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Advancements in Seed Treatment Methods and Storage Techniques of Marigold Seeds: An Overview

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Authors' contributions

This work was carried out in collaboration among all authors. 'All authors read and approved the final manuscript.

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ABSTRACT

Floriculture plays a pivotal role in boosting national economies by driving foreign exchange revenues. However, current productivity levels in floriculture, particularly in marigold (*Tagetes spp.*), are insufficient to meet the escalating global demand for ornamental flowers. Marigold, being one of

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the most commercially significant crops in this sector, requires improved seed quality to achieve optimal performance and higher yields. Major constraints, such as the limited availability of high-quality seeds, and the rapid decline in seed viability during storage, continue to hamper productivity. Additionally, conventional seed treatment practices and storage methods often fail to sustain seed vigour and germination rates over extended periods. This review offers an in-depth analysis of the latest advancements in seed treatment technologies and storage practices to enhance germination, disease resistance, and seedling establishment. By integrating the insights from seed treatments and post-harvest storage of seeds, this review paper addresses key challenges faced by the floriculture industry and aligns with the growing global demand for high-quality floral crops.

Keywords: Marigold; Tagetes erecta; seed pelleting; seed priming; seed treatment; storage; gamma irradiation; oil content; moisture content; relative humidity; temperature; storage containers.

1. INTRODUCTION

Marigold is a flower crop belonging to the Asteraceae family (Hoshi et al. 2019). Commonly cultivated marigold species are *Tagetes erecta* (African Marigold) and *Tagetes patula* (French Marigold), originated from Mexico and South Africa, respectively (Panda et al. 2021). The colours of African marigold flowers range from yellow, orange, gold, and red (Sowbhagya et al. 2004). In India, loose marigold flowers are used to create garlands, and ornamental flowers are used in landscape gardening (Riaz 2020).

Marigold has enormous potential for value addition, so it is gaining significant importance in the industry (Kanwar and Khandelwal 2013). Natural pigments and dyes have a wide range of usages currently including the culinary, cosmetic, medicinal, and fabric sectors. The risks associated with using artificial dyes and pigments on organisms and the environment made natural pigments and dyes an alternative (Venil et al. 2013). Flowers of marigold can be used as a natural source of phenolics (Manivannan et al. 2021). The main constituents of marigold flowers are patulitrin, quercetagetin, isorhamnetin, kaempferol and patuletin (Sanjaya et al. 2024). The lutein pigment naturally present in marigold can be extracted from marigold flower petals (Bosma et al. 2003, Deineka et al. 2007). Lutein can be used forcolouring and enhancingfood with nutrients (Kashyap et al. 2022). Lutein has antioxidant properties and it is a wise choice for eye health protection (Sowbhagya et al. 2004).

The essential oil and carotenoid extracts of marigolds have wide use in the food, medicine, cosmetic, and textile industries (Siriamornpun et al. 2012, Adeelet al. 2017). Marigold flowers are utilized in the production of poultry feed as they enhance the colour (Rajput et al. 2012). It can be also used as an analgesic and as a medicine for anti-inflammation (Bashir et al. 2008). Marigolds have antibacterial, fungicidal, insecticidal, mosquito-cidal, herbicidal qualities (Dharmagadda et al. 2005, Nikkon et al. 2011, Salinas-Sánchez et al. 2012, Du et al. 2017) which make them useful in many organic agricultural domains, particularly in vegetable culture (Santos et al. 2015). Marigold plantation as intercrop reduces nematode population (Hooks et al. 2010) and it can also be used as a trap crop for tomato fruit borer (Scarlato et al. 2023).

Since seeds are living things, during storage, their viability and vigour begin to decline even on the parent plant gradually, and consequently, they lose the capacity to germinate and produce healthy seedlings (Ellis 2019). Until subsequent sowing and marketing per demand, the seeds with optimum germination, vigour, and seed health must be maintained. The biggest bottlenecks in marigold production are poor seed set, non-availability of quality seeds (Meena et al. 2015), and loss of vigour and viability of the seeds during post-harvest storage (Rao et al. 2003). Production and supply of quality and vigorous seeds are important for the successful cultivation of flower crops. The demand for quality seeds is increasing among farmers and specific technologies are needed to improve seed yield and quality. Thus, management practices such as seed treatments, proper storage of seeds, *etc*. are required to achieve the same.

Seed enhancements may boost the quality toguarantee the accessibility of high-quality seed lotsfor sowing. Seed enhancement can be defined as the post-harvest treatments which improve seed germination or growth of seedlings that must be applied before sowing. Also, seed treatments play a key role in protecting the seeds from insects and pathogens at the emergence and early growth stages (Moumni et al.2023) and preserving the seeds for a long period without any contamination or deterioration. Tomaintain the planting value of seeds in field circumstances, it is also crucial to select proper seed packaging materials and storage conditions that will help to lengthen the longevity of the seeds. Careful handling throughout the storage phase can lessen the quantitative and qualitative loss of seed (Wainaina et al. 2023). This review encompasses current advances in improving the marigold seed quality through various pre-sowing seed treatments and proper post-harvest storage of seeds.

Seed characteristics: Marigold seeds are called achenes and have a simple, dry, one-seeded, indehiscent fruit with a thin but protective layer around the seed. Marigold seeds are plentiful in carotenoid chemicals, namely zeaxanthin and lutein. Essential oils extracted from marigold seeds have several constituents, including limonene, ocimene, and β-caryophyllene (Salehi et al. 2018) and a significant quantity of fatty acids (Hassanpouraghdam et al. 2011). Pusa Narangi Gaindagenotypes had the maximum oil content in seeds (36.73% and 33.10%), followed by Pusa Basanti Gainda (35.47 and 31.26%) at physiological and harvest maturity (Murali et al. 2019). The oil content of the mature seed heads increases and then beginsto decrease as they approach harvest maturity (Baydar 2005). Proteins or carbohydrates did not affect the longevity of seeds, but seeds with oil as their primary seed storage component had a shorter lifespan (Nagel and Borner 2010). Therefore, the viability of these seeds gets reduced within a short period. Proper management techniques are needed to maintain the vigour and viability of marigold seeds. Using the right pre-sowing seed treatments and optimizing seed storage are the two key actions that may be taken to improve the quality and maintain the viability of the seeds.

1.1 Enhancing Marigold Seed Quality through Pre-sowing Seed Treatments

Seed treatments will help improve the germination percentage, seedling quality characters, and crop growth. When treated, seeds become more resistant to pests, diseases, and environmental stresses. To promote seed development and address their challenges, seed treatment is an essential step. Seed treatments include physical, physiological, chemical, and biological treatments. Numerous plant aspects that boost production can be optimized by applying physical treatmentsin the right amounts (Liberatore et al. 2018). Physiological seed treatments assisted in overcoming dormancy and enhanced the seed germination percentage (Hashemirad et al. 2023). Chemical seed treatments can be used against insects, and soilborne and seed-borne pathogens to enhance vigour and crop growth (Mengesha et al. 2022). The relatively low quantity of pesticides used reduces environmental impact compared to broadcast applications. Biological seed treatments have gained more popularity within a short time (Sharma et al. 2015) and it also improves the seed parameters (Lamichhane et al. 2022). Due totheir socioeconomic benefits and safety for the environment, physical and biological seed treatments are being utilized extensively as substitutes forchemical treatments, either alone or in tandem with one another. In terms of ease of implementation, chemical treatments are generally simple and quick to apply, requiring minimal technical knowledge. Biological treatments, however, may require more expertise in handling live microorganisms and ensuring optimal conditions for their efficacy. Physical treatments, although effective, often involve the use of specialized equipment and may be less accessible to small-scale farmers due to higher initial costs. Continued research and innovation focused on increasing efficacy, safety, and ease of adoption of seed treatments will further help farmers and communities dependent on thriving agriculture.

Physical seed treatments: Physical ways of stimulating plant growth have gained popularity recently since they have less negative environmental effects. Physical factors can be utilized to induce positivechanges in seeds (Guiyun et al. 2022). The application of physical factors in appropriate doses can be an effective way to enhance many plant parameters that increase their productivity. Seed coating, seed pelleting, gamma irradiation, seed encrustation, seed colouring and other techniques are examples of physical seed treatment techniques. The two most promising of these are magnetic seed treatment and irradiation with ionizing radiation (Araujo et al. 2016).

Gamma irradiation: In comparison to other ionizing radiations, gamma rays are more cost-effective and have a greater penetration power, which allows for a wider range of applications for enhancing the performance of seeds (Hojjati et al. 2023). It has been depicted that gamma irradiation at low concentrationscan improve seed traits (Melki 2010, Maity et al. 2009). Low levels of gamma irradiation may improve the adaptive properties of seeds in unfavourable conditions (Oliveira et al. 2021). Ionizing radiation quickly pervades the polysaccharide granule, allowing for a quicker, simpler, and more effective radiation treatment (Bao et al. 2005).

Marigold seeds can be treated with lower doses of gamma irradiation for improved seed germination percentage (86%) (Aravind and Dhanavel 2021). Seeds of African marigold cv. 'Pusa Narangi Gainda' were exposed to gamma rays at doses of 0, 100, 200, 300, and 400 grays toinduce mutation. Shortly after radiation, seeds were sown, and 30 days old seedlings were transplanted. African marigold seeds exposed to 100 grays of gamma rays increased the growth and yield attributes (Singh et al. 2009).

Magnetic Seed Treatment: The bio-stimulation of seeds through magnetic fieldtreatment is probably the least problematic, least expensive, and least harmful to the environment. In many plants,seed germination and yield can be enhanced by using a magnetic field treatment (Rochalska 2005, Massah et al. 2019, Moon et al. 2000, Pietruszewski and Kania 2010, Yao and Shen 2015). The magnetic field enhances the respiration of the seed as well as its powerful metabolism, and under adverse conditions, the magnetic field speeds up germination and plant growth by aiding in the restoration of the normal metabolism of energy and respiration intensity (Rochalska 2005). The application of magnetic treatment may also encourage cell elongation and division, as it increases the root length and shoot length (Hussain et al. 2020). It can also increase the integrity of the seeds outer membrane and decrease electrical conductivity and cellular leakage in the seeds (Vashisth and Nagarajan 2010). The magnetic fieldsaffect the production of free radicals and contributes to increased seed vigour.

Afzal, Mukhtar (2012) reported that the marigold seeds treated with 100 mT produced a higher emergence percentage (4-fold) and emergence index (5-fold). They also stated that through magnetic seed treatment, the starch metabolism of the seed is enhanced and hence it leads to improved seed parameters.

Seed pelleting: Pelleting is a method by which size, shape and weight of seeds are increased by using fillers and binders. Binder is a liquid polymer formulation with adhesive qualities, and filler is a solid powder that makes up the majority of the seed pellets and seeds are stirred by rotating in cycles to get pelletized (Koirala et al. 2022). It has a positive impact on seedling emergence speed (Pedrini et al. 2023). As marigold seeds are light in weight, it is difficult for the precise sowing of the seeds. Pelleting of seeds helps the farmers to handle the seeds easily, making planting easier and facilitating seedling growth faster. When pelleting marigold seeds, 0.3% w/v methyl hydroxyethyl cellulose (MHEC) was the best binder option (Kangsopa et al. 2023) and it was also pointed out that the best choice for pelleting marigold seeds is the MHEC $CaSO_4$ matrix (Kangsopa et al. 2024). By pelleting the seeds, sowing can be done precisely making the thinning operation more easier (Afzal et al. 2020). Pelleting also improves the seedsability to uptake moisture and oxygen, which eventually results in a greater rate of germination (Kangsopa et al. 2018).

1.2 Physiological Seed Treatment

Physiological seed treatments alter the internal metabolic mechanisms of the seeds, thereby it enhances seed germination by breaking dormancy and also improves the seed quality. It includes seed priming, stratification of seeds (warm and cold), and alternate wetting and drying of seeds.

Seed priming: Priming is a physiological method that involves wetting and drying of seeds toaccelerate the pre-germinative process of metabolism for quick germination, development of seedlings, and overall yield under both normal and stressful settings. The overall aim of seed priming is to partly hydrate the seeds to a stage where germination events start, however under normal or stressful conditions, they would show quick germination (Singh et al. 2015). Seed priming improves the biochemical and physiological characteristics of seeds (Heidarieh et al. 2024). There are various forms of priming (Fig. 1), including hydro priming, osmo-priming, halo priming, sand matric priming, and bio priming. The more recent ones are magneto priming and nano priming.

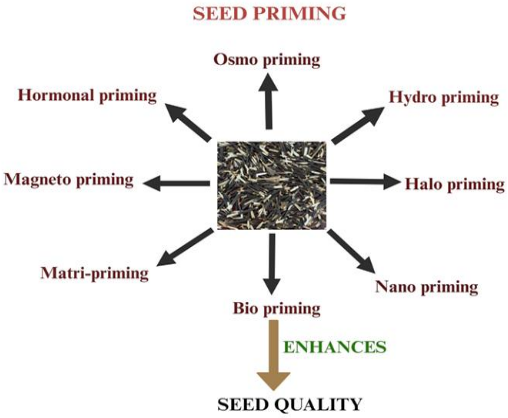

Fig. 1. Types of seed priming

Table 1. Different seed priming methods of marigold

SL No.	Treatment	Results	References
1	Seeds primed with deionized water for 12 hrs (Hydro priming)	Plants exhibited highest percentage of germination, plant establishment, height, 1000 seed weight, number of branches, and blossom yield.	Damabi, Singh (2014)
2	Seeds primed with 50mM $CaCl_2$for 24 hrs(Halo priming)	Improved germination index (24), germination percentage (88%), shoot length (5.10 cm), and root length (4.90 cm)	Afzal et al. (2009)
3	Seeds primed with GA_3 at 25 ppm for 30 mins	Improved germination percentage, stem height, flower number, size, and weight	Sharoa, Motial (1970)
4	Priming the seeds with 15ml/L seaweed	Enhanced seed germination by two-fold (84%)	Tavares, dos Santos (2020)
5	Seeds primed with Ascorbate (100 ppm) for 24 hrs at 25 °C	Increased germination percentage and minimized salinity effects	Afzal et al. (2017)
6	Seeds primed with de ionised water (2 ml) and applied a temperature drop treatment from 22 °C to 10 °C for 2 hrs every 24 hrs, for 6 days before sowing	Increased plant height (7.58 cm), leaf dry matter (209 mg), stem dry matter (195 mg), root dry matter (50.5 mg), flower dry matter (280 mg), plant dry matter (734.5 mg)	Sysoeva et al. (2010)
7	Seeds primed with 0.5% KNO_3 for 6 hrs and dehydrating at room temperature	Enhanced germination percentage in the genotype Hissar Jafri (89%)	Sindhu and Sehrawat (2019)

Priming prolongs the shelf life of seeds and improves their germination rate, homogeneity, and speed of germination (Table 1). Additionally, it improves tolerance to extreme temperatures and water stress (Doddagoudar et al. 2023). Seed priming has become popular because of its effectiveness, affordability, and adaptability in enhancing the performance of marigold seeds. Primed seeds germinate more quickly and uniformly when compared to unprimed seeds because of early imbibition, altered activation of enzymes, metabolism, biochemical mechanism of repair of cells, synthesis of proteins, strengthening of antioxidant defence system, and greater availability of ATP (Waqas et al. 2019, Paparella et al. 2015). Future research has to concentrate on creating suitable on-farm priming techniques and optimum priming protocols for different cultivars and types of marigolds in various agroclimatic zones.

1.3 Chemical Seed Treatment

Chemical seed treatments offer the benefit of protecting seeds from pests, diseases, and unfavourable soil conditions, enhancing germination rates and seedling vigour. However, they pose potential risks, such as environmental contamination and harm to non-target organisms, including beneficial soil microbes and pollinators. Additionally, overuse may lead to chemical resistance in pests, reducing long-term effectiveness. Numerous research has examined into how various chemical seed treatments affect marigold performance. Seeds treated with fungicides have shown to boost marigold flower yields (Anand 2021). All of the fungicides, including aureofungin solution, bavistin, thiram, roko, difolatan, indofil M-45,captan, and blitox 50 enhanced seed germination, boosted seedling vigour, reduced seed mycoflora and pre and post-emergence mortality of marigold seeds as compared to the control (Chandel and Mohinder 2003). Application of mancozeb (3.5g/kg) and chlorothalonil (5g/kg) to marigold seeds decreased the seed borne infection without having any adverse effects on seed germination (Chandel et al. 2010). Insecticidal seed treatments are also significant for enhancing the seed quality. Aphids, beetles, weevils, red spider mites and leaf hoppers are some of the major pests of marigold. Seed treatment with chlorax was effective in controlling the pests of marigold seeds (Kumar et al. 2014)

Fungicidal and insecticidal seed treatments have clearly demonstrated plant protection abilities that translate into improved productivity in marigold. When applied judiciously as one component of integrated management, seed treatments help in managing threats posed by fungi and insects during this critically vulnerable stage of the marigold life cycle.

1.4 Biological Seed Treatment

Seed treatment with biofertilizers is one of the biological seed treatments. Bio-fertilizers are ready-to-use live formulations of advantageous microorganisms that, when applied to seeds, increase the availability of nutrients primarily through their biological activity, support the development of the microflora, enhance soil health, andadd significantly to crop yields (Abrol et al. 2019). Through a variety of processes, including phosphate solubilization and mobilization, atmospheric nitrogen fixation, composting, phytohormone generation, and disease suppression, biofertilizers enhance plant growth and productivity. Microbes that promote plant growth restrict plant infections by producing antibiotics, siderophores, HCN, and ammonia, as well as hydrolytic enzymes like chitinase and β-1,3-glucanase. These processes also trigger the plant defense mechanism and competition for resources and habitat areas (Singh et al. 2021).

Marigold seeds treated with PGPR strains including *Azospirillum*, *Azotobacter*, *Bacillus*, *Pseudomonas*, *Rhizobium*, and *Serratia* increased germination rate, germination speed, seedling emergence, plant height, flower yield, and vase life (Flores et al. 2007). Treating marigold seeds with *Bacillus azotoformans* (1 × 10^9 CFU/ml) was effective against the seed-borne fungus *Alternaria tagetica* (Wu et al. 2001). Marigold seeds soaked in solutions containing 20% effective microorganisms, 2.4 g dm^{-3} Trichoderma, and 1% Goemar Goteo for 30 minutes enhanced germination energy (Majkowska-Gadomska et al. 2017). Using 20% vermicompost for marigold seed treatment also enhanced seed germination and boosts the growth of the plants (Shafique et al. 2021).

Biological and physical seed treatments are considered superior to chemical treatments as they offer eco-friendly solutions with minimal environmental impact and reduced risks to non-target organisms. Biological treatments utilize naturally occurring microorganisms to enhance seed health, while physical methods like ensure seed protection without harmful residues. These alternatives promote sustainable agriculture by improving seed quality and resilience without contributing to soil degradation.

2. OPTIMIZING MARIGOLD SEED STORAGE

Unsuitable post-harvest storage conditions canimpact seed quality by speeding up the loss of viability and shortening the seed's lifespan (Paravar et al. 2024). Marigold seeds might become less vigorousand viable if not stored properly (Rao et al. 2003). Temperature, moisture, and humidity are some of the abiotic variables that can impact the storability of seeds (Bakhtavar 2020). The soluble sugar, protein, and fat contents of the seeds gradually decreased as storage time increased, whereas the starch content increased (Ren et al. 2023). The antioxidant activity of the seeds decreased and hydrogen peroxide activity increased during the seed storage (Yalamalle et al. 2024). Appropriate storage techniques may help to increase the profit and prevent undesired losses. The market value of the produce shall rise with any sort of packaging technology that emphasizes extended storage periods and thus can minimize the losses (Berhe et al. 2023). Based on research studies, the following methods can help to preserve marigold seed vigour and viability.

Moisture content and relative humidity on seed storability: Storing the seeds after reducing the moisture content to the optimum level is found to retain the germination percentage of seeds even after long-term storage (Parihar et al. 2014, Kim 2018). Studies have found that drying the seeds to the optimal moisture content prevents deterioration during storage and maintains viability (Agbede et al. 2024). This usually involves drying in low-humidity conditions soon after harvest. It was stated that silica gel when combined with seeds in paper packets was effective for up to 4 months, but drying marigold seeds to a moisture content of about 8% and storing them in sealed moisture-resistant packages retained acceptable levels of germination (above 50 %) for 6 to 10 months at room temperature and relative humidity of 39%. Germination could be prolonged for 8 to 10 months in moisture-resistant containers and 6 to 8 months in paper packets containing silica gel when the seeds were kept at 15 ± 2 °C (Rao et al. 2003). Lower moisture may risk seed death while higher levels might lead to fungal growth. Checking moisture levels periodically with a seed moisture tester allows for adjustments through further drying or humidity regulation within the storage containers.

Temperature on seed storability: Storing seeds at low temperatures is proven to increase the storage life of the seeds and slow down the biological processes within the seed. Research has shown that storing marigold seeds at temperatures of 0 °C to 10° C maintains vigour and high seed germination percentages even after 24 months of storage. Temperatures below 0 °C, however, may cause freezing damage. Controlled seed storage rooms or commercial freezers work well. Singh, Jain (2004) stated that leachate conductivity did not accurately indicate viability loss when marigold seeds werestored at a low temperature. They concluded that seeds with a moisture content of 3% to 6% can be safely stored for a longer duration of time at -20 °C.

Moisture-proof containers and pre-storage seed treatments on seed storability: Airtight containers are often recommended for storing seeds to maintain seed viability and germination rates over time. It protects against fluctuations in temperature and humidity that can negatively impact seed germination rates (Probert et al. 2007). Interactions between seeds and their environment are greatly impacted by container parameters (Walters 2007). Storing seeds in airtight containers helps prevent fluctuations in seed moisture content during storage by protecting them from ambient humidity. Seeds might be preserved for shorter periods in cloth bags and longer in plastic bags (Vales et al. 2014). The use of laminated aluminium packets or thick polyethylene bags that prevent gas exchange is ideal for seed storage (Rao et al. 2006) and can maintain viability for up to two years if stored at optimal low temperatures.

The marigold seeds stored as dry flowers in a double-layered polythene bag with silica gelshowed the highest rates of germination, root length, shoot length, vigour index, seedling dry weight, germination rate index, and field emergence with the lowest electrical conductivity after ten months of storage (Kumar et al. 2014). An experiment was conducted in which marigold seeds were stored in 6 different types of containers like tin, plastic box, polythene bag, cotton bag, paper bag, and in trays in open condition (Vasudev et al. 2009). After ten months of storage, they found that seeds stored in tin showed the highest germination percentage, shoot length, root length, seedling dry weight, vigour index, and viability followed by the plastic bag. This might be because the tin box's impermeable nature served as a more effective moisture barrier. On the other hand, in an open environment, changing atmospheric relative humidity may have altered the moisture content of the seeds, which would have led to their degradation. Marigold seeds treated with thiram (2g/kg) + cytozyme (10g/kg) and stored in polyethylene bags resulted in the highest vigour and viability (Selvaraju et al. 1999). Seeds of marigold treated with chlorax and stored in a double-layered polythene bag showed better outcomes in terms of seed quality parameters, including significantly higher germination, shoot length, root length, vigour index, field emergence, and germination rate index (Kumar et al. 2014). For marigold, seed storage in a 300-gauge polythene packet or in a refrigerator may be advised for up to three months to preserve its quality (Ray et al. 2020). By using hermetic containers, seed storage duration can be significantly extended. Hermetic containers create a sealed environment that restricts oxygen and moisture exchange, reducing the risk of seed deterioration caused by fungal growth, insect activity, and seed respiration. This method also maintains optimal seed moisture content, preserving seed vigour and viability for longer periods.

3. CONCLUSION

Several studieshaveindicated that the quality and viability of marigold seeds can be effectively improved through seed treatment and optimal storage conditions. Seed quality can be improved by different seed treatments which can be physical, physiological, chemical or biological. Marigold seeds are relatively short-lived in storage, losing substantial germination capacity after few years even in cool, dry conditions. Proper storage techniques should therefore be followed for marigold seeds intended for propagation use after extended time periods. The research evaluated highlights the need for improving uniformity and productivity in commercial marigold production through optimized seed treatments and storage techniques. Future research should focus on developing standardized protocols for seed grading, priming, and coating to ensure consistency in seed quality. Additionally, studies should explore the scalability of biological and physical seed treatments, as well as the economic feasibility of advanced storage methods such as vacuum packing and modified atmosphere storage. Addressing these gaps can drive the sustainable intensification of marigold production, enabling growers to meet the rising global demand for this high-value crop.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

Abrol, A., Chaudhary, S., & Dhiman, S. (2019). Integrated nutrient management (INM) in commercial flower crops—a review. *Agricinternational, 6*(1), 17-22.

Adeel, S., et al. (2017). Appraisal of marigold flower based lutein as natural colourant for textile dyeing under the influence of gamma radiations. *Radiation Physics and Chemistry, 130*, 35-39.

Afzal, I., et al. (2009). Does halopriming improve germination and seedling vigour in marigold (*Tagetes* spp.). *Seed Science and Technology, 37*(2), 436-445.

Afzal, I., et al. (2012). Magnetic stimulation of marigold seed. *International Agrophysics, 26*(4), 335-339.

Afzal, I., et al. (2017). Inducing salt tolerance in French marigold (*Tagetes patula*) through seed priming. *Acta Scientiarum Polonorum Hortorum Cultus, 16*(3), 109-118.

Afzal, I., et al. (2020). Modern seed technology: Seed coating delivery systems for enhancing seed and crop performance. *Agriculture, 10*(11), 526.

Agbede, O. O., et al. (2024). Convective drying characteristics and moisture transfer properties of *Jatropha curcas* L. seeds. *Scientific African*, e02122.

Anand, T. (2021). Chemical and Biological Management of Leaf Spot and Flower Blight of Marigold. *Indian Journal.com, 14*(3), 399-403.

Araujo, S. D. S., et al. (2016). Physical methods for seed invigoration: Advantages and challenges in seed technology. *Frontiers in Plant Science, 7*, 646.

Aravind, S., & Dhanavel, D. (2021). Induced physical and chemical mutagenesis on marigold (*Tagetes erecta* L.) to determine the lethality, germination and seedling survivability. *International Journal of Botany Studies, 6*(3), 235-237.

Bakhtavar, M. A., & Afzal, I. (2020). Seed storage and longevity: Mechanism, types and management. In *Advances in Seed Production and Management* (pp. 451-468).

Bao, J., Ao, Z., & Jane, J. L. (2005). Characterization of physical properties of flour and starch obtained from gamma-irradiated white rice. *Starch‐Stärke, 57*(10), 480-487.

Bashir, S., & Gilani, A. H. (2008). Studies on the antioxidant and analgesic activities of Aztec marigold (*Tagetes erecta*) flowers. *Phytotherapy Research: An International Journal Devoted to Pharmacological and Toxicological Evaluation of Natural Product Derivatives, 22*(12), 1692-1694.

Baydar, H. A., & Erbas, S. (2005). Influence of seed development and seed position on oil, fatty acids and total tocopherol contents in sunflower (*Helianthus annuus* L.). *Turkish Journal of Agriculture and Forestry, 29*(3), 179-186.

Berhe, M., et al. (2023). Effect of storage duration and storage technologies on pest infestations and post-harvest quality loss of stored sesame seeds in Ethiopia. *Journal of Stored Products Research, 103*, 102161.

Bosma, T. L., Dole, J. M., & Maness, N. O. (2003). Optimizing marigold (*Tagetes erecta* L.) petal and pigment yield. *Crop Science, 43*(6), 2118-2124.

Chandel, S., & Mohinder, K. (2003). Effect of fungicidal seed treatment on seed variability, seed mycoflora and plant health of marigold. *Journal of Hill Research, 16*(1), 29-31.

Chandel, S., Da Silva, J. A. T., & Sharma, C. (2010). Management of alternaria leaf spot and flower blight of marigold (*Tagetes erecta* L.) cv. 'Crackerjack' by applications of fungicides and neem formulation. *Floriculture and Ornamental Biotechnology, 4*, 79-83.

Damabi, S. M., et al. (2014). Efficacy of seed priming on growth, flowering and seed yield in marigold (*Tagetes* spp.). *Journal of Ornamental Horticulture, 17*, 126-133.

Deineka, V., et al. (2007). Flowers of marigold (*Tagetes*) species as a source of xanthophylls. *Pharmaceutical Chemistry Journal, 41*, 540-542.

Dharmagadda, V., et al. (2005). Larvicidal activity of *Tagetes patula* essential oil against three mosquito species. *Bioresource Technology, 96*(11), 1235-1240.

Doddagoudar, S., et al. (2023). Improving the resilience of rice seedlings to low temperature stress through seed priming. *South African Journal of Botany, 162*, 183-192.

Du, R., et al. (2017). Inhibitory effect and mechanism of *Tagetes erecta* L. fungicide on *Fusarium oxysporum* f. sp. *niveum*. *Scientific Reports, 7*(1), 14442.

Ellis, R. H. (2019). Temporal patterns of seed quality development, decline, and timing of maximum quality during seed development and maturation. *Seed Science Research, 29*(2), 135-142.

Flores, A. C., Luna, A. A. E., & Portugal, V. O. (2007). Yield and quality enhancement of marigold flowers by inoculation with *Bacillus subtilis* and *Glomus fasciculatum*. *Journal of Sustainable Agriculture, 31*(1), 21-31.

Guiyun, C., et al. (2022). Cold atmospheric plasma treatment improves the γ-aminobutyric acid content of buckwheat seeds providing a new anti-hypertensive functional ingredient. *Food Chemistry, 388*, 133064.

Hashemirad, S., et al. (2023). Cold stratification requirement to break morphophysiological dormancy of fennel (*Foeniculum vulgare* Mill.) seeds varies with seed length. *Journal of Applied Research on Medicinal and Aromatic Plants, 35*, 100465.

Hassanpouraghdam, M. B., et al. (2011). Sesquiterpene rich volatile seed oil of *Tagetes patula* L. from northwest Iran. *Journal of Central European Agriculture, 12*(2), 0-0.

Heidarieh, Z., et al. (2024). Seed priming alleviates the adverse effects of drought stress on sesame genotypes by improving biochemical and physiological characteristics. *South African Journal of Botany, 167*, 256-269.

Hojjati, M., et al. (2023). Effect of gamma irradiation on structure, physicochemical and functional properties of bitter vetch (*Vicia ervilia*) seeds polysaccharides. *Radiation Physics and Chemistry, 202*, 110569.

Hooks, C. R., et al. (2010). Using marigold (*Tagetes* spp.) as a cover crop to protect crops from plant-parasitic nematodes. *Applied Soil Ecology, 46*(3), 307-320.

Hoshi, Y., Praphruet, R., & Hironaka, K. (2019). Genome size determination and chromosome characterization of two marigold species (Asteraceae). *Cytologia, 84*(1), 37-42.

Hussain, M. S., et al. (2020). Eco-friendly magnetic field treatment to enhance wheat yield and seed germination growth. *Environmental Nanotechnology, Monitoring and Management, 14*, 100299.

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*(3), 521-531.

Kangsopa, J., Singsopa, A., & Thawong, N. (2023). Effects of different binder types and concentrations on physical and quality properties in marigold (*Tagetes erecta* L.) seed pelleting. *Songklanakarin Journal of Science and Technology, 45*(4).

Kangsopa, J., Singsopa, A., & Thawong, N. (2024). A mono-layer matrix for pelleting marigold (*Tagetes erecta*) seeds. *Seed Science and Technology, 52*(1), 1-10.

Kanwar, J., & Khandelwal, S. (2013). Effect of plant growth regulators on growth and yield of African Marigold (*Tagetes erecta* Linn.). *Madras Agricultural Journal, 100*, 1.

Kashyap, P. K., et al. (2022). An efficient process for the extraction of lutein and chemical characterization of other organic volatiles from marigold (*Tagetes erecta* L.) flower. *Food Chemistry, 396*, 133647.

Kim, D. H. (2018). Extending *Populus* seed longevity by controlling seed moisture content and temperature. *PLoS One, 13*(8), e0203080.

Koirala, N., et al. (2022). A process to enhance germination of a wild pennycress variety. *Seed Science and Technology, 50*(2), 195-205.

Kumar, T. P., et al. (2014). Influence of seed treatment chemicals and containers on seed quality of marigold during storage. *The Bioscan, 9*(3), 937-942.

Kumar, T. P., et al. (2014). Seed storage quality as influenced by forms of seed and containers during storage in marigold (*Tagetes erecta*). *International Journal of Agricultural Sciences, 10*(2), 700-706.

Lamichhane, J. R., Corrales, D. C., & Soltani, E. (2022). Biological seed treatments promote crop establishment and yield: A global meta-analysis. *Agronomy for Sustainable Development, 42*(3), 45.

Liberatore, C. M., et al. (2018). Chemical and physical pre-treatments to improve in vitro seed germination of *Humulus lupulus* L., cv. Columbus. *Scientia Horticulturae, 235*, 86-94.

Maity, J. P., et al. (2009). Effects of gamma irradiation on edible seed protein, amino acids and genomic DNA during sterilization. *Food Chemistry, 114*(4), 1237-1244.

Majkowska-Gadomska, J., et al. (2017). The effect of selected biostimulants on seed germination of four plant species. *Acta Agrophysica, 24*(4).

Manivannan, A., Narasegowda, S., & Prakash, T. (2021). Comparative study on color coordinates, phenolics, flavonoids, carotenoids, and antioxidant potential of marigold (*Tagetes* sp.) with diverse colored petals. *Journal of Food Measurement and Characterization, 15*, 4343-4353.

Massah, J., et al. (2019). Effects of water magnetic treatment on seed germination and seedling growth of wheat. *Journal of Plant Nutrition, 42*(11-12), 1283-1289.

Meena, Y., et al. (2015). Effect of planting time, spacing and pinching on growth and seed yield traits in African marigold (*Tagetes erecta* L.) cv. Pusa Narangi Gainda. *Indian Journal of Agricultural Sciences, 85*(6), 797-801.

Melki, M., & Marouani, A. (2010). Effects of gamma rays irradiation on seed germination and growth of hard wheat. *Environmental Chemistry Letters, 8*(4), 307-310.

Mengesha, G. G., et al. (2022). Effects of cultivar resistances and chemical seed treatments on fusarium head blight and bread wheat yield-related parameters under field condition in southern Ethiopia. *Heliyon, 8*(1).

Moon, J. D., & Chung, H. S. (2000). Acceleration of germination of tomato seed by applying AC electric and magnetic fields. *Journal of Electrostatics, 48*(2), 103-114.

Moumni, M., Brodal, G., & Romanazzi, G. (2023). Recent innovative seed treatment methods in the management of seedborne pathogens. *Food Security, 15*(5), 1365-1382.

Murali, C., et al. (2019). Seed development and maturation in African marigold (*Tagetes erecta* L.). *Journal of Applied Horticulture, 21*(1), 81-84.

Nagel, M., & Borner, A. (2010). The longevity of crop seeds stored under ambient conditions. *Seed Science Research, 20*(1), 1-12.

Nikkon, F., et al. (2011). *Tagetes erecta* Linn. and its mosquitocidal potency against *Culex quinquefasciatus*. *Asian Pacific Journal of Tropical Biomedicine, 1*(3), 186-188.

Oliveira, N. M., et al. (2021). Hormetic effects of low-dose gamma rays in soybean seeds and seedlings: A detection technique using optical sensors. *Computers and Electronics in Agriculture, 187*, 106251.

Panda, P., et al. (2021). Multilocus genes based characterization of phytoplasma strains associated with Mexican and French marigold species in India. *European Journal of Plant Pathology, 161*(2), 313-330.

Paparella, S., et al. (2015). Seed priming: State of the art and new perspectives. *Plant Cell Reports, 34*, 1281-1293.

Paravar, A., Farahani, S. M., & Rezazadeh, A. (2024). How storage circumstance alters the quality of seeds of *Lallemantia iberica* and *Lallemantia royleana* produced under maternal drought stress. *Environmental and Experimental Botany, 217*, 105537.

Parihar, S., et al. (2014). Effect of seed moisture content and storage temperature on seed longevity of hemp (*Cannabis sativa*). *Indian Journal of Agricultural Sciences, 84*, 1303-1309.

Pedrini, S., et al. (2023). Customize the seeds, not the seeder: Pelleting of small-seeded species for ecological restoration. *Ecological Engineering, 196*, 107105.

Pietruszewski, S., & Kania, K. (2010). Effect of magnetic field on germination and yield of wheat. *International Agrophysics, 24*(3), 297-302.

Probert, R., et al. (2007). Seed quality for conservation is critically affected by pre-storage factors. *Australian Journal of Botany, 55*(3), 326-335.

Rajput, N., et al. (2012). Effect of dietary supplementation of marigold pigment on immunity, skin and meat color, and growth performance of broiler chickens. *Brazilian Journal of Poultry Science, 14*, 291-295.

Rao, C. C., Dadlani, N., & Dadlani, M. (2003). Maintenance and enhancement of germination and vigour in Marigold (*Tagetes* spp.) seed. *Seed Science and Technology, 31*(3), 745-751.

Rao, R., Singh, P., & Rai, M. (2006). Storability of onion seeds and effects of packaging and storage conditions on viability and vigour. *Scientia Horticulturae, 110*(1), 1-6.

Ray, J., & Bordolui, S. K. (2020). Seed storing potential of some marigold genotypes during storage. . Int. J. Curr. Microbiol. App. Sci. 2020;9(5):2470-2486.

Ren, R., et al. (2023). Cryopreservation of herbaceous Asteraceae seeds: Effects of seed reserves on seed germination and seedling regrowth. *Cryobiology, 112*, 104562.

Riaz, M., et al. (2020). Traditional uses, phyto-chemistry and pharmacological activities of *Tagetes patula* L. *Journal of Ethnopharmacology, 255*, 112718.

Rochalska, M., & Orzeszko-Rywka, A. (2005). Magnetic field treatment improves seed performance. *Seed Science and Technology, 33*(3), 669-674.

Salehi, B., et al. (2018). *Tagetes* spp. essential oils and other extracts: Chemical characterization and biological activity. *Molecules, 23*(11), 2847.

Salinas-Sánchez, D. O., et al. (2012). Insecticidal activity of *Tagetes erecta* extracts on *Spodoptera frugiperda* (Lepidoptera: Noctuidae). *Florida Entomologist, 95*(2), 428-432.

Sanjaya, S. S., et al. (2024). Inhibition of α-melanocyte-stimulating hormone-induced melanogenesis and molecular mechanisms by polyphenol-enriched fraction of *Tagetes erecta* L. flower. *Phytomedicine*, 155442.

Santos, P. C. D., et al. (2015). Phytotoxicity of *Tagetes erecta* L. and *Tagetes patula* L. on plant germination and growth. *South African Journal of Botany, 100*, 114-121.

Scarlato, M., et al. (2023). Flowering plants in open tomato greenhouses enhance pest suppression in conventional systems and reveal resource saturation for natural enemies in organic systems. *Agriculture, Ecosystems and Environment, 347*, 108389.

Selvaraju, P., Jacqueline, A., & Selvaraj, S. (1999). Effect of seed treatments and storage containers on viability and vigour of seeds in marigold (*Tagetes erecta* L.).

Shafique, I., et al. (2021). Efficiency of cow dung based vermi-compost on seed germination and plant growth parameters of *Tagetes erectus* (Marigold). *Heliyon, 7*(1).

Sharma, K., et al. (2015). Seed treatments for sustainable agriculture—A review. *Journal of Applied and Natural Science, 7*(1), 521-539.

Sharoa, A., Motial, V., & Basario, K. (1970). The effect of gibberellic acid (seed treatment) on the germination, vegetative growth, quantity and quality of marigold flowers (*Tagetes erecta* L.). *Science and Culture, 36*, 79-80.

Sindhu, K., & Sehrawat, S. (2019). Effect of seed priming on standard germination and electrical conductivity in marigold seeds. *International Journal of Current Microbiology and Applied Sciences*.

Singh, D., et al. (2021). Biofertilizers: Mechanisms and application. In *Biofertilizers* (pp. 151-166). Elsevier.

Singh, H., et al. (2015). Seed priming techniques in field crops—A review. *Agricultural Reviews, 36*(4), 251-264.

Singh, R., Jain, S., & Singh, A. (2004). Seed storage of African marigold (*Tagetes erecta* L.) for ex-situ conservation. *Seed Science and Technology, 32*(2), 503-509.

Singh, V. N., et al. (2009). Effect of gamma irradiation on African marigold (*Tagetes erecta* L.) cv. Pusa Narangi Gainda. *Journal of Horticultural Sciences, 4*(1), 36-40.

Siriamornpun, S., Kaisoon, O., & Meeso, N. (2012). Changes in colour, antioxidant activities and carotenoids (lycopene, β-carotene, lutein) of marigold flower (*Tagetes erecta* L.) resulting from different drying processes. *Journal of Functional Foods, 4*(4), 757-766.

Sowbhagya, H., Sampathu, S., & Krishnamurthy, N. (2004). Natural colorant from marigold-chemistry and technology. *Food Reviews International, 20*(1), 33-50.

Sysoeva, M., et al. (2010). Pre-sowing seed treatment with a temperature-drop influences plant growth and flowering in marigold and pansy. *The Journal of Horticultural Science and Biotechnology, 85*(3), 238-240.

Tavares, A. R., et al. (2020). Seaweed extract to enhance marigold seed germination and seedling establishment. *SN Applied Sciences, 2*(11), 1792.

Vales, M., et al. (2014). Effective and economic storage of pigeonpea seed in triple layer plastic bags. *Journal of Stored Products Research, 58*, 29-38.

Vashisth, A., & Nagarajan, S. (2010). Effect on germination and early growth characteristics in sunflower (*Helianthus annuus*) seeds exposed to static magnetic field. *Journal of Plant Physiology, 167*(2), 149-156.

Vasudev, H., et al. (2009). Effect of seed storage methods on seed quality of marigold (*Tagetes erecta*). *Mysore Journal of Agricultural Sciences, 43*(2), 239-245.

Venil, C. K., Zakaria, Z. A., & Ahmad, W. A. (2013). Bacterial pigments and their applications. *Process Biochemistry, 48*(7), 1065-1079.

Wainaina, I., et al. (2023). Application of state diagrams to understand the nature and kinetics of (bio) chemical reactions in dry common bean seeds: A scientific guide to establish suitable postharvest storage conditions. *Food Research International*, 113418.

Walters, C. (2007). Materials used for seed storage containers: Response to Gómez-Campo [Seed Science Research, 16, 291-294 (2006)]. *Seed Science Research, 17*(4), 233-242.

Waqas, M., et al. (2019). Advances in the concept and methods of seed priming. In *Priming and pretreatment of seeds and seedlings: Implication in plant stress tolerance and enhancing productivity in crop plants* (pp. 11-41).

Wu, W. S., et al. (2001). The effect of seed-borne pathogens on emergence of globe amaranth, calendula and *Tagetes* and the methods of control. *Journal of Phytopathology, 149*(2), 91-96.

Yalamalle, V. R., et al. (2024). Peroxidation of unsaturated fatty acids is associated with poor storability in onion seed. *Plant Physiology Reports*, 1-13.

Yao, W., & Shen, Y. (2015). Effect of magnetic treatment on seed germination of loblolly pine (*Pinus taeda* L.). *Scandinavian Journal of Forest Research, 30*(8), 639-642.

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