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Marigold Seed Pelleting with Plant Nutrients on Germination, Growth, Storage and Flower Yields

Jakkrapong Kangsopa[1,2], Aranya Singsopa[1], Nararat Thawong[1], Sukanya Baomeesri[1], Davika Rapeebunyanon[1], Sirikorn Charoenyai[1]

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ABSTRACT

Background: Seed pelleting, a method involving seed coatings to enlarge seed size, is advantageous for marigold seeds because it improves water utilization efficiency during germination. Furthermore, the incorporation of vital plant nutrients into seeds fosters germination and growth, facilitating accelerated growth and increased yield in marigold plants.

Methods: Marigold seeds were pelleted with NH_4NO_3 at rates of 0.048, 0.096 and 0.192 g, $NaH_2PO_4.H_2O$ at rates of 0.064, 0.128 and 0.256 g and KCl at rates of 0.013, 0.026 and 0.052 g. Growth was determined after incubation in 4 × 6 inch bags for 56 days. Storage longevity was determined after incubation in aluminum foil bags under controlled (15°C, 50% RH) and ambient conditions (27±2°C, 70% RH) for 6 months.

Result: Seeds pelleted with NH_4NO_3, $NaH_2PO_4.H_2O$ and KCl demonstrated superior germination rates and germination speed. $NaH_2PO_4.H_2O$ pelleting led to increased shoot dry weight. The use of 0.256 g $NaH_2PO_4.H_2O$ resulted in the highest germination rate over 6 months. Pelleting with all three nutrients resulted in higher plants, particularly 0.256 g $NaH_2PO_4.H_2O$, which led to more flowers per plant. Therefore, pelleting seeds with 0.256 g $NaH_2PO_4.H_2O$ is recommended to optimize the quality of marigold seeds.

Key words: Active ingredient, Growth regulator, Seed enhancement, Seed quality.

INTRODUCTION

Cultivating marigolds in nurseries before transplant is a common practice in Thailand. However, the majority of marigold seeds available in the country are hybrids, resulting in flat, elongated and lightweight seeds with limited food storage content (Kangsopa *et al*., 2024). These characteristics lead to low germination rates, reduced seedling vigor and a short storage shelf life. Consequently, growers need to double the number of seeds, making marigold seeds expensive. Additionally, their flat and lightweight nature makes them prone to dispersal and loss during the seedling preparation process.

To address these issues, seed pelleting technology has been introduced to enhance the size, weight and shape of marigold seeds (Afzal *et al*., 2020). This method facilitates easier handling, reduces the risk of breakage upon contact and enables compatibility with seedling machines. Moreover, seed pelleting helps alleviate nutritional deficiencies in seeds by supplementing essential nutrients crucial for germination and early seedling growth, especially primary nutrients (Siri, 2015; Prakash *et al*., 2019; Sharma *et al*., 2019; Panwar *et al*., 2023). This technology proves to be a promising solution for improving the efficiency and cost effectiveness of marigold seedling preparation. Nitrogen is critical for the synthesis of proteins and enzymes. During germination, it supports the conversion of stored proteins into amino acids and provides the necessary building blocks for growing seedlings (Osuna *et al*., 2015). Phosphorus is a key component of adenosine triphosphate (ATP), the energy currency of cells. It plays a vital role in energy transfer processes during germination, ensuring the efficient utilization of stored energy in the seed (Yang, 2018). Potassium is involved in enzyme activation and the regulation of water uptake. It helps maintain turgor pressure in cells, allowing the seed to take up water and swell during germination. Additionally, potassium aids in the breakdown of starch into sugars, providing an energy source for emerging seedlings (Sivanesan *et al*., 2011). These primary nutrients facilitate the biochemical processes necessary for the mobilization of stored reserves, energy transfer and the overall metabolic activities that lead to successful seed germination. Therefore, this research has the potential to be beneficial in addressing issues related to the use of seeds with internal quality factors, inappropriate

[1]Division of Agronomy, Faculty of Agricultural Production, Maejo University, Chiang Mai 50290, Thailand.
[2]Modern Seed Technology Research Center, Faculty of Agricultural Production, Maejo University, Chiang Mai 50290, Thailand.

Corresponding Author: Jakkrapong Kangsopa, Division of Agronomy, Faculty of Agricultural Production, Maejo University, Chiang Mai 50290, Thailand. Email: jakkrapong_ks@mju.ac.th

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morphology and short storage life. This, in turn, could lead to improved seed quality and an extended storage life, making them more suitable for prolonged cultivation.

Thus, the research aimed to examine changes in the germination, seedling vigor, longevity and yield of marigolds. This study seeks to enhance the efficiency of utilizing high-value yet uncertain quality seeds in the seedling preparation process while concurrently reducing cultivation costs for marigold growers.

MATERIALS AND METHODS

Marigold seed pelleting with plant nutrients

The present experiment was conducted at the Division of Agronomy, Faculty of Agricultural Production, Maejo University, Chiang Mai, from February 2023 to December 2023. Seeds of the hybrid marigold variety Sri Siam Deep Gold (AFM Flower Seeds Co., Ltd., Chiang Mai, Thailand) were utilized. The initial seed quality resulted in a germination rate of 58%, purity of 98% and moisture content of 8%. The marigold seeds were surface-sterilized with 1% sodium hypochlorite (NaOCl) for 10 seconds, washed with sterilized distilled water three times and dried with sterilized tissue paper. The seed pelleting formula for marigold followed the method described by Kangsopa *et al*. (2024). The marigold seed pelleting formula incorporated three types of plant nutrients with concentrations adapted from Kangsopa (2018) NH_4NO_3, $NaH_2PO_4.H_2O$ and KCl. The study comprised 11 methods, including non-pelleted seeds (T1); pelleted seeds with calcium sulfate (T2); NH_4NO_3 at rates of 0.048, 0.096 and 0.192 g (T3, T4 and T5, respectively); $NaH_2PO_4.H_2O$ at rates of 0.064, 0.128 and 0.256 g (T6, T7 and T8, respectively); and KCl at rates of 0.013, 0.026 and 0.052 g (T9, T10 and T11, respectively). Subsequently, the seeds underwent dehumidification and drying in a forced-air seed dryer at 35°C until the moisture content of the pelleted seeds reached approximately 7%. The investigation into the quality of the seeds pelleted with plant nutrients encompassed the germination percentage, germination speed, radicle emergence, seed storage, seedling growth, plant height and flower yields.

Seed storage in different conditions

The seeds were packaged in aluminum foil bags, with each treatment containing 20 g. All treatments were stored under controlled (15°C and 50% RH) and ambient conditions (27±2°C and 70% RH) for 6 months. At 2-month intervals, 50 seeds per replication per treatment under both storage conditions were collected and seed germination was tested under both laboratory and greenhouse conditions.

Seed measurement

Seed quality examination under laboratory conditions

The quality testing of 50 marigold seeds, both pelleted and non-pelleted, 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 using multiple measurements. The germination percentage was assessed in normal seedlings on days 5 (first count) and 14 (final count) (ISTA, 2019). The germination speed was assessed daily by counting the number of normal seedlings 5 to 14 days after sowing (AOSA, 1983). Normal seedlings were assessed daily for 14 days to determine the mean germination time (Ellis and Roberts, 1980). The mean shoot length and root length were determined in 10 seedlings 14 days after sowing (Jeephet *et al*., 2022). Subsequently, each part of the plants for each treatment was oven-dried at 60°C for 72 hours and then used to evaluate shoot and root dry weight.

Seed quality examination in greenhouse conditions

Germination testing of marigold seeds, both pelleted and non-pelleted, was carried out in seed trays with peat moss (Klasmann-Deilmann GmbH, Ltd., Germany), which was used as the seeding material. The first germination evaluations were assessed 5 days after sowing and the final count was recorded 14 days after sowing (ISTA, 2019). The germination speed was assessed in the same way as that determined under laboratory conditions. Shoot length and fresh shoot weight were assessed 14 days 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).

Plant growth and flower yield

Planting materials were prepared by mixing coconut coir, shredded coconut husk and potting soil at a ratio of 2:2:1. The mixture was placed in 4 × 6 inch planting bags. The plant height was evaluated every 7 days until reaching 56 days after sowing. Measurements were recorded from the base to the tip of the leaves using centimeters as the unit of measurement. At 56 days after sowing, the marigold plants were cut from all bloomed flowers and the sizes of the marigold flowers were categorized according to the standard (Tan-ut *et al*., 2017). This was measured by the diameter across the center of the flower, resulting in 3 sizes as follows: large size, 7.5-8 cm; medium size, 6-7 cm; and small size, 4-5 cm.

Statistical analysis

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

RESULTS AND DISCUSSION

Marigold seed pelleting on seed germination

In the laboratory, seeds pelleted with 0.192 g NH_4NO_3, 0.256 g $NaH_2PO_4.H_2O$ and 0.013 g KCl showed higher germination rates and faster germination compared to non-pelleted

seeds. The mean germination time revealed that pelleting seeds with 0.256 g $NaH_2PO_4.H_2O$ supported quicker germination consistent with greenhouse experiments (Table 1). Seeds pelleted with 0.256 g $NaH_2PO_4.H_2O$ maintained superior germination rates and faster germination than other methods observed under both laboratory and greenhouse conditions. This may be attributed to the flattened shape of pelleted seeds and nutrient accumulation, allowing the pelleting method to retain essential moisture, which is better for germination. Moreover, the addition of $NaH_2PO_4.H_2O$ and KCl promoted germination compared to the non-pelleted seeds. Seed pelleting enhances nutrient absorption and improves chemical processes (Siri, 2015). Pelleting seeds with nutrients contributes to better moisture retention, supporting germination (Anagha *et al*., 2021; Pedrini *et al*., 2021). Furthermore, as they are crucial for biochemical processes, increasing $NaH_2PO_4.H_2O$ and KCl also enhance germination compared to non-pelleted seeds. Phosphorus, a vital element in ATP, activates enzymes, breaking down complex seed substances (Lambers, 2022). Additionally, potassium in plant cells ensures energy and nutrient provision for successful germination. Variations in germination rates and speed were observed when pelleting seeds with 0.192 g NH_4NO_3 under laboratory conditions. Testing with the paper-based method under controlled humidity and nutrient levels yields more distinct results than greenhouse experiments. Nitrogen, which supports protein synthesis, enzyme activation, nucleic acid formation and energy transfer during seed germination (Osuna *et al*., 2015), plays a pivotal role in enhancing the quality of pelleted seeds, surpassing non-pelleted seeds. Therefore, germination and vigor were promoted by pelleting seeds with 0.256 g $NaH_2PO_4.H_2O$ considering outcomes from both laboratory and greenhouse conditions.

Marigold seed pelleting on seedling growth

Under laboratory conditions, all seed pelleting methods (T2-T5) showed significantly increased shoot lengths compared to non-pelleted seeds. These increases were 47%, 53%, 72% and 54% respectively, for (T2-T5) when compared to non-pelleted seeds. Pelleting seeds with 0.013 g KCl resulted in a significant increase in root length and dry root weight compared to non-pelleted seeds. On the contrary, pelleting seeds with 0.256 g of $NaH_2PO_4.H_2O$ resulted in a significant increase in shoot dry weight and a 62% increase compared to non-pelleted seeds. Under greenhouse evaluations, pelleting seeds with 0.256 g of $NaH_2PO_4.H_2O$ resulted in consistently higher shoot lengths and shoot dry weights compared to the other methods. This led to an increase of 67% and 133%, respectively, when compared to non-pelleted seeds. Examining pelleted seeds revealed a trend of increased seedling growth, particularly in shoot length, with 0.256 g $NaH_2PO_4.H_2O$ exhibiting a significant change (Table 2). Seed pelleting significantly supports moisture retention for seeds to use in the germination process (Siri, 2015; Jeephet *et al*., 2022). Direct phosphorus application through the pelleting material allows seedlings to immediately benefit from $H_2PO_4^-$ and HPO_4^{2-}, crucial for ATP formation and various metabolic activities (Yang, 2018; Lambers, 2022). The results from the experiments were clearly observed under greenhouse conditions. Even though there was some leaching through the moisture application stage, the experimental outcomes were still aligned with those conducted in the laboratory setting. For changes in seedling root length, significant alterations were observed with 0.013 g KCl. When roots receive K^+ after germination, they efficiently absorb nutrients, promoting water and nutrient absorption (Oosterhuis *et al*., 2014). This corresponds to the faster germination observed in seeds with well-developed root systems that effectively absorb

Table 1: Germination percentage (GP), speed of germination (SGP) and mean germination time (MGT) of marigold seed after pelleting with different types of plant nutrient, tested under laboratory and greenhouse conditions.

Treatment[1]	Laboratory condition			Greenhouse condition		
	GP (%)	SGP (plant/day)	MGT (day)	GP (%)	SGP (plant/day)	MGT (day)
T1	58ab[2, 3]	4.65ab	2.46a	53c	4.07b	2.07a
T2	51b	3.87b	2.28a	54c	4.10b	1.99ab
T3	65a	5.10a	1.94ab	61b	4.98ab	1.50b
T4	65a	4.97a	1.42b	70a	5.73a	1.50b
T5	64a	5.21a	1.68ab	62b	4.94ab	1.45b
F-test	**	**	**	**	**	**
CV.%	11.51	19.10	18.68	12.87	22.99	26.37

**: Significantly different P≤0.01.

[1]T1= Non-pelleted seed, T2= Pelleted with calcium sulfate (CS), T3= Pelleted with NH_4NO_3 0.192 g., T4= Pelleted with $NaH_2PO_4.H_2O$ 0.256 g. and T5= Pelleted with KCl 0.013 g.

[2]Data are transformed by the arcsine before statistical analysis and back transformed data are presented.

[3]Means within a column followed by the same letter are not significantly at P≤0.05 by DMRT.

the necessary nutrients. Furthermore, chloride ions (Cl^-) contribute to the osmotic balance within plant cells, influencing cell turgor pressure and maintaining structural integrity (Dadach *et al*., 2023). Therefore, with these factors, they promote and support distinct changes in both shoot and root lengths, as mentioned previously.

Marigold seed pelleting on seed storage

Under controlled conditions, pelleting seeds with 0.256 g $NaH_2PO_4.H_2O$ resulted in the highest germination rate over a storage period of 6 months, as assessed under laboratory conditions. Under greenhouse conditions, seeds pelleted with 0.256 g $NaH_2PO_4.H_2O$ exhibited significantly higher germination rates compared to the other treatments and were statistically different from non-pelleted seeds. Even after storage for 2-6 months, seeds pelleted with 0.256 g $NaH_2PO_4.H_2O$ maintained higher germination rates compared to the other methods (Table 3). Under ambient conditions, pelleting analysis revealed that seeds pelleted with 0.256 g $NaH_2PO_4.H_2O$ maintained significantly higher

Table 2: Shoot length (SHL), root length (RL), shoot dry weight (SDW) and rot dry weight (RDW) of marigold seed after pelleting with different types of plant nutrient, tested under laboratory and greenhouse conditions.

Treatment[1]	Laboratory condition				Greenhouse condition	
	SHL (cm)	RL (cm)	SDW (mg)	RDW (mg)	SHL (cm)	SDW (mg)
T1	6.26b[2]	3.18b	210b	130b	2.94c	288d
T2	9.22a	3.35ab	230b	220ab	3.89b	400c
T3	9.56a	3.57ab	290ab	230ab	4.22ab	536b
T4	10.76a	3.83ab	340a	240ab	4.91a	670a
T5	9.66a	4.13a	300ab	260a	4.43ab	520b
F-test	*	**	**	*	**	*
CV.%	13.62	15.79	15.07	30.15	20.62	11.03

*,**: Significantly different at P≤0.05 and P≤0.01, respectively.

[1]T1= Non-pelleted seed, T2= Pelleted with calcium sulfate (CS), T3= Pelleted with NH_4NO_3 0.192 g., T4= Pelleted with $NaH_2PO_4.H_2O$ 0.256 g. and T5= Pelleted with KCl 0.013 g.

[2]Means within a column followed by the same letter are not significantly at P≤0.05 by DMRT.

Table 3: Germination percentage[2] of stored marigold seeds at 2 months intervals months for 6 months using different plant nutrients under laboratory and greenhouse conditions.

Treatment[1]	Laboratory condition[2]				Greenhouse condition			
	After pelleting	2 M[4]	4 M	6 M	After pelleting	2 M	4 M	6 M
Controlled condition								
T1	40b[3]	34b	39b	38b	39b	27b	20b	16b
T2	43b	34b	38b	39b	44ab	23b	18b	25ab
T3	52ab	40ab	41ab	42ab	46ab	30b	29ab	26ab
T4	54a	49a	50a	51a	50a	43a	34a	28a
T5	51ab	45ab	38b	37b	48a	27b	22b	20ab
F-test	**	**	**	**	**	**	**	**
C.V.%	6.58	6.71	9.24	8.69	11.78	11.51	16.47	15.17
Ambient condition								
T1	40b	32c	32b	26b	39b	18b	24b	7b
T2	43b	37a-c	31b	24b	44ab	23ab	27b	10ab
T3	52ab	43a	36ab	34a	46ab	25ab	32ab	10ab
T4	54a	41ab	39a	39a	50a	39a	35a	14a
T5	51ab	35bc	38a	31ab	48a	28a	33a	13a
F-test	**	**	**	**	**	**	**	**
C.V.%	6.58	8.43	10.73	11.02	11.78	11.08	16.47	19.79

**:Significantly different at P≤0.01.

[1]T1= Non-pelleted seed, T2= Pelleted with calcium sulfate (CS), T3= Pelleted with NH_4NO_3 0.192 g., T4= Pelleted with $NaH_2PO_4.H_2O$ 0.256 g. and T5= Pelleted with KCl 0.013 g.

[2]Data are transformed by the arcsine before statistical analysis and back transformed data are presented.

[3]Means within a column followed by the same letter are not significantly at P≤0.05 by DMRT.

[4]M= Month after seed storage.

germination rates compared to non-pelleted seeds. Moreover, even after a 6-month storage period, this method consistently outperformed other techniques and non-pelleted seeds, as observed under laboratory conditions. Under greenhouse conditions, seeds pelleted with 0.256 g $NaH_2PO_4.H_2O$ and 0.013 g KCl exhibited significantly higher germination rates compared to the other methods (Table 3).

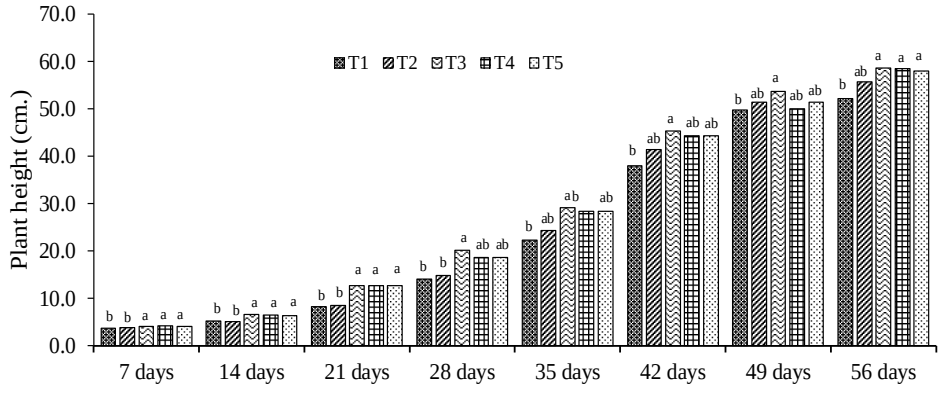
Under storage conditions, two environments, namely controlled and ambient conditions, demonstrated varying qualities of seed viability over a 6-month storage period. Storage under ambient conditions distinctly revealed a decline in seed quality after 4 months of storage. However, seeds pelleted with all three types of plant nutrients showed an elevated level of seed quality, with significantly higher germination rates than non-pelleted seeds. Particularly noteworthy is the pelleting method using 0.256 g $NaH_2PO_4.H_2O$, a phosphorus compound, which significantly enhanced seed germination compared to the other methods. Experimental results support the idea that supplementing seeds with nutrients improves seed vigor after extended storage periods. Bhatt *et al*. (2022) showed that temperature is a crucial factor in seed deterioration and germination regulation. Storing seeds at room temperature often leads to decreased germination rates, seed deterioration and viability loss, which are natural phenomena during storage (Nasreen *et al*., 2000). The combination of nutrient supplementation and pelleting methods unequivocally enhanced seed germination under both storage conditions.

Marigold seed pelleting on plant height

After testing marigold growth at 7, 14 and 21 days after sowing, pelleting seeds with all three types of plant nutrients resulted in significantly greater plant height compared to non-pelleted seeds and seeds pelleted with calcium sulfate. Evaluations between 28 and 49 days showed that pelleting seeds with 0.192 g NH_4NO_3 resulted in taller marigold seedlings compared to other methods, with statistically significant differences observed compared to non-pelleted seeds. However, seeds pelleted with all three types of plant nutrients did not differ in height but were significantly taller compared to non-pelleted seeds 56 days after sowing (Fig 1). These results indicate that pelleting seeds with NH_4NO_3, containing nitrate (NO_3^-) and ammonium (NH_4^+), played a crucial role in stimulating and regulating various enzyme activities during seed germination and early cell division in seedlings (Osuna *et al*., 2015; Coskun *et al*., 2016). Additionally, the application of $NaH_2PO_4.H_2O$, providing $H_2PO_4^-$ and HPO_4^{2-}, which are crucial for synthesizing enzymes involved in plant growth, has been documented (Marschner, 2012; Oosterhuis *et al*., 2014). Furthermore, adequate phosphorus facilitates the conversion of starch and sugar into cellular energy in plants, enhancing their capacity to synthesize active compounds and promote healthier growth, potentially resulting in increased plant height (Oosterhuis *et al*., 2014). Moreover, pelleting seeds with KCl in the form of K^+ has been found to stimulate photosynthesis and improve the absorption of water and nutrients by roots (Marschner, 2012). Plant nutrients demonstrate their role in promoting faster seed germination, thereby providing seedlings with essential nutrients around the root zone and accelerating growth compared to seeds lacking necessary nutrients (Tanaka and Makino, 2009). Rapid growth and development of seedlings increase the chances of synthesizing and acquiring nutrients quickly compared to non-pelleted seeds. When considering a period of 30 days onwards, it is evident that seedlings pelleted with plant nutrients exhibited increased height and accelerated growth compared to non-pelleted seeds.

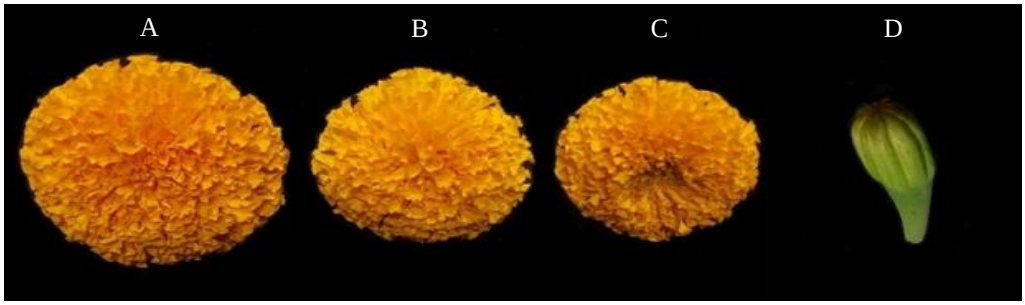
Marigold seed pelleting on flower yields

At 56 days after sowing, flower yield evaluation revealed comparable average yields among plants of all three size



[1]T1= Non-pelleted seed, T2= Pelleted with calcium sulfate (CS), T3= Pelleted with NH_4NO_3 0.192 g., T4= Pelleted with $NaH_2PO_4.H_2O$ 0.256 g. and T5= Pelleted with KCl 0.013 g. Within each graph, bars with different letters at the top are significantly different (p<0.05).

Fig 1: Plant height of marigold after pelleting different types of plant nutrient, tested under greenhouse condition.



Flower sizes: A= Large size (7.5-8 cm), B= Medium-sized (6-7 cm), C= Small-sized (4-5 cm) and D= Bud-sized (1-2 cm).

Fig 2: Marigold yield component 56 days after planting.

Table 4: Marigold yield of marigold after pelleting different types of plant nutrient, tested under greenhouse condition.

Treatment[1]	Marigold yield component (no. of flower/plant)		Flower size (no. of flower/plant)		
	Flower bud	Flower blooming	Large	Medium	Small
Non-pelleted seed	3.4b[1]	3.3b	1.0b	1.0	1.3
Pelleted with calcium sulfate (P)	3.3b	3.3b	1.0b	1.0	1.3
P + NH_4NO_3 0.192 g.	3.9ab	3.9ab	1.0b	1.1	1.8
P + $NaH_2PO_4.H_2O$ 0.256 g.	4.7a	4.8a	2.0a	1.1	1.8
P + KCl 0.013 g.	3.9ab	3.6ab	1.0b	1.1	1.5
F-test	**	**	*	ns	ns
C.V. %	8.58	10.89	7.42	5.04	4.68

ns,*,**: Not significantly difference and significantly different at P≤0.05 and P≤0.01, respectively.

[1]Means within a column followed by the same letter are not significantly at P≤0.05 by DMRT.

categories. Pelleting seeds with 0.256 g $NaH_2PO_4.H_2O$ resulted in a significantly higher flower count per plant. Flowers of large size measure 7.5-8 cm, medium-sized flowers measure 6-7 cm, small-sized flowers measure 4–5 cm and bud-sized flowers measure 1-2 cm (Fig 2). There was no statistically significant difference in the number of medium- or small-sized flowers per plant across all treatments. Moreover, pelleting seeds with 0.256 g $NaH_2PO_4.H_2O$ led to a substantially higher number of blooming flowers per plant compared to the other methods (Table 4). Pelleting seeds with all three types of plant nutrients promoted significantly greater height compared to non-pelleted seeds. These findings support plants in synthesizing growth nutrients more rapidly. Furthermore, seeds pelleted with 0.256 g $NaH_2PO_4.H_2O$ exhibited a higher number of flower buds compared to the other methods. Phosphorus from $NaH_2PO_4.H_2O$ enhances root growth and nutrient uptake efficiency (Chen *et al*., 2023). Additionally, it plays a crucial role in ATP production and serves as an energy transporter in various cellular processes (Chen *et al*., 2018). It promotes root elongation, branching and overall root structure, enabling efficient water and nutrient absorption, thus fostering robust plant growth. Phosphorus is also essential for deoxyribonucleic acid (DNA) and ribonucleic acid (RNA), critical molecules in cell division, protein synthesis and cellular functions (Chen *et al*., 2018). Acharya *et al*. (2020) advocated that enhancing seed quality can improve seed germination, potentially leading to increased growth and yield. Therefore, this experiment provides a method to increase the likelihood of uniform and rapid seed germination, facilitating rapid plant development. Consequently, plants become more robust and productive. Kangsopa *et al*. (2024) further supported the idea that seed encrusting of yellow pea seeds with plant nutrients increases the number of seeds per pod, pods per plant, seed weight per pod and pod weight per plant compared to untreated seeds.

CONCLUSION

The pelleting method using 0.256 g $NaH_2PO_4.H_2O$ resulted in superior seed quality, increased plant height and higher flower yields, as evidenced by the enhanced germination rate, speed of germination, shoot length, shoot dry weight and flower yields. Furthermore, it exhibited good storage quality for up to 6 months, with only a slight reduction in germination when stored under controlled conditions. Hence, this formulation method is recommended as the optimal approach for improving marigold seed quality.

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Conflict of interest

All authors declared that there is no conflict of interest.

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