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Seed pelleting-mediated suppression of early weed, disease and insect infestation in maize (*Zea mays* L.)

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Abstract

Early-stage weed competition, insect infestation, seed-borne pathogens and poor crop establishment are major constraints limiting maize productivity. A field experiment was conducted during *Rabi-Summer*, 2019-2020 at the National Seed Project, University of Agricultural Sciences, GKVK, Bengaluru, to evaluate the efficacy of seed pelleting formulations comprising polymer, metalaxyl, cyantraniliprole + thiamethoxam, diammonium phosphate (DAP), zinc, atrazine and *Azotobacter chroococcum* in reducing early biotic stresses and improving field establishment. Nine treatments were evaluated in a randomized complete block design (RCBD) with three replications. Weed infestation, disease incidence, insect infestation, seed mycoflora, and field establishment were recorded at different crop growth stages. No weed infestation was observed at 5 days after sowing (DAS) in any treatment. At 10 and 15 DAS, treatments containing atrazine significantly reduced weed infestation with the combination of polymer, metalaxyl, cyantraniliprole + thiamethoxam, DAP, atrazine, and *Azotobacter* (T₄) recording only 29.5 and 31.25 % weed infestation, respectively, compared with 73.2 and 96.75 % in the untreated control. Seed pelleting formulations containing insecticide markedly reduced insect damage, with T₇ recording the lowest infestation (1.28, 2.33, and 2.40 % at 15, 40, and 60 DAS, respectively). Treatments containing metalaxyl significantly reduced seed mycoflora, with the lowest incidence (2.0 %) observed in T₅, while untreated seeds recorded 5.0 %. The highest field establishment (88.67 %) was also achieved with T₅, indicating improved seedling emergence and stand establishment. The findings demonstrate that integrated seed pelleting effectively suppresses early weed, insect, and fungal infestation while enhancing field establishment, thereby providing an efficient seed-based strategy for improving crop establishment and sustaining maize productivity.

Keywords: Maize, Seed pelleting, Weed suppression, Insect infestation, Seed mycoflora, Field establishment, Metalaxyl, Atrazine, *Azotobacter chroococcum*

Introduction

Maize (*Zea mays* L.) is one of the world's most important cereal crops, serving as a major source of food, feed, fodder and industrial raw material owing to its high yield potential, wide adaptability and excellent nutritional value (Ludemann *et al.*, 2023; Ranum *et al.*, 2014)^[12, 13]. Being a C₄ crop, maize possesses superior photosynthetic efficiency and radiation-use efficiency, enabling higher biomass accumulation and productivity than many other cereal crops (Tollenaar and Lee, 2002)^[21]. In India, maize occupies an important position after rice and wheat and contributes substantially to national food security, livestock feed and the starch-based processing industry (Deka *et al.*, 2025)^[4].

Despite remarkable genetic improvement in maize hybrids, achieving their yield potential under field conditions remains challenging because of severe biotic stresses during crop establishment. Early growth stages are particularly vulnerable to weed competition, insect infestation, seed-borne and soil-borne pathogens, which adversely affect seedling emergence, plant stand, crop vigour and ultimately grain yield (Falloon, 1982 and Wilde *et al.*, 2004)^[5, 23]. Weed infestation during the initial growth period competes aggressively for moisture, nutrients, sunlight and space, resulting in substantial yield losses if not effectively controlled (Sahar *et al.*, 2011)^[16]. Similarly, insect pests such as fall armyworm (*Spodoptera frugiperda*), stem borers (*Chilo partellus* and *Sesamia inferens*), aphids and leafhoppers cause considerable damage during vegetative growth, leading to poor crop establishment and reduced productivity (Kumar *et al.*, 2005)^[11].

Seed-borne and soil-borne fungal pathogens further impair germination, seedling vigour and field establishment by causing seed decay, damping-off and root diseases (Falloon, 1982 and Wayne, 2003) [5, 22]. Consequently, protecting seeds during the early stages of crop growth has become an essential component of modern crop production systems. Conventional seed treatment with fungicides, insecticides or bioagents has been widely adopted to minimize early biotic stresses and improve crop performance (Taylor and Eckenrode, 1993; Giang and Gowda, 2007) [6, 20].

Seed pelleting is an advanced seed enhancement technology in which seeds are coated with inert materials along with biologically active compounds to improve seed size, shape, handling characteristics and planting precision while serving as a carrier for nutrients and crop protection agents (Roos, 1979; Scott, 1989 and Krishnasamy, 2003) [9, 15, 17]. Besides facilitating precision sowing, pelleted seeds create a favourable microenvironment around the spermosphere by retaining moisture and ensuring the gradual release of nutrients and protective chemicals during germination (Krishnasamy, 2003) [9].

The integration of fungicides, insecticides, herbicides, micronutrients and beneficial microorganisms into a single seed pelleting formulation provides multiple protective functions during the critical stages of crop establishment. Metalaxyl effectively suppresses seed- and soil-borne fungal pathogens, thereby reducing seedling mortality and seed mycoflora (Wayne, 2003; Rawal and Singh, 2010) [14, 22]. Systemic insecticides such as cyantraniliprole and thiamethoxam protect emerging seedlings from early insect attack through systemic translocation within plant tissues (Wilde *et al.*, 2004; Khandare *et al.*, 2017) [8, 23]. Atrazine incorporated into seed pellets minimizes early weed emergence around the spermosphere, thereby reducing crop-weed competition during the establishment phase (Sahar *et al.*, 2011; Sujatha and Ambika, 2016) [16, 19]. Likewise, beneficial microorganisms such as *Azotobacter chroococcum* promote nutrient availability, stimulate root development and enhance plant tolerance against biotic stresses, leading to improved crop establishment (Bony *et al.*, 2017) [2].

Several researchers have demonstrated that integrated seed treatment technologies significantly improve germination,

seedling vigour, field emergence, disease resistance and crop productivity across several field crops (Taylor and Eckenrode, 1993; Kumar *et al.*, 2007; Siddaraju *et al.*, 2015; Sujatha and Ambika, 2016) [10, 18, 19, 20]. However, information on integrating fungicides, insecticides, herbicides, nutrients and biofertilizers into a single seed pelleting formulation for simultaneous management of weeds, insects and diseases in maize remains limited.

Therefore, the present investigation was undertaken to evaluate the effectiveness of integrated seed pelleting formulations containing polymer, fungicide, insecticide, herbicide, nutrient sources and *Azotobacter chroococcum* in suppressing early weed, insect and disease incidence, reducing seed mycoflora and improving field establishment in maize. The study aims to generate scientific evidence for developing an efficient seed-based crop protection strategy capable of enhancing early crop establishment and improving maize productivity under field conditions.

Materials and Methods

Experimental site

A field experiment was conducted during the Rabi-Summer season (2019-2020) at the Seed Technology Research Unit, National Seed Project (Crops), University of Agricultural Sciences (UAS), Gandhi Krishi Vigyan Kendra (GKVK), Bengaluru, Karnataka, India.

Plant material

Seeds of the single-cross maize hybrid Hema were obtained from the National Seed Project (Crops), UAS, GKVK, Bengaluru. The seeds were dried to safe moisture content prior to pelleting.

Experimental design and treatments

The experiment was laid out in a Randomized Complete Block Design (RCBD) comprising nine treatments with three replications. Each experimental plot measured 3.6 × 3.9 m, while the net plot size was 3.5 × 3.8 m. The treatments consisted of different combinations of polymer, fungicide, insecticide, nutrients, herbicide and biofertilizer applied through seed pelleting.

Treatment	Seed pelleting components
T ₁	Untreated control
T ₂	Polymer + Metalaxyl + Cyantraniliprole + Thiamethoxam + DAP + Zinc + Atrazine
T ₃	Polymer + Metalaxyl + Cyantraniliprole + Thiamethoxam + DAP + Zinc + <i>Azotobacter chroococcum</i>
T ₄	Polymer + Metalaxyl + Cyantraniliprole + Thiamethoxam + DAP + Atrazine + <i>Azotobacter chroococcum</i>
T ₅	Polymer + Metalaxyl + Cyantraniliprole + Thiamethoxam + Zinc + Atrazine + <i>Azotobacter chroococcum</i>
T ₆	Polymer + Metalaxyl + DAP + Zinc + Atrazine + <i>Azotobacter chroococcum</i>
T ₇	Polymer + Cyantraniliprole + Thiamethoxam + DAP + Zinc + Atrazine + <i>Azotobacter chroococcum</i>
T ₈	Metalaxyl + Cyantraniliprole + Thiamethoxam + DAP + Zinc + Atrazine + <i>Azotobacter chroococcum</i>
T ₉	Polymer + DAP + Zinc + Atrazine + <i>Azotobacter chroococcum</i>

The dosage of each component was

- Polymer - 4.0 mL kg⁻¹ seed (Check this everywhere)
- Metalaxyl - 3.0 g kg⁻¹ seeds
- Cyantraniliprole + Thiamethoxam - 4.0 mL kg⁻¹ seed
- Diammonium phosphate (DAP) - 4.0 g kg⁻¹ seed
- Zinc - 2.0 g kg⁻¹ seed
- Atrazine - 10 g kg⁻¹ seed
- *Azotobacter chroococcum* - 2 g kg⁻¹ seed

Seed pelleting procedure

Seed pelleting was carried out using a rotary seed coater. Initially, seeds were rotated for 2-3 min to remove dust particles. The seeds were lightly moistened with water, followed by sequential application of binder and pelleting powder. Subsequently, fungicide (Metalaxyl), insecticide (Cyantraniliprole + Thiamethoxam), nutrients (DAP and zinc), herbicide (Atrazine), biofertilizer (*Azotobacter chroococcum*) and polymer were incorporated according to the respective treatments. Alternate applications of binder

and pelleting powder were continued until a uniform pellet diameter of approximately 3.5 mm was achieved. The pelleted seeds were then finished with a thin binder layer, dried under shade followed by forced-air drying, and stored until sowing.

Observations recorded

Five representative plants were randomly selected from each plot for recording observations. The following parameters were evaluated:

- Weed infestation (%) at 5, 10 and 15 DAS
- Disease score at 15 DAS
- Insect infestation (%) at 15, 40, 60 DAS and at harvest
- Seed mycoflora (%)
- Field establishment (%)

Statistical analysis

The experimental data were subjected to analysis of variance (ANOVA) appropriate for a Randomized Complete Block Design (RCBD). Treatment means were compared using the Critical Difference (CD) test at the 5% probability level ($P \leq 0.05$). Statistical significance was determined based on the calculated standard error of mean (SEm $\pm$), coefficient of variation (CV%), and CD values.

Result and Discussion

Weed infestation

No weed infestation was observed in any treatment at 5 DAS, indicating that weed emergence had not yet commenced during the initial stages of crop establishment. However, significant differences among treatments became evident at 10 and 15 DAS (Table 1 & Fig.1).

At 10 DAS, untreated control (T_1) recorded the highest weed infestation (73.2 %), whereas treatments containing atrazine in the seed pellet substantially reduced weed emergence. The minimum weed infestation was observed in T_5 (28.7 %), which was statistically comparable with T_4 (29.5 %), T_7 (32.2 %), T_8 (34.5 %) and T_9 (36.2 %). Similar trends were maintained at 15 DAS, where T_4 recorded the lowest weed infestation (31.25 %), closely followed by T_5 (35.25 %), T_8 (39.75 %) and T_9 (42.25 %), while untreated control (T_1) exhibited the highest infestation (96.75 %).

The marked reduction in weed infestation can be attributed to the gradual release of atrazine from the pelleted seed into the spermosphere immediately after sowing. The localized herbicide concentration effectively inhibited germination and establishment of susceptible weed species during the critical early growth period without affecting crop emergence. Reduced weed competition during early crop growth improves utilization of moisture, nutrients and solar radiation, thereby promoting vigorous seedling establishment.

The superiority of treatments combining atrazine with polymer, fungicide, insecticide and *Azotobacter chroococcum* suggests that integration of crop protection and biological components through seed pelleting provides effective early-season weed suppression. Similar observations on localized herbicide delivery through seed treatment improving weed management have been reported by Sujatha and Ambika (2016) and Sahar *et al.* (2011) ^[16, 19].

Disease incidence at seedling stage

Disease incidence remained absent (disease score = 0) in all treatments at 15 DAS (Table 1), indicating effective protection of seedlings during the vulnerable establishment phase. Although disease symptoms were not expressed, visual observations indicated that pelleted seedlings were healthier and more vigorous than untreated seedlings.

The absence of disease incidence may be attributed to prophylactic protection provided by metalaxyl, which effectively suppresses soil- and seed-borne fungal pathogens during germination and seedling establishment. Furthermore, incorporation of *Azotobacter chroococcum* in the pellet may have enhanced rhizosphere colonization and improved plant vigour, indirectly increasing tolerance against pathogen infection.

The combined action of fungicide and beneficial microorganisms likely created an unfavourable environment for pathogen multiplication, resulting in healthy crop establishment. Earlier reports by Falloon (1982) ^[5] and Wayne (2003) ^[22] also demonstrated that metalaxyl seed treatment significantly reduces seedling diseases and improves crop stand in maize.

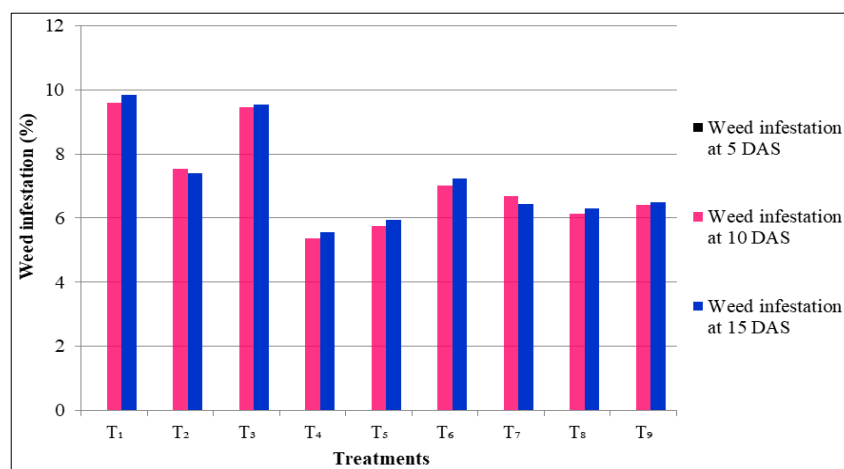


Fig 1: Influence of seed pelleting on weed infestation (%) of maize

Insect infestation

Seed pelleting significantly influenced insect infestation throughout crop growth (Table 2 & Plate.1). At 15 DAS,

untreated control (T_1) recorded the highest plant damage (5.22 %), whereas T_7 exhibited the lowest infestation (1.28 %), followed by T_8 (1.33 %), T_5 (1.37 %), T_3 (2.32 %) and

T₄ (2.49 %). The same trend continued at 40 DAS, where insect damage remained highest in untreated control (6.77 %), while T₇ (2.33 %), T₈ (2.41 %), T₅ (2.53 %) and T₃ (2.45 %) effectively minimized insect attack.

At 60 DAS and harvest, insect infestation stabilized with no further increase in damage. Treatments containing Cyantraniliprole + Thiamethoxam consistently maintained significantly lower insect infestation compared to untreated control (T₁). T₇ recorded the minimum infestation (2.40 %), followed by T₃ (2.45 %), T₈ (2.70 %) and T₅ (3.29 %), whereas untreated control exhibited the highest infestation (6.95 %).

The sustained reduction in insect damage can be explained by systemic protection provided by Cyantraniliprole and Thiamethoxam, which are absorbed during germination and translocated into emerging seedlings. Polymer coating ensures better adhesion and gradual release of insecticides, while improved seedling vigour resulting from nutrient and biofertilizer supplementation enables plants to better withstand insect attack (Kamdi *et al.*, 2012) ^[7].

These findings indicate that integrating systemic insecticides into seed pellets provides prolonged protection during the most susceptible growth stages, reducing dependence on repeated foliar insecticide applications. Similar observations have been reported by Chen *et al.* (2004) ^[3], Bennett *et al.* (1992) and Khandare *et al.* (2017) ^[1, 8].



Plate 1: Insect infestation at 30 DAS of pelleted seeds (T₅) Vs. control (T₁)

Seed mycoflora

Significant variation in seed mycoflora was observed among treatments (Table 3 & Plate 2). The highest seed mycoflora (5.00 %) occurred in untreated control (T₁), whereas the lowest infection (2.00 %) was recorded in T₅, followed by T₆ (2.33 %), T₄ (2.67 %), T₂ (3.00 %), T₈ (3.00 %) and T₃ (3.33 %).

The reduction in fungal contamination can primarily be attributed to the presence of metalaxyl, which effectively inhibits seed-borne fungal pathogens during storage and germination. Additionally, *Azotobacter chroococcum* may contribute to suppression of pathogenic microorganisms through competitive colonization of the seed surface and rhizosphere.

Reduced seed mycoflora improves seed health, minimizes pre- and post-emergence mortality and contributes to better field performance. Similar reductions in seed-borne fungal infection following fungicidal seed treatment have been reported by Wayne (2003) ^[22] and Rawal and Singh (2010) ^[14].



Plate 2: Seed mycoflora of pelleted seeds (T₅) VS. control (T₁)

Field establishment

Field establishment varied significantly among treatments (Table 3 & Fig. 2). Maximum establishment was recorded in T₅ (88.67%), followed by T₉ (87.00%), T₆ (86.67%), T₇ (86.67%), T₃ (86.33%) and T₈ (86.00%). The lowest establishment was recorded in T₂ (83.33%).

Improved field establishment in pelleted treatments may be attributed to the combined effects of enhanced seed protection, improved nutrient availability and better root colonization by *Azotobacter chroococcum*. The polymer coating also protects seeds during imbibition, while fungicide and insecticide components minimize early losses due to pathogens and insect pests.

Enhanced establishment directly contributes to uniform crop stand, improved resource utilization and ultimately higher productivity. The results demonstrate that multifunctional seed pelleting offers a practical strategy for improving early crop establishment under field conditions. Similar findings were reported by Bony *et al.* (2017) ^[2], who observed enhanced seedling emergence following biological seed pelleting.

Conclusion

The present investigation clearly demonstrated that multifunctional seed pelleting effectively minimized early biotic stresses in maize by integrating fungicide, insecticide, herbicide, nutrients and beneficial microorganisms into a single seed treatment. Treatments incorporating Atrazine successfully suppressed early weed emergence, while Cyantraniliprole + Thiamethoxam provided prolonged

protection against insect pests. Simultaneously, Metalaxyl reduced seed mycoflora and protected seedlings from fungal infection, whereas *Azotobacter chroococcum* enhanced seedling vigour and field establishment.

Among all treatments, T₅ emerged as the most promising combination owing to its superior performance in reducing weed infestation, minimizing seed mycoflora and achieving the highest field establishment. Likewise, T₇ proved highly effective in controlling insect infestation throughout crop growth. These findings confirm that seed pelleting serves as an efficient delivery system for multiple crop protection and nutritional inputs, resulting in healthier seedlings, reduced dependence on early field pesticide applications and improved crop establishment. Such integrated seed enhancement technology can substantially improve maize productivity while promoting efficient input utilization and sustainable crop production.

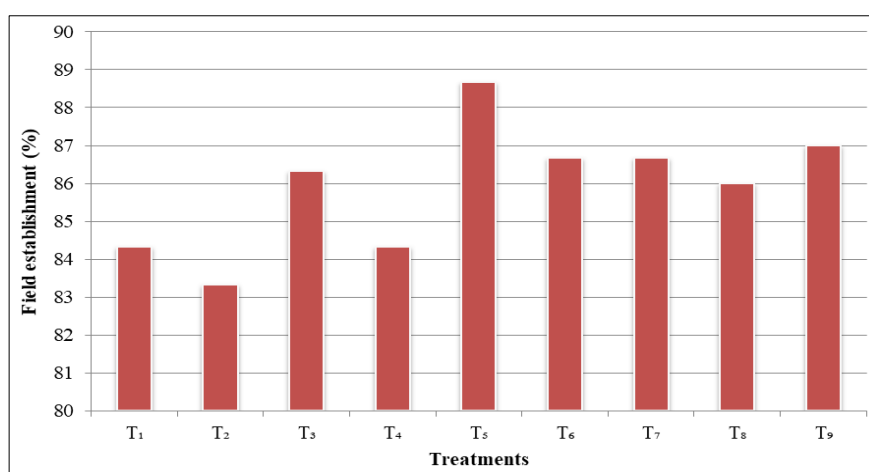


Fig 2: Influence of seed pelleting on field establishment (%) of maize

Table 1: Influence of seed pelleting on weed infestation (%) at 5, 10 and 15 DAS and disease score at seedling stage (15 DAS)

Treatments	Weed infestation (%)			Disease score 15 DAS
	5 DAS	10 DAS	15 DAS	
T ₁	0	73.2 (9.60)	96.75 (9.84)	0
T ₂	0	50.7 (7.54)	55.25 (7.41)	0
T ₃	0	80.2 (9.46)	90.75 (9.53)	0
T ₄	0	29.5 (5.37)	31.25 (5.57)	0
T ₅	0	28.7 (5.75)	35.25 (5.93)	0
T ₆	0	46.2 (7.00)	52.25 (7.22)	0
T ₇	0	32.2 (6.68)	42.13 (6.43)	0
T ₈	0	34.5 (6.13)	39.75 (6.30)	0
T ₉	0	36.2 (6.42)	42.25 (6.50)	0
Mean	-	45.7 (7.18)	53.94 (7.19)	-
S.Em±	-	0.48	0.52	-
CD (P=0.05)	-	1.34	1.42	-
CV (%)	-	6.42	6.81	-

Table 2: Influence of seed pelleting on insect infestation (%) at 15, 40, 60 DAS and at harvest of maize

Treatments	Insect infestation (% plant damage)			
	15 DAS	40 DAS	60 DAS	At harvest
T ₁	5.22	6.77	6.95	6.95
T ₂	4.02	4.55	4.75	4.75
T ₃	2.32	2.45	2.59	2.59
T ₄	2.49	3.67	3.67	3.67
T ₅	1.37	2.53	3.29	3.29
T ₆	4.86	6.53	6.77	6.77
T ₇	1.28	2.33	2.40	2.40
T ₈	1.33	2.41	2.70	2.70
T ₉	4.39	5.54	5.68	5.68
Mean	3.03	4.09	4.31	4.31
S.Em±	0.14	0.17	0.22	0.22
CD (P=0.05)	0.59	0.52	0.65	0.65
CV (%)	8.18	7.29	8.74	8.74

Table 3: Influence of seed pelleting on seed mycoflora (%) and field establishment (%) of maize

Treatments	Seed mycoflora (%)	Field establishment (%)
T ₁	5.00	84.33
T ₂	3.00	83.33
T ₃	3.33	86.33
T ₄	2.67	84.33
T ₅	2.00	88.67
T ₆	2.33	86.67
T ₇	5.00	86.67
T ₈	3.00	86.00
T ₉	4.67	87.00
Mean	3.44	85.93
S.Em±	0.23	0.96
CD (P=0.05)	0.68	2.87
CV (%)	11.35	1.93

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