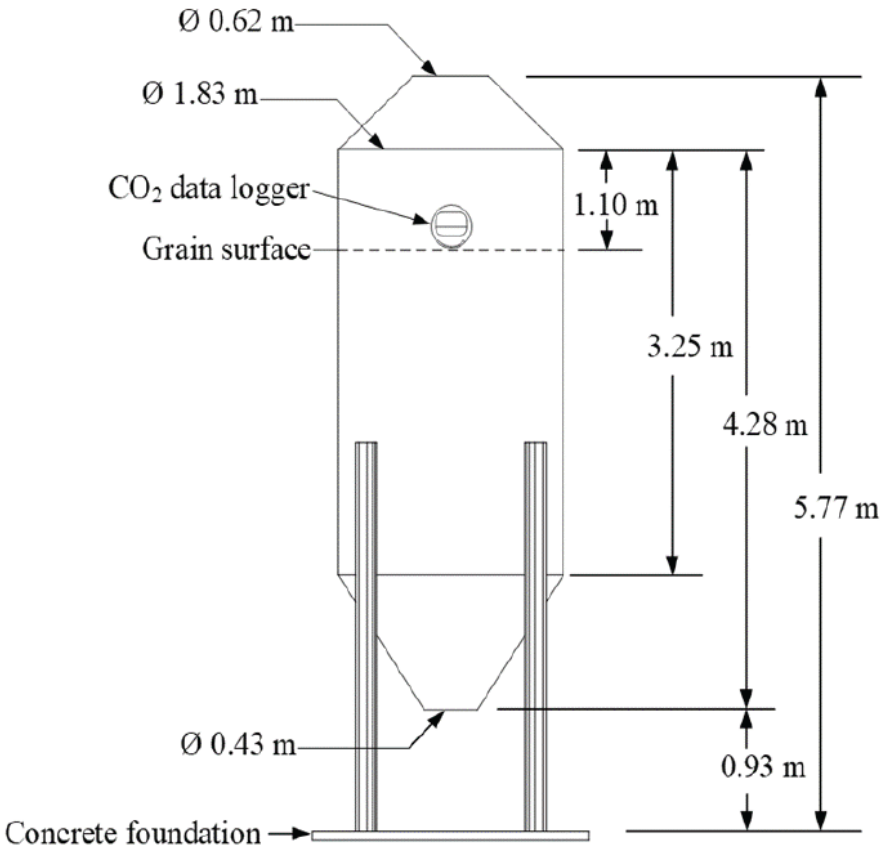


During the first 45 days of storage, corn with initial moisture contents of 13% $_{w.b}$ and 18%$_{w.b.}$ reached equilibrium moisture contents of approximately 17.9% $_{w.b}$ and 25.9% $_{w.b}$ respectively

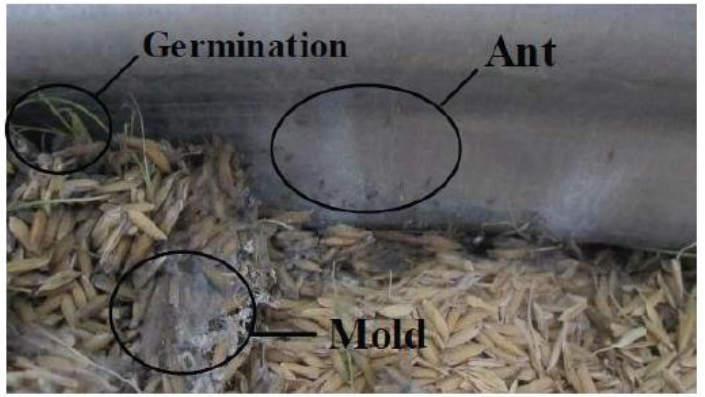
This behavior can be attributed to grain respiration and moisture release, which increased the relative humidity inside the storage bag

Reference: Coradi et al., 2022, pp.5

Monitoring Systems: Silo Storage



- **Tracks:** Temperature, Relative Humidity, and CO2.
- **Key Indicator:** CO2 concentration inside rises significantly higher than outside air.



Reference: Chotikasatian et al., 2017, p. 2

Monitoring Systems: Silo Storage (Cont.)

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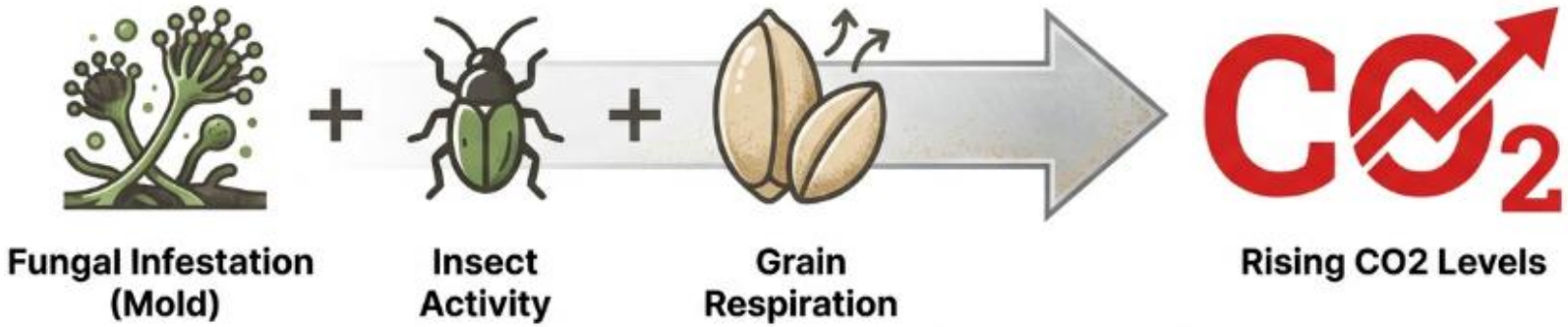
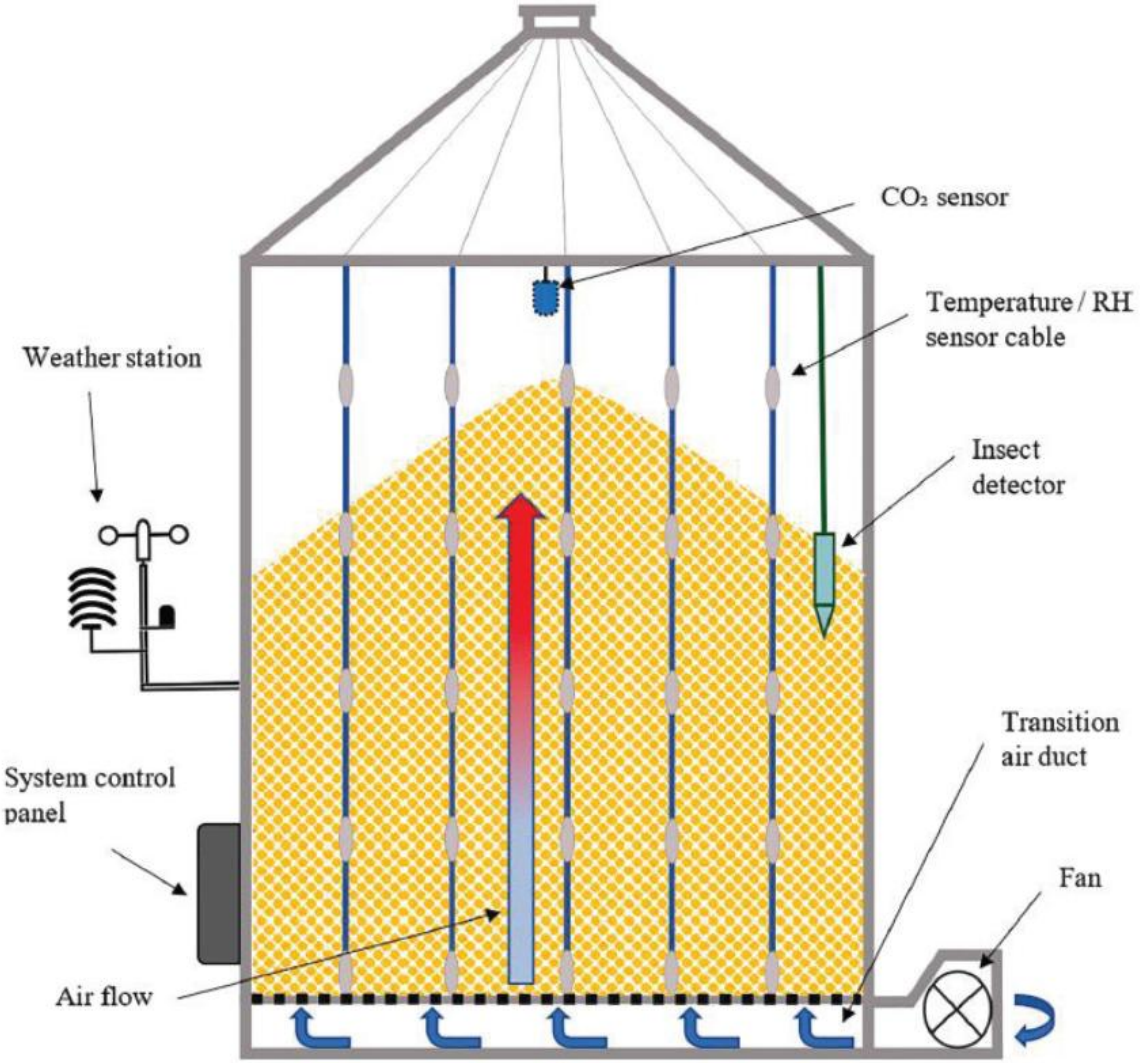
CO2 as an Early Warning System



Advantage: CO2 spikes indicate biological activity *before* physical spoilage is visible, allowing for timely ventilation.

Reference: Chotikasatian et al., 2017, p. 2

Monitoring Systems: Silo Storage (Cont.)



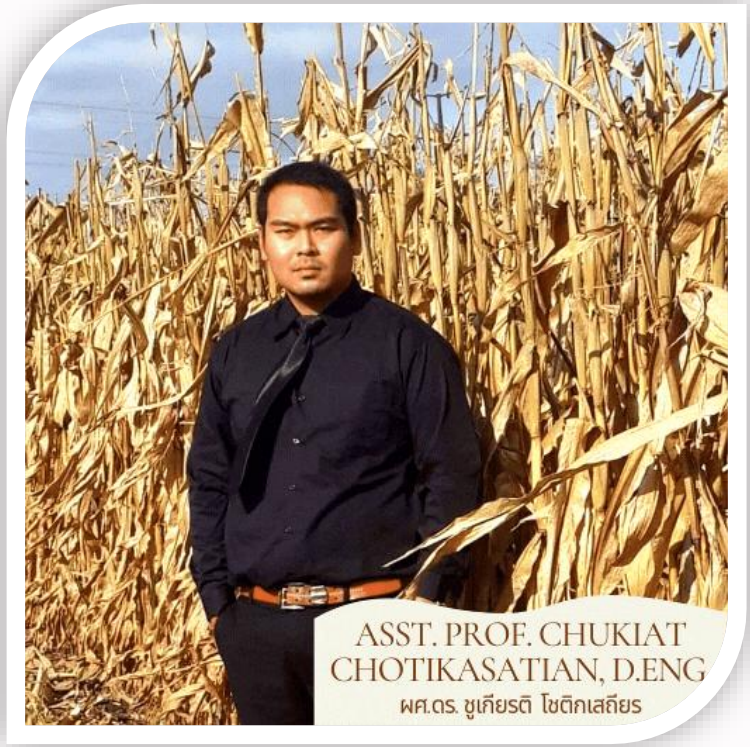
At the industrial scale, air quality monitoring systems are installed both inside and outside the silo to regulate aeration during storage

These systems provide real-time data that support ventilation control and help maintain safe storage conditions

Reference: Lutz & Coradi, 2022, p. 3

Summary

1. Effective storage requires control of:
   - Temperature
   - Relative humidity
   - CO_2 concentration
2. Increases in these variables often indicate:
   - Biological activity
   - Fungal growth
   - Quality deterioration
3. Therefore: Continuous environmental monitoring enhances storage stability and reduces losses



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Thank you very much for your kind attention.

Questions?

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Study Questions – Lecture 9

1. *Why is drying alone insufficient to ensure long-term storage stability of cereal grains?*
2. *How do temperature and relative humidity influence safe grain moisture content during storage?*
3. *Why is CO2 concentration considered an important indicator of grain quality during storage?*

Assignment – Lecture 9

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1. If storing rice in a controlled room at 30°C, what is the safe moisture content level?
2. If soybeans are stored in a silo at 25°C and 65%RH, what is the safe equilibrium moisture content?
3. Describe the structural function of weather monitoring systems and their application in controlling ventilation fans.

Safe Grain Moisture Content (% w.b.) in Equilibrium with Air at 65% Rh

Temperature (°F)	Barley	Corn (yd)	Rice (Rough)	Sorghum	Soybeans	Wheat (Duram)	Wheat (Hard)	Wheat (Soft)
30	13.1	16.2	14.9	14.4	12.7	15.2	15.9	14.4
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45	12.9	15.1	14.1	14.1	12.1	14.5	15.1	13.8
50	12.8	14.8	13.9	14.0	12.0	14.3	14.9	13.6
55	12.7	14.2	13.7	13.9	11.8	14.2	14.7	13.4
60	12.7	14.2	13.5	13.8	11.6	14.0	14.5	13.3
65	12.6	13.9	13.3	13.7	11.5	13.8	14.2	13.1
70	12.5	13.6	13.1	13.6	11.3	13.6	14.1	13.0
75	12.5	13.4	12.9	13.5	11.2	13.5	13.9	12.8
80	12.4	13.2	12.7	13.4	11.0	13.3	13.7	12.7
85	12.3	13.0	12.6	13.3	10.9	13.2	13.5	12.6
90	12.3	12.7	12.4	13.2	10.8	13.0	13.4	12.5
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100	12.1	12.4.	12.2	13.0	10.5	12.8	13.0	12.2

Reference: Loewer et al., 1994, p. 217

References

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Acknowledgements

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