International Journal of Agricultural Technology 2024 Vol. 20(6):2565-2578
Available online http://www.ijat-aatsea.com
ISSN 2630-0192 (Online)

Effect of organic seed coating agents on the physical characteristics and seed quality of tomato (*Lycopersicon esculentum* Mill.)

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Thawong, N., Phuakjaiphaeo, C., Hermhuk, S., Inthasan, J. and Kangsopa, J. (2024). Effect of organic seed coating agent on physical characteristics and seed quality of tomato (*Lycopersicon esculentum* Mill.). International Journal of Agricultural Technology 20(6):2565-2578.

Abstract Cultivating plants in organic agriculture requires the same level of care in seed coating technology as in conventional farming. The physical characteristics of six polymers indicated a slight alkaline nature. Other polymers showed similar viscosities and increased in viscosity as the concentration level increased, with xanthan gum exhibiting the highest viscosity at the same concentration level. Gelatin, carrageenan, sodium alginate, and gum arabic dissolved well when in film form. Coating seeds with 0.2% w/v sodium alginate showed a significantly higher radicle emergence percentage, radicle emergence speed, germination rate, germination speed, shoot length, and root length compared to non-coated seeds. Therefore, it is recommended to use 0.2% w/v sodium alginate for coating organic tomato seeds.

Keywords: Seed enhancement, Organic seed treatments, Seed quality, Polymer

Introduction

Effective crop management is crucial for achieving high-quality and high-yield agricultural production (Shah and Wu, 2019). In particularly, starting from the seed stage, proper care and management are essential to ensure robust seed germination and seedling vigor. Among general agricultural practices, coating seeds with chemical agents are commonly used to prevent pathogenic infections from fungal pathogens, both pre- and post-germination. However, organic farming methods contribute to enhance biological fertility in ecosystems (Agricultural Research Development Agency, 2000). When initiating organic crop cultivation, it is imperative to use seeds produced organically. One limitation of organic vegetable production is the inability to use chemical substances, which is permissible in conventional farming (Bonina and Cantliffe,

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2004). This drawback makes organic farming less efficient compared to conventional agricultural practices.

To elevate organic crop cultivation, the use of enhanced seeds via seed-coating technology is proposed. Film coating is applied around the seed shell to act as a carrier for active ingredients that can protect against fungal diseases. The selection of polymers within standard guidelines compatible with organic farming, as stipulated by the International Federation of Organic Agriculture Movements (IFOAM) (Agricultural Research Development Agency, 2000), has been considered (Deaker *et al*., 2004). Biopolymers are a type of polymer found in living organisms, primarily composed of amino acids (proteins), sugars (carbohydrates), and nucleic acids, forming long structures related to genetics, such as DNA and RNA, or proteins essential in cellular structures and fibers, such as chitin in arthropods and proteins in animal and plant tissues (Raj *et al*., 2011). These properties make biopolymers suitable as seed coatings to enhance seed quality and agricultural productivity, aligning with conventional farming practices. However, this study lacks specific formulations compliant with IFOAM standards and reports on their impact on seed quality, making it a preliminary investigation into both physical characteristics and seed quality.

Therefore, the objective of this experiment was to study the physical characteristics of different types of organic seed coatings and monitor changes in seed quality.

Materials and methods

This experiment was conducted at the Seed Technology Laboratory and Modern Seed Technology Research Center of the Agronomy Program, Faculty of Agricultural Production, Maejo University. Organic tomato seeds used as experimental seeds were cultivated in 2023 by the Learning Center for Organic Vegetable Seed Production at Maejo University. The experiment was conducted between October 2023 and February 2024.

Experimet was performed using complete randomized design and treatmets were T1 = non-coated seed, T2 = Gelatin 0.1 w/v, T3 = Gelatin 0.2 w/v, T4 = Gelatin 0.3 w/v, T5 = Carrageenan 0.1 w/v, T6 = Carrageenan 0.2 w/v, T7 = Carrageenan 0.3 w/v, T8 = Sodium alginate 0.1 w/v, T9 = Sodium alginate 0.2 w/v, T10 = Sodium alginate 0.3 w/v, T11 = Gum arabic 0.1 w/v, T12 = Gum arabic 0.2 w/v, T13 = Gum arabic 0.3 w/v, T14 = Guar gum 0.1 w/v, T15 = Guar gum 0.2 w/v, T16 = Guar gum 0.3 w/v, T17 = Xanthan gum 0.1 w/v, T18 = Xanthan gum 0.2 w/v and T19 = Xanthan gum 0.3 w/v.

Organic coating agent preparation

Gelatin, carrageenan, sodium alginate, gum arabic, guar gum, and xanthan gum (Union Chemical Ltd., Bangkok, Thailand) were selected from Agricultural Research Development Agency (2000) as suitable for use in organic farming systems. Subsequently, each type of polymer was prepared at three concentration levels: 0.1, 0.2, and 0.3 w/v. At each concentration level, the polymers were dissolved in distilled water at volumes of 99.9, 99.8, and 99.7 mL, respectively.

Tomato seed coating

This experiment utilized organic tomato seeds as the test seeds. Subsequently, the prepared organic coatings were applied to the seeds using a seed-coating machine Model CERES01 (Ceres International Co., Ltd, Bangkok, Thailand) rotating at 60 rpm. The coated seeds were then air dried at room temperature until their moisture content decreased to 7%.

Seed measurement for testing of organic coating agent physical characteristics

pH

The acidity–alkalinity of the organic coating formulas was assessed using a pH meter (model PH-80). A beaker containing 50 mL of the coating solution was prepared for measurement. This procedure was replicated four times for each formula.

Viscosity

The viscosity was determined using a Standard Ford Viscosity Cup no. 04. The cup contained 100 mL of the coating solution, with the opening sealed to prevent spillage. Upon releasing the seal, the timer started as the solution flowed. Timing ceased when the flow stopped entirely. Measurements were taken at 25±1°C and repeated four times per formula for accuracy. Recorded data were used to compute the solution’s viscosity, expressed in centistokes (cSt) (Korkasetwit, 2008).

Film weight

Thirty milliliters of each coating formula were poured into a clean Petri dish to avoid air bubbles. The dish was placed in an oven at 60°C for 18 hours. Afterward, the film was removed from the Petri dish and stored in a plastic bag. The film was then cut into 4 cm^2 pieces and weighed for each coating formula. This process was repeated four times for each treatment (Korkasetwit, 2008).

Film solubility

The dissolution testing of the film was conducted using a grid measuring 3×5 cm with 2×1.5 mm holes and a height of 1 cm. Film sheets from different coating formulas were cut into 4 cm^2 pieces and placed on the grid. The grid with the film sheets was initially weighed and then submerged in 100 mL of water within a beaker for 5 minutes. After this duration, the grid was removed, and the film sheets were dried in an oven at 60°C for 18 hours. The grid with the film sheets was weighed again. This process was replicated four times, and the solubility of the film was calculated using a formula (Korkasetwit, 2008).

Seed quality test in laboratory conditions

The seed quality test involved assessing 50 coated and non-coated seeds using the top-of-paper (TP) method in each of the four replications. The seeds were placed in a transparent plastic box measuring 110 × 110 × 30 mm (length × width × height) and then placed in a germination incubator set at 25°C, 80% relative humidity, 180 µE light intensity, and continuous 24-hour lighting. Subsequently, various aspects of seed quality were evaluated.

Radicle emergence was assessed on the 4^{th} day after sowing, when the radicle length reached at least 2 mm (ISTA, 2022). The speed of radicle emergence was evaluated daily from day 1 to day 4 after sowing, when the radicle length reached at least 2 mm (Kangsopa and Atnaseo, 2022). The germination percentage was evaluated by assessing normal seedlings at 4 days (first count) and 14 days after sowing (final count) (ISTA, 2019). The speed of germination was evaluated by assessing normal seedlings daily from 5 to 14 days after sowing. Then, the speed of germination was calculated based on the AOSA (1983) method. For each method, seedling growth was evaluated by assessing 10 seedlings 14 days after sowing. The shoot length of the seedlings was measured from the base of the epicotyl to the tip of the leaf, while the root length was measured from the base to the tip of the taproot. The total seedling length was measured from the tip of the root to the tip of the leaf (Kangsopa and Atnaseo, 2022).

Seed quality test in greenhouse conditions

The seed quality was assessed in the greenhouse, with peat moss as the medium and employing seedling trays with 104 compartments for testing. Each experimental method was conducted with four replications, with each replication using 50 seeds. The assessment methods were as follows:

The percentage of emergence was assessed by observing cotyledons emerging from the peat moss on the 4th day after sowing and was calculated following the method of Kangsopa and Atnaseo (2022). The speed of emergence was evaluated daily from 1 to 4 days after sowing when the cotyledons emerged from the peat moss (Kangsopa and Atnaseo, 2022). The germination percentage and speed of germination were evaluated using the same method under laboratory conditions. Shoot length and shoot fresh weight were assessed for both coated and non-coated seeds in each treatment on the 14th day after sowing.

Statistical analysis

The germination percentage was arcsine-transformed to normalize the data before statistical analysis. All data were analyzed by one-way analysis of variance (ANOVA) for a complete randomized design, and the differences between treatments were tested using Duncan's Multiple Range Test (DMRT).

Results

Physical characteristics of the organic coating agent

The evaluation of organic seed coatings in liquid form revealed that all polymers had an alkaline pH ranging from 8.33 to 8.53. Viscosity testing showed that xanthan gum at a concentration of 0.3 w/v exhibited higher viscosity compared to the other polymer types. Generally, gelatin and gum arabic showed similar viscosities at all three concentration levels. However, the polymer viscosity increased proportionally with the increase in concentration. When converted into film sheets for physical testing, all polymer types yielded films with similar weights, except for gum Arabic, which had a lower film weight compared to other polymers. Gelatin, carrageenan, sodium alginate, and gum arabic had relatively high-water solubility percentages, ranging from 52 to 87% on average. Guar gum and xanthan gum exhibited relatively low water solubilities, with percentages averaging between 3 and 8% when tested over 5 minutes (Table 1). When examining the film sheets (Figure 1), we observed different physical characteristics depending on the polymer type. The film derived from gum Arabic was prone to breaking, while the film produced from xanthan gum shrank easily without flexibility.

Table 1. Characteristics of various coating agents, including pH, viscosity, film weight, and dissolution of the prepared coating solutions

Organic coating agent	pH	Viscosity (cSt)	Film weight (mg)	Solubility of film (%)[1]
Gelatin 0.1 w/v	8.53 a[2]	5.01 g	100 a–d	84 a
Gelatin 0.2 w/v	8.53 a	6.79 g	100 a–d	79 ab
Gelatin 0.3 w/v	8.53 a	7.65 g	110 a–d	78 ab
Carrageenan 0.1 w/v	8.33 b	8.47 fg	80 c–e	87 a
Carrageenan 0.2 w/v	8.33 b	9.91 e–g	110 a–d	80 a
Carrageenan 0.3 w/v	8.33 b	29.49 c	130 ab	82 a
Sodium alginate 0.1 w/v	8.50 a	15.16 d–f	100 a–d	52 ab
Sodium alginate 0.2 w/v	8.50 a	18.84 d	100 a–d	63 ab
Sodium alginate 0.3 w/v	8.50 a	16.93 ed	100 a–d	60 ab
Gum arabic 0.1 w/v	8.45 ab	3.27 g	60 e	81 a
Gum arabic 0.2 w/v	8.45 ab	4.74 g	70 de	75 ab
Gum arabic 0.3 w/v	8.45 ab	4.32 g	90 c–e	70 ab
Guar gum 0.1 w/v	8.40 ab	10.31 e–g	90 b–e	3 c
Guar gum 0.2 w/v	8.40 ab	17.05 de	100 a–d	6 c
Guar gum 0.3 w/v	8.40 ab	31.47 c	140 a	7 c
Xanthan gum 0.1 w/v	8.50 a	28.83 c	70 de	3 c
Xanthan gum 0.2 w/v	8.50 a	71.88 b	110 a–d	8 c
Xanthan gum 0.3 w/v	8.50 a	119.44 a	130 ab	7 c
F-test	**	**	**	**
CV (%)	1.13	20.07	23.15	32.37

**: Significantly different at $P \leq 0.01$.[1] Data are transformed by the arcsine before statistical analysis and back transformed data are presented, [2] Means within a column followed by the same letter are not significantly at $P \leq 0.05$ by DMRT.

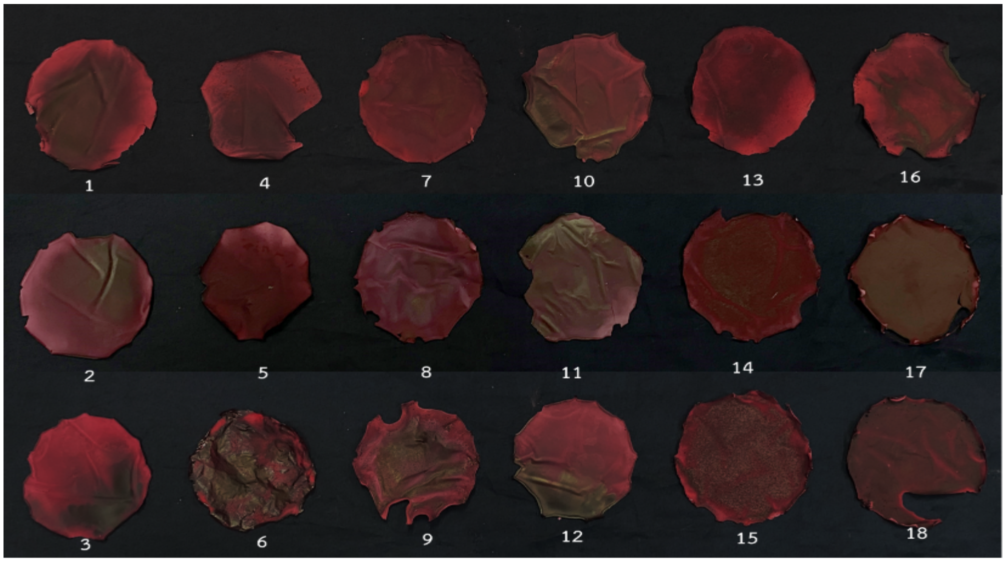

Figure 1. Films obtained from various coating solutions are as follows: F1 = Gelatin 0.1 w/v, F2 = Gelatin 0.2 w/v, F3 = Gelatin 0.3 w/v, F4 = Carrageenan 0.1 w/v, F5 = Carrageenan 0.2 w/v, F6 = Carrageenan 0.3 w/v, F7 = Sodium alginate 0.1 w/v, F8 = Sodium alginate 0.2 w/v, F9 = Sodium alginate 0.3 w/v, F10 = Gum arabic 0.1 w/v, F11 = Gum arabic 0.2 w/v, F12 = Gum arabic 0.3 w/v, F13 = Guar gum 0.1 w/v, F14 = Guar gum 0.2 w/v, F15 = Guar gum 0.3 w/v, F16 = Xanthan gum 0.1 w/v, F17 = Xanthan gum 0.2 w/v and F18 = Xanthan gum 0.3 w/v

Seed quality

Seed germination and vigor

In laboratory conditions, coating seeds with 0.2 w/v sodium alginate resulted in a significantly higher radicle emergence percentage compared to the other methods. Consistent with the results of coating seeds with 0.2 w/v sodium alginate, there was also a high speed of radicle emergence, although it was statistically no different than coating seeds with 0.1 w/v gelatin. Coating seeds with 0.3 w/v gelatin, 0.2 w/v carrageenan, 0.2 w/v sodium alginate, and 0.3 w/v gum Arabic resulted in significantly higher germination percentages than non-coated seeds, but no statistical difference was observed. Seeds coated with 0.2 w/v sodium alginate and 0.2 w/v gelatin demonstrated a higher germination speed compared to those coated with other polymers (Table 2).

Under greenhouse conditions, seeds coated with 0.2 w/v sodium alginate and 0.3 w/v gum Arabic showed a higher emergence percentage compared those coated with other polymers. This is consistent with the findings of speed of emergence, which were high and similar to coating seeds with 0.3 w/v guar gum but not significantly different from non-coated seeds. Seeds coated with 0.2 w/v sodium alginate had the highest germination rate, which was statistically different from those coated with other polymers. Seeds coated with 0.2 w/v sodium alginate also continued to demonstrate a significantly higher speed of germination compared those coated with other polymers and was similar to seeds coated with 0.3 w/v xanthan gum (Table 3).

Table 2. Radicle emergence percentage (RE), speed of radicle emergence (SRE), germination percentage (GE), and speed of germination (SGE) of tomato seeds after coating seeds with various organic coating agents, tested under laboratory conditions

Treatment	**Laboratory condition**			
	RE (%)[1]	SRE (root/day)	GE (%)	SGE (seedling/day)
T1	81 de[2]	15.29 ab	97 a–c	8.82 ab
T2	81 de	16.67 a	95 a–c	8.32 a–e
T3	80 e	15.04 ab	95 a–c	8.90 a
T4	84 c–e	7.33 d	99 a	7.88 c–e
T5	81 de	9.63 bc	94 a–c	7.98 b–e
T6	80 e	12.63 a–d	99 a	7.78 c–e
T7	83 c–e	7.83 dc	98 ab	7.84 c–e
T8	83 c–e	15.71 ab	97 a–c	8.41 a–d
T9	98 a	17.63 a	98 ab	8.88 a
T10	87 cd	11.92 a–d	97 a–c	8.39 a–d
T11	86 c–e	13.75 a–c	93 a–c	8.50 a–c
T12	93 b	11.88 a–d	97 a–c	8.23 a–e
T13	89 c	14.08 ab	98 ab	8.64 a–c
T14	83 c–e	14.38 ab	97 a–c	8.43 a–c
T15	83 c–e	12.21 a–d	97 a–c	8.13 a–e
T16	83 c–e	13.25 a–d	93 a–c	8.25 a–e
T17	80 e	10.42 a–c	95 a–c	7.53 de
T18	81 de	7.79 dc	89 c	7.49 e
T19	80 e	12.04 a–d	94 a–c	8.62 a–c
F-test	**	**	*	**
CV (%)	4.79	28.71	6.89	6.33

*, **: Significantly different at P ≤ 0.05 and P ≤ 0.01, respectively. [1] Data are transformed by the arcsine before statistical analysis and back transformed data are presented, [2] Means within a column followed by the same letter are not significantly at P ≤ 0.05 by DMRT.

Seedling growth

Under laboratory conditions, seeds coated with 0.2 w/v sodium alginate showed higher shoot length and root length compared to those coated with other polymers. After coating seeds with various methods, there were mostly no significant effects on the shoot growth of tomato seedlings. However, a negative change was observed when seeds were coated with 0.3 w/v gelatin, resulting in a shorter shoot length compared to non-coated seeds. Regarding root length, an increase in polymer concentration generally had an impact on the root elongation of tomato seedlings. Under greenhouse conditions, coating seeds with 0.3 w/v gum arabic resulted in a higher shoot length compared to other methods, but it did not differ significantly from coating seeds with 0.2 and 0.3 w/v sodium alginate, 0.1 w/v guar gum, and 0.3 w/v xanthan gum (Table 4).

Table 3. Emergence percentage (EMR), speed of emergence (SEMR), germination percentage (GE), and speed of germination (SGE) of tomato seeds after coated seeds with various organic coating agents, tested under grenehouse conditions

Treatment	Greenhouse condition			
	EMR (%)[1]	SEMR (seedling /day)	GE (%)	SGE (seedling/day)
T1	10 ab[2]	1.31 a–c	66 bc	3.05 ef
T2	5 b–f	0.56 c–f	37 g–i	3.13 ef
T3	4 b–f	0.50 d–f	38 g–i	3.17 ef
T4	3 f	0.38 ef	35 hi	2.92 ef
T5	4 b–f	0.50 d–f	40 g–i	3.84 de
T6	3 f	0.31 a–c	27 j	2.49 ef
T7	10 ab	1.19 a–d	43 f–h	4.12 c–e
T8	10 ab	1.32 a–c	40 g–i	3.90 de
T9	11 a	1.56 ab	80 a	7.04 a
T10	3 f	0.38 ef	32 ij	2.84 ef
T11	8 a–d	0.94 a–f	54 de	5.25 bc
T12	7 a–e	0.81 b–f	60 cd	5.50 b
T13	11 a	1.31 a–c	60 cd	5.63 b
T14	4 b–f	0.44 d–f	37 g–i	2.47 f
T15	8 a–d	0.94 a–e	44 fg	4.06 c–e
T16	10 ab	1.63 a	54 de	5.56 b
T17	7 a–e	0.81 b–f	49 ef	5.13 b–d
T18	3 f	0.19 f	43 f–h	3.29 ef
T19	3 f	1.13 a–e	69 b	7.04 a
F-test	**	**	**	**
CV (%)	32.19	53.91	10.67	18.36

**: Significantly different at $P \leq 0.01$. [1] Data are transformed by the arcsine before statistical analysis and back transformed data are presented, [2] Means within a column followed by the same letter are not significantly at $P \leq 0.05$ by DMRT.

Table 4. Shoot length and root length of tomato seeds after coating seeds with various organic coating agents, tested under laboratory and grenehouse conditions

Treatment	Laboratory condition		Greenhouse condition
	Shoot length (cm)	Root length (cm)	Shoot length (cm)
T1	2.20 bc[1]	8.79 bc	3.40 bc
T2	2.21 bc	8.79 bc	3.27 cd
T3	2.20 bc	8.79 bc	3.24 cd
T4	2.18 c	8.79 bc	3.42 bc
T5	2.20 bc	8.77 c	3.42 bc
T6	2.21 bc	8.77 c	3.37 b–d
T7	2.20 bc	8.79 bc	3.42 bc
T8	2.22 ab	8.79 bc	3.35 b–d
T9	2.24 a	9.03 a	3.68 ab
T10	2.21 bc	8.79 bc	3.69 ab
T11	2.21 bc	8.79 bc	3.42 bc
T12	2.21 bc	8.77 c	3.22 cd
T13	2.21 bc	8.77 c	3.78 a
T14	2.20 bc	8.79 bc	3.72 ab
T15	2.22 ab	8.79 bc	3.40 bc
T16	2.22 ab	8.78 c	3.42 bc
T17	2.21 bc	8.79 bc	3.45 bc
T18	2.22 ab	8.79 bc	3.16 d
T19	2.22 ab	8.76 c	3.68 ab
F-test	*	*	**
CV (%)	10.74	7.71	13.05

*, **: Significantly different at $P \leq 0.05$ and $P \leq 0.01$, respectively. [1] Means within a column followed by the same letter are not significantly at $P \leq 0.05$ by DMRT.

Discussion

Cultivating plants in organic agriculture often has disadvantages compared to conventional agriculture, which uses chemical pesticides both before and after seed germination. Due to these challenges, research to identify organic seed coating formulas that can be used in organic farming systems has become essential for enhancing seed efficiency. In this experiment, six types of polymers at three concentrations were tested for their physical properties and used to coat tomato seeds produced in organic farming systems. Subsequently, these seeds were evaluated using the following results.

This study found that most of the seed coatings prepared from the six types of polymers were alkaline. The pH value is a crucial parameter for seed germination processes, as it affects the water absorption and nutrient uptake of plants. An appropriate pH level helps seeds germinate and grow efficiently (Siri, 2015). However, tomato seeds tend to germinate well when the pH is between 5.5 and 7.0 (Arancon *et al*., 2012). Using seed coatings with polymers may require minimal amounts. Additionally, when the seed coatings form a thin film, they have minimal impact on seed quality. Further considerations may include the germination percentage of the seed varieties.

Viscosity is an important property that helps seeds adhere efficiently to coatings (Siri, 2015). Experimental results showed that as the concentration of the coating material increased, its viscosity also increased. Xanthan gum exhibited the highest viscosity when compared at the same concentration level. However, the advantage of high viscosity may help reduce the amount of coating material needed but could potentially impact the seed quality. Therefore, the viscosity of the coating material may vary depending on the specific type of plant seed (Siri, 2015).

The water solubility of coatings revealed that gelatin, carrageenan, sodium alginate, and gum arabic had high water solubility percentages when tested for the dissolution of polymer films of each type. In contrast, guar gum and xanthan gum at all three concentration levels showed minimal dissolution within the 5-minute test. This water solubility property is crucial for farmers when handling seeds in humid conditions. If coated seeds dissolve too quickly, the active ingredients may wash away before planting, potentially exposing farmers to hazardous substances. However, the water solubility tests of all six polymers still demonstrated water solubility. Therefore, this may not hinder water absorption or other factors necessary for seed germination (Siri, 2015; Kangsopa and Jeephet, 2021).

Post-coating seed quality assessments examining the impact on germination, seed vigor, and seedling growth revealed that after a 4-day period, seeds coated with 0.2 w/v sodium alginate exhibited a higher radicle emergence percentage and speed compared to seeds coated with other polymers. Additionally, there was no adverse effect on germination rate of germination speed, which remained higher than those of non-coated seeds, in both laboratory and field conditions. Sodium alginate is a naturally occurring polysaccharide with a linear structure known for its biodegradability, biocompatibility, and safety, providing strength, flexibility, and water retention abilities (Goh *et al*., 2012; Fertah *et al*., 2017). Moreover, its anionic polymer properties effectively interact with fats, proteins, and other polymers, readily dissolving in water (Frent *et al*., 2022). When used at a concentration of 0.2 w/v, it efficiently regulates moisture and air conditions, making it highly suitable for seed germination processes compared to other polymers and concentrations.

When considering seedling growth, it is evident that coating with 0.2 w/v sodium alginate still results in higher shoot and root lengths compared to other methods, indicating that sodium alginate does not adversely affect the shoot and root elongation of tomato seedlings. Sodium alginate, derived from seaweed, is a polymer containing sodium that exhibits favorable properties, aiding in adjusting the pH of the coating solution effectively and assisting in the dilution process and gel formation, making the coating flexible and able to control moisture absorption well (Fernando *et al*., 2010; Frent *et al*., 2022). However, upon overall assessment of the changes in seedling growth, it was found that all six types of polymers did not significantly impede seedling growth when examined under both laboratory and greenhouse conditions. Nonetheless, significant impacts may occur when combined with active substances, which should be explored in future studies for subsequent applications.

The properties of a coating substance can change depending on how it is prepared, stored, and applied. Improper storage conditions can adversely affect the physical characteristics of seed coatings, leading to the deterioration of coating quality and making them unsuitable for effective use in coating seeds. Additionally, it may cause the coating material to decay, negatively impacting the seed quality.

This study's findings indicated that coating seeds with 0.2% w/v sodium alginate yields physical properties similar to other coating substances. When tested for seed quality, tomato seeds coated with sodium alginate showed a significantly higher radicle emergence percentage, speed of radicle emergence, germination rate, speed of germination, shoot length, and root length compared to non-coated seeds. Therefore, sodium alginate at a concentration of 0.2% w/v is suitable for coating tomato seeds.

Acknowledgements

We would like to thank The National Research Council of Thailand (NRCT), for the financial support for this research. This project was conducting under the Research and Researcher for industries (RRI) project, 2022, [grant number: N41A650733]. The author would like to offer particular thanks to the Division of Agronomy, Faculty of Agricultural Production, Maejo University for materials and the use of laboratories and research sites.

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(Received: 10 April 2024, Revised: 7 November 2024, Accepted: 8 November 2024)