Storage Technology, and Control of Aflatoxin in Corn (Zea mays L.) with Internet of Things (IoT) Application

M Hadipernata, A Ni’matullah Al-Baarri, M Somantri, E Rahayu, S J Munarso, R Rachmat, Miskiyah, Misgyarta, M Hayuningtyas, and S Pangidoan

\(^1\)Center for Agricultural Postharvest Research and Development, Agency for Agricultural Research and Development, Indonesian Ministry of Agriculture, Indonesia.
\(^2\)Food Technology Department, Faculty of Animal and Agricultural Sciences, Diponegoro University, Semarang, Indonesia.
\(^3\)Electrical Engineering Department, Faculty of Engineering, Diponegoro University, Semarang, Indonesia

E-mail: mulya_nata@yahoo.com

Abstract. In the inappropriate storage, corn become a suitable medium for fungus growth. Aspergillus flavus, Aspergillus paraciticus, and Aspergillus nomius produce Aflatoxin that is harmful to humans. One of the problems of Indonesian corn farmer is that storage space does not meet the requirements and corn warehouses still adopt a manually control system. Internet of Thing (IoT) has the potential to be used to facilitate human activities such as transferring and processing data or information through an internet, autonomous, and virtual network. The research objective was to study the corn storage system which has a low aflatoxin content with the IoT Application. The methodology of the study were field observation and desk study related to issues. The results showed that the fungus in corn will grow very fast when the moisture content more than 14 percent. IoT design were be able to maintain moisture content of corn less than 14 percent. IoT system for corn storage consists of room storage, sensors, actuators, monitoring and data storage. Sensor were used for detection and monitoring of the corn condition. The information from this sensor is then processed by a computer program, then the feedback will be done by the actuator.

Keywords: corn, internet of things, storage system, quality

1. Introduction
The Indonesian Ministry of Agriculture has launched a program for improvement of food crop production, productivity, and quality, including pre-harvest and post-harvest activities. Regarding to the corn commodity, in 2020 Indonesian Government is targeting to be one of the corn exporter countries whom before it becomes an corn importer countries. The corn production target is 33.96 million tons in the 2020 with an increasing target production per year by 2.90%. In the 2024, the production is estimated to reach 38.07 million tons [1].

One of action programs to increase corn production is securing post-harvest product for reducing post-harvest losses. It requires application of good handling practices (GHP) to produce a good quality food products. One of the critical points in the corn post-harvest stage is storage stage and transportation [2;3]. In the inappropriate condition storage, corn become a suitable medium for fungus
growth. *Aspergillus flavus*, *A. paraciticus*, and *A. nomius* produce aflatoxin, as a secondary metabolite, that is harmful to human health. Several species of *Aspergillus* sp. that usually infect corn commodities from harvesting to processing stage are *A. flavus* and *A. paraciticus*. The main types of aflatoxins that infect food plant products include B1, B2, G1, and G2. Aflatoxin is poisoning the human body through the respiratory tract and mucosal tissue on the skin surface thus it cause death [4]. Therefore, an important measure have to be taken for maintaining corn quality during the storage stage in order to meet the quality standards of corn as a raw material for food and feed products.

Regarding corn storage system, there are some obstacles needed to be solved. In the farmer level, the storage space is limited and does not meet the requirements. It drives farmers to sell the corn immediately to collector traders even though its moisture content is still high. Rarely, the collector traders provide an adequate corn warehouses storage for maintaining corn quality, including its physically, chemically, and microbiology characteristics. As a result, when the corn kernels are sold to feed or food industry, these might be rejected because of its claimed as an under-quality raw material [5]. Another obstacle, most developed corn warehouses still adopt a manually control system. However, due to the change of environmental conditions, both in the micro and macro storage, which are fast and unpredictable, require a technology that has high flexibility and accuracy to control storage system.

Internet of things (IoT) offer a sophisticated system for monitoring environmental situation and arranging feedback as a response of the data input. This system facilitates human activities such as transferring and processing data or information through an internet, autonomous, and virtual network. The study is intended to explore the application prospect of IoT for controlling corn storage system. The following study can hopefully provides comprehensive description about the possibility of installation of integrated system, its mechanism, and the challenges to control corn storage system. Thus, this study might be able to stimulate further studies to overcome the need of a high flexibility and connectivity of storage system to control and maintain the quality of food product, mainly corn kernels.

### 2. Material and Methods

#### 2.1 Observation

Observation was performed in the farmer level and industry. Observation in the farmer level was conducted in Kendal District, Central Java to identify applied system for storing corn and measure its quality, such as moisture content and fungi population. Measurement of moisture content was conducted in the Laboratory of Rice Quality and Cereal Postharvest at Karawang District, West Java, whereas measurement of fungi population was performed in Indonesian Center for Agricultural Postharvest Research and Development at Bogor City, West Java. In the industry, the observation was performed in the feed industry lied on Bekasi City, West Java to identify the requirements of corn quality as feed raw material. Laboratory equipments used in the study were oven dryer (*Satake*), moisture tester, and laboratory equipment for analysis, such as petri dish, test tubes, test tube racks, 50 ml measuring flask, micropipette, 150 ml beak fiberglass, water-bath, and centrifuge.

#### 2.2 Desk Study

Desk study was performed to identify regulation related to regulation of corn quality in Indonesia, procedures for maintaining corn quality, and development of corn storage system using IoT from journal papers, technical report, laws and regulations that issued by Indonesian Government, etc.

### 3. Result and Discussion

#### 3.1. Corn Quality

Corn are not only used as a raw material in the feed industry, but also used as food staple in the certain region. Corn kernels consist of pericarp, germ, endosperm, and tip cap. Endosperm, the major part of the corn kernel (85%), contains protein (8%), fat (0.8%), fiber (2.7%), ash (0.3%), starch (87.6%), and sugar (0.62%). The other nutritional components in the corn kernel are mineral (P, K, Ca, Mg, Na, Fe,
Cu, Mn, and Zn) and vitamin (A, E, C, B1, B2, B3, B6, and B12) [6]. Indonesian Government has issued Indonesian Quality Standard number 3920:2013 [7] about the quality standard of corn kernels for consumption and raw material of food industry (Table 1) and Indonesian Quality Standard number 4483:2013 [8] about quality standard of corn kernels for feed product (Table 2).

### Table 1. Quality standard of corn kernels for food product (Indonesian Quality Standard:3920:2013)

| Quality parameters       | Unit         | Quality class |
|--------------------------|--------------|---------------|
|                          |              | I  | II  | III | IV  |
| Moisture content         | Max.(%)      | 14 | 14  | 14  | 15  |
| Damaged grains           | Max.(%)      | 2  | 4   | 6   | 8   |
| Discolored grain         | Max.(%)      | 1  | 3   | 7   | 10  |
| Cracked grains           | Max.(%)      | 1  | 2   | 3   | 3   |
| Dockage                  | Max.(%)      | 1  | 1   | 2   | 2   |
| Aflatoxin                | µg/kg        | 5  | 5   | 15  | 20  |

### Table 2. Quality standard of corn kernels for feed product (Indonesian Quality Standard:4483:2013)

| Quality parameters       | Unit         | Quality I       | Quality II      |
|--------------------------|--------------|-----------------|-----------------|
| Moisture content         | Max.(%)      | 14.0            | 16.0            |
| Crude protein content    | Min.(%)      | 8.0             | 7.0             |
| Mycotoxins               |              |                 |                 |
| – Aflatoxin              | Max. (µg/kg) | 150             | 150             |
| – Ochratoxin             | Max. (µg/kg) | 20              | Not required    |
| Damaged grains           | Max.(%)      | 3.0             | 5.0             |
| Cracked grains           | Max.(%)      | 2.0             | 5.0             |
| Discolored grain         | Max.(%)      | 2.0             | 4.0             |
| Foreign material         | Max.(%)      | 2.0             | 2.0             |

Based on the observation results, farmers do not prepare a particular room for storing corn. They store the corn kernel in their living room, kitchen, or terrace, thus the controlling environmental storage conditions, such as temperature, humidity, and aeration, are difficult. Before selling the corn to the collector traders, the corn is stored in the shelled corn and packed using plastic sacks. Furthermore, the collector traders distribute the corn kernel to the livestock farming and industry. Moisture content of corn kernels in the collector traders is about 13 to 19%. Some farmers prefer selling the corn in the field rather than storing the corn for a longer period in their houses, even though it has quite high moisture content (around 24-30%) and low price.

In the feed industry, raw materials used to produce feed pellet/concentrate are corn, wheat, soybeans, and several types of additives. Wheat, soybeans, and additives are still imported from several countries, while corn is obtained from several production centers in Indonesia, such as Gorontalo, North Sumatra, Lampung, Central Java, East Java, South Sulawesi and West Nusa Tenggara. The quality of corn produced in the Gorontalo area are more stable in maintaining the quality of water content and suppressing aflatoxin contaminant compared to other areas. The industry applies certain standard operating procedures for handling corn kernel, the main raw material for producing feed product. Corn quality standards established by feed industry are a maximum moisture content about 16%, a maximum foreign matter (empty seeds, dead seeds, broken seeds, and weevils) about 2%, a maximum aflatoxins about 80 ppm, 0% of mushrooms, 0% of lice, and its physically neither hot nor humid.
3.2. Maintaining Corn Quality

The growth of fungus that produces aflatoxin depends on corn moisture content and environmental temperature. Warm temperatures and high moisture content trigger corn damage, promote microorganism growth and insect infestation. When the grains have high moisture content, respiratory activity is still ongoing hence the damage risk is increased [9]. In addition, humidity and growing media affect fungal growth and aflatoxin production. Several studies have shown that peanuts and corn are suitable media for the fungus growth that produces aflatoxin [10]. The safe moisture content of corn for storing that is range of 12-13% [11].

Aflatoxin contamination may occur from pre-harvest to post-harvest stage. Soil is the natural habitat of *Aspergillus* spp. Spore transmission of the fungus from soil to plants may occur because of direct contact between the soil and plants or through the vector, such as air and insects. Affected factors in the productivity of fungi for producing aflatoxin are farming practices, environmental conditions, soil characteristics, and physical injuries to plants [12]. Soil stress caused by drought stress is a major factor that promotes aflatoxin contamination. In addition, high environmental temperatures and crop damage because of other biotic and abiotic factors contribute to aflatoxin contamination. Reducing aflatoxin contamination risk at the pre-harvest stage might be performed through some measures, such using resistant corn varieties to aflatoxin contamination, improving farming procedures, and applying proper fertilization [13;14].

The post-harvest stages that are susceptible to aflatoxin contamination and insect infestations include harvesting, drying, shelling, and storage. Delayed drying of the wet corn kernels or cobs (moisture content around 30-35%) is potential to increase fungal infection, more than 50%, and percentage of damaged grains [15]. As mention before, the high moisture content of the grains is an indication of respiration process or physiological metabolism thus increasing the damage risk.

Adopted drying method of corn in the farmer level is sun drying of physiologically ripe corn cobs with its stalks in the field for 7-14 days, particularly during dry season. In order to increase the drying
rate, the stalks are trimmed about 10 cm above the corn cobs. As a result, the moisture content of corn kernels decreased from 33% to 27%, but it does not reduce fungal contamination risk that could reach 18% [16]. It is confirmed by the research data (Table 3) that the longer drying process, the higher fungal population although the moisture content is decreased. It is occurred because of directly contact of the shelled corn to the air that is likely to be a vector of spore transmission. When the drying process performs on field by peeling the corn husks, exposure of fungal spores higher than that without peeling the corn husks. Therefore, paying attention to drying process condition, such as temperature, humidity, and packaging method, is necessary to maintain corn quality.

| Table 3. Water content and fungal population of corn for 12 days drying time in the field |
|-----------------------------------------------|------------|------------|------------|------------|
| Item                                          | Aging time (days) |            |            |            |
|                                               | 0          | 4          | 8          | 12         |
| Moisture content (%)                          | 32.2       | 31.3       | 29.2       | 27.99      |
| Fungal population                             |            |            |            |            |
| - Corn with cornhusk                          | 1.2 x 10^2 | 2 x 10^4   | 2.7 x 10^5 | 4 x 10^6   |
| - Corn without cornhusk                       | 5.0 x 10^10| 1.2 x 10^15| 5.8 x 10^11| 7 x 10^12  |

Another problem of the farmer was the absence of proper warehouse to store corn grain. Temperature and humidity of warehouse should be controlled in order to maintain corn quality. Due to some obstacles on postharvest stages, there are some problems on the corn grain quality collected from the farmer field (Table 4). Physical characteristic analysis results showed that in the 100 gr of grain contain damage grain of 4.45 gr, broken grain of 2.51 gram, and foreign material 0.05 gr. Molds population on the corn husks are denser than those of the corn grain. Sun drying process applied on the farmer causes the increase of molds population that influence to increase potency of aflatoxin contamination.

| Table 4. Corn quality collected from the farmer field |
|------------------------------------------------------|
| Quality Parameter | Value | Unit |
| Physical Characteristic                                |       |      |
| a. Damage grain                                        | 4.45  | %    |
| b. Broken grain                                        | 2.51  | %    |
| c. Moldy grain                                         | 0     | %    |
| d. Foreign material                                    | 0.05  | %    |
| Molds Population                                       |       |      |
| a. At harvesting stage                                 |       |      |
| - Corn grain                                           | 1.2 x 10^2 | CFU/g |
| - Corn husk                                            | 1.6 x 10^10 | CFU/g |
| b. After drying stage                                  |       |      |
| - Corn grain                                           | 1.6 x 10^4 | CFU/g |
| Aflatoxin                                              |       |      |
| a. Before drying                                       | 5.08  | ppb  |
| b. After drying                                        | 11.68 | ppb  |

3.3 Application of IoT for Controlling Corn Storage System

The IOT based on sensor includes one or more kinds of sensors, communication network and information processing system. Each sensor has a unique label, so that we can collect real-time data, that realize remote security monitoring and air quality monitoring by sensors. Internet of things can be applied in all aspects of corn, such as corn purchase, corn storage, corn logistics, and information
tracking after corn processing. Application of the IOT in corn storage can real-timely control grain data and improve the managerial level of grain storage. Real-time monitoring in grain temperature and humidity by information perception equipment such as sensor, and automatic adjust these conditions in corn storage.

The fungus in corn will grow very fast when the moisture content of the corn is more than 14 percent. With the growth of fungi, it will be easier for Aflatoxins to grow. For this reason, the IoT design that is built must be able to maintain a corn moisture content of less than 14 percent. Design of the IoT system for corn storage consists of room storage, sensors, actuators, monitoring and data storage. The sensor consists of sensors for temperature, water content, relative humidity and CO₂. The actuator will drive the air conditioner, blower and dehumidifier. Monitoring and controlling can be done by Camera [17] in room storage, mobile phone and computer. All data can be stored on the built server. Water content greatly affects the growth of fungi, so monitoring and controlling the moisture content of corn is the main thing done in the corn IoT system.

**Figure 3.** Mechanism of data transfer in the IoT system

The dimensions of the warehouse are very influential on the position of the sensors that are placed. Same with the number of blower users in the warehouse. This type of fan blower intake functions to increase the air entering the room and spread the heat from heater. While the fan output is used to remove excess hot air that rises to the top [18]. The placement of the sensor must be in an ideal position to be able captured consistent and stable indicators of temperature, humidity, oxygen and CO₂. In addition, the layout of pallets containing both bulk and bagged corn kernels in the warehouse must match the airflow from the blower and air conditioner, so that the sample can receive the same exposure to temperature and air flow consist to manage moisture content of corn.
4. Conclusion
The results study showed that IoT be able to overcome some obstacles in controlling corn storage system. IoT system designs must pay attention to the corn moisture content below 14%. The system are useful for monitoring environmental situation in the corn warehouses, then it recommend the follow-up actions as a response of data input that is detected by sensors.

Acknowledgments
This work is a part of research result supported by Program Prioritas Riset Nasional (PRN). Funding from Lembaga Pengelola Dana Pendidikan (LPDP), Ministry of Finance. Collaboration research between Ministry of Research and Technology—Agency of National Research and Innovation; Agency for Agricultural Research and Development, Ministry of Agriculture; and Diponegoro University.

References
[1] Ministry of Agriculture, 2019. Anual report
[2] Al-Baarri, A.N., Ogawa, M., Hayakawa, S. 2010. Scale-up studies on immobilization of lactoperoxidase using milk whey for producing antimicrobial agent. Journal of the Indonesian Tropical Animal Agriculture; 35(3), pp. 185–191.
[3] Hadipermata, M., Hidayah, N., and Nugraha, S. 2020. Determination of rice expiration time based on microbiological contaminant. IOP Conf. Series: Earth and Environmental Science 518 (2020) 012053. doi:10.1088/1755-1315/518/1/012053
[4] Kumar, P., Mahato, D.K., Kamle, M., Mohanta, T.K., dan Kang, S.G. 2017. Aflatoxins: a global concern for food safety, human health and their management. Front. Microbiol. 1, 2170
[5] Hadipermata, M., Al-Baarri, A.N., Somantri, M., Rahayu, E., Munarso, S.J., Rachmat, R.,; Miskiyah, Misgyarta., Hayuningtyas, M., and Pangidoan, S., 2020. Storage Technology to Produce Low-Aflatoxin Corn. Research Report. Ministry of Agriculture
[6] Suarni and Widowati, S. 2016. Struktur, Komposisi, dan Nutrisi Jagung, available at http://balitserael.litbang.pertanian.go.id/wp-content/uploads/2016/11/tiganol.pdf, accessed in October, 17th, 2020
[7] Indonesian Quality Standard. 2013. Indonesian Quality Standard 3920:2013, Corn kernels for food product. The National Standardization Agency of Indonesia.
[8] Indonesian Quality Standard. 2013. Indonesian Quality Standard 4483:2013, Corn kernels for feed product. The National Standardization Agency of Indonesia
[9] Danso, J.K., Osekre, E.A., Manu, N., Opit, G.P., Armstrong, P., Arthur, F.H., Campell, J.F., dan Mbata, G. 2017. Moisture content, insect pests and mycotoxin levels of maize at harvest and post-harvest in the Middle Belt of Ghana. Journal of Stored Products Research, 74, 46-55.
[10] Broto, W. 2018. Status cemaran dan upaya pengendalian aflatoksin pada komoditas serealia dan aneka kacang. Jurnal Litbang Pertanian, 37(2), 81-90
[11] Shanahan, J.F., Brown Jr., J.M. (2002): Aflatoxins. Colorado State University Cooperative Extension Report, vol. 0.306, pp. 1–4.
[12] Winter, G., dan Peregr, L. 2018. A review on the relation between soil and mycotoxins: Effect of aflatoxin on field, food, and finance. British Society of Soil Science. DOI: 10.1111/ejss.12813
[13] Guo, B., Chen, Z., Lee, R.D., dan Scully, B.T. 2008. Drought stress and preharvest aflatoxin contamination in agricultural commodity: genetics, genomics, and proteomics. Journal of Integrative Plant Biology, 50(10), 1281-1291
[14] Mahuku, G., Nzioki, H.S., Metegi, C., Kanampiu, F., Narrod, C., dan Makumbia, D. 2019. Pre-harvest management is a critical practice for minimizing aflatoxin contamination of maize. Food Control, 96, 219-236
[15] Miskiyah and Widaningrum. 2008. Pengendalian aflatoksin pada pascapanen jagung melalui penerapan HACCP. Jurnal Standarisasi 10 (1), 1-10
[16] Richana, N. (2020). Pascapanen Jagung. Badan Penelitian dan Pengembangan Pertanian,
Kementerian Pertanian

[17] Sudjadi, Somantri, M., Arfan, M., Santoso, I., Sukiswo, Nugroho, A. 2019. Smart Security System Using Camera Trap Based on Background Subtraction. International Journal of Engineering and Information Systems (IJEAIS), ISSN 2643-2643. Vol. 3 / No.5

[18] Wicaksana IS, Ubaidillah FI, Hadi YP, Wahyu ST, Istiadi. 2018. Perancangan sistem monitoring suhu gudang berbasis internet of things (IoT). Conference on Innovation and Application of Science and Technology. Universitas Widyagama Malang, 12 September 2018 : 503-511.