Original Article

A new alternative mono-layer matrix for pelleting cucumber (*Cucumis sativus*) seeds

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Abstract

Cucumber seeds are small, oblong, and flat, usually measuring 3–4 mm in length. However, their susceptibility to deterioration and sensitivity to poor storage conditions can result in decreased germination rates and reduced overall vigour. Nevertheless, seed pelleting can effectively shield seeds from harsh environmental factors and slow down the deterioration process, thereby preserving the seed quality. The objective of this research was to develop a matrix for pelleting cucumber seeds. The percent germination and radical emergence, as well as other important parameters, of the experimental pellets were compared to unpelleted cucumber seeds in laboratory and greenhouse conditions. The treatments in this experiment involved a mono-layer of pumice, talcum, bentonite, calcium sulphate, calcium carbonate, and zeolite, which were used as a matrix for pelleted seed in this experiment and bound with methylhydroxyethyl cellulose (MHEC). Pelleted seed treated with talcum and bentonite did not result in smooth and fragile pellets, whereas those treated with $CaSO_4$ exhibited low levels of friability (3.38%) and pellet dissolution (5.11 seconds). Seed pelleted with $CaSO_4$ showed significantly different

germination under laboratory and greenhouse conditions compared to other matrices and unpelleted seed. This indicates that $CaSO_4$ was suitable for pelleting 'YokKaow' cucumber seed.

Keywords: Calcium sulphate, Methylhydroxyethyl cellulose, *Cucumis sativus*, Cucumber seeds pelleting

1. Introduction

Currently, seed pelleting is an essential technology for the cultivation of field crops, horticulture, and flowering plants. Many crops require precision cultivation to reduce production costs and redundant management. However, most seed pelleting is a trade secret. It is important to find a formula that is suitable for the plant species so that it does not interfere with the germination process. Seed pelleting is the addition of inert materials, such as binders and fine powders, to vary the size, shape, and weight of the seed (Kangsopa, Hynes, & Siri, 2018; Pedrini, Merritt, Stevens, & Dixon, 2017; Taylor, 2003; Taylor & Harman, 1990). The pellets increase in size 50-fold from the original seed after seed pelleting. The pelleting material must possess several qualities. It should be readily available, cost-effective, compatible with conventional binders, allow for unhindered root emergence, have water absorption capabilities, and break up effortlessly (Taylor, 2003). Pellet materials used for pelleting include, for example, calcium carbonate, limestone, bentonite, zeolite, pumice, gypsum, talc, charcoal, acacia powder, vermiculite, and diatomaceous earth (Porter & Kaerwer, 1974; Taylor & Harman, 1990). Examples of pelleted seed include pelleted lettuce seed with calcium carbonate-gypsum and calcium sulphate (Kangsopa *et al*., 2018) or pumice (Jeephet, Atnaseo, Hermhuk, & Kangsopa, 2022) and pelleted carrot seed with calcium sulphate (Kangsopa, Jeephet, Singsopha, Thawong, & Chantain, 2021).

The seeds of regular cucumbers are easy to cultivate since they are large, measuring approximately 8–10 mm in length. In contrast, the 'YokKaow' cucumber variety, developed in Thailand and widely used in Thai cuisine, has smaller seeds that are approximately 3–4 mm in length. These seeds are thin, light, and have a low reserve of food, which makes them challenging to germinate. Moreover, cucumber seeds that have been stored for some time are prone to quality deterioration and seed coat breakdown, resulting in problems for growers (Khaldun & Haque, 2009; Powell & Matthews, 2005; TeKrony, 2003). To address these issues, seed pelleting techniques are crucial for increasing seed coat thickness, delaying deterioration, and improving germination. Additionally, seed pelleting can also be used to incorporate essential substances, such as plant nutrients, biological agents, and pesticides, to enhance seed germination (Contreras, Bennett, & Tay, 2008; Wurr & Fellows, 1985).

Pelleting seeds of the YokKaow cucumber variety can be challenging due to its small size and smooth surface, which resists adhesion. Therefore, the criteria for selecting pelleting materials for pelleting seeds must not hinder their ability to germinate. To guide our selection, we followed the guidelines proposed by Kangsopa *et al*. (2018), who evaluated various pelleting materials and their properties, such as particle size, water absorption, adhesion, and toxicity, to identify the most suitable substrates available in Thailand.

Commercial pelleted cucumber seeds have not yet appeared, making a new pelleting formulation essential. This is, therefore, one of the options for enhancing high-quality seeds. The goal of this research was to develop a matrix to produce pelleted cucumber seeds. Six pelleting matrices were applied to cucumber seeds to assess the physical characteristics of hardness, friability, and water solubility. Laboratory and greenhouse studies compared the germination and seedling growth of seeds coated with experimental pellets with that of the unpelleted cucumber seeds.

2. Materials and Methods

2.1 Cucumber seed pelleting

Seeds of the hybrid cucumber variety YokKaow (Lion Seeds®) had specific characteristics before experimentation, including a germination rate of 55%, a moisture content of 7%, and a seed length of approximately 3–4 mm. Six different types of pelleting materials were used in this experiment: pumice, talcum, bentonite, calcium sulphate, calcium carbonate, and zeolite. Pumice, a light and porous volcanic material, was found to absorb water well. Talcum had fine particles and good fluidity. Bentonite, a type of clay composed mainly of montmorillonite, was also evaluated. We also tested calcium sulphate, a soft sulphate mineral, and calcium carbonate, a common substance found in rocks. Finally, we investigated zeolite, a porous mineral that is also an aluminosilicate and a product of volcanoes. A 0.3% w/w aqueous-methylhydroxyethyl cellulose (MHEC) (Kingsun Chemical) solution was prepared for use as the pelleting binding agent. Pelleting was conducted in a rotary drum, Model SKK12, spinning at 40 rpm (Kangsopa *et al*., 2018). Filler materials were added to seeds with carefully measured application of MHEC by pipette to prepare the following six treatments in 10 g lots: unpelleted seeds; layer treatments of pumice, talcum, bentonite, calcium sulphate ($CaSO_4$), calcium carbonate ($CaCO_3$), and zeolite (Table 1). After pelleting with a mono-layer in each treatment, the seeds were approximately 1–1.5 mm in diameter. The pelleted seeds were then dried in a forced air dryer at 35°C until the moisture content reached 7–8%.

Table 1. Composition of experimental pellet matrices and additional treatments used for pelleting cucumber seeds.

Treatment	Filler[1] (g)	MHEC[2] (g)
Unpelleted seed	0	0
Pumice	50	0.3
Talc	50	0.3
Bentonite	50	0.3
$CaSO_4$	50	0.3
$CaCO_3$	50	0.3
Zeolite	50	0.3

All numbers represent weight of filler applied to 10 g of seed.
[1] Filler 2 is as indicated in the treatment column.
[2] MHEC = aqueous-methylhydroxyethyl cellulose.
NA: Not applicable.

2.2 Physical tests of pelleted seeds

The formation of cucumber seed pellets during the pelleting process was observed to assess the level of difficulty for each pelleting material in adhering to and covering the seed husks for pellet formation. This was accomplished by assigning a score of 1–5, with 1 indicating a very difficult process, 2 indicating a difficult process, 3 indicating a moderate process, 4 indicating an easy process, and 5 indicating a very easy process. To rate the dissolution period of the pelleted seeds, 10 ml of water was added to a 50 ml cylindrical glass container. The dissolution period was determined as the mean of 10 pelleted seeds per treatment and was concluded when the pelleted seeds cracked and split (Anderson, Conway, Pfeifer, & Griffin, 1970). The friability of pelleted seeds was assessed on 50 pelleted seeds per treatment using a Pharma friabilator tester at 25 ± 1 rpm for minutes (Kangsopa *et al*., 2018).

2.3 Germination testing and after ageing

In laboratory tests, 50 pelleted and non-pelleted seeds were tested using the between paper (BP) method in each of the four replications. Then, each treatment was placed in the germination incubator at 25°C, with 80% relative humidity, 180 μE light intensity, and 24-hour lighting. There were four replicates per treatment. Testing protocols followed those described by the International Seed Testing Association (ISTA, 2020). Initial germination counts were carried out 4 and 8 days after incubation, followed by daily germination recordings. Radicle emergence was counted as 2 mm-long radicles 72 hours after sowing, according to ISTA (2020). The germination rate, emergence rate (seedlings emerged/day), shoot length, and root length were determined. The mean germination time was calculated according to Ellis & Roberts (1981).

In greenhouse tests, 50 pelleted seeds per treatment were sown in peat moss (Klasmann-Deilmann GmbH, Ltd., Germany) in 340 × 340 × 60 mm seed trays. Germination counts and shoot length data were collected, as described for the laboratory tests. To examine the emergence, 50 seeds were selected for each method and planted in 4 replications. The cotyledons were observed from the planting material and evaluated on the 3rd day of the germination test.

2.4 Accelerated ageing test

Accelerated ageing of all treatments, pelleted and unpelleted seeds, was conducted in a humidity chamber with the following conditions: 100% relative humidity (RH) and 40°C for 48 hours. Laboratory and greenhouse tests on the accelerated aging of pelleted seeds were conducted as described above.

2.5 Statistical analysis

All experiments were conducted with four replications per treatment. The germination rate was arcsine transformed to normalise the data before statistical analyses were carried out. Laboratory and greenhouse treatments were arranged in a complete randomised plot design (CRD), and the data collected were analysed by one-way ANOVA. The difference between treatments was tested using Duncan's multiple range test (DMRT).

3. Results and Discussion

3.1 Physical appearance of pelleted seeds

Except for talcum and bentonite, which resulted in uneven and rough surfaces (Figures 1B,C), all four treatments produced smooth edges that followed the shape of the cucumber seeds. The talcum did not adhere to the surface of the cucumber seeds and broke easily. Pumice, talcum, and $CaSO_4$ formed the easiest (Figures 1A,B,D), followed by $CaCO_3$ and zeolite (Figures 1E,F). Bentonite was more difficult to form in the pelleting matrix and binder, and the cucumber seeds were not homogeneous (Table 2). Pelleting cucumber seeds significantly increased the final product weight. The 100 seed pellet weight ranged from 1.92- (pumice) to 2.62-times ($CaSO_4$) that of the unpelleted seeds. The pellets of pumice, $CaSO_4$, $CaCO_3$, and zeolite contained one cucumber seed per pellet.

$CaSO_4$ pellets had a dissolution period of 5.11 seconds, while other pelleting matrices took between 1.27 and 2.81 seconds. Solubility is an important parameter that must be tested. Because cucumber seed pelleting adds a thin layer of pelleting material to the seed coat, it may cause the covering to dissolve too easily when exposed to slight moisture from external factors. $CaSO_4$ was shown to take 5.11 seconds to split. Other pelleting materials with a solubility of 1.27–2.81 seconds showed that the solubility was too fast. The experimental results demonstrated that each seed pelleting method led to rapid dissolution of the pellet. In the case of cucumber seed pelleting, this involves coating the seed with a pelleting material similar to the film coating technique. This technique is similar to the seed encrusting method but with a slightly thicker layer. Moreover, cucumber seeds are already relatively large compared to seeds of tobacco, lettuce, and carrot, among others, so there is no need to increase their size by as much as 30–40 times. For these reasons, the layer of the pelleting matrix on the cucumber pelleted seeds dissolves faster than that of smaller seed varieties. In addition, Kangsopa *et al*. (2018) reported that lettuce seed pelleting with the first layer of calcium carbonate, followed by a second layer of bentonite, pumice, and gypsum, had 94, 29, and 35 seconds of water solubility, respectively. However, the solubility time was between 1 and 5 seconds and therefore did not impede the absorption of moisture and other germination factors of the seed. Cultivators require seed consistency, fast germination, and the absence of disease in the seedling stage.

Friability testing has been applied by the pharmaceutical industry for physical quality testing. This parameter is important for the seed pelleting industry. This is a criterion that indicates packaging and transportation potential (Jeephet *et al*., 2022). Pellet matrices of talcum, $CaSO_4$, and bentonite were highly friable compared to the other treatments (Table 2). This indicates that $CaSO_4$ is a more suitable pelleting material in combination with cucumber seeds than other types of pelleting materials.

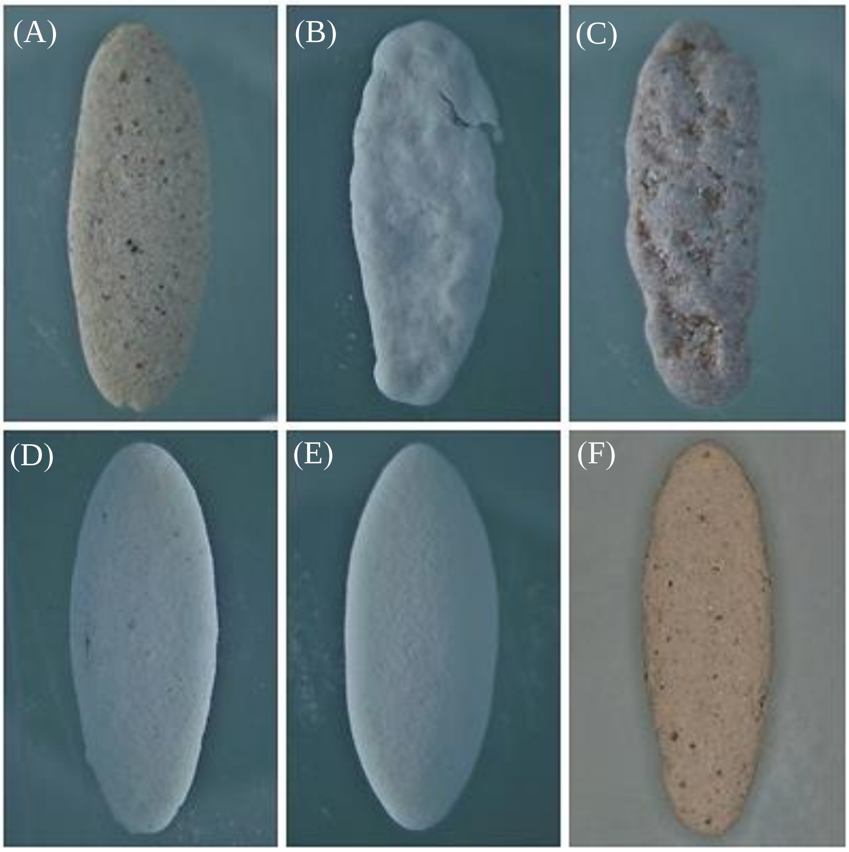

Figure 1. Physical appearance of cucumber seeds pelleted with difference matrices (10x Magnifications): (A) pumice; (B) talcum; (C) bentonite; (D) calcium sulfate; (E) calcium carbonate; (F) zeolite.

Table 2. Physical property of pelleted cucumber seed with different pelleting materials.

Treatment	Forming	Seeds/pellet	Pellet 100-seeds weight (g)	Pellet dissolution (seconds)	Friability (%)
Unpelleted	-	-	2.31 g	-	-
Pumice	5	1.00 b	4.43 f	2.81 b	11.46 c
Talcum	5	1.25 a	5.75 b	2.30 b	64.54 a
Bentonite	1	1.50 a	5.00 d	1.70 b	37.96 b
$CaSO_4$	5	1.00 b	6.04 a	5.11 a	3.38 d
$CaCO_3$	4	1.00 b	5.47 c	1.27 b	62.87 a
Zeolite	4	1.00 b	4.58 e	1.62 b	8.74 d
F-test	-	**	**	**	**
CV. (%)	-	7.71	2.21	2.73	8.91

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

3.2 Germination and seedling growth

Under laboratory conditions, all pellet matrices had a significantly higher germination percentage than the unpelleted seeds (Figure 2A). Zeolite pellets have less radicle emergence than other types of pelleting matrices (Figure 2C). All pelleting methods showed significantly higher root lengths than the unpelleted seeds (Figure 3); however, bentonite and $CaSO_4$ had significantly higher shoot lengths than the unpelleted seeds (Table 3). These pelleting matrices, when coated on seeds, showed that they did not interfere with the germination process; in contrast, the seed germination was greater than that of the unpelleted seeds. Jeephet *et al*. (2022) showed that the seed pelleting bilayer matrix of $CaSO_4$-zeolite, $CaSO_4$-pumice, $CaSO_4$-bentonite, $CaSO_4$-talcum, and $CaSO_4$-diatomaceous earth did not impede the germination of lettuce seeds. In addition, the pelleting material is composed of various plant nutrients, such as silica, sulphur, and calcium (Kathpalia & Bhatla, 2018). Thus, it is clearly more effective in supporting root and shoot length than unpelleted seeds.

Under greenhouse conditions, $CaSO_4$ had a significantly higher germination percentage (Figure 2B), emergence rate (Figure 2D), and shoot length compared to the other experimental pellet matrices (Table 3). $CaSO_4$ pellets showed the highest germination because the slight friability and slow absorption of water had a good germination promotion effect. In addition, the $CaSO_4$ pellet matrix was shown to promote seedling growth more than the other methods. Calcium sulphate is used in agricultural and horticultural fertilisers, dressings, and pesticides. It provides a natural source of calcium and sulphur, which can be directly assimilated by plants and is vital to fertilisation and healthy plant growth (Saint-Gobain Formula, 2009).

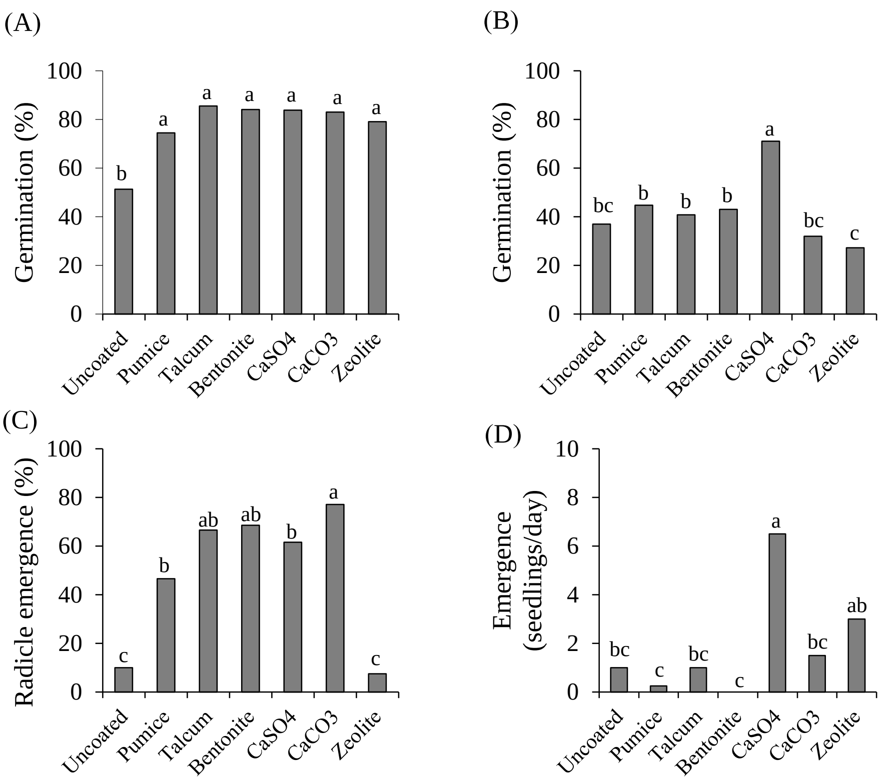

Figure 2. Germination and emergence (■) of pelleted cucumber seeds in the laboratory (A, C) and greenhouse (B, D).

Table 3. Root length, shoot length and mean germination time of pelleted cucumber seeds under laboratory and greenhouse conditions.

Treatment	Laboratory			Greenhouse
	Root length (cm)	Shoot length (cm)	Mean germination time (day)	Shoot length (cm)
Unpelleted	7.75 c	5.34 bc	8.19 a	4.28 bc
Pumice	12.01 ab	5.27 c	5.16 bc	3.93 c
Talcum	13.18 a	5.89 a-c	4.29 cd	4.20 bc
Bentonite	13.39 a	6.36 a	4.85 cd	4.24 bc
$CaSO_4$	12.66 a	6.41 a	4.81 cd	4.82 a
$CaCO_3$	13.33 a	5.85 a-c	4.88 cd	4.21 bc
Zeolite	10.57 b	6.12 ab	5.67 ab	4.37 b
F-test	**	**	**	**
CV. (%)	11.30	8.67	8.17	5.51

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

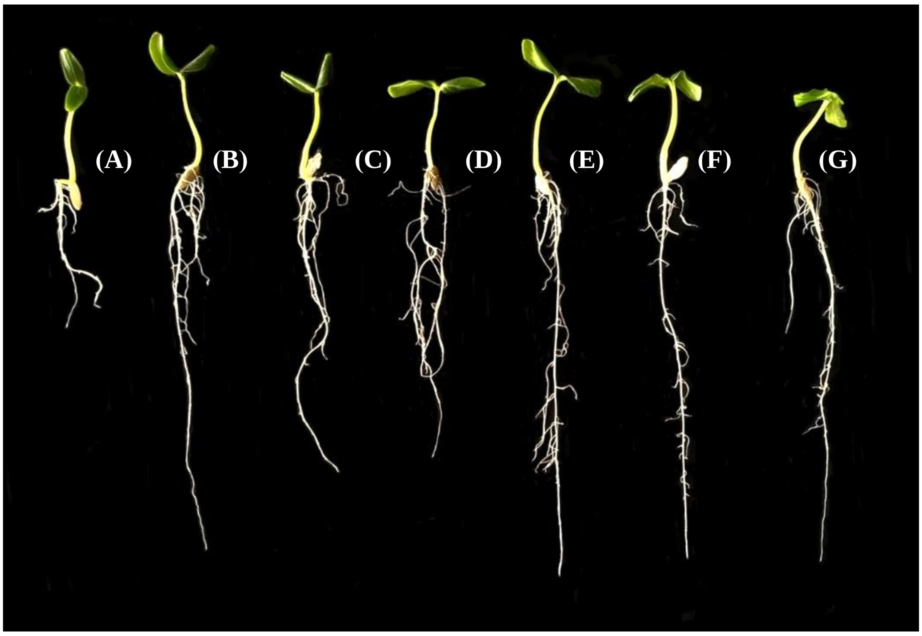

Figure 3. Effect of cucumber seeds pelleted with different matrices; radicle emergence 72 hours after planting and tested under laboratory conditions: (A) unpelleted seed; (B) pumice; (C) talcum; (D) bentonite; (E) calcium sulfate; (F) calcium carbonate; (G) zeolite.

3.3 Accelerated ageing tests

Under laboratory conditions, seed pelleting with $CaSO_4$, pumice, and zeolite showed higher and statistically significant germination rates compared to the other pelleting matrices (Figure 4A). Seed pelleting with talcum, bentonite, and $CaCO_3$ resulted in decreased radicle emergence compared to the other pelleting methods (Figure 4C). Under greenhouse conditions, seed pelleting with pumice showed higher germination rates but did not differ significantly from seed pelleting with $CaSO_4$, $CaCO_3$, and zeolite (Figure 4B). The emergence percentage showed that seed pelleting with bentonite had a higher emergence rate than other pelleting methods, followed by seed pelleting with talcum and $CaSO_4$ (Figure 4D).

Seed pelleting with $CaSO_4$ yielded higher quality seeds compared to other pelleting matrices. The process of pelleting seeds with $CaSO_4$ resulted in pelleted seeds with less friability, indicating that seed pelleting can help protect seed from unfavourable environmental conditions. Additionally, $CaSO_4$ contains important nutrients, such as calcium, which plays a crucial role in the synthesis of Ca, pectate, and protein and facilitates NO_3-N uptake. It also affects the activity of certain enzymes and increases protein synthesis in mitochondria (Liu *et al*., 2011). Furthermore, sulphur stimulates the activity of papainase enzymes, such as papain, bromelin, and ficin, as well as the synthesis of amino acids, including cysteine, cystine, and methionine, which are necessary for protein synthesis during seed germination (Bejandi, Sedghi, Sharifi, Namvar, & Molaei, 2009). Therefore, $CaSO_4$ is a superior pelleting matrix compared to the other treatments.

Torres & Filho (2003) found that accelerated ageing resulted in a lower percentage of melon seed viability and vigour. Similarly, this experiment showed a decrease in seed quality. However, Gawande, Mohapatra, & Johnson (1980) reported that seed pelleting material prevented various unfavourable environmental changes around the seed. This was demonstrated in the germination and radicle emergence percentage of $CaSO_4$ and zeolite pellets tested under laboratory conditions.

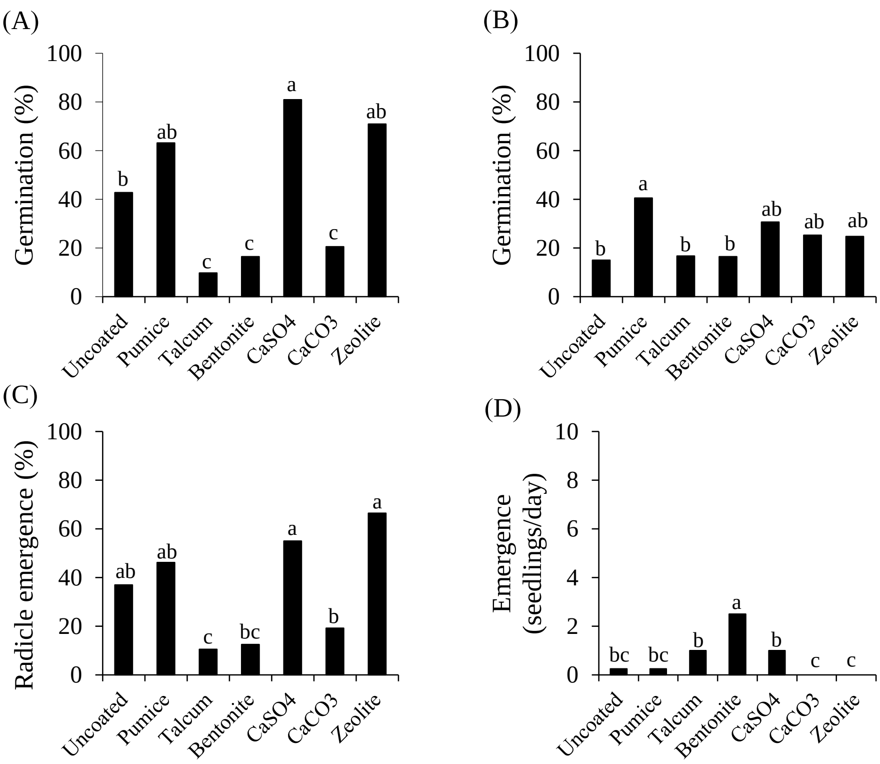

Figure 4. Germination and emergence (■) of accelerated aged pelleted cucumber seeds in the laboratory (A, C) and greenhouse (B, D).

4. Conclusions

Considering all of the physical properties, and laboratory and greenhouse tests, the best matrix material for the hybrid cucumber variety YokKaow seeds was $CaSO_4$ (50 g of $CaSO_4$) with the use of methylhydroxyethyl cellulose (0.3% w/w aqueous).

However, this experiment was merely an initial study. It is necessary to apply this seed pelleting formula to different environments for a period of 9–12 months to verify the long-term quality of the seeds. Additionally, it is important to plant the tested seeds in a field to compare their effectiveness with that of pelleted and unpelleted seeds.

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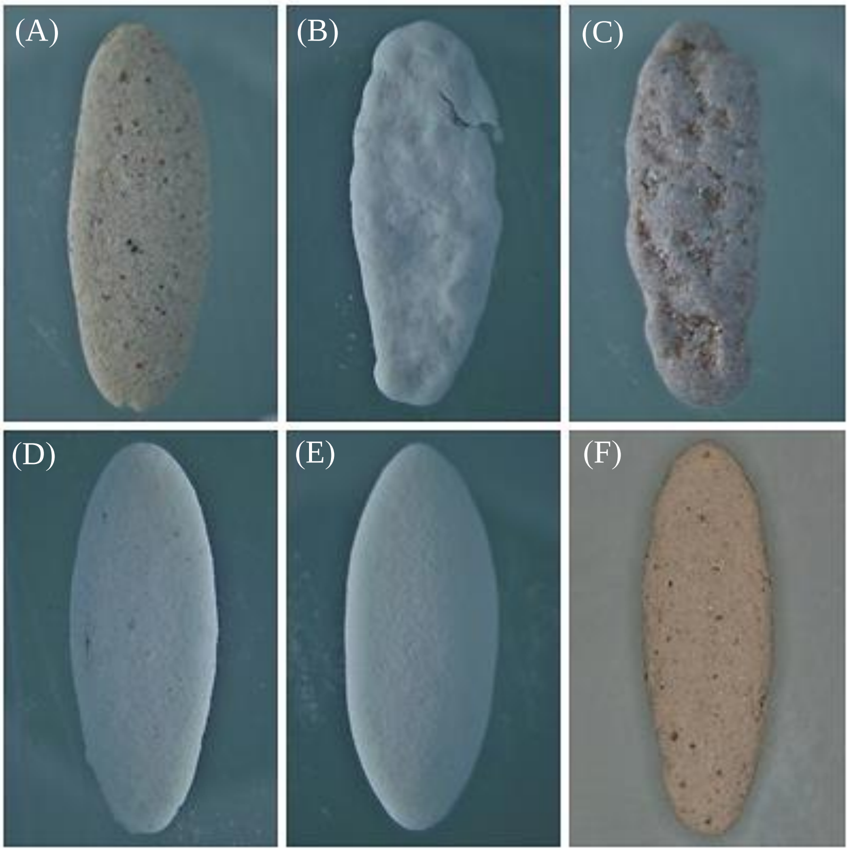

Figure 1. Physical appearance of cucumber seeds pelleted with difference matrices (10x Magnifications): (A) pumice; (B) talcum; (C) bentonite; (D) calcium sulfate; (E) calcium carbonate; (F) zeolite.

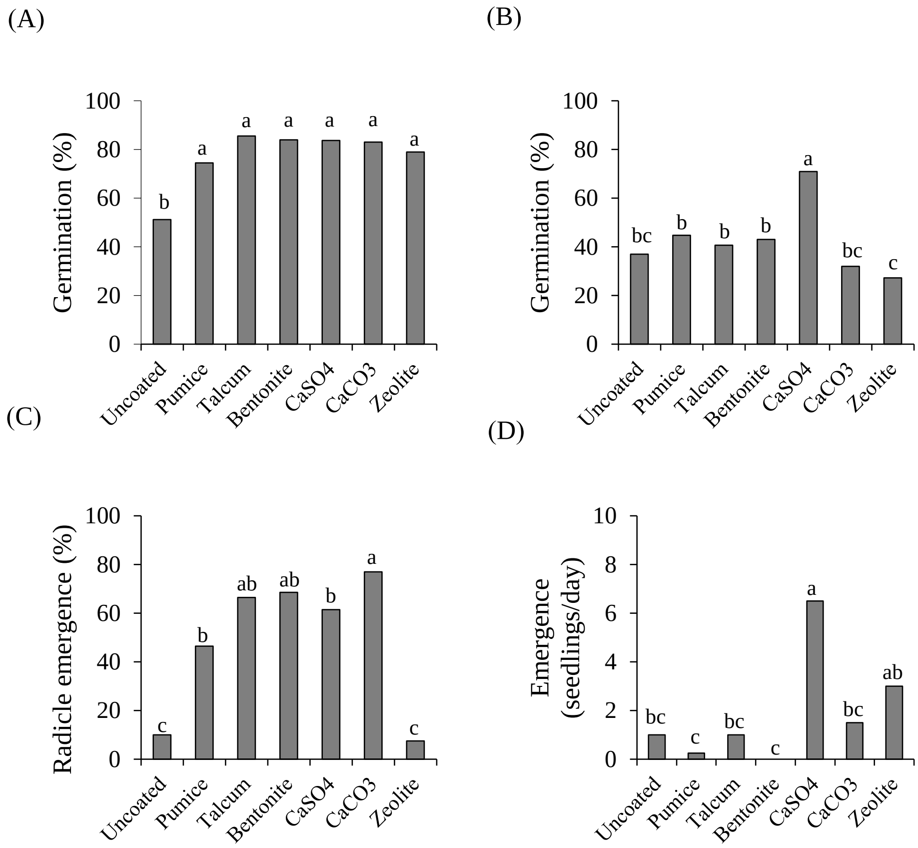

Figure 2. Germination and emergence (■) of pelleted cucumber seeds in the laboratory (A, C) and greenhouse (B, D).

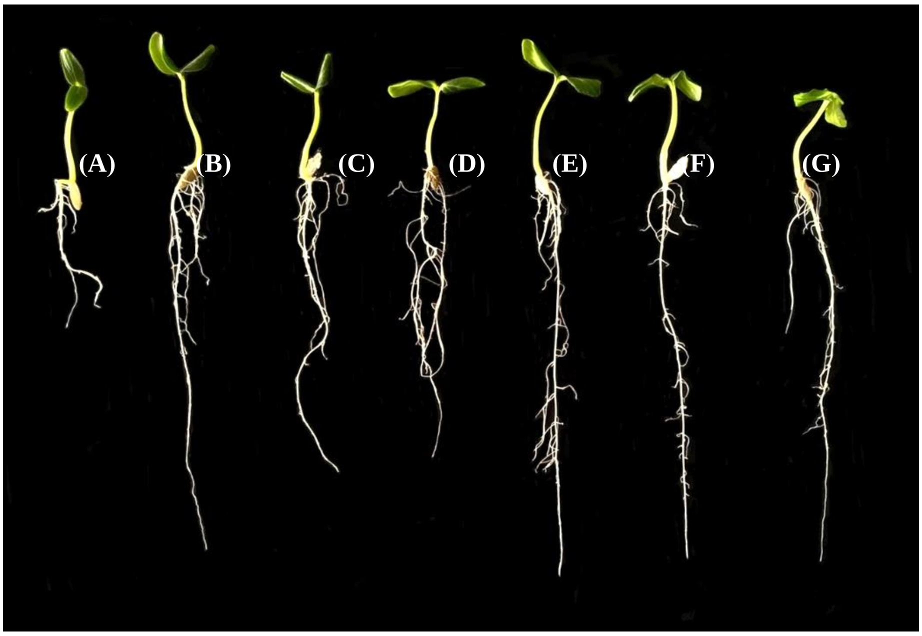

Figure 3. Effect of cucumber seeds pelleted with different matrices; radicle emergence 72 hours after planting and tested under laboratory conditions: (A) unpelleted seed; (B) pumice; (C) talcum; (D) bentonite; (E) calcium sulfate; (F) calcium carbonate; (G) zeolite.

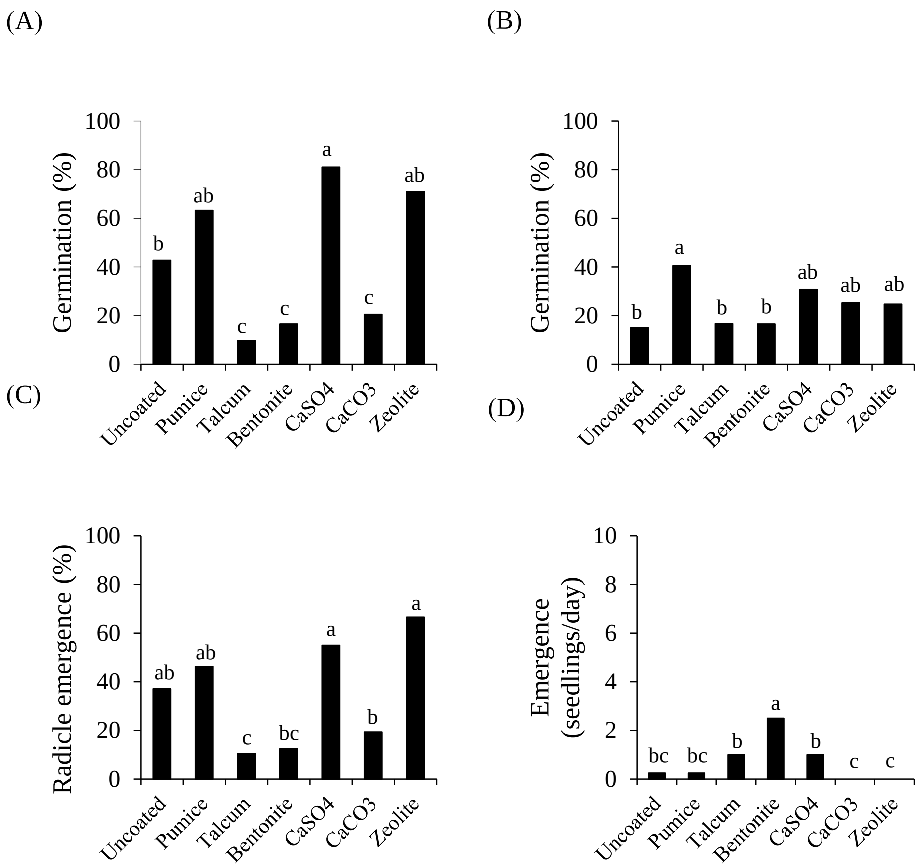

Figure 4. Germination and emergence (■) of accelerated aged pelleted cucumber seeds in the laboratory (A, C) and greenhouse (B, D).

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Treatment	Filler[1] (g)	MHEC[2] (g)
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Talc	50	0.3
Bentonite	50	0.3
$CaSO_4$	50	0.3
$CaCO_3$	50	0.3
Zeolite	50	0.3

All numbers represent weight of filler applied to 10 g of seed.
[1] Filler 2 is as indicated in the treatment column.
[2] MHEC = aqueous-methylhydroxyethyl cellulose.
NA: Not applicable.

Table 2. Physical property of pelleted cucumber seed with different pelleting materials.

Treatment	Forming	Seeds/pellet	Pellet 100-seeds weight (g)	Pellet dissolution (seconds)	Friability (%)
Unpelleted	-	-	2.31 g	-	-
Pumice	5	1.00 b	4.43 f	2.81 b	11.46 c
Talcum	5	1.25 a	5.75 b	2.30 b	64.54 a
Bentonite	1	1.50 a	5.00 d	1.70 b	37.96 b
$CaSO_4$	5	1.00 b	6.04 a	5.11 a	3.38 d
$CaCO_3$	4	1.00 b	5.47 c	1.27 b	62.87 a
Zeolite	4	1.00 b	4.58 e	1.62 b	8.74 d
F-test	-	**	**	**	**
CV. (%)	-	7.71	2.21	2.73	8.91

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

Table 3. Root length, shoot length and mean germination time of pelleted cucumber seeds under laboratory and greenhouse conditions.

Treatment	Laboratory			Greenhouse
	Root length (cm)	Shoot length (cm)	Mean germination time (day)	Shoot length (cm)
Unpelleted	7.75 c	5.34 bc	8.19 a	4.28 bc
Pumice	12.01 ab	5.27 c	5.16 bc	3.93 c
Talcum	13.18 a	5.89 a-c	4.29 cd	4.20 bc
Bentonite	13.39 a	6.36 a	4.85 cd	4.24 bc
$CaSO_4$	12.66 a	6.41 a	4.81 cd	4.82 a
$CaCO_3$	13.33 a	5.85 a-c	4.88 cd	4.21 bc
Zeolite	10.57 b	6.12 ab	5.67 ab	4.37 b
F-test	**	**	**	**
CV. (%)	11.30	8.67	8.17	5.51

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