Original Research Article

"Impact of Plant Essential Oils on Redgram Seed Quality Parameters"

Comment [s1]: The title is concise and informative, but could be more specific. Suggestion: Effects of Plant Essential Oils on Seed Quality Parameters of Redgram (*Cajanus cajan*) During Storage.

Abstract

A lab experiment was carried out at Entomology laboratory, Seed Research and Technology Centre and ICAR-Indian Institute of Rice Research, Rajendranagar, Hyderabad, Telangana to study effect of plant essential oils *viz, Gaultheria procumbens* oil @ 5 ml kg^{-1} seed , *Cedrus deodara* @ 5 ml kg^{-1} seed, *Cinnamomum camphora* @ 5 ml kg^{-1} seed, *Cymbopogan flexous* @ 5 ml kg^{-1} seed, *Eucalyptus radiata* @ 5 ml kg^{-1} seed, *Mentha piperita* @ 5 ml kg^{-1} seed, *Azadirachta indica* @ 5 ml kg^{-1} seed and Deltamethrin 2.8 EC @ 0.04 ml kg^{-1} seed on quality parameters in redgram during 2023-24. The experiment was laid out in completely randomized design and all the treatments were replicated thrice. Among the plant essential oils, *Mentha piperita* @ 5 ml kg^{-1} and *Eucalyptus radiata* showed superior performance over other treatments resulting highest germination, field emergence percentage, seedling vigour index I, seedling vigour index II and also had a great promise in pest management.

Comment [s2]: Add a brief concluding statement on the potential implications or applications of these findings.

Comment [s3]: Include the scientific name of redgram (*Cajanus cajan*) at first mention.

Comment [s4]: Clarify if this was a storage study, as implied by "during 2023-24"

Comment [s5]: Indicate the storage conditions (temperature, humidity) if applicable.

Keywords: Redgram, plant essential oils, seed quality.

1. Introduction

Comment [s6]: Add a clear statement of the research objective or problem statement at the end of the introduction.

Cajanus cajan Mill sp., also referred to as redgram, tur, or arhar, is a longstanding crop in this region, with cultivation tracing back 3500 years in the Indian subcontinent. It stands as the second most vital pulse crop after gram in the country. Pulses are crucial sources of protein for vegetarians in India, serving as the primary complement to staple cereals in the diet. With protein levels ranging from 22-25%, it has nearly twice the protein content of wheat and almost three times that of rice.

Globally, India and Myanmar dominate redgram production, contributing to 83% of the world's output. In India, redgram holds the largest acreage at 4.229 million hectares, with a total production of 3.54 million tons and a productivity of 887.68 kg ha^{-1} (Indiastat.com, 2019-20). In Telangana, redgram is cultivated in various soil types and different climatic zones, covering an area of 2.95 lakh hectares. The production and productivity in the region are reported at 2.07 lakh tons and 701 kg h^{-1}, respectively (DES Telangana 2019-20). Notably,

Comment [s7]: Try to update statistics, if more recent data is available.

redgram is a major crop in districts like Mahbubnagar, Adilabad, Rangareddy, Medak, Nalgonda, Warangal, and Khammam in Telangana.

Insects pose a significant threat to stored grains and grain products, causing losses ranging from five to ten per cent in temperate regions and 20 to 30 % in tropical zones (Nakakita, 1998). Particularly, *Callosobruchus chinensis* and *Callosobruchus maculatus*, major pulse beetles prevalent in Asia and Africa, can cause over 50 % damage to stored cereals and legumes (Giles, 1977; Sharma, 1984; Bindhu *et al.,* 2015; Khan *et al.,* 2015). Heavy infestation by ~~*Callosobruchus* *C.*~~ *chinensis* can lead to loss of germination capacity in seeds and render them unfit for human consumption. Additionally, ~~*Callosobruchus* *C.*~~*chinensis* infestations can cause qualitative losses alongside quantitative ones (Khare and Johari, 1984).

The insecticidal property of many essential oils is mainly attributed to monoterpenes, which are typically volatile and rather lipophilic compounds that can penetrate into insects rapidly and interfere with their physiological functions. Due to their high volatility, they have fumigant and gaseous action which are very important in controlling the stored-product insects. Jointly or independently, these compounds are used in the management of storage insects. Essential oils ~~are~~ have~~ing~~ a wide range of effects including~~*i.e.,*~~ insecticidal, repellent, antifeeding, and ovicidal activities, which are being used in the management of storage insects~~.~~ (Aliakbari *et al.,* 2010)

2. Materials and Methods

The experiment was carried out at Entomology laboratory, Seed Research and Technology Centre and ICAR-Indian Institute of Rice Research, Rajendranagar, Hyderabad, Telangana during 2023-24.

2.1 Collection and disinfestation of redgram seeds

The popular variety WRGe 97 was used in the experiment. The redgram variety was procured from certified seed producer of Seed Research and Technology Centre, College of Agriculture, Rajendranagar, Telangana. The seeds after procurement, were cleaned thoroughly by removing physical impurities and kept in an incubator at a temperature of 55

^{0}C for a period of four hours to kill the immature stages of the insects if any without affecting viability of the seeds (Soloman, 1951).

2.2 Collection and preparation of plant materials

Plant essential oils were synthesized at Indian Institute of Rice Research, Rajendranagar, Hyderabad, were collected and applied as seed treatment with dosage *i.e.,* 5 ml kg^{-1} seed whereas deltamethrin 2.8 EC was purchased from – company and applied @ 0.04 ml kg^{-1} seed. The experiment was conducted at Seed Research and Technology Centre, PJTSAU, Rajendranagar, Hyderabad, Telangana. The seeds were mixed manually using a seed drum to get uniform distribution of the test material and later packed in plastic containers. A Control was maintained by following the same procedure. The bottles were suitably labeled and kept in an incubator at a temperature of 28±1 ^{0}C and 70±5 per cent relative humidity (Hosamani *et al.,* 2018). The data on following parameters wereas recorded for each concentration of the test material.

2.3 Germination percentage:

Germination of the seeds was studied by using the paper towel method by maintaining three replications for each treatment (ISTA rules, 2022). One hundred redgram seeds were kept paper in moist paper towel and allowed to germinate in a walk-in germinator and the percentage was calculated bimonthly intervals by using the formula.

$$\text{Germination\%} = \frac{\text{Number of seeds germinated}}{\text{Total number of seeds}} \times 100$$

2.4 Seedling vigour index I&II:

For determining of the seedling vigour index, seven days old ten healthy germinated redgram seeds were selected from each replication of the treatment and shoot and root length of each of the ten seedlings was measured in centimeter and average length of the seedlings was calculated bimonthly intervals.

Seedling length = Shoot length + Root length

Seedling vigour index was calculated by multiplying germination percentage with seedling length as suggested by Abdul Baki and Anderson (1973).

Seedling vigour index (SVI) = Seed germination percentage x Seedling length (cm)

Comment [s8]: Standardized the use of degree symbols (°C)

Comment [s9]: The authors should provide the name of the company from which deltamethrin 2.8 EC was purchased. Including this information is important for research reproducibility and transparency. If there are concerns about endorsing a specific company, the authors could consider adding a statement that the mention of the company name does not imply endorsement.

Comment [s10]: Improved sentence structure and clarity in several places is required

Vigour index - I = Seedling length (cm) × Germination percentage

Vigour index - II = Dry weight × Germination percentage

2.5 Seed moisture content (%)

Moisture content of the seed was estimated by using Dicky-~~n j~~john moisture meter.

2.6 Field emergence percentage:

Field emergence test was conducted by randomly selecting hundred seeds from each treatment in three replications and sown them at four to five cm depth in seed bed with adequate moisture content. The number of seedlings emerged above the ground on the eighth day after sowing were evaluated and considered as normal seedlings. It is calculated bimonthly intervals using the formula

$$\text{Field emergence percentage} = \frac{\text{Number of emerged seedlings}}{\text{Total number of seeds}} \times 100$$

3 Results and Discussion

3.1 To study the effect of plant essential oils on germination percentage in redgram

Immediately after seed treatment, highest germination percentage was observed in *Mentha piperita* oil @ 5 ml kg^{-1} seed (91.00 per cent), which was on par with *Cinnamomum camphora* @ 5 ml kg^{-1} seed (90.67 per cent) and *Eucalyptus radiata* oil @ 5 ml kg^{-1} seed (90.00 per cent). In the remaining treatments, the observed germination ranged between 89.67 per cent to 86.67 per cent. Whereas, the lowest germination percentage was observed in the *Cymbopogan flexous* @ 5 ml kg^{-1} seed (49.67 per cent).

The observations at two months after storage, revealed that highest germination percentage (89.33 per cent) was recorded in *Mentha piperita* @ 5 ml kg^{-1} seed which was on par with *Cinnamomum camphora* @ 5 ml kg^{-1} seed (88.33 per cent), *Eucalyptus radiata* @ 5 ml kg^{-1} seed (88.00 per cent). Germination percentage in the rest of the treatments ranged from 87.33 per cent 85.33 per cent. The lowest germination percentage was observed in *Cymbopogan flexous* @ 5 ml kg^{-1} seed (47.00 per cent).

Similar trend was observed even after four months of treatment. The highest germination percentage, 85.67 per cent was recorded in *Mentha piperita* @ 5 ml kg^{-1} seed

which was on par with *Cinnamomum camphora* @ 5 ml kg^{-1} seed (84.67 per cent) and *Eucalyptus radiata* @ 5 ml kg^{-1} seed (84.00 per cent). Whereas germination percentage in other treatments ranged from 83.67 per cent to 82.00 per cent. While, lowest germination percentage was observed in *Cymbopogan flexous* @ 5 ml kg^{-1} seed (43.00 per cent).

The germination percentage of redgram seeds decreased progressively over storage periods, possibly due to ageing, food depletion, and decreased seed synthetic activity.

Present findings revealed that, *Mentha piperita* @ 5ml kg^{-1} seed was found to be statistically on par with the *Eucalyptus radiata oil,* however *E. radiata* was numerically lower than *M. piperita.*

These results are in conformity with the findings of Anjan Kumar Sarma (2021) who reported that *M. piperita* resulted in higher germination per cent when compared to *eucalyptus radiata* oil

Kritzinger *et al.* (2002) studied the effect of essential oils of *Mentha piperita* on storage fungi and germination of two varieties of cowpea viz., Ife brown and IT98-12 white. EO significantly inhibited growth of fungi on the white seed thereby increased the percentage of germination when compared to Ife brown cowpea seeds

The data recorded revealed that *Azadirachta indica* @ 5 ml kg^{-1} seed and deltamethrin 2.8 EC treatment had not showed any detrimental effect on germination.

The present results are in line with Rahman (1990) who evaluated the insecticidal seed treatments (deltamethrin 2.8 EC @ 3 ppm, neem oil @ 10 ml kg^{-1} seed) on cowpea seeds against *Callosobruchus phaseoli*. The germination ability of seeds was not affected by both treatments and also found effective against adults of *Callosobruchus phaseoli*.

The results indicated that among the treatments the lowest germination was recorded in seeds treated with *Cymbopogan flexous* @ 5ml kg^{-1} seed which was inferior to all other treatments.

The present findings are in accordance with Fatu *et al*. (2017) who tested essential oil *Cymbopogon citratus* on wheat seeds germination capacity during storage. Essential oil of *C. citratus* inhibited germination. The essential oil of *Cymbopogon citratus* is the only

component of the product that could cause irreversible changes in seed during storage (permanent loss of germination capacity).

Cymbopogan citratus at higher concentration affected germination growth, root length, hypocotyl length, abnormal sprouts, and dead seeds, this was presumably due to the presence of high allelopathic substances (Purwanto *et al.,* 2024).

Germination percentage was found to decrease with increase in storage duration due to increase in seed damage caused by *C. chinensis* in untreated control.

3.2 To study the effect of plant essential oils on seedling vigour index I in redgram

Immediately after seed treatment, the highest seedling vigour index was observed in *Mentha piperita* oil @ 5 ml kg^{-1} seed (2636) on par with *Eucalyptus radiata* @ 5 ml kg^{-1} seed (2577), *Cinnamomum camphora* @ 5 ml kg^{-1} seed (2554). Seedling vigour index in the rest of the treatments ranged from 2509 to 2399. The lowest seedling vigour index was observed in *Cymbopogan flexous* @ 5 ml kg^{-1} seed (1089).

The data recorded after two months of treatment revealed that the highest seedling vigour index was observed in *Mentha piperita* oil @ 5 ml kg^{-1} seed (2491). In the remaining treatments seedling vigour index ranged between 2382 to 2193. The lowest seedling vigour index was observed in *Cymbopogan flexous* @ 5 ml kg^{-1} seed (974).

After four months of seed treatment, significantly highest seedling vigour index was observed in *Mentha piperita* oil @ 5 ml kg^{-1} seed (2037) followed by *Eucalyptus radiata* @ 5 ml kg^{-1} seed (1970) and *Cinnamomum camphora* @ 5 ml kg^{-1} seed (1946) were on par with each other. Mean seedling vigour index I in remaining treatments were between 1899 to 1838. *Cymbopogan flexous* @ 5 ml kg^{-1} seed recorded the lowest seedling vigour index (720).

3.3 To study the effect of plant essential oils on seedling vigour index II in redgram

The data obtained immediately after seed treatment recorded that *Mentha piperita* @ 5 ml kg^{-1} seed (7535) and *Eucalyptus radiata* @ 5 ml kg^{-1} seed (7401) were superior over other treatments and both are on par with each other. Mean seedling vigour index observed

in remaining treatments ranged from 7308 to 6607. The significantly lowest vigour was recorded in *Cymbopogan flexous* @ 5 ml kg^{-1} seed (3599).

At two months after storage, highest seedling vigour index was recorded in *Mentha piperita* @ 5 ml kg^{-1} seed (7257), *Eucalyptus radiata* @ 5 ml kg^{-1} seed (7099) and *Cinnamomum camphora* @ 5 ml kg^{-1} seed (7093) which were on par with each other. In the remaining treatments the mean seedling vigour index ranged from 6725 to 6056. Lowest mean seedling vigour index was recorded in *Cymbopogan flexous* @ 5 ml kg^{-1} seed (3229).

The data obtained after four months of seed treatment recorded that *Mentha piperita* @ 5 ml kg^{-1} seed (6739) showed highest seedling vigour index and superior over other treatments. Followed by *Cinnamomum camphora* @ 5 ml kg^{-1} seed (6604) and *Eucalyptus radiata* @ 5 ml kg^{-1} seed (6577) and were on par with each other. In the rest of the treatments seedling vigour index varied from 6163 to 5603. *Cymbopogan flexous* @ 5 ml kg^{-1} seed resulted lowest seedling vigour index (2881).

Results revealed that *Mentha piperita*, exhibited highest seedling vigour index over other treatments.

The results are in conformity with the findings of Farrag and Moharam (2012) who reported that, cucumber seeds treated with 1, 2 and 3 per cent *Mentha piperita* oil exhibited an increase in seedling vigour index.

Babariya *et al.* (2016) reported that neem oil till four months of seed treatment had not affected seedling vigour index I and II.

Present findings are similar to the results of Mandali and Reddy (2014) who observed that neem oil treatment till four months of seed treatment resulted higher seedling vigour index when compared to control.

Cymbopogan citratus at higher concentration affected germination growth, root length, hypocotyl length, abnormal sprouts, and dead seeds, this was presumably due to the presence of high allelopathic substances (Purwanto *et al.,* 2024)

In all the treatments, gradual decrease in the seedling vigour index was observed from two months to six months of storage which could be due to increase in damaged seed, storage period and natural ageing process.

There was progressive reduction in vigour along with germination in untreated control such decrease in vigour could be attributed to the internal and external infestation by *Callosobruchus chinensis* which had contributed to the reduction in physiological and physical quality of redgram seeds affecting the growth of the seedlings.

3.4 To study the effect of plant essential oils on moisture in redgram

Immediately after seed treatment significant differences were not observed among the treatments with respect to the moisture contents of redgram seeds. However, the lowest moisture content (9.03 per cent) was observed in *Gaultheria procumbens* @ 5 ml kg^{-1} seed and *Mentha piperita* @ 5 ml kg^{-1} seed and highest in *Cymbopogan flexous* @ 5 ml kg^{-1} seed (9.17 per cent).

At two months after treatment imposition results revealed that the lowest moisture content (9.97 per cent) was in *Cedrus deodara* @ 5 ml kg^{-1} seed and *Cinnamomum camphora* @ 5 ml kg^{-1} seed. However, it was on par with *Azadirachta indica* @ 5 ml kg^{-1} seed (10.13 per cent), *Mentha piperita* @ 5 ml kg^{-1} seed (10.07 per cent), control (10.03 per cent). The highest moisture content was observed in *Gaultheria procumbens* @ 5 ml kg^{-1} seed (10.33 per cent) which was on par with *Eucalyptus radiata* @ 5 ml kg^{-1} seed (10.20 per cent), *Cymbopogan flexous* @ 5 ml kg^{-1} seed (10.17 per cent), Deltamethrin 2.8 EC (10.17 per cent).

The data recorded four months after treatment revealed no significant differences among treatments. Lowest moisture content was observed in *Mentha piperita* @ 5 ml kg^{-1} seed (10.60 per cent). Highest moisture content (10.70 per cent) was found in *Gaultheria procumbens* @ 5 ml kg^{-1} seed, *Cedrus deodara* @ 5 ml kg^{-1} seed, *Cymbopogan flexous* @ 5 ml kg^{-1} seed, *Eucalyptus radiata* @ 5 ml kg^{-1} seed, control.

The present results are in consonance with Sinha and Sinha (1992) who reported a increase in moisture content of the grain as a result of infestation by *S. oryzae* in maize.

Similarly, Malarkodi and Srimathi (2001) reported that the moisture absorption by the seed of maize was found to be in increasing order with advance in storage period.

The moisture content of seed directly related with storage condition and nature of seed protectants (Yadav *et al.,* 2018)

The level of seed moisture content was directly related to environmental conditions and storage period (Nishad *et al.,* 2020).

Cymbopogan citratus at higher concentration affected germination growth, root length, hypocotyl length, abnormal sprouts, and dead seeds, this was presumably due to the presence of high allelopathic substances (Purwanto *et al.,* 2024)

In the present investigation, moisture content of redgram seed did not show much variation even after four months after storage, because of being stored in hermetic storage condition.

3.5 To study the effect of plant essential oils on field emergence percentage in redgram

From the perusal of data immediately after treatment, the results for field emergence percentage showed a significant difference between plant essential oils. Significantly, the highest field emergence percentage (90.67 per cent) was recorded in *Mentha piperita* @ 5 ml kg^{-1} seed which was on par with *Cinnamomum camphora* @ 5 ml kg^{-1} seed (90.00 per cent), and *Eucalyptus radiata* @ 5 ml kg^{-1} seed (90.00 per cent). Field emergence percentage in the remaining treatments ranged between 88.67 per cent to 87.00 per cent. The lower mean field emergence percentage was recorded in *Cymbopogan flexous* @ 5 ml kg^{-1} seed (49.00 per cent) followed by *Cedrus deodara* @ 5 ml kg^{-1} seed (86.33 per cent).

At two months after seed treatment, *Mentha piperita* @ 5 ml kg^{-1} seed (89.00 per cent) showed the highest field emergence percentage which was on par with *Eucalyptus radiata* @ 5 ml kg^{-1} seed (88.67 per cent) and *Cinnamomum camphora* @ 5 ml kg^{-1} seed (88.00 per cent). Field emergence percentage in the rest of treatments ranged from 86.67 per cent to 84.33 per cent. The significantly lowest mean field emergence percentage was observed in *Cymbopogan flexous* @ 5 ml kg^{-1} seed (46.33 per cent).

The data recorded after four months of seed treatment revealed that *Mentha piperita* @ 5 ml kg^{-1} seed (85.67 per cent) and *Eucalyptus radiata* @ 5 ml kg^{-1} seed (85.33 per cent) were superior over other treatments and on par with each other. In the remaining treatments, the observed mean field emergence percentage ranged between 84.33 per cent to 80.67 per cent. The lowest mean field emergence percentage was recorded in *Cymbopogan flexous* @ 5 ml kg^{-1} seed (42.00 per cent).

Mentha piperita @ 5ml kg^{-1} seed showed significantly higher field emergence per cent than all other treatments except *Eucalyptus radiata* treatment.

The present findings are in confirmation with the results of Kritzinger *et al.* (2002) who studied the effect of essential oils of *Mentha piperita* on storage fungi and germination of two varieties of cowpea viz., Ife brown and IT98-12 white. EO significantly inhibited growth of fungi on the white seed thereby increased the per cent emergence when compared to Ife brown cowpea seeds.

The present results are in consonance with Terzic *et al.* (2023) who reported that *Mentha piperita* oil increased seedling growth of *Althea officinalis*

Among all the treatments *Cymbopogan flexous* was found to be inferior to all other treatments.

Similar observations were also made by Fatu *et al*. (2017) who evaluated essential oil *Cymbopogon citratus* on wheat seedling growth during storage. Essential oil of *C. citratus* inhibited germination. The essential oil of *Cymbopogon citratus* inhibited root growth.

Cymbopogan citratus at higher concentration affected germination growth, root length, hypocotyl length, abnormal sprouts, and dead seeds, this was presumably due to the presence of high allelopathic substances (Purwanto *et al.,* 2024)

Table 1. Effect of plant essential oils on Germination, seedling vigour index I of redgram seed

Dosage kg^{-1} seed	Germination			Seedling vigour index I		
	0 MAS	2 MAS	4 MAS	0 MAS	2 MAS	4 MAS
T_1 - Wintergreen oil @ 5ml kg^{-1} seed	88.67 (70.30)	87.33 (69.15)	83.67 (66.15)	2428 (49.29)	2239 (47.33)	1857 (43.11)
T_2 - Cedarwood oil @ 5ml kg^{-1} seed	86.67 (68.56)	85.33 (67.46)	82.00 (64.88)	2399 (48.99)	2193 (46.84)	1844 (42.95)
T_3 - Camphor oil @ 5ml kg^{-1} seed	90.67 (72.19)	88.33 (70.00)	84.67 (66.92)	2554 (50.55)	2343 (48.41)	1946 (44.12)

T_4 - Lemongrass oil @ 5ml kg^{-1} seed	49.67 (44.79)	47.00 (43.26)	43.00 (40.96)	1089 (33.01)	974 (31.23)	720 (26.85)
T_5 - Eucalyptus oil @ 5ml kg^{-1} seed	90.00 (71.55)	88.00 (69.72)	84.00 (66.40)	2577 (50.78)	2382 (48.81)	1970 (44.40)
T_6 - Peppermint oil @ 5ml kg^{-1} seed	91.00 (72.53)	89.33 (70.91)	85.67 (67.74)	2636 (51.35)	2491 (49.92)	2037 (45.15)
T_7 - Neem oil @ 5ml kg^{-1} seed	89.67 (71.23)	87.00 (68.85)	83.33 (65.88)	2509 (50.10)	2329 (48.27)	1899 (43.59)
T_8 – Deltamethrin 2.8 EC @ 5ml kg^{-1} seed	89.67 (71.23)	86.33 (68.29)	83.00 (65.63)	2473 (49.74)	2260 (47.55)	1859 (43.12)
Grand mean	88.00 (69.72)	86.00 (68.01)	82.67 (65.38)	2413 (49.13)	2261 (47.56)	1838 (42.87)
Control	84.89	82.74	79.11	2342	2164	1774
CD	1.18	1.41	1.36	1.05	0.83	1.19
SE(m)±	0.40	0.47	0.45	0.35	0.28	0.40
CV (%)	1.01	1.23	1.24	1.27	1.04	1.64

Table 2. Effect of plant essential oils on Seedling vigour index II, moisture content and field emergence of redgram seed

Dosage kg^{-1} seed	Seedling vigour index II			Moisture			Field emergence percentage		
	0 MAS	2 MAS	4 MAS	0 MAS	2 MAS	4 MAS	0 MAS	2 MAS	4 MAS
T_1 - Wintergreen oil @ 5ml kg^{-1} seed	6937 (83.29)	6725 (82.01)	6163 (78.51)	9.03 (17.48)	10.33 (18.74)	10.70 (19.09)	88.33 (70.03)	85.33 (67.46)	81.67 (64.62)
T_2 - Cedarwood oil @ 5ml kg^{-1} seed	6607 (81.29)	6056 (77.82)	5603 (74.86)	9.07 (17.52)	9.97 (18.40)	10.70 (19.09)	86.33 (68.30)	84.33 (66.66)	80.67 (63.89)
T_3 - Camphor oil @ 5ml kg^{-1} seed	7308 (85.49)	7093 (84.23)	6604 (81.27)	9.07 (17.52)	9.97 (18.40)	10.67 (19.06)	90.00 (71.55)	88.00 (69.72)	84.33 (66.66)

T_4 - Lemongrass oil @ 5ml kg^{-1} seed	3599 (60.00)	3229 (56.83)	2881 (53.68)	9.17 (17.62)	10.17 (18.59)	10.70 (19.09)	49.00 (44.41)	46.33 (42.88)	42.00 (40.38)
T_5 - Eucalyptus oil @ 5ml kg^{-1} seed	7401 (86.03)	7099 (84.26)	6577 (81.11)	9.10 (17.55)	10.20 (18.62)	10.70 (19.09)	90.00 (71.55)	88.67 (70.33)	85.33 (67.46)
T_6 - Peppermint oil @ 5ml kg^{-1} seed	7535 (86.81)	7257 (85.19)	6739 (82.10)	9.03 (17.48)	10.07 (18.49)	10.60 (18.99)	90.67 (72.19)	89.00 (70.61)	85.67 (67.73)
T_7 - Neem oil @ 5ml kg^{-1} seed	6976 (83.53)	6540 (80.87)	6028 (77.64)	9.10 (17.55)	10.13 (18.55)	10.67 (19.06)	88.67 (70.33)	86.67 (68.58)	83.67 (66.14)
T_8 – Deltamethrin 2.8 EC @ 5ml kg^{-1} seed	6943 (83.33)	6446 (80.29)	6114 (78.20)	9.07 (17.52)	10.17 (18.59)	10.63 (19.02)	88.33 (70.00)	86.33 (68.28)	83.33 (65.88)
Control	6776 (82.32)	6393 (79.96)	6035 (77.69)	9.10 (17.55)	10.03 (18.46)	10.70 (19.09)	87.00 (68.85)	85.00 (67.19)	81.00 (64.14)
Grand mean	6676	6315	5861	9.08	10.11	10.67	84.26	82.19	78.63
CD	0.93	1.19	0.77	N/A	0.15	N/A	1.72	1.48	0.87
SE(m)±	0.31	0.40	0.26	0.04	0.05	0.05	0.57	0.49	0.29
CV (%)	0.66	0.87	0.58	0.42	0.47	0.49	1.47	1.30	0.80

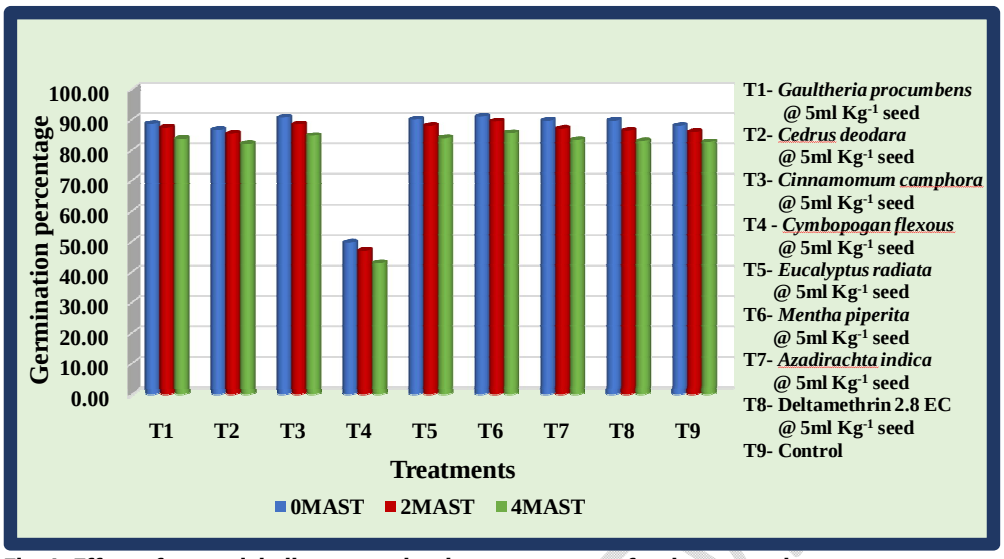

Fig. 1. Effect of essential oils on germination percentage of redgram seeds

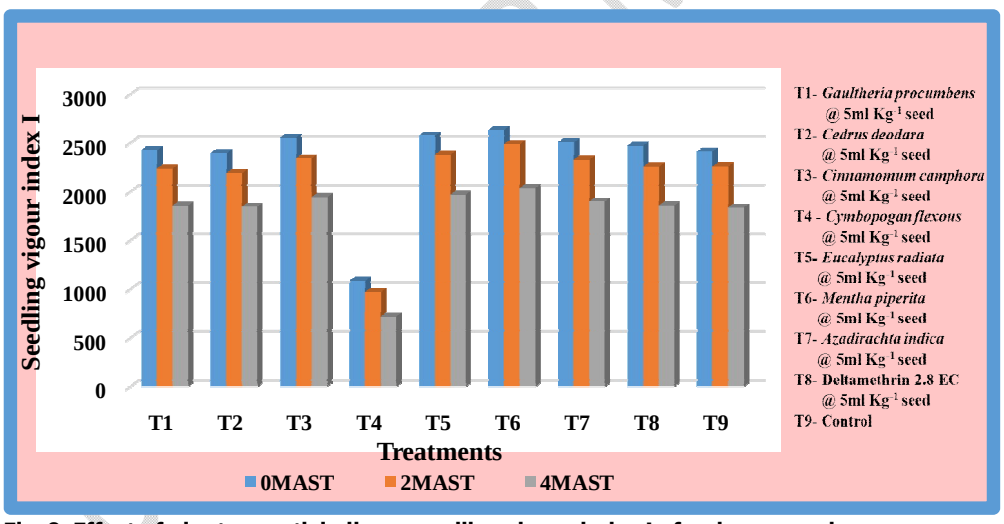

Fig. 2. Effect of plant essential oils on seedling vigour index I of redgram seeds

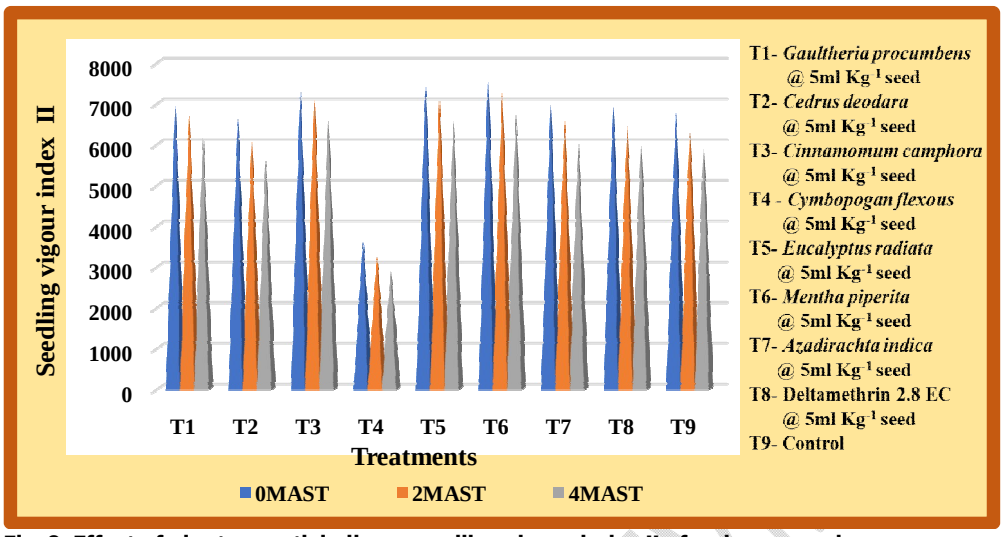

Fig. 3. Effect of plant essential oils on seedling vigour index II of redgram seeds

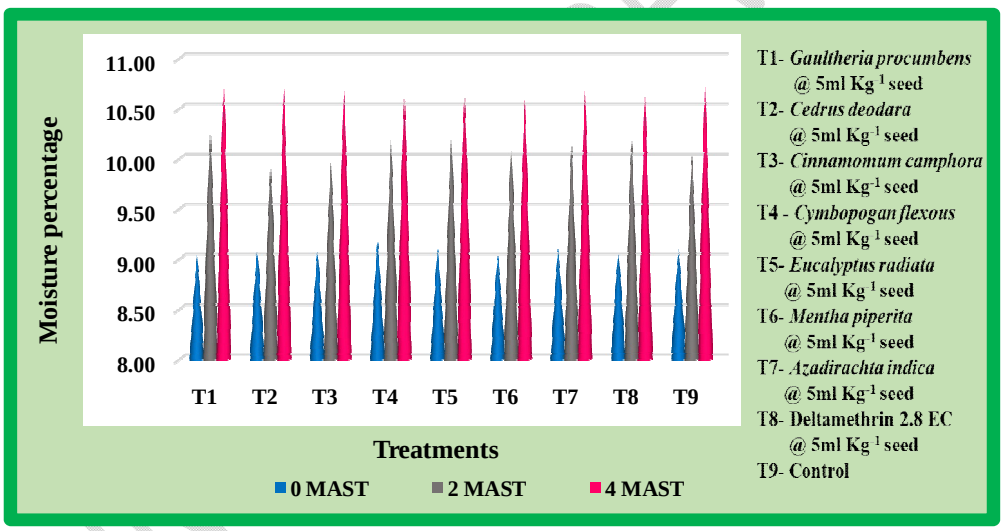

Fig. 4. Effect of plant essential oils on moisture percentage of redgram seeds

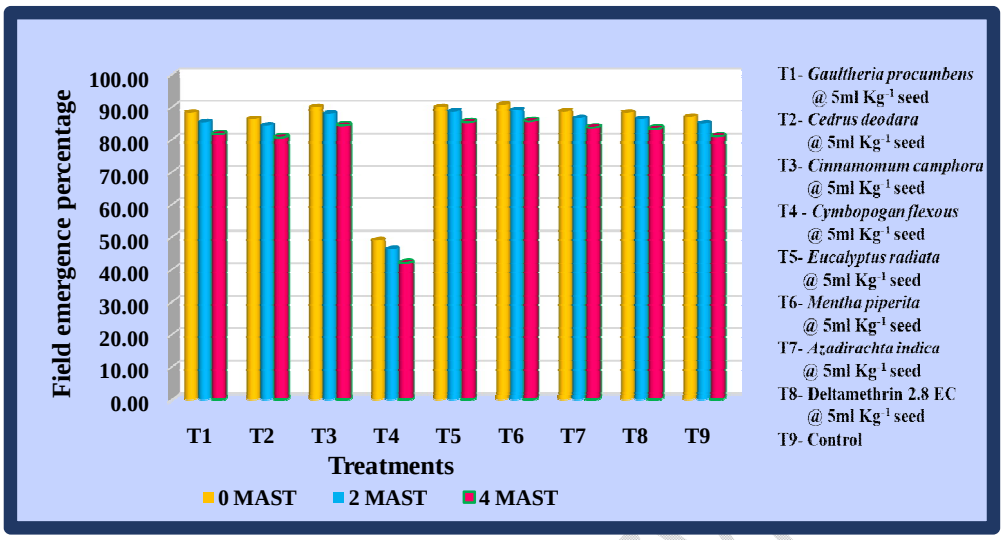

Fig. 5. Effect of plant essential oils on field emergence percentage of redgram seeds

CONCLUSION

During evaluation all tested plant essential oils were capable to maintained the seed germination, seedling vigour index -I and II, field emergence above IMSCS four months of ambient storage of redgram which were found significantly superior over control in reducing the seed infestation and weight loss except *Cymbopogan flexous*. Besides, chemical seed protectant deltamethrin 2.8 EC as check by *Mentha piperita* @ 5ml kg^{-1} seed and *Eucalyptus radiata* @ 5 ml kg^{-1} seed maintained maximum seed quality parameters with comparatively minimum bruchids infestation and weight loss upto four month of storage. Thus, the present investigation advocated that *Mentha piperita* @ 5ml kg^{-1} seed and *Eucalyptus radiata* @ 5 ml kg^{-1} seed may be utilizes as suitable eco-friendly seed protectants in stored redgram against pulse beetle, *Callosobruchus chinensis* Linn. for a long period of four months.

FUTURE LINE OF WORK

Using plant oils as natural fumigants can reduce health risks for farmers and are more affordable, ecofriendly and readily available than synthetic pesticides. They offer a promising alternative for enhancing seed quality parameters and controlling natural infestation of insects in stored products. However, more research is needed to develop to enhance formulations, improve efficacy and stability.

Comment [s11]: Break the conclusion into shorter, more focused sentences for better readability.
Include a statement about the significance of these findings for agriculture or seed storage practices.

Comment [s12]: Revise sentence structure for better flow and clarity.

Comment [s13]: Provide more specific research directions, such as:
- Investigating optimal concentrations and application methods for different plant oils.
- Studying the long-term effects of these treatments on seed viability and plant growth.
- Exploring combinations of plant oils for synergistic effects.

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Comment [s14]: Follow proper reference style

Comment [s15]: Follow Author's guidelines for references

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