Songklanakarin J. Sci. Technol.
45 (4), 494–500, Jul. – Aug. 2023

http://www.sjst.psu.ac.th

Original Article

Effects of different binder types and concentrations on physical and quality properties in marigold (*Tagetes erecta* L.) seed pelleting

Jakkrapong Kangsopa*, Aranya Singsopa, and Nararat Thawong

Division of Agronomy, Faculty of Agricultural Production,
Maejo University, San Sai, Chiang Mai, 50290 Thailand

Received: 11 November 2022; Revised: 16 May 2022; Accepted: 19 June 2023

Abstract

Binder is a substance that adheres the seeds and other pellet materials tightly together. However, the type of binder that is suitable varies by type of seed. Therefore, the objective of this experiment was to find an appropriate type and concentration of binder for pelleting marigold seeds, and to monitor changes in the physical characteristics of the pellets and in the quality of seeds after pelleting. The experiments followed a completely randomized design (CRD) with 4 replications. The results showed that pelleting the seeds with 0.3% w/v of either CMC or MHEC facilitated pellet formation. Pelleting with 0.3% w/v MHEC resulted in the lowest pellet friability (3%). Under laboratory conditions, the germination percentage of seeds pelleted with 0.3% w/v MHEC did not differ significantly from that of seeds pelleted with 0.1% w/v CMC, or from un-pelleted seeds. Seeds pelleted with 0.3% w/v MHEC had higher shoot length and root fresh weight than unpelleted seeds. In greenhouse conditions, seeds pelleted with 0.3% w/v MHEC had a significantly higher shoot length and shoot fresh weight than the unpelleted seeds. Therefore, 0.3% w/v MHEC was the most suitable binder choice for pelleting marigold seeds among the tested cases.

Keywords: adhesive, calcium sulfate, *Tagetes erecta*, marigold seeds

1. Introduction

Currently, seed enhancement technology is vital in various sectors of the global crop cultivation industry. Seed pelleting is a crucial method for improving seed quality, involving the coating of seeds with inert substances or different types of pelleting materials. This process results in changes in the size, shape, and weight of the pelleted seeds. Binders play a significant role in successful seed pelleting as they are adhesive substances with a viscosity ranging from 7.0 to 30.0 mm^2/s, depending on the specific case. Their main function is to firmly bind the seeds and other pelleting materials together (Pedrini, Merritt, Stevens, & Dixon, 2017). Various binders, including hydroxypropyl methylcellulose, carboxy methylcellulose, methylcellulose, hydroxyethyl methylcellulose, and ca-alginate gels, are currently used in seed pelleting (Siri, 2015). A good binder should be water-soluble with a suitable delay, without hindering water and air absorption that are crucial for seed germination (Arif, Sasmitaloka, Widayanti, & Yuliani, 2022; Taylor, 2003). Sikhao, Taylor, Marino, Catranis, and Siri (2015) found that 8-16% polyvinyl alcohol (PVA) effectively bound tomato and lettuce seeds. Mei et al. (2017) reported that pelleting seeds with 1.5% (w/w) PVA combined with CaO_2 improved germination and seedling growth under waterlogged conditions. Pelleting seeds with 0.01% w/v gum arabic resulted in higher germination index, germination rate, and shoot growth rate compared to unpelleted seeds (Somrat, Sawadeemit, Vearasilp, Thanapornpoonpong, & Gorinstein, 2018).

Marigold (*Tagetes erecta* L.) is a popular cut-flower plant in Thailand and around the world. The flowers are beautifully shaped, brightly colored, and can bloom for 1–2 weeks. They are commonly grown as ornamental plants in gardens or indoors for decoration. They can also be dried and processed for medicinal uses, food coloring, fabric dyes, and use in the cosmetics industry, etc. The production of marigold seeds in the seedling industry is an important step. Marigold

*Corresponding author
Email address: jakkrapong_ks@mju.ac.th

seeds tend to deteriorate easily after harvesting, so there are often problems with uneven germination of seedlings and flawed seedlings, which is a significant cause of seedlings suffering from damping-off disease caused by *Ceratobasidium* sp. (Saroj, Kumar, Saeed, Samad, & Alam, 2013). As a result, in modern cultivation, marigold seeds are often treated with various active ingredients, such as plant nutrients and antifungal chemicals. Seed pelleting is one of the options favored by the farmers growing marigold. Finding the appropriate binder type and concentration level is, however, one of the keys to successful marigold seed pelleting. The selection criteria for examining specific inert fillers for seed pelleting in this study were: 1) must be available in Thailand; 2) must be hydrophilic polymer; 3) must be carbohydrate derivative of cellulose; and 4) must not be toxic to marigold seeds.

The objective of this research was to find a suitable binder for producing pelleted marigold seeds. Six pelleting binders were applied to marigold seeds to assess the physical characteristics of pellets, including formation, friability, and dissolution period. Laboratory and greenhouse studies compared the germination and seedling growth of seeds in the experimental pellets to those of unpelleted marigold seeds.

2. Materials and Methods

This experiment was conducted at the Seed Technology Laboratory and the greenhouse of the Division of Agronomy, Faculty of Agricultural Production, Maejo University. 'Sri Siam Deep Gold' marigold seeds were produced in 2021. The quality characteristics of the marigold seeds were as follows: 69% initial germination, 98% purity, and 7% moisture. The experiment took place between January and June 2022. It followed a completely randomized design (CRD) with 4 replications. The details of the experiment are as follows.

2.1 Marigold seed pelleting

Three concentrations for the binders carboxymethyl cellulose (CMC) and methyl hydroxyethyl cellulose (MHEC) were selected. The experimental pelleting of seeds was done with 0.1, 0.2, and 0.3% (w/v) CMC and 0.1, 0.2, and 0.3% (w/v) of MHEC. A total of 120 g of calcium sulfate was used as pelleting material for each 10 g of marigold seeds. The marigold seeds were pelleted using an SKK12 rotary seed spreader at 35 rpm according to prior experimental methods (Kangsopa, Hynes, & Siri, 2018). Then, the seeds that had undergone pelleting were dehumidified with a KKU 40-2 model dehumidifier until the moisture content was 7±1%.

2.2 Physical tests on pelleted seeds

The difficulty levels of marigold seed pellet formation during the seed pelleting process were observed by considering how the pelleting materials were encapsulating the seeds. The difficulty levels of pellet formation were given scores ranging from 1 to 5, indicating that 1 = very difficult, 2 = difficult, 3 = moderate, 4 = easy and 5 = very easy (Jeephet, Atnaseo, Hermhuk, & Kangsopa, 2022). The number of seeds per pellet was determined from 100 pellets of seeds per treatment (Kangsopa, Thawong, Singsopa, & Rapeebunyanon, 2023). The average pellet weight was determined by assessing 100 randomly selected pellets (Kangsopa *et al*., 2018). The water solubility of the pellets was estimated from 10 selected pellets. The pellets were soaked in water individually and when they started to dissolve, the water solubility was calculated according to Anderson, Conway, Pfeifer, & Griffin (1969). The friability of the pellets was evaluated with 100 pellets of seeds from each experimental method using a 45-2200 model Tablet Friability Tester at 25 rpm for 4 minutes (Kangsopa *et al*., 2018).

2.3 Seed quality in laboratory conditions

The quality testing of 50 marigold seeds, both pelleted and unpelleted, was performed in transparent plastic boxes (110 × 110 × 30 mm, length × width × height) using the Top of Paper (TP) method with 4 repetitions. They were placed in a germination incubator at 25°C and 80% relative humidity with 24 hours of light exposure at 180 μE. Marigold seed quality was evaluated in various ways, as follows. Radicle emergence and speed of radicle emergence were randomly assessed on days 1 and 4 after planting when the seed had root germination at 2 mm. Germination percentage was assessed in normal seedlings on days 5 (first count) and 14 (final count) (ISTA, 2019). The speed of germination was assessed daily by counting the number of normal seedlings from days 5 to 14 after sowing (AOSA, 1983). Normal seedlings were assessed daily for 14 days to determine the mean germination time (Ellis & Roberts, 1980). Ten seedlings were assessed to indicate mean shoot length, root length, shoot fresh weight, and root fresh weight, which were assessed on day 14 after sowing (Klarod, Dongsansuk, Piepho, & Siri, 2021).

2.4 Seed quality in greenhouse conditions

Germination testing of marigold seeds, both pelleted and unpelleted, was carried out in seed trays with peat moss (Klasmann-Deilmann GmbH, Ltd., Germany) used as the seeding material. The first germination was assessed 5 days after planting and the final count was 14 days after sowing (ISTA, 2019). The speed of germination was assessed in the same way as when tested in the laboratory conditions. Cotyledon emergence was evaluated with germinated cotyledons emerged from the seeding material on day 4 after sowing. Shoot length and shoot fresh weight were assessed on day 14 after sowing. Shoots of 10 randomly selected seedlings were cut close to the planting material and then measured using a ruler (Jeephet *et al*., 2022).

2.5 Statistical analysis

The percentage of germination was arcsine-transformed to normalize the data before statistical analysis. All data were analyzed by one-way analysis of variance (ANOVA) (completely randomized design), and the difference between the treatments was tested by Duncan's multiple range test (DMRT).

3. Results and Discussion

3.1 Physical characteristics of marigold seed Pelleting

The binder is one of the key components determining success in seed pelleting. The binder binds the pelleting material and attaches it firmly to the seed. The type of binder and its concentration that are suitable depend on seed type (Siri, 2015).

Marigold seeds are usually elongated and slender in shape and attached to a pappus (Figure 1A). Marigold seeds pelleted with 0.1% w/v CMC or MHEC were cracked and corroded since the pelleting material did not completely encapsulate the seeds (Figure 1B, E). Pelleting seeds with 0.2% w/v CMC or MHEC resulted in the pelleting material completely encapsulating the seeds, but subsequent cracking of pelleting material was observed (Figure 1C, F). Pelleting with 0.3% w/v CMC or MHEC resulted in smooth pellets and complete encapsulation (Figure 1D, G). The use of 0.3% w/v CMC or MHEC in pelleting seeds resulted in easy pellet formation. The pellet 100-seeds weight averaged between 5 (0.3% w/v CMC) and 10 times (0.2% w/v MHEC) that of the unpelleted seeds.

Pellet friability is an important aspect in relation to their transport potential when they are used in combination with agricultural machinery (Kangsopa *et al*., 2018; Siri, 2015). Seeds pelleted with 0.1% w/v MHEC had the highest friability, at 66%. However, seeds pelleted with 0.1 and 0.2% w/v CMC or MHEC were fragile since the pelleting material did not completely encapsulate the seeds, making these choices unsuitable for marigold seed pelleting. Seeds pelleted with 0.3% w/v CMC or MHEC showed the lowest pellet friability at 4% and 3%, respectively.

A good seed pellet must be able to dissolve in water within a reasonable period of time. The type and concentration of the binder affect the water solubility of the pellets (Siri, 2015). Pellets with 0.1 and 0.2% w/v CMC and MHEC dissolved in water relatively quickly. Hence, both types and concentration levels are inappropriate for marigold seed pelleting. The use of 0.3% w/v CMC or MHEC resulted in slower dissolution of pellets, at 6.12 and 6.54 s, respectively (Table 1). In the study, it was found that 0.3 w/v CMC and 0.3 w/v MHEC had slower water dissolving properties than other binder concentrations. Carboxymethyl cellulose (CMC) and methyl hydroxyethyl cellulose (MHEC) are popularly used in seed pelleting because of their excellent binding and adhesive characteristics. The adhesion strength of these polymers plays a crucial role in forming a strong and uniform coating layer on the seed surface and bonding tightly during pelleting or coating (Siri, 2015). Both CMC and MHEC adhere strongly to the seed surface and to the other coating materials during pelleting or coating. Furthermore, pelleting material may assist in slowing down moisture absorption by either obstructing water movement towards micropyles of dry seeds or preventing damage to the temporal membrane (Javed *et al*., 2022). Binder agents significantly impact the length of the imbibition and active metabolism stages of germination (Aoki, Scofield, Wang, Offler, Patrick, & Furbank, 2006). Pelleting seeds with 0.3 w/v MHEC did not hinder sucrose secretion into the endosperm or the uptake of sucrose by the embryo as an energy source. Laboratory testing revealed that seeds pelleted with 0.3 w/v MHEC had a higher germination percentage than unpelleted seeds. While there was no significant difference in the results when tested under greenhouse conditions, pelleting seeds with 0.3 w/v MHEC led to a tendency for higher germination percentage.

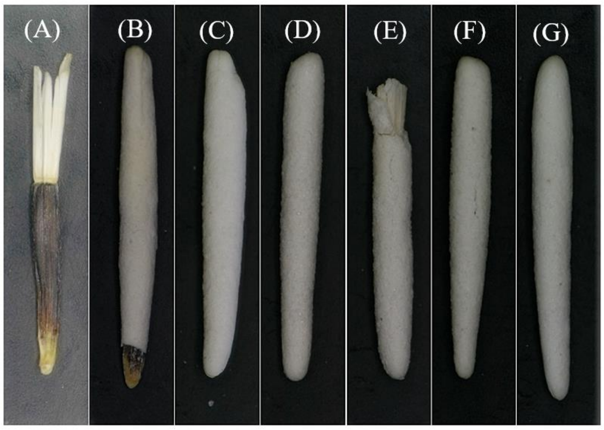

Figure 1. Physical appearance of seed pellets with different binder types and concentrations: (A) Marigold seed, (B) 0.1% CMC, (C) 0.2% CMC, (D) 0.3% CMC, (E) 0.1% MHEC, (F) 0.2% MHEC, and (G) 0.3% MHEC

Table 1. Physical properties of marigold seeds with different binders

Treatment	Forming	Seeds/pellet	Pellet 100-seeds weight (g)	Friability (%)	Dissolution period of pelleted (s)
Unpelleted seed	-	-	0.34 e	-	-
CMC 0.1%	3	1	2.45 c	25 b	1.85 c
CMC 0.2%	3	1	1.94 d	21 b	2.10 c
CMC 0.3%	5	1	1.80 d	4 c	6.12 a
MHEC 0.1%	3	1	2.98 b	66 a	1.85 c
MHEC 0.2%	4	1	3.54 a	16 b	2.83 b
MHEC 0.3%	5	1	2.77 b	3 c	6.54 a
F-test	-	ns	**	**	**
CV.%	-	1.10	7.96	10.62	10.8

ns: no significant difference. ** Interactions significantly different at $P \leq 0.01$. Means within each germination parameter with different letters are significantly different ($P \leq 0.05$). The coefficient of variation, CV (%), is the percentage variation in the mean across treatments.

3.2 Germination and speed of germination of marigold seeds in laboratory and greenhouse conditions

Good seed pellets must have good physical properties and must not impede the absorption of water or air by the seeds (Jeephet *et al*., 2022). Germination percentage is an important quality for all seeds (Bewley, Bradford, Hilhorst, & Nonogaki, 2013). The selection of binders must not interfere with the seed germination process. Under laboratory conditions, the germination percentage of seeds pelleted with 0.1% w/v CMC differed significantly from that of seeds pelleted with 0.3% w/v MHEC, and from all other treatments (Figure 2A). The germination percentage of seeds pelleted with 0.1% and 0.2% w/v CMC and 0.1% and 0.3% w/v MHEC was higher than that of seeds pelleted using other binder concentrations (Figure 2C). The results indicate that seeds pelleted with 0.1% w/v CMC had a higher germination percentage and speed of germination than seeds treated with the other methods. However, pellet formation was difficult and therefore, this choice was considered unsuitable for seed pelleting. The use of 0.3% w/v MHEC gave similar results to those with 0.1% w/v CMC and better results than unpelleted seeds. Therefore, 0.3% w/v MHEC is a good choice for use as a binder in marigold seed pelleting.

Under greenhouse conditions, marigold seeds pelleted with different binder types and concentrations showed no significant differences in germination percentage compared to unpelleted seeds (Figure 2B). However, seed pelleting with 0.3% w/v CMC and 0.3% w/v MHEC resulted in a significantly higher speed of germination than the other cases.

Based on the experimental results, it can be seen that pelleting seeds with 0.3% w/v MHEC had a significantly better positive impact on seed quality than any other seed pelleting tested. MHEC is an effective binder for seed pelleting and coating, resulting in improved physical properties, water retention capacity, and germination rates for various types of seeds. In addition, coating materials that contain MHEC can improve the quality and storability of coated seeds. For example, Jeephet *et al*. (2022) found that MHEC and CMC at different concentrations were effective at pelleting lettuce seeds without interfering with germination. Buakaew & Siri (2018) reported that lettuce seeds pelleted with 0.3% MHEC did not impede seed germination, while Chaiyasarn & Siri (2019) reported that tomato seeds pelleted with 0.7% MHEC showed no significant effects on germination percentage when tested in either laboratory or greenhouse conditions, indicating the potential suitability of MHEC as a binder for different types of seeds.

3.3 Seed quality of marigold seeds in laboratory and greenhouse conditions

3.3.1 Seed quality in laboratory conditions

Seeds pelleted with 0.3% w/v CMC and 0.2% w/v MHEC had a significantly lower percentage of radicle emergence than those pelleted with other methods. The mean germination times of seeds pelleted with 0.1 and 0.2% w/v CMC and 0.2 and 0.3% w/v MHEC were significantly longer than that of unpelleted seeds. Seeds pelleted with 0.1 and 0.2% w/v CMC and 0.3% w/v MHEC had higher shoots than seeds treated with other methods but did not differ significantly from unpelleted seeds. The use of 0.2 w/v MHEC resulted in data variability, but using 0.3 w/v MHEC still allowed seed germination even at this high concentration. Kangsopa *et al*. (2023) found that pelleting with 0.3 w/v

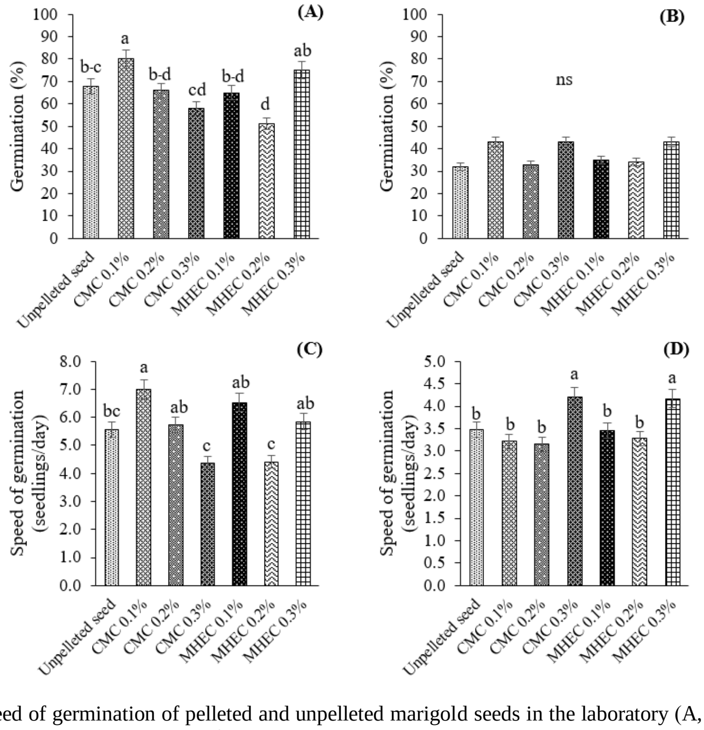

Figure 2. Germination and speed of germination of pelleted and unpelleted marigold seeds in the laboratory (A, C) and in a greenhouse (B, D). (The bars indicate mean ± standard deviation for each treatment.)

MHEC did not hinder radicle emergence in cucumber seeds. Both CMC and MHEC are water-soluble cellulose derivatives, and most of the seeds still exhibited evidence of radicle emergence after being tested for four days. However, properties of binders that may impede initial radicle emergence could depend on the type of seeds and the environmental conditions in which they are used. The impact of CMC or MHEC on mean germination time may also be influenced by factors such as seed type, binder concentration and type, and environmental conditions during germination (Berto, Ritchie, & Erickson, 2021).

Seeds pelleted with 0.1% w/v CMC produced significantly longer roots than seeds pelleted with 0.1% w/v MHEC but did not differ from seeds treated with other methods. Seeds pelleted with 0.1% w/v CMC and 0.3% w/v MHEC had higher shoot and root fresh weights than seeds treated with the other methods (Table 2). Based on the results of this study, pelleted seeds generally germinated faster than unpelleted seeds. This can provide more opportunities for the radicle to absorb nutrients, increase efficiency in using water, and promote the synchronous maturation of crops (Hill, Bradford, Cunningham, & Taylor, 2008). These factors can promote faster shoot and root growth. Using pelleting material to coat seeds can further increase water absorption and storage, leading to faster germination and longer moisture retention (Siri, 2015). Importantly, the use of 0.3 w/v MHEC did not hinder the germination and growth of marigold seedlings.

3.3.2 Seed quality in greenhouse conditions

There were no significant differences in cotyledon emergence and mean germination times of any of the pelleted seeds compared to unpelleted seeds. Seeds pelleted with 0.1% w/v MHEC had the longest shoots with an average of 10.08 cm, followed by seeds pelleted with 0.3% w/v MHEC with an average shoot length of 8.91 cm. Seeds pelleted with each of the three concentrations of MHEC and seeds pelleted with 1% w/v CMC had a significantly higher fresh shoot weight than unpelleted seeds (Table 3).

Four days after planting, none of the binder combinations had any significant effect on cotyledon emergence. The results indicate that using high concentrations of CMC or MHEC did not hinder cotyledon emergence under greenhouse conditions. Similarly, the mean germination time at eight days after planting indicated that pelleting seeds with either type of binder at different concentrations did not significantly increase normal seedling emergence compared to unpelleted seeds. Siri (2015) reported that seed pelleting modifies seed shape. The quality of the seeds should remain the same or be improved, while decreasing the quality of the seeds must be avoided.

Table 2. Radicle emergence (RE), mean germination time (MGT), shoot length (SHL), root length (RL), fresh shoot weight (SFW) and fresh root weight (RFW) of marigold seeds after pelleting with different types and doses of binder, tested under laboratory conditions

Treatment	Laboratory conditions					
	RE (%)	MGT (day)	SHL (cm)	RL (cm)	SFW (g)	RFW (g)
Unpelleted seed	55 a	4.60 a	3.02 ab	7.80 ab	0.31 c	0.31 b
CMC 0.1%	56 a	3.23 bc	4.24 a	9.20 a	0.36 a	0.41 a
CMC 0.2%	54 a	3.06 c	2.51 b	8.66 ab	0.33 a-c	0.31 b
CMC 0.3%	32 b	3.73 a-c	2.85 b	8.81 ab	0.33 a-c	0.29 b
MHEC 0.1%	56 a	4.17 ab	2.71 b	6.76 b	0.34 ab	0.31 b
MHEC 0.2%	32 b	2.94 c	2.56 b	7.64 ab	0.32 bc	0.31 b
MHEC 0.3%	53 a	3.46 bc	3.98 a	8.07 ab	0.37 a	0.39 a
F-test	**	**	**	*	*	**
CV.%	16.51	17.77	44.57	17.39	7.35	13.47

*, ** Interactions significantly differ at $P \leq 0.05$ and $P \leq 0.01$, respectively. Means within each germination parameter with different letters are significantly different ($P \leq 0.05$). The coefficient of variation, CV (%), is the percentage variation in the mean across treatments.

Table 3. Cotyledon emergence (COTE), mean germination time (MGT), shoot length, and fresh shoot weight of marigold seeds after pelleting with different types and doses of binders, tested under greenhouse conditions

Treatment	Greenhouse conditions			
	COTE (%)	MGT (day)	Shoot length (cm)	Shoot fresh weight (g)
Unpelleted seed	25	1.45	7.76 cd	2.87 c
CMC 0.1%	27	1.29	7.35 cd	3.77 ab
CMC 0.2%	23	1.51	7.19 cd	3.37 bc
CMC 0.3%	38	1.70	6.89 d	3.48 a-c
MHEC 0.1%	30	1.43	10.08 a	4.08 a
MHEC 0.2%	25	1.46	7.92 c	3.59 ab
MHEC 0.3%	34	1.78	8.91 b	3.90 ab
F-test	ns	ns	**	**
CV.%	32.78	28.84	7.21	11.78

ns: not significantly difference. ** Interactions significantly differ at $P \leq 0.01$. Means within each germination parameter with different letters are significantly different ($P \leq 0.05$). The coefficient of variation, CV (%), is the percentage variation in the mean across treatments

The study found that pelleting the seeds with 0.1 w/v MHEC resulted in increased shoot length and fresh weight of the seedlings. This is likely due to the physical properties of the pellet, which is highly porous and quickly dissolves in water (Rowe, Sheskey, & Quinn, 2009), allowing for better and faster germination. Pelleting with 0.3 w/v MHEC also produced a physically suitable pellet, with significant changes in shoot length and shoot fresh weight compared to unpelleted seeds. Similarly, Kangsopa *et al*. (2023) found that pelleting cucumber seeds with 0.1, 0.2, and 0.3 w/v MHEC resulted in higher shoot length and shoot fresh weight compared to unpelleted seeds when tested under greenhouse conditions.

4. Conclusions

The physical property tests and seed quality measures under laboratory and greenhouse conditions showed that the best binder for Sri Siam Deep Gold marigold seed pelleting was 0.3 (w/v) MHEC with 120 g of calcium sulfate as pelleting material per 10 g of marigold seeds.

However, this was merely a preliminary study. The formulations obtained from these findings should be further investigated regarding storage conditions at different temperatures to assess the shelf storage quality of pelleted seeds. Additionally, it is advisable to conduct field tests to evaluate the germination rate and seedling emergence rate, in order to verify the quality of pelleted seeds and explore their potential for future commercial applications.

Acknowledgements

This work (Grant No. RGNS 64-178) was supported by Office of the Permanent Secretary, Ministry of Higher Education, Science, Research and Innovation (OPS MHESI), Thailand Science Research and Innovation (TSRI). 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.

References

Afzal, I., Javed, T., Amirkhani, M., & Taylor, A. G. (2020). Modern seed technology: seed coating delivery systems for enhancing seed and crop performance. *Agriculture, 10*, 526. doi:10.3390/agriculture10110526

Anderson, R. A., Conway, H. F., Pfeifer, V. F., & Griffin, E. L. (1969). Gelatinization of corn grits by roll- and extrusion-cooking. *Cereal Science Today, 14*, 4-11.

Aoki, N., Scofield, G. N., Wang, X. D., Offler, C. E., Patrick, J. W., & Furbank, R. T. (2006). Pathway of sugar transport in germinating wheat seeds. *Plant Physiology, 141*(4): 1255–1263.

AOSA. (1983). *Seed vigor testing handbook*. Ithaca, NY: AOSA. (Contribution to the handbook on seed testing, 32).

Arif, A. B., Sasmitaloka, K. S., Widayanti, S. M., & Yuliani, S. (2022). Effect of pelleting on germination and vegetative growth of true seed of shallot (*Allium cepa* var ascalonicum L.). *Songklanakarin Journal of Science and Technology, 44*(3), 811–816. doi:10.14456/sjst-psu.2022.108

Berto, B., Ritchie, A. L. & Erickson, T. E. (2021). Seed-enhancement combinations improve germination and handling in two dominant native grass species. *Restoration Ecology, 29*(1), 13275. doi:10.1111/rec.13275

Bewley, J. D., Bradford, K. J., Hilhorst, H. W. M., & Nonogaki, H. (2013). *Seeds*: *Physiology of development, germination and dormancy* (3rd ed.). New York, NY: Springer.

Buakaew, S., & Siri, B. (2018). Physical properties and seed quality after pelleting with different binder and filler materials of lettuce seed (*Lactuca sativa* L.). *Khon Kaen Agriculture Journal, 46*, 469–480.

Chaiyasarn, S., & Siri, B. (2019). Effects of seed pelleting with different fillers types on seed quality and physical properties of hybrid tomato pellets. *Khon Kaen Agriculture Journal, 47*(3), 467–478.

Ellis, R.H., & E.H. Roberts. (1980). Improved equation for the prediction of seed longevity. *Annals of Botany, 45*, 13–30.

Hill, H., Bradford, K. J., Cunningham, J., & Taylor, A. G. (2008). Primed lettuce seeds exhibit increased sensitivity to moisture during aging. *Acta Hortic, 782*, 135–141.

ISTA. (2019). *International rules for seed testing*. Bassersdorf: International Seed Testing Association.

Jeephet, P., Atnaseo, C., Hermhuk, S., & Kangsopa, J. (2022). Effect of seed pelleting with different matrices on physical characteristics and seed quality of lettuce (*Lactuca sativa*). *International Journal of Agricultural Technology, 18*(5), 2009–2020.

Javed, T., Afzal, I., Shabbir, R., Ikram, K., Zaheer, M. S., Faheem, M., . . . Iqbal, J. (2022). Seed coating technology: An innovative and sustainable approach for improving seed quality and crop performance. *Journal of the Saudi Society of Agricultural Sciences, 21*(8), 536–545.

Kangsopa, J., Hynes, R. K., & Siri, B. (2018). Lettuce seeds pelleting: A new bilayer matrix for lettuce (*Lactuca sativa*) seeds. *Seed Science and Technology, 46*, 521-531. doi:10.15258/sst.2018.46.3.09

Kangsopa, J., Thawong, N., Singsopa, A., & Rapeebunyanon, D. (2023). Effect of seed pelleting with different binder types on the physical characteristics and seed quality of hybrid cucumber (*Cucumis sativus* L.). *International Journal of Agricultural Technology, 19*(2), 475–486.

Klarod, K., Dongsansuk, A., Piepho, H. P., & Siri, B. (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*, 107–124. doi:10.15258/sst.2021.49.2.03

Mei, J., Wang, W., Shaobing, P., & Nie, L. (2017). Seed pelleting with calcium peroxide improves crop establishment of direct-seeded rice under water logging conditions. *Scientific Reports, 7*, 4878. doi:10.1038/s41598-017-04966-1

Pedrini, S., Merritt, D. J., Stevens, J., & Dixon, K. (2017). Seed coating: science or marketing spin?. *Trends in Plant Science*, *22*, 106–116. doi: 10.1016/j.tplants. 2016.11.002

Rowe, R. C., Sheskey, P. J. & Quinn, M. E. (2009). *Handbook of pharmaceutical excipients*. (6th ed.). London, England: Pharmaceutical Press.

Saroj, A., Kumar, A., Saeed, S. T., Samad, A., & Alam, M. (2013). First report of tagetes erecta damping off caused by *Ceratobasidium* sp. from India. *Plant Disease*, *97*(9), 1251. doi:10.1094/PDIS-02-13-0145-PDN

Sikhao, P., Taylor, G. A., Marino, E. T., Catranis, C. M., & Siri, B. (2015). Development of seeds agglo meration technology using lettuce and tomato as model vegetable crop seeds. *Scientia Horticulturae*, *184*, 85–92. doi:10.1016/j.scienta. 2014.12.028

Siri, B. (2015). *Seed conditioning and seed enhancements*. Khon Kaen, Thailand: Klungnanawitthaya Printing.

Somrat, N., Sawadeemit, C., Vearasilp, S., Thanapornpoon pong, S., & Gorinstein, S. (2018). Effects of different binder types and concentrations on physical and antioxidant properties of pelleted sweet corn seeds. *European Food Research and Technology*, *244*, 547–554. doi:10.1007/s00217-017-2979-y

Taylor, A. G. (2003). Seed treatments. In B. D. J. Thomas & B. G. Murphy. (Eds.), *Encyclopedia of Applied Plant Sciences* (pp. 1291–1298), Cambridge, England: Elsevier Academic Press.