Controlling maize weevil in corn plants by improving cultivation technology and postharvest handling

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Abstract: The maize weevil is corn pests that reduce production and damages the storage quality. Therefore, pest management should simultaneously be carried out by applying all available technologies. This pest can damage up to 30% of plant productivity, not including the value of losses due to decreased quality of hazardous materials for health and safety, both as feed and feed. Aflatoxin contamination for example, can be dangerous if consumed. This paper is a desk study that reviews some literature, attempts to describe the role of cultivation technology improvement, crop protection, optimum watering, phosphate fertilization, the technology of postharvest handling, management of water content of corn kernels, sanitation, cleanliness, warehouse management, pesticide use, and fumigation in reducing the scale of damage and increasing the added value of production, and improving the quality of stored materials so that they are safe to use, both as food and feed. The utilization of cultivation technology management and good postharvest handling will have an impact on controlling and reducing the damage quality of storage materials and increasing the safe product quality for both food and feed needs as well.

1. Introduction
Maize weevil (*Sitophilus zeamais* Motsch) is the pest that can attack corn kernels starting from planting, especially on corn cobs that have imperfect cornhusk closure to the period of material storage. This pest population can increase along with the length of storage. The damage caused by these pests is enormous; some references state that the damage can reach 30% [1-3]. Yield losses due to pest infestation are quite large, especially in warehouse storage at the farm level [4].

Government has tried many efforts to save agricultural production using a lot of funds and time, but the results have not been satisfactory considering that until now the varieties or lines of corn that are resistant to maize weevil are still not available. Even if there are resistant seeds, it is likely due to the influence of the low seed moisture content, that kind of pest does not develop.

Some results of researching the literature show that one of the results of research that can be used as a reference in dealing with this pest attack is by improving cultivation technology and post-harvest handling [5, 9, 10, 11, 26, 28, 31].

This paper is try to explain the long term strategy in controlling maize weevil in corn plant as well as storage pest problem by reviewing some literatures and attempts to describe the role of cultivation technology improvement, crop protection, optimum watering, phosphate fertilization, technology of postharvest handling, management of water content of corn kernels, sanitation, cleanliness, warehouse management, pesticide use, and fumigation in reducing the scale of damage and increasing the added value of production, and improving the quality of stored materials so that they are safe to use, both as
2. Improving cultivation technology

2.1. Crop protection
It is necessary to do the crop protection from infestation of other pests before maize weevil attack the open cob due to imperfect cornhusk since it will be conducive to the entry of cob borer and corn stem borer. If such condition happens, the corn kernels will be easy to be attacked by maize weevil since the cobs are still in the crop. Therefore, it is necessary to protect plants from the beginning of growth to the harvest time.

2.2. Optimum watering
Water has many functions for crop growth, one of which is to dissolve the absorbed nutrients. Due to its immense benefits, water is often cited as a limiting factor in plant growth. Water plays an important role in the process of seed germination, which is one of the determining factors in plant life because more than 70% of the weight of protoplasm of a living cell consists of water. Water is used as a means of transportation of food solution from the endosperm or cotyledon to the growing point on embryonic axis, where it is needed to form protoplasm. Water provides facilities for the entry of oxygen into the seeds. Dry cell wall is almost not permeable to gas, but if the cell wall is filled with water, the gas will enter the cell by diffusion. Water is useful for diluting protoplasm in order to activate various functions [5].

In the case of maize planting, it is necessary to do hard efforts in providing water in such a way that the crops in the field get optimal water to grow and to develop perfectly. These efforts are made by preventing crops from experiencing drought during growth, giving optimal fertilization, and protecting plants with the right pesticides. This treatment will help increase crop resilience due to sufficient water supply to support normal crop development, which will strengthen the crop’s defense system from pests and diseases.

2.3. Phosphate fertilization
Phosphate fertilization affects the process of cell division, fat and albumin formation, and seed fertilization [6]. If the plant bears fruit, the effect of giving too much nitrogen will be reduced. The development of roots, especially lateral and fine roots, is the strength of stems in plants to prevent the fall of stems. Moreover, its important effect on the quality of plants, especially grass for fodder and vegetables, is the increase of resistance to certain diseases. Thus, giving phosphate fertilizer is a big chance for the maize plant to increase immunity against the main pests since planting because this fertilizer improves the quality of the seeds, and the seeds will be resistant to be attacked.

2.4. On time harvest
The right harvest time at 17 to 18% of moisture content will reduce insect pressure on the seeds. Visually, corn is ready for harvest when the stems, leaves, and husks dry out or turn yellow. Dry husks are yellow, and when peeled, the seeds look shiny. When the seeds are pressed with the nails, they do not make a trace, and there are black spots on the part of the seeds attached to the cob. To reduce the water content of the cob in the field, the upper stems should be trimmed along with partial or complete peeling of husks before harvesting. The way to harvest physiologically ripe maize is by rotating the cobs and husks or breaking the stalks of corn [7].
3. Technology improvement of postharvest handling

Postharvest handling is the stage from harvesting the postharvest in the field until it is ready to be sold at the market. Postharvest handling is an action prepared or carried out on agricultural products so they are ready and safe for consumption or further processing for the industrial sector.

According to experts, in the maize production process, the total energy required for production activities is about 32%. Meanwhile, for harvest and postharvest handling, the total energy required can reach 72%. This shows that harvest and postharvest handling requires hard work. As an illustration, the energy required in corn production process is as follows: for piracy is 16%, maintenance and planting are 12%, harvesting is 6%, drying is 60%, and transportation is 6% [8].

Corn damage due to incorrect postharvest handling can occur at any stage of activity because corn requires fast handling after harvest. There are several forms of damage to corn kernels. The first one is physical damage in the form of damage to the endosperm, mainly due to frequent changes in water content. Changes in water content are caused by weather such as heat, rain, changes of day and night, cracked grains in the next process that can become broken grains, and pulping process using improper batter or thresher. The second damage is biological damage, which is caused by pests, fungi, and microbes during storage. Pest attack will destroy part of the endosperm and the rest becomes defective corn kernels. Defective corn kernels are prone to fatty acid oxidation, produce free fatty acids, and cause an unpleasant odor. In storage, pests are a source of contamination that causes low quality of corn. The third damage is chemical damage due to chemical decomposition during storage, such as decreased levels of carbohydrates, protein, and fat caused by metabolism of insects and microbes as well as by the stored grains, and the chemical damaged condition of a material cannot be visually observed [7].

3.1. Management of water content of corn kernels

Water content is the amount of water contained in an object, such as soil (which is also called soil moisture), rocks, agricultural materials, and so on. Water content is widely used in scientific and engineering fields expressed in the ratio, from 0 (total dry) to the saturated value of water, where all pores are filled with water. The values can be volumetric or gravimetric (mass), wet or dry basis [22]. Water content has a theoretical maximum limit of 100 percent, while the water content based on dry weight can be more than 100 percent.

Water content shows the level of dryness and has an influence on the storability and quality of the harvest in the next process. Water content also affects the development of insect pests in the warehouse, the age of the corn kernels, and mechanical damage during harvest and postharvest handling. Water content is an important factor in the ability of corn kernels to maintain their viability. Moreover, to a certain extent, the lower the water content of the corn kernels, the longer the corn kernels can maintain their viability [9, 10, 11, 12].

Water content is a physical component that has a major effect on the infestation rate of stored materials in addition to temperature when stored, high and low quality of materials, and humidity [13]. During storage, water content, air temperature, and humidity determine the storability. Among those four factors mentioned above, water content is the most dominant factor affecting the level of skin hardness, which will affect the quality of the attack. Base on the [14] trial it was stated that the higher the water content of a material, the higher the intensity of the damage caused will be [15], which is during the observation of attack and damage at 6 months interval, sorghum kernels stored with low water content have low insect population development, but the increase in the initial water content of the material is greater, namely 12% to 14%. Furthermore, [16] conclude that sorghum water content of 10% to 14% is conducive for the development of maize weevils.

3.2. Sanitation

In general, sanitation is a planned control activity on the production environment, raw materials, equipment, and workers to prevent contamination and damage to the materials and to condition a clean, healthy, safe, and comfortable work environment [17]. Sanitation aims to obtain products that are safe and healthy as well as have good quality for consumers. Brooker et al. [18] storage material sanitation
is closely related to product quality and consumer health, so the condition of warehousing needs serious attention. Humidity in the air can affect the outside air and become a medium for the growth of fungi that attack grain in the warehouse, such as producing *Aspergillus*, which is very dangerous for consumers. To avoid such condition, air aeration can be a good solution. It is done by making air vents or using fans or eco-fans in the warehouse, so that the air is leached out.

3.3. Cleanliness
In the concept of integrated handling of maize weevils, besides sanitation, cleanliness of the storage area (warehouse) is also a major factor that must have serious attention because maize weevils are always hiding in dirty and unhygienic places. This is a great medium for maize weevils to hibernate and to hide. Cleanliness is intended to suppress the insect population from being carried away in the next storage period. Things that need to be considered in cleaning the warehouse are cleaning all warehousing structures, burning contaminated plant material or kernels, cleaning old sacks containing kernels residues, repairing cracked floors to prevent insects hiding in the cracks, and doing insecticide treatment to areas where maize weevils can hide.

3.4. Warehouse management
Warehouse for storing materials must be managed properly, such as the location of warehouse must be strategic and the direction of the building stretches from west to east so that the area of the walls exposed to the sun can be reduced and the warehouse remains cool. In order to avoid pest attacks, the warehouse is cleaned, the warehouse construction needs to be prevented from possible leaks, adequate air circulation and safety are needed, the warehouse ventilation must be sufficient and secure so that the indoor temperature remains stable and evenly distributed. The storage area with floors is equipped with an additional floor of basic supports made of wooden beams with a minimum height of 15 cm, so that the storage material does not come into direct contact with the floor. Driscoll and Srzednicki [19] the physical condition of warehouse is an important factor in the postharvest storage of agricultural commodities. The conditions of a good warehouse are:

1) It is necessary to observe what kind of warehouse roof is made of, whether the roof of the warehouse supports the growth of these pests.
2) The walls of the warehouse also affect the growth of pests. If the walls have gaps, it will make the pests easier to enter the warehouse.
3) Putting the base before the stored material affects the growth of pests because if the stored material directly contacts the floor, the moisture of the material will increase.
4) Ventilation also affects the storage material because the less the ventilation, the smaller the air exchange places will be, which affects the growth of pest populations.
5) Lighting must be placed inside and outside the room.

The environment around the warehouse should be away from bushes so that rats cannot climb through them, and the warehouse is not damp. Storage designated for seed sources, corncobs with husks are hung on *para-para* (bench mats) with smoking every day, while the seeds in the form of flakes, if possible, are mixed with dry ash (inert dust) then wrapped tightly with airtight plastic, and stored in a closed container. The container can be a wooden silo or a drum. If the water content of the seeds is 10%, then it does not need ash mixture. In the storage for consumption purposes, the water content of the shelled kernels is at least 12%, tightly wrapped in airtight plastic or cans, or wrapped in plastic covered with sacks and stored in a clean and dry place [20].

Traditional storage of corn kernels for a long time commonly will cause serious damage to the quality. Aerated bulk storage is an alternative technology that can be applied to maintain the quality of agricultural products during storage. However, design and operational procedures for this aerated storage system have not been developed yet. Darby [21] states that only the cold air aeration method is able to create temperature and humidity in the storage room that meet the requirements for storing corns
with water content of 13%. To create such air condition of the storage room, cold air aeration does not need to be carried out continuously throughout the day during storage. It is enough to operate aeration for 5 h with power consumption of 0.519 Kwh. The quality of stored corn kernels, such as water content, percentage of weight loss due to insect and fungal infestations, percentage of germination, and aflatoxin contamination of corns with cold air aeration, shows better results than aeration with bentonite absorbent. Design, construction, and operation of this cold air aeration equipment are easy to manufacture and cheap, and the materials are widely available on the market.

The secret of keeping stored kernels in good condition is to keep the kernel mass cool, evenly distributed, and dry [22]. In most parts of the world, this can be done through aeration, which is the treatment of kernels stored in cool ambient air at low flow rates. When the average ambient temperature is above 24 to 37°C, a grain cooler is necessary. Wikipedia [23] assert that in wet tropical condition, storage requires a cooling device for aeration as is done for temperate condition. It is further argued that grain aeration is a very useful way of preserving grains. This method is also a chemical-free mechanical method and, when done under good management, it is one of the cheapest ways to maintain grain quality. It is also emphasized that one of the most essential conditions for implementing aeration is the use of bulk handling methods.

As this aeration treatment has many benefits, it is important to study its use to overcome the problem of deteriorating the quality of kernels, especially corn in long-term storage in Indonesia. Sousa [24] that aeration is widely used for cooling and maintaining temperature uniformity of the entire mass of bulk beans, reducing heating in wet beans, putting fumigant gases, and eliminating odors and fumigant residues. However, design and operational procedures for storage systems equipped with aeration facilities still have many difficulties for practitioners who want to use them. Meanwhile, Respyan [25] limitations in more detail related to the application and design of aeration system. One of them is that technical information is very inadequate and provides difficulties to design according to specified performance. Moreover, there is a lack of easy approaches for users to access various the main things in the design.

3.5. Pesticide treatment

Insecticide treatment on the kernels in the storage material can be carried out if the kernels are intended only for seeds. Insecticide treatment is done in warehouse floor, bench mats (para-para), containers, sacks, and cracks on the walls or floors. The recommended insecticides can be seen in Table 1, but it is also recommended to use Fentron 500 EC (fenitrothion a.i.500 g L⁻¹) and Tribola 500 EC (poxsim a.i.500 g L⁻¹). Spraying treatment is carried out routinely every month or when the level of pest attack is medium.

| Active Ingredients | Formulation | Dosage [30] |
|--------------------|-------------|-------------|
| Methyl piriformis<sup>a</sup> | Silosan 25 EC | 0.5 gr b.a m⁻² |
| Metacrifos<sup>a</sup> | Damfin 950 EC | 1 gr b.a m⁻² |
| Tetrachlorvinphos<sup>a</sup> | Gardono 24 EC | 1-2 gr b.a m⁻² |
| Methyl Bromide<sup>+</sup> | Brom-0-Gas | 16-32 gr m⁻³ |
| Clopicrin<sup>b</sup> | Dowfum MC-2 | 16-32 gr m⁻³ |
| | Haltox | 16-32 gr m⁻³ |
| | Metabrom 980 | 16-32 gr m⁻³ |
| | Methylbrom | 16-32 gr m⁻³ |
| Aluminum phosphide<sup>b</sup> | Detia Gas EX-B G | 3-6 gr m⁻³ |
| | Gustixin | 3-6 gr m⁻³ |
| | Phostoxin tablet | 3-5 tablets t⁻¹ |

<sup>a</sup> The targets are buildings and sacks  
<sup>b</sup> The target is only sacks
3.6. Fumigation

Fumigation (from English, *fume*, which means *smoke*) is a method of controlling pests using pesticides. In this process, an area will be thoroughly treated with the application of gas or smoke, which aims to kill all the pests in it. This method is effective in killing pests that live inside building structures such as termites [26], or it can also kill target insects such as maize weevils and other types of warehouse pests. Fumigation is a chemical compound that, at certain temperatures and pressures, takes the form of a gas, acting as a breath poison since poisonous compounds are inhaled through the insect's respiratory tract. Fumigation can be carried out on piles of commodities, and then sealed with plastic sheets. Fumigation can also be carried out in airtight storage such as storage in silos, using airtight cans or packaging using plastic jerry cans, the bottles that are fully filled, and then the top of the bottles or jerry cans are coated with paraffin for a small-scale storage.

The most widely used fumigants are phosphate (PH$_3$) and Methyl Bromide (CHBr). Several types of fumigant compounds often used are methylbormide, carbon disulphide, hydricianic acid, phosphine, ethylene oxide, and ethylene dibromide. Insects such as rice weevils, rice moths, grain moths, lesser grain borers, can be treated by using fumigant carbon disulphide (CS$_2$) and phostoxin tablets. The use dosage is 30 cc CS$_2$ m$^{-3}$ of material for 24 to 48 hours in a closed room. The dosage for using phostoxin is 1 tablet per quintal of material. In addition, fumigation can also use the insecticide compound, Shenphos 57T (the active ingredient is not registered yet). The implementation of fumigation is carried out regularly every 2 or 3 months when the level of pest attack is moderate to severe. Fumigation can control all warehouse pests that attack agricultural products, which have been stored in warehouses.

3.7. CO$_2$, N$_2$, and ozone gas handling

Air regulation is done by changing the composition of the air in the storage room. The oxygen concentration in the storage room is conditioned as low as possible and is replaced by other gases from outside such as CO$_2$ and N$_2$ and Ozone. This method is very safe because it uses no pesticides that are harmful to humans. The atmosphere condition is maintained in conditions of low oxygen (less than 2% or if it is possible to reduce it again by about 0.5%) or the provision of high CO$_2$ levels (greater than 60%), the grains are safe for long storage with good and safe quality. The use of ozone gas can be considered as an effective way to suppress insect reproduction and reduce dynamics and activity, so that the growth of insect pests can be inhibited [27].

3.8. Mechanical handling

Physical and mechanical control is the act of changing a particular environment to kill or inhibit pest life, and is not part of general cultivation practice. Physical and mechanical control must be based on a thorough knowledge of the ecology of pest attacks so that it can be seen when, where, and how the action must be taken in order to obtain the results as effectively and efficiently as possible. Mechanical physical control can be done by burning, drying, using light, and utilizing sound, both ultrasonic and supersonic.

3.8.1. Inert dust utilization. The use of inert dust or non-reactive ash in preventing maize weevils from infesting corn kernels can be done since non-reactive ash does not damage the kernels quality. Inert Dust is all dry ash powder that is non-reactive, both in nature and made through the combustion process [28, 29] There are many types of inert dust available in nature, one of which is the most commonly used volcanic ash from volcanic eruptions. Volcanic ash contains about 53% of silica and 18% of alumina [30, 31]. Silica is the main ingredient in inert dust. The use of inert dust in preventing maize weevils and other pests in storage places at the farmer's level has been widely practiced in Java, which is by mixing the kernels to be stored with inert dust, mainly intended for special kernels as the next planting. Considering there is a lot of inert dust available in nature, its potential to be used for mechanical control of insect pests is prospective. Nugraha [29], showed that at seven days after infestation, the inert dust handling of volcanic ash with a concentration of 5 g kg$^{-1}$ of kernels could kill the target insects up to 89.17%. The application of volcanic ash to corn kernels significantly influenced the number of eggs, the
number of pupae, and the number of new imagos. Furthermore, it was found that the application of volcanic ash to the corn kernels had no effect on kernels germination, and did not damage the kernels quality.

3.8.2. Drying. Mechanical handling can be done by drying, a practical way to reduce the kernels moisture content on a large scale at the farmer’s level. In drying, other actions are needed such as periodic reversal. Generally, the drying process in rural areas is still in the traditional way, such as drying under the sun with mats or tarpaulin or plastic mats, in the yard or in the canal or road embankments. During drying, the kernels are left in the field; when it rains or at night, just cover it with a plastic bag or sack. Furthermore, Brooker et al [18] states that drying the kernels under the sun causes the grain content to break, and the weight loss is higher than drying with a dryer (drying machine). According to Wijaya [32], the lower or higher than 13.2% seed moisture content will reduce the kernels yield. Therefore, in addition to dealing with the high attack of warehouse pests, drying can also reduce the kernels damage due to the high moisture content. Research results by Nugraha [29], for rice commodities, for example, show that the yield loss in the paddy drying stage in irrigated rice ecosystems is 0.98%, for the rain fed rice ecosystems is 1.05%, and in the tidal land ecosystems is 1.52 %.

3.8.3. The hermetic storage. The utilization of hermetic storage systems includes placing the storage material (kernels) into containers that stop the movement of air (oxygen) and water between the outer atmosphere and the stored kernels. This technology has been applied in several countries in Southeast Asia. This system can use special plastic containers or smaller containers made of plastic or steel, or even clay pots. The storage sizes can range from 25 L to 300 t. This system can be used for grain, rice, and other cereal grains such as corns [31]. Hermetic storage improves the quality of the storage material and its viability because it maintains the stability of the water content, and reduces pest damage without using pesticides. The viability of kernels in the tropics can be increased from 6 to 12 months. The closed storage controls insects since they use oxygen and emit carbon dioxide during respiration, e.g., the oxygen level can reduce from 21% to less than 5% in 10 to 21 days [5] under such low oxygen condition, the insect activity is minimal and the reproduction stops. Additionally, rats and birds are not attracted to the stored material handled in this way. IRRI has developed Super Bags-IRRI plastic, which implements the hermetic system. According to Gummert and Rickman [28], the use of IRRI Super Bags is able to suppress the insect growth. This is indicated by the number of insects that live after 12 months of storage, namely 1.2 insects per kg of material, much lower than the open storage of 27.2 insects per kg of material. Chin and Kieu [27] also stated that the population of R. dominica, after storage for 12 months using IRRI bags, was only 14 beetles per 120 g of rice kernels.

4. Conclusions
The utilization of cultivation technology management and good postharvest handling will have an impact on reducing the damage quality of storage materials and increasing the safe product quality for both food and feed needs. Treatments using plant cultivation technology can be in the form of crop production, optimum water provision, phosphate fertilization, and harvesting on time. Meanwhile, improving technology for harvest and postharvest handling can be in the form of water content regulation, sanitation, cleanliness, warehouse management, pesticide handling, fumigation, treatment of CO2 gas, N2, and ozone, and mechanical handling in the form of utilizing inter dust, drying, and hermetic storage.

It is hoped that by applying and practicing such items of the above mention in the long term it is capable of controlling maize weevil in corn plant as well as overcoming the storage pest problems. The utilization of cultivation technology management and good postharvest handling will have an impact on reducing the damage quality of storage materials and increasing the safe product quality for both food and feed needs as well.
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