วารสารแก่นเกษตร
THAIJO

Content List Available at ThaiJo

Khon Kaen Agriculture Journal

Journal Home Page : https://li01.tci-thaijo.org/index.php/agkasetkaj

The effect of seed coating with different plant nutrient formulations on seed quality of tomato (*Lycopersicon esculentum*) seeds during storage

Kittiwan Klarod[1], Anoma Dongsansuk[1] and Boonmee Siri[1]*

[1] *Department of Agronomy, Faculty of Agriculture, Khon Kaen University, Khon Kaen 40002, Thailand*

ABSTRACT: Coating tomato seeds with plant nutrients can stimulate seed germination and seedling growth. However, there are few reports on shelf life after seeds are coated with plant nutrients. The good condition of seed storage is useful through increasing longevity and providing high seed quality. Therefore, this research aimed to study 6-month seed longevity after tomato seeds were coated in different ways. Tomato seeds were coated with different plant nutrient formulations (PNF) containing N, P, K, Ca, Mg, Fe, B, Mn, Cu and Zn. The five seed treatments were as follows: (1) uncoated seeds as a control (C), (2) Only polymer coated the seeds (PF0), seeds coated with a polymer mixture with a plant nutrition formulation (PNF) including (3) 1-fold PNF(PF1), (4) 4-fold PNF(PF4) and (5) 16-fold PNF(PF16). The coating polymer was 3% PVP-K90 and 1% PEG 6000 and it was used at the rate of 200 ml per kg in each treatment. All treatments were stored in a controlled chamber at 15°C with 50% RH and ambient conditions at room temperature and relative humidity for 6 months. Every 3 months all treatments were tested for percentage of seed germination, speed of seedling emergence, seedling length and seedling dry weight tested in laboratory and greenhouse. The results showed that in both storage methods, the percentage of seed germination of PF4 and PF16 tested in the laboratory were higher than control. The root length of PF16 seedlings was affected by high acidity in both conditions, but it stimulated shoot length resulting in the highest in total seedling length tested in the laboratory. Both of all storage methods and test conditions seedling dry weight were increased with increased PNF concentrations. All treatments stored in a controlled chamber for 6 months exhibited higher seed quality than ambient conditions, indicated by the percentage of seed germination and speed of seedling emergence tested in both conditions.

Keywords: coated tomato seed; longevity of tomato seed; plant nutrient; deterioration; seed quality

Introduction

One of the most popular plants is tomato (*Lycopersicon esculentum* Mill) because it is a basic ingredient in a large diversity of fresh and cooked foods. As the demand for tomato consumption increases there is an increase in tomato planting for seed production. In 2020, the Seed Association of Thailand (2021) reported that Thailand is a major tomato seed producing country, exporting tomato seeds ranking number one in monetary terms (1,266 million Baht) as well as by export quantity (43.5 tons). Seed is the starting factor for plant production. Therefore, post-harvest, reconditioning and seed storage processes are very important to the seed production system. Proper seed management ensures high quality seeds and successful crop production. Thailand is an important seed producer in Southeast Asia. There are several research organizations conducting researches to improve seed quality and prevent disease infection and insect infestation before seeds are sold.

---

* Corresponding author: boonmee@kku.ac.th

Received: date; March 2, 2022 Accepted: date; March 28, 2023 Published: date;

After harvesting and processing the seed, seed companies store the seed or collect to sell to farmers. Therefore, the proper storage of seeds affects long-term preservation of seeds and their quality. Many researchers reported that the speed of seed deterioration increased greatly depending on seed moisture content, storage temperature and relative humidity (RH), time of storage, types of seed and initial seed quality (Abdalla and Roberts, 1969; Yin et al., 2000; Hung et al., 2001; Amjad and Anjum, 2002). Temperature and moisture content in the storage place are the most important factors affecting seed longevity, but moisture content within the seed is usually more influential than temperature (Ellis et al., 1985). Alhamdan et al. (2011) reported that four kinds of vegetable seeds; carrot (*Daucus carota* L. cv. Nantes 2-Tito), cucumber (*Cucumis sativus* L. cv. Special), onion (*Alium cepa* L. cv. Red Creole) and tomato (*Lycopersicon esculentum* Mill. cv. Tanshet Star) showed significant differences in seed vigor after storing in different storage temperature and RH conditions. They revealed that seeds stored at 35°C showed faster seed deterioration than at the low temperatures (5 and 15°C) and at the higher RH levels (75 and 84%) they showed a decrease in seed quality evident by reducing seed germination and average germination time.

Klarod et al. (2021) reported that coating seed with plant nutrients increased tomato seedling emergence and growth. Moreover, there were several reported indicating that the coating tomato seed with various active ingredients such as fluorescent substances (Sikhao et al., 2014) and plant hormones (Klarod, 2016) can help extending it shelf life. Unfortunately, the effect of plant nutrient coating on tomato-seed shelf life have not yet reported. Therefore, this experiment was conducted to study the quality of tomato seeds coated with plant nutrients during 6 months in storage so as to investigate the effect of plant nutrient coating on the longevity of tomato seeds.

Material and Methods

This study was carried out at the Seed Processing Plant, Department of Agronomy, Faculty of Agriculture, Khon Kaen University, Khon Kaen, Thailand. The experiment was conducted during October 2018 and March 2019 and tomato seeds cv. SPP58-3 hybrid (A.G. Universal Seed Company, Khon Kaen, Thailand) were used as the seed material.

Seed coating treatments

The formulation for seed coating was prepared by using polymer solution comprising 3% (wt/v) of polyvinyl pyrrolidone K90 (PVP-K90; ISP Technologies Wayne NJ), 1% (wt/v) of polyethylene glycol 6000 (PEG 6000; Ajax Finechem Pty, Ltd., Auckland, New Zealand), 3% (wt/v) of titanium dioxide, 1% (wt/v) iriodin (Merck Ltd., Bangkok, Thailand) and 1.5% (wt/v) of red food coloring (Adinop Co. Ltd., Bangkok, Thailand). All tomato seeds were coated with this polymer solution at a rate of 200 ml per kg of seeds. There were five seed coating treatments **(Table 1)**: (1) uncoated seeds as a control (C); (2) seeds coated with only polymer (PF0); and seeds coated with polymer at (3) 1-fold, (4) 4-fold and (5) 16-fold of PNF (PF1, PF4 and PF16, respectively). The coated seeds were prepared using a Centricoater model SKK10 (Seeds Processing Plant, Khon Kaen University, Thailand).

The pH value of plant nutrient seed coating substance determination

All of seed coating substances were investigated for pH value in each treatment at 0, 3 and 6 months after storing. This pH value was investigated using a pH meter (Model HI 98103, Hanna Instruments, Inc., Rhode Island, USA) at room temperature.

Seed samples of 5 grams of all coating treatments were packaged in aluminum foil bags and held in storage for six months in a controlled chamber (15°C and 50% RH) and an ambient condition (non-air conditioned room).

After the seed coating process, coated seeds were dried using a seed dryer [Model SKK09 (Seeds Processing Plant, Khon Kaen University, Thailand), at 35°C to reduce seed moisture content to 7% (FW). Seed samples were taken from all seed treatments for seed quality determination and seedling growth for every 3 months.

Determination of seed germination and speed of seedling emergence

Seed quality by percentage of seed germination and speed of seedling emergence was evaluated for each method. Seedling growth was recorded by shoot and root length, total seedling length and seedling dry weight.

Three replicates of 100 seeds from each treatment were investigated for seed germination in laboratory. seeds were placed between two wet papers in Petri dishes and incubated in a germination chamber with a temperature of 30°C/25°C (16 hours day/ 8 hours night). Seed emergence under greenhouse conditions was determined by sowing seeds in well-prepared peat moss (Klasmann-Deilmann GmbH, Ltd., Germany) in 340×340×60 mm seed trays (52 round cells per sheet). The percentage of normal seedlings was evaluated at 5 (first count) and 14 (final count) days after sowing and calculated according by ISTA rule (2013). Seedling emergence was recorded daily from the first count at 5 days to the final count at 14 days after sowing. Speed of seedling emergence (seedlings/day) was calculated according to equation (1) (AOSA, 1983):

$$\begin{array}{l}\text{Speed of seedling emergence}\\ \text{(seedlings /day)}\end{array} = \frac{\text{No. of normal seedlings}}{\text{Days to first count}} + \ldots + \frac{\text{No. of normal seedlings}}{\text{Days to final count}} \quad \text{.....(1)}$$

Table 1 The contents of plant nutrients formulation (PNF) used in tomato seed coating treatments PF0, PF1, PF4 and PF16

Nutrients	Plant nutrient content (mol dm^{-3})				
	Control	PF0	PF1	PF4	PF16
K_2SO_4	0	0	0.5	2	8
$Ca(NO_3)_2$	0	0	2.5	10	40
KH_2PO_4	0	0	0.05	0.2	0.8
$MgSO_4$	0	0	0.3	1.2	4.8
KCl	0	0	0.05	0.2	0.8
FeEDTA	0	0	0.05	0.2	0.8
H_3BO_3	0	0	0.005	0.02	0.08
$MnSO_4 \bullet 4H_2O$	0	0	2.5×10^{-4}	1×10^{-3}	4×10^{-3}
$CuSO_4 \bullet 5H_2O$	0	0	5×10^{-5}	2×10^{-4}	8×10^{-4}
$ZnSO_4 \bullet 7H_2O$	0	0	1.5×10^{-4}	6×10^{-4}	2.4×10^{-3}
$(NH_4)6Mo_7O_{24} \bullet H_2O$	0	0	2.5×10^{-6}	1×10^{-5}	4×10^{-5}
pH of plant nutrient	0	7.43	3.56	2.77	2.03

Determination of seedling growth

Seedling growth tested in the laboratory was assessed by the length of shoot, root and total (shoot plus root) of normal seedlings. Three replicates of 100 seeds from each treatment were incubated between two wet papers in a box (110×110×65 mm) and then 10 seedlings from each replicate were randomly collected at 14-days after sowing (DAS) to measure shoot and root length.

Seedling dry weight was determined for seedlings grown under laboratory conditions. One hundred normal seedlings from each treatment with three replicates were dried in an oven at 80°C for 72 hours and weighed at room temperature (Klarod, 2016).

Statistical analysis

The experiment was run in completely randomized design (CRD) with 3 replications. Three replicates were used for assessing seed germination percentage and speed of seedling emergence in laboratory and greenhouse conditions. Data were analyzed by one-way ANOVA and the significance of the differences between means at $P<0.05$ was determined by the Least-Significant Difference (LSD) test. The seed germination percentage data were arcsin-transformed prior to be subjected to the analysis of variance (ANOVA). ANOVA of seed germination percentage, speed of seedling emergence and seedling growth was performed by using SAS 9.4 statistical software.

Results and discussion

The changes in seed germination after seed coating

After coating the seeds with plant nutrients, each treatment was tested for the quality of the seeds and they were wrapped in aluminum foil bags. The seeds were assessed after storing under controlled and ambient conditions for month 6th.

Table 2 Seed germination percentage under laboratory and greenhouse conditions of tomato seed coated with plant nutrients and stored under different storage conditions for 6 months

Treatments	Germination (%)					
	Laboratory			Greenhouse		
	storage period (months)			storage period (months)		
	0	3	6	0	3	6
Controlled condition						
Control	87 $^{c\,1/}$ (0)$^{2/}$	79 ^{c} (0)	79 ^{c} (0)	85 ^{c} (0)	77 (0)	57 ^{b} (0)
PF0	86 ^{c} (-1.15)	85 ^{bc} (+7.6)	86 ^{b} (+8.9)	89 ^{ab} (+4.7)	82 (+6.5)	68 ^{a} (+19.3)
PF1	90 ^{bc} (+3.45)	94 ^{a} (+18.9)	87 ^{ab} (+10.1)	88 ^{bc} (+3.5)	86 (+11.7)	73 ^{a} (+28.1)
PF4	94 ^{ab} (+8.05)	90 ^{ab} (+13.9)	91 ^{a} (+15.2)	90 ^{ab} (+5.9)	90 (+16.9)	70 ^{a} (+22.8)
PF16	96 ^{a} (+10.34)	92 ^{a} (+16.4)	91 ^{a} (+15.2)	92 ^{a} (+8.2)	87 (+13.0)	74 ^{a} (+29.8)
Mean	90.6	88.0	86.8	88.8	84.4	68.4
F-test	**	**	**	**	ns	**
c.v. (%)	0.356	0.397	0.304	0.226	0.801	0.403
Ambient condition						
Control	87 ^{c} (0)$^{2/}$	77 ^{b} (0)	72 ^{c} (0)	85 ^{c} (0)	83 (0)	54 ^{b} (0)
PF0	86 ^{c} (-1.15)	87 ^{a} (+12.9)	79 ^{b} (+9.7)	89 ^{ab} (+4.7)	82 (-1.2)	72 ^{a} (+33.3)
PF1	90 ^{bc} (+3.45)	85 ^{a} (+10.4)	82 ^{ab} (+13.9)	88 ^{bc} (+3.5)	83 (0.0)	68 ^{a} (+25.9)
PF4	94 ^{ab} (+8.05)	85 ^{a} (+10.4)	85 ^{a} (+18.1)	90 ^{ab} (+5.9)	88 (+6.0)	70 ^{a} (+29.6)
PF16	96 ^{a} (+10.34)	83 ^{a} (+7.8)	84 ^{ab} (+16.7)	92 ^{a} (+8.2)	92 (+10.8)	69 ^{a} (+27.8)
Mean	90.6	83.4	80.4	88.8	85.6	66.6
F-test	**	*	**	**	ns	**
C.V. (%)	0.356	0.366	0.304	0.226	0.555	0.442

$^{1/}$ ns, *, ** mean non-significant and significantly different at $P \leq 0.05$ and $P \leq 0.01$, respectively, between different treatments. The same small letters in the same column show non-significant difference at $P \leq$ 0.05 by LSD.

Seed germination data were transformed using the arcsine transformation.

Coefficient of variation, CV. (%), is the percentage variation in the mean across treatments.

$^{2/}$ A number in parentheses refers to percentage of increment (+) and decrement (-) compared to the controlled seed.

The assessment for both storage conditions was done at three-month intervals and the germination percentages under laboratory and greenhouse conditions were tested, as well as the speed of seedlings emergence. After the seeds were stored in both conditions, it was found that there was a reduction in the seed quality with increased period of seed storage.

The coated seeds had increased seed germination percentage compared with the uncoated seeds in all periods of seed storage. This might be because the seed moisture vapor exchange rate was controlled by polyvinyl seed coating substance during storage period.

Polyvinyl is a major component of polyvinyl pyrrolidone K-90 (PVP-K90), which is able to close the micropyle cavity, a tiny hole in the seed Since, these holes with small size can enhance water absorption from air into seed due to the increase of the capillary force. (West et al., 1985).

Coating seeds with plant nutrient formulation (PNFs) enhanced the percentage of seed germination about 3-10% with increased concentrations of PNF. Under laboratory condition, after being stored for three months, seeds coated with all of the PNFs had germination percentage significantly higher than the uncoated seed and were higher than 90%. Stowing the seed under controlled condition shown that the PNFs displayed higher seed germination than uncoated seeds by approximately 13-18% and 10-15% at month 3rd and 6threspectively. At a part of under ambient condition seed storage indicated that the seed germination with PNFs were increase around 7-10% and 13-18% at month 3rd and 6th, respectively. The experiment concluded that the all PNFs showed a higher significant difference of seed germination after 6 months of seed storage **(Table 2)**.

Under greenhouse conditions, for seeds tested after 6 months storage, the results suggested that seed coating with all of the PNFs improved seed germination more than uncoated seeds by approximately 22-29%. (**Table 2)**. This result indicates that the tomato seeds were able to absorb plant nutrients coated on the seed surface by the seed imbibition process and during seed germination by radicle absorption of plant nutrients coated on the seed surface.

The seeds absorbed plant nutrients which were a component of the phytate (Klarod et al., 2021). After the seeds were harvested, the phytate content was reduced by period of seed storage. Likewise, Verma et al. (2003) found that the TDH activity in Brassica spp. seeds stored for four years showed decreased TDH (total dehydrogenase) activity during seed storage. Also, Singh et al. (2017) reported that dehydrogenase activity significantly decreased after seed storage.

The changes in speed of seedling emergence

The speed of seedling emergence was calculated from the daily count. The results indicate that the speed of seedling emergence was significantly different among the treatments during the period of seed storage. The speed of seedling emergent for all treatments showed the same trends of change as the seed germination results for the final period of seed storage. Overall, the results indicate that the speed of the seedling emergence decreased with an increase of seed storage time and its rate decreased faster than the rate of seed germination.

The results suggest that the seed vigor was reduced with an increase in seed storage time, as indicated by a reduction of the speed of seedling emergence **(Table 3)**. Under the controlled condition of seed storage, PF1 showed a faster speed of seedling emergence than uncoated seed under the laboratory conditions by approximately 43 and 21% at month 3rd and 6th, respectively. Under ambient conditions, all coated seed treatments showed a significant difference in the speed of seedling emergence compared to the uncoated seeds. This was observed under both the laboratory and greenhouse conditions. All seed coating treatments were able to germinate faster than uncoated seeds when stored for longer periods of time **(Table 3)**.

The speed of seedling emergence under greenhouse conditions tested after month 3rd and 6th in storage were slower than that of before storage due to the influence of different temperature.

seed storage in the month 3rd was tested for seed vigor in early January of 2019, which was the low temperature range of the province of Khon Kaen (17.0-22.0°C d.uring day-time, and 17.0-22.0°C during night-time), when the month 6th of seed storage was tested for seed vigor in late March with high temperatures (29.0-33.3°C during day-time, and 26.0-30.4°C during night-time) (Meteorological station, Khon Kaen University). For this reason, seeds tested in the 6th month were able to emergence faster or not significant difference in the 3rd month. In the other hand, seed germination percentage tested at month 6th was significantly decreased.

Khanobdee (1992) reported that the optimum temperature for germination and t growth was in the range of 20–35 °C., Hence, after 3 months in storage, seed quality was affected and declined. The maintenance of seed quality depended on the factors as follows: 1) initial seed quality, 2) seed moisture content, 3) temperature, 4) relative humidity, 5) packing material and 6) gas exchange (Barton, 1943; Vertucci and Roos, 1990, 1993). The highest quality seeds were at physiological maturity (Bewley and Black, 1994). Seed quality can decline over the period of seed storage. Seed quality deterioration rate varies with the environment of the seed storage (Delouche el al., 1973). Harrington (1972) demonstrated that increased temperature and relative humidity in seed storage systems led to rapid quality deterioration. Nasreen et al. (2000) and Schmidt (2007) reported that the storing seed at room temperature often resulted in poor seed germination, seed quality reduction and loss of viability during storage. Chauhan and Nautiyal (2007) found the seed stored of *Nardostachys jatamansi* DC. at room temperature (10-35°C) lost its viability rapidly, while the longevity of seed stored in a controlled environment at (-5 - 0°C) could be maintained for two years.

The results from this experiment suggested that seed storage under the controlled conditions showed higher seed germination and speed of seedling emergence than under the ambient conditions **(Table 2 and 3)**.

In both conditions of seed storage, it was found that there was a decrease in seed germination and speed of germination as the period of seed storage increased **(Table 2 and 3)**. The findings indicate that during a prolonged period of seed storage, a decrease in seed quality may cause by a decrease in metabolism, enzyme activity, and storage reserves (Verma et al., 2003). Klarod (2021) studied the vigor of seeds coated with plant nutrient by accelerated aging method. Which was found that seed quality decreased with time of accelerated aging, and the nutrient-coated seed was stronger than uncoated seed. In addition, the seeds coated with plant nutrients-maintained dehydrogenase activity strongly, which could be stimulated the seed germination process.

Table 3 Speed of seedling emergence under laboratory and greenhouse conditions of tomato seed coated with plant nutrients and stored under different storage conditions for 6 months

Treatments	Speed of seedling emergence (seedlings /day)					
	Laboratory			Greenhouse		
	storage period (months)			storage period (months)		
	0	3	6	0	3	6
Controlled condition						
Control	12.77 ^{bc}[1/] (0)[2/]	10.38 ^{c} (0)	9.44 ^{c} (0)	9.63 (0)	7.48 (0)	5.59 ^{c} (0)
PF0	12.27 ^{c} (-3.9)	12.17 ^{b} (+17.2)	10.17 ^{bc} (+7.7).	9.98 (+3.6)	7.69 (+2.8)	7.52 ^{b} (+34.5)
PF1	13.15 ^{bc} (+3.0)	14.85 ^{a} (+43.1)	11.49 ^{a} (+21.7)	9.65 (+0.2)	8.13 (+8.7)	8.67 ^{a} (+55.1)
PF4	14.12 ^{a} (+10.6)	13.53 ^{ab} (+30.3)	10.73 ^{ab} (+13.7)	9.80 (+1.8)	8.63 (+15.4)	7.83 ^{b} (+40.1)
PF16	13.28 ^{ab} (+4.0)	12.35 ^{b} (+19.0)	9.91 ^{bc} (+5.0)	10.3 (+7.0)	8.42 (+12.6)	8.27 ^{ab} (+47.9)
Mean	13.12	12.66	10.35	9.87	8.07	7.58
F-test	**	**	**	ns	ns	**
c.v. (%)	3.61	7.52	5.17	3.52	8.80	6.07
Ambient condition						
Control	12.77 ^{bc} (0)[2/]	10.36 (0)	7.47 ^{b} (0)	9.63 (0)	7.23 ^{b} (0)	5.47 ^{c} (0)
PF0	12.27 ^{c} (-3.9)	10.49 (+1.3)	8.27 ^{a} (+10.7)	9.98 (+3.6)	7.17 ^{b} (-0.8)	7.51 ^{a} (+37.3)
PF1	13.15 ^{bc} (+3.0)	11.14 (+7.5)	8.59 ^{a} (+15.0)	9.65 (+0.2)	7.13 ^{b} (-1.4)	6.81 ^{b} (+24.5)
PF4	14.12 ^{a} (+10.6)	12.26 (+18.3)	8.85 ^{a} (+18.5)	9.80 (+1.8)	7.32 ^{b} (+1.2)	7.23 ^{a} (+32.2)
PF16	13.28 ^{ab} (+4.0)	10.01 (-3.4)	8.48 ^{a} (+13.5)	10.3 (+7.0)	8.13 ^{a} (+12.4)	7.48 ^{a} (+36.7)
Mean	13.12	10.85	8.33	9.87	7.40	6.90
F-test	**	ns	*	ns	*	**
C.V. (%)	3.61	7.98	4.8	3.52	4.91	4.71

[1/] ns, *, ** mean non-significant and significantly different at $P \leq 0.05$ and $P \leq 0.01$, respectively, between different treatments. The same small letters in the same column show non-significant difference at $P \leq 0.05$ by LSD.

Seed germination data were transformed using the arcsine transformation.

Coefficient of variation, CV. (%), is the percentage variation in the mean across treatments.

[2/] A number in parentheses refers to percentage of increment (+) and decrement (-) compared to the controlled seed.

Seed storage under low seed moisture content (6-7%), low temperature and low relative humidity (15°C, 50% RH) could preserve for 1-5 years (Duangphattra, 1986). Korkasetwit et al. (2008) reported that storing maize seed in a controlled condition (15°C and 50% RH) can maintain the seed germination percentage above 80% after months 4th in storage. Bhardwaj et al. (2014) studied the influence of temperature and storage time on the quality of *Rheum austral* seeds and found that the germination percentage of seed stored at room temperature was lower than that of under a controlled temperature -50°C. Temperature has a strong effect on the activity of enzymes in various physiological and biochemical processes, since high temperature accelerates the respiration process.

Effect of seed coating with plant nutrient formulation on seedling growth

Seedling growth was tested after coating and storing seeds for month 3rd and 6th. The results indicate that seed coating with all of the PNFs improved seedling growth over uncoated seeds before and after storing for both controlled and ambient conditions.

These results found that for the month 3rd and 6th of seed storage under the controlled conditions, PF16 displayed a shorter root length but longer shoot length than other the treatments, when tested under the laboratory conditions. The PF16 gave approximately 8.4-8.8 cm of root length for all period of seed storage under the controlled conditions **(Table 4)**.

Table 4 Shoot and root length at 14 Day after sowing (DAS) tested under laboratory conditions of tomato seed coated with plant nutrients stored under different storage conditions for 6 months

Treatments	Seedling length											
	Root length (cm)						Shoot length (cm)					
	storage period (months)						storage period (months)					
	0		3		6		0		3		6	
Controlled condition												
Control	10.5	(0) $^{2/}$	10.4 $^{a1/}$	(0) $^{2/}$	9.2 ^{ab}	(0)	5.4 ^{c}	(0)	5.7 ^{d}	(0)	6.1 ^{c}	(0)
PF0	9.9	(-5.7)	10.3 ^{a}	(-0.9)	9.4 ^{a}	(+2.2)	5.2 ^{c}	(-3.7)	6.0 ^{d}	(+5.3)	5.9 ^{d}	(-3.3)
PF1	10.8	(+2.9)	10.8 ^{a}	(+3.8)	9.4 ^{a}	(+2.2)	6.8 ^{b}	(+25.9)	6.9 ^{c}	(+21.1)	7.3 ^{c}	(+19.7)
PF4	9.9	(-5.7)	10.2 ^{a}	(-1.9)	9.5 ^{a}	(+3.3)	7.4 ^{b}	(+37.0)	8.1 ^{b}	(+42.1)	8.8 ^{b}	(+44.3)
PF16	8.6	(-18.1)	8.4 ^{b}	(-19.2)	8.8 ^{b}	(-4.3)	8.8 ^{a}	(+62.9)	8.9 ^{a}	(+56.1)	9.8 ^{a}	(+60.7)
Mean	9.94		10.02		9.26		6.72		7.12		7.58	
F-test	ns		*		*		**		*		**	
c.v. (%)	6.33		5.48		2.57		4.47		4.02		3.65	
Ambient condition												
Control	10.5	(0)	8.9	(0)	7.4 ^{b}	(0)	5.4 ^{c}	(0)	6.6 ^{c}	(0)	6.5 ^{d}	(0)
PF0	9.9	(-5.7)	8.5	(-4.5)	7.5 ^{b}	(+1.4)	5.2 ^{c}	(-3.7)	6.5 ^{c}	(-1.5)	6.9 ^{d}	(+6.2)
PF1	10.8	(+2.9)	10.2	(+14.6)	9.5 ^{a}	(+28.4)	6.8 ^{b}	(+25.9)	6.8 ^{c}	(+3.0)	7.7 ^{c}	(+18.5)
PF4	9.9	(-5.7)	8.5	(-4.5)	9.1 ^{a}	(+22.9)	7.4 ^{b}	(+37.0)	7.7 ^{b}	(+16.7)	8.6 ^{b}	(+32.3)
PF16	8.6	(-18.1)	7.7	(-13.5)	7.6 ^{b}	(+2.7)	8.8 ^{a}	(+62.9)	8.9 ^{a}	(+34.6)	9.6 ^{a}	(+47.7)
Mean	9.94		8.76		8.22		6.72		7.3		7.86	
F-test	ns		ns		*		**		**		**	
C.V. (%)	6.33		7.93		3.93		4.47		4.32		3.57	

[1/] ns, *, ** mean non-significant and significantly different at $P \leq 0.05$ and $P \leq 0.01$, respectively, between different treatments. The same small letter in the same column shows non-significant difference at $P \leq 0.05$ by LSD.

Seed germination data were transformed using the arcsine transformation.

Coefficient of variation, CV. (%), is the percentage variation in the mean across treatments.

[2/] A number in parentheses refers to the percentage of increment (+) and decrement (**-**) compared to the controlled seed.

For the seed stored under the ambient conditions, it was found that seeds coated with PF1 and PF4 displayed a longer root length than the other treatments after the seeds were stored for months 6th. In addition, seeds coated with PF16 still showed the longest shoot length over the period of seed storage (months 0-6th) and were significantly different from other treatments. The uncoated seeds and seeds coated with only the polymer (PF0) showed lower shoot length compared to seeds coated with plant nutrient formulations (PF1, PF4 and PF16).

Table 5 Seedling length and seedling dry weight at 14 Day after sowing (DAS) tested under laboratory conditions tested of tomato seed coated with plant nutrients and stored under different storage conditions for 6 months

Treatments	Seedling length											
	Seedling length (cm)						Seedling dry weight (g)					
	storage period (months)						storage period (months)					
	0		3		6		0		3		6	
Controlled condition												
Control	15.9 $^{b1/}$	(0)$^{2/}$	16.1 ^{b}	(0)	15.3 ^{c}	(0)	0.522 ^{bc}	(0)	0.503 ^{b}	(0)	0.577 ^{b}	(0)
PF0	15.1 ^{b}	(-5.0)	16.3 ^{b}	(+1.2)	15.3 ^{c}	(0)	0.494 ^{c}	(-5.4)	0.504 ^{b}	(+0.2)	0.557 ^{b}	(-3.5)
PF1	17.6 ^{a}	(+10.7)	17.7 ^{a}	(+9.9)	16.7 ^{b}	(+9.2)	0.498 ^{c}	(-4.6)	0.605 ^{ab}	(+20.3)	0.670 ^{a}	(+16.1)
PF4	17.3 ^{a}	(+8.8)	18.3 ^{a}	(+13.7)	18.3 ^{a}	(+19.6)	0.557 ^{ab}	(+6.7)	0.593 ^{ab}	(+17.9)	0.653 ^{a}	(+13.2)
PF16	17.4 ^{a}	(+9.4)	17.3 ^{a}	(+7.5)	18.6 ^{a}	(+21.6)	0.573 ^{a}	(+9.8)	0.693 ^{a}	(+37.8)	0.680 ^{a}	(+17.9)
Mean	16.66		17.14		16.84		0.529		0.579		0.627	
F-test	ns		*		**		*		*		**	
c.v. (%)	6.33		4.96		2.73		3.52		7.18		4.277	
Ambient condition												
Control	15.9 ^{b}	(0)	15.5 ^{c}	(0)	13.9 ^{b}	(0)	0.522 ^{bc}	(0)	0.445	(0)	0.318 ^{b}	(0)
PF0	15.1 ^{b}	(-5.0)	15.0 ^{c}	(-3.2)	14.4 ^{b}	(+3.6)	0.494 ^{c}	(-5.4)	0.510	(+14.6)	0.310 ^{b}	(-2.5)
PF1	17.6 ^{a}	(+10.7)	17.0 ^{a}	(+9.7)	17.2 ^{a}	(+23.7)	0.498 ^{c}	(-4.6)	0.520	(+16.9)	0.303 ^{b}	(-4.7)
PF4	17.3 ^{a}	(+8.8)	16.2 ^{b}	(+4.5)	17.7 ^{a}	(+27.3)	0.557 ^{ab}	(+6.7)	0.490	(+10.1)	0.413 ^{a}	(+29.9)
PF16	17.4 ^{a}	(+9.4)	16.6 ^{b}	(+7.1)	17.2 ^{a}	(+23.7)	0.573 ^{a}	(+9.8)	0.530	(+19.1)	0.420 ^{a}	(+32.1)
Mean	16.66		16.06		16.08		0.529		0.490		0.353	
F-test	*		*		**		*		ns		**	
C.V. (%)	5.42		3.37		3.32		3.52		6.00		8.759	

[1/] ns, *, ** mean non-significant and significantly different at $P \leq 0.05$ and $P \leq 0.01$, respectively, between different treatments. The same small letters in the same column showed non-significant difference at $P \leq 0.05$ by LSD.

Seed germination data were transformed using the arcsine transformation.

Coefficient of variation, CV. (%), is the percentage variation in the mean across treatments.

[2/] A number in parentheses refers to the percentage of increment (+) and decrement (-) compared to the control seeds.

The results of the seedling length (sum of root and shoot length) showed that all seeds coated with the PNFs (PF1-PF16) had a higher total seedling length than that of uncoated seeds and PF0 under laboratory and greenhouse conditions for the whole period of seed storage **(Table 5)**. After month 6th in seed storage, the controlled condition tested found that the PNFs had a higher seedling dry weight than PF0 and uncoated seed. In Ambient condition tested indicated that PF4 and PF16 shown higher seedling dry weight than other treatment **(Table 5)**.

The noticeable reduction of seedling dry weight with an increase of storage time was observed for all seed coating treatments under ambient storing condition **(Table 5)**.

Before storing seeds, the coated seeds with all concentrations of PNF showed a higher seedling length than the seeds coated with PF0 and uncoated seeds. After month 3rd in seed storage under greenhouse conditions, the coated seeds with PF16 showed longer seedling length and was significantly different compared to the uncoated seeds and seeds coated with PF0. In addition, PF16 showed the longest seedling length among all treatments after month 6th of seed storage **(Table 6)**.

All concentrations of the PNFs showed a higher total seedling length tested under greenhouse condition after month 3rd in seed storage than under ambient conditions. After month 6th of seed storage, the seeds showed no significant difference in total seedling length among treatments.

throughout the period of 6 months of seed storage showed the higher seedling dry weight of PNFs compared to other treatments for the stored seeds under both controlled and ambient conditions **(Table 6)**. this experiment can be said that the storage period has no effect on the growth of seedlings, but providing plant nutrients resulted in seedlings being able to grow better.

Table 6 Seedling length and seedling dry weight at 14 Day after sowing (DAS) tested under greenhouse conditions tested for tomato seeds coated with plant nutrients after coating and storage periods under different storage conditions for 6 months

Treatments	Seedling length											
	Total seedling length (cm)						Seedling dry weight (g)					
	storage period (months)						storage period (months)					
	0		3		6		0		3		6	
Controlled condition												
Control	13.8 ^{b}[1/]	(0)[2/]	8.6 ^{bc}	(0)	8.91 ^{c}	(0)	5.42 ^{c}	(0)	5.65 ^{d}	(0)	6.14 ^{c}	(0)
PF0	13.7 ^{b}	(-0.7)	8.2 ^{c}	(-4.7)	8.90 ^{c}	(-0.1)	5.29 ^{c}	(-2.4)	6.04 ^{d}	(+6.9)	5.97 ^{d}	(-2.8)
PF1	14.9 ^{a}	(+8.0)	9.1 ^{ab}	(+5.8)	9.43 ^{b}	(+5.8)	6.89 ^{b}	(+27.1)	6.99 ^{c}	(+23.7)	7.27 ^{c}	(+18.4)
PF4	15.1 ^{a}	(+9.4)	8.5 ^{bc}	(-1.2)	9.21 ^{b}	(+3.4)	7.42 ^{b}	(+36.9)	8.06 ^{b}	(+42.7)	8.79 ^{b}	(+43.2)
PF16	15.1 ^{a}	(+9.4)	9.4 ^{a}	(+9.3)	9.74 ^{a}	(+9.3)	8.88 ^{a}	(+63.8)	8.88 ^{a}	(+57.2)	9.84 ^{a}	(+60.3)
Mean	14.52		8.76		9.23		6.78		7.12		7.60	
F-test	*		*		**		**		*		**	
c.v. (%)	2.67		2.48		1.448		4.47		4.02		3.65	
Ambient condition												
Control	13.8 ^{b}	(0)	8.4 ^{b}	(0)	8.2	(0)	5.42 ^{c}	(0)	6.64 ^{c}	(0)	6.51 ^{d}	(0)
PF0	13.7 ^{b}	(-0.7)	8.5 ^{b}	(+1.2)	8.3	(+1.2)	5.29 ^{c}	(-2.4)	6.45 ^{c}	-2.9)	6.89 ^{d}	(+5.8)
PF1	14.9 ^{a}	(+8.0)	8.9 ^{a}	(+6.0)	8.4	(+2.4)	6.89 ^{b}	(+27.1)	6.76 ^{c}	(+1.8)	7.65 ^{c}	(+17.5)
PF4	15.1 ^{a}	(+9.4)	8.9 ^{a}	(+6.0)	8.3	(+1.2)	7.42 ^{b}	(+36.9)	7.69 ^{b}	(+15.8)	8.60 ^{b}	(+32.1)
PF16	15.1 ^{a}	(+9.4)	9.9 ^{a}	(+17.9)	8.7	(+6.1)	8.88 ^{a}	(+63.8)	8.87 ^{a}	(+33.6)	9.62 ^{a}	(+47.8)
Mean	14.52		8.92		8.38		6.78		7.28		7.85	
F-test	*		**		ns		**		**		**	
C.V. (%)	2.67		1.352		4.77		4.47		4.32		3.570	

[1/] ns, *, ** mean non-significant and significantly different at $P \leq 0.05$ and $P \leq 0.01$, respectively, between different treatments. The same small letters in the same column shows non-significant difference at $P \leq$ 0.05 by LSD.

Seed germination data were transformed using the arcsine transformation.

Coefficient of variation, CV. (%), is the percentage variation in the mean across treatments.

[2/] A number in parentheses refers to the percentage of increment (+) and decrement (-) compared to the control seeds.

The results of seedling growth **(Tables 4-6)** Indicates that coating tomato seeds with plant nutrients can stimulate seedling growth. This result was in line with Ros et al. (2000) and Sochorec and Knot (2012) who noted that the coating grass seed with phosphate and nitrogen stimulated seedling growth more than the control (uncoating) seeds. Bose and Mishra (1999) reported that *Brassica juncea* seed primed with calcium salts improved seedling growth by increasing the rate of cell division in the root tips. Nevertheless, in this study, it was found that the coating with PF16 negatively affected root length, but enhanced shoot growth and dry weight accumulation of the tomato seedlings. This might be because the PF16 had too high concentration of PNF, resulting in increased toxicity to the root. This result was supported by Kang et al. (2011), who noted that not only nutrient concentration but also pH value around the root, which was related with osmotic stress, and tomato seedlings had a tendency to reduce shoots more than roots against the stress.

The change of seed-coating substance pH

Seed coating substances were tested for their pH values every three months. The results indicate that the pH of PF0 (polymer only) remained unchanged during storage. The pH of PF1 decreased as storage time increased. In addition, PF4 and PF16 that their coating substance had acid property, the acidity gradually decreases over time in storage **(Figure 1)**. Kaewkham (2014) reported that the pH of seed coated with substances (PVP-k90) did not change after month 6th seed storage. After mixing with other active ingredients, the pH of the coating was more neutralized after month 6th seed storage (Sikhao, 2014). The pH of coating substance in this study (PF4 and PF16) shown high acidity and interfered the root elongation **(Table 4)**, which is consistent with the research of Arduini et al. (1998) reported that the pH value at 3.5-6.5 had an effect on root elongation rate by gradually decreasing with increased acidity.

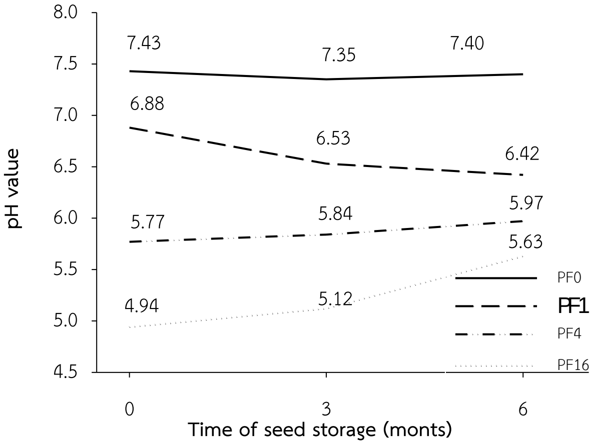

Figure 1 The pH value of seed coating substances after storing for six months

Conclusion

The seed coated with PF16 showed a higher seed germination percentage than uncoated by approximately 15.2% and 29.8% when tested under laboratory and greenhouse conditions, respectively. And the trend of seed germination capacity in PF16 was unchanged over the storage period compared to uncoated seeds. The PF1 seeds showed a higher speed of seedling emergence throughout the period of seed storage. In addition, coating tomato seeds with plant nutrient substance resulted in an increase of seedling dry weight with an increase of nutrient concentrations. Therefore, the coating seed with PF16 treatment gave the highest seed germination percentage and seedling growth for both after coating and during storage of seeds for 6 months.

In addition, the effect of coating on seed quality during storage were studied in two storage conditions. PF4 and PF14 shown the higher seed germination percentage and maintained more than 90% of seed germination after

6 months of storage under laboratory tested. In the growth test found that after 6 months of seed storage, seed coating with plant nutrients (PF16) has the highest growth and dry weight accumulation and seed coated with all of PNFs could improve seedling growth compared to uncoated seed.

Acknowledgements

We would like to thank the Research and Researchers for Industries (RRI) for the financial support for this research. We would also like to thank AG Universal Seed Company, Khon Kaen, Thailand for donating tomato seeds for this project. Thanks to the Seed Processing Plant, Faculty of Agriculture and Faculty of Pharmaceutical Sciences, Khon Kaen University, Thailand for laboratory facilities for this research.

References

Abdalla, F.H., and E.H. Roberts. 1969. The effect of seed storage conditions on the growth and yield of barley, broad beans and peas. Annals of Botany. 33: 169-184.

Alhamdan. A.M., A.A. Alsadon, S.O. Khalil, M.A. Wahb-Allah, M. El. Nagar, and A.A. Ibrahim. 2011. Influence of Storage Conditions on Seed Quality and Longevity of Four Vegetable Crops. American-Eurasian Journal of Agricultural and Environmental Sciences. 11(3): 353-359.

Amjad, M., and M.A. Anjum. 2002. Effect of relative humidity and ageing period on the quality of onion seed. International Journal Agriculture Biology. 4(2): 291-296.

Arduini, I., C. Kettner, D.L. Godbold, A. Onnis, and A. Stefani. 1998. pH influence on root growth and nutrient uptake of Pinus pinaster seedlings. Chemosphere. 36: 733-738.

Association of Official Seed Analysts (AOSA). 1983. Seed Vigor Testing Handbook on Seed Testing. Association of Official Seed Analysis.

Barton, L.V. 1943. Effect of moisture fluctuations on the viability of seeds in storage. Boyce Thompson institute plant research. 13: 35–45.

Bewley, J.D., and M. Black. 1994. Seeds: Physiology of Development and Germination, 2 Ed. New York, Plenum Press.

Bhardwaj R., M. SOOD, and U. Thakur. 2014. Effect of storage temperature and period on seed germination of *Rheum australe* D Don: an endangered medicinal herb of high-altitude Himalaya. International Journal of Farm Sciences. 4(2): 139-147.

Bose, B., and T. Mishra. 1999. Influence of pre-sowing soaking treatment in *Brassica juncea* seeds with Mg salt on growth, nitrate reductase activity, total protein content and yield responses. Physiology and Molecular Biology of Plants. 5: 83-88.

Chauhan, R. S., and M. C. Nautiyal. 2007. Seed germination and seed storage behaviour of Nardostachys jatamansi DC., an endangered medicinal herb of high-altitude Himalaya. Current Science. 92(11): 1620-1624.

Delouche, J.C., R.K. Mathes, G.M. Dougherty, and A.H. Boyde. 1973. Storage of seeds in subtropical and tropical regions. Seed Science and Technology. 1: 671-700.

Duangphattra, C. 1986. Seed Technology. Department of Agronomy, Faculty of Agriculture, Kasetsart University. Bangkok.

Ellis, R.H., T.D. Hong, and E.H. Roberts. 1985. Handbook of Seed Technology for Genebanks, Vol. I. Principle and Methodology. International Board for Plant Genetic Resources, Rome.

Harrington, J.F. 1972. Seed storage and longevity. In Kozlowski, T.T. (Ed.), Seed biology. 3: 145-245.

Hung, L.Q., T.D. Hong, and R.H. Ellis. 2001. Constant, fluctuating and effect temperature and seed longevity: a Tomato *Lycopersicon esculentum* Mill. Exemplar. Annals of Botany. 88(3): 465-470.

ISTA. 2013. International Rules for Seed Testing. Seed Science and Technology. Glattbrugg, Switzerland.

Klarod, K. 2016. Effects of Seed Coating Formulas with Plant Hormones on Seed Quality and Storability of Tomato Seed. Master of Science Thesis in Agronomy, Graduate School, Khon Kaen University.

Kang, Y.I., J.M. Park. S.H. Kim, N.J. Kang, K.S. Park, S.Y. Lee, and B.R. Jeong. 2011. Effects of root zone pH and nutrient concentration on the growth and nutrient uptake of tomato seedlings. Journal of Plant Nutrition. 34(5): 640-652.

Kaewkham, T. 2014. Development of Seed Coating Formulations for Control Gummy Stem Blight (Didymella bryoniae) in Hybrid Cucumber Seed. Doctor of Philosophy Thesis in Agronomy, Graduate School, Khon Kaen University.

Khanobdee, J. 1992. Vegetable seed production. Odeon Store Publishing House, Bangkok.

Klarod, K., A. Dongsansuk, H.P. Piepho, and B. Siri. 2021. Seed coating with plant nutrients enhances germination and seedling growth, and promotes total dehydrogenase activity during seed germination in tomato *(Lycopersicon esculentum).* Seed Science and Technology. 49(2): 107-124.

Korkasetwit, S., P. Chitropas, and B. Siri. 2008. Effect of coating substance on coating characterization and quality of super sweet corn seed. Thai Journal of Agricultural Science. 39(3): 218-221.

Nasreen S, B.R. Khan, and A.S. Mohmad. 2000. The effect of storage temperature, storage period and seed moisture content on seed viability of soyabean. Pakistan Journal of Biological Science. 3(12): 2003-2004.

Ros, C., R.W. Bell, and P.F. White. 2000. Phosphorus seed coating and soaking for improving seedling growth of *Oryza sativa* (rice) cv. IR66. Seed Science and Technology. 28(2): 391-401.

Schmidt, L. 2007. Seed storage. In: Oel en, K. (ed). Guide to handling of tropical and subtropical forest seed. Humlebaek, Dinamerca: Danida Forest Seed Centre. 2000: 225-254.

Seed Association of Thailand. 2021. Statistical data on imports, exports, controlled seeds. Retrieved from Formathttps://thasta.com/statistics/statistics/. On Jan. 25, 2021.

Sikhao, P. 2014. Effects of Seed Coating by Polymer with fluorescent Compound on Cucumber Seed Quality. Doctor of Philosophy Thesis in Agronomy, Graduate School, Khon Kaen University.

Sikhao P., P. Teerapornchaisit, A.G. Taylor, and B. Siri. 2014. Seed coating with riboflavin, a natural fluorescent compound, for authentication of cucumber seeds. Seed Science and Technology. 42: 171-179.

Singh, D.K., V. Kumar, S.K. Tehlan, and V.S. Mor. 2017. Evalution of biochemical changes associated with seed quality under naturally stored conditions in fennel. International Journal of Chemical Studies. 5: 1800-1803.

Sochorec, M., and P. Knot. 2012. The effect of fertilizer seed coating on the germinating capacity and initial development of some turf grass species and white clover. Acta Universitatis Agriculturae Et Silviculturae endelianae Brunensis. 5: 199-204.

Verma, S.S., U. Verma, and R.P.S. Tomer. 2003. Studies on seed quality parameters in deteriorating seeds in Brassica (*Brassica campestris*). Seed Science and Technology. 31(2): 389-396.

Vertucci, C.W., and E.E. Roos. 1990. Theoretical basis of protocols for seed storage. Plant Physiology. 94: 1019–1023.

Vertucci, C.W., and E.E. Roos. 1993. Theoretical basis of protocols for seed storage II. The influence of temperature on optimal moisture levels. Seed Science Research. 3: 201–213.

West, S.H., S.K. Loftin, M. Wahl, C.D. Batich, and C.L, Beatty. 1985. Polymers as moisture barriers to maintain seed quality. Crop science. 25: 941-944.

Yin, Y., G. Rongqi, S. Qingquan, and L. Shengfu. 2000. Effect of storage temperature and container type on the vigour of Welsh onion seeds with low moisture content. Australian Journal Experimental Agriculture. 398: 1025-1028.