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Effect of organic seed treatments on seed health and quality of cowpea (*Vigna unguiculata* L.) during storage

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Abstract
Cowpea (*Vigna unguiculata* L.) is a vital legume crop, but its post-harvest viability is often compromised by deteriorating seed quality, insect damage, and fungal infestations during storage. While chemical protectants are common, their environmental and health risks have driven the search for organic alternatives. This study evaluated the efficacy of nine organic seed treatments on the health and quality of two cowpea varieties, *Phule Sonali* and *Phule Rakhumai*, during 300 days of storage under ambient conditions. The treatments included neem leaf powder, neem oil, castor oil, karanj oil, vekhand powder, turmeric powder, citronella oil, and ash, compared against an untreated control. Key parameters assessed were moisture content, germination percentage, root and shoot length, vigor indices, seedling dry weight, electrical conductivity, test weight, seed mycoflora, and pulse beetle (*Callosobruchus chinensis*) infestation. Results demonstrated that all organic treatments were superior to the control, with neem oil (5 ml/kg) being the most effective. It maintained the lowest moisture content (7.48%), highest germination (77.17%), and superior vigor indices and seedling dry weight. Neem oil also significantly suppressed fungal growth (31.50% mycoflora) and provided the strongest protection against pulse beetle infestation (3.67% at 9 months). Castor oil and neem leaf powder also showed significant, though slightly lesser, benefits. The study concludes that organic seed treatments, particularly neem oil, offer a highly effective, eco-friendly, and economically viable strategy for preserving cowpea seed quality, reducing post-harvest losses, and promoting sustainable agriculture for resource-limited farmers.

Keywords: Cowpea, organic seed treatment, neem oil, castor oil, seed vigour, pulse beetle, seed storage, mycoflora, sustainable seed management

Introduction

Pulses have formed the cornerstone of Indian agriculture and nutrition since the dawn of civilization, with archaeological evidence from Indus Valley sites establishing India as one of the world's oldest pulse-domesticating regions. Among these ancient crops, cowpea (*Vigna unguiculata*), locally termed lobia or chawli, holds particular significance as a climate-resilient protein source, often termed as the "poor man's meat" due to its rich protein content of 20-25 percent. Characterized by its remarkable resilience, cowpea thrives in poor soils and low-rainfall conditions, making it a vital crop for climate-smart agriculture. However, farmers face significant post-harvest challenges, including reduced germination percentage, loss of vigour, and increased incidence of seed-borne fungi and insect damage during storage. While chemical seed treatments are common, their prolonged use poses risks related to environmental pollution and human health, leading to a shift toward organic alternatives. Natural substances are gaining attention for their antimicrobial properties, with extensive research validating their efficacy. For instance, neem leaf powder has been shown to effectively maintain seed quality in pulses like chickpea and cowpea (Patil, 2000; Maraddi, 2002) [32, 28], while neem oil has provided robust protection against pulse beetles (*Callosobruchus chinensis*) (Pandey et al., 1976; Nishad et al., 2020) [31, 30]. Similarly, castor oil and karanj oil have demonstrated long-term protective effects, maintaining high germination for over 18 months (Ramesh Babu et al., 1989; Gowda et al., 2018) [6, 14], with karanj oil showing efficacy comparable to chemical insecticides (Vir, 1994) [8].

Plant-based powders such as vekhand (sweet flag) and turmeric, along with inert materials like ash, have also been scientifically validated for significantly reducing seed damage and pest infestation (Khan and Borle, 1985; Ali et al., 2006; Shaheen and Khaliq, 2005) [20, 2, 38]. Therefore, this study focuses on evaluating the efficacy of these organic treatments in maintaining the seed health and quality of cowpea during storage, building upon the established potential of these natural agents.

Methodology

Seed Material and Treatments

Freshly harvested seeds of Cowpea varieties Phule Sonali and Phule Rakhumai were obtained from the Pulses and Oilseed Crops Research and Training Centre, Pandharpur, MPKV Rahuri. The initial culture of pulse beetle (*Callosobruchus chinensis* L.) was obtained from the Entomology Laboratory, Seed Technology Research Unit, MPKV, Rahuri, following the identification key of *Callosbruchus* spp. given by Raina (1970) [35]. Seeds were subjected to nine different treatments: T_1 (Control), T_2 (Neem leaf powder @ 5 g/kg), T_3 (Neem oil @ 5 ml/kg), T_4 (Castor oil @ 5 ml/kg), T_5 (Karanj oil @ 5 ml/kg), T_6 (Vekhand powder @ 10 g/kg), T_7 (Turmeric powder @ 5 g/kg), T_8 (Citronella oil @ 5 ml/kg), and T_9 (Ash @ 5 g/kg).

Experimental Design

The experiment was laid out in a Factorial Completely Randomized Design (FCRD) with two varieties and nine treatments, replicated three times. Treated seeds were stored in High-Density Polyethylene (HDPE) bags under ambient conditions at the Seed Technology Research Unit, MPKV, Rahuri.

Parameters Evaluated

Initial observations for germination (%), root length (cm), shoot length (cm), vigour index I and II, seedling dry weight (mg/10 seedlings), electrical conductivity (dSm-1), test weight (g), moisture content (%) and seed mycoflora (%) were recorded before storage. Subsequent observations were recorded at monthly intervals during the storage period.

Seed quality parameters were assessed following standard protocols: moisture content by hot air oven method (Anon., 1999) [4], germination by between paper method as per ISTA procedure (Anon., 1996) [3], root and shoot length measurements on 8th day, seedling vigour indices I and II calculated using formulas suggested by Abdul-Baki and Anderson (1973) [1], seedling dry weight after oven drying at 85±1°C for 24 hours, electrical conductivity measured using Digital Electrical Conductivity meter (Presley, 1958) [34], test weight as per ISTA rules (Anon., 1999) [4], and seed mycoflora by blotter test (Anon., 1999) [4].

For bio-efficacy testing, treated seeds were kept in bottle containers with 10 pairs of pulse beetles released in each bottle. Observations were performed every three months to check the efficacy of organic treatments against pulse beetle (*Callosobruchus chinensis*), with seed infestation percentage calculated based on characteristic holes made by beetles.

Statistical Analysis

The data obtained from all parameters were analyzed using Factorial Completely Randomized Design (FCRD) as described by Snedecor and Cochran (1967) [44]. For germination percent, moisture content, seed mycoflora and pulse beetle infestation, corresponding arcsine values were taken. Whenever results were significant, critical differences (C.D.) at 5% level of significance were calculated and used for comparing the treatments.

Result and Disscussion

The present research entitled "Effect of organic seed treatments on seed health and quality of cowpea (*Vigna unguiculata* L.) during storage" was undertaken at the Seed Technology Research Unit, M.P.K.V., Rahuri during the period from September 2024 to June 2025. The experiment was initiated in September 2024, with the first observation recorded at the time of storage. A second observation was taken 60 days after storage, followed by regular monthly observation. After that, observations were taken every month to check the seed health and quality during the storage period. The findings of the study and their explanation are given below.

Moisture content (%)

Effect of seed treatment on moisture content (%) of Cowpea

The results on seed moisture content as influenced by seed treatment are presented in Table 1 (Figure 1).

The seed moisture content showed significant differences among the botanical treatments at all stages of storage, except at initial days of storage i.e. immediately after receipt of seed sample.

At the initial stage of storage, the varieties, Phule Sonali (V_1) recorded slightly higher moisture content at 8.70% than Phule Rakhumai (V_2) at 8.60%. Among the treatments, the highest moisture content was recorded in T_1 (control) at 8.73%, followed by T_4 (Castor oil) at 8.68%, while the lowest value was recorded in T_9 (ash) at 8.62%.

Table 1: Effect of seed treatment on moisture content (%) of cowpea

Treatment	Storage period (September 2024 - June 2025)									
	Initial	60	90	120	150	180	210	240	270	300
a. Variety										
V_1	8.70 (17.15)	8.65 (17.10)	8.60 (17.05)	8.56 (17.01)	8.48 (16.93)	8.36 (16.81)	8.17 (16.60)	7.93 (16.36)	7.81 (16.23)	7.61 (16.02)
V_2	8.60 (17.06)	8.53 (16.98)	8.50 (16.95)	8.45 (16.90)	8.38 (16.83)	8.28 (16.72)	8.11 (16.55)	7.87 (16.29)	7.75 (16.16)	7.56 (15.96)
SE±	0.01	0.01	0.01	0.02	0.01	0.01	0.02	0.01	0.01	0.01
C.D at 5%	0.03	0.03	0.02	0.05	0.04	0.03	0.05	0.03	0.02	0.03
b. Treatment										
T_1	8.73 (17.18)	8.66 (17.11)	8.64 (17.10)	8.58 (17.03)	8.54 (16.99)	8.53 (16.98)	8.35 (16.80)	8.16 (16.59)	8.04 (16.47)	7.86 (16.28)
T_2	8.64 (17.09)	8.56 (17.01)	8.54 (17.00)	8.51 (16.96)	8.40 (16.85)	8.31 (16.75)	8.13 (16.57)	7.84 (16.25)	7.76 (16.17)	7.56

										(15.95)
T_3	8.66 (17.12)	8.59 (17.04)	8.50 (16.95)	8.48 (16.93)	8.32 (16.76)	8.24 (16.68)	8.06 (16.49)	7.77 (16.19)	7.66 (16.07)	7.48 (15.87)
T_4	8.68 (17.13)	8.57 (17.02)	8.53 (16.98)	8.49 (16.94)	8.42 (16.86)	8.26 (16.70)	8.08 (16.51)	7.79 (16.21)	7.67 (16.08)	7.50 (15.89)
T_5	8.65 (17.10)	8.62 (17.07)	8.53 (16.98)	8.50 (16.95)	8.39 (16.84)	8.28 (16.72)	8.11 (16.55)	7.81 (16.23)	7.73 (16.14)	7.53 (15.92)
T_6	8.63 (17.08)	8.58 (17.03)	8.56 (17.01)	8.50 (16.95)	8.48 (16.93)	8.36 (16.81)	8.18 (16.61)	7.96 (16.39)	7.81 (16.22)	7.61 (16.01)
T_7	8.63 (17.08)	8.56 (17.01)	8.54 (16.99)	8.50 (16.95)	8.47 (16.92)	8.29 (16.73)	8.15 (16.58)	7.95 (16.38)	7.79 (16.21)	7.55 (15.94)
T_8	8.64 (17.09)	8.61 (17.06)	8.54 (16.99)	8.49 (16.94)	8.41 (16.86)	8.31 (16.76)	8.12 (16.56)	7.89 (16.31)	7.75 (16.16)	7.58 (15.98)
T_9	8.62 (17.07)	8.60 (17.05)	8.55 (17.00)	8.50 (16.95)	8.46 (16.91)	8.33 (16.77)	8.09 (16.52)	7.96 (16.38)	7.82 (16.24)	7.64 (16.04)
SE±	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01
C.D.at 5%	NS	0.03	0.02	0.05	0.04	0.03	0.04	0.03	0.02	0.03
Interaction										
V_1T_1	8.79 (17.25)	8.72 (17.18)	8.70 (17.16)	8.65 (17.10)	8.64 (17.09)	8.58 (17.03)	8.41 (16.86)	8.19 (16.63)	8.07 (16.50)	7.89 (16.31)
V_1T_2	8.70 (17.15)	8.62 (17.07)	8.59 (17.05)	8.59 (17.05)	8.45 (16.90)	8.36 (16.81)	8.16 (16.60)	7.89 (16.31)	7.80 (16.22)	7.59 (15.99)
V_1T_3	8.72 (17.18)	8.64 (17.09)	8.54 (16.99)	8.55 (17.00)	8.37 (16.81)	8.30 (16.74)	8.10 (16.54)	7.81 (16.23)	7.69 (16.10)	7.51 (15.91)
V_1T_4	8.74 (17.20)	8.62 (17.07)	8.58 (17.03)	8.54 (16.99)	8.49 (16.94)	8.32 (16.76)	8.12 (16.56)	7.83 (16.25)	7.74 (16.15)	7.53 (15.93)
V_1T_5	8.71 (17.17)	8.68 (17.13)	8.58 (17.03)	8.54 (16.99)	8.45 (16.90)	8.34 (16.79)	8.14 (16.58)	7.86 (16.28)	7.77 (16.19)	7.56 (15.96)
V_1T_6	8.69 (17.14)	8.63 (17.08)	8.60 (17.05)	8.55 (17.01)	8.54 (17.00)	8.42 (16.87)	8.20 (16.64)	8.03 (16.46)	7.85 (16.27)	7.65 (16.06)
V_1T_7	8.62 (17.07)	8.61 (17.06)	8.59 (17.05)	8.55 (17.00)	8.43 (16.88)	8.27 (16.71)	8.18 (16.62)	7.92 (16.34)	7.77 (16.18)	7.53 (15.93)
V_1T_8	8.63 (17.09)	8.67 (17.12)	8.59 (17.05)	8.54 (16.99)	8.39 (16.84)	8.31 (16.75)	8.15 (16.59)	7.88 (16.30)	7.79 (16.21)	7.58 (15.98)
V_1T_9	8.68 (17.13)	8.66 (17.11)	8.59 (17.04)	8.55 (17.00)	8.54 (16.99)	8.38 (16.83)	8.04 (16.47)	8.01 (16.44)	7.83 (16.25)	7.68 (16.09)
V_2T_1	8.66 (17.11)	8.60 (17.05)	8.58 (17.04)	8.52 (16.97)	8.43 (16.88)	8.47 (16.92)	8.29 (16.73)	8.12 (16.56)	8.01 (16.44)	7.82 (16.24)
V_2T_2	8.58 (17.03)	8.50 (16.95)	8.49 (16.94)	8.43 (16.88)	8.35 (16.80)	8.25 (16.69)	8.10 (16.54)	7.78 (16.20)	7.72 (16.23)	7.52 (15.92)
V_2T_3	8.60 (17.05)	8.53 (16.98)	8.45 (16.90)	8.42 (16.86)	8.27 (16.71)	8.17 (16.61)	8.02 (16.45)	7.73 (16.14)	7.63 (16.03)	7.44 (15.83)
V_2T_4	8.61 (17.06)	8.51 (16.96)	8.48 (16.93)	8.44 (16.89)	8.34 (16.79)	8.20 (16.64)	8.03 (16.46)	7.75 (16.16)	7.61 (16.01)	7.46 (15.85)
V_2T_5	8.59 (17.04)	8.55 (17.00)	8.49 (16.94)	8.45 (16.90)	8.33 (16.78)	8.22 (16.66)	8.08 (16.51)	7.76 (16.17)	7.68 (16.09)	7.49 (15.88)
V_2T_6	8.57 (17.02)	8.52 (16.97)	8.51 (16.96)	8.45 (16.90)	8.42 (16.86)	8.31 (16.75)	8.15 (16.59)	7.89 (16.32)	7.76 (16.17)	7.57 (15.97)
V_2T_7	8.63 (17.09)	8.50 (16.95)	8.48 (16.93)	8.45 (16.90)	8.50 (16.95)	8.31 (16.75)	8.11 (16.55)	7.98 (16.41)	7.82 (16.24)	7.56 (15.96)
V_2T_8	8.64 (17.09)	8.54 (16.99)	8.49 (16.94)	8.43 (16.88)	8.43 (16.88)	8.32 (16.76)	8.09 (16.52)	7.89 (16.32)	7.71 (16.12)	7.58 (15.98)
V_2T_9	8.56 (17.01)	8.54 (16.99)	8.51 (16.96)	8.45 (16.90)	8.38 (16.83)	8.27 (16.71)	8.13 (16.57)	7.90 (16.32)	7.80 (16.22)	7.60 (16.00)
S.E±	0.03	0.03	0.02	0.05	0.04	0.03	0.05	0.03	0.02	0.03
C.D at 5%	NS	NS	0.07	0.14	0.12	0.09	0.14	0.09	0.07	0.09

V_1: Phule sonali, V_2: Phule Rakhumai, T_1: Control, T_2: Neem leaf powder, T_3: Neem oil, T_4: Castor oil, T_5: Karanj oil, T_6: Vekhand powder, T_7: Turmeric powder, T_8: Citronella oil, T_9: Ash

The interaction effect between variety and treatment on seed moisture content was observed to be non-significant during the initial storage period. In terms of interaction, the combination V_1T_1 (Phule Sonali × Control) had the highest initial moisture content with 8.79%, whereas the lowest was recorded in V_2T_9 (Phule Rakhumai × Ash) with 8.56%.

At the ends of 300 days of storage period, significant differences were observed in seed moisture content due to the effects of varieties, treatments and their interactions. Among the varieties, Phule Sonali (V_1) retained slightly higher moisture (7.61%**)** compared to Phule Rakhumai (V_2), which recorded 7.56%. Among the treatments, T_3 (neem oil) recorded the lowest moisture content (7.48%), followed by T_4 (Castor oil) at 7.50%. On the other hand, the highest moisture was recorded in T_1 (control) at 7.86%. In the interaction effect, the combination V_2T_3 (Phule Rakhumai × Neem oil) recorded the lowest moisture content (7.44%), followed by V_2T_4 (Phule Rakhumai × Castor oil) at 7.46%. the highest moisture content was recorded in V_1T_1 (Phule Sonali × Control) at 7.89%.

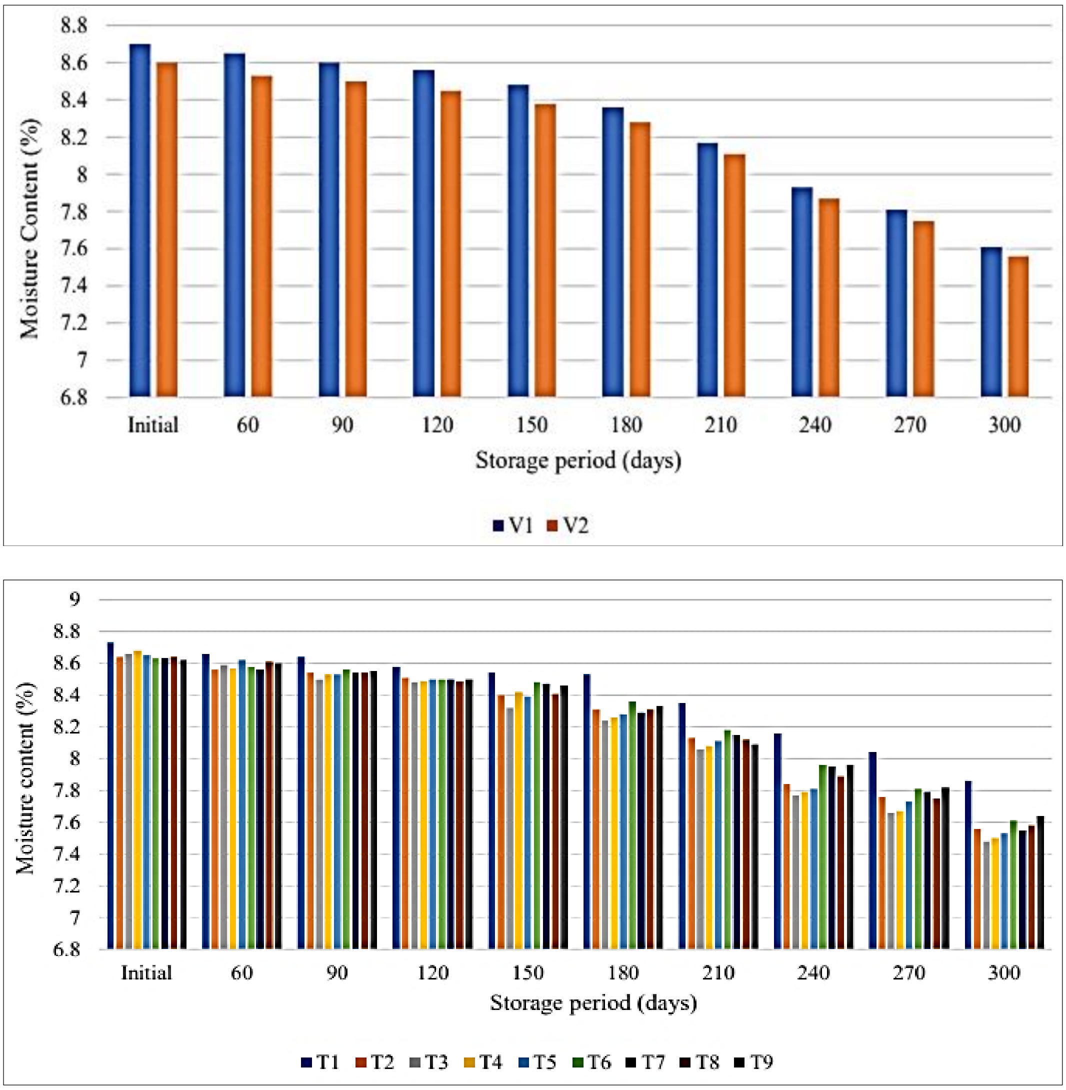


Fig 1: Effect of seed treatment on moisture content (%)

By the end of 300 days, moisture content had significantly decreased, with values ranging between 7.44 and 7.89% across different treatment and variety combinations. The data clearly indicated that treated seeds with neem oil (T_3), castor oil (T_4) and neem leaf powder (T_2), retained lower moisture levels compared to untreated control (T_1).

Neem oil acts as a natural protectant by forming a thin coating on the cowpea seed surface, which minimizes moisture fluctuations and prevents fungal and insect infestation during storage. Similar result were observed by Merwade (2000) [29] in chickpea, Divyashree (2006) [11] in greengram and Jyothi *et al*. (2022) [19] in cowpea.

Germination (%)

Effect of seed treatment on seed germination (%) on cowpea: The results on germination percentage as influenced by seed treatment effect during storage period are presented in Table 2 with graphical representation in Figure 2.

At initial days of storage, cowpea seeds exhibited high germination percentages across all treatments and both varieties. Statistical analysis revealed that the effects of variety, treatment and their interaction were non-significant. Among the varieties, Phule Rakhumai (V_2) showed highest (91.07%), while Phule Sonali (V_1) recorded lower germination (90.67%).

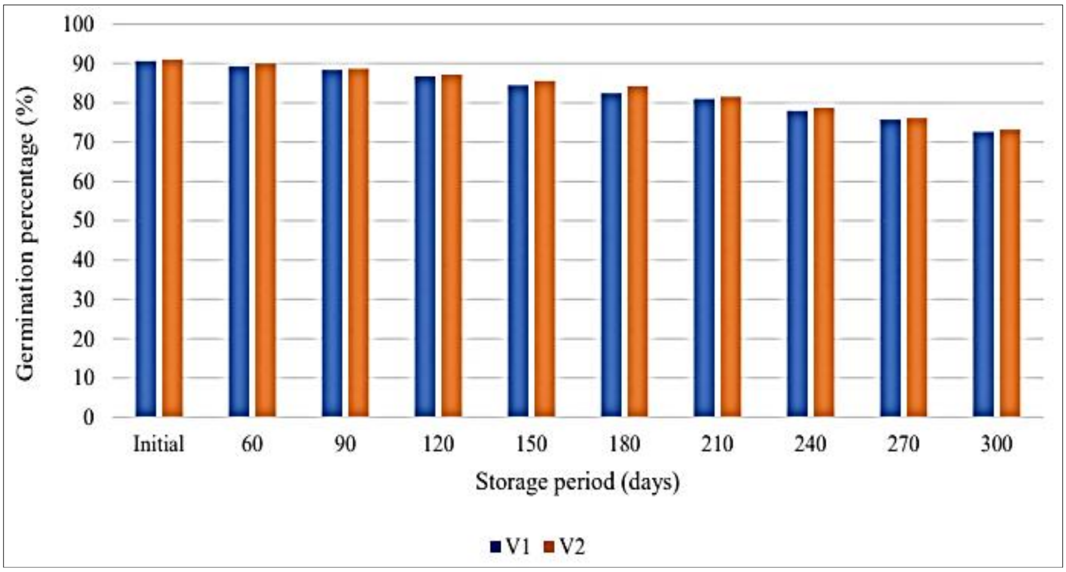
Table 2: Effect of seed treatment on seed germination (%) of Cowpea

Treatment	Storage period (September 2024 - June 2025)									
	Initial	**60**	**90**	**120**	**150**	**180**	**210**	**240**	**270**	**300**
a. Variety										
V_1	90.67 (72.21)	89.26 (70.92)	88.37 (70.12)	86.74 (68.71)	84.52 (66.98)	82.44 (65.27)	81.00 (64.19)	78.00 (62.06)	75.67 (60.49)	72.59 (58.47)
V_2	91.07 (72.61)	90.00 (71.61)	88.70 (70.41)	87.19 (69.06)	85.59 (67.74)	84.26 (66.66)	81.56 (64.60)	78.81 (62.63)	76.07 (60.75)	73.19 (58.86)
SE±	0.22	0.21	0.10	0.09	0.13	0.08	0.14	0.09	0.08	0.06
C.D at 5%	NS	0.63	0.35	0.28	0.38	0.25	0.40	0.27	0.25	0.20
b. Treatment										
T_1	91.33 (72.88)	87.67 (69.46)	84.17 (66.56)	82.67 (65.40)	80.83 (64.04)	79.50 (63.08)	77.83 (61.92)	74.67 (59.78)	70.67 (57.21)	65.83 (54.23)
T_2	91.17 (72.71)	89.67 (71.27)	89.00 (70.63)	87.33 (69.16)	87.33 (69.17)	85.33 (67.49)	82.83 (65.54)	79.17 (62.85)	77.17 (61.46)	76.33 (60.89)

T_3	91.67 (73.22)	91.67 (73.26)	90.50 (72.05)	89.00 (70.63)	87.67 (69.45)	85.50 (67.62)	84.00 (66.43)	82.17 (65.02)	80.17 (63.56)	77.17 (61.46)
T_4	90.83 (72.38)	90.83 (72.42)	89.50 (71.11)	88.17 (69.89)	86.50 (68.45)	85.33 (67.48)	83.67 (66.17)	81.67 (64.66)	80.00 (63.44)	77.00 (61.34)
T_5	91.17 (72.21)	89.67 (71.27)	89.50 (71.10)	88.83 (70.48)	83.50 (66.04)	82.50 (65.30)	81.33 (64.42)	78.00 (62.04)	75.17 (60.12)	72.17 (58.16)
T_6	90.17 (71.72)	89.33 (70.95)	87.67 (69.44)	85.50 (67.62)	83.50 (66.06)	81.83 (64.79)	79.00 (62.73)	76.67 (61.12)	73.83 (59.23)	70.50 (57.10)
T_7	90.83 (72.38)	88.50 (70.19)	88.00 (69.74)	86.50 (68.45)	84.67 (66.95)	83.50 (66.05)	81.00 (64.16)	77.67 (81.80)	75.50 (60.33)	72.50 (58.37)
T_8	90.50 (72.05)	89.33 (70.95)	88.17 (69.89)	87.00 (68.87)	85.67 (67.77)	82.83 (65.53)	81.17 (64.29)	77.83 (61.91)	75.00 (60.00)	72.00 (58.05)
T_9	90.17 (71.72)	90.00 (71.59)	90.33 (71.89)	87.67 (69.44)	86.33 (68.33)	83.83 (66.30)	80.67 (63.92)	77.83 (61.92)	75.33 (60.22)	72.50 (58.37)
SE±	0.19	0.19	0.09	0.08	0.11	0.07	0.12	0.08	0.07	0.06
C.D.at 5%	NS	0.54	0.26	0.24	0.33	0.22	0.36	0.23	0.22	0.17
Interaction										
V_1T_1	91.00 (72.54)	87.33 (69.17)	83.67 (66.16)	82.00 (64.90)	80.67 (63.92)	79.00 (62.73)	77.67 (61.80)	74.00 (59.35)	70.33 (57.01)	65.67 (54.13)
V_1T_2	91.00 (72.54)	89.33 (70.97)	89.00 (70.63)	86.67 (68.59)	87.00 (68.89)	84.67 (66.96)	82.67 (65.40)	79.00 (62.73)	77.67 (61.80)	76.00 (60.67)
V_1T_3	91.33 (72.88)	91.33 (72.92)	90.33 (71.89)	89.00 (70.63)	87.33 (69.16)	85.00 (67.21)	83.67 (66.18)	82.00 (64.90)	80.00 (63.44)	77.00 (61.34)
V_1T_4	90.67 (72.21)	90.33 (71.92)	88.67 (70.33)	89.00 (70.63)	87.00 (68.88)	85.00 (67.21)	83.67 (66.17)	81.00 (64.16)	80.00 (63.44)	77.00 (61.35)
V_1T_5	91.00 (72.54)	89.33 (70.97)	90.00 (71.58)	88.67 (70.33)	83.00 (65.65)	80.67 (63.92)	80.00 (63.44)	76.67 (61.12)	74.00 (59.34)	71.00 (57.42)
V_1T_6	90.00 (71.57)	89.00 (70.64)	87.67 (69.44)	85.00 (67.21)	82.00 (64.90)	80.33 (63.68)	78.00 (62.03)	76.33 (60.89)	73.67 (59.13)	70.33 (57.00)
V_1T_7	90.67 (72.21)	88.00 (69.74)	87.67 (69.44)	86.00 (68.03)	84.33 (66.69)	82.33 (65.15)	81.67 (64.65)	78.00 (62.03)	75.33 (60.22)	72.33 (58.27)
V_1T_8	90.33 (71.89)	89.00 (70.64)	88.00 (69.74)	86.67 (68.59)	84.67 (66.95)	82.00 (64.90)	81.67 (64.65)	77.67 (61.80)	75.00 (60.00)	72.00 (58.05)
V_1T_9	90.00 (71.57)	89.67 (71.25)	90.33 (71.89)	87.67 (69.44)	85.67 (67.76)	83.00 (65.65)	80.00 (63.44)	77.33 (61.57)	75.00 (60.00)	72.00 (58.05)
V_2T_1	91.33 (72.88)	88.00 (69.74)	84.67 (66.95)	83.33 (65.91)	81.00 (64.16)	80.00 (63.44)	78.00 (62.03)	75.33 (60.22)	71.00 (57.42)	66.00 (54.33)
V_2T_2	91.33 (72.88)	90.00 (71.58)	89.00 (70.63)	88.00 (69.74)	87.67 (69.44)	86.00 (68.03)	83.00 (65.67)	79.33 (62.96)	76.67 (61.12)	76.67 (61.12)
V_2T_3	92.00 (73.57)	92.00 (73.59)	90.67 (72.22)	89.00 (70.63)	88.00 (69.73)	86.00 (68.04)	84.33 (66.69)	82.33 (65.15)	80.33 (63.68)	77.33 (61.57)
V_2T_4	91.00 (72.54)	91.33 (72.92)	90.33 (71.89)	87.33 (69.15)	86.00 (68.03)	85.67 (67.76)	83.67 (66.18)	82.33 (65.15)	80.00 (63.44)	77.00 (61.34)
V_2T_5	91.33 (72.88)	90.00 (71.58)	89.00 (70.63)	89.00 (70.63)	84.00 (66.42)	84.33 (66.69)	82.67 (65.40)	79.33 (62.96)	76.33 (60.89)	73.33 (58.91)
V_2T_6	90.33 (71.89)	89.67 (71.25)	87.67 (69.44)	86.00 (68.04)	85.00 (67.22)	83.33 (65.91)	80.00 (63.44)	77.00 (61.34)	74.00 (59.34)	70.67 (57.21)
V_2T_7	91.00 (72.54)	89.00 (70.64)	88.33 (70.03)	87.00 (68.88)	85.00 (67.21)	84.67 (66.95)	80.33 (63.68)	77.33 (61.57)	75.67 (60.44)	72.67 (58.48)
V_2T_8	90.67 (72.21)	89.67 (71.25)	88.33 (70.03)	87.3369.15)	86.67 (68.59)	83.67 (66.16)	80.67 (63.93)	78.00 (62.03)	75.00 (60.00)	72.00 (58.05)
V_2T_9	90.33 (71.89)	90.33 (71.92)	90.33 (71.89)	87.67 (69.44)	87.00 (68.89)	84.67 (66.95)	81.33 (64.40)	78.33 (62.26)	75.67 (60.44)	73.00 (58.69)
S.E±	0.66	0.65	0.31	0.29	0.39	0.26	0.43	0.28	0.26	0.20
C.D at 5%	NS	NS	0.92	0.84	1.14	0.76	1.25	0.81	0.76	0.59

V_1: Phule sonali, V_2: Phule Rakhumai, T_1: Control, T_2: Neem leaf powder, T_3: Neem oil, T_4: Castor oil, T_5: Karanj oil, T_6: Vekhand powder, T_7: Turmeric powder, T_8: Citronella oil, T_9: Ash

Among treatments, the highest germination was recorded in T_3 (Neem oil) with 91.67%, followed by T_1 (Control) at 91.33%, T_2 (Neem leaf powder) and T_5 (Karanj oil) both at 91.17%. The lowest germination was found in T_6 (Vekhand powder) and T_9 (Ash), each recording 90.17%. Although, none were statistically significant. Similarly, interaction effects between variety and treatment combinations were non-significant at initial stage. However, individual combinations such as V_2T_3 (Phule Rakhumai × Neem oil) at 92.00% and V_1T_3 (Phule Sonali × Neem oil) at 91.33% showed the highest germination, while V_1T_6 (Phule Sonali × Vekhand powder) and V_1T_9 (Phule Sonali × Ash) recorded the lowest, each at 90.00%.



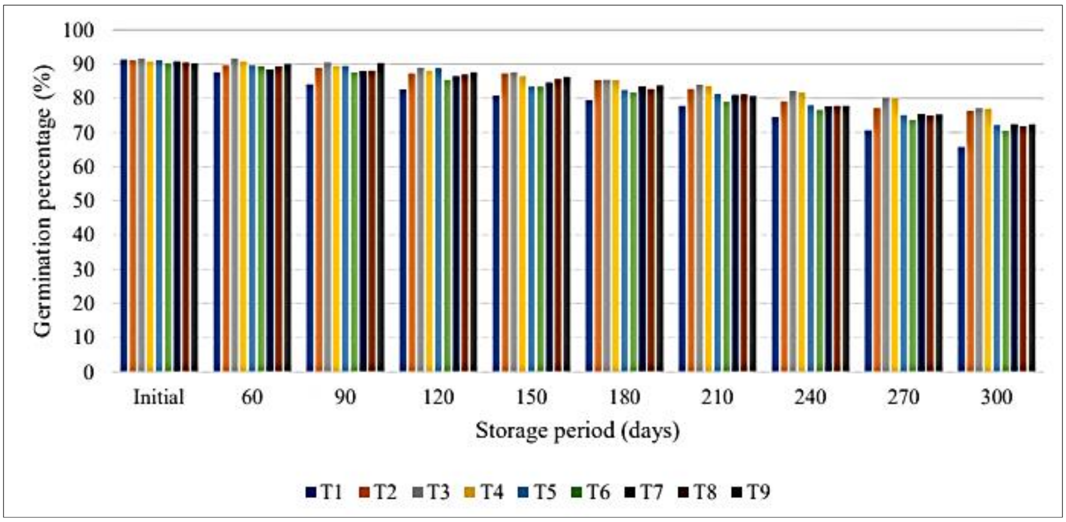


Fig 2: Effect of seed treatment on germination content (%)

At the end of storage period (300 days), significant differences found among varieties, treatments and their interactions. Variety V_2 (Phule Rakhumai) maintained a higher germination of 73.19% compared to 72.59% in V_1 (Phule Sonali). Among treatments, T_3 (Neem oil) was most effective in preserving seed viability, recording 77.17% germination and it was on par with T_4 (Castor oil) at 77.00% and T_2 (Neem leaf powder) at 76.33%. The lowest germination was recorded in T_1 (Control) at 65.83%, indicating substantial deterioration in untreated seeds.

The interaction between variety and treatment was significant at the end of storage period. The combination V_2T_3 (Phule Rakhumai × Neem oil) maintained the highest germination at 77.33%, followed by V_1T_3 (Phule Sonali × Neem oil) and V_2T_4 (Phule Rakhumai × Castor oil), both at 77.00%. In contrast, the lowest germination was recorded in V_1T_1 (Phule Sonali × Control) at 65.67% and V_2T_1 (Phule Rakhumai × Control) at 66.00%.

Seed treatment with neem oil @ 5 ml/kg of seed resulted in significantly higher germination percentage throughout the storage period, followed by castor oil @ 5ml/kg of seed. The use of neem oil along with certain botanicals effectively reduced seed deterioration during storage. These botanicals helped in minimizing pulse beetle infestation and also inhibited the development of storage fungi, thereby helping to retain better germination. Similar results have been reported by Gupta *et al*. (2018) [15] in chickpea, Mandali and Reddy (2014) [27] in red gram and Rathod *et al*. (2018) [36] in pigeon pea.

Root Length (cm)

Effect of seed treatment on root length (cm) in cowpea

The results on root length as influenced by seed treatments during storage period are presented in Table 3 (Figure 3). It was noticed that root length decreased with the advancement of storage period irrespective of seed treatment.

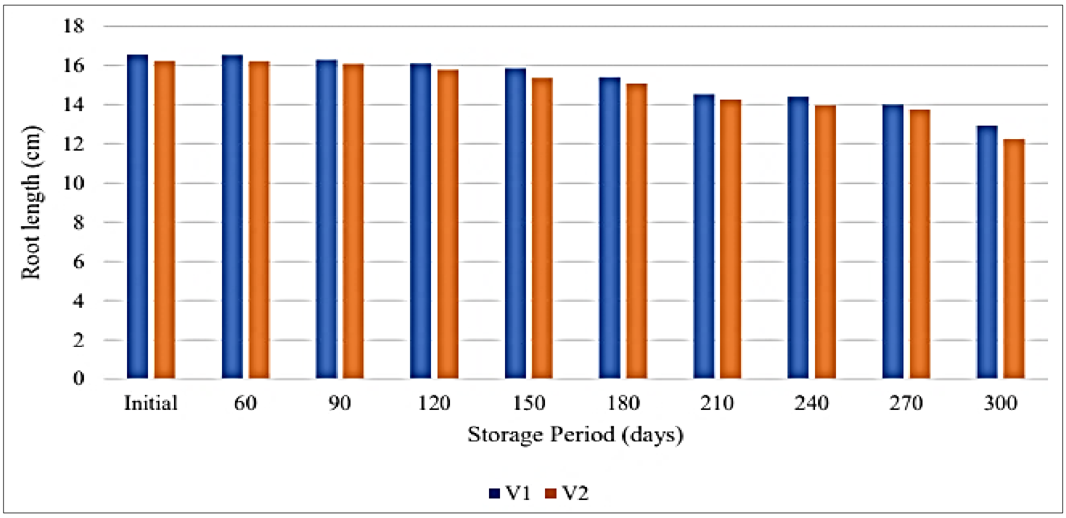
Table 3: Effect of seed treatment on root length (cm) in Cowpea

Treatment	Storage period (September 2024 - June 2025)									
	Initial	60	90	120	150	180	210	240	270	300
a. Variety										
V_1	16.55	16.53	16.30	16.09	15.85	15.40	14.52	14.40	14.01	12.92
V_2	16.23	16.21	16.08	15.78	15.35	15.07	14.25	13.98	13.74	12.27
SE±	0.02	0.02	0.03	0.03	0.03	0.03	0.05	0.06	0.06	0.04
C.D at 5%	0.06	0.07	0.09	0.10	0.09	0.08	0.13	0.17	0.18	0.11
b. Treatment										
T_1	16.37	16.32	15.87	15.59	14.93	14.69	13.39	13.03	12.82	11.68
T_2	16.37	16.33	16.34	15.89	15.57	15.25	14.42	14.22	13.97	12.62
T_3	16.43	16.40	16.37	16.27	16.04	15.69	14.92	14.92	14.60	13.43
T_4	16.41	16.39	16.32	16.23	15.97	15.63	14.82	14.85	14.47	13.32
T_5	16.42	16.43	16.28	16.07	15.80	15.38	14.84	14.82	14.46	12.75
T_6	16.37	16.36	15.99	15.68	15.34	14.89	14.08	13.51	13.21	12.05
T_7	16.35	16.34	16.06	15.87	15.53	15.50	14.36	14.16	13.95	12.83
T_8	16.39	16.38	16.25	16.04	15.74	15.08	14.30	14.05	13.86	12.43
T_9	16.38	16.36	16.22	15.82	15.50	15.05	14.33	14.16	13.52	12.30
SE±	0.01	0.02	0.02	0.02	0.03	0.02	0.04	0.05	0.05	0.03
C.D.at 5%	NS	NS	0.08	0.07	0.08	0.07	0.12	0.14	0.15	0.09
Interaction										
V_1T_1	16.52	16.49	16.02	15.69	15.55	14.95	13.55	13.09	13.02	12.10
V_1T_2	16.52	16.50	16.17	16.06	15.76	15.42	14.66	14.66	14.18	12.92
V_1T_3	16.59	16.56	16.53	16.42	16.22	15.88	15.23	15.23	14.81	13.75
V_1T_4	16.57	16.55	16.46	16.36	16.20	15.83	15.10	15.10	14.80	13.73
V_1T_5	16.58	16.58	16.41	16.22	16.02	15.55	14.71	14.71	14.77	13.10
V_1T_6	16.53	16.52	16.12	15.84	15.53	15.08	14.00	14.02	13.45	12.50

V_1T_7	16.51	16.50	16.21	16.04	15.71	15.39	14.55	14.37	13.26	12.82
V_1T_8	16.54	16.53	16.38	16.19	15.95	15.26	14.42	14.18	13.91	12.76
V_1T_9	16.53	16.52	16.36	15.99	15.69	15.24	14.48	14.26	13.86	12.64
V_2T_1	16.19	16.15	15.71	15.49	14.31	14.43	13.22	12.97	12.62	11.27
V_2T_2	16.21	16.17	16.10	15.71	15.38	15.07	14.18	13.79	13.76	12.32
V_2T_3	16.27	16.25	16.21	16.15	15.85	15.50	14.62	14.62	14.39	13.10
V_2T_4	16.25	16.23	16.18	16.10	15.73	15.43	14.54	14.60	14.14	12.90
V_2T_5	16.28	16.27	16.15	15.91	15.58	15.20	14.97	14.93	14.15	12.40
V_2T_6	16.20	16.19	15.85	15.52	15.14	14.69	14.16	13.00	12.97	11.60
V_2T_7	16.20	16.18	15.91	15.69	15.35	15.60	14.17	13.96	14.63	12.83
V_2T_8	16.23	16.22	16.11	15.88	15.52	14.89	14.18	13.91	13.82	12.09
V_2T_9	16.23	16.19	16.08	15.65	15.31	14.85	14.18	14.06	13.17	11.96
S.E±	0.06	0.07	0.09	0.09	0.09	0.08	0.14	0.17	0.19	0.11
C.D at 5%	NS	NS	0.27	0.28	0.27	0.24	0.40	0.50	0.53	0.33

V_1: Phule sonali, V_2: Phule Rakhumai, T_1: Control, T_2: Neem leaf powder, T_3: Neem oil, T_4: Castor oil, T_5: Karanj oil, T_6: Vekhand powder, T_7: Turmeric powder, T_8: Citronella oil, T_9: Ash

At initial days of storage, although the treatment and interaction effects were statistically non-significant, varietal differences in root length were evident. The variety Phule Sonali recorded a higher root length of 16.55 cm, whereas Phule Rakhumai recorded a slightly lower root length of 16.23 cm. Among the treatments, the highest root length was recorded in seeds treated with neem oil (T_3) and karanj oil (T_5), recording 16.43 cm and 16.42 cm, respectively. In terms of interaction, the combination V_1T_3 (Phule Sonali × Neem oil) showed the maximum root length of 16.59 cm, while V_2T_1 (Phule Rakhumai × Control) recorded the lowest root length of 16.19 cm.



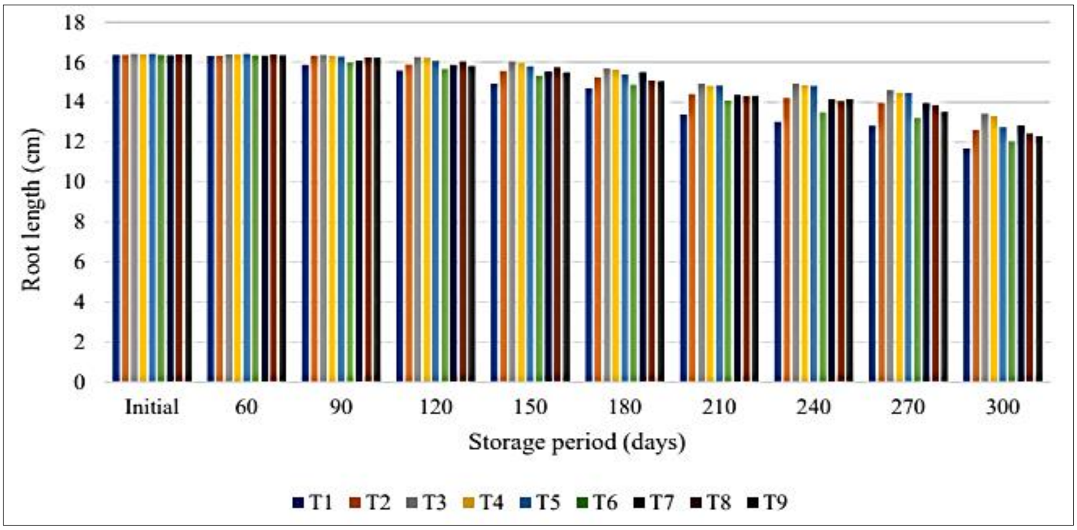


Fig 3: Effect of seed treatment on Root length (%)

At the end of 300 days of storage period, the effects of variety, treatment and their interaction on root length were all statistically significant. The variety Phule Sonali (V_1) maintained its superiority with a root length of 12.92 cm, while Phule Rakhumai (V_2) recorded 12.27 cm. Among the treatments, neem oil (T_3) was the most effective, maintain highest average root length of 13.43 cm, followed by castor oil (T_4) at 13.32 cm. In terms of variety × treatment interaction, the highest root length was recorded in Phule Sonali treated with neem oil (V_1T_3), recording 13.75 cm, followed by Phule Sonali with castor oil (V_1T_4) at 13.73 cm. The lowest value of 11.27 cm was recorded in Phule Rakhumai without any treatment (V_2T_1).

This indicates that neem oil treatments were most effective in preserving root growth potential over extended storage durations. These botanicals reduced physiological deterioration by suppressing fungal invasion and insect infestation, thereby preserving seed vigour. The protective action of their bioactive compounds helped sustain metabolic activity, resulting in better root elongation during germination. Similar results observed by Asawalam and Anaeto (2014) [5] in cowpea, Swaroop Singh and Sharma (2003) [46] in green gram and Veer Singh and Yadav (2002) [47].

Shoot Length (cm)

Effect of treatment on shoot length (cm) in Cowpea

The results on shoot length as influenced by seed treatments during storage period are presented in Table 4 and Figure 4. It was noticed that shoot length decreased with the advancement of storage period irrespective of seed treatment.

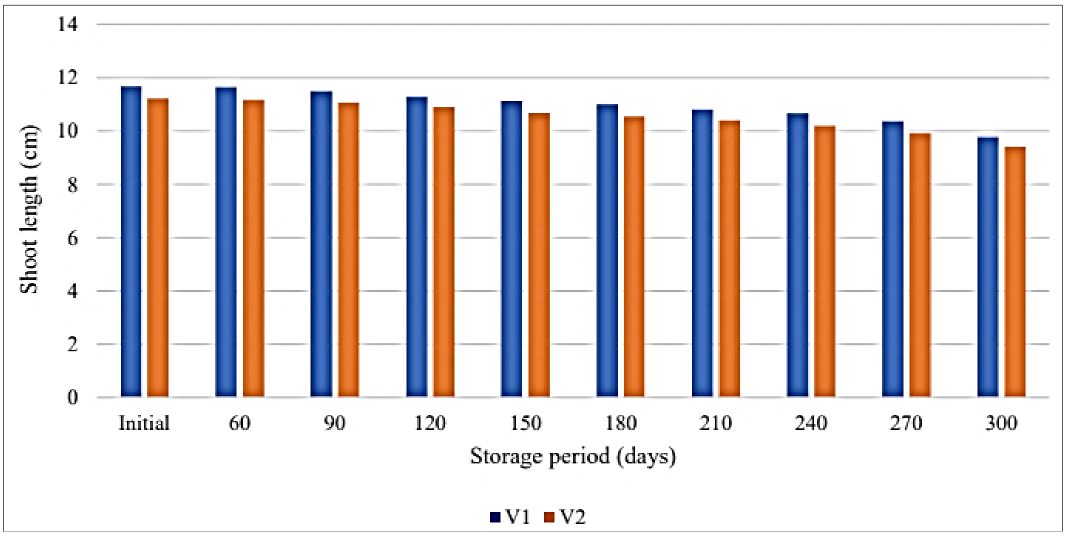
Table 4: Effect of treatment on shoot length (cm) in Cowpea

Treatment	Storage period (September 2024 - June 2025)									
	Initial	60	90	120	150	180	210	240	270	300
a. Variety										
V_1	11.69	11.66	11.51	11.29	11.13	11.00	10.81	10.66	10.37	9.79
V_2	11.23	11.18	11.08	10.90	10.68	10.55	10.41	10.20	9.92	9.43
SE±	0.02	0.03	0.03	0.03	0.03	0.03	0.03	0.02	0.02	0.03
C.D at 5%	0.07	0.07	0.10	0.09	0.07	0.07	0.08	0.07	0.07	0.08
b. Treatment										
T_1	11.53	11.39	11.07	10.78	10.60	10.47	10.26	10.08	9.66	8.78
T_2	11.46	11.43	11.28	11.16	10.93	10.83	10.66	10.51	10.34	9.92
T_3	11.55	11.54	11.53	11.30	11.08	10.95	10.82	10.64	10.40	9.99
T_4	11.52	11.47	11.37	11.25	11.02	10.90	10.76	10.59	10.35	9.94
T_5	11.47	11.46	11.45	11.23	11.02	10.90	10.75	10.50	10.21	9.81
T_6	11.42	11.37	11.18	10.93	10.77	10.66	10.44	10.25	9.91	9.30
T_7	11.44	11.37	11.29	10.98	10.89	10.69	10.58	10.46	10.19	9.43
T_8	11.44	11.40	11.19	11.07	10.84	10.74	10.56	10.40	10.13	9.66
T_9	11.48	11.41	11.31	11.17	11.02	10.83	10.64	10.48	10.14	9.69
SE±	0.02	0.02	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.02
C.D.at 5%	NS	NS	0.08	0.07	0.06	0.06	0.07	0.06	0.06	0.07
Interaction										
V_1T_1	11.66	11.63	11.56	10.97	10.84	10.75	10.50	10.32	9.91	8.98
V_1T_2	11.68	11.66	11.50	11.38	11.18	11.07	10.90	10.77	10.63	10.14
V_1T_3	11.75	11.71	11.60	11.54	11.33	11.21	11.06	10.89	10.63	10.21
V_1T_4	11.73	11.72	11.58	11.51	11.28	11.16	11.02	10.88	10.63	10.16
V_1T_5	11.69	11.69	11.58	11.49	11.28	11.13	10.91	10.75	10.45	10.02
V_1T_6	11.65	11.60	11.43	11.11	11.02	10.89	10.68	10.49	10.15	9.48
V_1T_7	11.66	11.62	11.46	10.90	10.90	10.70	10.50	10.48	10.22	9.37
V_1T_8	11.66	11.63	11.38	11.29	11.11	10.98	10.80	10.65	10.37	9.86
V_1T_9	11.71	11.64	11.55	11.39	11.21	11.07	10.88	10.73	10.39	9.89
V_2T_1	11.21	11.15	10.58	10.58	10.36	10.19	10.02	9.83	9.41	8.57
V_2T_2	11.23	11.19	11.06	10.93	10.67	10.59	10.42	10.25	10.05	9.70
V_2T_3	11.29	11.23	11.45	11.05	10.82	10.69	10.58	10.39	10.17	9.77
V_2T_4	11.28	11.22	11.16	10.99	10.76	10.63	10.51	10.29	10.07	9.72
V_2T_5	11.24	11.23	11.32	10.96	10.75	10.67	10.58	10.24	9.96	9.60
V_2T_6	11.19	11.14	10.92	10.76	10.52	10.42	10.19	10.01	9.66	9.11
V_2T_7	11.21	11.11	11.12	11.07	10.88	10.68	10.67	10.44	10.17	9.48
V_2T_8	11.21	11.16	11.00	10.85	10.57	10.50	10.32	10.15	9.88	9.46
V_2T_9	11.25	11.18	11.07	10.94	10.83	10.58	10.39	10.23	9.89	9.49
S.E±	0.07	0.08	0.10	0.09	0.08	0.08	0.08	0.07	0.07	0.08

V_1: Phule sonali, V_2: Phule Rakhumai, T_1: Control, T_2: Neem leaf powder, T_3: Neem oil, T_4: Castor oil, T_5: Karanj oil, T_6: Vekhand powder, T_7: Turmeric powder, T_8: Citronella oil, T_9: Ash

At initial days of storage, the shoot length of cowpea seedlings was significantly influenced by variety, while the effects of treatment and variety × treatment interaction were non-significant. Among the varieties, Phule Sonali (V_1) recorded higher shoot length (11.69 cm) compared to Phule Rakhumai (V_2) (11.23 cm). Among the treatment, the highest shoot length was recorded in T_3 (neem oil) (11.55 cm), followed T_1 (control) (11.53). Interaction-wise, the combination V_1T_3 (Phule Sonali × Neem oil) recorded the highest shoot length (11.75 cm), followed by V_1T_4 (Phule Sonali × Castor oil) (11.73 cm).

At the end of 300 days of storage period, a significant decline in shoot length was recorded across varieties, treatments and their interaction. Phule Sonali (V_1) maintained a significantly higher shoot length (9.79 cm) than Phule Rakhumai (V_2) (9.43 cm), indicating better vigour retention. Among treatments, the highest shoot length was recorded in T_3 (Neem oil) (9.99 cm), it was on par with T_4 (Castor oil) (9.94 cm) and T_2 (Neem leaf powder) (9.92 cm), while the minimum was found in T_1 (control) (8.78 cm), reflecting a considerable loss of vigour in untreated seeds. The interaction effect was statistically significant, where V_1T_3 (Phule Sonali × Neem oil) recorded the maximum shoot length (10.21 cm), it was on par with V_1T_4 (Phule Sonali × Castor oil) (10.16 cm) and V_1T_2 (Phule Sonali × Neem leaf powder) (10.14 cm). On the other hand, the lowest value was recorded in V_2T_1 (Phule Rakhumai × Control) (8.57 cm).



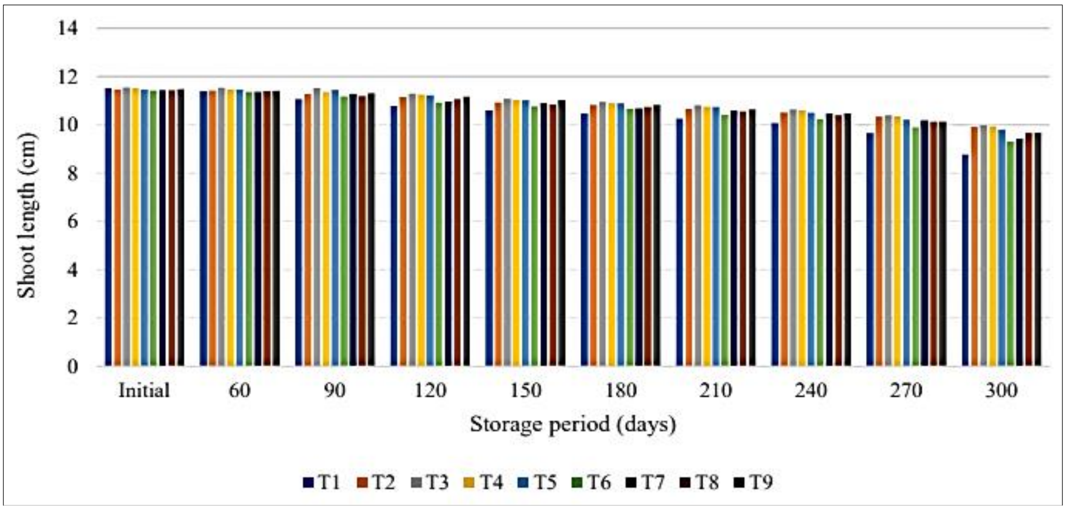


Fig 4: Effect of seed treatment on shoot length (%)

These results confirm that organic treatments, particularly neem oil, helped maintain better seedling shoot length during prolonged storage. These botanicals minimize biochemical deterioration and reduce storage pests, ensuring better metabolic activity in emerging seedlings. As a result, treated seeds retained higher vigour and produced seedlings with superior shoot growth compared to untreated seeds.

It was observed that the root length of Cowpea seed decreased, irrespective of seed treatment during storage. The decrease in root length of seedling of Cowpea seed could be described to the ageing or deterioration of seed, which is progressive process accompanied by accumulation of metabolites, which progressively depress germination and growth of seedling (Floris, 1970) [13], with increasing age ultimately reducing the dry matter and vigour of Cowpea seed during storage.

Vigour Index-I

Effect of seed treatment on vigour index-I in Cowpea

The results on vigour index-I as influenced by seed treatments during storage period are presented in Table 5 and Figure 5. It was noticed that vigour index-I decreased with the advancement of storage period irrespective of seed treatment.

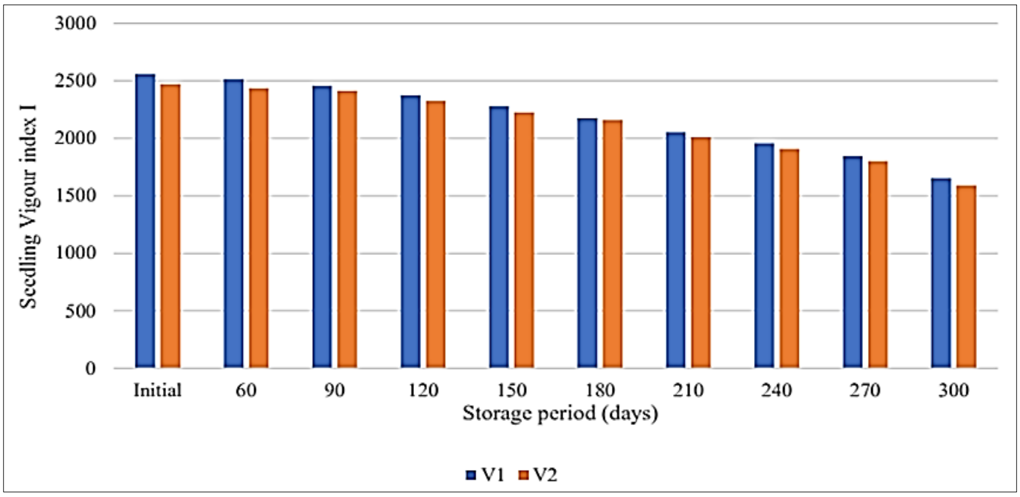
Table 5: Effect of seed treatment on vigour index-I in Cowpea

Treatment	Storage period (September 2024 - June 2025)									
	Initial	60	90	120	150	180	210	240	270	300
a. Variety										
V_1	2561	2516	2458	2375	2281	2177	2053	1957	1847	1652
V_2	2471	2435	2413	2326	2228	2160	2012	1908	1801	1591
SE±	11.01	11.97	5.57	5.31	5.95	5.85	7.69	8.06	6.81	4.89
C.D at 5%	31.58	34.33	15.98	15.24	17..07	16.78	22.05	23.12	19.54	14.01

b. Treatment										
T_1	2529	2415	2267	2179	2063	2000	1840	1725	1588	1347
T_2	2522	2474	2475	2361	2296	2225	2078	1958	1876	1720
T_3	2546	2540	2524	2453	2377	2277	2162	2100	2004	1807
T_4	2521	2515	2478	2417	2335	2264	2140	2077	1986	1791
T_5	2529	2486	2482	2424	2239	2167	2081	1974	1853	1627
T_6	2490	2462	2381	2275	2179	2089	1936	1822	1707	1505
T_7	2509	2438	2407	2321	2237	2187	2020	1913	1823	1613
T_8	2503	2466	2419	2358	2276	2138	2018	1903	1799	1590
T_9	2497	2484	2487	2366	2289	2168	2014	1918	1782	1594
SE±	9.53	10.36	4.82	4.60	5.15	5.07	6.66	6.98	5.90	4.23
C.D.at 5%	NS	NS	13.84	13.20	14.78	14.53	19.09	20.03	16.93	12.13
Interaction										
V_1T_1	2574	2456	2307	2186	2129	2030	1868	1733	1612	1384
V_1T_2	2567	2516	2463	2378	2317	2243	2113	2009	1927	1753
V_1T_3	2586	2582	2541	2488	2406	2303	2199	2142	2035	1845
V_1T_4	2568	2554	2487	2474	2391	2294	2185	2104	2034	1840
V_1T_5	2575	2526	2519	2457	2266	2152	2050	1952	1866	1642
V_1T_6	2536	2503	2415	2290	2177	2086	1925	1871	1739	1546
V_1T_7	2554	2475	2425	2314	2244	2148	2046	1939	1769	1605
V_1T_8	2548	2507	2443	2382	2291	2152	2060	1929	1821	1629
V_1T_9	2542	2525	2521	2400	2304	2184	2029	1933	1819	1622
V_2T_1	2483	2374	2226	2173	1998	1969	1813	1717	1564	1309
V_2T_2	2476	2433	2488	2344	2275	2207	2042	1907	1825	1688
V_2T_3	2505	2497	2508	2417	2347	2252	2125	2059	1973	1769
V_2T_4	2475	2477	2470	2359	2278	2233	2095	2050	1937	1742
V_2T_5	2484	2445	2445	2391	2212	2182	2112	1997	1840	1613
V_2T_6	2444	2421	2347	2260	2181	2093	1948	1772	1675	1463
V_2T_7	2464	2402	2388	2328	2230	2225	1995	1887	1877	1622
V_2T_8	2458	2425	2395	2335	2261	2124	1977	1877	1777	1552
V_2T_9	2452	2443	2453	2331	2274	2153	1999	1903	1745	1566
S.E±	33.03	35.90	16.71	15.94	17.85	17.55	23.06	24.19	20.44	14.66
C.D at 5%	NS	NS	NS	45.73	51.20	50.35	66.14	69.33	58.63	42.03

V_1: Phule sonali, V_2: Phule Rakhumai, T_1: Control, T_2: Neem leaf powder, T_3: Neem oil, T_4: Castor oil, T_5: Karanj oil, T_6: Vekhand powder, T_7: Turmeric powder, T_8: Citronella oil, T_9: Ash

At initial days of storage, the effect of variety on vigour index I was found to be significant. The variety Phule Sonali (V_1) recorded a higher vigour index (2561) compared to Phule Rakhumai (V_2) (2471) and the difference was statistically significant. However, the effect of treatments on vigour index was non-significant. Among treatments, higher vigour index values were recorded in T_3 (Neem oil) (2546), followed by T_5 (2529), whereas the lowest was in T_6 (2490). The interaction effect between variety and treatment (V×T) was non-significant, but, the combination V_1T_3 (Phule Sonali × Neem oil) recorded the highest vigour index (2586), followed by V_1T_5 (Phule Sonali × Karanj oil) (2575). At the end of 300 days of storage period, the effect of variety, treatment and their interaction on vigour index I was statistically significant. The variety Phule Sonali (V_1) showed a higher vigour index (1652) as compared to Phule Rakhumai (V_2) (1591) and the difference was significant. Among the treatments**,** T_3 (Neem oil) maintained the highest vigour index (1807), followed by T_4 (Castor oil) (1791), while the lowest vigour index was recorded in the control treatment T_1 (1347). The interaction effect was also significant, with V_1T_3 (Phule Sonali × Neem oil) recorded the highest vigour index I (1845), followed by V_1T_4 (Phule Sonali × Castor oil) (1840) and V_2T_3 (Phule Rakhumai × Neem oil) (1769). The lowest vigour was recorded in V_2T_1 (Phule Rakhumai × Control) with a value of 1309.



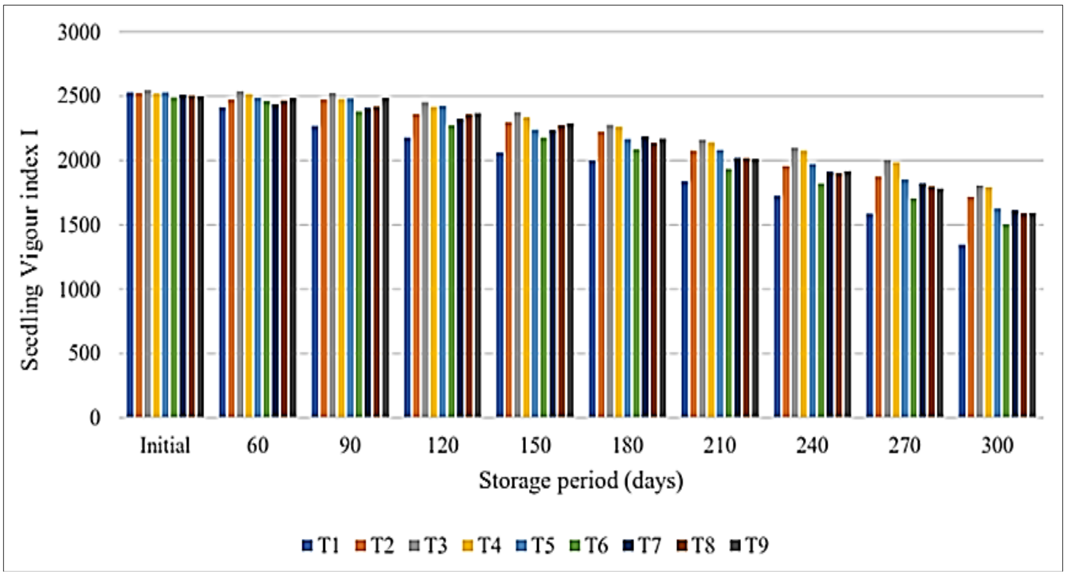


Fig 5: Effect of seed treatment on vigour index-I

Vigour index-I decreased with advancement of storage period irrespective of seed treatment. Seed treated with neem oil @ 5 ml/kg of seed showed higher vigour index-I due to higher germination percentage, root and shoot length. Similar findings regarding with vigour-I was reported by Patil & Bagde (2015) [33] in pigeon pea, Babariya (2016) [8] in mungbean, Gupta *et al.* (2018) [15] in chickpea and Rathod *et al*. (2018) [36] in pigeon pea.

Vigour Index-II

Effect of seed treatment on vigour index-II in Cowpea

The results on vigour index-II as influenced by seed treatments during storage period are presented in Table 6 (Figure 6). It was noticed that vigour index-II decreased with the advancement of storage period irrespective of seed treatment.

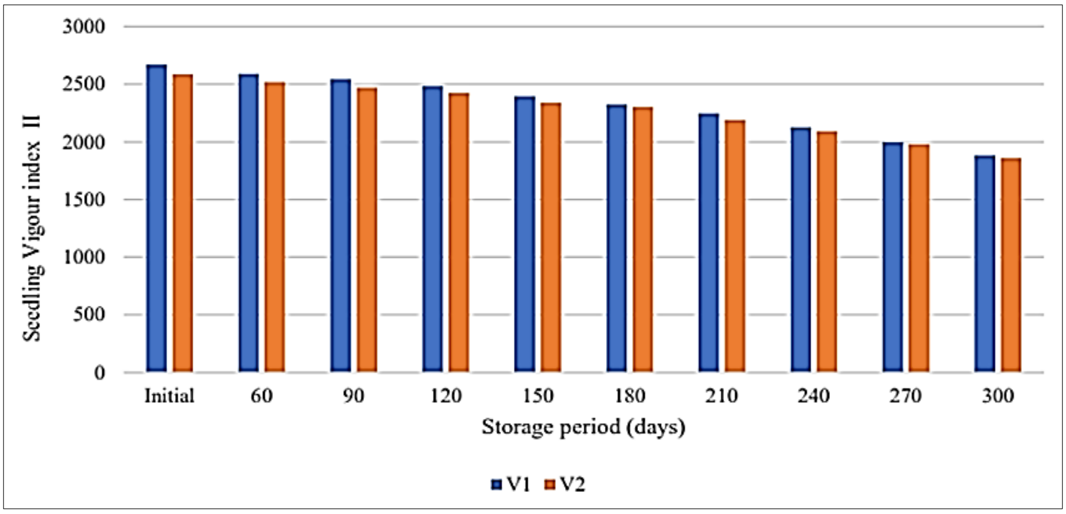
Table 6: Effect of seed treatment on vigour index-II in Cowpea

Treatment	Storage period (September 2024 - June 2025)									
	Initial	60	90	120	150	180	210	240	270	300
a. Variety										
V_1	2668	2589	2543	2483	2394	2323	2246	2124	1998	1884
V_2	2588	2518	2468	2422	2342	2303	2190	2093	1981	1860
SE±	6.84	7.37	3.90	3.78	4.99	3.94	7.73	6.28	4.92	4.30
C.D at 5%	19.61	21.14	11.19	10.84	14.31	11.30	22.18	18.00	14.11	12.32
b. Treatment										
T_1	2642	2489	2358	2312	2222	2173	2071	1930	1764	1595
T_2	2637	2562	2525	2466	2414	2376	2279	2145	2050	1983
T_3	2664	2629	2584	2532	2473	2395	2328	2260	2161	2036
T_4	2631	2598	2543	2496	2419	2380	2312	2225	2131	2007
T_5	2645	2569	2553	2521	2352	2306	2250	2138	2019	1897
T_6	2593	2531	2464	2399	2310	2261	2132	2016	1892	1767
T_7	2633	2506	2475	2438	2350	2332	2224	2124	1975	1876
T_8	2612	2548	2498	2444	2388	2294	2201	2082	1956	1848
T_9	2596	2547	2548	2463	2385	2303	2165	2059	1958	1842
SE±	5.92	6.38	3.38	3.27	4.32	3.41	6.70	5.44	4.26	3.72
C.D.at 5%	16.98	18.31	9.69	9.39	12.40	9.78	19.21	15.59	12.22	10.67
Interaction										
V_1T_1	2684	2524	2385	2329	2250	2194	2103	1925	1772	1603
V_1T_2	2680	2599	2568	2487	2439	2401	2317	2180	2086	2000
V_1T_3	2703	2664	2624	2578	2511	2423	2357	2288	2179	2053
V_1T_4	2674	2630	2563	2561	2472	2412	2350	2244	2157	2034
V_1T_5	2689	2604	2613	2560	2382	2295	2249	2135	2006	1890
V_1T_6	2632	2563	2507	2421	2310	2253	2155	2038	1904	1789
V_1T_7	2659	2551	2496	2461	2385	2308	2282	2124	1959	1864
V_1T_8	2655	2583	2536	2456	2403	2308	2205	2105	1953	1872
V_1T_9	2634	2581	2594	2491	2392	2316	2195	2080	1970	1854
V_2T_1	2600	2454	2331	2296	2195	2152	2039	1936	1756	1586
V_2T_2	2594	2526	2482	2445	2389	2352	2242	2110	2013	1966
V_2T_3	2625	2593	2544	2486	2435	2367	2300	2231	2144	2019
V_2T_4	2587	2567	2522	2432	2365	2347	2274	2207	2105	1980
V_2T_5	2601	2533	2493	2483	2322	2316	2252	2141	2032	1904
V_2T_6	2553	2498	2422	2376	2310	2269	2109	1994	1881	1745

V_2T_7	2607	2461	2454	2414	2316	2356	2165	2123	1990	1888
V_2T_8	2570	2512	2460	2432	2372	2280	2196	2059	1960	1823
V_2T_9	2557	2514	2503	2436	2378	2291	2135	2037	1947	1831
S.E±	20.51	22.11	11.70	11.34	14.97	11.82	23.20	18.83	14.76	12.89
C.D at 5%	NS	NS	33.57	32.53	42.94	33.89	67.26	54.43	42.34	36.97

V_1: Phule sonali, V_2: Phule Rakhumai, T_1: Control, T_2: Neem leaf powder, T_3: Neem oil, T_4: Castor oil, T_5: Karanj oil, T_6: Vekhand powder, T_7: Turmeric powder, T_8: Citronella oil, T_9: Ash

At initial days of storage, the effect of variety on vigour index II was found to be statistically significant. The variety Phule Sonali (V_1) recorded a significantly higher vigour index (2668) as compared to Phule Rakhumai (V_2) (2588). The treatment effect was also significant, with T_3 (Neem oil) recorded the highest vigour index (2664), followed by T_5 (Karanj oil) (2645). The lowest vigour index was recorded in T_6 (2593). However, the interaction effect between variety and treatment (V×T) was non-significant at initial stage. Numerically, the combination V_1T_3 (Phule Sonali × Neem oil) recorded the highest vigour index II (2703), followed by V_1T_5 (Phule Sonali × Karanj oil) (2689). In contrast, the lowest was recorded in V_2T_6 (Phule Rakhumai ×Vekhand powder) (2553).



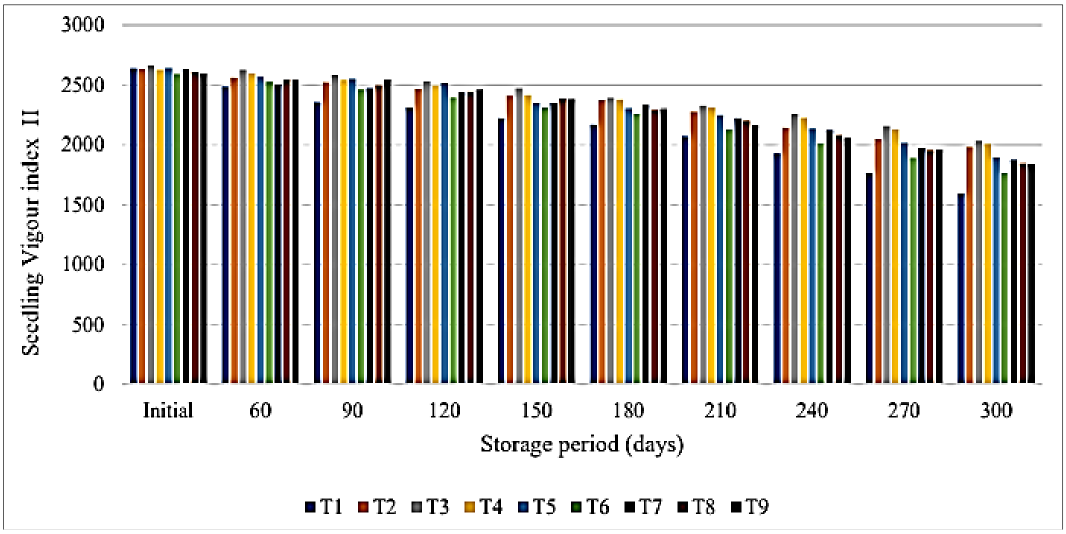


Fig 6: Effect of seed treatment on vigour index-II

At the end of 300 days of storage period, the effects of variety, treatment and their interaction on vigour index II were all statistically significant**.** The variety Phule Sonali (V_1) maintained a higher vigour index (1884) compared to Phule Rakhumai (V_2) (1860) and this difference was significant. Among treatments, T_3 (Neem oil) was superior, recorded the highest vigour index (2036), followed by T_4 (Castor oil) (2007) and T_2 (Neem leaf powder) (1983). The lowest vigour index was recorded in the T_1 (control) with a value of 1595, showing the effectiveness of organic seed treatments in prolonging seed vigour. The interaction effect was found significant. The combination V_1T_3 (Phule Sonali × Neem oil) with the highest vigour index (2053), followed by V_1T_4 (Phule Sonali × Castor oil) (2034) and V_2T_3 (Phule Rakhumai × Neem oil) (2019). On the other hand, V_2T_1 (Phule Rakhumai × Control) recorded the lowest value (1586), indicating significant seed vigour loss in untreated seeds.

Vigour index-II decreased with advancement of storage period irrespective of seed treatment. Seed treated with neem oil @ 5 ml/kg of seed showed higher vigour index-II. This highlights the long-term protective effect of neem oil, during extended seed storage.

This may be attributed to their bioactive compounds which suppress seed- borne mycoflora and bruchid infestation, thereby reducing seed deterioration. As a result, seeds retained better germination potential, seedling growth and physiological quality throughout the storage period. Similar impact on viability and vigour maintenance by seed treatment with plant oils and botanicals and insect control has been proven in pulses by several workers (Lele and Mustapha, 2000; Songa and Rono, 2010; Yusuf *et al*. 2011; Wahedi *et al*.2015) [25, 45, 29].

Seedling dry weight (mg)

Effect of seed treatment on seedling dry weight (mg) in Cowpea

The results on seedling dry weight as influenced by seed treatments during storage period are presented in Table 7 along with its graphical representation in Figure 7. It was observed that seedling dry weight decreased with the advancement of storage period irrespective of seed treatment.

Table 7: Effect of seed treatment on seedling dry weight (mg) in Cowpea

Treatment	Storage period (September 2024 - June 2025)									
	Initial	60	90	120	150	180	210	240	270	300
a. Variety										
V_1	29.42	29.00	28.77	28.62	28.32	28.18	27.72	27.22	26.39	25.93
V_2	28.41	27.97	27.82	27.78	27.38	27.33	26.85	26.55	26.02	25.39
SE±	0.04	0.03	0.02	0.03	0.02	0.03	0.06	0.05	0.05	0.05
C.D at 5%	0.11	0.08	0.05	0.08	0.07	0.09	0.19	0.14	0.13	0.14
b. Treatment										
T_1	28.93	28.39	28.02	27.98	27.49	27.34	26.61	25.85	24.97	24.23
T_2	28.92	28.58	28.37	28.25	27.86	27.85	27.52	27.10	26.56	25.98
T_3	29.06	28.68	28.56	28.45	28.21	28.02	27.72	27.50	26.96	26.39
T_4	28.96	28.61	28.41	28.31	27.96	27.89	27.63	27.25	26.64	26.06
T_5	29.02	28.65	28.52	28.39	28.17	27.96	27.68	27.42	26.86	26.30
T_6	28.76	28.33	28.11	28.06	27.67	27.64	27.00	26.30	25.63	25.07
T_7	28.99	28.32	28.13	28.19	27.76	27.93	27.45	27.34	26.16	25.88
T_8	28.87	28.52	28.33	28.09	27.88	27.70	27.11	26.75	26.08	25.66
T_9	28.79	28.31	28.21	28.10	27.63	27.48	26.85	26.45	25.99	25.42
SE±	0.03	0.03	0.01	0.02	0.02	0.03	0.06	0.04	0.04	0.04
C.D.at 5%	NS	0.07	0.04	0.07	0.06	0.07	0.16	0.12	0.11	0.12
Interaction										
V_1T_1	29.49	28.90	28.51	28.40	27.89	27.77	27.07	26.00	25.20	24.42
V_1T_2	29.45	29.09	28.86	28.70	28.36	28.35	28.03	27.60	26.86	26.32
V_1T_3	29.59	29.17	29.05	28.97	28.75	28.50	28.17	27.90	27.23	26.67
V_1T_4	29.49	29.11	28.91	28.77	28.42	28.38	28.08	27.70	26.96	26.42
V_1T_5	29.55	29.15	29.03	28.87	28.70	28.46	28.11	27.85	27.10	26.63
V_1T_6	29.25	28.80	28.59	28.48	28.17	28.05	27.63	26.70	25.84	25.44
V_1T_7	29.33	28.99	28.47	28.62	28.28	28.04	27.94	27.23	26.01	25.77
V_1T_8	29.39	29.02	28.82	28.33	28.39	28.15	27.00	27.10	26.03	26.00
V_1T_9	29.27	28.78	28.71	28.41	27.92	27.90	27.44	26.90	26.26	25.75
V_2T_1	28.36	27.88	27.54	27.55	27.09	26.90	26.14	25.70	24.74	24.03
V_2T_2	28.40	28.07	27.88	27.79	27.35	27.34	27.01	26.60	26.26	25.65
V_2T_3	28.53	28.18	28.06	27.93	27.67	27.53	27.27	27.10	26.69	26.11
V_2T_4	28.43	28.11	27.92	27.85	27.50	27.40	27.17	26.80	26.31	25.71
V_2T_5	28.49	28.15	28.01	27.90	27.64	27.46	27.24	26.98	26.62	25.96
V_2T_6	28.27	27.86	27.63	27.63	27.18	27.22	26.37	25.90	25.42	24.69
V_2T_7	28.65	27.65	27.79	27.75	27.25	27.82	26.95	27.45	26.30	25.98
V_2T_8	28.34	28.02	27.85	27.85	27.37	27.25	27.22	26.40	26.13	25.32
V_2T_9	28.30	27.83	27.71	27.79	27.33	27.05	26.25	26.00	25.73	25.09
S.E±	0.11	0.09	0.05	0.08	0.07	0.09	0.19	0.15	0.14	0.14
C.D at 5%	NS	NS	0.14	0.24	0.21	0.26	0.56	0.43	0.39	0.41

V_1: Phule sonali, V_2: Phule Rakhumai, T_1: Control, T_2: Neem leaf powder, T_3: Neem oil, T_4: Castor oil, T_5: Karanj oil, T_6: Vekhand powder, T_7: Turmeric powder, T_8: Citronella oil, T_9: Ash

During the initial stage of storage, the effect of variety on seedling dry weight was found to be statistically significant. The variety Phule Sonali (V_1) recorded a superior mean seedling dry weight of 29.42 mg, which was significantly higher than that of Phule Rakhumai (V_2) at 28.41 mg.

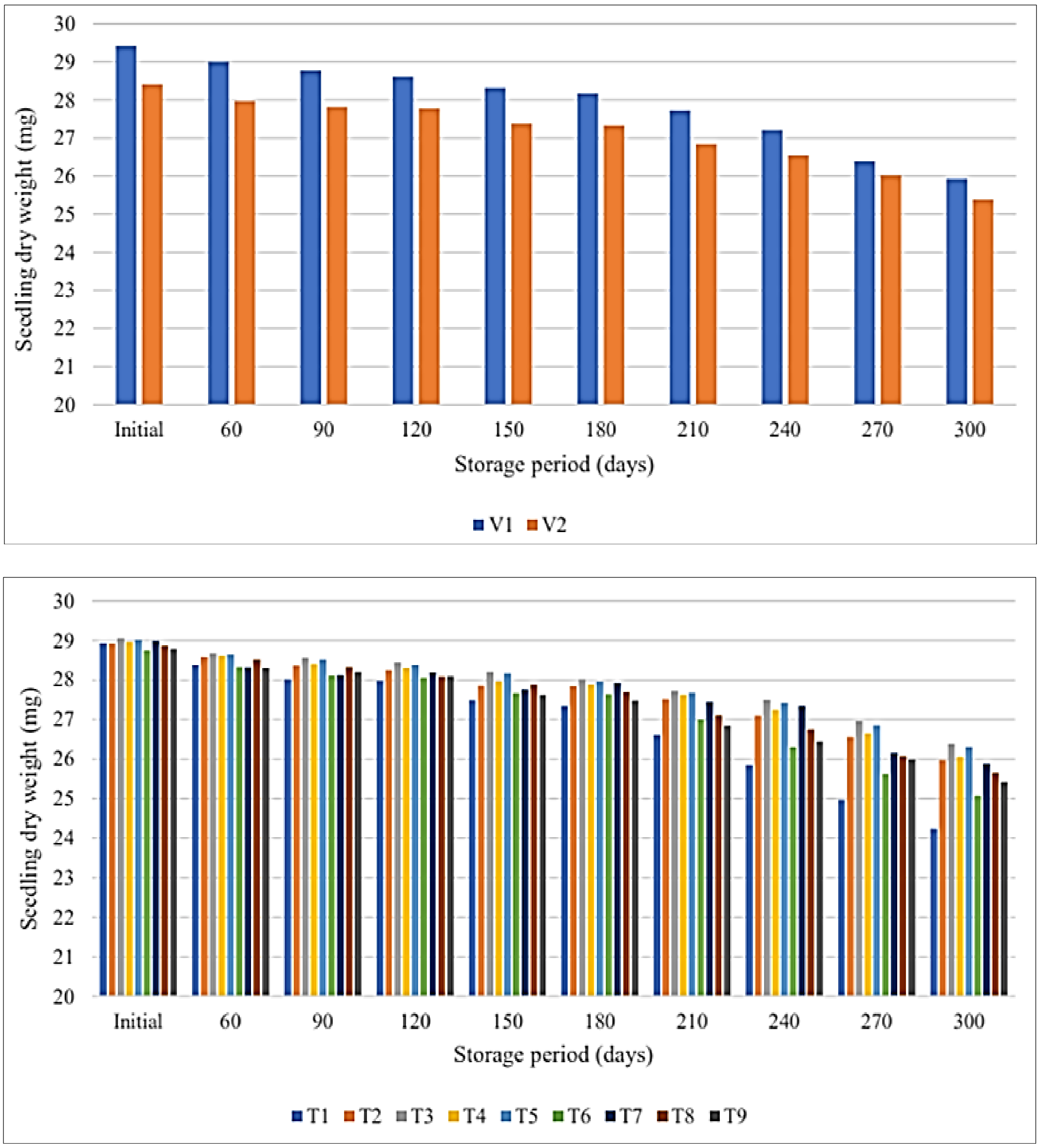


Fig 7: Effect of seed treatment on Seedling dry weight (mg)

The influence of seed treatments on seedling dry weight at initial stage was non-significant, although numerically the highest values were recorded in T_3 (Neem oil) with 29.06 mg, followed by T_5 (Karanj oil) with 29.02mg**.** Among the variety- treatment interaction, the V_1T_3 (Phule Sonali × Neem oil) interaction recorded the highest seedling dry weight with 29.59 mg, followed by V_1T_5 (Phule Sonali × Karanj oil) with 29.55 mg. whereas the lowest was recorded in V_2T_6 (Phule Rakhumai × Vekhand powder) with 28.27 mg.

At the end of 300 days of storage period, the effects of variety, treatment and their interaction on seedling dry weight were found to be statistically significant. The variety Phule Sonali (V_1) continued to outperform with a mean seedling dry weight of 25.93 mg, which was significantly higher than Phule Rakhumai (V_2) with 25.39 mg. Among the treatments, T_3 (Neem oil) remained the most effective, resulting in the highest dry weight (26.39 mg), it was on par with T_5 (Karanj oil) with 26.30 mg**.** The lowest value was recorded in the untreated control (T_1) with 24.23 mg.

The interaction effect was significant at at the end of 300 days of storage period. The combination V_1T_3 (Phule Sonali × Neem oil) recorded the highest seedling dry weight of 26.67 mg, it was on par with V_1T_5 (26.63 mg)**.** The lowest value was recorded in V_2T_1 (Phule Rakhumai × Control) at 24.03 mg. Indicating the adverse effects of storage without treatment.

These results clearly demonstrate that neem oil treatments were effective in maintaining seedling biomass over extended storage. Seed treated with botanicals particularly neem oil showed higher seedling dry weight due to higher test weight, root shoot length and less deterioration of seed. Similar findings were observed by Babu and Ravi (2008) [7] in soybean, Dwivedi (2024) [12] in field pea and Kottagorla (2024) [21] in cowpea.

Electrical Conductivity (dSm^{-1})

Effect of seed treatment on electrical conductivity (dSm-1) in Cowpea

The results on electrical conductivity as influenced by seed treatments during storage period are presented in Table 8 and Figure 8. It was noticed that electrical conductivity increased with the advancement of storage period irrespective of seed treatment.

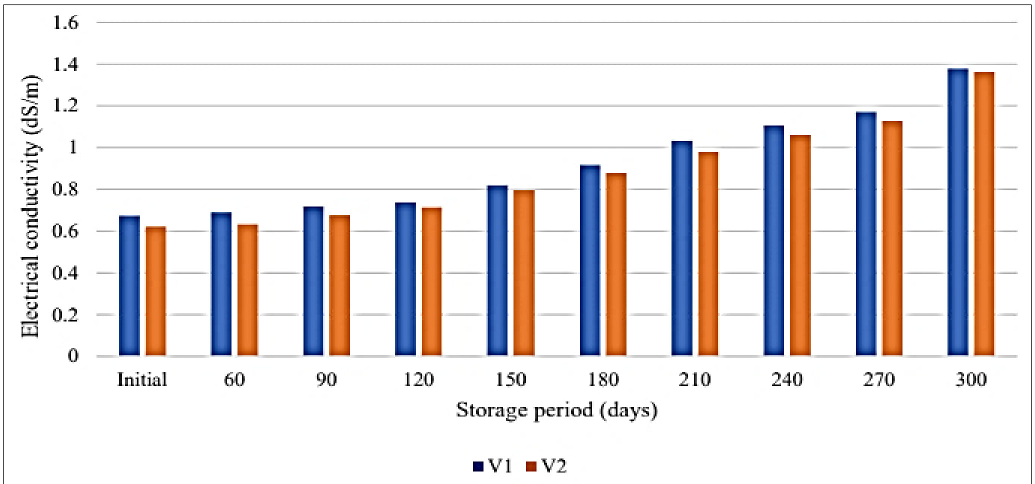
At initial days of storage, the electrical conductivity (EC) of cowpea seeds showed significant difference between the two varieties. Variety V_1 (Phule Sonali) recorded a slightly higher EC value (0.674 dS/m) compared to variety V_2

(Phule Rakhumai), which recorded 0.621 dS/m. The treatment effect was non-significant at initial storage period. Among treatments, the EC ranged from 0.639 (T_3 - neem oil) to 0.659 dS/m (T_9 - ash). Interaction effect between variety and treatment was statistically non-significant at initial days. the lowest was observed in V_2T_3 (neem oil × Phule Rakhumai) at 0.612 dS/m. However, the combination V_1T_2 (neem leaf powder × Phule Sonali) recorded the highest EC at 0.683 dS/m.

Table 8: Effect of seed treatment on electrical conductivity (dSm-1) in Cowpea

Treatment	Storage period (September 2024 - June 2025)									
	Initial	60	90	120	150	180	210	240	270	300
a. Variety										
V_1	0.674	0.689	0.717	0.738	0.820	0.916	1.034	1.107	1.171	1.379
V_2	0.621	0.634	0.676	0.714	0.797	0.878	0.980	1.060	1.127	1.362
SE±	0.003	0.010	0.011	0.004	0.003	0.002	0.005	0.003	0.006	0.005
C.D at 5%	0.009	0.029	0.032	0.011	0.009	0.005	0.013	0.009	0.017	0.014
b. Treatment										
T_1	0.640	0.649	0.680	0.816	0.861	0.949	1.052	1.150	1.285	1.508
T_2	0.649	0.654	0.677	0.687	0.773	0.867	0.968	1.038	1.072	1.290
T_3	0.639	0.650	0.669	0.680	0.768	0.863	0.964	1.035	1.057	1.262
T_4	0.644	0.667	0.682	0.683	0.774	0.865	0.965	1.039	1.064	1.287
T_5	0.649	0.667	0.697	0.728	0.808	0.897	1.017	1.057	1.112	1.367
T_6	0.650	0.658	0.747	0.761	0.845	0.930	1.040	1.138	1.246	1.463
T_7	0.655	0.675	0.720	0.745	0.836	0.913	1.015	1.109	1.163	1.363
T_8	0.644	0.663	0.689	0.707	0.795	0.884	1.013	1.086	1.126	1.382
T_9	0.659	0.672	0.710	0.714	0.818	0.906	1.028	1.100	1.214	1.413
SE±	0.003	0.009	0.010	0.003	0.003	0.001	0.004	0.003	0.005	0.004
C.D.at 5%	NS	NS	NS	0.009	0.008	0.004	0.012	0.008	0.015	0.012
Interaction										
V_1T_1	0.663	0.680	0.705	0.836	0.880	0.955	1.085	1.184	1.306	1.522
V_1T_2	0.683	0.684	0.703	0.711	0.786	0.885	0.978	1.061	1.110	1.263
V_1T_3	0.666	0.681	0.695	0.702	0.783	0.883	0.972	1.067	1.100	1.266
V_1T_4	0.669	0.693	0.708	0.663	0.760	0.879	0.974	1.027	1.043	1.293
V_1T_5	0.677	0.693	0.723	0.738	0.823	0.915	1.043	1.090	1.144	1.371
V_1T_6	0.672	0.686	0.729	0.780	0.865	0.948	1.080	1.173	1.279	1.489
V_1T_7	0.679	0.698	0.747	0.751	0.848	0.933	1.068	1.134	1.182	1.383
V_1T_8	0.670	0.691	0.714	0.723	0.802	0.903	1.038	1.108	1.145	1.400
V_1T_9	0.687	0.696	0.731	0.732	0.835	0.940	1.062	1.122	1.227	1.420
V_2T_1	0.616	0.618	0.654	0.816	0.842	0.942	1.018	1.116	1.263	1.493
V_2T_2	0.614	0.624	0.650	0.664	0.760	0.848	0.959	1.016	1.034	1.318
V_2T_3	0.612	0.619	0.643	0.657	0.752	0.843	0.955	1.003	1.014	1.258
V_2T_4	0.619	0.640	0.656	0.703	0.788	0.851	0.956	1.050	1.084	1.280
V_2T_5	0.622	0.640	0.671	0.717	0.793	0.878	0.990	1.024	1.079	1.362
V_2T_6	0.628	0.629	0.764	0.741	0.824	0.912	1.000	1.103	1.213	1.436
V_2T_7	0.631	0.652	0.693	0.738	0.823	0.893	0.962	1.083	1.144	1.343
V_2T_8	0.619	0.635	0.665	0.690	0.788	0.865	0.988	1.064	1.106	1.364
V_2T_9	0.632	0.648	0.688	0.697	0.801	0.872	0.993	1.077	1.201	1.405
S.E±	0.009	0.030	0.033	0.011	0.009	0.005	0.014	0.009	0.018	0.015
C.D at 5%	NS	NS	NS	0.032	0.028	0.014	0.040	0.026	0.050	0.042

V_1: Phule sonali, V_2: Phule Rakhumai, T_1: Control, T_2: Neem leaf powder, T_3: Neem oil, T_4: Castor oil, T_5: Karanj oil, T_6: Vekhand powder, T_7: Turmeric powder, T_8: Citronella oil, T_9: Ash



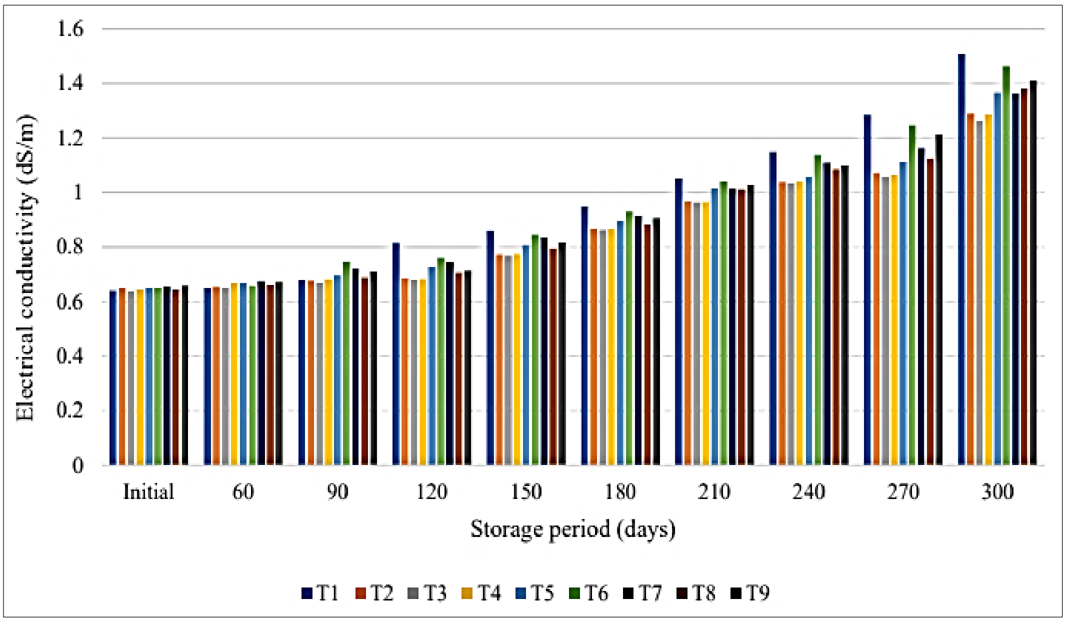


Fig 8: Effect of seed treatment on electrical conductivity (dSm^{-1})

At the end of 300 days of storage period, significant differences were observed among varieties, treatments and their interactions. Variety V_1 (Phule Sonali) show a slightly higher EC value of 1.379 dS/m, while V_2 (Phule Rakhumai) recorded 1.362 dS/m. Among treatments, the maximum EC was recorded in control (T_1) at 1.508 dS/m, indicating higher membrane deterioration, while the minimum was in T_3 (neem oil) with 1.262 dS/m, suggesting its effectiveness in maintaining seed membrane integrity. Interaction effect revealed that the combination V_1T_1 (Phule Sonali × control) recorded the highest EC value (1.522 dS/m), whereas the lowest was found in V_2T_3 (Phule Rakhumai) at 1.258 dS/m.

The electrical conductivity of seed leachate indicates the membrane integrity and quality of seed and it is negatively related with seed quality. Hampton *et al.* (1995) [16] reported that the electrical conductivity was increased with increment in storage period.

Thus, the botanicals make the seed antifeedant and unpalatable to insects and reduces the cracks and aberrations of the seed coat and reduce the leaching of the electrolytes. These results are in agreement with Patil (2000) [32] in chickpea, Malimath S. D. (2005) [26] in garden pea, Mahesh babu and Ravi Hunje (2008) [7] in soybean, Isak M. (2017) [17] in cowpea, Shinde P. and Hunje R. (2019) [40] in chickpea. These results clearly demonstrate that neem oil (T_3), was most effective in minimizing the increase in electrical conductivity over prolonged storage, indicating better seed quality retention.

Test Weight (g)

Effect of seed treatment on test weight (g) in Cowpea

The results on test weight as influenced by seed treatments during storage period are presented in Table 9 (Figure 9). It was noticed that test weight decreased with the advancement of storage period irrespective of seed treatment. At initial days of storage, the test weight was significantly influenced by varietal differences, while treatment and interaction effects were statistically non- significant (NS). Between the two varieties, Phule Sonali (V_1) recorded higher test weight (13.61 g) compared to Phule Rakhumai (V_2) (9.65 g). Among treatments, although not significant at initial days, neem oil (T_3) recorded a numerically higher test weight (11.72 g), followed by castor oil (T_4) (11.68 g). The lowest test weight was recorded in the untreated control (T_1) (11.62 g).

The interaction of variety and treatment at initial period showed that the maximum test weight (13.67 g) was recorded in the V_1T_3 (Phule Sonali × Neem oil) combination, followed by V_1T_4 (Phule Sonali × Castor oil) (13.64 g) and V_1T_5 (Phule Sonali × Karanj oil) (13.62 g). In contrast, the lowest test weight was recorded in the V_2T_1 (Phule Rakhumai × Control) treatment (9.69 g).

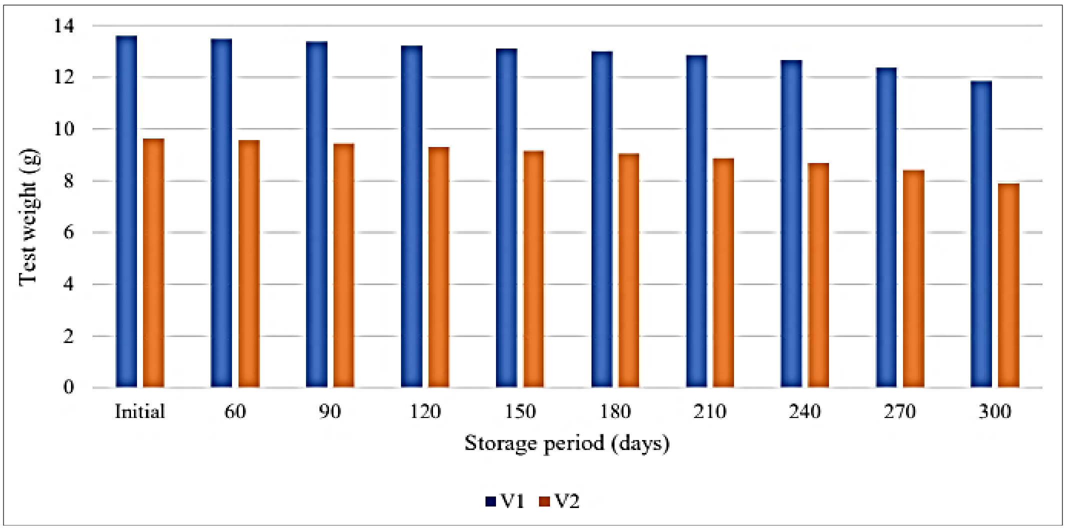
Table 9: Effect of seed treatment on test weight (g) in Cowpea

Treatment	Storage period (September 2024 - June 2025)									
	Initial	60	90	120	150	180	210	240	270	300
a. Variety										
V_1	13.61	13.49	13.38	13.22	13.12	13.02	12.86	12.66	12.38	11.87
V_2	9.65	9.58	9.44	9.31	9.17	9.06	8.87	8.70	8.43	7.92
SE±	0.05	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.02	0.02
C.D at 5%	0.15	0.03	0.04	0.04	0.04	0.05	0.05	0.05	0.06	0.06
b. Treatment										
T_1	11.62	11.42	11.31	10.94	10.87	10.72	10.54	10.34	9.85	8.65
T_2	11.64	11.49	11.40	11.27	11.16	11.13	10.88	10.70	10.57	10.20
T_3	11.72	11.61	11.48	11.40	11.27	11.16	11.01	10.83	10.60	10.24
T_4	11.68	11.56	11.47	11.38	11.25	11.15	10.99	10.81	10.59	10.21

T_5	11.67	11.59	11.46	11.37	11.24	11.12	10.97	10.80	10.48	10.08
T_6	11.66	11.52	11.36	11.25	11.08	10.95	10.79	10.54	10.20	9.54
T_7	11.64	11.50	11.41	11.27	11.15	11.04	10.88	10.70	10.45	10.02
T_8	11.67	11.56	11.39	11.25	11.14	11.03	10.88	10.69	10.43	10.05
T_9	11.67	11.55	11.42	11.30	11.19	11.09	10.89	10.71	10.47	10.03
SE±	0.04	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.02	0.02
C.D.at 5%	NS	0.03	0.03	0.03	0.03	0.04	0.05	0.04	0.06	0.05
Interaction										
V_1T_1	13.56	13.40	13.29	12.78	12.81	12.61	12.55	12.31	11.83	10.62
V_1T_2	13.58	13.45	13.35	13.22	13.13	13.18	12.88	12.67	12.53	12.20
V_1T_3	13.67	13.56	13.45	13.38	13.24	13.14	12.99	12.81	12.57	12.22
V_1T_4	13.64	13.51	13.44	13.35	13.23	13.14	12.98	12.80	12.57	12.18
V_1T_5	13.62	13.54	13.43	13.38	13.23	13.13	12.94	12.78	12.46	12.05
V_1T_6	13.60	13.48	13.33	13.14	13.04	12.93	12.80	12.51	12.17	11.52
V_1T_7	13.57	13.46	13.36	13.25	13.12	13.02	12.88	12.67	12.43	11.98
V_1T_8	13.62	13.51	13.36	13.21	13.12	13.00	12.88	12.66	12.40	12.02
V_1T_9	13.62	13.49	13.39	13.25	13.17	13.06	12.89	12.68	12.43	12.00
V_2T_1	9.69	9.44	9.32	9.09	8.93	8.82	8.52	8.37	7.87	6.68
V_2T_2	9.70	9.53	9.44	9.31	9.18	9.07	8.87	8.73	8.60	8.20
V_2T_3	9.77	9.66	9.50	9.41	9.29	9.17	9.02	8.85	8.63	8.27
V_2T_4	9.74	9.62	9.50	9.40	9.27	9.16	9.00	8.81	8.62	8.23
V_2T_5	9.73	9.63	9.49	9.35	9.24	9.11	9.00	8.82	8.50	8.12
V_2T_6	9.72	9.56	9.39	9.35	9.11	8.97	8.78	8.56	8.23	7.57
V_2T_7	9.71	9.54	9.45	9.28	9.17	9.06	8.88	8.72	8.47	8.05
V_2T_8	9.72	9.60	9.41	9.29	9.16	9.07	8.88	8.71	8.47	8.08
V_2T_9	9.71	9.60	9.45	9.34	9.21	9.11	8.89	8.74	8.50	8.07
S.E±	0.15	0.02	0.04	0.04	0.04	0.05	0.06	0.05	0.07	0.06
C.D at 5%	NS	NS	0.13	0.13	0.12	0.16	0.18	0.16	0.19	0.17

V_1: Phule sonali, V_2: Phule Rakhumai, T_1: Control, T_2: Neem leaf powder, T_3: Neem oil, T_4: Castor oil, T_5: Karanj oil, T_6: Vekhand powder, T_7: Turmeric powder, T_8: Citronella oil, T_9: Ash

At the end of 300 days of storage period, treatment and interaction effects were all statistically significant. Test weight declined over time in all combinations, but the rate of decline varied with variety and treatment. Between varieties, Phule Sonali (V_1) recorded a significantly higher test weight (11.87 g) compared to Phule Rakhumai (V_2) (7.92 g). Among treatments, neem oil (T_3) maintained the highest test weight (10.24 g) at the end of storage, followed by castor oil (T_4) (10.21 g). The untreated control (T_1) showed the lowest test weight (8.65 g).



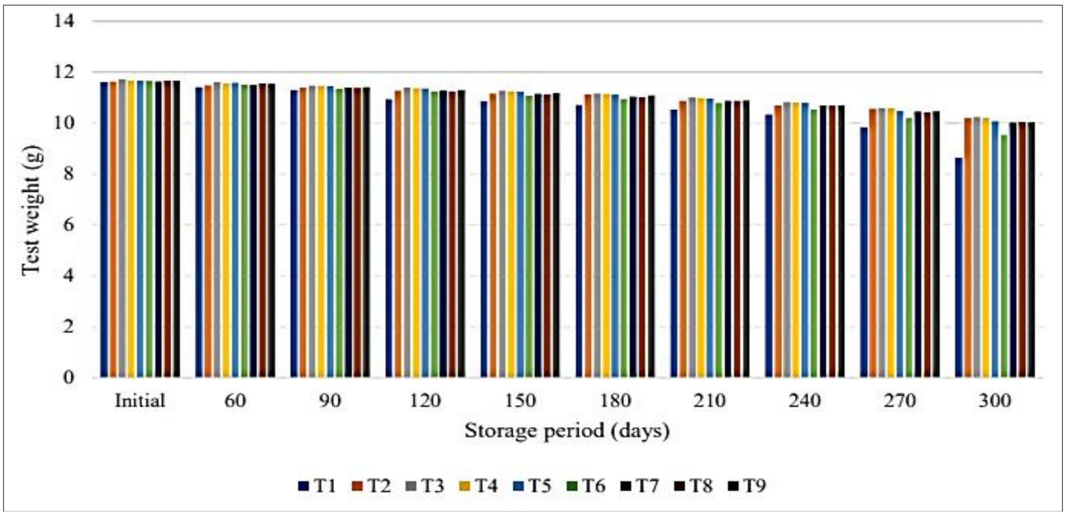


Fig 9: Effect of seed treatment on test weight (g)

The interaction effect was significant, with the highest test weight (12.22g) observed in the V_1T_3 (Phule Sonali × Neem oil) combination. This was followed by V_1T_2 (Phule Sonali × Neem leaf powder) (12.20 g) and V_1T_4 (Phule Sonali × Castor oil) (12.18 g). On the other hand, V_2T_1 (Phule Rakhumai × Control) had the lowest test weight (6.68 g).
Similar findings were reported by Choudhary *et al.* (2017) [10] in cowpea, Durga Bhavani B. (2024) in green gram, Singh S. & Gupta R. (2022) [15] in green gram. Phule Sonali (V_1) variety exhibited higher test weight compared to Phule Rakhumai(V_2), primarily due to its bold and larger grain size which contributes to greater seed mass per unit volume. The higher grain boldness ensures more endosperm accumulation, resulting in superior seed density and weight, whereas Phule Rakhumai, being relatively smaller seeded, recorded lower test weight.

Seed mycoflora (%)

Effect of seed treatment on seed mycoflora (%) in Cowpea

The results on seed mycoflora as influenced by seed treatments during storage period are presented in Table 10 with Figure 10. It was noticed that seed mycoflora increased with the advancement of storage period irrespective of seed treatment.

Table 10: Effect of seed treatment on seed mycoflora (%) in Cowpea.

Treatment	Storage period (September 2024 - June 2025)									
	Initial	60	90	120	150	180	210	240	270	300
a. Variety										
V_1	8.56 (17.00)	9.44 (17.83)	11.70 (19.97)	13.78 (21.73)	18.22 (25.16)	21.96 (27.87)	27.22 (31.39)	29.93 (33.11)	34.07 (35.66)	37.15 (37.52)
V_2	8.48 (16.91)	8.52 (16.93)	10.85 (19.16)	13.19 (21.25)	16.78 (24.06)	21.44 (27.53)	25.48 (30.27)	28.93 (32.50)	32.19 (34.51)	36.04 (36.85)
SE±	0.14	0.32	0.26	0.14	0.12	0.10	0.13	0.13	0.12	0.15
C.D at 5%	NS	NS	0.74	0.40	0.35	0.31	0.37	0.38	0.36	0.43
b. Treatment										
T_1	8.00 (16.42)	8.17 (16.56)	14.33 (22.24)	17.33 (24.59)	25.33 (30.21)	27.33 (31.52)	33.50 (35.35)	38.17 (38.14)	43.50 (41.26)	47.00 (43.28)
T_2	8.50 (16.93)	8.50 (16.85)	11.67 (19.96)	11.83 (20.11)	18.17 (25.22)	21.17 (27.39)	27.00 (31.30)	29.50 (32.90)	31.33 (34.03)	36.00 (36.87)
T_3	8.17 (16.59)	8.33 (16.76)	10.00 (18.39)	11.50 (19.81)	13.33 (21.41)	16.50 (23.96)	21.33 (27.49)	24.50 (29.67)	28.50 (32.25)	31.50 (34.14)
T_4	9.00 (17.45)	9.17 (17.56)	10.50 (18.88)	11.67 (19.96)	13.50 (21.55)	16.67 (24.09)	21.67 (27.74)	24.83 (29.89)	28.67 (32.36)	31.83 (34.34)
T_5	8.67 (17.12)	9.50 (17.93)	10.50 (18.89)	13.50 (21.54)	16.67 (24.05)	21.17 (27.39)	25.83 (30.54)	29.50 (32.90)	33.50 (35.36)	37.17 (37.56)
T_6	8.83 (17.27)	10.00 (18.39)	11.50 (19.78)	15.67 (23.31)	21.17 (27.39)	24.50 (29.66)	28.83 (32.47)	32.17 (34.55)	37.83 (37.96)	41.50 (40.11)
T_7	8.67 (17.12)	9.67 (18.09)	10.67 (19.02)	13.00 (21.13)	16.00 (23.56)	22.00 (27.97)	27.00 (31.30)	29.50 (32.90)	34.67 (36.07)	37.83 (37.96)
T_8	8.17 (16.59)	8.67 (17.04)	11.17 (19.48)	12.67 (20.84)	14.50 (22.38)	22.83 (28.54)	24.83 (29.89)	27.67 (31.73)	31.33 (34.04)	34.67 (36.07)
T_9	8.67 (17.12)	8.83 (17.23)	11.17 (19.47)	14.17 (22.09)	18.83 (25.72)	23.17 (28.77)	27.17 (31.40)	29.00 (32.58)	28.83 (32.47)	31.83 (34.35)
SE±	0.12	0.27	0.22	0.12	0.10	0.09	0.11	0.11	0.11	0.13
C.D.at 5%	NS	NS	0.64	0.35	0.31	0.26	0.32	0.32	0.31	0.37
Interaction										
V_1T_1	8.00 (16.41)	8.67 (17.05)	14.67 (22.52)	18.33 (25.35)	26.33 (30.87)	28.33 (32.16)	35.33 (36.47)	40.67 (39.61)	45.00 (42.13)	47.67 (43.66)
V_1T_2	8.67 (17.12)	9.00 (17.35)	11.67 (19.95)	12.67 (20.85)	19.00 (25.84)	21.00 (27.27)	27.33 (31.52)	29.67 (33.00)	32.67 (34.86)	36.33 (37.07)
V_1T_3	8.33 (16.77)	8.33 (16.75)	10.33 (18.75)	11.67 (19.96)	13.67 (21.69)	16.67 (24.09)	22.67 (28.42)	24.67 (29.78)	30.33 (33.41)	32.33 (34.65)
V_1T_4	8.67 (17.12)	9.67 (18.00)	10.33 (18.75)	11.00 (19.37)	14.00 (21.97)	16.33 (23.84)	22.00 (27.97)	25.33 (30.22)	28.33 (32.14)	32.67 (34.86)
V_1T_5	8.67 (17.12)	10.00 (18.42)	11.00 (19.36)	14.33 (22.24)	18.67 (25.59)	21.33 (27.51)	26.33 (30.87)	30.00 (33.21)	34.67 (36.07)	37.67 (37.86)
V_1T_6	9.00 (17.44)	10.67 (19.03)	12.33 (20.56)	15.67 (23.31)	21.33 (27.51)	25.00 (30.00)	30.00 (33.21)	32.33 (34.65)	38.33 (38.25)	42.33 (40.59)
V_1T_7	8.33 (16.77)	10.33 (18.73)	11.33 (19.65)	13.00 (21.13)	16.67 (24.07)	21.67 (27.74)	27.67 (31.73)	29.33 (32.79)	36.00 (36.87)	38.00 (38.06)
V_1T_8	8.33 (16.77)	9.00 (17.39)	11.67 (19.97)	12.67 (20.85)	15.00 (22.79)	24.00 (29.33)	24.67 (29.78)	28.00 (31.95)	31.67 (34.24)	35.33 (36.47)
V_1T_9	9.00 (17.46)	9.33 (17.72)	12.00 (20.26)	14.67 (22.51)	19.33 (26.08)	23.33 (28.88)	29.00 (32.58)	29.33 (32.79)	29.67 (33.00)	32.00 (34.45)
V_2T_1	8.00 (16.43)	7.67 (16.07)	14.00 (21.96)	16.33 (23.84)	24.33 (29.56)	26.33 (30.87)	31.67 (34.24)	35.67 (36.67)	42.00 (40.40)	46.33 (42.89)
V_2T_2	9.33 (16.75)	8.00 (16.35)	11.67 (19.97)	11.00 (19.37)	17.33 (24.60)	21.33 (27.51)	26.67 (31.09)	29.33 (32.79)	30.00 (33.21)	35.67 (36.67)
V_2T_3	8.00 (16.41)	8.33 (16.77)	9.67 (18.03)	11.33 (19.66)	13.00 (21.13)	16.33 (23.83)	20.00 (26.57)	24.33 (29.56)	26.67 (31.09)	30.67 (33.63)
V_2T_4	9.33 (17.78)	8.67 (17.12)	10.67 (19.01)	12.33 (20.56)	13.00 (21.13)	17.00 (24.35)	21.33 (27.51)	24.33 (29.56)	29.00 (32.58)	31.00 (33.83)
V_2T_5	8.67 (17.12)	9.00 (17.44)	10.00 (18.42)	12.67 (20.85)	14.67 (22.52)	21.00 (27.27)	25.33 (30.22)	29.00 (32.58)	32.33 (34.65)	36.67 (37.26)
V_2T_6	8.67 (17.10)	9.33 (17.75)	10.67 (19.01)	15.67 (23.31)	21.00 (27.27)	24.00 (29.33)	27.67 (31.73)	32.00 (34.44)	37.33 (37.66)	40.67 (39.62)

V_2T_7	9.00 (17.46)	9.00 (17.44)	10.00 (18.39)	13.00 (21.13)	15.33 (23.05)	22.33 (28.20)	26.33 (30.87)	29.67 (33.00)	33.33 (35.26)	37.67 (37.86)
V_2T_8	8.00 (16.41)	8.33 (16.69)	10.67 (18.99)	12.67 (20.84)	14.00 (21.96)	21.67 (27.74)	25.00 (30.00)	27.33 (31.52)	31.00 (33.83)	34.00 (35.67)
V_2T_9	8.33 (16.77)	8.33 (16.74)	10.33 (18.69)	13.67 (21.68)	18.33 (25.35)	23.00 (28.65)	25.33 (30.22)	28.67 (32.37)	28.00 (31.95)	31.67 (34.24)
S.E±	0.43	0.96	0.78	0.42	0.37	0.32	0.39	0.39	0.38	0.45
C.D at 5%	NS	NS	NS	1.21	1.07	0.93	1.12	1.13	1.10	1.33

V_1: Phule sonali, V_2: Phule Rakhumai, T_1: Control, T_2: Neem leaf powder, T_3: Neem oil, T_4: Castor oil, T_5: Karanj oil, T_6: Vekhand powder, T_7: Turmeric powder, T_8: Citronella oil, T_9: Ash

At initial days of storage, the effect of variety on mycoflora infection was found to be non-significant. Both varieties, Phule Sonali (V_1) and Phule Rakhumai (V_2), recorded almost similar levels of infection. Likewise, the treatment effect and interaction effect (V×T) were also non-significant at initial days of storage.

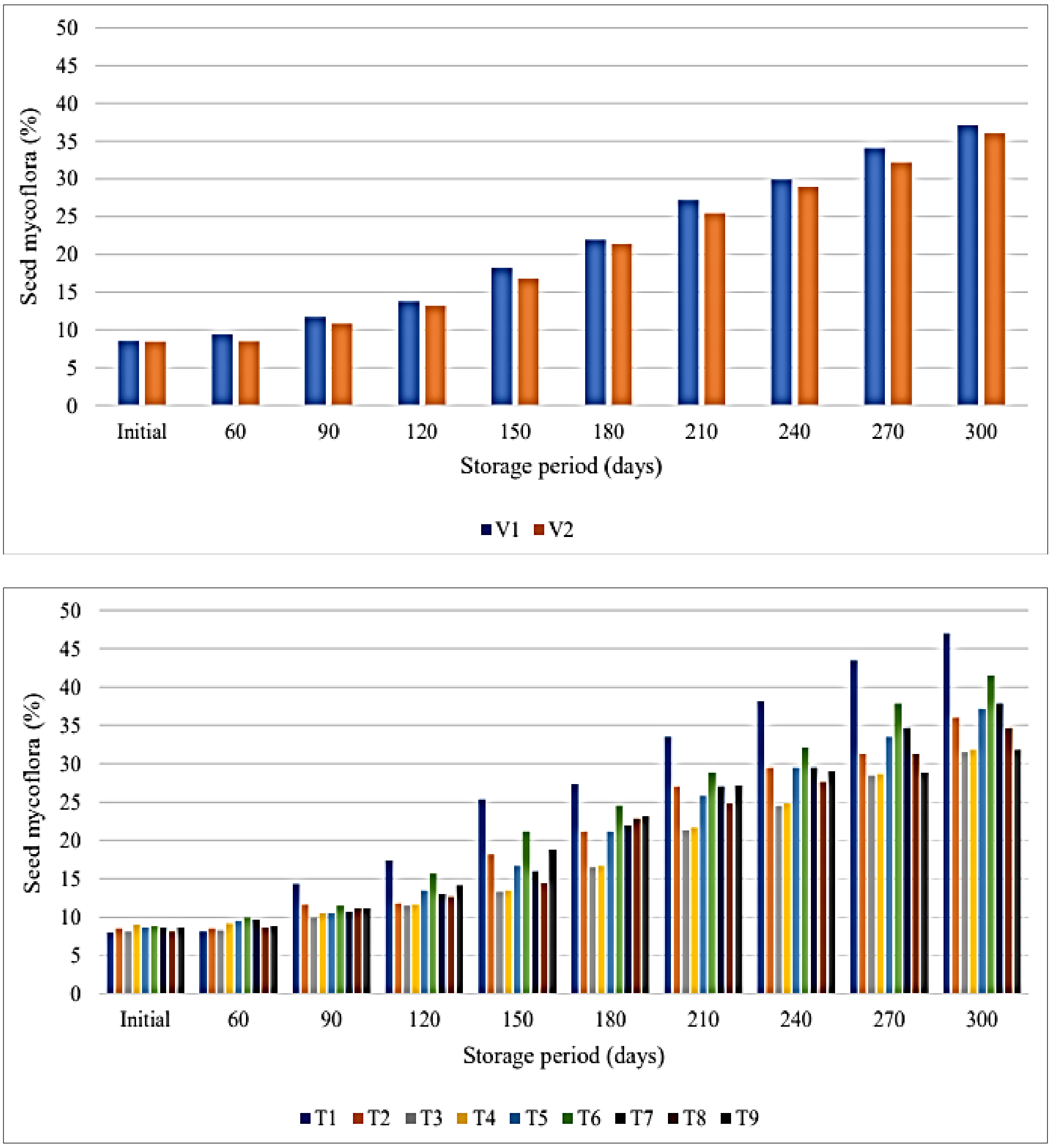


Fig 10: Effect of seed treatment on seed mycoflora (%)

At the end of 300 days of storage period, the effects of variety, treatment and their interaction on mycoflora infection were significant**.** The variety Phule Rakhumai (V_2) recorded lower infection (36.04%) compared to Phule Sonali (V_1) **(**37.15%). Among the treatments, the lowest mycoflora infection was observed in T_3 (neem oil) with 31.50%, it was on par with T_4 (castor oil) with 31.83%. In contrast, the highest infection was recorded in the untreated control (T_1) at 47.00%, confirming the detrimental effect of no treatment.

The interaction effect (V × T) also recorded significant variation. The V_2T_3 (Phule Rakhumai × Neem oil) combination had the lowest infection (30.67%**),** while the highest infection was recorded in V_1T_1 (Phule Sonali × Control) (47.67%)**,** followed by V_2T_1 (Phule Rakhumai × Control) (46.33%). These results highlight the effectiveness of neem oil in controlling fungal growth during prolonged storage and underscore the susceptibility of untreated seeds to fungal infestation. Similar result was observed by Shivanna & Hiremath (2000) [39] in cowpea, Bhale & Khare (2005) in cowpea, Sahu & Kar (2009) in blackgram, Awurum *et al.* (2014) in cowpea, Hassan *et al.* (2015) in groundnut, Anil *et al.* (2025) in soybean.

Seed treatment with neem oil @ 5ml showed lowest seed mycoflora throughout the period of storage. During study, the different mycoflora observed were *fusarium oxysporum*, *Aspergillus niger*, *Aspergillus flavus*. Among the mycoflora observed during the storage of Cowpea seed, *Aspergillus spp*. occupied the major percentage.

Bioefficacy Test

The bio efficacy test was undertaken to find out the effect of different botanicals against pulse beetle in Cowpea seed. The experiment was conducted in the Entomology laboratory at STRU, MPKV, Rahuri.

The seeds of Cowpea were treated with neem leaf powder @ 5 g/kg of seed, neem oil @ 5 ml/kg of seed, castor oil @ 5 ml/kg of seed, karanj oil @ 5 ml/kg of seed, vekhand powder @ 10 g/kg of seed, turmeric powder @ 5 g/kg of seed, citronella oil @ 5 ml/kg of seed, ash @ 5 g/kg of seed. From treated seed 100-gram seed was taken out from each replication and kept in 200 ml capacity plastic jar and 10 pairs of pulse beetle was released in each set and the observations was recorded on pulse beetle infestation. The data generated was statistically analysed and presented below.

Pulse beetle infestation (%)

Effect of seed treatment on pulse beetle infestation (%) in Cowpea

The result in Table 11 indicated significant difference in respect of per cent pulse beetle infestation during storage period. Per cent seed infestation was recorded on 3rd, 6th and 9th month after storage period. The graphical representation is presented in Figure 11.

Table 11: Effect of seed treatment on pulse beetle infestation (%) in Cowpea

Treatment	Storage period (months)		
	3	6	9
a. Variety			
V_1	2.19 (6.80)	5.33 (12.67)	14.26 (21.30)
V_2	2.00 (6.48)	4.56 (11.65)	10.41 (18.12)
SE±	0.09	0.21	0.19
C.D at 5%	0.27	0.61	0.55
b. Treatment			
T_1	4.33 (12.00)	11.67 (19.97)	26.00 (30.62)
T_2	0.00 (0.00)	2.17 (8.35)	8.83 (17.26)
T_3	0.00 (0.00)	1.33 (6.54)	3.67 (11.02)
T_4	0.00 (0.00)	1.50 (6.93)	3.83 (11.25)
T_5	1.00 (5.74)	3.50 (10.76)	8.17 (16.56)
T_6	2.33 (8.74)	6.33 (14.55)	16.17 (23.56)
T_7	4.00 (11.54)	5.83 (13.94)	15.00 (22.63)
T_8	3.17 (10.19)	5.33 (13.30)	10.83 (19.13)
T_9	4.00 (11.54)	6.83 (15.11)	18.50 (25.38)
SE±	0.08	0.18	0.16
C.D.at 5%	0.24	0.53	0.48
Interaction			
V_1T_1	4.33 (12.00)	12.00 (20.27)	28.67 (32.37)
V_1T_2	0.00 (0.00)	2.33 (8.74)	9.67 (18.11)
V_1T_3	0.00 (0.00)	1.33 (6.54)	4.00 (11.54)
V_1T_4	0.00 (0.00)	1.67 (7.33)	4.00 (11.48)
V_1T_5	1.00 (5.74)	3.67 (11.02)	9.33 (17.78)
V_1T_6	2.67 (9.36)	7.00 (15.34)	19.67 (26.31)
V_1T_7	4.00 (11.54)	6.67 (14.95)	18.67 (25.60)
V_1T_8	3.67 (11.02)	6.00 (14.15)	12.67 (20.83)
V_1T_9	4.00 (11.54)	7.33 (15.70)	21.67 (27.73)
V_2T_1	4.33 (12.00)	11.33 (19.67)	23.33 (28.88)
V_2T_2	0.00 (0.00)	2.00 (7.95)	8.00 (16.41)
V_2T_3	0.00 (0.00)	1.33 (6.54)	3.33 (10.50)
V_2T_4	0.00 (0.00)	1.33 (6.54)	3.67 (11.02)
V_2T_5	1.00 (5.74)	3.33 (10.50)	7.00 (15.34)
V_2T_6	2.00 (8.13)	5.67 (13.67)	12.67 (20.81)
V_2T_7	4.00 (11.54)	5.00 (12.92)	11.33 (19.67)
V_2T_8	2.67 (9.36)	4.67 (12.46)	9.00 (17.44)
V_2T_9	4.00 (11.54)	6.33 (14.51)	15.33 (23.04)
S.E±	0.28	0.63	0.57
C.D at 5%	0.81	1.86	1.65

V_1: Phule sonali, V_2: Phule Rakhumai, T_1: Control, T_2: Neem leaf powder, T_3: Neem oil, T_4: Castor oil, T_5: Karanj oil, T_6: Vekhand powder, T_7: Turmeric powder, T_8: Citronella oil, T_9: Ash

All the treatments were significantly superior over untreated control in checking per cent seed infestation. During storage period trend of pulse beetle infestation was increasing with storage period.

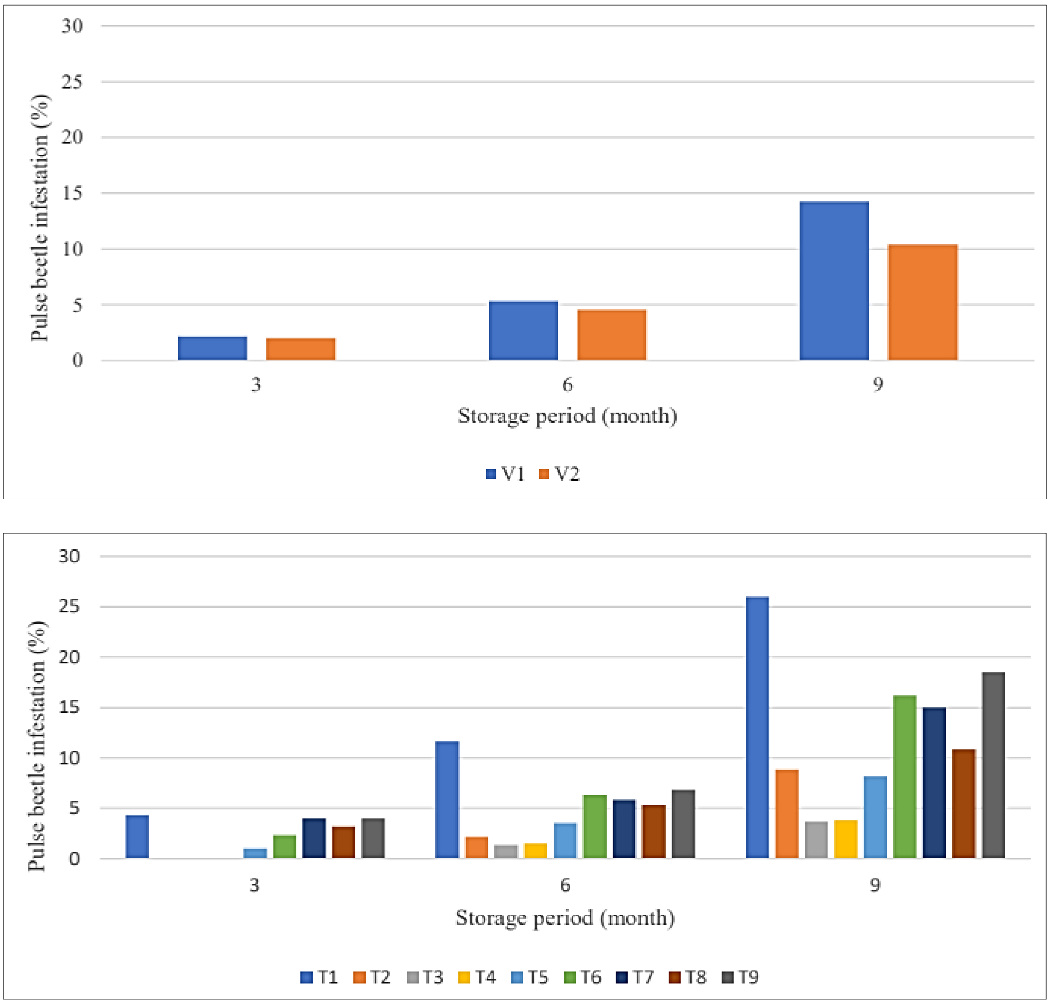


Fig 11: Effect of seed treatment on pulse beetle infestation (%)

At three months of storage, a significant difference was observed between the two cowpea varieties. Phule Sonali (V_1) recorded a pulse beetle infestation of 2.19%, which was slightly higher than Phule Rakhumai (V_2) at 2.00%. Among treatments, neem oil (T_3), castor oil (T_4) and neem leaf powder (T_2) were highly effective, recording 0.00% infestation. In contrast, untreated control (T_1) had the highest infestation of 4.33%. Interaction effects showed zero infestation in combinations like V_1T_3, V_1T_4, V_1T_2 and their respective counterparts V_2T_3, V_2T_4, V_2T_2. On the other hand, treatments like V_1T_1 (4.33%) (Phule Sonali × Control) and V_2T_1 (Phule Rakhumai × Control) (4.33%) had the highest infestation.

At 6 months of storage, V_1 (Phule Sonali) recorded 5.33% infestation, which was higher than V_2 (Phule Rakhumai) with 4.56%. Among the treatments, neem oil (T_3) at 1.33% and castor oil (T_4) at 1.50% remained the most effective. The untreated control (T_1) was the highest infestation of 11.67%, followed by ash (T_9) at 6.83%. In the interaction effect, V_1T_1 (Phule Sonali × Control) showed the highest infestation at 12.00%, followed by V_2T_1 (Phule Rakhumai × Control) with 11.33%. Lowest infestation was recorded in combinations like V_1T_3 (1.33%)**,** V_2T_3 (1.33%) and V_2T_4 (1.33%)**.**

At the end of 9 month of storage period, the trend continued with further increase in pulse beetle infestation. Phule Sonali (V_1) reached 14.26%, significantly higher than Phule Rakhumai (V_2) at 10.41%. Neem oil (T_3) and castor oil (T_4) treatments still provided strong control with infestation of 3.67 and 3.83%, respectively. The control treatment recorded the highest infestation at 26.00% followed by ash (T_9) 18.50% and vekhand powder (T_6) 16.17%**.** In interaction, V_1T_1 (Phule Sonali × Control) had the highest infestation at 28.67%, followed by V_2T_1 (Phule Rakhumai × Control) at 23.33%. The least infestation was recorded in V_2T_3 (3.33%), V_2T_4 (3.67%) and V_1T_3 (4.00%).

The present investigation recorded that absolute protection of seeds was found in seed treated with neem oil @ 5 ml/kg of seed, followed by castor oil @ 5 ml/kg of seed, owing to their bioactive constituents that act as repellents, oviposition deterrents and growth inhibitors. Neem oil offers immense antifeedant properties due to its efficacy in suppressing the feeding sensation in insects, at a concentration even less than 1 parts per million (Isman *et al.*, 1991) [18]. It induces sterility in insects by preventing oviposition and interrupting sperm production in males (Chaudhary *et al.*, 2017) [9]. Similar findings were observed by Rathod *et al.* (2018) [36] in pigeon pea, Rashmi *et al.* (2014) [37] in pigeon pea, Singh *et al.* (2017) [43] in chickpea, Kumar *et al.* (2018) [24] in black gram.

Conclusion

The present study demonstrates that organic seed treatments significantly influence the health and quality of cowpea seeds during storage. Among the various treatments evaluated, neem oil at 5 ml/kg of seed (T_3) emerged as the most effective in maintaining seed quality parameters throughout the 300-day storage period. This treatment consistently maintained lower moisture content (7.48%), higher germination percentage (77.17%), superior root and shoot length, and higher vigor indices compared to other treatments and the untreated control. Castor oil (T_4) and neem leaf powder (T_2) also showed significant benefits, though they were slightly less effective than neem oil.

The organic treatments effectively reduced seed deterioration by suppressing fungal growth and minimizing pulse beetle infestation. Neem oil treatment recorded the lowest seed mycoflora (31.50%) and pulse beetle infestation (3.67%) at the end of the storage period, highlighting its potent antimicrobial and insect-repellent properties. The untreated control seeds showed the highest deterioration across all parameters, with increased moisture content, reduced germination, and higher pest infestation.

Varietal differences were also observed, with Phule Sonali generally maintaining better seed quality than Phule Rakhumai across most parameters. However, the interaction effects revealed that the combination of Phule Rakhumai with neem oil treatment (V_2T_3) produced some of the best results in several parameters.

These findings underscore the potential of organic seed treatments, particularly neem oil, as viable alternatives to chemical treatments for maintaining seed quality during storage. They offer an eco-friendly, cost-effective solution for smallholder farmers to reduce post-harvest losses and improve seed viability, ultimately contributing to better crop establishment and yields. The study supports the adoption of these organic treatments as sustainable seed management practices in cowpea cultivation.

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