Original Research Article

A Comparative Study on the Impact of Sulphur Nanoparticles on the Growth and Yield of Groundnut-Mustard Crop Sequence in Central Gujarat

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Abstract

In the present era of farming, the farmers were not using the secondary fertilizers for supplementing the sulphur nutrient and groundnut and mustard crops require the higher amount of sulphur. While, the traditional sulphur fertilizers have very low nutrient use utilization efficiency, moreover nano fertilizers have high nutrient use efficiency. So, the present experiment was conducted with using the different sources of sulphur. The existing experiment was conducted using completely randomized design with 11 treatments replication 4 times. The results reveal that the significantly higher plant height at 30 DAS was registered with the application of RDF + sulphur nanoparticles @ 4 mg S/kg (T10), than rest of the treatments. The significantly higher plant height, branches/plant and biological yield of groundnut-mustard cropping sequence was obtained with the fertigation of RDF + sulphur nanoparticles @ 3 mg S/kg soil, 50% at basal & 50% at 30 DAS (T_9). It can be concluded that application of 3 mg S/kg soil, 50% at basal & 50% at 30 DAS can be an optimum dose of sulphur in pot experiment through fertigation under sulphur deficient soil.

Key words: Sulphur nano fertilization, plant height, branches and biological yield

Introduction

Sulphur nanoparticles are miniscule particles of sulphur with dimensions on the nanoscale, typically ranging from 1 to 100 nm in size. These nanoparticles have gained significant attention in scientific research and various applications due to their unique properties and potential uses (Sahoo*et al.*, 2021). Due to their small size and high surface area, sulphur nanoparticles possess enhanced reactivity, making them useful in various applications.This means that they can be more readily absorbed by plant roots, making them a more efficient sulphur source (Huber, 2005). The enhanced reactivity of sulphur nanoparticles can reduce the risk of sulphur leaching into groundwater, minimizing environmental pollution.Sulphur nanoparticles are being explored as a potential fertilizer source in modern agriculture.

Sulphur is an essential nutrient for plant growth, and sulphur deficiency can lead to reduced crop yields and quality (Teng*et al*., 2019). Traditionally, sulphur has been supplied to crops through elemental sulphur or sulphate-based fertilizers (Riley*et al*., 2002).

Sulphur nanoparticles can be applied to crops through various methods, including foliar spraying, soil application, or as a component of controlled-release fertilizers. While the use of sulphur nanoparticles as a fertilizer source shows promise, ongoing research is needed to refine application methods, determine optimal dosages, and assess their long-term impact on soil and crop health. It's essential to use sulphur nanoparticles responsibly to minimize any potential adverse environmental effects (Khan and Rizvi, 2017; Beig*et al*., 2022)).

Groundnut (*Arachis hypogaea*), also known as the peanut, is a legume crop grown mainly for its edible seeds. It is widely grown in the tropics and subtropics, important to both small and large commercial producers. It is classified as both a grain legume and, due to its high oil content, an oil crop (Semba*et al*., 2021).The groundnut plant is an annual herbaceous plant growing 30 to 50 cm (12 to 20 inch) tall. As a legume, it belongs to the botanical family Fabaceae, also known as Leguminosae, and commonly known as the legume, bean, or pea family (Rajput*et al*., 2020). Like most other legumes, peanuts anchorage symbiotic nitrogen-fixing bacteria in their root nodules. The leaves are opposite and pinnate with four leaflets (two opposite pairs; no terminal leaflet); each leaflet is 1 to 7 cm long and 1 to 3 cm across.The flowers are yellow and pea-like, and they are arranged in clusters. The female flowers are borne on stalks that grow downwards into the soil, where the pods develop. The pods are oval-shaped and contain 2-4 seeds.Groundnuts are a good source of protein, oil, and fibre (Tan*et al*., 2020). They are also a good source of vitamins and minerals, including vitamin E, folate, and magnesium.Groundnuts are used in a variety of dishes, both spicy and sweet. They can be eaten raw, roasted, boiled, or fried. They are also used in peanut butter, peanut oil, and other peanut products.Groundnuts are a valuable crop that provides food and income for millions of people around the world. They are also a good source of nutrients and can be used in a variety of dishes (Mupunga*et al*., 2017).

Mustard is an annual, cool-season crop that is grown for its seeds, which are used as a spice and condiment, and for its oil. Mustard is a member of the Brassicaceae family.Mustard is a relatively easy crop to grow and can be grown in a variety of soils. It prefers full sun and well-drained soil (Kayacetin, 2020). Mustard is typically sown in the spring or fall. The seeds should be sown about 1/2 inch deep and 1-2 inches apart. Mustard plants need regular watering, especially during the flowering and pod development stages.Mustard is harvested

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when the pods are brown and dry. The pods are threshed to remove the seeds. Mustard seeds can be stored in an airtight container in a cool, dry place.Mustard seeds are used to make mustard oil, which is a cooking oil with a strong flavour (Sharma*et al*., 2021). Mustard seeds are also used to make prepared mustard, which is a condiment made by mixing mustard seeds with vinegar, water, and other spices. Mustard greens, the leaves of the mustard plant, are also edible and can be eaten raw or cooked.Mustard is a versatile crop that has many uses (Kayacetin, 2020). It is a good source of nutrients, including vitamins C and K, and it has been shown to have some health benefits, such as reducing inflammation and improving heart health (Iqbal*et al*., 2004).

Sulphur is an essential nutrient for plants and play a vital role as a constituent of amino acids, proteins, and vitamins and photosynthesis, the production of chlorophyll, and make resistance to pests and diseases (Uchida, 2000).Groundnut and mustard are both high-yielding crops that require a lot of sulphur. The sulphur requirement of these crops varies depending on the soil type, climate, and variety of crops grown (Khurana*et al*., 2018).Adequate sulphur fertilization can help to improve the protein and oil content of groundnut and mustard seeds.It plays an important role in flowering and pod development as well as pod setting (Devi*et al*., 2012). Therefore, the present experiment was carried out focusing on above mentioned issues they were emerging in farming.

Materials and methods

The SML firm supplied the elemental sulphur fertilizer, which was used as fertigation in accordance with the treatment instructions. It included 90% elemental sulphur on a weight-for-weight basis. The green synthesis process was used to prepare the sulphur nanoparticle at the Department of Nanotechnology, Anand Agricultural University, in Anand, Gujarat. The DLS equipment was used to characterize the nanoparticles' size, pdi, kcps, and zeta potential after preparation. FTIR and UV spectroscopy are also used. The synthetic sulphate nanoparticles were crystalline in form, spherical in shape, and contained 35% sulphate on a weight-per-weight ratio, according to diacid mixture analysis. The graphical representation of synthesis of sulphur nano particles were given in fig. 1.

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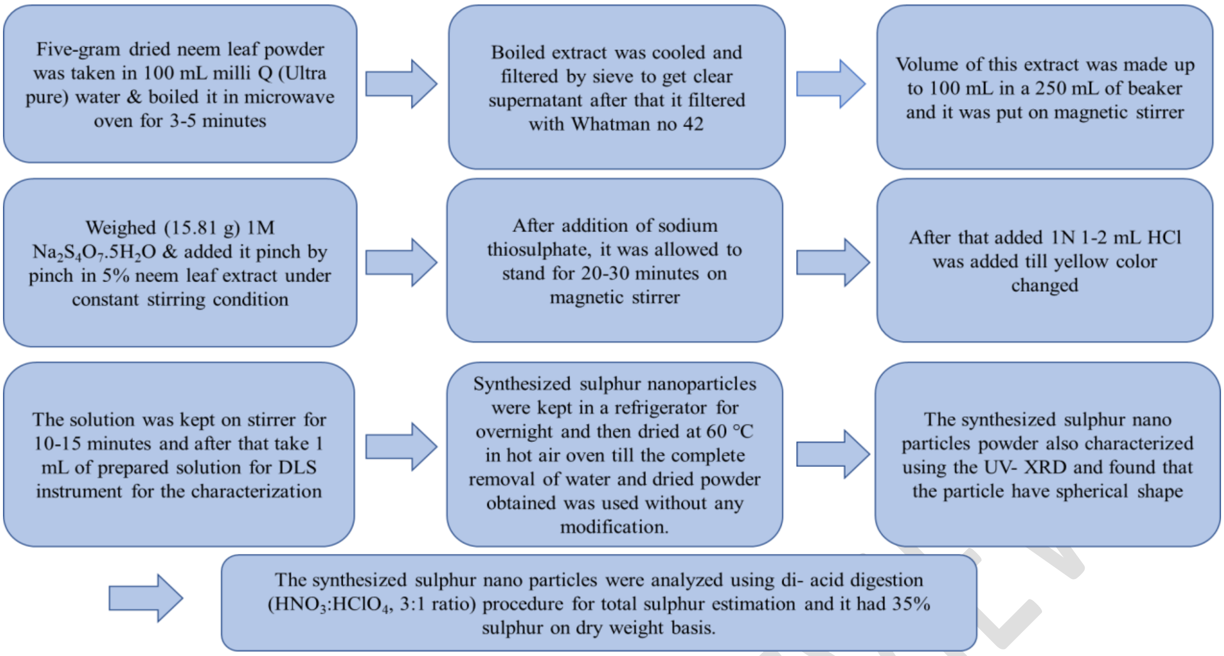

Fig.1: Synthesis of sulphur nanoparticles

During the kharif (groundnut) and rabi (mustard) seasons of the years 2021–2022, the pot experiment was conducted at Polyhouse, Centre for Advanced Research in Plant Tissue Culture, Anand Agricultural University, Anand (Gujarat). The information on the materials utilised, the experimental procedures performed, and the techniques used throughout the inquiry is given below. Anand is a geologically significant experimental site, located at 22° 32'8.794" N latitude, 72°58'29.29" E longitude, and 45.1 m above mean sea level. This area experiences a semiarid and subtropical climate. With an average annual rainfall of 865 mm, the monsoon season starts by the third week of June and ends by the middle of September. This rainfall is entirely due to the South-West monsoon currents.Although the region receives an acceptable amount of rainfall on average, partial droughts occur frequently, about once every three to four years. The bulk soil sample was collected, and the various parameters were determined. The texture of the experimental soil was loamy sand, and its reactivity to pH was neutral (Jackson, 1973). EC 7.78, Jackson (1973) Organic carbon at 0.30 dS/m (Walkley & Black, 1934) Available phosphorus is 3.56 g kg^{-1} (Olsen *et al.*, 1954). Available potassium is 30.44 kg ha^{-1} (Jackson, 1973). Available sulphur is 210.04 kg per hectare (Williams &Steinbergs, 1959). 5.16 ppm, DTPA extractable Zn, Fe, Mn, and Cu were 0.65, 4.46, 5.88, and 1.05 ppm, respectively (Lindsay & Norvell, 1978). The current study was set up using a four-repetition, completely randomized design. The treatment details of this experiment were as Control (only RDF) (T_1), RDF + Elemental S @ 8 mg S/kg soil(T_2), RDF + Elemental S @ 8 mg S/kg soil, 50% at basal & 50% at 30 DAS (T_3), RDF + Sulphur

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nanoparticles @ 1 mg S/kg soil (T_4), RDF + Sulphur nanoparticles @ 1 mg S/kg soil, 50% at basal & 50% at 30 DAS (T_5), RDF + Sulphur nanoparticles @ 2 mg S/kg soil (T_6), RDF + Sulphur nanoparticles @ 2 mg S/kg soil, 50% at basal & 50% at 30 DAS (T_7), RDF + Sulphur nanoparticles @ 3 mg S/kg soil (T_8), RDF + Sulphur nanoparticles @ 3 mg S/kg soil, 50% at basal & 50% at 30 DAS (T_9), RDF + Sulphur nanoparticles @ 4 mg S/kg soil (T_{10}), RDF + Sulphur nanoparticles @ 4 mg S/kg soil, 50% at basal & 50% at 30 DAS (T_{11}).(**Note:** Sulphur was applied through fertigation as per the treatments and the flow rate of dripper kept at 4 L water per hour). The sulphur applied in both the crops of *kharif* and *rabi* season as per the treatment details.

Statistical Analysis

The analyses of variance of all the parameters micronutrient content and uptake, were performed using the F-test (Gomez and Gomez,1984). The treatment means comparisons were carried out by Duncan's New Multiple Range test (DNMRT) using SPSS 16.0 software for Window (SPSS Inc., Chicago, IL, USA).

RESULT & DISCUSSION

Growth and yield attributes ofGroundnut

Days to Emergence

The data presented in table 1 indicated that application of SNPs and elemental sulphur didn't influence significantly the days to emergence of groundnut. The seeds took a consistent 5-6 days to emerged after sowing.

Periodical Plant height

The data pertaining to periodical plant height of groundnut measured at 30 and 60 DAS as well as at harvest as affected by sulphur nano-particles and elemental sulphur application were furnished in table 1.The data revealed that the periodical plant height of groundnut was significantly affected by application of sulphur nano particles and elemental sulphur.

The findings furnished in table 1 unveil the significant influence of varying treatments of SNPs and elemental sulphur on plant height at 30, 60 DAS and at harvest. Notably, treatment T_{10} exhibited the highest plant height at 60 DAS and harvest which was 55.63 and 65.02 cm, respectively except at 30 DAS. The significantly higher plant height at 30 DAS was obtained with the application of RDF + sulphur nanoparticles @ 4 mg S/kg soil (T_9) as a

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basal. However, it was at par with treatments T_2, T_3, T_9 and T_{11} at 30 DAS, while at 60 DAS and at harvest T_9 was at par with treatments T_{10} and T_{11}. Conversely, the control treatment recorded the lowest plant height throughout the crop growth periods (30, 60 DAS and harvest), which was 30.11, 47.18 and 54.65 cm, respectively. The treatment T_9 registered 17.91 and 18.97% at 60 DAS and at harvest, while T_{10} was 21.18% at 30 DAS higher plant height than control (T_1).

It's possible that the concentration of 3 mg S/kg soil used in T_9 provides the optimal amount of sulphur for the specific soil conditions under pot experiment of groundnut. Higher doses may not always translate to better results and can sometimes even have negative effects on plant growth. It may be T_9 providing more balanced supply of nutrients, resulting in improved growth parameters of groundnut. Sulphur is involved in the formation of chlorophyll the pigment responsible for photosynthesis. These results emphasize the substantial impact of different levels of sulphur nanoparticles (SNPs) on plant height at all the stages, highlighting the potential of the application of sulphur nanoparticles, in promoting significant growth of groundnut. Due to high specific surface area and reactivity of SPNs, they facilitated the release of sulphur in a form that is readily available to plant for a longer period.Thesimilar findings were reported by Maity *et al*. (2017), Najafi *et al*. (2020), Ragab and Saad-Allah, (2020) and Khairan*et al*. (2022), who observed significant increase in shoot and root biomass of groundnut plants treated with sulphur nanoparticles compared to control treatment.

Periodical Branches plant^{-1}

The data presented in table 1, revealed that application of different treatments of SNPs and elemental sulphur significantly affected the branches of groundnut at 60 DAS and at harvest. Among different treatments, treatment T_9 recorded significantly higher branches per plant (8.31 and 8.54) than the rest of the treatments except T_{11}, T_3 and T_{10} treatments at 60 DAS, while at harvest it was at par with T_{10} and T_{11} treatments. The control recorded the lowest branches plant^{-1} (7.36 and 7.53) at 60 DAS and harvest. The percentage increase in branches plant^{-1} under T_{10} was 12.90 and 13.41% over control (T_1). The increase in branches was mainly due to increase in plant height under T_9 over rest of the treatments. The SNPs enhanced plant growth, leading to increased branching over control. The similar findings were reported by Mahajan *et al*. (2016).

Biological yield

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The data furnished in table 2, showed that the significantly higher biological (grain and haulm) yield (65.58 g/pot) was obtained with the application of RDF + sulphur nanoparticles @ 3 mg S/kg soil, 50% at basal & 50% at 30 DAS (T_9) over rest of the treatments except T_{11}. While, the lowest biological yield was obtained under control treatment (T_1). The percentage increment in biological yield was in the tune of 14.03% over the control untreated pot.

The growth and yield attributes as well as yield was found better under T_9 shows that the biological yield ultimately found high in this treatment. And increasing the dose of sulphur found at par with T_9 but not highest. The 3 mg/kg dose of sulphur can be an optimum dose of sulphur for the fertilization of crop.

The similar findings were reported by Samreen *et al*., 2022; Singh *et al*., 2016 and Rathore *et al*., 2015 they reported that application of sulphur increase the growth parameters as well as yield of crops.

Growth and yield parameters of mustard

Days to emergence

The data presented in table 1 indicate that the effect of different treatments of SNPs and elemental sulphur was not significant to days of emergence of mustard seed. On an average it took 7 to 8 days for emergence of mustard seed.

Periodical Plant Height (cm)

The data pertaining to periodical plant height measured at different days *i.e*., 30, 60 DAS and at harvest as affected by sulphur nano-particles and elemental sulphur application were presented in table 1. The data revealed that the periodical plant height of mustard was significantly affected by application of sulphur nano particles and elemental sulphur. The significantly higher plant height of 33.14 at 30 DAS was registered with the application of RDF + sulphur nanoparticles @ 4 mg S/kg soil (T_{10}) and 95.76 and 123.59 cm at 60 DAS and at harvest, respectively was obtained under T_9, than rest of the treatments. The treatment T_2, T_3, T_9 and T_{11} was found at par at 30 DAS, while at 60 DAS T_9 was at par with T_3, T_{10} and T_{11} treatments. Moreover, at harvest T_2, T_3, T_{10} and T_{11} being at par with T_9. The treatment T_1 registered the lowest plant height with values of 27.01, 81.22 and 104.82 cm at 30, 60 DAS and harvest, respectively. The percentage increase in plant height under T_6 and T_9 over control was 22.69, 17.90 and 17.90%, respectively at 30, 60 DAS and harvest.

It's possible that the concentration of 3 mg S/kg soil used in T_{10} provides the optimal amount of sulphur for the specific soil conditions, of mustard. Increasing the sulphur

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concentration to 4 mg S/kg soil in T_{11} may exceed the crops' requirements, leading to reduced effectiveness. And also, T_{10} have balanced nutrition of other essential nutrient s for the mustard, so the growth and yield parameters of mustard was more. Sulphur nanoparticles might release sulphur slowly over time, and the lower concentration in T_{10} may have been more effective in providing a sustained supply of sulphur to the crop.

The findings reported by Hasanuzzaman*et al*. (2020) are in line with the present study, who noted that mustard yield parameters were significantly improved over control due to application of SNPs and elemental sulphur because it plays a vital role in photosynthesis and chlorophyll formation.

Branches plant^{-1}

The data pertaining to branches plant^{-1} observed at different days *i.e*., 60 DAS and at harvest as affected by different treatments of sulphur nano-particles and elemental sulphur had been presented in table 1. The significantly higher branches plant^{-1}with the value of 13.23 and 15.45 at 60 DAS and at harvest, respectively, was obtained with the treatment T_9, than rest of the treatments, barring T_{10} and T_{11} at 60 DAS, but at harvest it was significantly the higher. Minimum branches plant^{-1} was observed under control (RDF) (T_1) treatment with values of 11.52 and 13.30 at 60 DAS and at harvest, respectively. The similar findings were reported by Bhupender *et al*. (2012) and Salem *et al*. (2016), they reported that application of sulphur increased the branches plant^{-1} over control in mustard crop.

Biological yield

The data given in table 2, revealed that the significantly higher biological (grain and stover) yield (35.94 g/pot) was registered with the fertilization of RDF + sulphur nanoparticles @ 3 mg S/kg soil, 50% at basal & 50% at 30 DAS (T_9) over the remaining treatments except T_{10} and T_{11}. While the lowest biological yield was obtained under control treatment (T_1). The percentage increase in biological yield was in the tune of 17.87% over the control untreated pot.

The growth and yield attributes as well as yield was found better under T_9 shows that the biological yield ultimately found high in this treatment. And increasing the dose of sulphur found at par with T_9 but not highest. The 3 mg/kg dose of sulphur can be an optimum dose of sulphur for the fertilization of crop. The similar findings were reported by Samreen *et al*., 2022; Singh *et al*., 2016 and Rathore *et al*., 2015 they reported that application of sulphur increase the growth parameters as well as yield of crops.

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Conclusion

It can be concluded that application of RDF + sulphur nanoparticles @ 3 mg S/kg soil, 50% at basal & 50% at 30 DAS (T_9) through fertigation gives better results in terms of plant height, branches/plant and biological yield of groundnut-mustard cropping sequence in sulphur deficient soil under controlled condition of pot experimentation.

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Table 1: Impact of various treatments on periodical plant height of groundnut-mustard cropping sequence

Treatments	Periodical Plant height (cm)					
	Groundnut			Mustard		
	30 DAS	60 DAS	At harvest	30 DAS	60 DAS	At harvest
T_1	30.11±1.36^{d}	47.18±1.60^{c}	54.65±1.83^{d}	27.01±1.01^{e}	81.22±1.72^{d}	104.82±2.72^{c}
T_2	34.58±0.71^{ab}	51.41±2.44^{abc}	60.58±1.43^{abc}	31.17±0.64^{abc}	87.01±2.55^{bcd}	114.49±3.53^{abc}
T_3	34.79±0.99^{ab}	50.71±0.48^{bc}	59.28±0.85^{bcd}	31.36±0.78^{abc}	89.36±1.40^{abc}	114.5±1.07^{abc}
T_4	31.54±0.78^{cd}	47.64±0.78^{c}	55.69±0.91^{cd}	28.38±0.70^{de}	82.01±1.55^{cd}	105.84±1.06^{c}
T_5	31.6±0.25^{cd}	49.3±1.09^{c}	57.63±1.58^{cd}	28.64±0.64^{cde}	84.88±1.88^{cd}	109.29±2.43^{c}
T_6	31.91±0.83^{bcd}	49.43±0.75^{c}	57.78±0.88^{cd}	28.7±0.78^{cde}	85.09±1.63^{cd}	109.82±2.00^{c}
T_7	33.75±0.29^{abc}	49.91±1.42^{bc}	58.35±1.61^{cd}	30.35±0.26^{bcd}	85.93±1.97^{cd}	110.9±3.78^{bc}
T_8	33.8±0.88^{abc}	50.4±1.11^{bc}	58.92±1.30^{bcd}	30.64±1.05^{abcd}	86.77±2.21^{bcd}	111.98±3.12^{bc}
T_9	35.06±0.30^{a}	55.63±0.96^{a}	65.02±1.32^{a}	31.6±0.48^{ab}	95.76±2.16^{a}	123.59±2.79^{a}
T_{10}	36.49±0.73^{a}	51.84±1.21^{abc}	60.81±1.41^{abc}	33.14±0.66^{a}	89.44±2.08^{abc}	114.62±2.69^{abc}
T_{11}	35.4±0.76^{a}	54.54±1.28^{ab}	63.75±1.50^{ab}	31.91±0.69^{ab}	93.89±1.96^{ab}	121.18±3.76^{ab}

The unique lowercase letters linked with the values represent statistically significant differences as assessed by Duncan's multiple range test at a significance level of p 0.05, as well as their standard error of mean uncertainties.

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Table 2: Impact of various treatments on branching/ plant and biological yield groundnut-mustard cropping sequence

Treatments	Periodical branches/plant				Biological yield (g/pot)	
	Groundnut		Mustard		Groundnut	Mustard
	60 DAS	At harvest	60 DAS	At harvest		
T_1	7.36±0.16^{b}	7.53±0.26^{b}	11.52±0.24^{b}	13.3±0.28^{b}	57.51	30.49
T_2	7.73±0.29^{ab}	7.91±0.30^{ab}	12.11±0.46^{b}	13.98±0.47^{b}	61.90	33.14
T_3	7.78±0.14^{ab}	7.97±0.14^{ab}	12.19±^{b}0.21	14.08±0.24^{b}	60.42	33.68
T_4	7.37±0.22^{b}	7.55±0.22^{b}	11.53±0.34^{b}	13.33±0.40^{b}	59.91	30.88
T_5	7.37±0.10^{b}	7.54±0.10^{b}	11.54±0.16^{b}	13.32±0.18^{b}	60.96	31.60
T_6	7.4±0.06^{b}	7.58±0.06^{b}	11.59±0.15^{b}	13.38±0.11^{b}	58.91	31.76
T_7	7.64±0.14^{b}	7.83±0.21^{ab}	11.97±0.37^{b}	13.82±0.59^{b}	61.77	32.60
T_8	7.64±0.17^{b}	7.83±0.17^{ab}	11.97±0.27^{b}	13.82±0.31^{b}	59.67	33.07
T_9	8.31±0.17^{a}	8.54±0.17^{a}	13.23±0.26^{a}	15.47±0.30^{a}	65.58	35.94
T_{10}	7.85±0.19^{ab}	8.04±0.20^{ab}	12.3±0.31^{ab}	14.2±0.35^{b}	60.83	34.31
T_{11}	7.91±0.09^{ab}	8.1±0.09^{ab}	12.38±0.13^{ab}	14.3±0.15^{b}	64.52	35.11
SEm ±					**1.22**	**0.61**
CD (p=0.05)					**3.50**	**1.76**
CV %					**3.98**	**3.70**

The distinct lowercase letters associated with the values indicate statistically significant differences as determined by Duncan's multiple range test at a significance level of $p \leq 0.05$ along with their standard error of mean uncertainties.

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