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A study of polymer for delay germination in hybrid sweet corn seed production

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Abstract The results showed that the pH values of each coating substance formulation exhibited statistically significant differences. Notably, the highest pH value was observed in the coating substance mixed with CMC. Similarly, the viscosity of the coating substances showed significant variations, with the commercial coating substance having the highest viscosity. Following this, the coating substances mixed with CMC, HPMC, NaAlg, and PVP-K30 demonstrated progressively lower viscosities. To assess the uniformity of the coating, the surface characteristics of the seeds were visually examined. The results indicated that seeds coated with the commercial coating substance exhibited the highest coating uniformity. Subsequently, the uniformity levels decreased in the following order: seeds coated with a mixture of PVP-K30, HPMC, CMC, and NaAlg. For the seed quality test after coating, the results showed that all types of polymers had no statistically significant effect on the germination percentage and germination index. If further studies are conducted on the types and concentrations of polymers, it is possible to develop seed coating formulations to delay germination.

Keywords: *Zea mays*, Seed coating, Sodium alginate, Film properties, Seed quality

Introduction

Sweet corn (*Zea mays* var. rugosa) belomgs to Poaceae. It is considered as a globally important economic crop in high demand of the market. It serves as a vital source of food for both humans and animals, sweet corn can be consumed as fresh pod form and is processed into various industrial food products. In 2021, sweet corn had a global cultivation area of approximately 205,800,000 hectares and a total production of approximately 1,210,000,000 tons, making it the second most produced crop in the world, following sugarcane (FAO, 2021). In 2022, in Thailand, there was an approximate cultivation area of 210,000 rai, resulting in a total production of approximately 450,000 tons (Office of Agricultural Economics, 2023). In 2018, Thailand exported a substantial amount of sweet corn, totaling 532,370 tons, with an estimated value of 7.956 billion Baht (Office

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of Agricultural Economics, 2019). Currently, farmers prefer to cultivate sweet corn hybrid varieties over open-pollinated varieties due to their higher yields and consistency. There is a substantial use of hybrid seeds, with single-cross hybrid varieties accounting for over 95% of the total. Among these, the shrunken-2 gene controlled single-cross hybrid sweet corn varieties have a production share of more than 85% of the seed market. In seed production, it is considered a crucial factor for the quantity of sweet corn production. High-quality seeds play a significant role in terms of growth, adaptation, and yield in suitable environmental conditions when compared to low-quality seeds. They can help reduce losses significantly. The process of producing high-quality seeds begins with selecting superior parent plants or seed populations and involves techniques in seed production, harvesting, and proper storage. This ensures that farmers obtain high-quality seeds for cultivation, which is essential for maximizing sweet corn production (Siri, 2009).

In general process of producing sweet corn seed is concerned male flowers typically bloom before the female flowers, necessitating the need for careful planning, and established the planting schedule for the parent varieties in advance which observed in the hybrid sweet corn variety Songkhla 84-1. Chainat Field Crops Research Center (2019) recommended to plant the female parent line before the male parent line for 3 days. It increased costs and labor in the management process. Additionally, it is added complexity to the production field as it involved more steps in seed production. Currently, there are various technologies for improving the quality of seeds, and one commonly used method is seed coating. This technology involves not only coating a thin film uniformly on the surface of the seed without altering its shape but also enhancing adhesion between the seed and active substances. This helps to protect the seed and facilitate the absorption of active ingredients (Siri, 2015). To enhance the quality of seeds, seed coating techniques are developed by the pharmaceutical industry. These techniques involve using polymers with suitable levels of viscosity and a combination of beneficial active substances to improve seed quality. Furthermore, polymers are a crucial component added to the coating formulation to enhance the adhesion of various active substances to the seeds. This is essential because if active substances detach or are lost, it can reduce their effectiveness. Additionally, adhesion agents can be employed to regulate water entry and exit (Sikhao, 2016). In the study conducted by Yildirim (2020), wheat seeds were coated with aloe vera and glycerol to investigate the effects on germination delay and viability under different water levels. This research has sparked interest in the application of polymers to seed coating with the aim of extending the germination period. According to the report by McGee *et al.* (1993), soybean seeds were coated with Ethylcellulose, a polymer known for reducing the water uptake rate of seeds, which assists seeds in germinating under stressed conditions. Furthermore, a study examined the physical, physiological, and sanitary characteristics of corn seeds, researchers used to investigate the effects of coating seeds with polymers. It found to be lower percentages of skips and double seeds that received corn seeds coated with the polymer PolySeed CF, compared to graphite-treated seeds or seeds coated with other polymers or left non-coated. The improvement of seed quality enhanced the plants' ability to thrive. Additionally, film seed coating with the polymer PolySeed CF led to reduce dust formation and the leached of applied insecticides (Avelar *et al.*, 2012).

Currently, the most research is concentrated on seed coating methods to enhance germination percentages and germination indices of seedlings. Typically, studies on coating formulations aimed to protect seeds from pests or improved germination rates. However, many efficient seed coating techniques remain undisclosed due to legal patent issues and intellectual property rights protection. Consequently, these effective methods are often held as trade secrets by patent holders (Taylor *et al.*, 1998; Murphy, 2017). At the same time, the limited research has been explined on seed coating to delay germination. Studies were undertaken to explore suitable coating formulations involving various types of polymers in germination tests. These tests were evaluated germination rates and germination times of coated seeds, specifically focused on delaying the germination of sweet corn seeds.

Materials and methods

Preparation of seed coating substances formulations

The seed coating formulation was prepared using a commercial coating substance (Centor Oceania Co., Ltd.) mixed with various polymers (Chemipan Corporation Co., Ltd.), including Hydroxypropyl Methylcellulose (HPMC), Sodium Alginate (NaAlg), Carboxymethyl Cellulose (CMC), and Polyvinylpyrrolidone K30 (PVP-K30). These polymers were used in combination with the plasticizer Polyethylene Glycol 6000 (PEG6000) and the additive titanium dioxide. Distilled water was used as the solvent, and the volume was adjusted to 100 ml. The mixture was placed in a beaker and covered with aluminum foil. Subsequently, It determined the proportions of the coating substance, examining properties such as viscosity and acidity-alkalinity (pH) in its liquid form.

Sweet corn seed coating

The experimental design employed a Completely Randomized Design (CRD) and involved applying various polymer coatings to sweet corn hybrid seeds provided by the Chainat Field Crops Research Center. The study involved the preparation of six different seed coating methods to delay germination. These methods included coating seeds with only a commercial coating substance (T1), coating seeds with a commercial coating substance and 1% Hydroxypropyl Methylcellulose (HPMC) (T2), coating seeds with a commercial coating substance and 1% Sodium Alginate (NaAlg) (T3), coating seeds with a commercial coating substance and 1% Carboxymethyl Cellulose (CMC) (T4), coating seeds with a commercial coating substance and 1% Polyvinylpyrrolidone K30 (PVP-K30) (T5), and using non-coated seeds as a control (T0). The coating process can be performed using a rotating disk seed coating machine (model RRC150) by applying 200 ml of coating substance per 1 kilogram of seeds. After coating, the seeds are dried using a hot air oven at a temperature of 35 °C to reduce moisture levels to a level similar to before coating. The uniformity of the coating is checked and the properties of coated and non-coated seeds were examined. Data collection included germination, germination index, and moisture content.

The pH of coating substance

The coating substance obtained from every preparation method was tested for its acidity and alkalinity (pH) using a pH *meter* (model PH100). The coating substance was placed in a beaker with a volume of 50 ml. The pH meter was immersed in the coating substance. The results are recorded on the displayed values.

The viscosity of coating substance

The viscosity of all coating substance formulas was determined using the Ford Viscosity Cup (model ASTM D1200). A volume of 50 ml of each coating was poured into a beaker, and the viscosity was tested four times by measuring the time it took for the coating to stop flowing after allowing it to flow. These measurements were taken at a temperature of 25 ± 1 °C, and the time taken for the substance to flow served as an indicator of its viscosity.

The uniformity of coating

To evaluate the uniformity of the coating substance adhering to the seeds, a sample of 10 coated seeds from each treatment was visually inspected. The surface characteristics of the seeds were observed with the naked eye, and a scoring system was employed to assess the uniformity of the coating. In this system, a score of 5 points indicates that 100% of the seed surface is smooth and even, a score of 4 points indicates that 80–99% of the seed surface is smooth and even, a score of 3 points denotes that 60–79% of the seed surface is smooth and even, a score of 2 points signifies that 40–59% of the seed surface is smooth and even, a score of 1 point represents that 20–39% of the seed surface is smooth and even, and a score of 0 points indicates that 0–19% of the seed surface is smooth and even.

Seed moisture content

Seed moisture content was analyzed using the RHINO RR Moisture machine (model HC2-AW-USB-SW), which calculates seed moisture by measuring Water Activity. Both coated and non-coated seeds were loaded into the probes, and these probe sets were placed into the sample holder. The machine provided water activity values, which were then converted by software to indicate seed viability as seed moisture content in percentage and recorded as results.

Germination percentage of seeds in laboratory conditions

The percentages of germination of coated and non-coated sweet corn seeds with every treatment were checked by the between paper method using paper as the planting material. The test plants were grown in 4 replicates, each with 50 seeds. The samples were subsequently placed in a test incubator at a temperature of 25 ± 2 °C, and the evaluation involved counting normal seedlings. The first count was conducted at 4 days after germination, with the final count performed at 7 days after cultivation (ISTA, 2019).

$$\text{seed germination (\%)} = \left[\frac{\text{number of normal seedlings}}{\text{number of seeds}}\right] \times 100$$

Germination index

All coated and non-coated sweet corn seeds were cultivated according to the method of seed germination examination in the laboratory. Counting the number of normal seedlings was performed is 4 days (first count) and 7 days (final count) (ISTA, 2019).

$$\text{seeds germination index} = \sum\left[\frac{\text{daily seedlings}}{\text{number of days after cultivation}}\right]$$

Statistical data analysis

A Completely Randomized Design (CRD) trial comprising 6 treatments with 4 replicates was designed. The data were analyzed using Analysis of Variance (ANOVA), and comparisons between means were performed using Duncan's New Multiple Range Test (DMRT) within the Statistical Analysis System (SAS).

Results

Physical properties of coating substance

The study involved the formulation of coating substances mixed with various polymers, including only a commercial coating substance, Hydroxypropyl Methylcellulose (HPMC), Sodium Alginate (NaAlg), Carboxymethyl Cellulose (CMC), and Polyvinylpyrrolidone K30 (PVP-K30). The study revealed that the pH values of each coating substance formulation exhibited statistically significant differences, ranging between 7.1 and 7.7 for all coating formulations. Notably, the highest pH value was observed in the coating substance mixed with CMC (T4), which measured as 7.75 (Table 1).

Table 1. The pH, viscosity of the coating substance formula, and the uniformity of the coating on the surface of sweet corn seeds were assessed for each coating substance

Coating substance[1/]	pH	Viscosity (m/s)	Uniformity (%)
T1	7.12e	0.0013e	85.00a
T2	7.43c	0.0027c	71.00b
T3	7.62b	0.0118b	52.50c
T4	7.75a	0.0026d	58.50c
T5	7.28d	0.0250a	75.50b
F-test	**	**	**
C.V. (%)	0.90	0.35	11.47

** = significantly different at $P \leq 0.01$, [1/]T1: Only a commercial coating substance, T2: Commercial coating substance mixed with 1% HPMC, T3: Commercial coating substance mixed with 1% NaAlg, T4: Commercial coating substance mixed with 1% CMC and T5: Commercial coating substance mixed with 1% PVP-K30.

Similarly, the viscosity of the coating substances showed significant variations, with the commercial coating substance (T1) having the highest viscosity. Its flow rate was measured at 0.0013 m/s. Following this, the coating substance mixed with CMC (T4), HPMC (T2), NaAlg (T3), and PVP-K30 (T5) demonstrated progressively lower viscosities (Table 1).

To assess the uniformity of the coating, the surface characteristics of the seeds were visually examined. The results indicated that seeds coated with the commercial coating substance (T1) exhibited the highest coating uniformity, reaching 85.00%. Subsequently, the uniformity levels decreased in the following order: seeds coated with a mixture of PVP-K30 (T5), HPMC (T2), CMC (T4), and NaAlg (T3) (Table 1).

Effects of different polymers coating substances on the quality of sweet corn seeds after coating

The examples of sweet corn seeds, some coated and others non-coated, with various coating formulations containing different polymers for each treatment were shown in Figure 1. The quality of the seeds was examimed which included seed moisture content, germination, and germination index. It found that the seed moisture content percentages for different coating treatments were not statistically significant differences. Seeds coated with the commercial coating alone (T0) was the highest moisture content at 12.38%, followed by seeds coated with NaAlg (T3), CMC (T4), non-coated seeds (T0), HPMC (T2), and PVP-K30 (T5), in descending order (Table 2).

Table 2. Seed moisture content, seed germination and germination index of non-coated and coated seed with each coating substance formulations after coating

Coating substance[1/]	Moisture Content (%)	Germination (%)	Germination index
T0	12.00	95.00	13.57
T1	12.38	93.50	13.61
T2	11.84	93.50	13.48
T3	12.09	93.00	13.53
T4	12.06	95.00	13.70
T5	11.82	91.00	13.88
F-test	ns	ns	ns
C.V. (%)	3.23	4.55	5.09

ns = non statistical significant difference, [1/]T0: control, T1: coating seeds with only a commercial coating substance, T2: coating seeds with a commercial coating substance mixed with 1% HPMC, T3: coating seeds with a commercial coating substance mixed with 1% NaAlg, T4: coating seeds with a commercial coating substance mixed with 1% CMC and T5: coating seeds with a commercial coating substance mixed with 1% PVP-K30.

Additionally, there was no statistically significant difference in the effect on seed germination under laboratory conditions. Seeds coated with CMC (T4) exhibited the highest germination percentage at 95.00%, matching the non-coated seeds (T0). Following closely were seeds coated with the commercial coating (T1) and those coated with HPMC (T2), both at 93.50% germination (Table 2).

Furthermore, the germination index was not statistically significant difference. However, for seeds coated with the commercial coating along with PVP-K30 (T5), they achieved the highest germination index at 13.88. Seeds coated with CMC (T4) came next, followed by seeds coated with the commercial coating (T1), non-coated seeds (T0), seeds coated with NaAlg (T3), and seeds coated with HPMC (T2), respectively (Table 2).

Figure 1. Characteristics of coated and non-coated seeds with different coating formulations: T0: control, T1: coated seeds with only a commercial coating substance, T2, T3, T4 and T5: coating seeds with a commercial coating substance mixed with HPMC, NaAlg, CMC and PVP-K30, respectively

Discussion

The research approach can be extended to the coated seeds of other crops that necessitate delayed germination for diverse purposes in the future. Additionally, it is exemplified the application of seed coating technology to diminish costs, labor, and time in seed production processes, encompassing field management practices. This investigated the effects of coating sweet corn seeds with various coating substances, both commercial and combined with different types of polymers such as Hydroxypropyl Methylcellulose (HPMC), Sodium Alginate (NaAlg), Carboxymethyl Cellulose (CMC), and Polyvinylpyrrolidone K30 (PVP-K30), on seed germination delay. Coating seeds with the appropriate materials and concentrations can alleviate limitations in the early growth and development of seedlings, thereby improving stand establishment and seedling vigor (Javed *et al.*, 2022) While seed coating has been studied for various purposes, including the mitigation of biotic and abiotic stress effects (Chandrika *et al.*, 2017), there are limited studies on polymers for germination delay. For example, research by Willenborg *et al*. (2004) indicated that canola seeds coated with a polymer film exhibited increased germination under low-temperature and moisture stress conditions. Regarding the properties of the coating substances, the pH values of all treatment methods fell within the range of 7.1 to 7.7. This aligns with the suitable soil pH range for sweet corn cultivation (5.5 to 6.8) (Chainat Field Crops Research Center, 2019). The viscosity of the coating substances ranged from 0.0013 to 0.0250 m/s, with lower flow rates indicating higher viscosity. It's worth noting that the viscosity of solutions like HPMC can depend on factors such as concentration, type, and temperature (Ghadermazi *et al.*, 2019). Proper adjustment of the solvent proportion may be required to maintain low viscosity, as it can affect appearance and uniformity (Afzal *et al.*, 2020). In terms of coating uniformity in this experiment, values ranged from 52.50% to 85.00%, with statistically significant differences at the 99% confidence level. Seeds coated with the commercial coating substance (T1) exhibited the highest uniformity (85%), followed by coating with PVP-K30 (T5) at 75.50%, which was not statistically different from coating with HPMC (T2) at 71.00%. The coating with NaAlg (T3) had the lowest uniformity (52.50%), which was not statistically different from coating with CMC (T4). Despite variations in coating uniformity, the quality of the seeds after coating was not significantly affected. Both coated and non-coated seeds had moisture content ranging from 11.82% to 12.38%. Additionally, there was no statistically significant difference in germination percentage and germination index. A similar study by Behboud *et al*. (2021) reported that the use of 2% NaAlg had an impact on oxygen and water absorption into seeds.

In conclusion, this study found that coating sweet corn seeds with different polymer-based formulations were significantly affected the quality of the coated seeds, including moisture content, germination percentage, and germination index. Furthermore, the coatings were unable to delay the germination of hybrid sweet corn seeds.

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