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Studies on effect of new insecticide molecules on seed quality of hybrid maize (*Zea mays* l.) during storage

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Abstract

A storage experiment was conducted to evaluate the effect of new insecticide molecules on the seed quality of hybrid maize (MAH 14-138) at the Seed Unit, University of Agricultural Sciences, Raichur, under ambient conditions from November 2024 to July 2025. The experiment was laid out in a Completely Randomized Design (CRD) with 11 treatments in four replications. The treatments *viz*., Spinetoram 11.7 SC (1, 2, 3 ppm), Flupyradifurone 200 SL (2, 4, 8 ppm), Emamectin benzoate 5 SG (2 ppm), Deltamethrin 2.8 EC (1 ppm), Spinosad 45 SC (2 ppm) and Imidacloprid 600 FS (5 ml/kg of seed). Monthly observations on seed quality parameters up to nine months of storage revealed that seeds treated with Spinosad 45 SC @ 2 ppm consistently maintained superior seed quality, whereas untreated seeds recorded the lowest performance. At the ninth month, Spinosad-treated seeds exhibited the highest germination (91.00 %), seedling dry weight (63.10 mg) and seedling vigour index-I (2522) and also showed the lowest seed infestation (0.00 %) and electrical conductivity (0.58 dS/m). Overall, the study demonstrated that Spinosad 45 SC @ 2 ppm is highly effective in safeguarding hybrid maize seed quality and provides complete protection against *Sitophilus* spp. infestation for up to nine months of storage.

Keywords: Hybrid maize, new insecticide molecules, seed infestation and seed quality

Introduction

Seeds are the fundamental input in agriculture, serving as living entities that encapsulate the genetic potential for crop growth and productivity. The preservation of seed viability, vigour and genetic integrity during storage is critical for ensuring sustainable agricultural production and food security. Among cereals, maize (*Zea mays* L.), known as the "Queen of Cereals," is a C_4 crop with high photosynthetic efficiency and wide adaptability to diverse agro-climatic conditions (Walters, 2022) [27]. It is globally important as food, feed and a raw material for numerous industrial applications, including starch, oil, protein, alcohol, sweeteners and biofuel. Nutritionally, maize seeds contain approximately 70 % starch, 10 % protein and 4 % oil, offering a balanced supply of carbohydrates, fats, proteins and fibres (Prasanna *et al*., 2001) [18].

Globally, maize is cultivated on 206.3 million hectares, producing 780 million tonnes with an average productivity of 3,150 kg/ha. In India, it ranks third among cereals after rice and wheat, covering 10.74 million hectares and yielding 38.08 million tonnes with an average productivity of 3,545 kg/ha. Karnataka is one of the leading maize-producing states, with 1.91 million hectares under cultivation and 5.91 million tonnes of production (Anon, 2024). Despite its high yield potential, hybrid maize seeds are more prone to deterioration than open-pollinated varieties due to their high starch content and susceptibility to fungal and insect attacks (Rame Gowda *et al*., 2002) [19]. Membrane damage during storage accelerates loss of viability and vigour, particularly in hybrids, leading to poor germination, seedling mortality and vulnerability to pathogens (Zhou *et al*., 1989) [29].

Post-harvest losses constitute a major challenge in maintaining grain quality. In India, storage losses are estimated at 14 million tonnes annually, valued at approximately ₹7,000 crores, with insects alone responsible for nearly ₹1,300 crores (Anon, 2020). More than 600 insect species are associated with stored grains, of which around 100 cause significant economic damage. In maize, major storage pests include *Sitophilus* spp., *Rhizopertha dominica, Tribolium castaneum* and *Sitotroga cerealella,* with *Sitophilus weevils* being the most destructive worldwide (Champ and Dyte, 1977) [7].

Insecticides remain the most practical and cost-effective method for minimizing seed damage and preventing storage pest infestations. However, continuous and indiscriminate use of conventional chemicals has resulted in resistance development among pest populations, as well as environmental and health concerns. These limitations necessitate the exploration of novel insecticide molecules that are more target-specific, effective at lower doses, and safer for non-target organisms. Novel insecticides, also termed "new molecules," differ structurally from traditional compounds and often act through unique physiological or biochemical mechanisms, offering an alternative approach to resistance management. They exhibit improved selectivity, enhanced residual efficacy and reduced ecological toxicity, making them compatible with integrated pest management (IPM) programs (Satpathy *et al*., 2017).

Compounds such as spinetoram, spinosad, flupyradifurone, emamectin benzoate, imidacloprid and deltamethrin have shown broad-spectrum efficacy against key storage pests, providing long-lasting protection with minimal environmental impact. Considering the need for safe, efficient and sustainable seed protection technologies, the present investigation was undertaken to evaluate the efficacy of new insecticidal seed treatments in maintaining the quality of hybrid maize seeds during storage and in controlling Sitophilus spp. infestation under ambient conditions.

Material and Methods

An experiment was conducted at Seed Unit, University of Agricultural Sciences, Raichur, Karnataka during November

2024 - July 2025, for a period of nine months to evaluate the effect of seed treatment with new insecticide molecule on seed quality of hybrid maize seeds during storage. The freshly harvested seeds of maize hybrid MAH 14-138 were obtained from Zonal Agricultural Research Station (ZARS), V C Farm, Mandya, Karnataka for the present investigation. The experiment consists of eleven different treatments, including a control *Viz*., T_1: Spinetoram 11.7 SC @ 1 ppm (8.5 mg/kg), T_2: Spinetoram 11.7 SC @ 2 ppm (17 mg/kg), T_3: Spinetoram 11.7 SC @ 3 ppm (25.6 mg/kg), T_4: Flupyradifurone 200 SL @ 2 ppm (0.01 ml/kg), T_5: Flupyradifurone 200 SL @ 4 ppm (0.02 ml/kg), T_6: Flupyradifurone 200 SL @ 8 ppm (0.04 ml/kg), T_7: Emamectin benzoate 5 SG @ 2ppm (40 mg/kg), T_8: Deltamethrin 2.8 EC @ 1 ppm (0.04 ml/kg), T_9: Spinosad 45 SC @ 2ppm (2 mg/kg), T_{10}: Imidacloprid 600 FS @ (5 ml/kg), T_{11}: Untreated control. The experiment was laid out in a Completely Randomized Design (CRD) with four replications.

For imposition of treatments, the freshly harvested seeds with a high percentage of seed germination, low moisture content (<12 %) of maize hybrid seeds were taken for the seed treatment. Before undertaking seed treatment, the seeds were thoroughly checked for the incidence of pest infestation. Four kilograms of freshly harvested seeds were taken for each treatment. The required quantity of insecticide was diluted in water to achieve a total volume of 5 mL for treating 1 kg of seed, ensuring proper coating. The seeds were mixed manually for approximately two minutes to achieve uniform distribution of the insecticide with the seed mass, then shade-dried to achieve a safe moisture content. Treated seeds were packed in 2 kg capacity gunny bags and stored under ambient conditions.

The germination test was carried out by following between paper method. 100 seeds from each treatment were taken in four replications and placed uniformly on germination paper. The roll towels were kept in a germination chamber maintained at 25 ± 2ºC temperature and 90 ± 5 per cent relative humidity. The number of normal seedlings from each replication was counted on the 7th day, and the mean germination was expressed as a percentage (Anon, 2013). Similarly, Seedling dry weight (mg/seedling) was determined as per ISTA rules (Anon, 2013).

Seedling vigour index-I was calculated by multiplying germination percentage with total seedling length (cm) (Abdul-Baki and Anderson, 1973) [1]. Seed infestation (%) was assessed based on the number of seeds with holes using the formula by Adams and Schulten (1978) [2]. Electrical conductivity (dS/m) of seed leachates was measured with a digital conductivity meter after correcting for distilled water EC (Milosevic *et al*., 2010) [15]. Data were statistically analyzed following the procedures of Panse and Sukhatme (1985) [17].

Results and Discussion

Seed germination (%) did not differ significantly during the initial months of storage, but from the second month onward, significant differences among treatments were observed. Germination declined over time across all treatments, with spinosad 45 SC @ 2 ppm (T_9) consistently maintaining the highest values, retaining 91.00 % after nine months. Seeds treated with spinosad 45 SC (T_9) and emamectin benzoate 5 SG @ 2 ppm (T_7) maintained germination above 90 %, whereas the untreated control (T_{11}) declined sharply from 96.50 % to 77.50 %. flupyradifurone 200 SL @ 2 ppm (T_4) and imidacloprid 600 FS 5 ml/kg (T_{10}) showed intermediate retention (83.50 % and 83.00 %, respectively) (Table 1) (Fig. 1).

The superior performance of spinosad 45 SC @ 2 ppm (T_9) is attributed to its strong insecticidal activity, low mammalian toxicity and residual effect that prevents pest infestation and seed deterioration (Thompson *et al*., 2000; Sparks, 2008) [22, 25]. Emamectin benzoate 5 SG @ 2 ppm (T_7) and deltamethrin 2.8 EC @ 1 ppm (T_8) also preserved germination better than the untreated control (T_{11}), due to reduced insect feeding and protective effects against fungal invasion (Ishaaya *et al*., 2002; Arthur, 1994) [6, 11]. These findings align with Kavitha and Subramanyam (2007) [13], who reported that insecticidal seed coatings significantly reduce germination loss in maize during extended storage.

The data on seed infestation (%) clearly show that, during the initial three months of storage, there was no incidence of insect pest infestation, regardless of all the treatments, including untreated seeds, indicating the effectiveness of all insecticidal seed treatments in providing complete protection against insect pests during the early storage period. From the fourth month onward, marginal increases in infestation were recorded in some treatments, with significant differences emerging from the fifth month onwards. By the end of the storage period, spinosad 45 SC @ 2 ppm (T_9) recorded zero seed infestation. This was closely followed by emamectin benzoate 5 SG @ 2 ppm (T_7 - 0.25 %) and deltamethrin 2.8 EC @ 1 ppm (T_8 - 0.50 %). Among the spinetoram treatments, T_1 (1 ppm), T_2 (2 ppm) and T_3 (3 ppm) maintained low infestation levels of 1.25 %, 0.75 % and 0.50 %, respectively. In contrast, the untreated control (T_{11} -10.25 %) recorded the highest infestation at the ninth month (Table 1).

During the first three months of storage, no insect infestation was observed across all treatments, including untreated seeds. In storage ecosystems, pest buildup follows a predictable pattern; when seeds are initially free from contamination, insects like *Sitophilus zeamais* or *Rhyzopertha dominica* require time to complete their first life cycle before visible damage appears (Rees, 2004) [20]. The effectiveness of spinosad has also been reported against *Sitophilus oryzae* and *Tribolium castaneum* in wheat (Fang *et al*., 2002) [8] and in chickpea seeds, where it minimized seed damage (Vidyashree *et al*., 2014) [26].

Seedling dry weight of hybrid maize was statistically at par across treatments up to the third month of storage, with values ranging narrowly between 70.52 mg to 70.62 mg at one month after storage. By the ninth month, spinosad 45 SC @ 2 ppm (T_9 - 63.10 mg) continued to maintain the highest dry weight, closely followed by emamectin benzoate 5 SG @ 2 ppm (T_7 - 62.50 mg) and deltamethrin 2.8 EC @ 1 ppm (T_8 - 62.00 mg). These treatments were significantly superior to the untreated control (T_{11} - 53.11 mg), indicating better retention of seed reserves for seedling growth under prolonged storage (Table 2).

Spinosad 45 SC @ 2 ppm (T_9) consistently maintained the highest seedling dry weight throughout storage, followed by emamectin benzoate 5 SG @ 2 ppm (T_7) and deltamethrin 2.8 EC @ 1 ppm (T_8). This superior performance can be attributed to their ability to provide effective insect protection, reduce biotic stress and minimize metabolic losses, thereby conserving seed reserves critical for biomass accumulation (Kumar *et al*., 2019) [14]. In contrast, untreated seeds (T_{11}) exhibited a sharper decline, largely due to greater susceptibility to insect damage and tissue deterioration. These findings are in agreement with Yogitha (2017) [28] in cowpea, who also reported the positive role of insecticidal and fungicidal seed treatments in improving dry matter accumulation.

During the first month of storage, seedling vigour index - I value was statistically non-significant across treatments, reflecting the initially high vigour of all hybrid maize seed lots. From the second month onwards, significant differences emerged, with spinosad 45 SC @ 2 ppm (T_9) consistently recording the highest seedling vigour index - I throughout storage, maintained highest seedling vigour, ranging from 3246 to 2522 by the end of the storage period, followed closely by emamectin benzoate 5 SG @ 2 ppm (T_7 - 3224 to 2441) and deltamethrin 2.8 EC @ 1 ppm (T_8 - 3205 to 2369). In contrast, the untreated seeds (T_{11}) exhibited the lowest seedling vigour index (3085 to 1667) from the first to the ninth month of storage (Table 2).

This outcome is corroborated by Padmasri *et al.* (2019) [16], who reported that spinosad-treated maize seeds achieved significantly higher seedling vigour index - I value compared to untreated seeds. Spinetoram 11.7 SC @ 3 ppm (T_3) maintained higher seedling vigour during later storage than lower doses, indicating a dose-dependent benefit. Similar trends were reported by Kaur *et al.* (2019) [12], who observed that increased spinetoram concentration reduced storage pest infestation and delayed vigour loss in maize seeds. The decrease in the seed vigour index may be due to age induced decline in germination, decrease in root and shoot length and seedling dry weight and higher electrical conductivity (Gupta *et al*, 1998) [9].

Electrical conductivity (EC) of hybrid maize seed leachates increased significantly with storage from two to eight months across all treatments. At eight months, seeds treated with spinosad 45 SC @ 2 ppm (T_9 - 0.58 dS/m) recorded the lowest EC, comparable to emamectin benzoate 5 SG @ 2 ppm (T_7 - 0.62 dS/m), followed by deltamethrin 2.8 EC @ 1 ppm (T_8 - 0.64 dS/m). Among spinetoram treatments, spinetoram 11.7 SC @ 3 ppm (T_3) performed better than lower doses (T_1 and T_2), while flupyradifurone 200 SL (T_4 - T_6) and imidacloprid 600 FS @ 5 ml/kg (T_{10}) showed intermediate EC values. The untreated control (T_{11}) recorded the highest EC (0.94 dS/m), indicating maximum membrane deterioration (Table 3) (Fig. 2).

EC is a sensitive indicator of membrane integrity and seed vigour, with higher values reflecting increased solute leakage due to loss of cell membrane semipermeability (Hampton and Tekrony, 1995) [10]. Lower EC in spinosad, emamectin benzoate and deltamethrin-treated seeds is attributed to reduced insect infestation and slower biochemical degradation, which limits lipid peroxidation and protein denaturation, maintaining membrane stability (Suma *et al.*, 2014) [24]. These results are consistent with Srinivasan *et al.* (2010) [23], who reported that Spinosad-treated maize seeds retained higher germination and lower EC compared to untreated seeds during prolonged storage.

Table 1: Effect of seed treatment with new insecticide molecules on seed germination (%) and seed infestation (%) of hybrid maize seeds during storage

Treatments	Seed germination (%)				Seed infestation (%)			
	1 MAS	3 MAS	6 MAS	9 MAS	1 MAS	3 MAS	6 MAS	9 MAS
T_1: Spinetoram 11.7 SC @ 1 ppm	98.00 (81.86)*	95.50 (77.79)	91.50 (73.12)	85.00 (67.22)	0.00 (0.00)*	0.00 (0.00)	0.25 (1.43)	1.25 (6.34)
T_2: Spinetoram 11.7 SC @ 2 ppm	98.00 (83.04)	96.50 (79.50)	92.50 (74.12)	87.00 (68.87)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.75 (4.30)
T_3: Spinetoram 11.7 SC @ 3 ppm	98.50 (83.89)	97.00 (80.16)	92.50 (74.12)	88.00 (69.72)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.50 (2.87)
T_4: Flupyradifurone 200 SL @ 2 ppm	97.50 (81.01)	94.50 (76.57)	91.00 (72.66)	83.50 (66.03)	0.00 (0.00)	0.00 (0.00)	0.75 (4.30)	1.75 (7.53)
T_5: Flupyradifurone 200 SL @ 4 ppm	97.50 (81.01)	95.00 (77.23)	91.50 (73.06)	84.00 (66.41)	0.00 (0.00)	0.00 (0.00)	0.50 (2.87)	1.50 (6.93)
T_6: Flupyradifurone 200 SL @ 8 ppm	98.00 (83.04)	96.00 (78.45)	92.00 (73.56)	86.50 (68.44)	0.00 (0.00)	0.00 (0.00)	0.25 (1.43)	1.00 (5.74)
T_7: Emamectin benzoate 5 SG @ 2 ppm	98.50 (83.89)	97.50 (81.01)	93.50 (75.35)	90.00 (71.56)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.25 (1.43)
T_8: Deltamethrin 2.8 EC @ 1 ppm	98.50 (83.89)	97.00 (80.16)	93.00 (74.85)	88.50 (70.18)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.50 (2.87)
T_9: Spinosad 45 SC @ 2 ppm	99.00 (85.92)	98.00 (83.04)	94.50 (76.47)	91.00 (72.56)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
T_{10}: Imidacloprid 600 FS @ 5 ml/kg	97.50 (81.01)	94.50 (76.47)	90.50 (72.10)	83.00 (65.65)	0.00 (0.00)	0.00 (0.00)	0.75 (4.30)	2.00 (8.13)
T_{11}: Untreated control	96.50 (79.30)	93.50 (75.25)	87.50 (69.43)	77.50 (61.68)	0.00 (0.00)	0.00 (0.00)	3.00 (9.97)	10.25 (18.67)
Mean	97.95 (82.53)	95.91 (78.69)	91.82 (73.53)	85.64 (67.86)	0.00 (0.00)	0.00 (0.00)	0.50 (2.21)	1.80 (5.89)
S. Em. ±	1.73	1.16	0.99	0.38	0.00	0.00	0.17	0.23
CD @ 1%	NS	4.50	3.83	1.47	NS	NS	0.67	0.87

MAS: Months after storage, NS: Non-significant, *Figures in the parenthesis indicate the arcsine transformed values

Table 2: Effect of seed treatment with new insecticide molecules on seedling dry weight (mg) and seedling vigour index - I of hybrid maize seeds during storage

Treatments	Seedling dry weight (mg)				Seedling vigour index - I			
	1 MAS	3 MAS	6 MAS	9 MAS	1 MAS	3 MAS	6 MAS	9 MAS
T_1: Spinetoram 11.7 SC @ 1 ppm	70.54	68.73	62.33	59.40	3156	2933	2526	2148
T_2: Spinetoram 11.7 SC @ 2 ppm	70.55	69.12	65.52	61.63	3171	2993	2629	2259
T_3: Spinetoram 11.7 SC @ 3 ppm	70.56	69.28	67.03	61.84	3200	3034	2666	2332
T_4: Flupyradifurone 200 SL @ 2 ppm	70.53	68.58	61.65	56.60	3131	2890	2461	2081
T_5: Flupyradifurone 200 SL @ 4 ppm	70.53	68.69	62.05	58.40	3134	2913	2491	2105
T_6: Flupyradifurone 200 SL @ 8 ppm	70.55	68.89	64.25	59.90	3162	2959	2572	2223
T_7: Emamectin benzoate 5 SG @ 2 ppm	70.61	69.74	69.18	62.50	3224	3079	2768	2441
T_8: Deltamethrin 2.8 EC @ 1 ppm	70.61	69.45	68.43	62.00	3205	3045	2712	2369
T_9: Spinosad 45 SC @ 2 ppm	70.62	69.86	69.21	63.10	3246	3104	2826	2522
T_{10}: Imidacloprid 600 FS @ 5 ml/kg	70.52	68.29	61.08	55.91	3130	2887	2441	2059
T_{11}: Untreated control	70.52	67.10	58.79	53.11	3085	2808	2225	1667
Mean	70.56	68.88	64.50	59.49	3168	2968	2574	2201
S. Em. ±	0.03	0.56	0.49	0.23	33	35	27	14
CD @ 1%	NS	NS	1.89	0.90	NS	136	106	53

MAS: Months after storage
NS: Non-significant

Table 3: Effect of seed treatment with new insecticide molecules on electrical conductivity (EC) (dS/m) of hybrid maize seeds during storage

Electrical conductivity (EC) (dS/m) - November 2024 to July 2025				
Treatments	**2 MAS**	**4 MAS**	**6 MAS**	**8 MAS**
T_1: Spinetoram 11.7 SC @ 1 ppm	0.34	0.39	0.57	0.75
T_2: Spinetoram 11.7 SC @ 2 ppm	0.31	0.36	0.53	0.70
T_3: Spinetoram 11.7 SC @ 3 ppm	0.29	0.35	0.51	0.67
T_4: Flupyradifurone 200 SL @ 2 ppm	0.37	0.44	0.63	0.78
T_5: Flupyradifurone 200 SL @ 4 ppm	0.36	0.42	0.59	0.76
T_6: Flupyradifurone 200 SL @ 8 ppm	0.32	0.36	0.54	0.73
T_7: Emamectin benzoate 5 SG @ 2ppm	0.27	0.32	0.47	0.62
T_8: Deltamethrin 2.8 EC @ 1 ppm	0.28	0.34	0.49	0.64
T_9: Spinosad 45 SC @ 2 ppm	0.25	0.31	0.44	0.58
T_{10}: Imidacloprid 600 FS @ 5 ml/kg	0.38	0.45	0.65	0.79
T_{11}: Untreated control	0.42	0.48	0.72	0.94
Mean	0.33	0.39	0.56	0.72
S. Em. ±	0.01	0.01	0.01	0.02
CD @ 1%	0.03	0.04	0.04	0.07

MAS: Months after storage

Conclusion

The results indicated that spinosad 45 SC @ 2 ppm (T_9) was the most effective treatment in maintaining seed germination, seedling vigour and dry weight, while completely preventing seed infestation and minimizing membrane deterioration over the nine-month storage period. Emamectin benzoate 5 SG @ 2 ppm (T_7) and deltamethrin 2.8 EC @ 1 ppm (T_8) also performed better than other treatments and the untreated control, sustaining high germination values and low electrical conductivity. The superior performance of these treatments is attributed to their strong and persistent insecticidal activity, reduced seed deterioration, and preservation of physiological and biochemical integrity. Therefore, spinosad 45 SC @ 2 ppm emerges as an effective and eco-friendly alternative to conventional chemical protectants and fumigation, due to its microbial origin, low mammalian toxicity, rapid degradation and minimal residue accumulation.

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