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A comprehensive review on host plant resistance of wonder crop, soybean (*Glycine max*) against whitefly (*Bemisia tabaci*)

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ABSTRACT

Whiteflies are significant pests that adversely affect soybean yield qualitatively and quantitatively. Understanding the host plant resistance traits of soybean against whiteflies is crucial for developing resistant cultivars for sustainable management of whitefly. This review provides an overview of the defensive proteins, secondary metabolites, signalling molecules, and antioxidant systems involved in soybean's resistance mechanisms. Additionally, it discusses the genetic and molecular basis of resistance, breeding strategies, and the influence of environmental and agronomic factors.

Keywords: Biochemistry, Defence mechanisms, Resistance, Soybean, Whitefly

Around the world, soybeans are expanding in temperate, tropical, and subtropical climates. It is grown in an area of 11.50 m.ha in India, producing 14.12 mt overall and 1239 kg/ha of productivity. A popular crop in many countries, soybean (*Glycine max*) is prized for its high oil (20%) and protein content (40%). Due to a number of biotic and abiotic variables, India's soybean yield is lower than the global productivity of 2809 kg/ha. Diseases and insect pests are major biotic barriers to soybean production in India, accounting for 32% of yield loss (Sharma and Shukla, 1997). Soybean provides substratum for about 275 species of insect pests in India, out of these only a dozen of species like girdle beetle, tobacco caterpillar, green semilooper, Bihar hairy caterpillar, stem fly, aphids, jassids and whitefly etc., attained the major pest status. About 380 species of insects have been reported on soybean crop from many parts of the world. Whitefly (*Bemisia tabaci* Genn.) is an insect that attack soybean leaves. Whiteflies can cause injury, either directly or indirectly. Direct damage occurred when the stylets of whiteflies pierced the leaves and sucked the liquid that causes chlorosis in plants (Gulluoglu *et al.*, 2010a). While the indirect harm, the sooty mould that *B. tabaci* excretes grows on the leaves because of the honeydew it produces, which lowers photosynthetic activity and may be detrimental to the quality of agricultural products (Perring *et al.*, 2018; Solanki and Jha, 2018).

Furthermore, *B. tabaci* feeding on leaves can result in yellowing and crumpling, which in turn causes reduced plant growth and malformed fruits. Furthermore, whiteflies are also known to have a role in the transmission of viruses. It has the ability to spread over 500 different plant viruses, most of which are in the genera Begomovirus, Carlavirus, Crinivirus, Ipomovirus, and Torradovirus (Götz and Winter, 2016; Lu *et al.*, 2019). Yield losses up to 80% had been documented under severe incidence (Rani *et al.*, 2016). The typical life cycle of a whitefly consists of six stages: the egg, four juvenile stages (also known as nymphal instars), and the adult stage (Perring *et al.*, 2018). The well-known species *Bemisia tabaci* has a complicated life cycle that includes different stage, eggs, nymphs, and adults. They are highly dispersible and multiply quickly. The management of whiteflies using insecticides can be difficult due to their quick development of resistance and resurgence. Host plant resistance in integrated pest management (IPM) practice is generally compatible with other elements. The morphological, physiological, biochemical, and molecular features of the host plant affect how the insect interacts with it (Padilha *et al.*, 2021). Plants defence mechanisms against insects were primarily linked to secondary metabolites, while they were also somewhat correlated with primary metabolites (Slansky, 1990; Isah, 2019). It transmits plant viruses and inflict direct feeding damage that have a significant negative impact on soybean output. Sustainable agriculture depends on the development of whitefly-resistant soybean varieties. The purpose of this review is to systematic record the metabolic processes that underlie soybeans' defence against whiteflies.

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Whitefly physiology favouring its dominance

In each of the aforementioned instances, the whitefly's activity and feeding habits are the only reasons for the harm. The insect's senses act as a mediator between it and its host plant. In order to find and identify the plants they eat, insects use tactile, chemical (olfactory, gustatory), and visual signals (Atkins, 1981). *B. tabaci* is drawn to surfaces that reflect yellow light between 500 and 700 nm. Mound (1962) discovered that two categories of transmitted light wavelengths—the yellow and blue/ultraviolet portions of the spectrum attract *B. tabaci*. According to his conjectures, yellow radiation caused settling behaviour, while ultraviolet radiation caused migrating behaviour. Cabbage whitefly reacted to crushed cabbage leaves, demonstrating a responsiveness to smell, and the greenhouse whitefly reacted to the sex pheromone (Li Tzu Yin and Maschwitz, 1983). In the other species of whiteflies under investigation, the tobacco whitefly (Dowell, 1979) and the citrus blackfly (Mound, 1962). There was no discernible reaction to smell stimuli and also taste is a feeling of chemical interaction, in whitefly epipharyngeal organ's innervation indicates that it is unquestionably a taste organ (Weber, 1930). Additionally, because it is the esophagus's starting point, it gives this organ complete and instant control over the chemical makeup of the plant sap that is ingested. Here we have discussed various plant parameter which confers resistance against whitefly.

Physical, physiological, biochemical and signalling traits of plants that confer resistance to whitefly: Physical characteristics of resistance physically affect insect herbivores by limiting their range of motion or making it more difficult for them to feed. Trichomes and acylsugars are two of the main physical characteristics that give plants resistance to whiteflies when they feed on them. Trichomes, which are specific hairs on the surface of plants, can be variously sized, arranged, and shaped epidermal protuberances. Their capacity to synthesis, secrete, and store materials allows them to be divided into glandular and nonglandular categories (Tissier, 2012). Plant defence against whiteflies is significantly influenced by glandular trichomes and the exudates they produce (Kisha, 1981) was the first to report seeing whiteflies ensnared on tomato leaves. Additional investigation showed that glandular type IV and VI trichomes have a critical role in decreasing the rate of oviposition and adult survival in whiteflies (Channarayappa *et al.*, 1992). Whitefly probing behaviour was interrupted by type IV glandular trichomes, according to a detailed profile of the insects eating activities (Narita *et al.*, 2023). While keeping the structure and quantity of trichomes on the leaf surface, CRISPR/Cas9 mutagenesis of

acylsugar acyltransferase genes dramatically reduced acylsugar levels and resistance against whitefly in *Nicotiana benthamiana* plants (Feng *et al.*, 2021). For instance, field tests on cotton cultivars revealed that cotton plants with higher trichome densities had higher whitefly population densities, suggesting a negative relationship between trichome density and resistance to whiteflies (Zia *et al.*, 2011; Prado *et al.*, 2016; Siddiqui *et al.*, 2021; Suthar *et al.*, 2021). However, positive correlations between overall trichome density and whitefly resistance in cotton have also been reported (Thomas *et al.*, 2014; Zhu *et al.*, 2018). Similar variations have been observed in studies on soybean (McAuslane, 1996; Baldin *et al.*, 2017). Furthermore, the contribution of trichome length to plant defenses against whitefly has been investigated, revealing negative correlation between trichome length and plant defenses against whitefly in eggplant and black gram plants (Taggar and Gill, 2012; Hasanuzzaman *et al.*, 2016). Apart from trichomes, the possible role of other anatomical characteristics including leaf colour, shape, and thickness in plant defences against whiteflies has been studied. For instance, okra-shaped cotton variants showed greater resistance to whiteflies than broad-leaved varieties (Chu *et al.*, 2002). In tomato breeding lines, narrower and thinner leaves were linked to higher resistance to whiteflies (Pal *et al.*, 2021). Another factor is leaf colour; eggplant cultivars with more green light-reflecting leaves and higher overall brightness showed greater resistance to whiteflies (Hasanuzzaman *et al.*, 2016). These physical characteristics have been linked in numerous studies to resistance, although it is still unclear exactly what part they play in the interactions between whiteflies and plants. In-depth research is required to identify the distinct roles of these features, classify them, and take them into account in resistance breeding initiatives.

Plant chemical traits also confers resistance to whitefly. These plant compounds either directly or indirectly contribute significantly to plant resistance against insect herbivores by drawing in the herbivores' natural enemies and shielding the plants from harm (Yactayo-Chang *et al.*, 2020). Several compounds that support direct or indirect defences against whiteflies have been identified in the context of whitefly-plant interactions. Soybeans produce various proteins and enzymes that deter whiteflies. Protease inhibitors in soybeans inhibit digestive proteases in whiteflies, impairing their protein digestion and leading to malnutrition (Jongsma and Bolter, 1997). Peroxidases produce reactive oxygen species (ROS) that cause oxidative damage to whitefly cells, thereby deterring them. Chitinases degrade chitin in the exoskeleton of whiteflies, weakening their structure and making them more vulnerable to external stresses (Zhu *et al.*, 2008). Lipoxigenases catalyze the

formation of volatile organic compounds that can act as repellents to whiteflies or attract their natural predators (Croft *et al.*, 1993). Phenylalanine Ammonia-Lyase (PAL) is involved in the synthesis of phenolic compounds, which can have toxic effects on whiteflies and strengthen plant cell walls against herbivory (MacDonald and D'Cunha, 2007). Plant signalling pathway against whitefly also contributes Plant defence against whiteflies is mostly dependent on the jasmonic acid (JA) signalling pathway, a conserved core route that controls plant response to insect herbivory (Erb and Reymond, 2019). Research employing *Arabidopsis* mutants with differing degrees of JA defence has revealed that the JA signalling system regulates basal defence against whiteflies. (Zarate *et al.*, 2007). Whitefly survival and fecundity were improved when JA signalling pathways were manipulated in tobacco plants through virus-induced gene silencing or genetic mutation of MYC2 (Li *et al.*, 2014). Whitefly survival and fecundity in tomato were found to be higher on JA-deficient spr2 mutant plants and lower on JA-overexpression 35S-prosystemin transgenic plants in comparison to control plants (Sun *et al.*, 2017).

Recent advances in whitefly management

Secondary metabolites: Plant defence against insect herbivores is significantly influenced by secondary metabolites. (Luo *et al.*, 2023), however, few numbers of defense have been investigated for their role in whitefly resistance. Tobacco plants with whitefly feeding had higher levels of numerous terpenoids, including cedinene. Moreover, cedinene was found to positively control resistance to whiteflies when its levels were altered by silencing the 5-epi-aristolochene synthase gene or over-expressing it. Numerous phenolic glycosides from tomato plants were shown to contribute to plant defences against whiteflies, as demonstrated by metabolites profiling and feeding experiments (Xia *et al.*, 2021). One important class of secondary metabolites found in crucifers is glucosinolates, which have been demonstrated to enhance resistance to whiteflies when they build up to abnormally high concentrations but not in natural settings. Elbaz *et al.* (2012) discovered that the overexpression of AtMYB29 led to a significant decrease in the survival and developing rate of whitefly nymphs when aliphatic glucosinolate accumulated. When AtMYB28 and AtMYB51 were overexpressed, the amounts of aliphatic and total glucosinolates were elevated to abnormally high levels, which dramatically decreased whitefly oviposition preference for *Arabidopsis thaliana* plants. (Markovich *et al.*, 2013). Certain phenolic chemicals, including rutin, p-coumaric acid, caffeic acid, chlorogenic acid, and ferulic acid, were shown to rise in tobacco plants in response to

whitefly infestations, indicating a possible function for these compounds in resistance (Zhang *et al.*, 2017). Similarly, lignin and rutin (as well as its derivatives) demonstrated a positive correlation with whitefly resistance in cassava and soybean. (Vieira *et al.*, 2016; Perez-Fons *et al.*, 2019). Improved knowledge of the role of plant secondary metabolites in whitefly resistance may be useful in the creation of new insecticides.

Defense proteins: It is well known that defence proteins build up in reaction to a whitefly infestation, but little is known about how important a role they play in protecting plants from whiteflies. Additional case studies, such to the one carried out by Du *et al.* (2022), are required to address this information gap. Important insights into the true role of these defence proteins in resistance to whiteflies could be gained from studies that use purified proteins in feeding experiments and genetic change of plant genes expressing defence proteins triggered by whitefly infestations (Howe and Jander, 2008). The role defence proteins play in resistance to whiteflies has been the subject of numerous research, with CYS6, a tobacco plant protease inhibitor, receiving special attention. Through genetic modification of CYS6 and feeding tests using pure CYS6, the direct role of CYS6 in plant defence against whiteflies has been demonstrated. Tomato and cassava plants produced considerably more β -1,3-glucanase, chitinase, and peroxidase when whiteflies were present (Antony and Palaniswami, 2006). Furthermore, a whitefly infection increased the activity of polyphenoloxidase in pepper and cucumber plants as well as superoxide dismutase, peroxidase, and polyphenoloxidase in tomato and soybean plants (Zhang *et al.*, 2008; Latournerie- Moreno *et al.*, 2015; de Lima Toledo *et al.*, 2021; Harish *et al.*, 2023). Furthermore, it was shown that the expression of several pathogenesis-related proteins in tomatoes was elevated in the presence of whiteflies (Puthoff *et al.*, 2010). It is well known that defence proteins build up in reaction to a whitefly infestation, but little is known about how important a role they play in protecting plants from whiteflies.

Indirect defences: Apart from providing immediate protection, feeding whiteflies can cause plants to emit volatile organic compounds (VOCs) that draw in the whitefly's natural enemies and aid in plant defence. Nomikou *et al.* (2005) discovered that two predatory mites, *Typhlodromips swirskii* and *Euseius scutalis*, exhibited a noteworthy inclination towards cucumber plants infested with whiteflies as opposed to those that were not infested. This preference was facilitated by the volatiles that the plants released. The predatory mirid *Macrolophus basicornis* was drawn to tomato plants harbouring a

combination of adult, nymphal, and egg whitefly infestations, as demonstrated by Silva *et al.* (2018). Regarding parasitoids, Zhang *et al.* (2013) showed that the accumulation of ocimene/myrcene following a whitefly infestation in *Arabidopsis* plants successfully attracted the whitefly parasitoid *Encarsia formosa*. Melon plants emitted methyl salicylate and tetradecane in response to whitefly herbivory, which helped to attract the whitefly parasitoid *E. desantisi* (Silveira *et al.*, 2018). Similar to this, when whiteflies infested tomato plants, they released myrcene and β -caryophyllene, which helped the parasitic wasp *E. formosa* find its host (Chen *et al.*, 2020). Plant characteristics including architecture and glandular trichomes, in addition to volatile organic compounds (VOCs), also play a role in indirect defences against insect herbivores (Pearse *et al.*, 2020). Therefore, more study is needed to thoroughly investigate the potential of indirect defences in controlling whiteflies by looking at the traits of plants that make natural enemy-mediated plant protection possible.

Genetic basis of resistance: Plant resistance against whiteflies has been engineered using both traditional and biotechnology-based breeding techniques. Numerous genetic resources that can be used to improve plant resistance to whiteflies have been developed as a result of these research efforts. Conventional breeding for plant resistance involves incorporating resistance traits from highly resistant plant accessions into target crop cultivars. So far, conventional resistance breeding has been reported only in tomato. In the first attempt, a tomato cultivar carrying the Mi-1 gene, Motelle, was obtained from the crossing between *S. lycopersicum* Moneymaker and *S. peruvianum*; detailed mapping revealed that Motelle differed from Moneymaker only in the presence of a 650 kb region containing the Mi-1 gene from *S. peruvianum* (Ho *et al.*, 1992). While Motelle was initially obtained for nematode control, subsequent studies revealed that plants of this cultivar displayed significantly lower susceptibility to whitefly than Moneymaker (Nombela *et al.*, 2000; Jiang *et al.*, 2001). Since then, several more studies have been reported using wild relatives of cultivated tomato as donor of whitefly resistance. For example, plant traits associated with whitefly resistance from the wild tomato *S. pimpinellifolium* accession TO-937 were introgressed into Moneymaker, resulting in lines with increased whitefly resistance (Rodriguez-Lopez *et al.*, 2011; Escobar-Bravo *et al.*, 2016). Biotechnology-based resistance breeding Biotechnology-based breeding, which is the intentional modification or introduction of genetic components in crops, is a potential replacement for crop breeding since it is more concentrated and efficient. Plant-mediated RNA interference (RNAi) of

whitefly genes and ectopic expression of insecticidal proteins or foreign genes that control the production of insecticidal compounds in plants have been investigated in the context of biotechnology-based resistance breeding against whiteflies. Naturally occurring resistances and their utilization in resistance breeding Whiteflies have a wide range of host plants; different species show variations in fertility and survival on different plant species as well as cultivars or ecotypes of the same plant species (Zang *et al.*, 2006; Xu *et al.*, 2011). Wild relatives of farmed crops sometimes exhibit greater resistance to insect pests than do agricultural cultivars. (Li *et al.*, 2018; Ferrero *et al.*, 2020). The naturally occurring resistance found in these plants, as well as the genes or quantitative trait loci (QTLs) associated with resistance, can be directly utilised in resistance breeding. (Broekgaarden *et al.*, 2011). Thus, a lot of research has been done to identify QTLs, or plant resistance genes, and use them in breeding initiatives. Sometimes Plant resistance genes or QTLs conferring resistance to whitefly in tomatoes have been thoroughly studied in connection to resistance genes or QTLs because of the significance of whiteflies in tomato production. Numerous QTLs, or whitefly resistance genes, have been discovered in tomatoes and provide valuable genetic resources for tomato breeding. Mi-1 is the gene that has been the focus of the most research among these (Nombela and Muñiz, 2010). The resistance to root knot nematodes that Mi-1, a member of the nucleotide-binding, leucine-rich repeat family of resistance genes, originally conferred was discovered (Roberts and Thomason, 1986). It was later discovered to also confer resistance against insects that feed on phloem, such as whiteflies and aphids (Rossi *et al.*, 1998; Nombela *et al.*, 2003). Following further investigation, a number of plant characteristics, including Hsp90, salicylic acid, and plant age and size, were found to potentially influence the whitefly resistance provided by Mi-1 (Rodriguez-Lopez *et al.*, 2015; Pascual *et al.*, 2023). It was discovered that two major genes and polygenes regulate soybean whitefly resistance, with the major genes having an inheritability of more than 85% (Xu *et al.*, 2010). Plant-mediated RNA interference of whitefly genes Resistance breeding for the management of whiteflies has made use of RNAi, a particular post-transcriptional gene silencing mechanism caused by double-stranded RNA (dsRNA) or small interfering RNA (siRNA). According to a bioassay, producing the dsRNA precursor enhanced whitefly mortality, considerably downregulated V-ATPase A transcription, and shielded tobacco plants against a severe whitefly infestation (Thakur *et al.*, 2014). In a similar vein, the expression of siRNA in common beans and tomatoes and dsRNA in lettuce that targets the V-ATPase gene of whiteflies greatly enhanced resistance to whiteflies (Pizetta

et al., 2022). Further research has used RNA interference (RNAi) to downregulate whitefly genes, demonstrating the approach's promising potential for managing whiteflies (Malik *et al.*, 2016; Eakteiman *et al.*, 2018). Tobacco plants were rendered resistant to whiteflies by the production of dsRNA targeting ecdysone receptor, acetylcholinesterase, and two trehalose-6-phosphate synthase genes in whiteflies (Malik *et al.*, 2016; Gong *et al.*, 2022). Notably, using phloem-specific promoters to produce dsRNA with phloem-specific expression has proven to be quite efficient in controlling whiteflies. Significantly higher whitefly mortality was observed in tobacco plants with phloem-specific production of dsRNA targeting two genes involved in maintaining osmotic pressure in whiteflies (Raza *et al.*, 2016). Similarly, in *A. thaliana*, phloem-specific expression of dsRNA targeting whitefly detoxification genes extended the developmental period of whitefly nymphs (Eakteiman *et al.*, 2018). Tobacco plants exhibited strong resistance against whiteflies when a designed artificial miRNA targeting three whitefly genes—sex lethal, acetylcholinesterase, and orckinin—was overexpressed (Zubair *et al.*, 2020). The transgenic tobacco plants produced by nuclear transformation outperformed transplastomics in terms of managing whiteflies. Subsequent investigation showed that the incapacity of whiteflies to consume dsRNA from plastids may be the cause of the reduced efficacy of transplastomic plants. This work not only demonstrates the distinctions between chewing-mouthpart insects and whiteflies, but it also offers reference data for RNAi-based resistance breeding against whiteflies that can be optimised.

Challenges and Plants' resistance-inhibiting factors in whitefly management

Whitefly species, host plants, climatic zones, and other climate-related variables vary, which affects how the species responds to climate change. Whitefly populations' development, mortality, and fecundity rates have been found to be significantly influenced by temperature and the effects of host plants. The length of the developing process decreases as temperatures rise within the thermal optimum (Madueke and Coaker, 1984; Sengonca and Liu, 1999; Muñiz and Nombela, 2001; Bonato *et al.*, 2007; Xie *et al.*, 2011). Because of how temperature affects an insect's physiology, these tendencies are frequently seen in insects. Reduced fertility is one of the additional consequences of rising temperatures (particularly above the optimal threshold) on life history features (Bonato *et al.*, 2007; Xie *et al.*, 2011; Guo *et al.*, 2013). Elevated CO₂ and O₃ increased developmental time of whiteflies (Cui *et al.*, 2012; Wang *et al.*, 2014), but elevated CO₂ did not affect adult

longevity (Koivisto *et al.*, 2011) and fecundity of whiteflies (Wang *et al.*, 2014). Few studies have been done on how high O₃ affects the lifespan and fertility of whiteflies. Human transfer of infected plant materials contributes to the spread of whiteflies, but there is growing fear that climate change may allow establishment in previously unsuitable areas (Bebber *et al.*, 2013). Pest adaptation and resistance breakdown in whiteflies, like many other pests, have the potential to adapt to resistant soybean varieties over time, leading to resistance breakdown. Continuous monitoring and the development of integrated pest management strategies are crucial to sustain the effectiveness of resistance traits. The deployment of genetically modified or gene-edited soybean varieties faces regulatory hurdles and public acceptance issues. Ensuring that these new varieties meet safety standards and gaining public trust are essential for the successful implementation of biotechnological solutions. The development and commercialization of resistant soybean varieties must be economically viable for farmers. The costs associated with breeding, regulatory approval, and adoption need to be balanced with the potential benefits of reduced pesticide use and increased crop yield. Multifactorial pest pressure in soybean crop is often subject to attacks by multiple pests simultaneously. Developing soybean varieties with broad-spectrum resistance that can effectively manage whiteflies and other common pests remains a significant challenge.

Plant morphology and physiology are influenced by climate factors in addition to insect behaviour and development. Under various environmental circumstances, the resistance of *S. pennellii* and *L. hirsutum*, *F. glabratum* accessions to *B. tabaci* was examined (Kennedy *et al.*, 1981). Independent of day length, a lab experiment revealed that one of the accessions of *L. hirsutum*, *F. glabratum* was noticeably more vulnerable when grown in reduced light conditions. Only low light intensity and a short photoperiod led to certain *S. pennellii* accessions being susceptible; all other light regimes produced plants that were comparatively resistant. It required three to four weeks for the transition from resistance to vulnerability and vice versa, which was evident in the freshly formed leaves. This indicates that morphological and/or physiological characteristics are most likely the basis for this type of resistance. According to an initial study, salt in the soil or water may also be detrimental to *S. pennellii* (Jackson *et al.*, 1973). The impact of pesticides on natural enemies is frequently cited as the reason for pest population explosions following insecticidal spraying. However, despite the high adult mortality rate, the increase in *B. tabaci* populations in cotton following DDT spraying was explained by the spray's increased nitrogen content in the leaves (Saad, 1975; Weisser, 1980).

Future prospects in whitefly management

Advanced genomic approaches for managing whitefly with the advent of high-throughput sequencing technologies, future research should focus on the comprehensive genomic and transcriptomic analysis of soybean varieties that exhibit resistance to whiteflies. Identifying resistance-associated genes and their regulatory networks can pave the way for the development of genetically modified soybean cultivars with enhanced resistance and also detailed metabolomic studies are needed to understand the specific biochemical pathways and metabolites involved in soybean resistance. By comparing the metabolomic profiles of resistant and susceptible soybean varieties, key resistance-related metabolites can be identified and potentially used as biomarkers for breeding programs.

CRISPR-Cas9 and Gene Editing technology It is use precisely to edit resistance genes holds significant promise. Targeted gene editing can enhance existing resistance traits or introduce new resistance mechanisms, offering a powerful tool for developing whitefly-resistant soybean varieties as well as Host-Induced Gene Silencing (HIGS) is a novel approach where plants are engineered to produce RNA molecules that silence critical genes in the pest. Future research could explore the feasibility of using HIGS to disrupt vital physiological processes in whiteflies, thereby reducing their population and impact on soybean crops and also Investigating the role of microbial endophytes in enhancing soybean resistance to whiteflies is a promising area. Symbiotic relationships between soybeans and beneficial microbes can be leveraged to induce systemic resistance, providing an eco-friendly and sustainable approach to pest management.

In conclusion, this comprehensive review has provided insights into the intricate biochemical mechanisms underlying soybean resistance to whiteflies. Through an exploration of various resistance factors, including secondary metabolites, phytohormones, and defense-related proteins, we have gained a deeper understanding of the complex interplay between soybean plants and their insect adversaries. The elucidation of these biochemical pathways not only enhances our fundamental knowledge of plant-insect interactions but also holds immense practical significance for agricultural sustainability. By harnessing this knowledge, researchers and breeders can develop novel strategies for breeding whitefly-resistant soybean cultivars, thereby reducing reliance on chemical pesticides and minimizing crop losses. However, despite significant advances, challenges remain on the path towards effective whitefly management in soybean crops. The dynamic nature of pest populations, coupled with environmental influences

and regulatory constraints, necessitates continued research and innovation in this field. Looking ahead, future research directions should focus on leveraging cutting-edge technologies such as genomics, metabolomics, and gene editing to unravel the genetic basis of resistance and accelerate the development of resistant soybean varieties. Additionally, interdisciplinary collaborations and integrated pest management approaches will be essential for addressing the multifaceted challenges posed by whitefly infestations. In essence, by bridging the gap between basic research and practical applications, we can pave the way for sustainable soybean production systems that are resilient to whitefly pressures, ensuring food security and environmental conservation for generations to come.

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Genetic variability and correlation studies in advanced breeding lines of soybean [*Glycine max* (L.) Merrill]

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ABSTRACT

An experiment with 37 advanced breeding lines was conducted to study the genetic variability and association among seed yield and related traits along with direct and indirect effects in order to identify promising soybean genotypes. The genotypes were raised in randomized block design with three replications at experimental farm of department of genetics and plant breeding, CSKHPKV Palampur during *kharif* season under rainfed conditions. Analysis of variance revealed the presence of sufficient genetic variability for all the traits studied. High heritability coupled with high genetic advance was recorded for pod insertion height, plant height, branches per plant, 100-seed weight, seed yield per plant and pods per plant indicating the preponderance of additive gene action suggesting effective selection for these traits. Correlation coefficient analysis showed the significant and positive association of plant height, nodes on main stem, inter-node length, pods per plant, seeds per pod, biological yield per plant and harvest index with seed yield per plant both at phenotypic and genotypic levels. When the direct and indirect effects were estimated, the highest positive direct effect on seed yield per plant was exhibited by harvest index followed by biological yield per plant. Based on path coefficient analysis, harvest index and biological yield per plant could be considered as the direct selection indices for yield improvement in soybean.

Keywords: Correlation, Heritability, Path Analysis, Selection, Soybean, Variation

Oilseed crops are associated with a wide range of agricultural, culinary and industrial uses along with numerous health benefits. The dual-purpose soybean is rich in protein (40%) and oil (20%) (Pratap *et al.*, 2016; Tiwari and Tiwari, 2023). Soybean is the most popular and fascinating bean in the world which provides vegetable protein for millions of people and ingredients for hundreds of chemical products. Soybean contains all nine essential amino acids i.e. methionine, histidine, isoleucine, leucine, lysine, phenylalanine, threonine, tryptophan and valine making it a complete source of protein (Michelfelder, 2009). In addition, soybean is also rich in various vitamins (A, B, C, D and K), fats, minerals like Ca and P and isoflavones.

Soybean is also known as 'Golden bean', 'Wonder crop', 'Poor man's meat', 'Yellow jewel', 'Meat of the field' and 'Miracle crop' due to high-quality protein and vegetable oil. Most of Indians are vegetarians, hence, there is a greater reliance on plant-based commodities as a source of protein. Soybean is the cheapest alternative source of protein (Zarkadas *et al.*, 2007; Trivedi *et al.*, 2023). Soy-based nutritious food products such as tofu, soy milk, soy sauce, miso, bean sprouts and natto etc. have been developed for human consumption while oil extracted soy meal (NPK 7-1.5-1) is used as a nutritious animal feed (Pratap *et al.*, 2012). Worldwide, soybean is grown over an area of 129.52 million hectares with total production and productivity of

371.69 million tonnes and 28.7 q/ha, respectively. In India, its cultivation reached about 12.27 million hectares with total production of 12.99 million tonnes and average productivity of about 10.59 q/ha (Anonymous 2022a). Madhya Pradesh, popularly known as 'Soya State' as it contributed significantly in every way to the development and advancement of soybean production throughout the years (Verma *et al.*, 2021). In Himachal Pradesh, it occupies an area of 600 ha with production of 900 tonnes and productivity of 15 q/ha (Anonymous, 2022b).

Selection is a fundamental part of any breeding programme by which genotypes with high yield in a given environment can be developed. Yield per unit area is the ultimate end product of components of several metric characters, which shows polygenic inheritance and thus highly influenced by environment which hinders direct selection for such complex traits. Heritability estimates assist plant breeders in selecting the best selection strategies for the target traits and in achieving the highest genetic gain as it expresses the reliability of phenotypic value as a guide to the breeding value. High heritability along with high genetic advance offers the most suitable condition for selection. It also indicates the presence of additive genes in the trait and further suggests reliable crop improvement through selection of such traits (Ogunniyan and Olakojo 2015). Proper understanding of association of different traits, provide more reliable selection criteria to achieve high seed yield (Paul and Kumar, 2019). However, selection

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for yield via highly correlated characters becomes convenient if the direct and indirect contribution of different characters to yield is quantified using path coefficient analysis (Dewey and Lu, 1959) which separates the correlation coefficients into their components of direct and indirect effects. Therefore, the present study was conducted to study the selection strategy and interrelationships via estimating degree of variability, heritability, genetic advance, correlation and path coefficient analyses for the improvement of seed yield and other related traits in soybean.

MATERIALS AND METHODS

Experimental site: The Experimental Farm of Department of Genetics and Plant Breeding (Fig. 1) is located at an elevation of 1290.80 m (a.m.s.l.) with 32°09' N latitude and 76°55' E longitude. Agroclimatically, Palampur comes under mid-hills or Zone-II of Himachal Pradesh. High rainfall (2500 mm per annum) and a sub-temperate climate define this region. The soil is acidic, having a silty clay loam texture and a pH ranging from 5.0 to 5.6.



Fig. 1. Experimental Farm located at an elevation of 1290.80 m (a.m.s.l.)

Experimental material: The experimental material was comprised of 34 fixed advanced breeding lines involving 14 crosses of soybean along with three checks i.e. Hara Soya, Him Soya and Shivalik. During *kharif*, 2021 the experiment was laid out in randomized block design with three replications with plot size of 2.0 m × 0.90 m² (2 rows of 2 meters length each) having row-to-row and plant-to-plant spacing of 45 cm and 10 cm, respectively. For optimum soybean development, the prescribed package of practices was implemented.

Data collection and biometrical analysis: Data was collected from five random competitive plants selected from each genotype in each replication for traits such as plant height (cm), pod insertion height (cm), branches per plant, nodes on main stem, inter-node length (cm), pods per plant, seeds per pod, pod length (cm), 100-seed weight (g), biological yield per plant (g), seed yield per plant (g) and

harvest index (%). However, days to 50% flowering and days to 75% maturity were recorded on plot basis. The recorded data was analyzed for analysis of variance (ANOVA) as per the method given by Panse and Sukhatme (1985). The phenotypic, genotypic and environmental coefficients of variation, as well as heritability (h² bs), were examined as per Burton and De Vane (1953) and Johnson *et al.* (1955). Genetic advance was calculated according to Johnson *et al.* (1955). Phenotypic and genotypic coefficients of correlation were calculated as per the method given by Al-Jibouri *et al.* (1958). Direct and indirect effects of the component traits on the seed yield were studied by the method suggested by Dewey and Lu (1959).

RESULTS AND DISCUSSION

The results of analysis of variance for various traits were presented in Table 2. The mean sum of squares due to

genotypes was significant for all the studied traits which indicated the presence of sufficient amount of genetic variability among the genotypes for all the traits. Significant differences in soybean have also been noted by Reni and Rao (2013), Suresh Rao *et al.* (2014), Kumar *et al.* (2015), Chandrawat *et al.* (2017), Jain *et al.* (2017), Sileshi (2019) and Verma *et al.* (2021).

Genetic components of variability: Variability parameters like phenotypic coefficient of variation (PCV), genotypic coefficient of variation (GCV), heritability in broad sense (h^2_{bs}) and expected genetic advance expressed as per cent of mean for 14 morphological traits presented in Table 3. The estimates of PCV in the current study were higher than the corresponding GCV for all traits, which suggested the contribution of environmental factors as well as genotypes to the variation. Similar results were reported by Reni and Rao (2013), Kumar *et al.* (2015), Chandrawat *et al.* (2017), Sileshi (2019) and Verma *et al.* (2021) in soybean.

Moderate PCV along with moderate GCV values were recorded for plant height (13.10 and 11.50), pod insertion height (17.26 and 15.07), branches per plant (15.54 and 13.83), pods per plant (16.13 and 12.54), 100-seed weight (12.50 and 11.80), biological yield per plant (14.72 and 11.46) and seed yield per plant (17.26 and 14.11). These results are in conformity with the earlier findings of Akram *et al.* (2011) who observed moderate PCV and GCV values for seed yield per plant, plant height and number of pods per plant, Kumar *et al.* (2014) for pods per plant and biological yield per plant and Dutta *et al.* (2021) for plant height, branches per plant and 100-seed weight. Low values of PCV and GCV were obtained for days to 50% flowering (5.67 and 4.65), days to 75% maturity (3.03 and 2.55) and nodes on main stem (6.32 and 5.52). Similar results were reported by Mehra *et al.* (2020) for days to 50% flowering and days to 75% maturity. Heritability is a reliable indicator to know the proportion of genetic variability transmitted from one generation to next. In the present study, the highest values of heritability was observed for 100-seed weight (89.13) followed by inter-node length (82.14), branches per plant (79.18), plant height (77.02), pod insertion height (76.25), nodes on main stem (76.25), days to 75% maturity (70.79), days to 50% flowering (67.16), seed yield per plant (66.89), pod length (61.83), biological yield per plant (60.55) and pods per plant (60.51) which indicated the capacity of the genotypes to pass on genes to their progeny for these characters. Jain *et al.* (2015) recorded high heritability for days to 50% flowering, days to 75% maturity, plant height, branches per plant, pods per plant, 100-seed weight, biological yield per plant and seed yield per plant.

The estimates of high heritability coupled with high genetic advance suggested that direct selection could be effective for improvement of these traits. In the present study high heritability coupled with high genetic advance was recorded for pod insertion height, plant height, branches per plant, 100-seed weight, seed yield per plant and pods per plant. These results were in accordance with Reni and Rao (2013), Ekka and Gabriel (2016), Chandrawat *et al.* (2017) and Dutta *et al.* (2021).

High/moderate heritability along with moderate genetic advance was observed for inter-node length, pod length, biological yield per plant, seeds per pod and harvest index. High heritability coupled with low genetic advance was recorded for days to 50% flowering, days to 75% maturity and nodes on main stem. Akram *et al.* (2011) found high heritability and low genetic advance for days to 50% flowering and days to 75% maturity. Baria *et al.* (2022) observed similar high heritability along with moderate genetic advance for pod length and seeds per pod.

Correlation coefficient: Correlation studies simply measures the magnitude of relationships between various morpho-physiological traits and economic production. When two traits are highly genetically correlated, the genes that contribute to the traits are usually co-inherited. The estimated phenotypic and genotypic correlation coefficients for fourteen traits presented in Table 4.

Correlation studies revealed higher magnitude of correlation values at genotypic level as compared to the correlation at phenotypic level for most of the character pairs indicated the inbuilt association among various traits but its phenotypic expression was contracted by the influence of environmental factors. Plant height, nodes on main stem, inter-node length, pods per plant, seeds per pod, biological yield per plant and harvest index showed significant and positive association with seed yield per plant at both phenotypic and genotypic levels. Whereas, 100-seed weight showed significant and positive correlation with seed yield per plant at phenotypic level only. Higher yield could result from selection based on these characters. These results are in accordance with the earlier findings of Baig *et al.* (2017) for plant height and 100-seed weight, Chandel *et al.* (2017) for pods per plant, pod length, biological yield per plant and harvest index, Guleria *et al.* (2019) for days to 50% flowering and days to 75% maturity, Banerjee *et al.* (2022) for seeds per pod, biological yield per plant, 100-seed weight, and harvest index.

Path coefficient analysis: Path coefficient analysis (Table 5) revealed that the highest positive direct as well as indirect effect on seed yield per plant were contributed by

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harvest index followed by biological yield per plant indicated the major contribution of these traits towards seed yield per plant. The phenotypic selection of these traits should be prioritized for the development of high yielding genotypes. These results are in accordance with Sileshi (2019) and Kumar *et al.* (2020) who reported the high positive direct effects of harvest index and biological yield per plant.

The significant and positive association of pods per plant with seed yield per plant was due to high positive indirect effect via harvest index. The significant and positive correlation of 100-seed weight with seed yield per plant was due to high positive indirect effect via biological yield per plant. These traits have also been noted as significant direct contributors influencing seed yield in soybean by previous researchers Jain *et al.* (2015), Chandel *et al.* (2017), Khadka *et al.* (2020), Verma *et al.* (2021) and Banerjee *et al.* (2022). The significant and positive correlation of biological yield per plant with seed yield per plant was mainly due to its own high positive direct effect which was counterbalanced by negative indirect effect via harvest index. The significant and positive correlation of harvest index with seed yield per plant was mainly due to its own high positive direct effect which was

counterbalanced up to some extent by negative indirect effect via biological yield per plant.

It can be concluded from the above study that sufficient amount of genetic variability was present among the genotypes for all the studied traits. Six genotypes *viz.*, P3-10-1-2 (Hardee × JS 20-87), P5-1-1-1 (JS 97-52 × PS 1225), P120-9-1-3 (Hardee × Hara Soya), P108-14-2-6-2 (PS 1469 × Hara Soya), P101-18-2-2-1 (Pb 1 × Hara Soya) and P101-18-2-2 (Pb 1 × Hara Soya) performed better for seed yield and component traits and can be used further. Correlation studies revealed higher magnitude of correlation at genotypic level as compared to the correlation at phenotypic level which suggested the greater contribution of genetic factors in character development. Significant and positive association of plant height, nodes on main stem, inter-node length, pods per plant, seeds per pod, biological yield per plant and harvest index with seed yield per plant was observed at both phenotypic and genotypic levels. Path coefficient analysis showed the highest positive direct as well as indirect contribution of harvest index and biological yield per plant on seed yield per plant indicating the major contribution of these traits towards seed yield per plant.

Table 1 List of soybean genotypes used in the study

S. No.	Genotype	Pedigree/Source	S. No.	Genotype	Pedigree/Source
1.	P108-14-25-2	PS 1469 × Hara Soya	20.	P19-1-5-2	P 9-2-2 × Hara Soya
2.	P3-10-1-2	Hardee × JS 20-87	21.	P118-14-2-3-1	PS 1469 × Hara Soya
3.	P101-18-1-2	Pb 1 × Him Soya	22.	P19-1-2-1	P 9-2-2 × Hara Soya
4.	P101-18-3-1	Pb 1 × Him Soya	23.	P104-5-12-1-1	PK 472 × Hara Soya
5.	P5-1-1-1	JS 97-52 × PS 1225	24.	P99-1-7-3-1	PS 1466 × Hara Soya
6.	P108-14-2-6-1	PS 1466 × Hara Soya	25.	P112-11-3-3	SL 679 × Hara Soya
7.	P98-21-1-4	P 9-2-2 × Hara Soya	26.	P120-9-1-1	Hardee × Hara Soya
8.	P19-7-1	P 9-2-2 × Hara Soya	27.	P101-18-2-2-1	Pb 1 × Hara Soya
9.	P98-21-1-2	P 2-2 × Hara Soya	28.	P101-20-2-1	Pb 1 × Him Soya
10.	P108-14-2-6-2	PS 1469 × Hara Soya	29.	P101-12-3-1	Pb 1 × Hara Soya
11.	P59-1-1	Hara Soya × JS-335	30.	P108-14-1-2	PS 1469 × Hara Soya
12.	P101-18-1-1	Pb 1 × Hara Soya	31.	P120-9-1-3	Hardee × Hara Soya
13.	P104-2-1-4-1	PK 472 × Hara Soya	32.	P108-14-2-3-1	PS 1469 × Hara Soya
14.	P101-16-1-2	P 13-4 × Him Soya	33.	P101-18-1-3-3	Pb 1 × Hara Soya
15.	P19-1-5-1	P 9-2-2 × Hara Soya	34.	P15-1-4-1	P 9-2-2 × Hara Soya
16.	P120-1-1-3	Hardee × Hara Soya	35.	Hara Soya	Himso 1520 × Bragg (C)
17.	P99-24-1-1-4	PS 1466 × Him Soya	36.	Him Soya	Selection from cross JS-79-295 × Lee (C)
18.	P101-18-2-2	Pb 1 × Hara Soya	37.	Shivalik	Selection from PL-7355
19.	P108-2-1-3-1	PS 1469 × Hara Soya			

Table 2 Analysis of variance for seed yield and component traits in soybean

Characters	Mean Sum of Squares		
	Replication	Genotypes	Error
Df	2	36	72
Days to 50% flowering	5.9	26.7*	3.7
Days to 75% maturity	0.9	36.2*	4.4
Plant height (cm)	4.2	299.5*	27.1
Pod insertion height (cm)	1.7	11.9*	1.1
Branches per plant	0.1	1.0*	0.1
Nodes on main stem	0.5	1.3*	0.1
Inter-node length (cm)	0.1	0.8*	0.1
Pods per plant	12.5	148.5*	26.5
Seeds per pod	0.0	0.1*	0.0
Pod length (cm)	0.3	0.3*	0.1
100-seed weight (g)	0.1	8.4*	0.4
Biological yield per plant (g)	5.9	102.2*	18.2
Seed yield per plant (g)	3.3	11.1*	1.6
Harvest index (%)	33.6	31.4*	8.8

*significant at $P \leq 0.05$

Table 3 Genetic parameters of variability for different yield and component traits in soybean

	Range-	Low	Moderate	High			
GCV and PCV		<10	10-20	>20 (Chandrawat <i>et al.</i> , 2017)			
Heritability		<30	30-60	>60 (Chandrawat <i>et al.</i> , 2017)			
GA (as % of mean)		<10	10-20	>20 (Prakash <i>et al.</i> , 2021)			

Traits	Mean±SE	Range		PCV (%)	GCV (%)	h ² (bs)	GA (as % of mean)
		Min	Max				
Days to 50% flowering	59.6±1.1	55.7	66.6	5.7	4.6	67.2	7.8
Days to 75% maturity	127.9±1.2	120.3	133.7	3.0	2.6	70.8	4.4
Plant height (cm)	82.9±3.0	65.2	103.8	13.1	11.5	77.0	20.8
Pod insertion height (cm)	12.6±0.6	8.5	16.3	17.3	15.1	76.2	27.1
Branches per plant	4.0±0.2	2.9	5.1	15.5	13.8	79.2	25.3
Nodes on main stem	11.4±0.2	9.9	12.8	6.3	5.5	76.2	9.9
Inter-node length (cm)	5.2±0.1	4.4	6.2	10.5	9.4	82.1	17.6
Pods per plant	50.8±2.9	35.5	62.4	16.1	12.5	60.5	20.1
Seeds per pod	2.4±0.1	1.8	2.9	11.4	7.7	45.8	10.8
Pod length (cm)	3.6±0.1	3.1	4.5	10.3	8.1	61.8	13.1
100-seed weight (g)	13.8±0.4	11.2	19.3	12.5	11.8	89.1	22.9
Biological yield per plant (g)	46.2±2.5	37.3	64.7	14.7	11.5	60.5	18.4
Seed yield per plant (g)	12.6±0.7	10.3	16.6	17.3	14.1	66.9	23.8
Harvest index (%)	27.5±1.7	20.4	33.7	14.7	9.9	45.9	13.9

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Table 4 Estimates of correlation coefficient at phenotypic (P) and genotypic (G) level for traits in soybean

Traits		Days to 75% maturity	Plant height (cm)	Pod insertion height (cm)	Branches/plant	Nodes on main stem	Inter-node length (cm)	Pods/plant	Seeds/pod	Pod length (cm)	100-seed weight (g)	Biological yield/plant (g)	Harvest index (%)	Seed yield/plant (g)
Days to 50% flowering	P	0.526*	0.140	-0.140	-0.038	0.069	-0.173	0.101	-0.074	-0.182	0.004	-0.048	0.096	0.064
	G	0.832*	0.230*	-0.273*	-0.046	0.109	-0.202*	0.082	-0.069	-0.205*	-0.034	-0.046	0.124	0.093
Days to 75% maturity	P	1	0.063	-0.077	-0.174	-0.061	-0.079	0.095	-0.211*	-0.158	-0.047	-0.114	0.070	-0.000
	G	1	0.103	-0.142	-0.249*	-0.107	-0.096	0.050	-0.201*	-0.308*	-0.081	-0.210*	0.134	-0.032
Plant height (cm)	P		1	0.282*	0.453*	0.293*	0.438*	0.268*	0.176	-0.003	0.032	0.181	0.112	0.271*
	G		1	0.399*	0.549*	0.375*	0.493*	0.375*	0.358*	0.036	0.051	0.258*	0.213*	0.388*
Pod insertion height (cm)	P			1	0.427*	0.156	0.336*	-0.085	0.002	-0.163	0.137	0.066	-0.093	-0.020
	G			1	0.527*	0.201*	0.421*	-0.161	0.133	-0.237*	0.158	0.107	-0.202*	-0.047
Branches per plant	P				1	0.384*	0.502*	0.099	0.206*	0.149	-0.047	0.148	0.075	0.183
	G				1	0.522*	0.591*	0.102	0.437*	0.283*	-0.022	0.217*	0.127	0.258*
Nodes on main stem	P					1	0.298*	0.329*	0.211*	0.123	-0.056	0.159	0.271*	0.379*
	G					1	0.364*	0.360*	0.377*	0.131	-0.066	0.279*	0.346*	0.497*
Inter-node length (cm)	P						1	0.329*	0.236*	0.171	0.151	0.378*	0.132	0.438*
	G						1	0.386*	0.434*	0.216*	0.192*	0.543*	0.188*	0.584*
Pods per plant	P							1	0.185	0.074	0.203*	0.372*	0.439*	0.711*
	G							1	0.385*	0.214*	0.196*	0.454*	0.597*	0.837*
Seeds per pod	P								1	0.209*	0.194*	0.314*	0.232*	0.464*
	G								1	0.544*	0.367*	0.418*	0.472*	0.682*
Pod length (cm)	P									1	-0.054	-0.026	0.159	0.155
	G									1	-0.161	0.093	0.266*	0.264*
100-seed weight (g)	P										1	0.199*	0.046	0.197*
	G										1	0.232*	-0.071	0.131
Biological yield per plant (g)	P											1	-0.333*	0.541*
	G											1	-0.190*	0.613*
Harvest index (%)	P												1	0.602*
	G												1	0.658*

*Significant at P≤0.05

Table 5 Estimation of direct and indirect effects of different traits on seed yield at phenotypic (P) and genotypic (G) level in soybean

Traits		Days to 50% flowering	Days to 75% maturity	Plant height (cm)	Pod insertion height (cm)	Branches/plant	Nodes on main stem	Inter-node length (cm)	Pods/plant	Seeds/pod	Pod length (cm)	100-seed weight (g)	Biological yield/plant (g)	Harvest index (%)	Seed yield/plant (g)
Days to 50% flowering	P	0.005	0.014	0.003	-0.002	0.001	0.000	-0.001	0.002	-0.001	0.000	0.000	-0.039	0.082	0.064
	G	0.199	-0.115	0.005	-0.054	0.006	-0.001	-0.003	-0.011	0.018	-0.035	-0.003	-0.043	0.130	0.093
Days to 75% maturity	P	0.002	0.027	0.001	-0.001	0.004	0.000	-0.001	0.002	-0.002	0.000	0.001	-0.093	0.060	-0.000
	G	0.166	-0.139	0.002	-0.028	0.035	0.001	-0.002	-0.007	0.053	-0.052	-0.008	-0.194	0.140	-0.032
Plant height (cm)	P	0.001	0.002	0.019	0.004	-0.010	0.002	0.003	0.006	0.002	0.000	0.000	0.148	0.096	0.271*
	G	0.046	-0.014	0.022	0.079	-0.076	-0.003	0.008	-0.051	-0.095	0.006	0.005	0.238	0.224	0.388*
Pod insertion height (cm)	P	-0.001	-0.002	0.005	0.013	-0.009	0.001	0.002	-0.002	0.000	0.000	-0.002	0.054	-0.079	-0.020
	G	-0.054	0.020	0.009	0.199	-0.073	-0.002	0.007	0.022	-0.035	-0.040	0.016	0.098	-0.212	-0.047
Branches per plant	P	0.000	-0.005	0.008	0.006	-0.022	0.002	0.004	0.002	0.002	0.000	0.001	0.120	0.064	0.183
	G	-0.009	0.034	0.012	0.105	-0.139	-0.004	0.010	-0.014	-0.116	0.048	-0.002	0.200	0.133	0.258*
Nodes on main stem	P	0.000	-0.002	0.005	0.002	-0.008	0.006	0.002	0.008	0.002	0.000	0.001	0.130	0.232	0.379*
	G	0.022	0.015	0.008	0.040	-0.072	-0.008	0.006	-0.049	-0.100	0.022	-0.007	0.257	0.363	0.497*
Inter-node length (cm)	P	-0.001	-0.002	0.008	0.004	-0.011	0.002	0.007	0.008	0.003	0.000	-0.002	0.309	0.113	0.438*
	G	-0.040	0.013	0.011	0.084	-0.082	-0.003	0.016	-0.053	-0.115	0.037	0.019	0.500	0.197	0.584*
Pods per plant	P	0.000	0.003	0.005	-0.001	-0.002	0.002	0.002	0.024	0.002	0.000	-0.003	0.303	0.376	0.711*
	G	0.016	-0.007	0.008	-0.032	-0.014	-0.003	0.006	-0.136	-0.102	0.036	0.020	0.419	0.626	0.838*
Seeds per pod	P	0.000	-0.006	0.003	0.000	-0.004	0.001	0.002	0.004	0.012	0.000	-0.003	0.256	0.199	0.464*
	G	-0.014	0.028	0.008	0.026	-0.061	-0.003	0.007	-0.052	-0.265	0.093	0.037	0.385	0.494	0.682*
Pod length (cm)	P	-0.001	-0.004	0.000	-0.002	-0.003	0.001	0.001	0.002	0.002	0.001	0.001	0.021	0.136	0.155
	G	-0.041	0.043	0.001	-0.047	-0.039	-0.001	0.004	-0.029	-0.144	0.170	-0.016	0.086	0.279	0.264*
100-seed weight (g)	P	0.000	-0.001	0.001	0.002	0.001	0.000	0.001	0.005	0.002	0.000	-0.015	0.162	0.040	0.197*
	G	-0.007	0.011	0.001	0.031	0.003	0.001	0.003	-0.027	-0.097	-0.027	0.100	0.214	-0.075	0.131
Biological yield per plant (g)	P	0.000	-0.003	0.003	0.001	-0.003	0.001	0.003	0.009	0.004	0.000	-0.003	0.815	-0.285	0.541*
	G	-0.009	0.029	0.006	0.021	-0.030	-0.002	0.009	-0.062	-0.111	0.016	0.023	0.922	-0.199	0.613*
Harvest index (%)	P	0.000	0.002	0.002	-0.001	-0.002	0.002	0.001	0.010	0.003	0.000	-0.001	-0.272	0.857	0.602*
	G	0.025	-0.019	0.005	-0.040	-0.018	-0.003	0.003	-0.081	-0.125	0.045	-0.007	-0.175	1.048	0.658*

*Significant at P≤0.05

Bold diagonal values indicate the direct effects (P) = Phenotypic level, (G) = Genotypic level Residual effects (P) = 0.01703, (G) = -0.0099

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Proper sowing method and nitrogen level improve above ground biomass, yield and nitrogen use efficiency of spring sunflower (*Helianthus annuus* L.) in coastal soil

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ABSTRACT

A field trial was conducted at Regional Research Station (CSZ), BCKV, Akshaynagar, Kakdwip, West Bengal on sunflower during spring season of 2022 and 2023 in strip-plot design with two sowing methods (furrow and pit sowing) in the vertical strips and six N levels (0, 40, 80, 120, 160 and 200 kg/ha) in the horizontal strips. Results revealed significant impact of sowing method and N level on seed yield of sunflower crop. Furrow sowing with 200 kg N/ha produced the highest seed (2.6 t/ha) and stover yield (8.4 t/ha), accounting 337% and 113% more than control plots (without N). The agronomic efficiency (AEN) varied from 7.6 to 14.1 kg/kg N for furrow-sown crop and 2.3 to 15.0 kg/kg N for pit-sown crop. In both sowing methods, mean AEN was higher with 120 kg N/ha and decreased with further increase in N levels upto 200 kg/ha. The average internal efficiency (IEN), exhibited a similar trend to that of AEN. At the end of second year of cropping, the maximum N-gain (108.2 kg/ha) was recorded in furrow-sown crop that received 200 kg N/ha. In case of furrow sowing, the gross return (₹120000/ha) the net return (₹60509/ha) and benefit:cost ratio (2.02) reached the peak at 200 kg N/ha. In conclusion, the practice of furrow sowing (at shallow depth) along with 200 kg N supply per ha stands out as the most preferable and effective agronomic management for spring sunflower in coastal soil.

Keywords: Coastal soil, Economics, Nitrogen use efficiency, Sowing method, Sunflower, Yield

Sunflower (*Helianthus annuus*) is the India's fourth-most important non-conventional oilseed crop after soybean, mustard and groundnut. Its cultivation has spread nationally, becoming a staple crop in many regions due to its versatility, nutritional value and economic significance (Mahapatra *et al.*, 2023). Its popularity is mainly due to short growth period, high oil content (35-48%), photoinsensitivity, drought tolerance adaptability and high productivity of 1218 kg/ha (Indiastat, 2022). The potential for sunflower cultivation has been expanded in West Bengal as a result of the adoption of hybrids. This crop has recently been incorporated into a number of crop-intensification initiatives in non-traditional areas including Kakdwip region of West Bengal dominated by rice-fallow system because of its high production potential when grown with guaranteed irrigation facilities (Alipatra *et al.*, 2019a and b).

Conventionally, sunflower growers in the study location follow traditional methods of seed sowing like broadcasting and line sowing on flat beds. In both the cases, the crop yield suffers due to poor crop stand and bird menace. Hence, the adoption of an alternate sowing technique may lead to increased seed as well as oil yield of sunflower.

Bakht *et al.* (2011) also opined that sowing technique is one of the most important elements of adaptability (Kundu *et al.*, 2023). During 2022-23, the crop had grown covering 364 thousand hectares area, resulting in 363 thousand tonnes production with 996 kg/ha productivity (Indiastat, 2023). Sunflower being a deep-rooted crop, is very much responsive to nutrients. Recently released sunflower hybrids require high amount of nutrients, especially nitrogen as it removes 47 kg N/ha in order to produce one ton of seed (Banerjee *et al.*, 2014). Nitrogen speeds up the metabolic processes which improve both vegetative and reproductive growth of sunflower (Khaliq and Cheema, 2005). Moreover, low N status in coastal soil of West Bengal warrants the high requirement of N-fertilizer by sunflower crop to produce higher yield. These soils are prone to water-logging also, that results in significant losses of N via denitrification. Hence, in the present study it is hypothesized that biomass production, nitrogen use efficiency and N balance in post-harvest soil may be improved by optimum N supply and right sowing technique. The specific objectives include (i) to determine the effect of variable N rates and sowing methods on aboveground biomass, N concentration, yield and NUE of spring sunflower; (ii) to assess N balance in post-harvest soil; and (iii) to evaluate the economic viability of treatments in spring sunflower cultivation.

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MATERIALS AND METHODS

Study site: A replicated field study was conducted at the Regional Research Station (Coastal Saline Zone) of Bidhan Chandra Krishi Viswavidyalaya (latitude 22°40'N, longitude 88°18'E and 7 m above MSL), Akshaynagar, Kakdwip, South 24-Parganas, West Bengal during spring season (January to April) of 2022 and 2023. Average maximum and minimum temperature fluctuated between 22.0 to 40.2°C, and 10.5 to 26.5°C, respectively during the cropping season (January to April). The average monthly relative humidity ranged between 87 to 93%. The total average rainfall during the experimental period was 53.9 mm from January to April. The average amount of evaporation during the cropping season was 205.1 mm with the highest value in March. The soil at the site is a shallow, nearly level and somewhat poorly drained clay type (sand, silt, and clay composition of 25%, 32% and 42%, respectively) with a pH of 5.9; electrical conductivity of 1.5 dS/m; total organic carbon of 0.6%; available nitrogen of 155.0 kg/ha, available phosphorus of 97.5 kg/ha and available potassium of 325.0 kg/ha at 0 to 30cm depth.

Experimental design: A two-factor field experiment in strip-plot design was established, assigning two sowing methods (FS, furrow sowing; PS, pit sowing) in the vertical strips and six N levels [N0:0 kg N/ha; N40: 40 kg N/ha; N80 (RDN): 80 kg N/ha; N120:120 kg N/ha; N160:160 kg N/ha; N200: 200 kg N/ha] in the horizontal strips. Under furrow sowing, furrows (3-5 cm depth) were opened with the help of tyne leaving 60 cm space in between two adjacent furrows. Then seeds were hand-dibbled at an interval of 30 cm with 2 seeds at each position. In the case of pit sowing, pits (3-5 cm depth) were dug with the help of khurpi at each planting position, maintaining the spacing of 60 cm × 30 cm. Then seeds were hand-dibbled with 2 seeds within each pit. For both the sowing methods, the optimum population of 55,555 plants/ha was maintained by thinning and gap filling at 32 DAS. The experiment consisted of 4 replications with 12 treatment combinations with 48 total number of plots. Each plot was 3m wide and 4m long with a 50-cm buffer between plots.

Cultural practices: The hybrid 'SUN FARM' was grown as the test crop suitable for both *rabi* and spring seasons. Seeds were sown on January 21 in both the years. All treatments received the same amount of phosphorus (40 kg/ha) and potassium (40 kg/ha) through single super phosphate (SSP) and muriate of potash (MoP) respectively. Entire dose of SSP and MoP were added to the soil prior to sowing in each plot. Urea was applied in two equal splits at sowing and 33 days after sowing (DAS), as per treatment details.

Altogether nine irrigations were provided to the crop from January 21 to March 31 (during 0 to 69 DAS) to fulfil the demand of crop. One hand weeding was done on February 11 (at 21 DAS) to promote early crop growth. The crop was harvested on May 1 (at 100 DAS) in both the years irrespective of physiological maturity.

Plant sampling: In each plot, three plants were selected randomly to record the aboveground biomass at different stages of crop growth (50, 75 and 100 DAS) by cutting at the soil surface and separated into leaf, stem, capitulum and seed. The samples were then dried in a hot air oven at a temperature of 60°C for 10 hours or till constant weight was obtained. Total N was estimated by KEL Plus (Make: Pelican; Model-DistylEmVa; Capacity = 15-20 samples/hour) following Micro-Kjeldahl's method (AOAC, 1995).

Determination of yield and estimation of NUEs: Seed and stover yield were estimated plot-wise and then converted into t/ha. To estimate the NUE of crop, agronomic efficiency (AE), internal efficiency (IE), recovery efficiency (RE), partial factor productivity (PFP) and partial nitrogen budget (PNB) were calculated according to Liu *et al.* (2011), with slight modifications done by Ray *et al.* (2018). Nitrogen harvest index (NHI) was estimated as per the formula given by Fageria (2014).

Nitrogen balance: The N balance sheet was prepared at the end of second year cropping according to nutrient balance sheet approach proposed by Mozumder *et al.* (2014) and Rana *et al.* (2017). Expected balance was derived from subtracting the value of total N from that of total N uptake, where total N is the sum of initial N content and N applied through fertilizer. Total N uptake was calculated as the sum of N uptake in stover and grain. Actual N balance represents the values derived from post-harvest soil analysis. Finally, net gain or loss of N in post-harvest soil was calculated by subtracting actual balance from expected balance.

Economic analysis: The total cost of hybrid sunflower cultivation was worked out on the basis of prevailing market prices of inputs and outputs during spring season of respective years. Gross returns of the economic product obtained from the crops were computed using the local prices for sunflower seeds and stover. Net return was computed by deducting the total cost of cultivation from the gross returns. The B:C ratio was determined by dividing gross return by the total cost of cultivation.

Statistical analysis: All the data recorded in the present study were subjected to analysis of variance (ANOVA) as strip-plot design (Gomez and Gomez, 1984). Excel software

(version 2010, Microsoft Inc., WA, USA) and SPSS (version 21.0) were used to draw graphs and figures.

RESULTS AND DISCUSSION

Aboveground biomass

There was significant difference in aboveground biomass production of different plant parts between furrow and pit sown crop with N levels, as discussed below.

Leaf, stem and total biomass: Irrespective of studied factors (sowing method and N levels) leaf, stem and total biomass (leaf + stem + capitulum + seed) increased progressively upto 100 DAS (Figure 1A, 1B, 1C and Figure 2). Furrow-sown crop had higher leaf, stem and total biomass at 100 DAS (35.6, 58.3 and 158.13 g/plant, respectively) accounting 4%, 11% and 9% more than pit-sown crop, respectively. Increase in N doses from 0 to 200 kg/ha brought significant improvement in leaf, stem and total biomass, irrespective of sowing methods. Application of N200 registered the highest leaf, stem and total biomass at 100 DAS (45.2, 81.4 and 202.9 g/plant, respectively) accounting 73%, 180% and 117% more leaf, stem and total biomass than the plants in control plot (zero-N) respectively. Interaction effect (SM × N) on leaf, stem and total biomass was significant at specific date of observations (Figure 1A, 1B and 1C). However, application of 200 kg N/ha resulted in higher leaf as well as total biomass in pit-sown crop at 75 DAS and furrow-sown crop at 100 DAS. The furrow-sown crop when fertilized with 200 kg N/ha registered the highest stem as well as total biomass at 100 DAS (84.5 and 208.8 g/plant, respectively), accounting 128% and 100% more than plants in control plots. Hence, it is clearly seen that the crop planted in furrows exhibited a significant rise in plant biomass as compared to pit-sown crop. Furrow sowing not only exhibited quick emergence but also accelerated growth of the crop due to more N acquisition and finally resulted in higher plant biomass. In addition, plants with furrow sowing met their requirements from loosened surface fertile soil which augmented biomass production and N-utilization. In contrary, under pit sowing it was difficult to maintain irrigation water within plot, as the land was not levelled properly before seed sowing. Hence, less moisture availability to pit-sown crop might have led to poor utilization of N-fertilizer. Moreover, delayed growth of pit-sown crop might have failed to acquire more N because of mismatch between critical stages of crop growth and N-availability. In our study, N-fertilization also played a vital role in augmenting plant biomass production. Higher

N doses might had significantly boosted the chlorophyll content of leaves, as well as cell division and elongation, finally resulting in greater leaf area and total plant biomass. Other researchers (Cechin and Fumis, 2004; Yadav *et al.*, 2009) also registered maximum plant height, shoot dry matter and other growth attributes of sunflower with higher N supply.

Nitrogen (N) concentration: Nitrogen concentration (%) in different plant parts at various stages of crop growth as influenced by sowing methods and N levels are narrated below.

Leaf, stem and grain N concentration: Nitrogen concentration in leaf and stem of sunflower crop gradually increased upto 75 DAS and then declined for furrow-sown crop. But for pit sown crop, leaf and stem N concentration was found to be the highest at 100 DAS and 75 DAS respectively (Figure 3A, 3B and 3C). The leaf N concentration varied significantly due to sowing methods at 50 DAS and 75 DAS; however, the variation was non-significant at 100 DAS. Exactly the reverse trend was noticed for stem N concentration. Furrow-sown crop exhibited significantly higher leaf and stem N concentration at 75 DAS (1.87%) and 100 DAS (0.92%) respectively, accounting 7% and 9% more than pit-sown crop, respectively. Significantly higher grain N concentration at 100 DAS (2.24%) was obtained with furrow-sown crop, registering 9% more than pit-sown crop. Leaf, stem and grain N concentrations were found to improve significantly with increasing level of N upto 200 kg/ha, irrespective of observation dates (Figure 3A, 3B and 3C). Application of 200 kg N/ha recorded significantly higher leaf and stem N concentration at 50 DAS (0.13% and 1.29%), 75 DAS (2.58% and 1.76%) and 100 DAS (2.44% and 1.39%), accounting 225% and 153%, 99% and 179%, and 171% and 196% more than the crop under control plot (without N), respectively. At 100 DAS, significantly the highest grain N concentration (3.00%) was recorded in plants receiving 200 kg N/ha, accounting 104% more than control plots (without N). The variation in leaf N concentration due to interaction effect (SM × N) was significant at 50 DAS only and the furrow-sown crop receiving 200 kg N/ha was found to accumulate more leaf N (Figure 3A, 3B and 3C). However, the variation in stem N concentration due to interaction effect (SM × N) was non-significant at all dates of observations. Significantly the highest grain N concentration at 100 DAS (3.14%) was found in furrow-sown crop that received 200 kg N/ha (Figure 3C).

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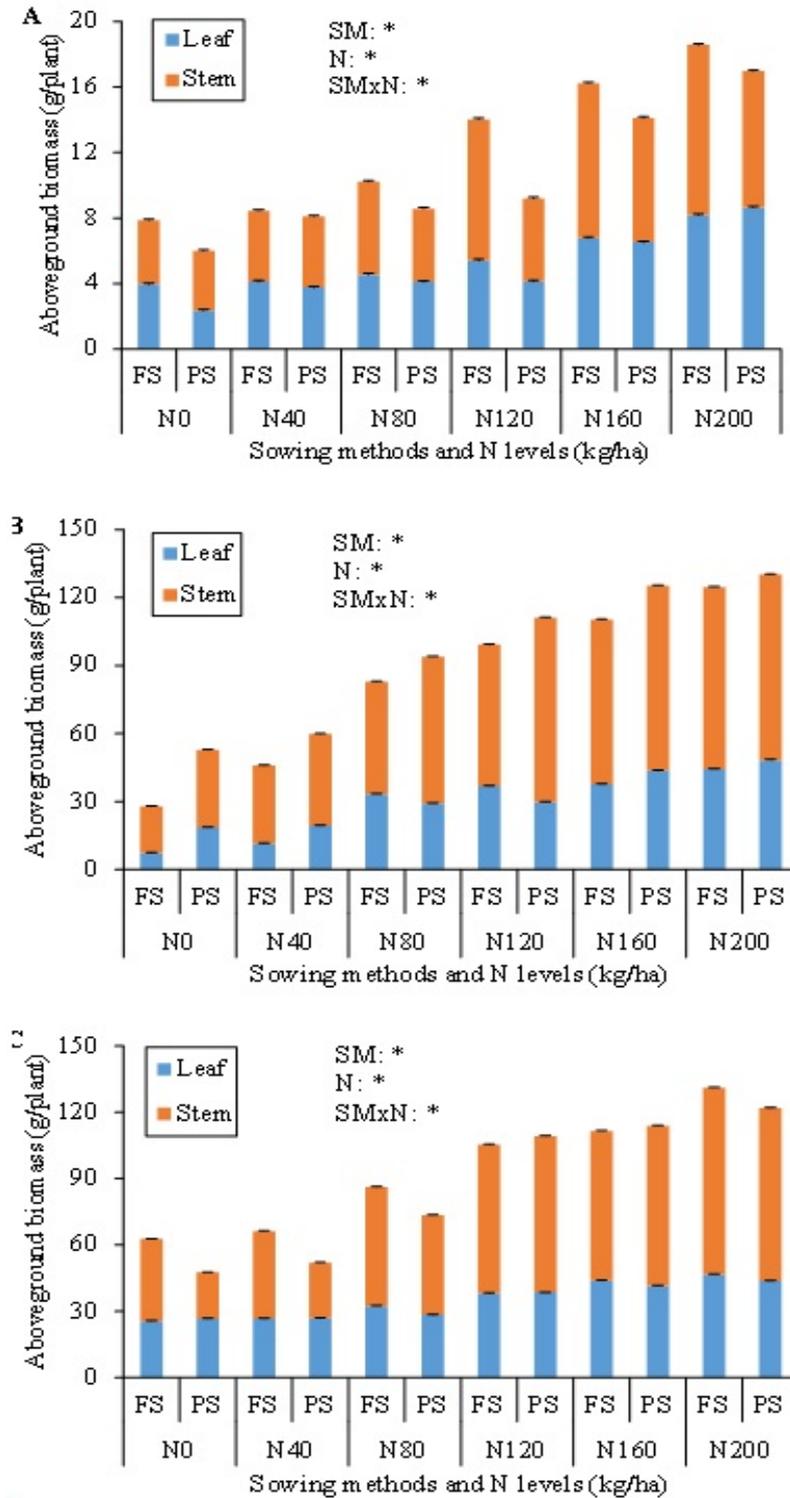


Fig. 1. Pooled mean (n = 6) aboveground biomass of spring sunflower crop at 50 DAS (A), 75 DAS (B) and 100 DAS (C) under different N levels (N0, N40, N80, N120, N160 and N200 kg/ha) and sowing methods (FS = Furrow sowing, PS = Pit sowing). Error bars represent standard deviation. The significant factors (SM and N) and their interaction (SM x N) from the two-way ANOVA are indicated (**p < 0.05) in relation to N levels and sowing methods.

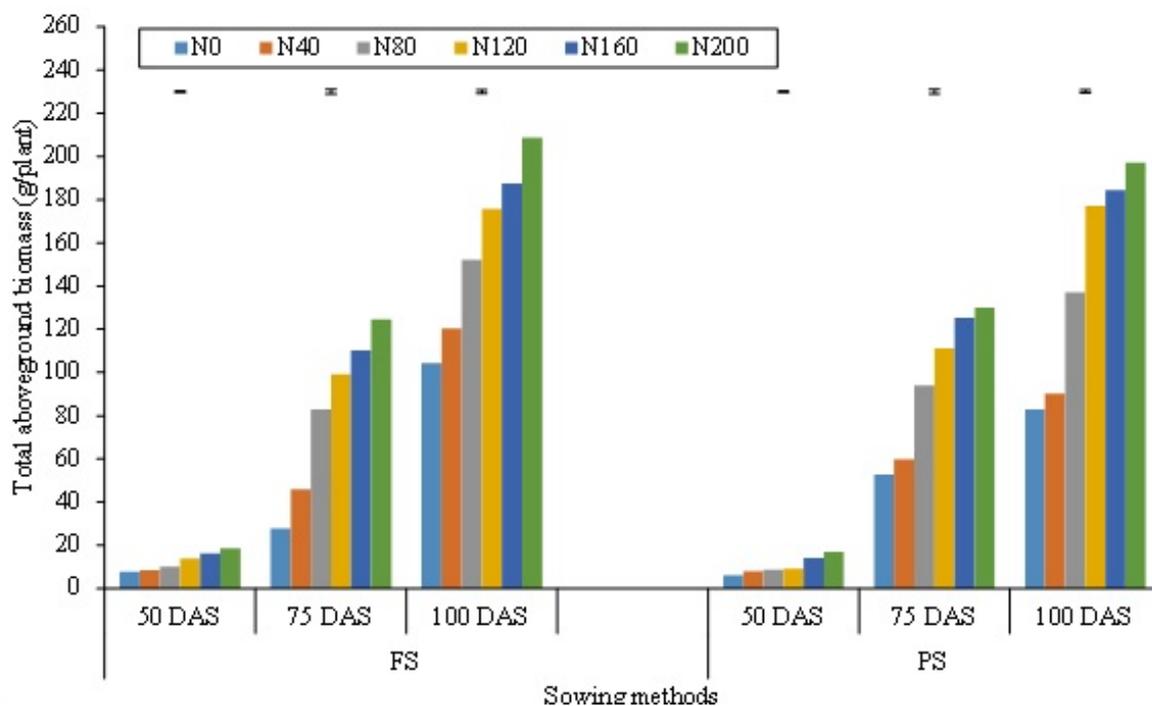


Fig. 2. Pooled mean (n = 6) total aboveground biomass of spring sunflower crop at 50, 75 and 100 DAS under different N levels (N0, N40, N80, N120, N160 and N200 kg/ha) and sowing methods (FS = Furrow sowing, PS = Pit sowing). Error bars represent CD (p < 0.05) at respective date of observation.

Table 1 Different indices for nitrogen use efficiency (NUE) of spring sunflower as influenced by sowing methods and N levels (pooled data of 2 years)

Treatment combination	Agronomic efficiency (AEN) (kg/kg N)	Internal efficiency (IEN) (kg/kg N)	Recovery efficiency (REN) (%)	Partial factor productivity (PFPN) (kg/kg N)	Partial nitrogen budget (PNB) (kg/kg N)	Nitrogen harvest index (NHI) (%)
FS × N0	NA	11.2	NA	NA	NA	55.6
FS × N40	7.6	11.6	0.6	22.3	1.9	54.6
FS × N80	13.4	15.6	0.7	20.8	1.3	47.3
FS × N120	14.1	15.6	0.8	19.0	1.2	44.9
FS × N160	11.7	13.7	0.8	15.4	1.1	44.8
FS × N200	10.0	11.2	0.9	12.9	1.2	43.4
PS × N0	NA	7.7	NA	NA	NA	52.8
PS × N40	2.3	7.1	0.4	9.7	1.4	50.6
PS × N80	14.8	15.8	0.7	18.5	1.2	50.6
PS × N120	15.0	15.4	0.8	17.5	1.1	40.7
PS × N160	12.9	14.7	0.8	14.7	1.0	42.5
PS × N200	11.1	11.2	0.8	12.6	1.0	41.9

FS = furrow sowing; PS = pit sowing; Subscript digits signify respective dose of N in kg/ha; NA = Not applicable

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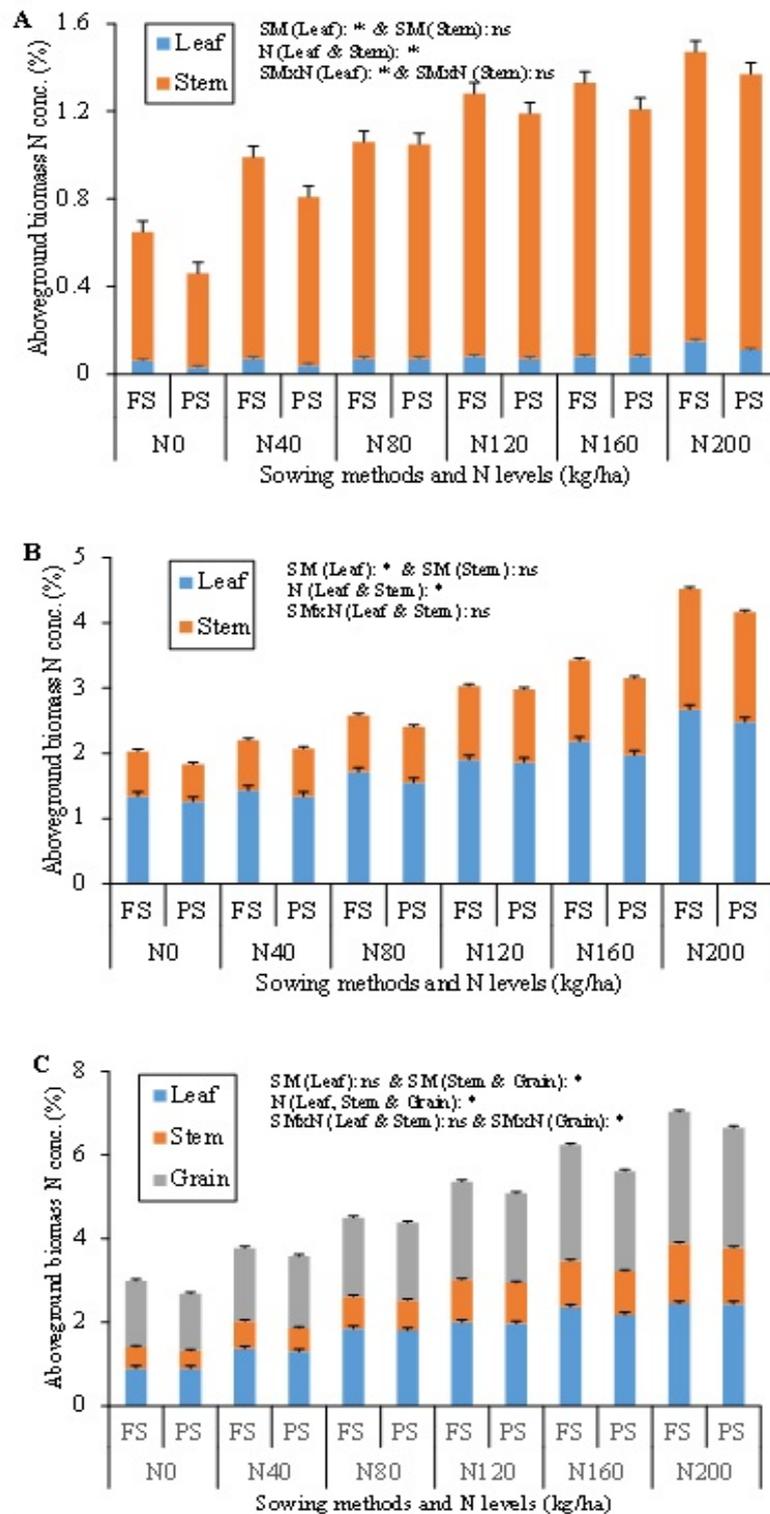


Fig. 3. Pooled mean (n = 6) aboveground biomass N concentration of spring sunflower crop at 50 DAS (A), 75 DAS (B) and 100 DAS (C) under different N levels (N0, N40, N80, N120, N160 and N200 kg/ha) and sowing methods (FS = Furrow sowing, PS = Pit sowing). Error bars represent standard deviation. The significant factors (SM and N) and their interaction (SM x N) from the two-way ANOVA are indicated (**p < 0.05, otherwise non-significant) in relation to N levels and sowing methods.

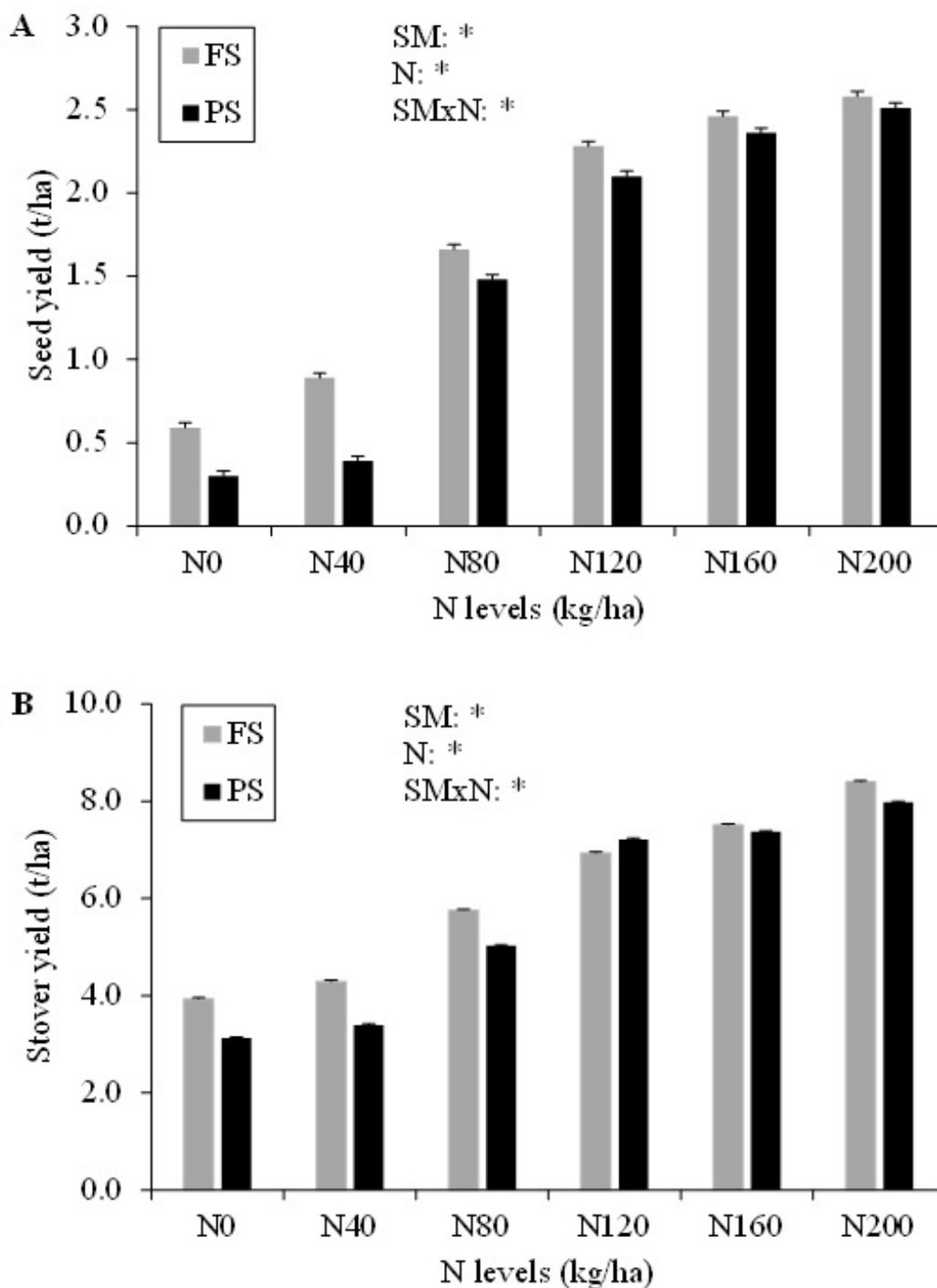


Fig. 4. Pooled mean (n = 6) seed yield (A) and stover yield (B) of spring sunflower crop under different N levels (N0, N40, N80, N120, N160 and N200 kg/ha) and sowing methods (FS = Furrow sowing, PS = Pit sowing). Error bars represent standard deviation. The significant factors (SM and N) and their interaction (SM x N) from the two-way ANOVA are indicated (**p < 0.05) in relation to N levels and sowing methods.

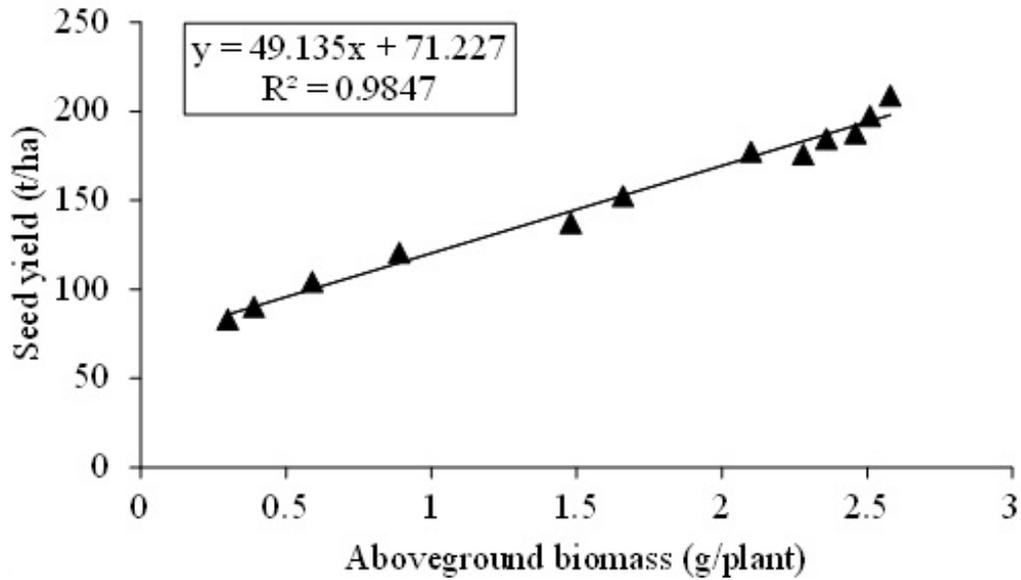


Fig. 5. Relationship between seed yield and aboveground biomass in spring sunflower crop

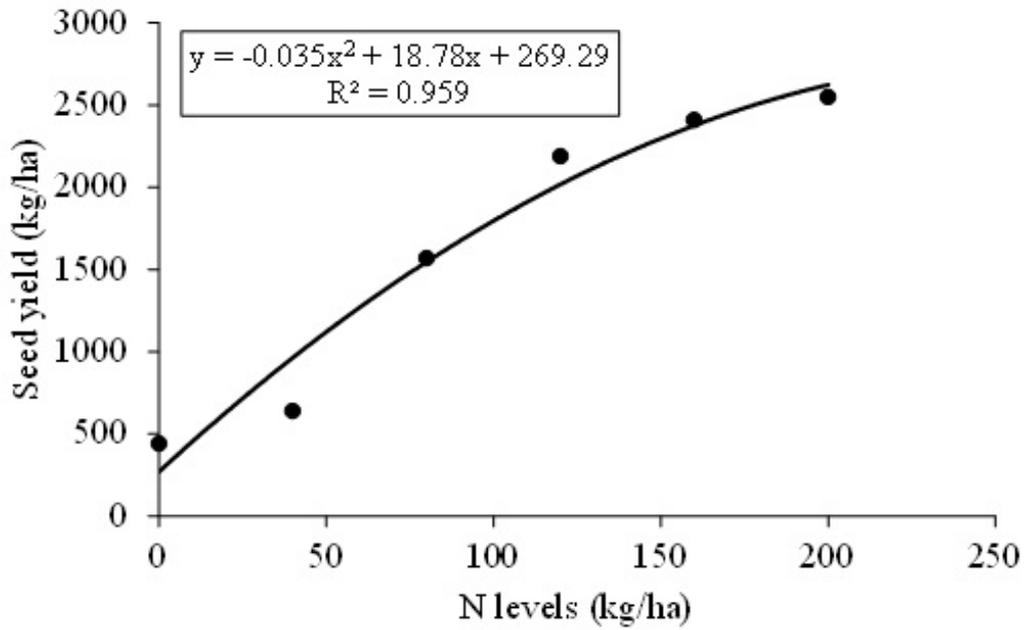


Fig. 6. Functional relationship between N dose and seed yield of spring sunflower crop

Table 2 Assessment of net gain or loss of nitrogen after second year crop-harvest as influenced by sowing methods and N levels in spring sunflower (pooled data of 2 years)

Treatment combination	Initial N (kg/ha) (A)	Fertilizer N (kg/ha) (B)	Total N (kg/ha) C = A + B	Total N uptake (kg/ha) (D)	Expected balance E = C - D	Actual balance* (kg/ha) (F)	Net gain (+) or loss (-) of N (kg/ha) G = F - E
FS × N0	155	NA	155	52.5	102.5	163.1	60.6
FS × N40	155	40	195	77.1	118.0	188.2	70.3
FS × N80	155	80	235	106.8	128.2	194.4	66.2
FS × N120	155	120	275	146.3	128.7	207.0	78.3
FS × N160	155	160	315	179.6	135.4	219.5	84.1
FS × N200	155	200	355	231.1	123.9	232.1	108.2
PS × N0	155	NA	155	38.5	116.5	181.9	65.4
PS × N40	155	40	195	55.2	139.8	194.4	54.6
PS × N80	155	80	235	94.0	141.0	200.7	59.7
PS × N120	155	120	275	136.3	138.7	207.0	68.3
PS × N160	155	160	315	160.5	154.5	225.8	71.3
PS × N200	155	200	355	203.2	151.8	232.1	80.3

*Represents soil test values of N at the end of cropping season; FS = furrow sowing; PS = pit sowing; Subscript digits signify respective dose of N in kg/ha

Table 3 Financial benefit from spring sunflower cultivation as influenced by sowing methods and N levels (pooled data of 2 years)

Treatment combinations	Total cost of cultivation (₹/ha)	Financial benefit (₹/ha)		
		*Gross return (₹/ha)	Net return (₹/ha)	B:C ratio
FS × N0	55277	31480	-23797	0.57
FS × N40	57104	44200	-12904	0.77
FS × N80	57619	77920	20301	1.35
FS × N120	58133	105080	46947	1.81
FS × N160	58976	113440	54464	1.92
FS × N200	59491	120000	60509	2.02
PS × N0	58557	18260	-40297	0.31
PS × N40	60639	22400	-38239	0.37
PS × N80	60899	69260	8361	1.14
PS × N120	61413	98440	37027	1.60
PS × N160	62256	109160	46904	1.75
PS × N200	62771	116360	53589	1.85

FS = furrow sowing; PS = pit sowing; Subscript digits signify respective dose of N in kg/ha; B:C = benefit:cost ratio; *Calculated based on selling price of sunflower seed @ ₹ 40/kg and sunflower stover @ ₹ 2/kg

Seed and stover yield: Furrow sown crops out-yielded crops under pit sowing significantly with respect to both seed (1.8 t/ha) and stover yield (6.1 t/ha), showing 14% and 8% increment over pit-sown crop. A linear positive relationship (Figure 5) was observed between seed yield and aboveground biomass ($R^2 = 0.984$). Therefore, by increasing AGB there is possibility of improving seed yield of spring sunflower. So, the higher AGB production in furrow-sown produced led to better seed yield than that of

pit-sown crop. In addition to that, the furrow sowing provided aerated soil and favourable environment to the plants which helped in efficient utilization of nutrients (Ahmad *et al.*, 2000) and soil moisture (Bindu *et al.*, 2017). Nitrogen (N) application effect was also found to be significant on crop yields. A linear positive relationship (Figure 6) was also observed between seed yield and N levels ($R^2 = 0.96$). The highest seed yield (2.6 t/ha) and stover yield (8.2 t/ha) were obtained with the supply of 200

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kg N/ha, accounting 480% and 132% more than control plot (zero-N). The possible reason for such yield increase with the highest N supply could be production of a greater number of kernels/capitulum, heavier kernels and higher capitulum diameter (Krishnamurthy *et al.*, 2011). In our study, plants in control plots (zero-N) under both sowing methods gave significantly lower amount of stover and seed yields. These results substantiate the findings of Rondanini *et al.* (2007) and Cantagallo *et al.* (2009), who also reported that any shortage in N supply affects growth and development of both source and sink, and finally declines the number of seeds/capitulum. Interactive effect of studied factors (SM x N) on seed and stover yield of test crop were significant (Figure 4A and 4B). The furrow-sown crop raised with 200 kg N/ha produced the highest seed yield (2.6 t/ha) as well as stover yield (8.4 t/ha), registering 3% and 5% more yields than that of pit-sown crop at same N application rate.

Crop nitrogen use efficiency : The tested hybrid sunflower exhibited higher nitrogen use efficiency (as estimated by mean AE, IE, RE, PFP, PNB and NHI) under furrow sowing than that of pit-sowing (Table 1). Prolific root growth under furrow-sowing might have helped the plant to utilize N efficiently. Furrow-sown and pit-sown crop exhibited AEN at a range of 7.6 to 14.1 kg/kg N and 2.3 to 15.0 kg/kg N respectively, IEN at a range of 11.2 to 15.6 kg/kg N and 7.1 to 15.8 kg/kg N respectively, REN at a range of 0.6 to 0.9% and 0.4 to 0.8% respectively, and NHI at a range of 43 to 56% and 41 to 53% respectively. For furrow sown crop, both AEN and IEN were maximum with 120 kg N/ha. But in case of pit sown crop, AEN and IEN were maximum with 120 kg N/ha and 80 kg N/ha, respectively. Both the parameters were found to decrease with further increase in N supply upto 200 kg/ha. Irrespective of sowing methods, PFPN and NHI were maximum with 40 kg N/ha and declined thereafter, indicating poor rate of N utilization at higher dose. Dobermann *et al.* (2003) also observed maximum AEN with low N dose under well managed system. Lower IEN at 200 kg N/ha indicates the luxury consumption of N that may create mineral toxicities due to low internal N conversion rate. Nitrogen, at higher application rate, was subjected to loss by leaching, erosion and denitrification or volatilization and therefore was not utilized fully by the crops (Banerjee *et al.*, 2014), which might have great influence on REN.

Nitrogen balance in post-harvest soil: A balance sheet of N against soil-plant system had been drawn at the end of second year cropping (Table 2). The maximum N-gain of

108 kg/ha (63% higher than RDN) was noticed furrow-sown crop that raised with 200 kg N/ha. However, the N-gain was also satisfactory in plots having pit-sown crop (irrespective of N-levels). This could be attributed to synergistic effect or positive interaction between N and P, and N and K (Zubillaga *et al.*, 2002). The N-gain in post-harvest soil of control plots (zero-N) was less due to exhaustive nature of hybrid sunflower crop (Bodake and Rana, 2009) and low inherent N content of experimental soil (155 kg/ha).

Financial benefit: Economic benefit of spring-planted hybrid sunflower cultivation, in terms of gross return (GR), net return (NR), and benefit:cost (B:C) ratio, was observed to vary with studied factors namely sowing method and N levels (Table 3). Interaction (sowing method × N levels) effect exerted a significant effect on above mentioned economic indicators. The highest GR (₹ 120000/ha) was recorded in furrow-sown crop that received 200 kg N/ha, followed by pit-sown crop at 200 kg N/ha (₹ 116360/ha). Furthermore, furrow-sown crop on receiving 200 kg N/ha fetched the highest NR (₹ 60509/ha) and B:C ratio (2.02), closely followed by furrow-sown crop at 160 kg N/ha (NR ₹ 54464/ha and B:C ratio 1.92). The above response was found due to higher seed and stover yield realized in former case. Total cost of cultivation was found to vary among two sowing methods, and it was more in case of pit-sowing on account of higher labour engagement during seed sowing. So, the higher labour wages in pit-sowing brought down the interaction effect (pit sowing × N levels) on sunflower economics. Alipatra and Banerjee (2018) also found relatively low gross return with poor N supply and high gross return with balanced fertilizer rate.

Summarily, the sunflower crop when grown in spring season is benefitted by following furrow sowing (at 3-5 cm depth) along with 200 kg N supply per ha for achieving higher productivity and nitrogen balance.

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Impact of microwave radiation on sunflower (*Helianthus annuus*) seed germination and seedling growth: Mechanisms, benefits and challenges

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ABSTRACT

This study investigates the germination and growth performance of sunflower seedlings under various microwave irradiation treatments over a 14-day period. The treatments included T1: dry sunflower seeds irradiated with 100 MHz microwave intensity for 5 minutes; T2: dry seeds irradiated with 300 MHz; T3: dry seeds irradiated with 500 MHz; T4: 24 hours pre-soaked seeds irradiated with 100 MHz; T5: 24 hours pre-soaked seeds irradiated with 300 MHz; and T6: 24 hours pre-soaked seeds irradiated with 500 MHz. Germination analysis revealed that on day 4, T4 exhibited the highest germination percentage (35.79%), followed by T5 (43.20%) and T6 (38.88%). By day 10, T5 peaked at 83.94%, significantly outperforming the control group (33.33%). The germination index reached its zenith in T5 (92.59%) by day 12, while the control remained at 40.74%. Mean germination time was longest in T4 (14.00 days) by day 14, and the mean germination rate showed a decline in the control group from 1.23 to 0.07. In the growth analysis, relative growth rates (RGR) steadily increased, with T5 achieving the highest value (0.128) at 75 days. The net assimilation rate (NAR) was initially negative but became positive by day 45, peaking in T4 (0.110). Leaf area ratio (LAR) growth was significant in T5 (0.622) at 75 days, while specific leaf area (SLA) notably increased in all treatments, especially T5 (1.519). The seedling vigor index was highest in T5 (4942.855) at 30 days, compared to the control (722.752). These findings suggest that the combination of 24-hour pre-soaking and 300 MHz microwave irradiation significantly enhances germination, growth, and overall seedling vigor, highlighting its potential for agricultural applications under the studied conditions.

Keywords: Germination, Growth, *Helianthus annuus*, Mechanisms, Microwave irradiation, Yield

Microwave radiation has emerged as a promising technology for enhancing seed germination and seedling growth in various crops, including *Helianthus annuus* (sunflower). Its potential in agriculture lies in its ability to induce physical and biochemical changes in seeds, which can improve water absorption, activate enzymes, and accelerate metabolic processes critical to germination. Studies have shown that microwave irradiation can improve seed vigor, accelerate germination, and enhance early seedling development by altering seed coat permeability and stimulating cellular activities (Aladjadjiyan, 2002; Amirnia, 2014; Wang and Tang, 2001). Microwave energy has been widely studied for its impact on seed germination across multiple crops. Aladjadjiyan (2002) investigated the effects of microwave radiation on ornamental perennial crops and found improvements in vitality indices and electroconductivity, which are key markers of seed health and germination potential. Similar results were observed by Amirnia (2014) in *Glycine max* (soybean) seeds, where microwave exposure significantly improved germination rates and early seedling growth. These findings indicate that microwave treatment can be a valuable tool for enhancing

the growth of economically significant crops like sunflower. Additionally, microwave energy has been utilized for disinfestation and pest control in stored agricultural products (Vadivambal *et al.*, 2007), further supporting its potential application in seed treatment.

The underlying mechanisms of microwave radiation involve its ability to generate heat and electromagnetic energy that penetrate biological materials, affecting seed moisture content and enzymatic activities (Nelson, 1987; Ferriss, 1984). This process may stimulate cell division and elongation in seeds, leading to improved seedling growth. For instance, Talei *et al.* (2013) demonstrated that rice (*Oryza sativa*) seeds treated with microwave radiation exhibited faster germination and more robust seedling growth. In another study, sunflower seeds exposed to microwave radiation showed enhanced water absorption and enzyme activity, both of which are crucial for the early stages of germination (Tran, 1979). However, the effectiveness of microwave treatment depends on several factors, including the duration, frequency, and intensity of exposure. While moderate doses can improve seed vigor, excessive microwave exposure can lead to adverse effects such as cellular damage and reduced germination (Benlloch *et al.*, 2013; Zhao *et al.*, 2012). This dual nature of microwave effects was evident in research on *Triticum aestivum* (wheat), where certain levels of microwave radiation improved germination rates, but higher doses

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caused a decline in seed viability (Abu-Elsaoud and Qari, 2017). Thus, determining the optimal microwave exposure parameters is critical for maximizing its benefits while minimizing potential harm.

Moreover, microwave radiation has been compared with other physical seed treatments, such as radiofrequency (RF) radiation and conventional thermal treatments. These studies suggest that microwaves offer a more efficient and controlled method for stimulating seed germination without the extensive heat buildup associated with conventional thermal processes (Mohsenkhah *et al.*, 2018; Talei *et al.*, 2013). In particular, microwave treatments have been shown to enhance germination and seedling growth while preserving the seed's internal structure, offering an advantage over more invasive techniques (Howard *et al.*, 2000). In sunflower (*Helianthus annuus*), seed germination and early growth are critical factors that influence final crop yield. Microwave radiation has the potential to optimize these early developmental stages, improving both germination speed and uniformity. Research by Szopinska and Dorna (2021) on carrot (*Daucus carota*) seeds supports the idea that microwave treatments can increase germination rates and enhance seed health by reducing microbial contamination and seed dormancy. The present study aims to evaluate the effects of microwave radiation on sunflower seed germination and seedling growth. By examining both the benefits and challenges of this treatment, we hope to provide insights into the mechanisms underlying microwave-induced seed enhancement and its potential applications in sustainable agriculture.

MATERIALS AND METHODS

Land preparation: Sunflower requires loose and friable soil for the germination of seed. The soil is brought to fine tilth by ploughing 4-5 times followed by planking after each ploughing. Field was made free from weeds and stubbles of previous crop and added 250 kg of farm yard manure along with 500 kg of commercial red soil and allowed for final ploughing. The soils samples were collected according standard sampling procedure described by Gandhi *et al.* (2022a); Smita *et al.* (2013); Priyamvada *et al.* (2012) to understand the fertility status of the soil used for cultivation of sunflower during *kharif* season.

Soil and water analysis: Soil samples were collected randomly from the 7 sampling points and mixed thoroughly to get a composite soil sample and analyzed for soil quality parameters according to standard testing procedures described by Gandhi *et al.* (2022b), Priyamvada *et al.* (2013), Gandhi *et al.* (2015). Bore well water was used as source for irrigation throughout the crop production and

collected water sample in pre cleaned plastic water bottles and allowed for analysis water quality parameter according to standard testing procedures described by Gandhi *et al.* (2020a).

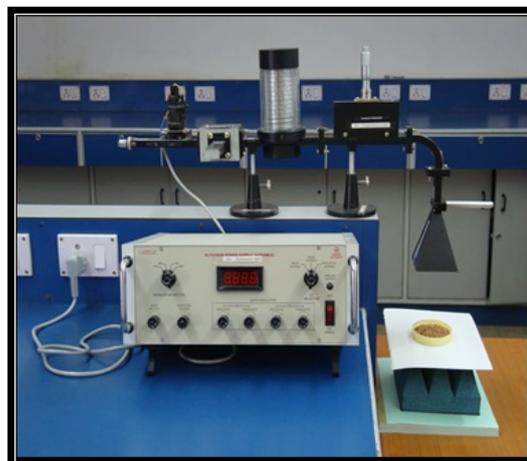


Fig. 1. Microwave irradiation of dry and pre-soaked sunflower seeds



Fig. 2. Systematic classification of sunflower

Selection and Treatment of Seeds: The sunflower (*Helianthus annuus*) is a tall, annual herbaceous plant in the Asteraceae family, known for its large, bright yellow flower head. It has a rough, hairy stem and broad, heart-shaped leaves arranged alternately (Figure 2). The flower head, up to 30 cm in diameter, consists of sterile outer ray florets and fertile inner disk florets arranged in a Fibonacci spiral. Sunflowers are pollinated mainly by bees, and their seeds, rich in oil, are valuable for consumption and oil extraction. Widely cultivated for agriculture and ornamental purposes, sunflowers also play a role in phytoremediation, absorbing heavy metals from soils. The sunflower (*Helianthus annuus*)

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hybrid DRSH-1 (ICAR-IIOR) was used for the current study, with seeds divided into two groups. Group 1 seeds were further categorized as T1, T2 and T3, subjected to microwave irradiation at 100 MHz, 300 MHz, and 500 MHz for 5 minutes. Group 2 seeds were categorized as T4, T5 and T6, where seeds were soaked in normal tap water for 24 hours before being irradiated at the same frequencies and durations, labeled as T4, T5 and T6 (Figure 1 and 3). A

control group of untreated seeds was included for comparison. These treatments were designed to assess the effects of microwave radiation and soaking on sunflower seed germination, growth, and biochemical responses. The results of this study could provide insights into optimizing sunflower cultivation and improving seed quality through innovative treatment methods.

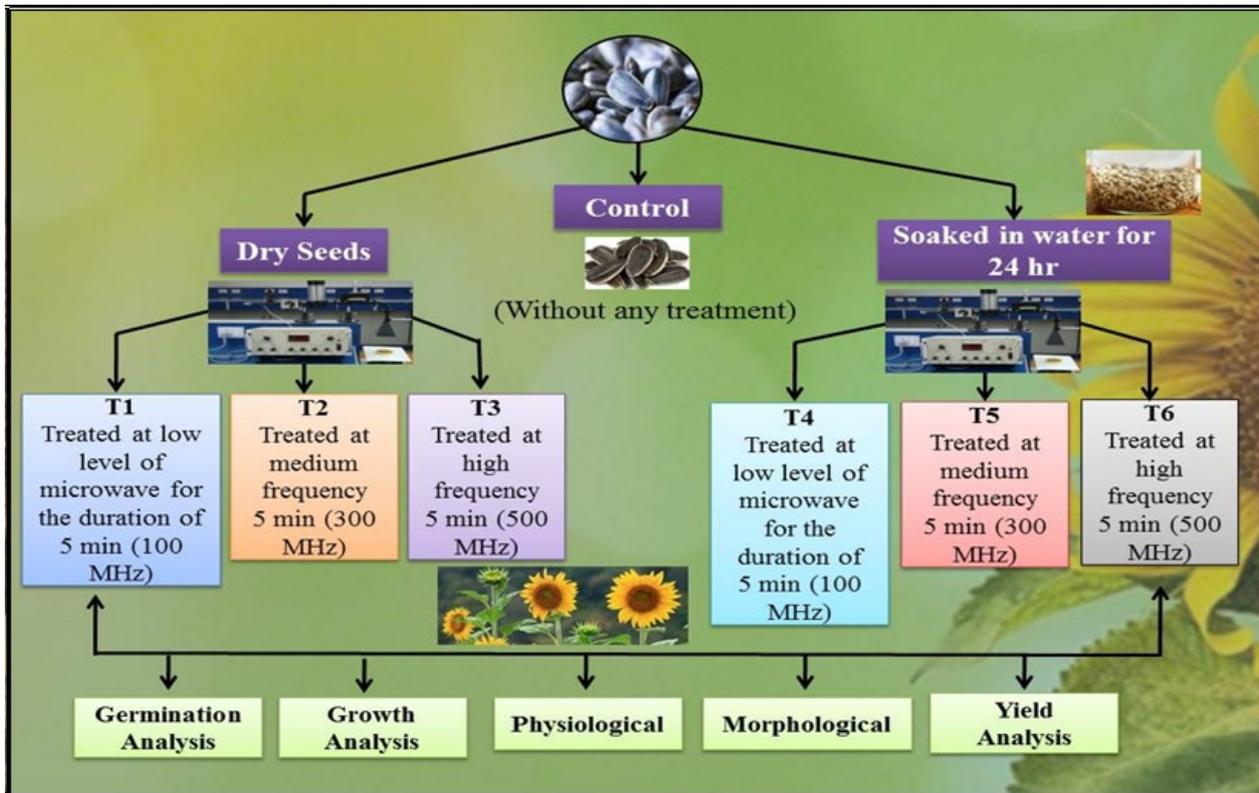


Fig. 3. Schematic diagram of the experimental workflow to study the impact of microwave irradiation on sunflower crop growth and yield

Seed sowing and Irrigation: The seeds were sown at a depth of 3 cm, with two seeds placed per hole along the furrows. A spacing of 60 x 30 cm was consistently maintained across the field to ensure optimal plant growth. Irrigation was administered immediately after sowing, followed by a second irrigation on the 4th day. Subsequent irrigation was provided at regular intervals of 4 to 5 days to maintain adequate soil moisture levels. This systematic irrigation schedule was designed to support seed germination and promote healthy plant development throughout the growing period.

Weather monitoring: Weather monitoring during the *kharif* season was conducted using a digital thermo-hygrometer to record temperature and humidity,

and a rain gauge to measure rainfall. The equipment was placed in an open, unobstructed area within the field, mounted at a height of approximately 1.5 to 2 meters. Temperature and humidity were recorded at regular intervals (8:00 AM, 12:00 PM, and 4:00 PM), while rainfall was measured daily at 8:00 AM. Calibration of the instruments was performed according to the manufacturer's instructions, and regular maintenance was ensured to avoid any data inaccuracies. The collected weather data was systematically logged and analyzed for trends throughout the growing season.

Germination analysis :Seed germination was recorded when the radicle had grown beyond 2 mm in length. The rate of germination, referred to as the Seed Germination Rate, was determined by the number of seeds that

germinated per unit of time. Germination Percentage (GP) and growth Index (GI), Mean germination time (MGT), Mean germination rate (MGR) and co-efficient of variation (CV) were calculated using the following formulas, tabulated in Table 1 (Gandhi *et al.*, 2015).

Growth analysis: To evaluate plant growth parameters, specific data points were collected to calculate instantaneous and mean values over time. Dry weights of the total plant (W), leaves (WL), stem (WS), and roots (WR), along with leaf area (A), were recorded to analyze various growth indices, as shown in Table 2. The Relative Growth Rate (RGR), defined by Blackman, was calculated to assess the rate of increase in dry matter relative to existing biomass, serving as an overall indicator of growth efficiency (Gandhi *et al.*, 2020b). The Net Assimilation Rate (NAR), representing the net carbon gain from photosynthesis minus respiration, was analyzed by periodically measuring dry weight and leaf area. NAR is expressed as dry weight gain per unit leaf area. The Leaf Area Ratio (LAR), calculated by dividing leaf area by total plant dry weight, provided insight into the portion of the plant involved in photosynthesis, while the Leaf Weight Ratio (LWR), the ratio of leaf dry weight to total plant dry weight, served as a dimensionless index of leafiness on a weight basis (Gandhi *et al.*, 2020a). Specific Leaf Area (SLA), the ratio of leaf area to leaf dry weight, was measured to assess leaf density, while Specific Leaf Weight (SLW), the reciprocal of SLA, provided insights into leaf thickness. Leaf Area Duration (LAD) was calculated to evaluate the persistence and contribution of leaf area to plant productivity over time (Gandhi *et al.*, 2019).

Physiological analysis

The inhibition of seedling growth was evaluated by comparing the reduction in growth between treated and control plants, enabling an assessment of the inhibitory effects of various treatments. Seedling vigor, indicating a seed's ability to perform during germination and emergence, was measured using the seedling vigor index (SVI). This index links germination success to seedling growth, providing a holistic view of early plant development in terms of both quantity and quality. To assess the resilience of seedlings under stress, tolerance indices were calculated, offering insight into how much growth was maintained in adverse conditions. These indices quantified the seedlings' ability to withstand and continue growing despite stress. Additionally, percentage phytotoxicity was determined to examine the effects of heavy metals on sunflower root and shoot growth, monitored over intervals from 15 to 120 days. This metric helped assess the toxic impacts of heavy metals, providing critical insights into the extent to which plant growth was

inhibited by these stress factors. The combined evaluations of growth inhibition, SVI, tolerance indices, and phytotoxicity offered a comprehensive understanding of seedling performance under both normal and stressful conditions, shedding light on key growth and resilience characteristics of the seeds.

Morphological analysis: In this experiment, various growth parameters were measured to assess plant growth and productivity, including shoot length, root length, fresh weight, dry weight, leaf number and morphology, flower count, and pod count per plant. Shoot length was measured periodically from soil level to the tip of the highest shoot, with the final measurement taken at harvest. For root length, plants were uprooted, and the longest root was measured after cleaning off soil particles. Fresh weight of shoots, roots, and leaves was recorded immediately post-harvest, ensuring minimal moisture loss. After weighing, samples were dried in a hot air oven at 70°C for 48 hours until constant weight was achieved, and dry weight was recorded. The number of leaves per plant was counted manually, noting leaf morphology such as shape and color. Flower counts were conducted daily during the flowering phase, documenting any variations. Pod counts were recorded at the end of pod development, ensuring all fully developed pods were counted, with observations on pod size and appearance for quality assessment. Measurements were taken at regular intervals throughout the experiment to monitor growth and development.

Yield analysis: In this study, seed yield, relative percentage of enhancement, and crop productivity were evaluated to assess plant performance under various experimental conditions. Mature seeds were harvested from fully developed pods, cleaned to remove moisture, and weighed using an electronic balance for precision. Average seed yield for each treatment was calculated by summing individual yields and dividing by the number of plants. To compare treated plants with the control group, the relative percentage of enhancement in seed yield was determined using the formula given in Table 4. This quantified the impact of treatments on seed yield. Crop productivity was assessed by measuring total biomass and seed yield per unit area, expressed as yield per hectare. The harvest index was calculated by dividing economic yield (seed yield) by total biological yield (above-ground biomass), indicating the efficiency of biomass conversion into reproductive output. All measurements were conducted meticulously to ensure accuracy, and the collected data were analyzed to draw conclusions about the impact of treatments on seed yield and overall crop performance.

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Table 1 Empirical formulas used to calculate germination analysis of sunflower treated with different frequencies of microwave during *kharif* cultivation

S.No.	Formulas used to calculate growth parameters
01	$\% \text{ of Germination} = \frac{\text{Number of Seeds Germinated}}{\text{Total Number of Seeds Planted}} \times 100$
02	$\text{Germination Index (GI)} = \sum_{i=1}^k \frac{\text{No. of germinated seeds}}{\text{the count day}}$ Where i=1 day one, k is the last day of observation
03	$\text{Mean Germination Time (MGT)} = \frac{\sum_{i=1}^k n_i t_i}{\sum_{i=1}^k n_i}$ Where t_i is the time from day one to the last day of observation, n_i is an observed number of germinated seeds every day and k is the last germination day of observation.
04	$\text{Mean Germination Rate (MGR)} = \frac{1}{\text{Mean Germination Time}}$
05	$\text{Co-efficient of variation of the time} = \frac{S_t}{\text{Mean Germination Time}} \times 100$

Table 2 Empirical formulas used to calculate growth analysis of sunflower treated with different frequencies of microwave during *kharif* cultivation

S.No	Formulas used to calculate growth parameters
01	$\text{Relative Growth Rate} = \frac{\log_e W_2 - \log_e W_1}{T_2 - T_1}$
02	$\text{Net Assimilation Rate} = \frac{W_2 - W_1}{T_2 - T_1} \times \frac{\log_e A_2 - \log_e A_1}{A_2 - A_1}$ Where W_1, W_2 are dry weight of seedlings, at time T_1 and T_2 respectively. A_1 and A_2 are leaf area at time T_1 and T_2 .
03	$\text{Leaf Area Ratio} = \frac{A}{W}$
04	$\text{Leaf Weight Ratio (LWR)} = \frac{W_L}{W}$ Where W is total dry weight of seedling and W_L is dry weight of leaves at time t
05	$\text{Specific Leaf Area (SLA)} = \frac{A}{W_L}$
06	$\text{Specific Leaf Weight (SLW)} = \frac{W_L}{A}$
07	$\text{Leaf Area Duration (LAD)} = \frac{LA_1 + LA_2 (T_2 - T_1)}{2}$

Table 3 Empirical formulas used to calculate physiological analysis of sunflower treated with different frequencies of microwave during *kharif* cultivation

S.No	Formulas used to calculate growth parameters
01	$Tolerance\ indices = \frac{Mean\ root\ length\ of\ treated\ seed}{Mean\ root\ length\ of\ control}$
02	$percentage\ of\ inhibition = \frac{Length\ of\ control - Length\ of\ treated\ seed}{Length\ of\ control} \times 100$
03	$Percentage\ of\ Phytotoxicity = \frac{\frac{S}{R} length\ of\ control - \frac{S}{R} length\ of\ treated\ seed}{\frac{S}{R} length\ of\ control} \times 100$
04	Seed vigor index = Germination percentage × Seedling length

Table 4 Empirical formulas used to calculate yield and productivity analysis of sunflower treated with different frequencies of microwave during *kharif* cultivation

S.No.	Formulas used to calculate growth parameters
01	$Crop\ growth\ rate = \frac{W_2 - W_1}{T_2 - T_1} \times \frac{1}{P}$
02	$Crop\ productivity = \frac{Crop\ yield}{Duration\ of\ crop}$
03	$Relative\ production\ efficiency = \frac{EYD - EYE}{EYE} \times 100$ EYD- Equivalent yield under improved /diversified system EYE- Existing system yield

Statistical analysis: Principal Component Analysis (PCA) was employed to interpret the observed data related to the impact of microwave radiation on the germination and seedling growth of *Helianthus annuus* (sunflower) during the *kharif* season. The objective of PCA was to reduce the dimensionality of the dataset while retaining the variability present in the data, thereby facilitating the identification of patterns and relationships among the measured parameters. The dataset included various growth metrics, such as seed germination rate, shoot length, root length, fresh weight, dry weight, leaf number, and morphological traits of the seedlings. Prior to conducting PCA, the data were standardized to ensure that each variable contributed equally to the analysis, preventing biases due to differences in measurement scales. This standardization involved transforming the raw data into z-scores, which represent the number of standard deviations each observation is from the mean. Following data standardization, the covariance matrix was calculated to identify the relationships between the variables. Eigenvalues and eigenvectors were then

derived from the covariance matrix to determine the principal components. The eigenvectors corresponding to the largest eigenvalues represented the directions in which the data varied the most. These principal components were extracted and analyzed to assess the contribution of each original variable to the overall variance. The first few principal components were examined for their cumulative variance explained, which indicated the extent to which they captured the variability in the dataset. A scree plot was generated to visually assess the eigenvalues of the principal components, aiding in the decision of how many components to retain for further analysis.

RESULTS AND DISCUSSION

Germination analysis: This study examined the effects of microwave irradiation and pre-soaking on sunflower seed germination under controlled conditions (25°C, 80% RH) during *kharif* cultivation. Sunflower seeds, either dry and pre-soaked for 24 hours, were irradiated at frequencies of

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100 MHz, 300 MHz, and 500 MHz for 5 minutes, and compared to a control group. The experiment focused on GP, GI, MGR, MGT, and CV to assess uniformity. The observed germination percentage illustrated in Figure 4. From the figure it is observed that germination was delayed until day 4 for all treatments. Pre-soaked seeds irradiated at 300 MHz (T5) exhibited the highest germination rates throughout the experiment, starting at 43.20% on day 4 and reaching 94.44% by day 14. Pre-soaked seeds irradiated at 500 MHz (T6) followed closely, with a final germination rate of 85.19%. Dry seed treatments lagged behind, with T2 (300 MHz) showing the highest germination rate among them at 81.48% by day 14. The control group showed significantly lower germination, with only 42.59% at the end of the observation period. Germination indices mirrored these trends (Figure 5), with T5 consistently demonstrating superior performance. Microwave irradiation, particularly at 300 MHz, combined with pre-soaking, significantly enhanced germination speed and uniformity. In contrast, dry seed treatments and higher microwave intensities showed slower or less consistent germination, indicating that pre-soaking and moderate microwave exposure are optimal for improving seed germination.

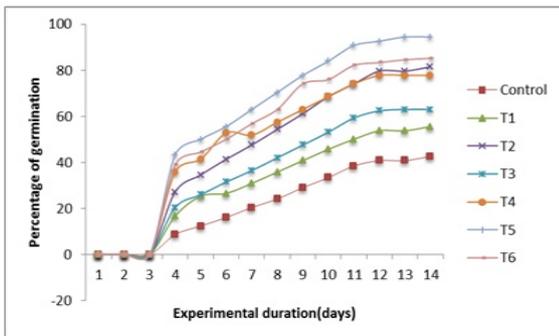


Figure 4. Sunflower germination percentage under different microwave frequencies during *kharif* cultivation

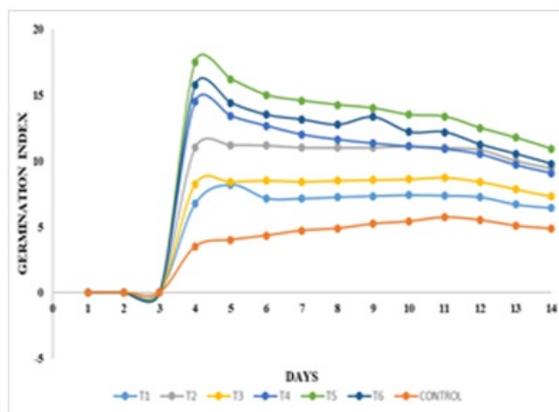


Figure 5. Germination Index of sunflower exposed to various microwave frequencies during *kharif* cultivation

MGR obtained results were shown in Figure 6. From the figure it is concluded that pre-soaked seeds irradiated at 300 MHz (T5) consistently showed the highest MGR, particularly in the early stages, reaching an MGR of 1.23 by day 4. In contrast, dry seed treatments and the control group had slower MGRs, with the control starting at 0.54. By day 14, the MGR across all treatments had stabilized at 0.07, marking the completion of germination. MGT observations were graphically represented in Figure 6. The obtained results are reveals that pre-soaked seeds irradiated at 300 MHz (T5) exhibited faster germination, with an MGT of 1.82 by Day 4, significantly faster than dry seeds or the control (0.81). This trend continued throughout the experiment, with T5 maintaining the lowest MGT of 4.66 by Day 10, indicating quicker germination compared to dry seeds, which had a higher MGT and slower overall germination. CV values were calculated by the standard empirical formula and the results were graphically shown in Figure 7. Pre-soaked seeds irradiated at 300 MHz (T5) also demonstrated the lowest CV, indicating uniform germination. On Day 4, T5 had a CV of 25.87, while the control exhibited a high variability of 93.75, indicating less uniform germination. Dry seeds showed greater variability across all treatments. The CV decreased as the experiment progressed, but T5 consistently maintained better uniformity compared to other treatments.

Growth Analysis: The RGR values for the treated plants were consistently higher than the control throughout the study (Figure 8). At 15 days, the control had the lowest RGR of 0.001, while irradiated treatments ranged from 0.062 to 0.072. T5, which was pre-soaked and irradiated at 300 MHz, showed the highest RGR at all intervals. By Day 75, the control's RGR improved slightly to 0.075 but still lagged behind the irradiated plants, indicating that microwave treatment accelerates biomass accumulation, especially during the early growth stages. The NAR, which measures the plant's ability to assimilate dry matter relative to its leaf area, also varied significantly between the treatments and the control (Figure 8). At 15 days, the control group showed a negative NAR (-1.383), reflecting poor assimilation efficiency. In contrast, T5 and T6 had much lower negative values (-0.072 and -0.098, respectively), indicating that microwave irradiation mitigated the early inefficiency in dry matter assimilation. By 30 days, all treatments exhibited positive NAR values, with T5 and T4 (300 MHz) achieving the highest values of 0.083 and 0.299, respectively. This trend continued through Day 45, with irradiated treatments maintaining stable NAR, while the control demonstrated only modest improvements by Day 75.

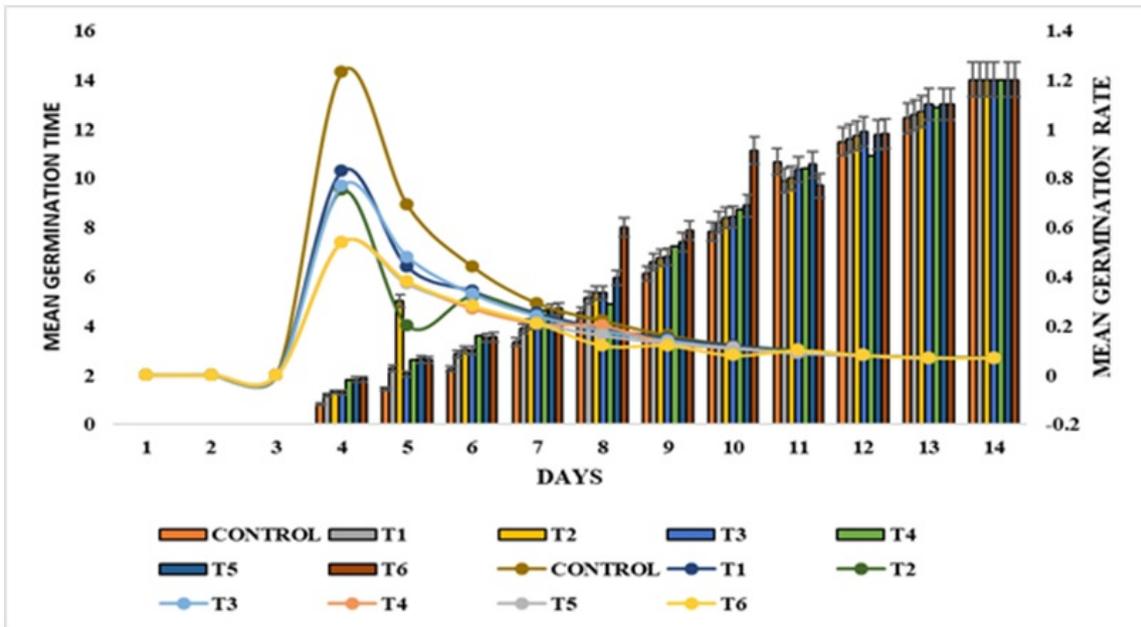


Figure 6. MGT and MGR of sunflower exposed to different microwave frequencies during *kharif* cultivation

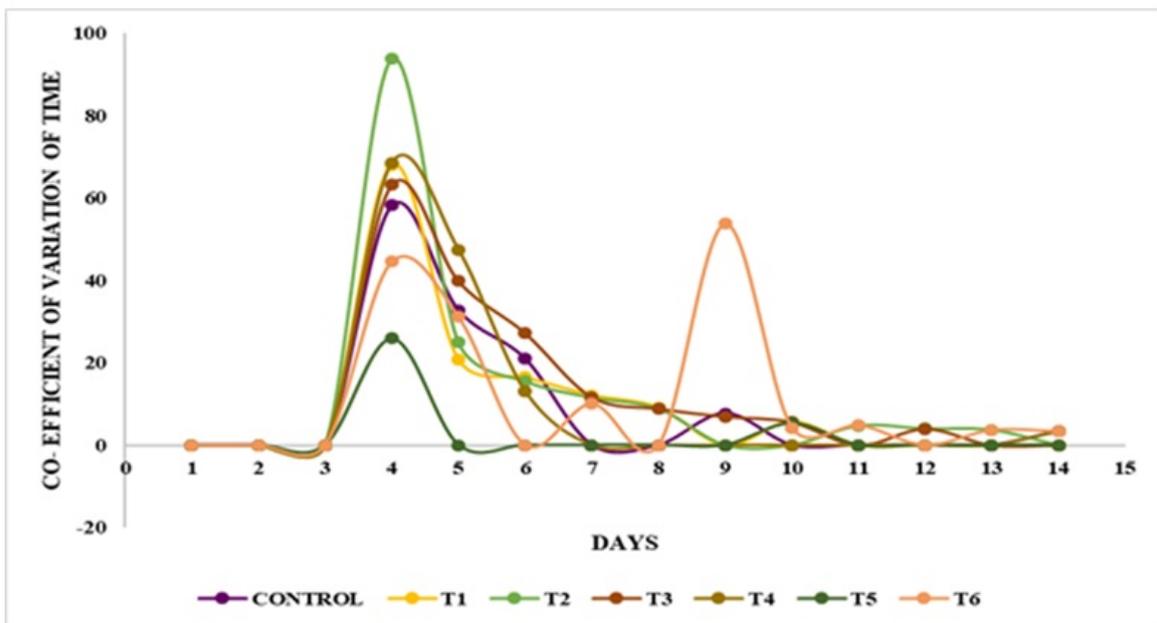


Figure 7. Co-efficient of variation of time of sunflower exposed to different microwave frequencies during *kharif* cultivation

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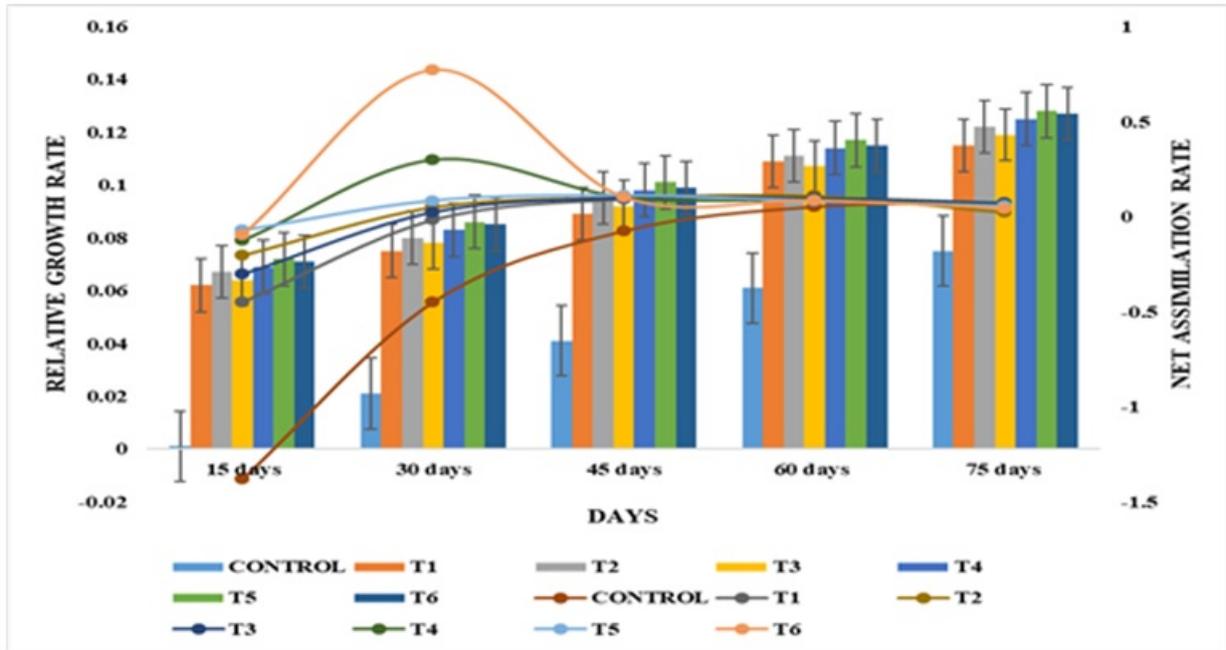


Figure 8. RGR and NAR of sunflower exposed to different microwave frequencies during *kharif* cultivation

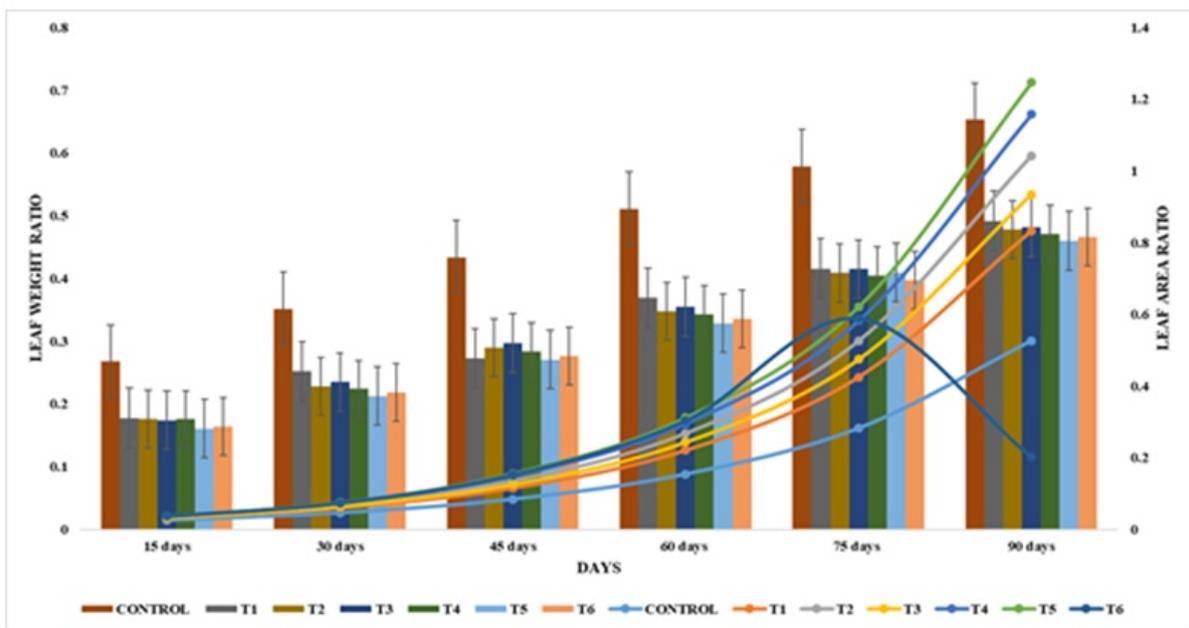


Figure 9. LAR and LWR of sunflower exposed to different microwave frequencies during *kharif* cultivation

The LAR, representing the leaf area per unit of plant biomass, was another parameter showing significant variation across treatments (Figure 9). At 15 days, the control had the lowest LAR (0.026), whereas irradiated treatments such as T5 and T6 reached values of 0.037. By Day 90, T5 and T6 continued to display the highest LAR values (1.247 and 1.158, respectively), while the control group showed significantly lower values (0.527). These findings suggest that microwave irradiation promotes both early and sustained leaf expansion, resulting in larger leaf areas relative to biomass. This increase in leaf area likely contributed to the higher RGR and NAR observed in irradiated plants. In terms of the LWR, which measures the leaf mass relative to total plant mass, the control group consistently showed higher values compared to the irradiated plants throughout experimental period (Figure 9). At 15 days, the control exhibited a LWR of 0.268, significantly higher than T5 (0.161) and T6 (0.164). By Day 90, the control reached 0.653, while the irradiated treatments displayed lower values ranging from 0.460 to 0.482. These lower LWR values in irradiated plants suggest a more balanced biomass distribution between leaves and other plant parts, contributing to more robust overall growth.

SLA, which indicates leaf area per unit of leaf mass, was also higher in irradiated treatments compared to the control (Figure 10). At 15 days, the control group had an SLA of 0.096, whereas T5 and T6 showed much higher values of 0.227 and 0.224, respectively. By Day 90, T5 exhibited the highest SLA value of 2.710, while the control remained much lower at 0.807. This increase in SLA suggests that irradiated plants produced thinner, more expansive leaves that could capture more light, enhancing photosynthesis efficiency.

Conversely, the SLW, which measures leaf thickness, showed an inverse trend compared to SLA (Figure 10). The control group had the highest SLW values at all stages, beginning with 10.427 at 15 days and decreasing to 1.239 by Day 90. In contrast, irradiated treatments showed consistently lower SLW values, with T5 exhibiting the lowest. This indicates that microwave irradiation led to thinner, more efficient leaves, further contributing to improved growth. LAD, which quantifies the cumulative leaf area available for photosynthesis over time, revealed a substantial advantage for the irradiated treatments (Figure 11). At 15 days, the control group had a LAD of 1.943, while T5 and T6 had much higher values of 13.410 and 12.375, respectively. By Day 75, T5 reached a LAD of 497.708, compared to only 71.070 for the control group. The higher LAD values in irradiated plants suggest that these plants maintained a larger photosynthetically active leaf area for a longer duration, contributing to their

superior growth performance. The overall impact of microwave irradiation on germination and growth parameters of sunflower represented in Figure 12.

Physiological Analysis: The study investigates various tolerance indices, percentage of inhibition, SVI and phytotoxicity in sunflower plants subjected to microwave irradiation over 120 days period. Tolerance indices were calculated to assess the plant's ability to withstand microwave-induced stress, with irradiated treatments (T1-T6) showing consistently high tolerance throughout the study (Figure 13). The treatment T5 (pre-soaked, irradiated at 300 MHz) exhibited the highest tolerance index, peaking at 2.077 after 15 days and decreasing slightly to 1.972 by day 90, indicating that T5 is the most resilient to microwave stress. The gradual decrease in tolerance indices across all treatments suggests that the plants adjusted to microwave-induced stress over time, particularly during the early growth stages. Among all treatments, T1, which received the least irradiation, displayed the lowest tolerance index, implying that higher levels of microwave exposure contribute to improved stress tolerance in sunflower plants. The study examined the percentage of phytotoxicity to assess any toxic effects caused by microwave irradiation presented in Figure 13. Most treatments showed negative phytotoxicity percentages, suggesting that the plants experienced growth stimulation rather than toxic stress. At 15 days, T5 exhibited a phytotoxicity percentage of -16.650, the most negative value among the treatments, indicating minimal toxic effects and significant growth promotion. As the plants matured, phytotoxicity percentages became slightly positive for T5 and T6 by day 90 (3.362 and 3.437, respectively), suggesting a mild increase in toxicity after prolonged exposure, although the overall impact remained minor, with plants continuing to show robust growth.

The percentage of inhibition was also evaluated to determine the extent to which growth was hindered by microwave irradiation (Figure 14). Surprisingly, the data revealed negative inhibition percentages for all treatments, indicating that microwave exposure stimulated rather than inhibited growth. T5 exhibited the highest negative percentage of inhibition (-135.357) at 15 days, highlighting accelerated growth due to microwave treatment. This growth stimulation trend continued over time, with T5 and T6 maintaining the most substantial negative inhibition percentages at 90 days (-106.923 and -86.282, respectively), suggesting that moderate to high levels of microwave irradiation significantly boost growth. SVI further supported the beneficial effects of microwave irradiation on sunflower growth (Figure 15). At 15 days, T5 showed the highest SVI (3771.934), reflecting strong early development. By day 90, T5's SVI increased dramatically

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to 15242.616, while T6 followed closely at 12378.110, indicating that moderate to high microwave intensities greatly enhance seedling vigour and overall plant health. The rising SVI values across all treatments over time further demonstrate the positive impact of microwave exposure on sunflower development.

Morphological Analysis: The morphological analysis of sunflower plants exposed to microwave radiation revealed significant growth improvements over a six-day period. Root length showed the most pronounced increase in treatments T5 (29.98 cm) and T6 (29.12 cm), nearly doubling the control's 15.20 cm (Figure 16). Shoot length also increased significantly, with T5 (131.42 cm) and T6 (116.18 cm) outperforming the control (62.80 cm), indicating enhanced nutrient mobilization and photosynthesis (Figure 16). Similarly, the number of leaves increased in T5 (36.78) and T6 (32.51) compared to the control (17.56), likely due to accelerated cell division (Figure 17). Leaf length and width were larger in T5 (52.93 cm, 24.34 cm) and T6 (46.89 cm, 20.97 cm) compared to the control (27.32 cm, 9.49 cm), resulting in a higher leaf area for irradiated plants (Figure 18 and 19). Fresh and dry weights followed the same trend, with T5 (84.46 g fresh, 37.78 g dry) and T6 (81.56 g fresh, 36.14 g dry) nearly doubling the control, suggesting improved biomass accumulation (Figure 20). Seedling length also increased, with T5 (161.40 cm) and T6 (145.30 cm) performing significantly better than the control (78.06 cm). Overall, microwave irradiation, particularly T5, consistently promoted sunflower growth across all parameters (Figure 21).

The yield and productivity analysis of microwave-irradiated sunflower plants showed significant enhancements across various parameters. T6 had the highest seed test weight at 55.42 g, followed by T5 at 52.51g, both exceeding the control's 53.96 g, indicating improved seed quality. For seed yield, T6 (21.31 g) outperformed the control (20.74 g) and all other treatments, reflecting better plant health and vigor due to microwave exposure. T5 also showed a competitive yield of 20.18 g. The relative percentage of enhancement (R-P-E) further highlights T6's effectiveness, with an R-P-E of 91.121%, significantly surpassing the control. Other treatments, such as T5 (80.987%) and T3 (76.682%), also demonstrated substantial improvements. In terms of crop productivity, T6 achieved the highest at 0.178 kg/m², closely followed by T5 at 0.168 kg/m², while the control yielded 0.173 kg/m². These results indicate that microwave irradiation enhances individual plant performance and overall yield potential, benefiting commercial sunflower production (Figure 22).

Soil and water analysis: The soil profile indicates a predominantly clayey texture with 53% clay, 38% dust, and only 6% sand. The soil has good total pore space (40.64%) and moderate permeability (5.92 cm/h), suggesting adequate water movement. The specific gravity and volume weight are 2.05 g/cc and 1.32 g/cc, respectively, showing typical soil density. Chemically, the soil is slightly alkaline with a pH of 7.3 and low electrical conductivity (0.01 dS/m), indicating minimal salinity. The organic matter content is 1.09%, and nutrient availability is moderate with phosphorus at 57.4 mg/kg, potassium at 64.2 mg/kg, and nitrogen at 72.3 mg/kg. The CaCO₃ content is 2.98%, which may affect soil structure and nutrient availability.

Weather report during experimental duration: The weather report from October 2022 to early March 2023 shows fluctuating humidity, rainfall, and temperature patterns. Humidity remained high, generally above 85%, peaking at 92.71% in early January. Rainfall occurred mostly in October, with significant precipitation of 96.4 mm during the second week, followed by dry weeks from November onward. Maximum temperatures ranged between 28°C to 33.5°C, while minimum temperatures showed a steady decline in November and January, reaching as low as 10.35°C in mid-January. The weather stabilized with higher temperatures in February and early March (Figure 23).

The PCA results of germination analysis (Figure 24) suggest that PC1 (with high values like 3.32 for DAYS and 1.43 for Percentage of Germination) explains the majority of variation, likely representing a primary factor influencing germination metrics overall. PC2 captures unique aspects, notably for Germination Index and Mean Germination Rate (with high positive loadings in PC2), suggesting these variables have distinct characteristics not captured in PC1. Positive and negative values in PC2, such as the opposite loadings of Mean Germination Rate and Mean Germination Time, indicate diverse influences across metrics, particularly in how time-related variables behave. The PCA results of growth analysis (Figure 25) indicate that PC1 explains the most variation in the data, with high values for DAYS and RGR, pointing to a major underlying factor impacting overall growth and leaf traits. PC2 highlights unique characteristics of NAR and SLW, which show negative and positive loadings, respectively, suggesting these variables are influenced differently than those in PC1. Positive and negative PC2 loadings across leaf traits imply diverse growth dynamics, particularly in how specific growth and leaf weight ratios interact with leaf area measures.

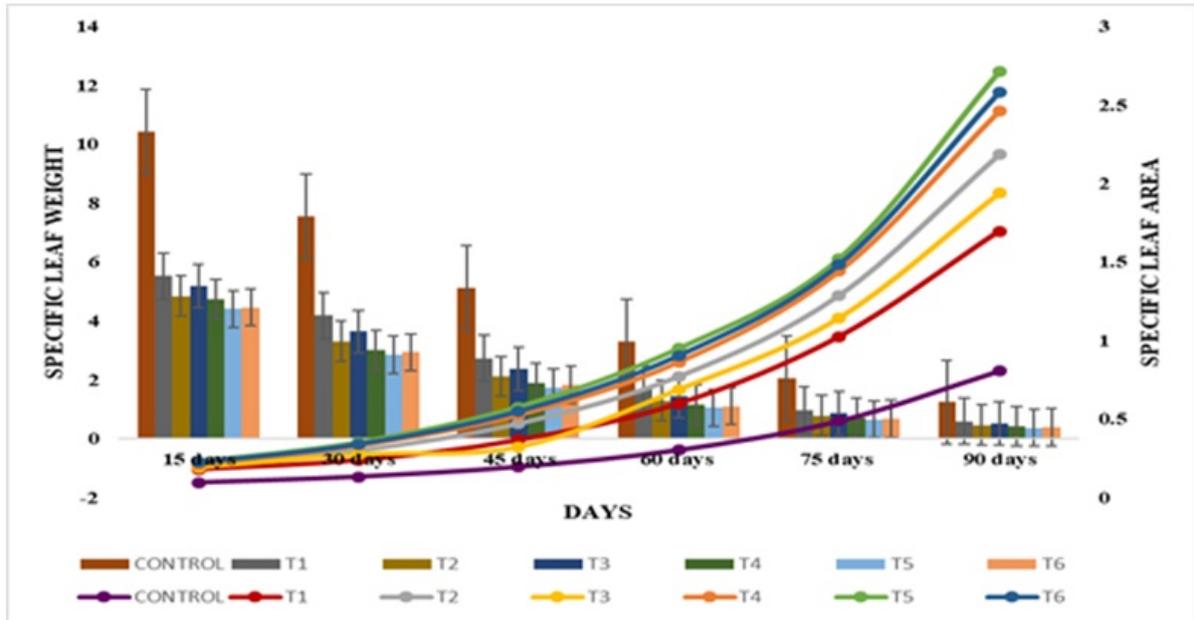


Figure 10. SLA and SLW of sunflower exposed to different microwave frequencies during *kharif* cultivation

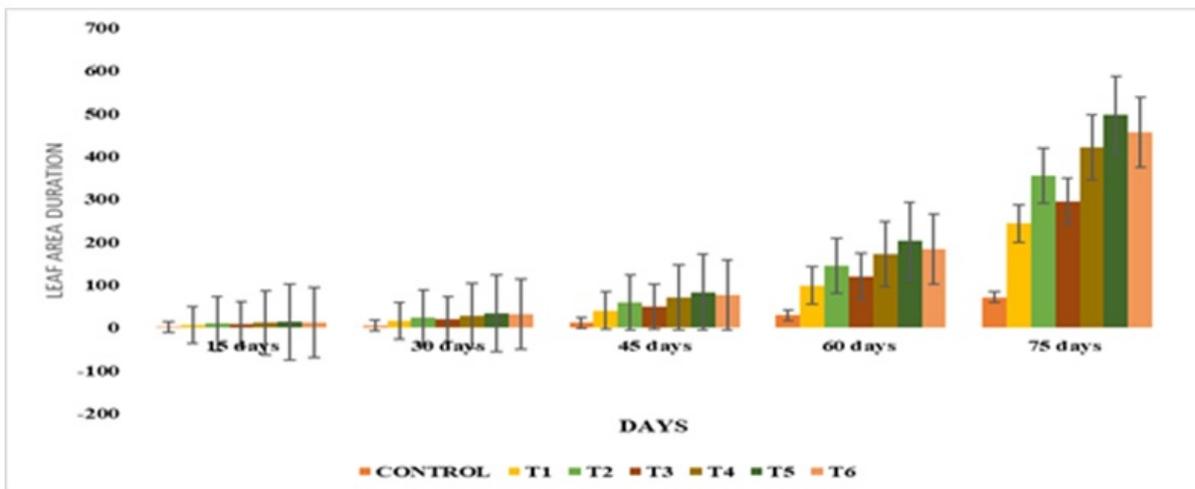


Figure 11. LAD of sunflower exposed to different microwave frequencies during *kharif* cultivation

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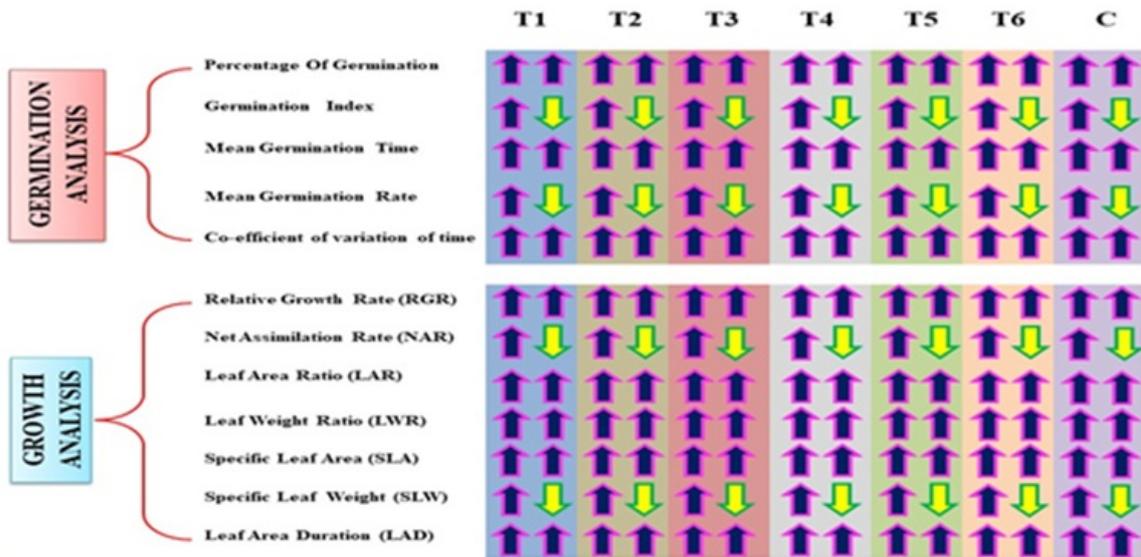


Figure 12. Change in germination and growth parameters of sunflower under different frequencies of microwave irradiation

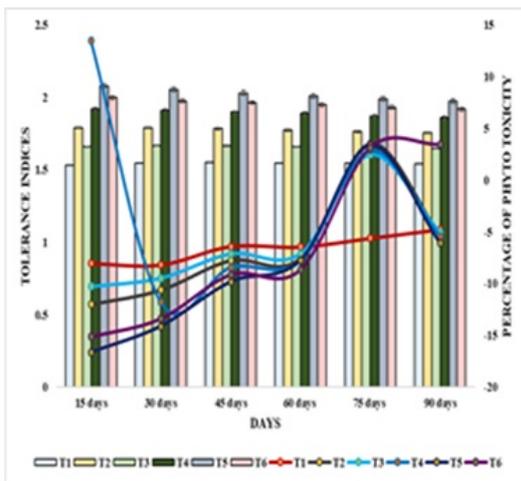


Figure 13. Tolerance indices and % of phytotoxicity of sunflower exposed to different microwave frequencies during *kharif* cultivation

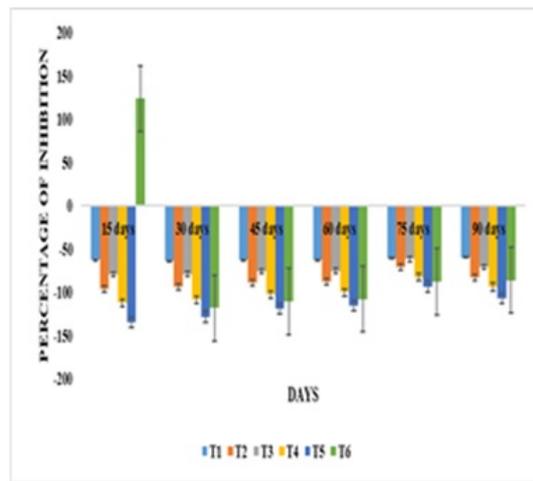


Figure 14. % inhibition of sunflower exposed to different microwave frequencies during *kharif* cultivation

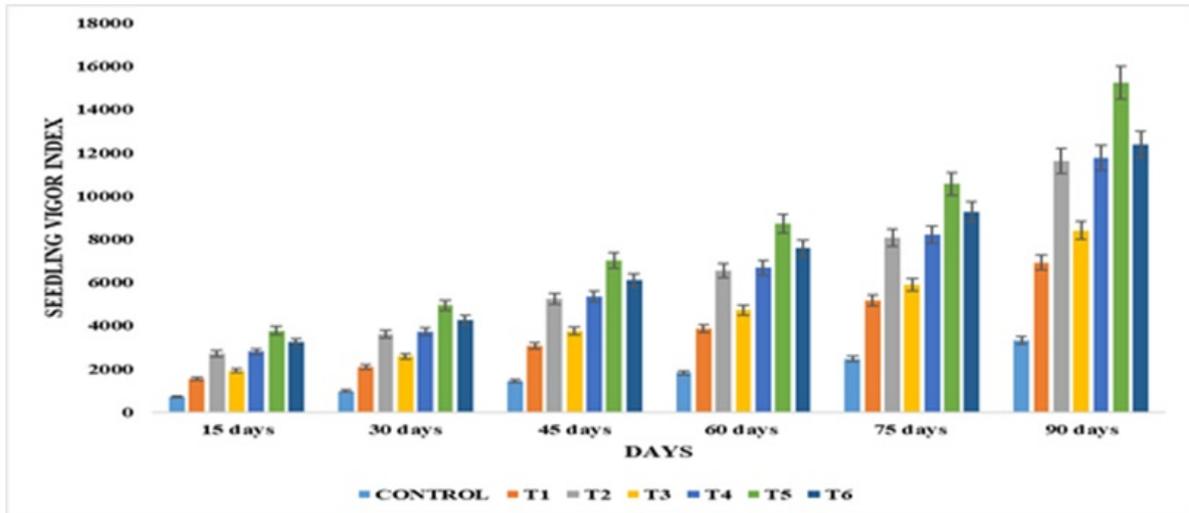


Figure 15. SVI of sunflower exposed to different microwave frequencies during *kharif* cultivation

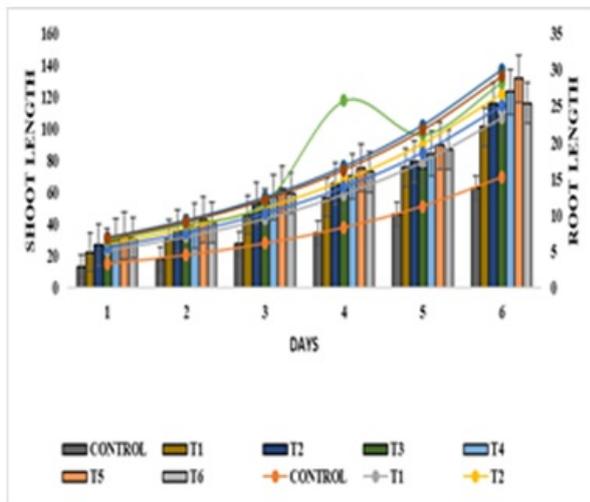


Figure 16. Impact of microwave irradiation on root and shoot length of sunflower

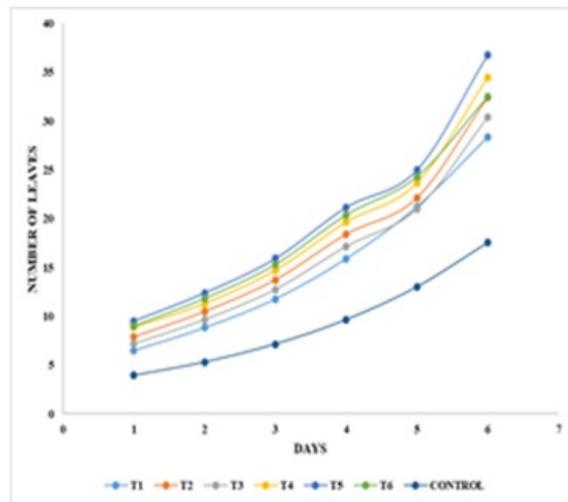


Figure 17. impact of microwave irradiation on sunflower leaf count

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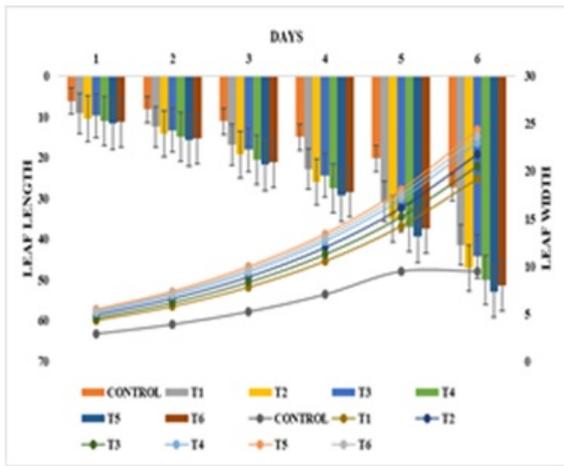


Figure 18. impact of microwave irradiation on leaf width and leaf length of sunflower

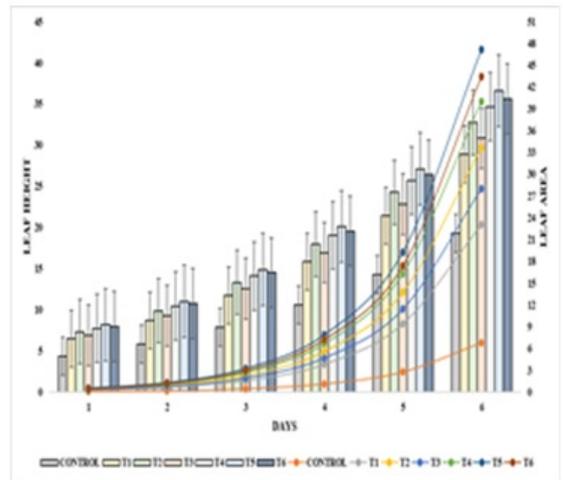


Figure 19. impact of microwave irradiation on leaf height and leaf area of sunflower

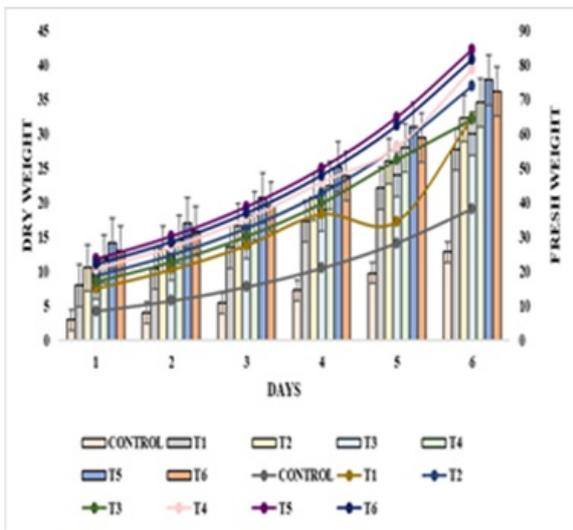


Figure 20. impact of microwave irradiation on fresh and dry biomass of sunflower plant

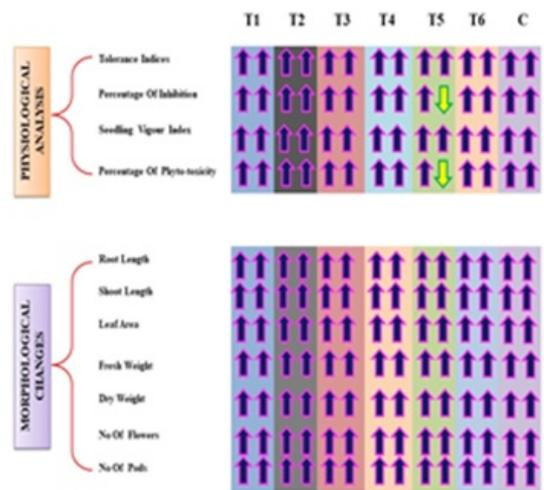


Figure 21: Change in physiological and morphological parameters of sunflower under different frequencies of microwave irradiation

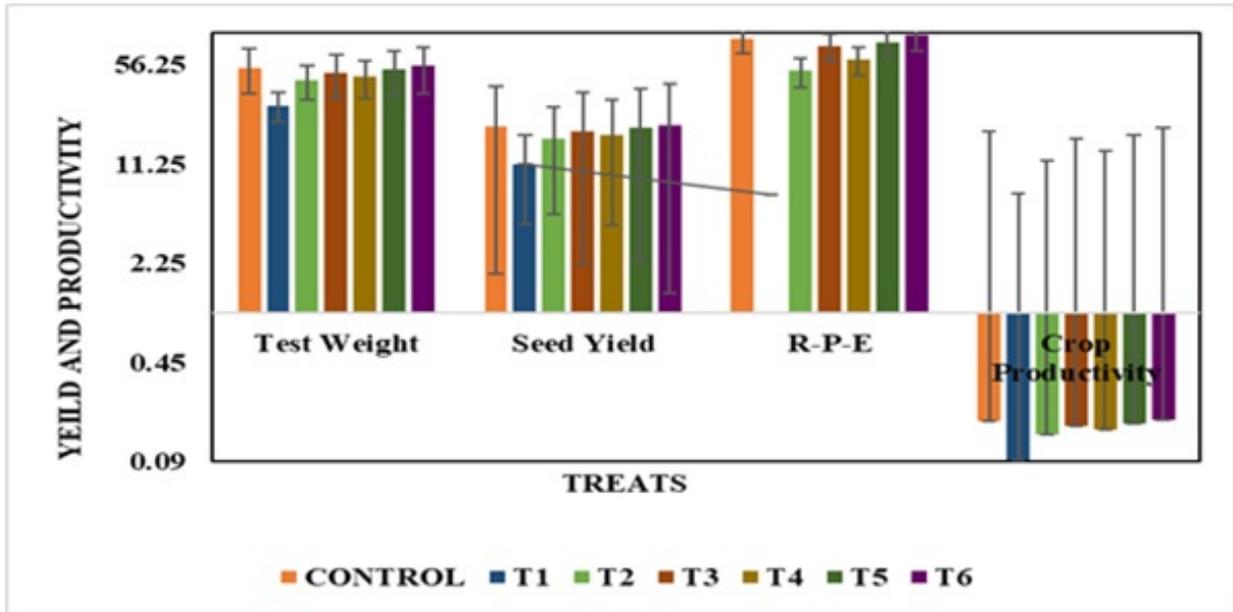


Figure 22. Impact of microwave irradiation on yield and productivity of sunflower crop

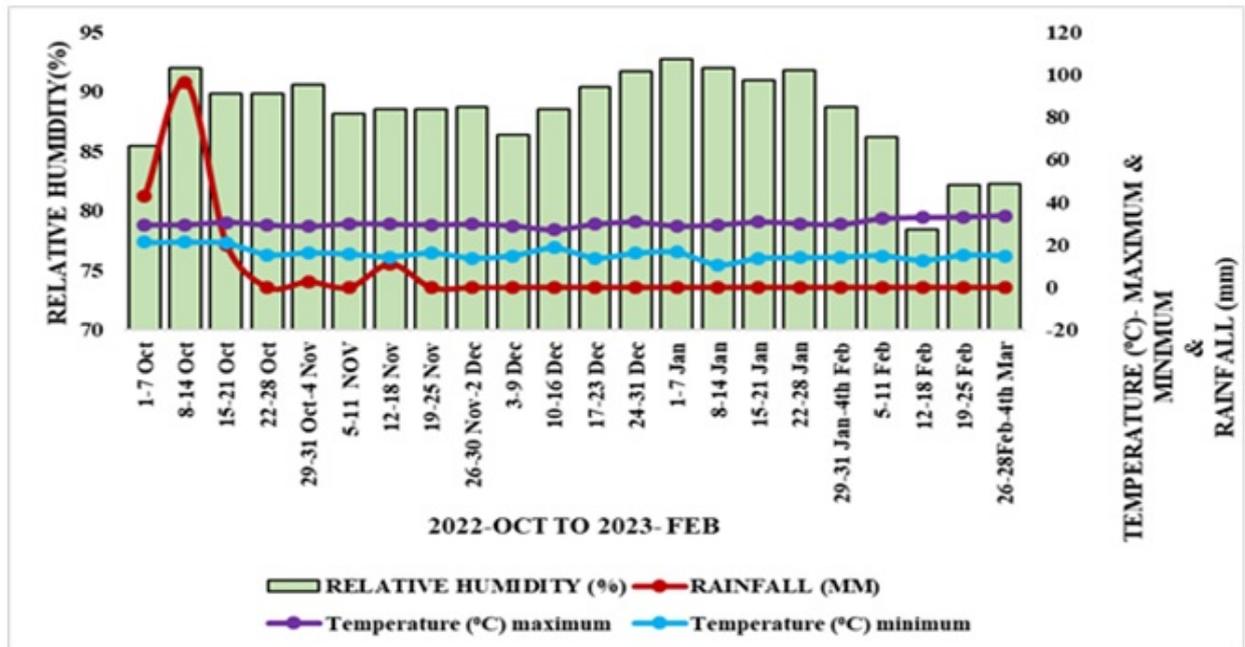


Figure 23. Graphical representation of weather report during experimental period

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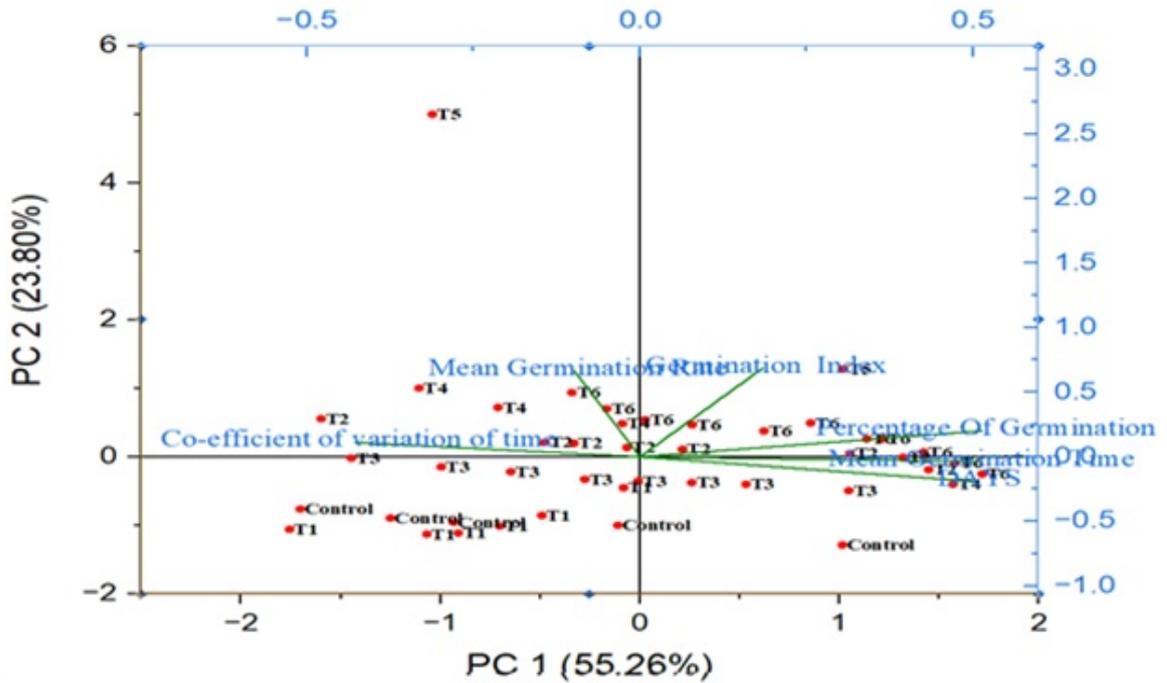


Figure 24. PCA report of germination analysis of sunflower irradiated with microwave during *kharif* cultivation

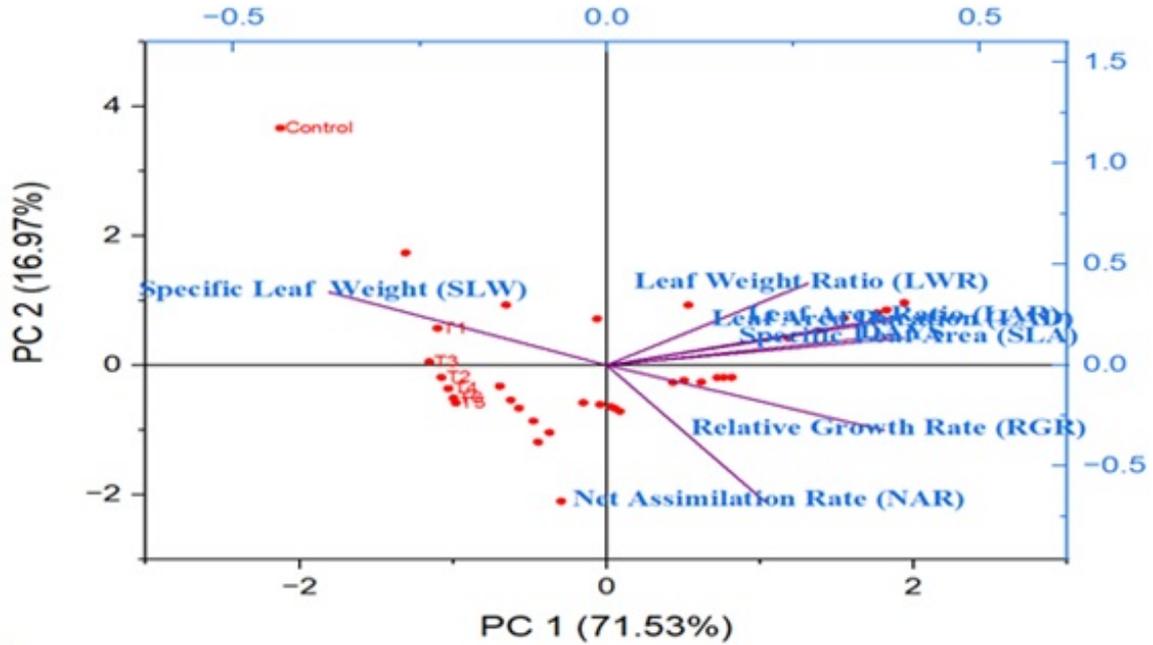


Figure 25. PCA report of growth analysis of sunflower irradiated with microwave during *kharif* cultivation

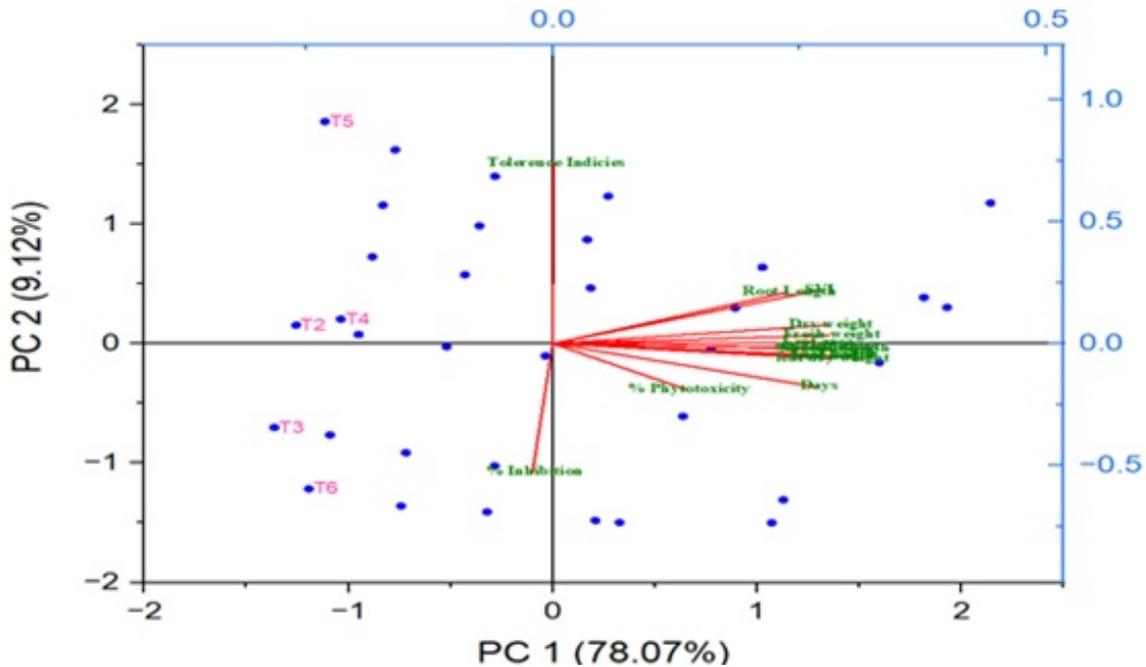


Figure 26. PCA report of physiological and morphological analysis of sunflower irradiated with microwave during *kharif* cultivation

The PCA report of physiological and morphological behavior (Figure 26) reveals that the duration of the experiment (days) is the most significant factor affecting plant growth and response, showing the highest loading in the first principal component. This indicates that time has a substantial influence on the observed parameters. Tolerance indices also play a notable role, suggesting their importance in understanding plant resilience under stress. The percentage of inhibition, although less impactful, provides insight into how stress affects plant growth, while the Seed Vigor Index (SVI) contributes moderately, reflecting the growth potential of seedlings under different conditions. Phytotoxicity, with a relatively lower but negative loading, suggests that increased phytotoxicity inversely impacts plant health. Core growth parameters such as shoot and root length, number of leaves, and leaf dimensions each have minor contributions individually but collectively are essential for assessing overall plant growth. Fresh and dry weights, reflecting water content and biomass accumulation, provide relevant insights into plant health but with limited impact on the variance. The PCA findings indicate that days, tolerance indices, % inhibition, and SVI are the primary factors influencing plant growth and response under experimental conditions, while growth traits and weights offer supportive data on health and resilience.

The findings from this study demonstrate that microwave irradiation, particularly in combination with pre-soaking, significantly enhances sunflower seed germination and growth. These results align with previous research and provide new insights into the effects of microwave treatments in agriculture. The highest germination rates, particularly in T5 (pre-soaked, 300 MHz), suggest that microwave irradiation improves seed coat permeability, leading to faster water absorption and enzymatic activation. Aladjadjiyan (2002) reported similar results, showing that microwave exposure enhances water uptake and stimulates enzyme activity in seeds, leading to faster germination. Similarly, Talei *et al.* (2013) found that pre-soaked rice seeds exposed to microwaves exhibited higher germination rates, indicating that pre-soaking amplifies the effects of microwave radiation. The significant improvement observed in T5 suggests that the 300 MHz frequency is optimal for germination, while higher intensities, like 500 MHz (T6), may cause cellular stress, as noted by Nelson (1987), who reported that excessive microwave radiation can cause seed damage due to thermal effects.

The increased germination rates in pre-soaked seeds irradiated at 300 MHz and 500 MHz corroborate the findings of Amirnia (2014) and Mohsenkhan *et al.* (2018), who both observed that moderate microwave radiation

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positively impacts seed germination by increasing cellular respiration and metabolism. Pre-soaking further enhances this process by allowing seeds to absorb water before irradiation, promoting faster enzymatic activation and germination as demonstrated in previous research by Ferriss (1984). The growth analysis studies revealed that irradiated seeds, especially those in T5, exhibited the highest RGR, NAR and LAR. These findings align with Vadivambal *et al.* (2007), who reported that microwave irradiation accelerates biomass accumulation and improves growth parameters in wheat. The increase in leaf area and SLA in irradiated plants, particularly T5 and T6, suggests that microwave irradiation stimulates photosynthesis, enhancing plant growth. This observation is supported by Benlloch *et al.* (2013), who demonstrated that microwave treatments improve enzyme activity and leaf expansion, leading to better photosynthetic efficiency. The thinner, more expansive leaves in T5 indicate increased light capture and photosynthesis, contributing to higher RGR and NAR. This is consistent with the findings of Howard *et al.* (2000), who observed that microwave treatment enhances leaf expansion and dry matter accumulation in pepper plants. The study by Wang and Tang (2001) also noted that microwave irradiation improves plant vigor and enhances leaf structure.

Seedling vigor, as measured by the SVI, was highest in T5, highlighting the positive impact of microwave irradiation on seedling growth and resilience. The increased SVI reflects improved metabolic activity, consistent with Abu-Elsaoud and Qari (2017), who reported enhanced seedling vigor in barley exposed to microwave radiation. The tolerance indices in T5 and T6 were also significantly higher than the control, indicating that microwave irradiation at moderate intensities helps seeds withstand environmental stress, as noted by Nelson (1996), who highlighted the potential of microwave treatments to enhance stress tolerance in plants. The positive effects of microwave treatment on seedling vigor and growth are further supported by González and Pérez (2002), who found that microwave irradiation improved seedling development and plant health by stimulating cellular processes. This was corroborated by Grondeau and Samson (1994), who reviewed the use of microwave and heat treatments to enhance plant resilience to stress factors.

The combination of pre-soaking and microwave irradiation, particularly at 300 MHz, emerges as an effective strategy to improve sunflower seed germination and growth. This approach is in line with the findings of Ponomarev *et al.* (1996), who demonstrated that low-intensity microwave irradiation enhances seed germination and plant growth in several crop species. The enhanced germination rates, seedling vigor, and growth

performance observed in this study suggest that microwave irradiation can be integrated into agricultural practices to improve crop productivity. Ferriss (1984) and Wang & Tang (2001) demonstrated that microwave treatment not only improves germination but also promotes seed sanitation by eliminating pathogens, further enhancing seed performance. The positive effects of microwave irradiation on sunflower growth observed in this study are consistent with the results of Kontar *et al.* (2015), who found that microwave irradiation increased the germination rates and growth performance of grain and vegetable crops. Microwave irradiation, particularly at 300 MHz, significantly improves sunflower seed germination, growth, and seedling vigor. This study aligns with research from Aladjajiyan (2002), Amirnia (2014), Vadivambal *et al.* (2007), and others, all of whom demonstrated the benefits of microwave irradiation for enhancing plant growth. However, higher microwave frequencies, such as 500 MHz, should be used cautiously, as they may cause thermal stress and reduce germination efficiency, as noted by Nelson (1987). Microwave irradiation can affect seed germination by inducing changes in the seed coat and water uptake, which leads to enhanced enzymatic activity. The increase in seed germination, particularly at 300 MHz and 500 MHz frequencies, may be due to the disruption of the seed coat and improved water permeability, allowing faster imbibition and enzymatic activation. Higher frequencies (300 MHz and 500 MHz) likely facilitated cellular respiration and metabolism, leading to better energy production and quicker radicle emergence. However, at 500 MHz, a slight reduction in germination was observed, possibly due to overheating or stress caused by excessive radiation.

Pre-soaking the seeds for 24 hours prior to irradiation significantly enhanced the germination rate, likely due to better moisture uptake before radiation treatment. This moisture content may have amplified the positive effects of microwave radiation, allowing for faster and more uniform germination. Pre-soaked seeds likely benefitted from more optimal enzymatic and metabolic activation during germination, as evidenced by the superior performance of T4, T5 and T6 compared to their dry-seed counterparts. The optimal microwave intensity for promoting germination appeared to be around 300 MHz, as seen in T2 and T5, where the highest germination percentages were recorded. Excessive radiation (500 MHz) showed diminishing returns and may even have caused thermal stress, resulting in suboptimal germination rates compared to the 300 MHz treatments. This study demonstrates that microwave irradiation, particularly at 300 MHz for 5 minutes, can significantly enhance the germination rate of sunflower seeds, especially when combined with pre-soaking. This

treatment strategy could be applied in agricultural practices to promote faster and more efficient seed germination. However, care must be taken with higher microwave intensities (500 MHz), as they may induce stress or damage to the seeds, reducing germination efficiency. Further research could focus on varying soaking times and different microwave intensities to optimize germination across various seed types.

The results of the PCA were visualized using biplots, which displayed the loadings of the original variables on the principal components along with the observations. This visualization enabled the identification of clusters or groupings among the experimental treatments, highlighting how microwave radiation influenced different growth parameters. Variables that contributed significantly to the first principal component were particularly scrutinized, as they provided insights into the most critical factors affecting seed germination and seedling growth under microwave radiation exposure. By interpreting the PCA results, we were able to discern patterns that might not have been evident through traditional analysis methods. This analysis not only elucidated the mechanisms by which microwave radiation affects sunflower seed germination and growth but also allowed for a better understanding of the benefits and challenges associated with its application in agricultural practices. The findings from PCA are essential for developing strategies that optimize seed performance under varying radiation conditions, ultimately contributing to improved crop yields and sustainability in sunflower cultivation during the *kharif* season.

The study demonstrated that moderate microwave irradiation at 300 MHz combined with pre-soaking significantly enhances sunflower seed germination, improving rates, speed, and uniformity. Pre-soaking facilitates faster enzymatic activation and water absorption, while microwave treatment enhances seed coat permeability. Excessive exposure at 500 MHz negatively impacted performance due to cellular stress. Dry seed treatments showed slower and less uniform germination, underscoring the advantages of combining pre-soaking with moderate microwave irradiation. Irradiated plants exhibited improved RGR, NAR, LAR, SLA and LAD, indicating enhanced biomass accumulation and photosynthesis. Physiological analyses revealed that treatment T5 (300 MHz) notably enhanced growth, stress tolerance, seedling vigor, and reduced phytotoxicity, achieving the highest tolerance index and SVI. While some slight phytotoxicity emerged later, overall plant health remained robust. Yield and productivity assessments indicated significant improvements in test weight, seed yield, relative percentage of enhancement, and crop productivity, particularly in T6, highlighting the potential of microwave irradiation as an

effective agricultural technique. Further research is needed to explore the mechanisms behind these enhancements and optimize treatment conditions for various crops.

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Chemical stability and sensory quality of high-oleic garlic-flavored peanuts, salted crispy peanuts, and salted dried peanuts

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ABSTRACT

High-oleic peanuts have attracted the attention of food processors and consumers for their good keeping quality and purported multiple health benefits. It is of interest to investigate whether high-oleic peanuts can replace their normal-oleic counterparts in Asian style foods. After long-term storage, Huayu 668 garlic-flavored peanuts exhibited a much lower peroxide value, and a comparable or lower acid value as compared with normal-oleic peanuts; the peroxide value of Huayu 668 salted crispy peanuts was on a par with salted dried normal-oleic Tianfu 3 prepared with special shelf life extension processing, while the acid value was more than twice as high. The peroxide value and acid value of all the peanut products herein did not exceed the upper limits specified in China national standard. Significant genotype × storage interactions (garlic flavor and total) and genotype effects (roasted peanut flavor, crunchiness and total) were detected in sensory quality indicators for garlic and salted crispy/dried peanut products, respectively. High-oleic Huayu 668 did not show any disadvantages in terms of organoleptic quality compared to normal-oleic peanuts. The outcome of this study suggested that Huayu 668 could be used for garlic-flavored peanut production and had potential in salted crispy peanut and salted dried peanut processing.

Keywords: Acid value, Eating quality, Groundnut, Oxidative stability, Peroxide value, Shelf life

Peanuts are a popular food for global consumers (Kundu *et al.*, 2023; Ambika *et al.*, 2023). High-oleic peanuts, distinguished by their extended shelf life and purported health benefits over their normal-oleic counterparts, are of particular interest. However, the following information needs to be noted. The World Health Organization underscores optimal dietary ratios, advocating 1:1.5:1 for SFAs (saturated fatty acids)/MUFAs (monounsaturated fatty acids)/PUFAs (polyunsaturated fatty acids), and 5-10:1 for ω -6/ ω -3 PUFAs in oils (Chen *et al.*, 2023). Correspondingly, the Chinese Nutrition Association recommends ratios of 1:1:1 and 4-6:1, respectively (Chen *et al.*, 2023). High-oleic peanuts, rich in oleic acid (at least 75%) and low in linoleic acid (below 7%), diverge significantly from these guidelines on MUFA to PUFA ratios. While this imbalance may be crucial for infants who rely on a more uniform food source, it is generally not considered a significant issue for adults with diverse diets.

The viability of high-oleic peanuts as substitutes for normal-oleic types in specific food applications hinges on factors like chemical stability and mouthfeel. On the market there is a plethora of peanut foods, among them fried peanuts processed from Virginia-type kernels are most preferable, with traditional varieties Luhua 10, Huayu 22 and Huayu 9610 predominating in China. Nevertheless, high-oleic peanut varieties outside China are mainly of runner type. Reportedly, Huayu 963, a Virginia-type

high-oleic cultivar, showed promise as a replacement for Huayu 22 in fried peanut applications (Wang *et al.*, 2020; Mu *et al.*, 2021). Despite a similar overall preference to Huayu 22, Huayu 963 offered a sweeter flavor (Wang *et al.*, 2020). Shelf life assessments indicated that Huayu 963 fried kernels lasted approximately 1.92 years, 3.69 times that of Huayu 22 (Mu *et al.*, 2021). Nepote *et al.* (2006) noticed that the high-oleic runner-type Granoleico was more oxidatively stable than normal-oleic Tegua for fried salted peanuts, with negligible differences in sensory properties.

Due to their unique flavor and no "internal heat" generation after ingestion, garlic-flavored peanuts, salted crispy peanuts, and salty dried peanuts, all of which are boiled peanuts, have gained great popularity in Northeast China, North China, Southern China, and Singapore-Malaysia-Thailand region respectively (Tang *et al.*, 2011), but so far there have been scanty reports on the use of high-oleic peanut raw materials for processing these peanut foods (Han *et al.*, 2021). This study aimed to evaluate the chemical stability and sensory attributes of these peanut products using high- and normal-oleic peanut varieties.

MATERIALS AND METHODS

Peanuts, processing, packaging and storage : Huayu 668 is a high-oleic Spanish-type peanut variety bred by the Molecular Breeding Team of Shandong Peanut Research Institute (SPRI). Huayu 23 is a runner peanut variety bred by the Cross Breeding Team, SPRI. Huayu 23, Dabaisha

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and Tianfu 3 are normal-oleic peanut varieties. The garlic-flavored peanuts (in shell) were produced using Huayu 668, Huayu 23 and Dabaisha (Baishan 171) following standard processing procedures (Zhou and Pan 2014) on November 23, 2021, with natural flavored Huayu 668 (in shell) included for comparison. The salted crispy peanuts (in shell) were prepared with Huayu 668 on April 10, 2021, according to the dry-roasting production process (Tang *et al.*, 2011). The salted dried peanuts (in shell), however, were prepared with Tianfu 3 on May 8, 2021, using specific undisclosed production techniques. The recommended storage period for the normal-oleic peanut products is 300 days.

Peanuts were stored in their original polyethylene plastic bags under room conditions (room temperature=22°C~24°C, relative humidity=65%~73%) just before sensory evaluation at SPRI, Qingdao, China.

Determination of peroxide value (PV) and acid value (AV): The PV and AV of the peanut food products were determined on November 15, 2022 with two replicates, using the cold solvent indicator titration procedure and a titration method respectively as described in China national food standards (China National Health and Family Planning Commission 2016a; b).

Sensory evaluation: Sensory evaluation was performed only when both the PV and AV of the food products complied with China national food standard (China National Health and Family Planning Commission 2014).

A sensory evaluation panel of five trained individuals with good sensory discrimination ability was selected to taste five random samples of the garlic-flavored peanuts and rate them according to the six sensory indicators, including garlic flavor, sweetness, crispness, fineness, bitterness and off-flavor (Table 1), based on Han *et al.* (2021), Chen *et al.* (2010) and Tang *et al.* (2011). Total was obtained by adding up the values of aforementioned six sensory indicators. The garlic-flavored peanuts were evaluated for sensory quality on March 10, 2022 and November 17, 2022.

Likewise, sensory evaluation of the salted crispy peanuts and salted dried peanuts was conducted using the five sensory indicators listed in Table 2 *viz.*, roasted peanutty flavor, sweet and salty taste, crunchiness, fineness and off-flavor. The total was the sum of values of these five sensory indicators mentioned above. The salted crispy peanuts were evaluated for sensory quality on August 3, 2021, and November 17, 2022.

Statistical analysis: Statistical analysis of the results from PV/AV measurements (completely randomized design) and the sensory evaluation (split-plot design with long-term

storage or not as whole plot factor and genotype as subplot factor) were carried out with the DPS package 14.50 (Tang and Zhang 2013).

Table 1 Sensory evaluation criteria for garlic-flavored peanuts

Marks	Garlic flavor	Sweetness	Crunchiness	Fineness	Bitter taste	Off-flavor
8-10	Strong	Moderate	Appropriate	Delicate	Absent	Absent
5-7	Average	Average	Average	Average	Slight	Slight
1-4	Slight	Absent	Not crunchy	Coarse	Marked	Marked

After Han *et al.* (2021), Chen *et al.* (2010)9 and Tang *et al.* (2011)4.

Table 2 Sensory evaluation criteria for salted crispy peanuts and salted dried peanuts

Marks	Roasted peanutty flavor	Sweet and salty taste	Crunchiness	Fineness	Off-flavor
8-10	Strong	Moderate	Appropriate	Delicate	Absent
5-7	Average	Average	Average	Average	Slight
1-4	Slight	Absent	Not crunchy	Coarse	Marked

After Han *et al.* (2021), Chen *et al.* (2010)9 and Tang *et al.* (2011)4.

RESULTS AND DISCUSSION

PVs and Avs after long-term storage: The PV and AV of garlic-flavored peanuts were determined 357 days after production. The PV of the three garlic-flavored peanut products ranged from 0.0235 to 0.2845 g/100 g and the AV ranged from 0.3615 to 0.4725 mg/g (Table 3), well below the upper limit of 0.5 g/100 g for PV and 3 mg/g for AV allowable by China national food standard (China National Health and Family Planning Commission 2014). Huayu 668 had a significantly lower PV at the 1% probability level than Huayu 23 and Dabaisha (Table 3). Huayu 668 and Huayu 23 had a significantly lower AV at the 1% probability level than Dabaisha (Table 3). When processed into garlic-flavored peanuts, the high-oleic variety Huayu 668 exhibited high chemical stability.

The salted crispy peanuts prepared with Huayu 668 and the salted dried peanuts prepared with Tianfu 3 were analyzed for PV and AV 584 or 556 days after production, respectively. Both had a PV and a AV below the upper limits permissible by China national food standard (China National Health and Family Planning Commission 2014) (Table 4). No significant difference was detected in PV between Huayu 668 (0.2910 g/100g) and Tianfu 3 (0.3210 g/100g). Huayu 668 had a significantly higher AV than Tianfu 3 at 1% probability level (0.8990 vs 0.4010 mg/g) (Table 4).

Sensory quality of the garlic-flavored peanuts: Of all the seven indicators listed in Table 5, only two were detected to be significantly different. Neither storage nor genotype effects were significant, with only two indicators, garlic flavor and total, having significant storage × genotype

interactions (for garlic flavor, $p=0.0018<0.01$; for total, $p=0.0234<0.05$) (Table 5).

As a total, for all the indicators, there was no appreciable reduction in the sensory quality of the varieties after long-term storage compared to before long-term storage. Of interest were Huayu 668 and Huayu 23. Before long-term storage, both cultivars were not significantly different in garlic flavor. However, after long-term storage, Huayu 668 showed a higher garlic flavor score than Huayu 23 at the 5% probability level, albeit failing to reach the 1% probability level (Table 5).

Sensory quality of the salted crispy/dried peanuts:

Among the six indicators from Table 6, merely three, *viz.*, roasted peanutty flavor, crunchiness and total, significantly differed in genotype effects. Neither storage nor storage \times genotype interactions were significant. Taken together, the roasted peanutty flavor score for Huayu 668 was 6.80, while that for Tianfu 3 was 5.10 ($p=0.0084<0.01$). The crunchiness score for Huayu 668 was 7.40, whereas that for Tianfu 3 was 5.90 ($p=0.0493<0.05$). The total score for Huayu 668 was 34.50, as against 29.90 for Tianfu 3 ($p=0.0124<0.05$). As shown in Table 6, the differences were present only prior to long-term storage.

In the case of garlic-flavored peanuts, after prolonged storage, high-oleic Huayu 668 had a PV one order of magnitude lower than the two normal-oleic varieties, and a comparable or lower AV. The PV and AV of natural flavored Huayu 668 were significantly higher and lower than those of garlic-flavored Huayu 668 at 1% level respectively. These disparities should be attributed to differences in processing. Allicin had been shown to be effective in maintaining the quality and shelf life of a wide range of foods such as dried sausages, fresh pork, grapes, fresh-cut yams, prickly pears and *Agaricus bisporus* mushrooms (Horita *et al.*, 2016), and we postulated that it might have a similar role in peanuts as well. Before and after prolonged storage, Huayu 668 was comparable to or higher than normal-oleic varieties in terms of garlic flavor and total organoleptic score, and comparable in the remaining five sensory indicators. Interestingly, one study on spicy peanuts showed that the spiciness of high-oleic peanuts was stronger than that of normal-oleic peanuts (Wang *et al.*, 2021). Although the difference in off-flavor between genotypes did not reach the 5% significance level, a p -value of 0.0522 was noted. When the two specific periods were analyzed separately, prior to long-term storage, no significant differences in off-flavors were detected between the three varieties, but after long-term storage, Huayu 668 was found to have a much lighter off-flavor than the two normal-oleic varieties.

Unlike the three varieties for garlic-flavored peanuts in

this study, which were processed using the same procedure by a specific food company, the two varieties for salted crispy peanuts and salted dried peanuts were the products of two food processors with distinct production processes. This made the results of this study for salted peanuts not only reflect the effects of genotype and extended storage period, but also introduce the compounding effects of processing mode and production date. After a long period of storage, PV was comparable between Huayu 668 salted crispy peanuts produced using conventional processing, and Tianfu 3 salted dried peanuts produced using a special process to extend the shelf life (Mr. Ji Dong Kou, personal communication), with AV being more than twice that of the latter, but neither exceeded the upper limits in China national food standard (China National Health and Family Planning Commission 2014). In a previous study, we found that roasted peanuts with high oleic acid content had a stronger roasted peanutty flavor and were much crunchier (Wang *et al.*, 2020). Likewise, in the present study, prior to prolonged storage, Huayu 668 outperformed Tianfu 3 in three organoleptic indicators (roasted peanutty flavor, crunchiness and total) at 1% or 5% level, but this advantage was not maintained beyond prolonged storage.

Research on other types of peanut products has shown that consuming high-oleic peanuts provides various health benefits, including lower levels of low-density lipoprotein cholesterol, enhanced cognitive function, support for controlling blood glucose and blood pressure, and reduced risk of non-alcoholic fatty liver disease (Han *et al.*, 2022). However, the specific health benefits of Asian-style high-oleic peanut foods investigated in this study remain to be studied.

The PV and AV of all the garlic-flavored and salted crispy/dried peanut products in this study did not exceed the upper limits ($PV \leq 0.5$ g/100 g and $AV \leq 3$ mg/g) set by China national standard (China National Health and Family Planning Commission 2014). After long-term storage, the PV of Huayu 668 garlic-flavored peanuts was significantly better than that of normal-oleic peanuts. The AV, on the other hand, was comparable or lower. The PV of Huayu 668 salted crispy peanuts was on a par with normal-oleic Tianfu 3 salted dried peanuts prepared by special process, while the AV was more than twice as high, seemingly indicating that Huayu 668 was not advantageous over specially processed Tianfu 3 in terms of shelf life related indicators for salted crispy/dried peanuts if the 28-day difference in production date and hence in the overall storage period between the two was ignored. Significant genotype \times storage interactions (garlic flavor and total) and genotype effects (roasted peanut flavor, crunchiness and total) were detected in sensory quality indicators for garlic-flavored and salted crispy/dried peanut products, respectively. For the two types of products

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involved in this report, the high-oleic Huayu 668 did not show any disadvantages in terms of organoleptic quality compared to the normal-oleic peanuts. The outcome of this study suggested that high-oleic Huayu 668 could be used for

garlic-flavored peanut production and still had potential in salted crispy/dried peanut processing considering its superior sensory scores prior to long-term storage.

Table 3 PV and AV of three garlic-flavored peanut products after long-term storage (357DAP)

Shelf life indicator	Huayu 668 (natural flavored, CK)	Huayu 668 (garlic-flavored)	Huayu 23 (garlic-flavored)	Dabaisha (garlic-flavored)
PV (g/100g)	0.1285±0.0049B	0.0235±0.0013C	0.2845±0.0064A	0.2745±0.0049A
AV (mg/g)	0.2635±0.0163C	0.3615±0.0078B	0.3815±0.0219B	0.4725±0.0064A

Values marked with the same upper-case letters in the same row indicated no significant difference at the 1% probability levels. Values were expressed as mean ± standard deviation. DAP=days after production.

Table 4 PV and AV of two salted crispy/dried peanut products after long-term storage

Shelf life indicator	Huayu 668 (584DAP)	Tianfu 3 (556DAP)
PV (g/100g)	0.2910±0.0198	0.3210±0.0084
AV (mg/g)	0.8990±0.0424A	0.4010±0.0212B

Values marked with the same upper-case letters in the same row indicated no significant difference at the 1% probability levels. Values were expressed as mean ± standard deviation.

Table 5 Sensory quality of three garlic-flavored peanut products

Index	Before long-term storage (107DAP)			After long-term storage (359DAP)		
	Huayu 668	Huayu 23	Dabaisha	Huayu 668	Huayu 23	Dabaisha
Garlic flavor	7.80±0.84ABCa	7.60±0.55ABCab	5.60±1.52Cc	8.40±1.14ABa	6.20±1.30BCbc	8.60±0.89Aa
Sweetness	7.60±1.82	7.80±1.64	5.80±1.92	7.60±0.89	7.20±1.48	8.40±1.14
Crunchiness	8.00±0.71	7.60±1.67	7.60±2.07	7.80±1.30	7.20±0.84	7.60±0.89
Fineness	9.00±0.00	8.20±1.10	8.00±1.00	8.40±0.55	8.00±0.71	8.00±1.22
Bitter taste	8.40±0.89	8.40±0.89	8.40±0.89	8.60±0.89	8.80±0.45	8.80±0.84
Off-flavor	8.60±0.80	8.40±0.55	8.40±0.55	9.20±0.84	8.40±1.14	8.40±1.14
Total	49.40±3.51a	48.00±4.85ab	43.80±2.59b	50.00±4.64a	45.80±1.31ab	49.80±4.15a

Values marked with the same upper- and lower-case letters in the same row indicated no significant difference at the 1% and 5% probability levels, respectively. Values were expressed as mean ± standard deviation.

Table 6 Sensory quality of the salted crispy peanuts and salted dried peanut products

Index	Before long-term storage		After long-term storage	
	Huayu 668 (115DAP)	Tianfu 3 (87DAP)	Huayu 668 (584DAP)	Tianfu 3 (556DAP)
Roasted peanutty flavor	7.20±1.30A	4.80±0.45B	6.40±1.52	5.40±1.52
Sweet and salty taste	7.80±1.79	7.00±1.22	5.40±1.34	5.40±1.14
Crunchiness	7.80±2.68a	5.60±1.52b	7.00±1.58	6.20±0.84
Fineness	7.00±1.73	6.60±1.52	7.00±1.73	6.20±1.79
Off-flavor	6.80±0.84	6.00±1.87	6.60±2.41	6.60±1.67
Total	36.60±7.70a	30.00±4.24b	32.40±4.98	29.80±5.12

Values of the first and second columns followed by the different upper- and lower-case letters in the same row indicated significant difference at the 1% and 5% probability levels, respectively. Values were expressed as mean ± standard deviation.

Declaration of competing interest: The authors declare that they have no competing interests.

Ethics and Disclosures: The individuals involved in the sensory evaluation were informed of the results of the shelf life determination indicators PV and AV (both within the limits set by the China National Food Standard) and were willing to participate in this study.

Availability of data and material: Related data are available upon request.

Author Contributions: CJJ, WWG, ZWW, XZW and HWH were involved in peanut raw material preparation, sensory evaluation, and summarization of the research work. SQM conducted chemical analysis. ZY supervised the work and participated in drafting the manuscript. CTW and CJJ were responsible for conceiving the idea, designing the experiments, and preparing the final version of the manuscript.

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Yield and economics as influenced by omission and addition of technologies from recommended soybean production technologies

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ABSTRACT

The field experiment was conducted during *kharif* seasons of 2017 and 2018 to study the effect of deletion and addition of different agronomic practices from recommended package of practices on yield attributes and yield of soybean. The additional use of micronutrients (Zn, B and Mo) and secondary nutrient sulphur (S) along with recommended package of practices (RPP) showed significant positive effect on plant height, pods per plants, yields and harvest index. On pooled basis, the addition of micronutrients (Zn, B and Mo) and secondary nutrient sulphur as soil application with RPP increased the yield by 6.0 and 3.21% as compared to RPP, respectively. On the contrary, the deletion of any recommended practice from the RPP reduced the yield by 1.14 to 71.69% as compared to RPP. Similarly, the addition of micronutrients and secondary nutrients with RPP recorded higher harvest index as compared to deletion of individual recommended practice. Economics point of view, all the treatments differ significantly among themselves in respect to the cost of cultivation, significantly the highest cost of cultivation was associated with additional use of micronutrients (Zn, B and Mo) with RPP and lowest with control. Significantly the highest net returns were registered with RPP + Zn, B, Mo application and remained statistical identical with RPP + S application, RPP alone, 50% RDF (recommended dose of fertilizers) as basal + 2% urea spray at pod initiation stage and RPP + narrow row spacing (30 cm). In case of B: C ratio, significantly the highest B:C ratio was recorded with omission of RDF treatment and remained statistical identical with control treatment followed by 50% RDF as basal + 2% urea spray at pod initiation. Furthermore, when comparing yields and economics (except B:C ratio) of all the treatments with RPP in terms of positive and negative effect, the differential yields and economics both were positive with additional use of micro and secondary nutrients. Similarly, the negative trend was observed with the deletion of any practice from RPP except in case of 50% RDF + 2% urea spray where the yield showed negative trend and net income showed positive trend. Moreover, the highest positive partial factor productivity (PFP) registered with omission of RDF followed by control and then 50% RDF as basal + 2% urea spray. Whereas, other treatments exhibited negative trend in term of PFP the lowest negative values were registered with RPP + Zn, B, Mo and RPP + 25 kg S /ha.

Keywords: Differential yields, Economics, Partial factor productivity, Soybean, Yields

Soybean (*Glycine max* [L.] Merrill) is a leading leguminous oil yielding crop of India as well as world. It is a protein-rich food (42%) which may help in alleviating malnutrition of Indian population and occupies the premier position in the country (Raghavendra *et al.*, 2020). Further, yield gap analysis between improved technology and farmers' practice for soybean tends to be very wide (Billore *et al.*, 2020). Therefore, it has been a matter of concern that in spite of yield levels achieved in demonstrations under real farm conditions (average 1.8 t/ha), crop harvested by progressive farmers (2.0 to 2.5 t/ha), and the national productivity still hovers around 1.0 t/ha (Billore *et al.*, 2004; Tiwari and Tiwari, 2023). However, soybean yield gap, reflects the actual yield gap in rainfed environment and is essentially due to non-adoption of improved crop management practices (Bhatia *et al.*, 2008). Furthermore, farmers either do not generally adopt fertilizer

recommendations or resort to imbalanced fertilization. Currently, farmers apply only N and P fertilizers with ignorance of other micro and secondary nutrients application and addition of these macronutrients (NP) solely cannot resolve the decline in soil fertility. Moreover, India has suffered decades of K stripping from soil without replenishment inducing critically low levels and limiting production in many regions (Tandon and Tiwari, 2011; Madar *et al.*, 2020). It has been estimated that fertilization accounts for nearly 50% of all crop yields in India (Randhawa & Tandon 1982). Fertilizer has certainly played a critical role in India's green revolution, but yet, per hectare consumption of fertilizer is still much less than neighboring countries in Asia. This unfortunate situation is compounded by imbalanced use of N, P₂O₅ and K₂O (nutrient consumption ratio 6.9:2.9:1). The fertilizer consumption is far below than actual nutrient removal. The Major problem in soybean production is the stagnant productivity in the country in general and especially

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Madhya Pradesh in particular (Nahatkar *et al.*, 2005) where, varieties with high yield potentials and improved production technologies are available. The poor productivity is because of resource poor farmers, who are very reluctant towards adaptation of proper scientific management practices during crop production process under field condition. Therefore, study has been conducted to determine the yield gap of soybean through addition or deletion of technological component from the recommended package of practices.

MATERIALS AND METHODS

Site description and soil characteristics: A field experiment was conducted during *kharif* seasons of two consecutive years (2017 and 2018) at the Research farm of ICAR-Indian Institute of Soybean Research, Indore, Madhya Pradesh, (India) which lies in Vidhyanchal range of Malwa Plateau (22°4'37" N latitude, 75°52'7" E longitude and 540 m above the mean sea level). The climate of the Malwa Plateau of Madhya Pradesh is semiarid with an average annual rainfall of 800 mm of which 80% is received through south-west monsoons during July-September. Soils are deep black cotton with low to medium in organic carbon and available phosphorus and high in potassium. The soil

(0-30 cm layer) had a pH 7.5 (1:2.5 soil: water ratio), Walkley-Black C (oxidizable-SOC) 0.53%, alkaline KMnO₄-oxidizable-N 298 kg/ha 0.5 M NaHCO₃-extractable P 14.9 kg/ha and 1 N NH₄OAc-extractable K 340 kg/ha.

Experimental setup, design and treatments: The experiment comprised 13 treatments (Table 1) and were laid out in RBD with 3 replications.

The soybean cv JS 20-34, was sown with a seed rate of 65 kg/ha during second fortnight of June in 2017 and 2018 with a row spacing of 45 cm. The sowing of soybean was done by seed drill. The soybean crop was harvested during second fortnight of October 2017 and 2018. At maturity, the soybean was harvested manually. The harvested produce was left in the field for 3 days for sun-drying. The threshing of the soybean, harvested from 21.6 m² area was done manually using thresher and the grains were cleaned and weighed. The yield per plot was adjusted at 9-10 % moisture for soybean and expressed as kg/ha. The weight of stover was also recorded, separately.

Statistical analyses: All data recorded were analyzed with the help of analysis of variance (ANOVA) technique (Gomez and Gomez, 1984) for randomized block design using SAS 9.3 software (SAS Institute, Cary, NC).

Table 1. Treatment details

T1	Recommended package of practices (RPP)- (Full package of practices includes land preparation- one ploughing, two cultivators followed by planking; Nutrients were supplied through inorganic fertilizers as per recommended doses (RDF) amounting 24 kg N + 64 kg P ₂ O ₅ + 32 kg K ₂ O were applied as basal through IFFCO NPK complex fertilizer 12:32:16. Soybean seed was treated with thiram + carbendazim (2:1) @ 3 g/kg of seed. Soybean weeds were controlled by using the pre-emergence spray of herbicide diclosulam 84 WDG @ 22 g ai/ha. Insects were controlled through the spray of chlorantraniliprole @ 100 ml/ha)
T2	RPP + Zn, B, Mo: + Zn (25 kg/ha through ZnSO ₄), B (1 kg/ha through Na ₂ [B ₄ O ₅ (OH) ₄]·8H ₂ O), Mo (1 kg/ha through (NH ₄) ₆ Mo ₇ O ₂₄)
T3	RPP + 25 kg S/ha: through bentonite sulphur
T4	RPP+ 50% RDF as basal + 2% urea spray at pod initiation stage
T5	RPP + narrow row spacing (30 cm)
T6	RPP + 50% seed rate (30 kg/ha)
T7	Omission of RDF
T8	Omission of seed treatment
T9	Omission of bio-fertilizer
T10	Omission of herbicide
T11	Omission of insecticide
T12	Only Hand weeding no herbicide use
T13	Control (land preparation and seed and sowing)

RESULTS AND DISCUSSION

The results of the two-year study were pooled and only the average values are discussed throughout this paper. Plant height was significantly influenced by different treatments. Significantly highest plant height was registered with the addition of micro and secondary nutrients to the recommended package of practices (RPP) and remained statistical identical with 50 % RDF + 2% urea spray. The addition of micronutrients significantly enhanced the pod bearing ability of soybean (Chaitra and Hebsur, 2018). The lowest plant height and pods/plants were associated with control. The results indicated that the individual component of the RPP significantly influenced the productivity and economics of the soybean (Table 2). The maximum yield was associated with full package of practices + micronutrients (Zn, B, Mo) and remained statistically identical with RPP + 25 kg/ha S application followed by RPP, RPP with 50 % RDF + 2% urea spray and RPP + narrow planting as compared to remaining treatment. The yield increased by 6.0% with addition of micronutrient with RPP and 3.2% under RPP + 25 kg S/ha as compared to RPP alone. Similarly, the significantly highest biological yield was registered under RPP + micronutrients (Zn, B, Mo) followed by RPP + narrow row spacing (30 cm) and remained statistically on par with RPP + 25 kg S/ha application, RPP, RPP with 50 % RDF + 2% urea spray. The results showed that the use of optimum seed rate is must for achieving the highest productivity of soybean followed by plant protection activities and nutrient management. The use of inappropriate soybean production technologies were prominent threats to soybean production and could have been factors in the low yields (Mbanya, 2011). In India, at least 50% or more of recent increases in agricultural production are credited to fertilizers (Randhawa and Tandon, 1982). The high-input management system had greater yield stability across all weather years (Balboa *et al.*, 2019). The addition of the micronutrients as soil application may enhances the enzymatic activities and availability of the nutrients in the soil. Application of micronutrient in adequate dose with suitable sources increase soybean yield (Priester *et al.*, 2012; Ngo *et al.*, 2014; Lacerda *et al.*, 2017).

Invariably, the addition of micro and secondary nutrients with RPP substantially enhanced the soybean yield (6.0 and 3.2%) and omission of any of the recommended practice from RPP appreciably reduced the yield (1.1 to 41.8%) as compared to RPP. The lowest seed yield was observed under RPP + 50% seed rate (30 kg/ha) and followed by control treatment. The decrease was 71.7% under RPP + 50% seed rate (30 kg/ha) followed by 52.3% under control, 23.6% under omission of herbicide

application, 23.3% under omission of inter-cultural operations (Dora), 20.5% under omission of insecticide applications, 16.0% under omission of recommended dose of fertilizers, 11.8% under omission of seed treatment, 11.5% under omission of bio-fertilizers, 2.5% under RPP + narrow row spacing (30 cm) and 1.14% under 50 % RDF + 2% urea spray as compared to RPP. The maximum decline in soybean yield due 50% seed rate which indicated that maintain the optimum plant population is essential element for harvesting the maximum yield (Billore and Srivastava, 2014). Secondly the timely weed management carried out either by herbicides or inter-cultivation operations in soybean is a very crucial factor for achieving the higher yield (Billore *et al.*, 2006; Raghavendra *et al.*, 2020). Nutrient management practices either through synthetic fertilizers or bio-fertilizers that influence nutrient availability, crop productivity and environmental stewardship (Raghuvveer and Keeerti, 2017). Balanced and timely nutrient management led to sustainable yield (Reddy *et al.*, 2010) and quality of soybean and reduces environmental risks. Balanced and strategic nutrition management can assist in integrated pest management to reduce pests and diseases infestation and reduces the pesticide requirement to control them (Hellal and Abdelhamid, 2013). The more than 11% yield gap due to the omission of seed treatment because seed treatment is essential component of the technology which ensures the healthy germination and restrict the disease infection to germinating seed and new emerged seedlings and maintain the optimum plant population for achieving the maximum yield. The yield gap owing to omission of bio-fertilizers might be due the rhizobium and PSB inoculation supply adequate amount of nitrogen to the high nitrogen demanding crop and increase the phosphorus availability to the crop. The RPP, however, are not being fully adopted by farmers probably due to a lack of information on these or their poor economic conditions or inefficiencies in technology delivery systems (Tomar and Sharma, 2002; Sharma *et al.*, 2006; Dupare *et al.*, 2011; Kumar *et al.*, 2012; Singh *et al.*, 2013). This study advocates that agricultural sustainability can only be accomplished using a whole-systems approach (Jones *et al.*, 2013). The significantly highest harvest index was registered under RPP + Zn, B, Mo application (45.3%) followed by RPP + 25 kg S/ha application (45.1%) as compared to remaining treatment (Table 2). The lowest harvest index was observed with RPP + 50% seed rate (36.0%) and control (37.7%). Furthermore, omission of individual technology (recommended dose of fertilizers, seed treatment, narrow row spacing (30 cm), inter-cultural operations (Dora), insecticide application) did not vary significantly with respect to harvest index. Production economics of different

recommended soybean production technologies are presented in Table 2. The highest cost of cultivation was registered with RPP + Zn, B, Mo application (₹ 28,203/ha) followed by RPP + 25 kg S/ha application (₹ 26,943/ha). The lowest cost of cultivation was registered under control (₹ 15,538 /ha) followed by omission of recommended dose of fertilizers (₹ 19,851/ha). The additional use of micro and secondary nutrient to the RPP enhanced the cost of cultivation and the omission of any recommended technologies decreased the cost of cultivation. The similar trend was also observed in case of gross and net income except 50 % RDF + 2% urea spray where the cost of cultivation was in negative trend as compared to RPP and gross and net returns was in positive trend. The highest

gross (₹ 106913/ha) and net returns (₹ 78710/ha) was registered under RPP + micronutrient application (Zn, B, Mo) followed by RPP + 25 kg S/ha application. However, the lowest gross (₹ 61135/ha) and net returns (₹ 37396/ha) were registered under RPP + 50% seed rate (30 kg/ha) followed by control. The differential cost benefit ratio or partial factor productivity was found in negative trend among the different treatment except 50 % RDF + 2% urea spray (+0.23) and control (+0.43), where the B:C ratio values were in positive trend. This might be due to the omission of the technologies which reduces the cost of inputs. The variation in economical parameters might be due to the differences existed in cost of cultivation and total revenue generation.

Table 2 Effect of recommended soybean production technologies on yields and cost of cultivation

Treatment	Plant height (cm)	Pods/plant (Nos.)	Grain yield (kg/ha)	Straw yield (kg/ha)	Biological yield (kg/ha)	Harvest Index (%)	Cost of cultivation (₹/ha)	Gross income (₹/ha)	Net income (₹/ha)	B:C ratio
RPP*	61.4ab	43.9c	2739bc	3529b	6268ab	43.7b	25543c	101693b	76150a	2.95c
RPP + Zn, B, Mo	62.6a	45.7a	2905a	3508b	6414a	45.3a	28203a	106913a	78710a	2.77cde
RPP + 25 kg S /ha	62.2ab	45.0b	2827ab	3440bc	6267ab	45.1a	26943b	104181ab	77239a	2.84cd
RPP +50% RDF + 2% urea spray	61.6ab	42.7e	2708bc	3365cd	6074b	44.6ab	23808g	100271b	76464a	3.18b
RPP + narrow row spacing (30 cm)	58.6bc	36.4h	2673c	3674a	6347b	42.1c	25543c	99781b	74239a	2.88c
RPP + 50% seed rate (30 kg/ha)	54.5d	43.6d	1595g	2836g	4431f	36.0f	23739h	61135g	37396f	1.56h
Omission of RDF	51.9de	35.5i	2362de	3306de	5668c	41.7c	19851k	88340cd	68490b	3.42a
Omission of seed treatment	59.7bc	36.8g	2451d	3298de	5750c	42.6c	25473e	91348c	65875bc	2.56ef
Omission of bio-fertilizer	59.4bc	37.3f	2456d	3328d	5785c	42.5c	25498d	91487c	65990bc	2.56ef
Omission of herbicide	52.8de	32.9l	2216e	3202e	5418d	40.9d	23739i	83223e	59485d	2.48fg
Omission of insecticide	58.0c	33.8j	2273e	3069f	5343d	42.5c	23149j	84844de	61695cd	2.64def
Intercultural operations (dora)	52.8de	33.2k	2222e	3054f	5277d	42.1c	24643f	82247e	57605de	2.32g
Control	50.3e	28.2m	1798f	2697f	4765e	37.7e	15538l	68372f	52834e	3.38ab

*RPP= Recommended package of practices

Table 3 Effect of recommended soybean production technologies on differential yields, cost of cultivation and factor productivity

Treatment	Differential grain yield (kg/ha)	Differential biological yield (kg/ha)	Differential cost of cultivation (₹/ha)	Differential gross income (₹/ha)	Differential net income (₹/ha)	Differential B:C Ratio (Partial factor productivity)
RPP*	-	-	-	-	-	-
RPP + Zn, B, Mo	+166.2ef	+146.2ef	+2660c	+5220fg	+2560fe	-0.18efg
RPP + 25 kg S /ha	+88.3efg	-1ef	+1400h	+2488fg	+1089fg	-0.11fg
RPP + 50% RDF as basal + 2% urea spray	-31.0fg	-194.2e	-1735g	+1422g	+314g	+0.23defg
RPP + narrow row spacing (30 cm)	-66.3fg	+79.0ef	-	-1912g	-1911fg	-0.07fg
RPP + 50% seed rate (30 kg/ha)	-1143.8a	-1836.7a	-1804f	-40557a	-38753a	-1.39a
Omission of RDF	-377.3cd	-599.7d	-5692b	-13352de	-7660ef	+0.47bc
Omission of seed treatment	-287.3de	-518.0d	-70j	-10344ef	-10274de	-0.39cde
Omission of bio-fertilizer	-282.5de	-482.8d	-45k	-10205ef	-10160de	-0.39cde
Omission of herbicide	-523.2c	-850.2c	-1804e	-18469cd	-16665c	-0.47bc
Omission of insecticide	-465.7c	-925.2c	-2394d	-16849cd	-14455cd	-0.31cdef
Intercultural operations (dora)	-517.0c	-991.3c	-900i	-19445c	-18545bc	-0.62b
Control	-941.3b	-1503.2b	-10005a	-33320b	-23315b	+0.43bcd

*RPP= Recommended package of practices

YIELD AND ECONOMICS AS INFLUENCED BY RECOMMENDED SOYBEAN PRODUCTION TECHNOLOGIES

The present investigation clearly brought out the fact that the addition or deletion of any technology from the RPP has differential effects on growth, yield and economics of soybean. The additional use of secondary (S) and micro (Zn, B, Mo) nutrients to the RPP showed positive response with respect to growth and yield of soybean over RPP alone while the deletion of any recommended practice from the RPP have negative impact on growth and yield. Similarly, the substantially higher cost of cultivation, gross and net returns was registered with micro and secondary nutrients application with RPP, while the lowest values of these parameters were observed under RPP + 50% seed rate (30 kg/ha) followed by control. The present study advocated that the recommended soybean package practices with the additional use of micronutrients are essential for sustainable soybean production.

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Dynamics of oilseeds production and future potentials in Karnataka

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ABSTRACT

This study aims to analyse the trends in the changing patterns of crops and the status of oilseed cultivation in Karnataka over the past two decades. Secondary data from the Department of Economics and Statistics (DES) was collected for the period 2001-02 to 2020-21. The data was further divided into two study periods, i.e., Period I (2001-02 to 2010-11) and Period II (2011-12 to 2020-21). The data was analysed using Compound Annual Growth Rates (CAGR), Cuddy Della Valle Index (CDVI) and Markov Chain analysis. The results on growth rates for oilseeds indicated fluctuations with varying trends for area, production and productivity. Instability indices showcased the variability in area, production and productivity. Transitional probability matrices revealed crop retention and area shifts between crops. Additionally, cropwise analysis of major oilseeds such as groundnut, soybean, sunflower and others highlighted specific trends and challenges for each crop. All oilseeds together in Period I registered a marginal decline in cultivation area (-0.91%), while production (1.43%) and yield (2.36%) grew positively. Although the cultivation area declined significantly (-3.82%), production maintained its positive growth (0.93%), with increased crop productivity (4.94%) significantly in Period II. Individual crop analysis revealed varied trends; for instance, groundnut saw stable production with a notable increase in yield (2.10%). District-wise categorization based on Relative Spread Index (RSI) and Relative Yield Index (RYI) for various oilseed crops highlighted efficiency disparities thus necessitates targeted interventions for enhanced productivity. These findings underscore the need for strategic measures to bring sustainability and to develop a strong oilseed economy in the state.

Keywords: Growth rate, Instability, Oilseeds, Trends

Oilseeds occupy the second important position after food grains in terms of area and production in the agrarian economy of a country. During 2020-21, India's domestic edible oil production was 9.5 million tonnes while the domestic oil consumption touched 22.5 million tonnes. The gap of 13 million tonnes is filled with imports that cost the country US\$ 13.5 billion (₹1.17 lakh crore). The major problem faced by India is that an increase in domestic production is not keeping pace with the increasing demand consequent to population growth. Edible oil is the only major commodity within the agro-based product basket where India has witnessed a high trade deficit (60% imports), while in most other agro-products, country has a trade surplus (Dastagiri *et al.*, 2022; Anupam, 2023). India faces significant imports of vegetable oils, driven by rising consumption for both edible and industrial purposes. Nine oilseeds, including soybean, groundnut, rapeseed and mustard dominate India's vegetable oil production, yet domestic production struggles to keep pace with soaring demand. Karnataka, a key agricultural state, cultivates major oilseed crops such as groundnut, soybean and sunflower leveraging its diverse agro-climatic conditions (Sunil *et al.*, 2023). However, oilseed cultivation in Karnataka faces several challenges, including reliance on rainfall and cultivation on marginal lands. Despite

Karnataka's rich agricultural potential, achieving sustainable oilseed production remains a priority amidst the state's growing population and economic diversification. India's achievements in oilseed production are commendable, especially considering its significant contribution predominantly under rainfed conditions.

However, challenges persist, including policy interventions and the need to align production with escalating demand. This study focused on comprehensively examine the growth and instability of oilseeds in Karnataka, analyse the dynamics of oilseed cultivation in the state and identify potential areas for further oilseed cultivation.

MATERIALS AND METHODS

Karnataka has a diversified cropping pattern across regions based on rainfall pattern, soil type and climatic conditions. The present paper attempts to study oilseeds viz., groundnut, soybean, sunflower, sesame, safflower, niger, castor and linseed. The study was based on the secondary data collected from various published sources viz. Agricultural Statistics at a Glance and website of Directorate of Economics and Statistics (DES). The historical performance of oilseeds has been assessed for the State. The data from the past two decades from 2001-02 to 2020-21. It was further divided into two study periods i.e., Period I (2001-02 to 2010-11) and Period II (2011-12 to

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2020-21). The pace of agricultural development of a region can be ascertained through measuring growth in area, production and yield of crops in that particular region. The study has assessed the compound growth rates of the area, production and yield of oilseed crops for the period 2001-2020.

The compound annual growth rates (CAGR) of area, production and yield of oilseeds were estimated as follows:

$$Y_t = AB^t e$$

$$\ln Y_t = \ln A + (\ln B)t + \ln e$$

Where,

$$B = (1+r)$$

Y_t = Area/Production/Yield of major oilseeds in the i^{th} period,

t = a time variable (1, 2, 3,....., n),

A and B are parameters to be estimated,

r = compound growth rate, and

e = error term

Cuddy and Della Instability Index: To examine the stability in the growth of oilseeds across the state, the coefficient of variation was estimated using the following procedure.

$$CV = \alpha/\mu \times 100$$

Where,

CV = Co-efficient of variation

α = Standard deviation of the variable

μ = Mean of the variable.

The formula suggested by Cuddy and Della (1978) was used to compute the degree of variation around the trend.

$$\text{Instability Index} = CV \times \sqrt{1-R^2}$$

Where, R^2 = Coefficient of determination from a time-trend regression adjusted by the number of degrees of freedom

Markov Chain Analysis: Markov chain analysis was used to study the shift in area between the crop groups which provided insight into the changes in cropping options among the crop groups. The estimation of the probability matrix (P) was central to this analysis and was done by using the LINGO software (Version 20) package. The elements P_{ij} of the matrix indicated the probability that the area would switch from the i^{th} crop group to the j^{th} crop over a period of time and the diagonal elements P_{ii} indicated the probability that the area share of a crop would be retained in successive periods. The average area under a particular crop was considered to be a random variable which depended only on its past area of cultivation to that crop and which was denoted algebraically by:

$$A_{jt} = \sum_{i=0}^n A_{it} - 1 * P_{ij} + e_{jt} \dots\dots\dots(1)$$

Where,

A_{jt} = Area under j^{th} crop group during period t

$A_{i,t-1}$ = Area under i^{th} crop group during $t-1$

P_{ij} = Probability of shifting area from i^{th} crop group to j^{th} crop group

e_{jt} = The error term which is statistically independent of $e_{i,t-1}$, and

n = Number of crop groups

The transitional probabilities P_{ij} , which can be arranged in a $(c \times n)$ matrix, have the following properties,

$$1. \quad 0 \leq P_{ij} \leq 1 \text{ for all } i, j.$$

$$2. \quad \sum_{j=1}^r P_{ij} = 1 \text{ for all 'i'}$$

Thus, the expected shift in area under cultivation between each crop group during study period 't' is obtained by multiplying the area under cultivation of the crop group in the previous period (t-1) with the transitional probability matrix.

To identify potential districts for technology, transfer in oilseed cultivation, the Relative Spread Index (RSI) and Relative Yield Index (RYI) were computed using the following formulas:

$$\text{RSI} = \frac{\text{Area of the particular crop expressed as \% of total cultivable area in the district}}{\text{Area of that crop expressed as \% to the total cultivable area in the country}} \times 100$$

$$\text{RYI} = \frac{\text{Mean yield of a particular crop in a district}}{\text{Mean yield of that particular crop in the country}} \times 100$$

Based on the RSI and RYI values, the districts were categorized into three groups as suggested by Ramamurthy et al., 2018: Most efficient districts ($RSI > 125$ and $RYI > 125$): These districts exhibit high spread and productivity, making them bio-physically suitable for the cultivation of the crop. Efficient districts ($RSI < 125$ and $RYI > 125$): These areas have low spread but high productivity, indicating suitability for the particular crop. Moderately efficient districts ($RSI > 125$ and $RYI < 125$): Despite high spread, these districts have lower productivity but remain bio-physically suitable for oilseed cultivation.

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RESULTS AND DISCUSSION

Area, production and yield of oilseed crops in Karnataka: Karnataka cultivated annual oilseed crops over 17.22 lakh hectares of area, producing 11.03 lakh tonnes and yielding 676 kg per hectare annually (two decades mean). Majority of the oilseeds were cultivated under rainfed ecosystem (70%). The area under oilseeds experienced a deceleration in general, and this was due to most of the oilseeds crop area being switched to cash crops like sugarcane and cotton (Behera and Basavaraja, 2017) due to their relative lower profitability against competing crops under the prevailing crop growing conditions and their marketing.

Over the past two decades, Karnataka witnessed dynamic shifts in the cultivation pattern, production and yield of oilseed crops (Fig 1). The area under cultivation experienced fluctuating patterns with an increasing trend and reached its pinnacle in 2005-06 at 28.57 lakh ha while declining subsequently to a low of 9.49 lakh ha in 2018-19. Similarly, oilseed production displayed a nearly increasing trend with peaks observed in 2005-06 at 17.15 lakh tonnes. However, the area and production of oilseeds witnessed a tendency towards decline with varying levels of fluctuations over the study period. Despite this, the yield per hectare demonstrated a notable upward trend, particularly evident from 2007-08 to 2017-18, with yields surpassing 1000 kg/ha in subsequent years. The trend suggests harnessing productivity potentials by adopting more efficient agricultural practices, use of high-yielding varieties to contribute towards improved productivity despite fluctuations in area and production levels (Lokesh and Dandoti, 2017). Overall, challenges persist in maintaining consistent production levels. The trend towards enhanced yield signifies promising developments in oilseed cultivation in the state of Karnataka.

Share of Karnataka state in area and production to the total oilseeds in India: An attempt was made to analyse the state's share in both area and production for respective oilseed crops against the national level during 2020-21 and the overall period (Table 1). This study offers an overview of the importance of each crop in the state to the national oilseed economy. According to the data, the state held the highest share of sunflower cultivation area at 53.13% in 2020-21 and maintained this lead with 56.16% over the entire period at the national level. The state contributed 47.18% to sunflower production in 2020-21 and 44.20% over the entire period in terms of production. Safflower emerged as the dominant crop, occupying the second largest share both in area and production, with a substantial

presence of 51.75% in cultivation area and 53.73% in production during 2020-21 against only 24.90% share in the area during 2020-21 and 30.05% for the overall period. Groundnut holds the next highest position, with an area share of 11.99% in 2020-21 and 13.29% for the overall period and production shares of 7.03% (2020-21) and 7.27% (overall period). Sesamum and soybean also have marginal shares with respect to area and production during 2020-21 ranging from 1.28% to 2.41% and 2.48% to 2.99%, respectively. During and for overall period these crops had a share in area and production ranging from 3.53% to 1.96% and 4.76% to 1.59%, in that order. Castor, Linseed and Niger as minor oilseeds have the lowest shares both in area and production. These results emphasize the importance of sunflower, safflower and groundnut in Karnataka's oilseed economy, given their significant contributions to both cultivated area and production, whereas crops like sesamum and soybean hold a marginal significance and castor, linseed and niger play minor roles in the state's oilseed landscape (Reddy and Immanuelraj, 2017).

Distribution of oilseeds to the total oilseed area and production in Karnataka: The analysis reveals the distribution and share of each oilseed crop to the total oilseed area and production in Karnataka. The data for 2020-21 and mean values spanning 2001 to 2020 on oilseeds area and production (Table 2) indicated the dominance of groundnut both in the area (59.62% and 43.14%) and production (57.69% and 48.82%). Meanwhile, soybean holds the second-largest share in the area (25.72%) and production (30.18%) in 2020-21 which increased substantially against the overall period in both area (11.03%) and production (14.80%). Whereas, sunflower was a significant contributor both in terms of area (36.45%) and production (27.82%) in the overall period compared to 2020-21. The decline in sunflower area and production in recent years was mainly attributed to the widespread incidence of pests and diseases in the major sunflower growing districts of the state. Other crops like safflower, sesamum and castor maintained relatively consistent shares, while linseed and niger exhibited minor contributions. On the whole, groundnut, soybean and sunflower emerged as the key contributors to both the area under cultivation and production of oilseeds in Karnataka, reflecting their importance in the agricultural landscape of the region. These shifts in crop shares reflect changing agricultural practices, market demands, possibly natural and environmental factors underscoring the dynamic nature of oilseed cultivation in Karnataka over time (Motebennur and Naregal, 2015).

Table 1 Share of oilseeds area and production in Karnataka to the Indian oilseeds (Percent)

Crop	Area (% share to all India)		Production (% share to all India)	
	2020-21	Overall period (2001 to 2020)	2020-21	Overall period (2001 to 2020)
Castor	0.45	1.62	0.22	0.90
Groundnut	11.99	13.29	7.03	7.27
Linseed	0.57	2.58	0.40	1.77
Niger	0.75	5.59	0.58	4.71
Safflower	51.75	24.90	53.73	30.05
Sesamum	1.28	3.53	2.48	4.76
Sunflower	53.13	56.16	47.18	44.20
Soybean	2.41	1.96	2.99	1.59
Total oilseeds	4.19	6.60	3.47	3.93

Note: Figures indicate percentage crop share of the state to the respective crop at the national level

Table 2 Distribution of oilseeds to the total oilseed area and production in Karnataka (percent)

Crop	Area		Production	
	2020-21	Overall period (2001 to 2020)	2020-21	Overall period (2001 to 2020)
Castor	0.33	0.84	0.29	1.08
Groundnut	59.62	43.14	57.69	48.82
Linseed	0.08	0.53	0.04	0.25
Niger	0.08	1.06	0.02	0.39
Safflower	2.40	3.40	1.54	3.66
Sesamum	1.82	3.56	1.62	3.08
Sunflower	9.92	36.45	8.62	27.82
Soybean	25.72	11.03	30.18	14.80
State oilseed area (lakh ha & production (lakh t)	12.09	17.19	12.50	11.03
Total oilseeds	100	100	100	100

Note: Figures indicate percentage crop share of the state to the total oilseed at the state level

Growth rate of oilseed crops in Karnataka: The mean area for all oilseeds together declined in Period II (12.47 lakh ha) over Period I (21.97 lakh ha) thus influenced towards decrease in production (12.47 lakh tonnes to 9.58 lakh tonnes) (Table 3). The droughts and insufficient monsoon rains have also affected the production and productivity of oilseeds in Karnataka (Behera and Basavaraja, 2017). Despite the reduction in the oilseeds area, with technological interventions, there was an increase in the productivity from 572 kg/ha to 781 kg/ha in Period II. The compound annual growth rate (CAGR) analysis for total oilseeds in Karnataka for area, production and productivity reveals significant trends across two distinct periods. In Period I, while there was a slight decline in cultivation area by -0.91%, production and yield showed positive growth rates of 1.43% and 2.36%, respectively. However, in Period II, a notable downturn in

cultivated area was marked by a significant negative growth (-3.82%) at 1% probability level. Despite the reduction in area, production maintained a positive albeit lower growth rate (0.93%), while the productivity growth rate surged impressively by 4.94%. Critical review for the Overall period for Karnataka experienced a substantial decline both in cultivated area (-4.71%) and production (-1.62%) during the entire study period from 2001 to 2020. However, the productivity demonstrated a commendable positive growth rate of 3.24% denotes significance at the 1% level. These findings underscore the need for strategic interventions to address challenges and capitalize on the opportunities for sustainable growth in the oilseed sector in Karnataka.

The crop wise analysis of growth performance on selected indicators for each oilseed crop presents interesting facts considering their importance and adaptability in the state as significant contributors to the oilseed economy.

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Castor: The mean area under castor declined in Period II (0.09 lakh ha) over Period I (0.20 lakh ha) with a consequent reduction in the production (0.17 lakh tonnes to 0.06 lakh tonnes). The productivity also declined from 864 kg/ha to 727 kg/ha in Period II. The compound annual growth rate reveals a reduction in castor cultivation in Karnataka. During Period II, there was a significant decline both in area (-15.79%) and production (-15.01%), indicating substantial setbacks in castor farming. The growth in productivity in Period I decreased whereas it witnessed positive growth in Period II. The long-term analysis of growth in the area (-8.94%), production (-10.27%) and productivity (-1.46%) indicated a substantial reduction. The reduction could be due to several production constraints *viz.*, inadequate rainfall, long duration of crop, impotent genotype, non-adoption of improved technologies, biotic stress like gray-mold and capsule borer infestation and market-related problems. This suggests challenges in sustaining castor cultivation, potentially influenced by factors such as market demand, technological changes, input costs, or climatic conditions (Mohan Kumar and Yamanura, 2019).

Groundnut: The mean area under groundnut declined from 8.70 lakh hectares in Period-I to 6.11 lakh hectares in Period-II thus contributed to a decline in production from 5.83 lakh tonnes to 4.92 lakh tonnes in Period II. The biotic, technological, institutional, socio-economic constraints inhibit the yield potential in groundnut crop. The rising input prices also showed a greater negative impact on groundnut cultivation (Seedari *et al.*, 2022). Interestingly, there was a significant increase in per hectare productivity from 666 kg/ha in Period I to 808 kg/ha in Period II. Thus, groundnut cultivation in Karnataka exhibited varied trends in different periods. The decline in area in Period II was compensated by enhanced productivity in this period with greater impetus on technology and market-driven factors. Notably, the critical review of growth in Period II and also long-term analysis implied a significant decrease in the growth of groundnut (-2.84%) area and an increase in (2.10%) productivity, indicating potential challenges to be addressed or shifts required in agricultural practices to promote its cultivation as the crop constitute one of the major oilseeds crops of the state (Nayak *et al.*, 2021).

Linseed: The performance of linseed cultivation between Period I and Period II, significant differences emerge across various metrics. The mean area dedicated to linseed cultivation experienced a notable decline from 0.13 lakh hectares in Period I to 0.04 lakh hectares in Period II, resulting in an overall mean area of 0.09 lakh hectares.

This shift reflects a substantial compound annual growth rate decrease of -4.43% in Period I and a staggering -22.66% in Period II, leading to an overall decrease in growth rate (-13.73%). Mean production similarly saw a decline from 0.04 lakh tonnes in Period I to 0.01 lakh tonnes in Period II, with an overall mean production of 0.02 lakh tonnes. While Period I displayed a modest growth rate of 1.29% in mean production, Period II witnessed a significant growth decrease of -19.29%, contributing to an overall growth of -11.50%. Interestingly, despite these fluctuations, the mean yield experienced a slight increase from 303 kg/ha in Period I to 346 kg/ha in Period II, resulting in an overall mean yield of 324 kg/ha. The CAGR for mean yield demonstrated stability, with Period I recording a growth rate of 5.98% and Period II of 4.36%, culminating in an overall growth of 2.58%. The cultivation of the crop was reduced over the period for reasons like the occurrence of diseases and pests, lack of availability of location-specific high-yielding varieties and lack of labour, etc. (Bharadi and Kurubetta, 2018; Acharya *et al.*, 2012). These findings underscore the dynamic nature of linseed cultivation, impacted by shifts in cultivation area and production, albeit with relatively stable yield levels across the periods evaluated.

Niger: Niger cultivation in Karnataka exhibited significant changes in production and area during the studied periods. The comparison between Period I and Period II for niger cultivation highlights significant changes. In Period I, the mean area was 0.28 lakh hectares with a decline growth rate of -3.39% and mean production was 0.06 lakh tonnes with a growth rate of 3.87%. The mean yield was 235 kg/ha with a notable growth rate of 7.51%. However, in Period II, there was a sharp decline across all metrics, with mean area dropping to 0.07 lakh hectares (-31.00%), mean production falling to 0.02 lakh tonnes (-32.78%) and mean yield decreasing to 244 kg/ha (-2.58%). Overall, niger cultivation witnessed a decline in mean area and production, while mean yield remained relatively stable, albeit with a slight decrease. These fluctuations suggest the need for further investigation into factors affecting Niger cultivation in the region, including market demands, climate conditions, improved varieties and agricultural policies (Panday *et al.*, 2014).

Safflower: The mean area under safflower declined in Period II (0.37 lakh ha) over Period I (0.79 lakh ha) with a consequent reduction in the production (0.54 lakh tonnes to 0.26 lakh tonnes). the decline in area, which was due to higher income from competing crops such as sorghum and Bengal gram (Behera and Basavaraja, 2017). The cultivation of safflower in Karnataka displayed varying

trends in production and area over the observed periods. During Period II, both area and production showed significant declines, with decreases of -8.90% and -7.54% respectively at 5% significance level, highlighting potential challenges or shifts in cultivation preferences. However, overall trends showed no significant changes in area and production, with yield increasing slightly by 0.93%. These findings suggest the need for further examination of factors influencing safflower cultivation, such as market dynamics, input costs and agronomic practices.

Sesame: Sesame cultivation in Karnataka exhibited significant changes in production and area over the observed periods. The mean area under sesame declined from 0.80 lakh hectares in Period I to 0.41 lakh hectares in Period II thus contributed to a decline in production from 0.43 lakh tonnes to 0.24 lakh tonnes in Period II. On the other hand, the productivity of the crop increased from 525 kg/ha in Period I to 629 kg/ha in Period II. During Period II, there was a notable decrease in both area and production, with declines of -11.14% and -5.03% respectively at 1% and 5% significance levels, suggesting potential challenges or shifts in cultivation strategies. However, overall trends indicated no significant changes in area and production, with yield increasing significantly by 2.66% at 5% significance level. These fluctuations underline the importance of further research into factors influencing sesame cultivation, including market dynamics, technological advancements and climatic conditions.

Sunflower: The mean area under sunflower declined substantially in Period II (2.77 lakh ha) over Period I (9.75 lakh ha). The area under sunflower was decreased over the years due to its lower remunerative prices, owing to widespread pest and disease incidence, poor seed quality and less investment of private companies in seed companies (Seedari *et al.*, 2022). Thus, resulting in a substantial decrease in production (4.54 lakh tonnes to 1.59 lakh tonnes). Interestingly, on the other hand productivity of the crop increased from 471 kg/ha in Period I to 621 kg/ha in Period II. Sunflower cultivation in Karnataka displayed negative trends over the specified study periods. During Period II, there was a significant (of 1% probability level) decline both in area (-15.69%) and production (-10.72%). Whereas, per hectare yield exhibited a significant increase of 5.90% at 5% probability level. A critical review of the entire study period implied that although the sunflower area (-11.73%) declined but was not significant and on the other hand production decreased significantly by -8.98%. The trend in growth rates of area, production sunflower during period I could be due to government initiatives in the form of TMO as well as price and marketing support for oilseed

growers (Jha *et al.*, 2012). On a positive note, the per hectare yield demonstrated a significant increase of 3.12%. These findings suggest a concerning trend of decreasing production levels alongside an increase in yield per hectare, indicating potential production efficiency with technological interventions in sunflower in Karnataka.

Soybean: The mean area under soybean cultivation exhibited a notable increase from 1.22 lakh hectares in Period I to 2.56 lakh hectares in Period II, reflecting a significant upward trend with growth rates of 12.94% and 6.18%, respectively. This expansion contributed to a substantial rise in production, soaring from 0.81 lakh tonnes to 2.45 lakh tonnes during the same periods, with impressive growth rates of 12.37% and 8.53% respectively. Remarkably, there was a significant improvement in per-hectare productivity, with yields climbing from 686 kg/ha in Period I to 955 kg/ha in Period II, highlighting advancements in soybean farming practices amidst this period, showcasing growth rate of -0.5% and 2.21% respectively, the growth rate was significantly increased over the study period because of good adaptability, attributed to shifting cultivation of soybean crop from earlier intercrop to a monocrop in the recent years due to favorable price in the market in Karnataka that indicated its importance and potential for further expansion in Karnataka's agricultural landscape (Jamanal and Sadaqath, 2017).

Instability in area, production and productivity of oilseeds in Karnataka: The instability index, measured through the Cuddy Della Valle Index (CDVI), offers valuable insights into the extent of stability of oilseed crop production in Karnataka across study periods (Table 4). Analysing the CDVI values, it is evident that the instability levels vary among different oilseed crops during the two study periods while, for the overall period, fluctuations were observed both in area and production. Castor cultivation demonstrated relatively stable trends in both area and production, with moderate fluctuations observed in yield. Groundnut cultivation also exhibited stability in the area, production and yields showed moderate instability. Linseed cultivation showed moderate instability across all metrics, indicating fluctuations in area, production and yield. Niger cultivation appeared moderately instable in terms of area and yield, production showed higher instability. Safflower cultivation displayed moderate instability in area, production and yield. Sesamum cultivation showed low to moderate instability in area and yield, while production was highly unstable. Sunflower cultivation exhibited moderate to high instability in area and production, with moderate unstable yields. Soybean cultivation displayed moderate

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instability in area, production and yield. These findings underscore the importance of understanding and managing variability and risks associated with oilseed crop production. Such insights can inform policymakers and stakeholders in developing strategies to enhance stability and resilience in oilseed agriculture, thereby contributing to sustainable agricultural development in Karnataka.

Competing crops for oilseeds: The transitional probability matrix provides insights into the dynamics of area shifts between different crop groups in Karnataka. Table 5 indicates the retention of area for oilseeds and the competition with other crops. The row elements indicate the extent of loss in area to the competing crops, while the column elements signify the probability of area gained from other crops and the diagonal elements represent the probability of retention in the previous year's area. Among the various crop groups, total oilseeds exhibit a notable retention probability of 34 percent, indicating a significant likelihood of maintaining the cultivated area over the years. However, there is a moderate probability of loss in the area to the competing crops, particularly millets, such as jowar, ragi, bajra with transitional probabilities of 60 percent. On the other hand, all oilseeds put together have limited potential for gaining area from other crop groups. This suggests a stable but somewhat vulnerable position of oilseeds in Karnataka's agricultural landscape, due to competition primarily from millets. Other crop groups such as cereals, fruits, vegetables, commercial crops and condiments and spices also exhibit varying dynamics in area retention and competition, indicating the complex interplay of factors shaping Karnataka's agricultural sector in respect of crop choice.

Categorisation of districts in Karnataka: The categorization of districts in Karnataka for various crops reveals distinct patterns of efficiency in their cultivation (Table 6) based on the Relative Spread Index (RSI) and Relative Yield Index (RYI). Sunflower cultivation thrives most in Davangere, while Shimoga and Chikballapur also demonstrate efficient production. Conversely, districts such as Koppal, Gadag, Bagalkot and others demonstrated moderate efficiency, aligning with the findings of Chandhana *et al.* (2022) and Ramamurthy *et al.* (2018), suggested a wide variation but relatively lower productivity levels. Groundnut cultivation showcases Udupi as the efficient district, with several others such as Chitradurga, Tumkur, Chikballapur and Bellary demonstrating moderately efficient. Linseed cultivation primarily concentrates in Bagalkot. The Niger cultivation, districts

like Hassan, Ramanagara and Mandya exhibit moderate efficiency, while Safflower cultivation sees Bidar and Gulbarga as most efficient, with Dharwad, Gadag and others showing efficient production. Sesamum cultivation finds efficiency in districts like Koppal, Mandya and Chikmagalur. Similar findings to the study by Nagaveni *et al.* (2021), while Soybean cultivation efficiency was observed in Bidar and Belgaum. This categorization aids in identifying regions where agricultural interventions can yield the greatest impact, whether through targeted technology transfer or strategic crop substitution, ultimately fostering sustainable agricultural practices and enhancing overall productivity in Karnataka.

The analysis of oilseed cultivation trends in Karnataka over the past two decades reveals a significant insight into the sector's dynamics. Despite a notable decline in cultivated area and production, particularly in the second period, the commendable growth in yield underscores the sector's resilience and potential for sustainable development. Groundnut and soybean emerged as promising crops with consistent growth patterns, while castor and niger faced challenges, indicating the need for targeted interventions. The instability index highlighted varying levels of stability across different oilseed crops. Groundnut cultivation demonstrates stability in the area but moderate instability in production and yield, Castor cultivation emerges as relatively stable, with moderate fluctuations in yield. Linseed, niger, safflower, sesamum, soybean and sunflower cultivations all exhibit varying degrees of instability across different parameters, guiding policymakers in managing risks effectively through multiple strategies. The categorization of districts based on efficiency provided valuable insights for targeted interventions, aiming to enhance productivity and bring sustainability to Karnataka's oilseed sector. On the whole, the analysis underscores the importance of informed decision-making and strategic interventions to ensure the sector's resilience and long-term growth amidst evolving challenges and opportunities. There is a need to identify region-specific constraints and efforts to create necessary infrastructure and execute oilseed development programs efficiently should be maintained to provide favorable conditions for oilseed production.

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Table 3 Growth rates of area, production and productivity of oilseed crops in Karnataka

Crop	Years	Mean area ('000 ha)	CAGR (%)	Mean production ('000 tonnes)	CAGR (%)	Mean yield (kg/ha)	CAGR (%)
Castor	Period I	20.10	0.07	17.42	-1.58	864	-1.65
	Period II	8.69	-15.79***	6.29	-15.01***	727	0.93
	Overall	14.39	-8.94	11.86	-10.27	796	-1.46*
Groundnut	Period I	871.20	-0.36	583.83	1.15	666	1.52
	Period II	611.49	-1.21	492.80	2.3	808	3.56*
	Overall	741.35	-2.84***	538.31	-0.8	737	2.10***
Linseed	Period I	13.99	-4.43***	4.27	1.29	303	5.98
	Period II	4.09	-22.66	1.29	-19.29***	346	4.36
	Over all	9.04	-13.73	2.78	-11.50***	324	2.58*
Niger	Period I	28.80	-3.39***	6.58	3.87*	235	7.51***
	Period II	7.80	-31.00***	2.06	-32.78***	244	-2.58
	Over all	18.30	-16.84	4.32	-16.01	239	1.01
Safflower	Period I	79.75	-5.06***	54.56	-1.43	701	3.83
	Period II	37.02	-8.90**	26.07	-7.54**	719	1.49
	Over all	58.38	-7.61	40.32	-6.75	710	0.93
Sesamum	Period I	80.80	0.4	43.51	3.78	525	3.37
	Period II	41.68	-11.14***	24.51	-5.03**	629	6.88***
	Over all	61.24	-6.54	34.01	-4.05***	577	2.66***
Sunflower	Period I	975.54	-3.17	454.41	-0.42	471	2.85
	Period II	277.28	-15.69***	159.22	-10.72***	621	5.90**
	Over all	626.41	-11.73	306.81	-8.98***	546	3.12***
Soybean	Period I	122.18	12.94***	81.13	12.37***	686	-0.5
	Period II	256.89	6.18***	245.18	8.53**	955	2.21
	Over all	189.54	8.63	163.15	11.58	820	2.72**
Total oilseeds	Period I	2197.40	-0.91	1247.38	1.43	572	2.36
	Period II	1247.16	-3.82***	958.02	0.93	781	4.94**
	Over all	1722.28	-4.71	1102.70	-1.62*	676	3.24***

Note: 1)***significant at 1% level, **significant at 5% level and *significant at 10%
2) Period I: 2001-02 to 2010-11 and Period II:2011-12 to 2020-21

Table 4 Instability index in area, production and productivity of oilseeds in Karnataka

Crop		Area	Production	Yield
Castor	Period I	13.51	24.83	17.28
	Period II	21.72	34.56	24.15
	Over all	23.98	28.70	19.94
Groundnut	Period I	9.77	23.85	18.49
	Period II	12.11	20.82	14.77
	Over all	12.46	23.29	16.11
Linseed	Period I	12.40	39.12	29.41
	Period II	14.24	20.16	25.05
	Over all	23.50	42.14	26.77
Niger	Period I	9.24	17.80	20.49
	Period II	27.19	31.69	18.82
	Over all	30.77	38.51	24.90
Safflower	Period I	8.28	17.68	19.26
	Period II	23.90	23.29	17.94
	Over all	16.84	22.60	18.46
Sesamum	Period I	22.12	44.21	25.54
	Period II	16.91	20.01	12.88
	Over all	23.54	41.07	21.37
Sunflower	Period I	33.29	40.31	18.55
	Period II	15.82	22.25	18.12
	Over all	30.55	35.89	19.11
Soybean	Period I	22.06	21.53	25.09
	Period II	11.53	23.25	24.72
	Over all	18.16	20.73	25.36
Total oilseeds	Period I	18.22	22.70	17.80
	Period II	8.77	17.53	15.59
	Over all	16.75	22.22	16.55

DYNAMICS OF OILSEEDS PRODUCTION AND FUTURE POTENTIALS IN KARNATAKA

Table 5 Dynamics of area shift between different crop groups in Karnataka

	Cereals	Millets	Pulses	Oilseeds	Fruits	Vegetables	Commercial crops	Condiments and spices	Drugs and plantation crops
Cereals	0.52	0	0	0.28	0	0	0.18	0	0.01
Millets	0.15	0	0.37	0.18	0.03	0.08	0.07	0.08	0.06
Pulses	0.06	0	0.72	0	0.04	0.03	0.13	0.01	0.01
Oilseeds	0	0.60	0.06	0.34	0	0	0	0	0
Fruits	0.07	0	0	0	0.25	0.05	0.63	0	0
Vegetables	0	0.74	0.18	0	0.08	0	0	0	0
Commercial crops	0.58	0.27	0	0	0.03	0.08	0.04	0	0
Condiments and Spices	0	0	0	0	0.02	0	0.31	0.67	0
Drugs and Plantation Crops	0	0.54	0	0	0	0	0	0	0.46

Table 6 Categorisation of Districts in Karnataka

Crop	Most Efficient District	Efficient District	Moderately Efficient District
Sunflower	Davangere	Shimoga, Chikballapur	Koppal, Gadag, Bagalkot, Raichur, Chamarajanagar, Bijapur, Bellary, Chitradurga, Gulbarga, Yadgir, Belgaum, Haveri, Dharwad, Chikmagalur, Bidar
Groundnut	None	Udupi	Chitradurga, Tumkur, Chikballapur, Bellary, Yadgir, Gadag, Koppal, Dharwad, Kolar, Haveri, Bagalkot, Raichur, Chamarajanagar, Davangere, Bijapur, Belgaum
Linseed	None	None	Bagalkot
Niger	None	None	Hassan, Ramanagara, Mandya, Bidar, Mysore
Safflower	Bidar, Gulbarga	None	Dharwad, Gadag, Bijapur, Koppal, Belgaum, Chitradurga, Bagalkot, Haveri, Raichur, Yadgir
Sesamum	Koppal, Mandya, Chikmagalur	Mysore, Ramanagara, Bidar, Gulbarga	
Soyabean	None	None	Bidar, Belgaum

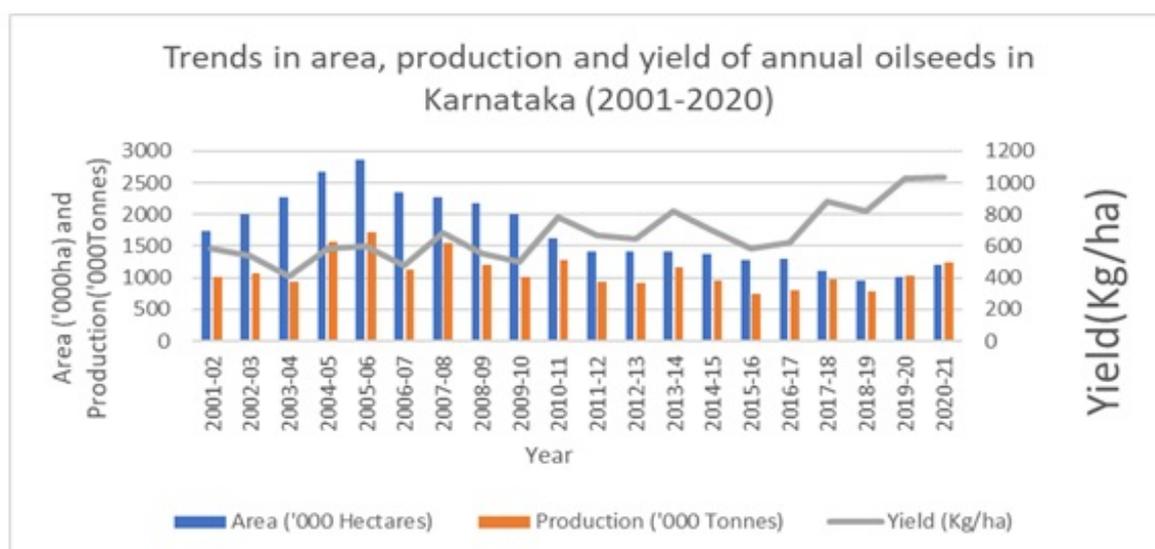


Fig. 1. Trends in area, production and yield of annual oilseeds in Karnataka (2001-2020)

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Yield gap and production constraints in rapeseed-mustard: A case study from North western hills of Jammu & Kashmir

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ABSTRACT

Studies show that there exists a gap between potential and production of oilseeds in the country and so is the case in the Union Territory of Jammu & Kashmir. Brown sarson is the sole member of the rapeseed-mustard group that fits well in the predominant paddy-oilseed sequence in Kashmir valley situated in the Northwestern Himalayas, that makes it a major rabi crop in the valley. The production however is still below potential hovering around 7.9 q/ha. The present study indicated an extension gap of 5.3 q/ha and a technology gap of 3.8 q/ha in brown sarson. Nearly 36% of the respondents attributed this to late sowing of crop, 20% to lack of awareness and 12% to lack of quality seed. Interventions including mechanization, supply of quality seed, frontline demonstrations, awareness programmes, processing and marketing facilities will be crucial in bridging the yield gaps in oilseed in Jammu & Kashmir.

Keywords: Brown sarson, Constraints, Temperate ecology, Yield gap

Enormous gap between the potential yields and actual production has been a great challenge and also an opportunity to tap the untapped potential in field crops in India (Sofi and Wani, 2022; Mubarak *et al.*, 2023a; Thakur *et al.*, 2022). The demand for the vegetable oils has increased due to ever expanding population and changing life style during the last few years. Several initiatives viz., the Technology Mission on Oilseeds, project on frontline demonstrations in oilseed crops and All India Coordinated Research Project on Rapeseed Mustard (AICRPRM) were taken up with an aim to enhance production and achieve self-reliance in oilseed. This paved a way for meeting different challenges and complexities in the oilseed sector (Hegde, 2009; Anupam Barik, 2023) enabling country to secure 4th rank in oilseed production in the world. The country is also one of the largest importers of vegetable oils. Taking these into account, government of India has been emphasizing on enhancing production of oilseeds and consequently, ICAR through the network of research and technology dissemination institutes spread all over the country, has been making special efforts for the development and popularization of oilseed technologies. Despite all these efforts there still exists gap between potential and production. In Jammu & Kashmir, Brown sarson is major oilseed crop grown in *rabi* season and it is the sole member of the rapeseed-mustard group that fits well in the predominant paddy-oilseed sequence in Kashmir. Due to continuous efforts of concerned agencies, the area under its cultivation increased from 65950 ha in 2015 to around 98916 a by 2021 in the Union Territory (Anonymous,

2021; Trivedi *et al.*, 2023). The productivity (7.9 q/ha) however is still well below the potential (Sheikh *et al.*, 2013). In view of aforesaid problems, the present study was therefore carried out with an aim to dwell into the reasons for lower yields in the farmers fields and also find out the yield gaps.

MATERIALS AND METHODS

The study was conducted during year 2022 in district Kulgam which falls in Kashmir Division of the Union Territory of Jammu & Kashmir. Nestled in the lap of Peer Panchal mountain Range, the district is bounded by Pulwama in the North, Shopian in the West, Ramban in the South and Anantnag in the East. The geographical area of the district is 1067 Sq kms with 84.98% of population living in rural areas. Agriculture is the main source of livelihood of about 80% of total population in the district (Bhat, 2014). It is characterized by temperate climatic conditions with mild summers and harsh winters. Soils are clay loam, silt loam and loamy in texture. Rice is major agricultural crop cultivated in *kharif* season and brown sarson is a major *rabi* crop. The present study was conducted to know the gaps between the present production and potential of oilseed and also find-out the reasons for low yields. Both primary and secondary sources of data were used to generate information related to the objectives of the study. The primary sources of information included farming community of the district and the secondary source of information included government agencies (SKAUST-Kashmir and Agriculture Development Department). Major portion of secondary data was collected from Mountain Research Center for Field Crops (MRCFC)-SKUAST-Kashmir and for primary data

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purposive sampling technique was adopted in which 50 farmers associated with oilseed production were selected for generating information through personal interaction and questionnaire designed for the purpose. The farmers were selected from seven villages including Tulinowpora, Srandoo, Kujer, Demidullah, Sangas, Frisal and Kaharwat. Yield gap analysis was carried out using formulae given below:

(i) Extension gap= Demo yield - Farmers' practice yield

(ii) Technology gap= Potential yield - Demo yield

(iii) Technology Index = $\frac{\text{Potential yield} - \text{Demo yield}}{\text{Potential yield}} \times 100$

RESULTS AND DISCUSSION

Yield gaps: The secondary data collect from the mountain Research Center for Field Crops (MRCFC)-SKUAST-Kashmir (Table 1), revealed that the yield potential of the varieties released by the center ranged between 14 to 17 q/ha which is more than double of the what is realized in farmer's fields (7.9 q/ha). Shalimar sarson-2 for instance has a yield potential of 17 q/ha. It means the gap between the obtained and potential yields is 126%. Information collected from Krishi Vigyan Kendra, Kulgam, SKUAST-Kashmir showed that the yield under frontline demonstration programmes ranges between 11.6 to 14.5q with a mean of 13.2q/ha (Table 1). Data in Table 1 indicated an extension gap of 5.3q and technology gap of 3.8 q/ha. This indicates that with effective transfer of technology there can be around 76% increase in production.

Use of new genotypes and matching production technologies will therefore play an important role in bridging the gaps (Prajapati *et al.*, 2021; Mubarak *et al.*, 2023b).

Major constraints related to oilseed production

A. Technical constraints:

A1. Poor crop stand: Time of sowing is considered the most important agronomical practice for harvesting good crop. Due to lack of soil moisture the germination of oilseed gets delayed and results in poor crop establishment. Late sowing due to non-availability of sowing equipments also leads to poor establishment of the crop. Light pre-sowing irrigation and timely availability of machinery and sowing equipment can lead to good crop establishment.

A2. Faulty sowing method: Generally broadcasting method is adopted by farmers that leads to uneven distribution of seed in the field. This in turn results into poor crop stand and leads to poor utilization of resources and low productivity of the crop. Use of seed drill/seed-cum fertilizer drill can ensure line sowing and good crop establishment.

A3. Weed management: The *rabi* weeds grow very quickly during spring season due to availability abundant soil moisture during the season. Brown sarson therefore experience a tough competition with weeds. Thus, weeds become a serious yield limiting factor and proper tillage and use of recommended herbicides becomes important to reduces weed infestation (Jorgensen 2018; Desai *et al.*, 2016).

Table 1 Yield gaps of brown sarson in district Kulgam

Parameter	Yield (q/ha)	References
Average yield in farmers field	7.9	Sheikh <i>et al.</i> , 2014
Yield range in FLDs	11.6 to 14.5	Annual Progress Reports of KVK Kulgam for the year 2015 to 2021
Average yield under Frontline Demonstrations (Demo yield)	13.2	Annual Progress Reports of KVK Kulgam for the year 2015 to 2021
Potential yield of the latest variety Shalimar sarson -2	17.0	Sofi and Wani, 2022
Extension gap	5.3	
Technology gap	3.8	

B. Biotic and abiotic stresses: Biotic and abiotic stresses play a significant role in rapeseed production in Jammu and Kashmir. Abiotic stresses are primarily unavoidable but have a high impact on growth and productivity of this crop in the region. Sometimes various abiotic stresses occur together and affect the crop severely. Frost sometimes have a devastating effect on the crop and may cause crop failure. In addition, low-temperature stress is commonly expected in the region during the growing season which affects crop growth and decreases seed yield. It has a direct effect on the flowering and siliqua development and prevents seed formation, thereby causing considerable yield loss. Heat stress from flowering to maturity has also been observed to affect the overall growth, metabolism and productivity of this crop (Sofi and Wani 2022.). Use of suitable varieties and crop management can help minimize the adverse impact of these stresses (Pathak *et al.*, 2022)

The September and October months in Kashmir valley often remains dry. Thus soil moisture and atmospheric moisture deficit leads to low soil moisture for rabi crops. This hampers timely germination and establishment of the crop. Brown sarson being predominant rabi crop, experience low soil moisture at the time of sowing, which leads to delayed germination and poor establishment of the crop. In case the dry spell prolongs, light Pre-sowing irrigation is recommended for better crop establishment.

Water stagnation is another cause of crop stress. Generally waterlogging occurs from December onwards, because 70% of annual precipitation is received from Western disturbances during December to June (692.0 mm). The growth stages of brown sarson during this period are sensitive to water stagnation. Thus, it is imperative to ensure a good drainage during the vegetative and flowering stages of crop for achieving higher yields. Raised bed method of seed sowing may help in minimize the deleterious effect of water logging in brown sarson under the valley conditions.

The disease incidence in brown sarson is not a serious issue in the region because the environmental conditions are not favourable for disease development and spread during the growing season of the crop. However, the insect pest problems in rapeseed-mustard have been found increasing in intensity during the recent past. The insect pests particularly cabbage butterfly and mustard aphid are recorded as the major pest which cause significant loss to the crop during the season. The mustard aphid, *Lipaphis erysimi*, continues to be the key pest damaging oilseed crop due to favourable environmental conditions for its survival, fecundity, growth and development and distribution of the pest. They also secrete sticky honeydew which act as a medium for sooty mold development and this in turn reduces the photosynthetic efficiency of the plants. In case

of severe infestation, leaves become curled, plant fails to develop pods, the young pods when developed fail to become mature and cannot produce healthy seeds. As a result, plants lose their vigour and growth becomes stunted. Adoption of integrated pest management suggested in the SKUAST-Kashmir package of practice reduces losses due to pest attack.

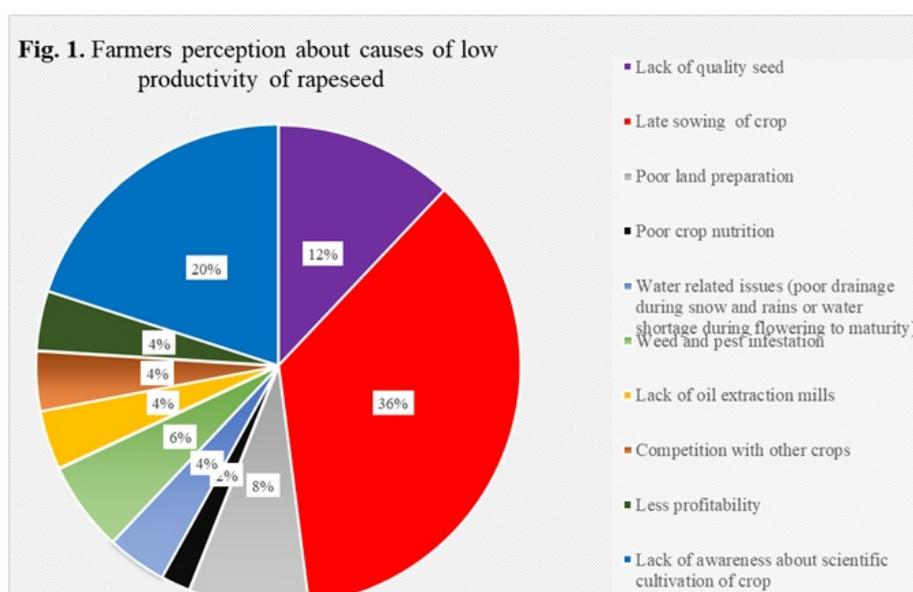
Beside the above constraints, there is direct competition of oilseed crop with the fodder crops. Fodder oat also fits in the rice-based cropping system and limits the horizontal expansion of the brown sarson. With the increase in Livestock population the demand for green fodder also increases and thus horizontal expansion of oilseed crops may face tough competition in future. Thus increasing yields per unit area seems to be the only way forward.

Farmers perception regarding low oilseed production

The analysis of the data presented in Fig. 1 reveals that majority of the farmers (36%) consider late sowing as a major reason of low production of rapeseed. 20% farmers believed that lack of awareness is the major reason, while 12% said that it may be due to poor quality seed. For rest of the reasons mentioned in the questionnaire the percentage of farmers considering these to be the major reasons was small, ranging between 2 to 8%. The analysis of the data presented in table 2 also reveals that highest rank and corresponding score was again recorded for late sowing and lack of awareness. Interaction with the farmers and the data analysis indicates that farmers need interventions especially with regard to resolving the issue of late sowing and lack of awareness. The issue of late sowing as discussed with the experts of MRCFC, SKUAST-Kashmir is really a big reason barring exploitation of full potential of varieties developed by the center. This issue can possibly be addressed through the intervention of mechanization. According to Ravinder *et al.* (2019) farm mechanization has a huge role in agriculture and earlier some researchers have highlighted the importance of mechanization in double cropping system under Kashmir conditions (Zargar and Mubarak, 2011). While interacting with the farmers, small land holding was preventing them from purchase of machinery like tractor and tractor driven implements. This issue can be resolved through relevant machinery like small tractors and tillers, which suit to the land holding and also by establishing custom hiring centers. This study also reflects the need to work in groups which unfortunately is missing in the district. While enquiring about the reasons of lack of group farming in the district, the experts said that the major reason they believe is the deficit of trust among the farmers.

Table 2 Reason of low production of Brown sarson in district Kulgam

Reason	Rank	Score on 1-10 scale
Lack of quality seed	6	4
Late sowing of crop	3	7
Poor land preparation	5	5
Poor crop nutrition	6	4
Water related issues (poor drainage during snowfall and rains or water shortage during flowering to maturity)	6	4
Weed and pest infestation	4	6
Lack of oil extraction mills	8	2
Competition with other crops	7	3
Less profitability	6	4
Lack of awareness about scientific cultivation of crop	3	7



The recent initiatives of government of Indian for the promotion of Farmer Producer Organizations (FPOs) provide a good opportunity to the farmers to do farming in groups. This will help in promotion of mechanization, access to farm inputs, value addition of agriculture produces and creation of better marketing facilities.

The next important reasons as per the study was lack of awareness about improved practices of oilseed farming among the farmers. In this regard it can be suggested that the agencies involved in the dissemination of technologies must increase their outreach and convince farmers to adopt improved practices. Frontline demonstrations on best proven technologies have been considered very effective in bridging the yield gaps (Mubarak and Shakoor, 2019), as

it works on the principle of seeing is believing and is quite effective in motivating farmers. Farmer-scientist interactions, kisan ghosties, farmer field visits, diagnostic visits and field days will also be helpful in spreading the technical Know-how. The primary data indicates that there are other reasons, which substantially impact the oilseed production and lack of quality seed is one of these. The seed chain for oilseed needs proper supervision before it reaches farmers. This is crucial to maintain the quality standards of seed. low profitability due to lack of oilseed extraction plants, lack of packing and branding facilities and also lack of market linkages are other reasons farmers show less interest in oilseed cultivation. Weed and insect pest infestation, poor drainage and poor crop nutrition also add

YIELD GAP AND PRODUCTION CONSTRAINTS IN RAPESEED-MUSTARD IN HILLS OF J & K

to the problem. Interventions like mechanization, creating awareness and supplying good quality seed will be crucial in realizing higher yields of rapeseed in UT of Jammu & Kashmir.

Increasing demand for oil and decreasing cultivable land makes it important that productivity of oilseed must increase to reduce dependency on imports. The findings of present study indicate that late sowing of crop followed by lack of awareness about improved technologies and poor quality seed are major reasons for lower production in the farmers field. Other factors like weed and pest incidence, water management and crop nutrition also impact the yield in brown sarson. Lack of oil extraction plants and proper market linkage are some other reasons that farmers don't take oilseed farming seriously. It can therefore be concluded that mechanization, supply of quality seed, increasing number of frontline demonstration & awareness programmes, providing processing and marketing facilities are vital for the promotion of oilseed production in Jammu & Kashmir Union Territory.

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Effect of biopriming and integrated management on the incidence of major diseases of sesame (*Sesamum indicum* L.)

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ABSTRACT

Field trials were conducted to evaluate the impact of biopriming and integrated disease management (IDM) on disease incidence in sesame during two consecutive *kharif* seasons of 2020 and 2021 at Regional Research Station, Vrindhachalam, Tamil Nadu. The treatments consisted of three modules, viz., Bio-intensive module (M1): Seed treatment with *Trichoderma asperellum* @ 10 g/kg + furrow application of enriched *Trichoderma* (2.5 kg *Trichoderma asperellum* + 100 kg vermicompost) @ 250 kg/ha + spray of *Pseudomonas fluorescens* @ 10 g/l at 30-35 DAS and wettable sulphur @ 2 g/l at 50-60 DAS; Chemical module (M2): Seed treatment with carbendazim @ 2 g/l + spray of combi-product (Tebuconazole 50% + Trifloxystrobin 25%) @ 0.5 g/l at 30-35 DAS and second spray @ 2 g/l at 50-60 DAS; Adaptive module (M3): Seed treatment with *Trichoderma asperellum* @ 10 g/kg + furrow application of enriched *Trichoderma* (2.5 kg *Trichoderma asperellum* + 100 kg vermicompost) @ 250 kg/ha + spray of combi-product (Tebuconazole 50% + Trifloxystrobin 25%) @ 0.5 g/l at 30-35 DAS and second spray at 50-60 DAS and Control (M4): Untreated check. The results revealed that the adaptive module, M3, was highly effective and recorded significantly the lowest disease incidence of root rot (20.7%), severity of Alternaria (11.6%), phyllody (21.9 PDI) and powdery mildew (18.2 %) with highest seed yield of 632 kg/ha and highest benefit:cost ratio of 2:62. This module can be used for the effective management of major diseases in sesame.

Keywords: Biopriming, Integrated disease management, Leaf spot, Root rot, Sesame

Sesamum (*Sesamum indicum* L.) is an important oilseed crop that belongs to the family Pedaliaceae. Due to richness in oil content (about 50%), protein (about 23%) and carbohydrate (15%), cultivation of sesame is preferred in India (Ranganatha *et al.*, 2012). Besides, it also possesses different anti-bacterial, anti-viral, antifungal properties. For these reasons, sesame is often called the "Queen of oilseeds". The low productivity of the crop can be attributed to biotic stresses, poor management practices and cultivation of sesame in marginal and sub-marginal lands (Madhuri and Karuna Sagar, 2018; Mandviwala *et al.*, 2023). Sesame is cultivated during the summer season in the Tamil Nadu and is affected by major diseases in sesame resulting in low productivity. Root rot of sesame is caused by the pathogen *Macrophomina phaseolina* and it is a very serious and damaging pathogen in all sesame growing areas and causes considerable yield losses (Meena *et al.*, 2018). Besides foliar diseases, such as the Alternaria and Cercospora leaf spots can also cause substantial losses (Palakshappa *et al.*, 2020; Sangeetha *et al.*, 2023) impacting the profit of the farmers. Chemical fungicides are the first option for farmers to combat the diseases because of their easy adaptability and immediate action. However, due to the health and environmental hazards resulting from the use of chemical fungicides in plant disease control, it is considered appropriate to limit their use. Seed priming is a

pre-sowing seed enhancement technique that boosts the speed, vigour and uniformity of seedling formation (Demir and van de Venter, 1999). Biopriming is also a sustainable tool to improve the stress tolerance ability of seeds during early seedling growth (Fallahi *et al.*, 2011). Biopriming and integrated management have therefore attained importance in modern agriculture to mitigate the hazards associated with the intensive use of chemicals for disease management. The study was therefore undertaken to assess the impact of biopriming and integrated disease management on reducing disease incidence and enhancing sesame crop yields in Tamil Nadu.

MATERIALS AND METHODS

Field trials were conducted at Regional Research Station, Vrindhachalam *kharif* seasons of 2020 and 2021 under All India Coordinated Research Programme on Sesame with four IDM modules: Bio intensive (M1): ST with *Trichoderma asperellum* @ 10 g/kg, furrow application of enriched *Trichoderma* (2.5 kg *Trichoderma* sp. + 100 kg Vermicompost) @ 250 kg/ha, spray of *Pseudomonas fluorescens* @ 10 g/l at 30-35 DAS, wettable sulphur @ 2 g/l at 50-60 DAS; Chemical (M2): ST with carbendazim @ 2 g/kg, spray combi product (Tebuconazole 50% + Trifloxystrobin 25%) @ 0.5 g/l at 30-35 DAS and second spray at 50-60 DAS; Adaptive (M3): ST with *T. asperellum* @ 10 g/kg, furrow application of enriched

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Trichoderma (2.5 kg *Trichoderma* sp. + 100 kg Vermicompost) @ 250 kg/ha and spray of combi product (Tebuconazole 50% + Trifloxystrobin 25%) @ 0.5 g/l at 30-35 DAS and second spray at 50-60 DAS and Untreated Check (M4) in randomized block design with five replications using the variety, VRI-1. The incidence of *Macrophomina* root rot and phyllody disease was recorded individually by counting the number of affected and healthy plants at random quadrat selected in each plot and the percent incidence was calculated. The foliar diseases such as *Alternaria* and powdery mildew were recorded using the scoring scale. In each plot, 10 random plants were selected and all the leaves were scored for the severity of *Alternaria* and powdery mildew leaf spot by using 0-5 scale (0 - No infection, 1-1 to 10% leaf area infected, 2 -11 to 25% leaf area infected, 3 - 26 to 50% leaf area infected, 4 - 51 to 75% leaf area infected and 5-76 to 100% leaf area infected; AICRP on Sesame and Niger, 1998). The disease incidence and disease index were worked out using the formula as given below:

$$\text{Disease incidence} = \frac{\text{Number of infected plants}}{\text{Total number of plants}} \times 100$$

$$\text{PDI} = \frac{\text{Sum of numerical ratings}}{\text{Total number of leaves scored} \times \text{Maximum grade}} \times 100$$

At maturity, the plants were harvested and the grain yield was calculated by dividing the seed weight by the harvested area and converted to per hectare basis. The benefit : Cost (B:C) ratio was worked out from the cost of cultivation and the gross returns calculated using the prevailing local market prices. The data were analysed following standard statistical procedures using one-way ANOVA at $p = 0.05$ (Panse and Sukhatme, 1985).

RESULTS AND DISCUSSION

The results revealed that all the modules were superior over the control (Untreated check) in suppressing the disease incidence in sesame during both the *kharif* seasons of 2020 and 2021. Among the modules, the adaptive (M3) involving seed treatment with *Trichoderma asperellum* @ 10 g/kg + furrow application of enriched *Trichoderma* (2.5 kg *Trichoderma asperellum* + 100 kg Vermicompost) @ 250 kg/ha + spray of combi-product (Tebuconazole 50% + Trifloxystrobin 25%) @ 0.5 g/l at 30-35 DAS and second spray at 50-60 DAS was found to be the most effective integrated management practice. The significantly lowest disease incidence of root rot disease incidence (20.7%), phyllody incidence (21.9%), leaf spot (11.6 PDI) and powdery mildew (18.2 PDI) with higher yield of 632 kg/ha.

This was followed by Module II M2 comprising of ST with carbendazim @ 2 g/kg, spray of combi product (Tebuconazole 50% + Trifloxystrobin 25%) @ 0.5 g/l at 30-35 DAS and second spray at 50-60 DAS which recorded root rot disease incidence (25.1%), phyllody incidence (26.3%), leaf spot (14.9 PDI) and powdery mildew (26.7 PDI) with yield of 584 kg/ha. In control, the maximum root rot disease incidence (42.3%), phyllody incidence (36.4%), leaf spot (20.3 PDI) and powdery mildew (34.6 PDI) with minimum yield of 483 kg/ha was recorded. The BCR varied significantly among the treatments. Higher BCR was recorded in M3- Adoptive treatment (2.62) whereas the check recorded the least (1.29).

The present investigation is in line with the findings of Meena (2021) who also reported significant reductions in root rot, phyllody, *Alternaria* leaf spot and powdery mildew diseases of sesame in Tamil Nadu by following the adaptive module consisting of biocontrol agent and combination of chemical fungicides. Mahalakshmi (2020) reported that among the different treatments tested in field condition, the minimum incidence of *Alternaria* leaf spot with higher yield were recorded in seed treatment with *T. viride* @ 10 g/kg+ furrow application of *T. viride* (2.5 kg/ha enriched in 100 kg of FYM) @ 250 kg/ha + foliar spray of myclobutanil @ 1 g/l. Lakhran and Ahir (2020) reported that seed treatment with *Trichoderma viride*, neem cake and carbendazim independently were most effective in reducing the incidence of chickpea dry root rot caused by *Macrophomina phaseolina*.

In the present experiment, seed treatment (biopriming) with *Trichoderma asperellum* recorded significantly lesser disease incidence. It is inferred that seed treatment with biocontrol agents provides longer protection than the chemicals agents which suppress the soil and seed-borne pathogens only during the early crop growth stage. The lower disease incidence in the plants bio-primed with biocontrol agents could be attributed to the decrease in the level of stress markers and the increase in the levels of defense enzymes such as peroxidase, lipoxygenase, total phenolics etc. which was not visible in the infected control (Das *et al.*, 2023). The beneficial effects of integrated disease management along with the use of bioagents for biopriming have also been highlighted by Meena (2021). *Trichoderma* can combat many plant diseases, promote plant growth, improve nutrient utilization efficiency, enhance plant resistance, and repair agrochemical pollution (Fontana *et al.*, 2021). It is known that *Trichoderma* can be utilized as an effective weapon against many soil borne pathogens including *Macrophomina*. They have been gaining momentum as an important biocontrol agent for management of plant diseases in present day green agriculture due to their ecofriendly nature, minimizing the

use of chemicals and giving a cheaper and more efficient alternative to the chemical pesticides. The principles guiding the effectiveness of *Trichoderma* against plant pathogens are competition, mycoparasitism as well as the induction of host resistance (Xin Yao *et al.*, 2023)

Based on the findings of our study, the adaptive module incorporating seed treatment with *Trichoderma asperellum*, soil application of enriched *Trichoderma* with

vermicompost and spraying of combi-product chemical fungicide effectively managed the major diseases of sesame. The intervention resulted in a significant reduction in disease incidence, substantial yield enhancement and improved cost economics. The findings are valuable for implementing eco-friendly sesame disease management strategies and ensuring sustained yields.

Table 1 Bio priming and integrated management of major diseases of sesame (Pooled mean of *kharif* 2020 and 2021)

Modules	Root rot (%)	Phyllody (%)	Alternaria leaf spot (PDI)	Powdery mildew (PDI)	Yield (kg/ha)	B:C ratio
M1-Biointensive Module	32.6 (34.7)	30.7 (33.6)	16.7 (24.0)	29.3 (32.7)	526	1.68
M2-Chemical Module	25.1 (29.9)	26.3 (30.7)	14.9 (22.6)	26.7 (31.0)	584	2.00
M3-Adoptive Module	20.7 (26.8)	21.9 (27.8)	11.6 (19.8)	18.2 (25.1)	632	2.62
M4-Untreated check	42.3 (40.5)	36.4 (37.1)	20.3 (26.7)	34.6 (35.9)	483	1.29
CD (p=0.05)	5.965	4.218	4.010	5.137	58.765	
SE(m)	1.915	1.354	1.287	1.649	18.863	
SE(d)	2.708	1.915	1.820	2.332	26.676	
CV (%)	12.981	9.383	12.372	11.821	7.583	

*Mean of five replications

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Effect of planting methods and humic acid application on productivity of soybean (*Glycine max* L.)

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ABSTRACT

An experiment was carried out during rainy season of 2022 and 2023 with 8 treatment combinations in randomised block design with three replications. Treatment T2 (Bed planting method with 15 kg HA + 100% RDF) gave significantly higher plant population (7.0), effective plant population (6.4), plant height (124 cm) at 120 DAS, number of branches/plant (8.6) at 120 DAS, dry matter accumulation (21.2 g/plant) at harvest, number of pods/plant (72.3), seed yield (1969 kg/ha), straw yield (2851 kg/ha), oil yield (374.2 kg/ha), protein yield (753.3 kg/ha) as compared to flat planting. Further results indicated that Treatment T2 (100% RDF + 15 kg/ha humic acid application on BP) proved beneficial for higher net returns (₹49,739) and BC ratio (1.2).

Keywords: Bed planting, Flat planting, Humic acid, Land configuration, Soybean

Soybean is a rich source of nutrition, contains 40-45% protein, well balanced amino acids 18-22%, 20-22% cholesterol free omega 3 rich oil (Sharma, 2023; Mondal *et al.*, 2023). Punjab is facing over exploitation of groundwater for paddy cultivation in rainy season as it consumes more water compared to any other crop. Punjab's groundwater table is declining by 0.5 meters per annum on an average. Moreover, intensity and frequency of rainfall trend is decreasing and erratic. Diversification with less water requiring crops is recommended by agriculture experts and state government as it could be the best alternative of paddy for Punjab farmers. Soybean is the leading source of edible oils constituting about 30% of the world supply among other oilseed crops.

Conventional flat planting method is commonly used for growing soybean in India and is irrigated by flooding, but it results lower water use efficiency, poor crop stand, nutrient loss, soil crust formation and poor aeration in crop root zone ultimate affects crop growth and yield. Water conservation technologies such as ridge-furrow and raised bed planting have been found very effective in efficient use of water and minimizing evaporative losses (Tripathi, 2017). In order to reduce cost of production and chemical fertilizer residue in edible oil and other soya products, organic substances like farm yard manure, green manure, poultry manure etc are required to be used in soybean cultivation but these are not sufficiently available for large scale area. Therefore, humic acid(HA) could be the best source of organic compounds. Humic acid is a group of molecules that bind to roots and assist them to absorb water and nutrition.

Humic acid (HA) products that are commercially available are being used successfully to nourish the plants. Humic acid through foliar spray or soil application was reported to boost growth, nutrient uptake, and yield, as well as the quality of various crop production (Abou Tahoun, 2022). Therefore, the present investigation was undertaken to study the effect of planting method and humic acid on productivity of soybean crop.

Field experiment was conducted at Students Research Farm, Khalsa College, Amritsar, during the rainy season of 2022 and 2023. Situated at 31°-38' North latitude and 74°-52' East longitude, Amritsar experiences a semi-humid climate with extreme temperatures. The soil analysis revealed that the experimental field's soil is loamy sand, slightly saline (7.9 pH), poor in organic carbon (0.40%), low in available nitrogen (169.6 kg/ha), and medium in phosphorus (26.4 kg/ha) and medium in available potassium (253.4 kg/ha). The experiment comprising of total 8 treatment combinations- T1 (Bed planting method with 100% RDF), T2 (Bed planting method with 15 kg HA + 100% RDF), T3 (Bed planting method with 15 kg HA + 75% RDF), T4 (Bed planting method with 15 kg HA + 50% RDF), T5 (Flat planting with 100% RDF), T6 (Flat planting with 15 kg HA + 100% RDF), T7 (Flat planting with 15 kg HA + 75% RDF) and T8 (Flat planting method with 15 kg HA + 50% RDF) in randomised block design with three replications and the soybean variety KDS-726 was sown on 12 May, 2022 and 9 May, 2023. Humic acid was applied @ 15 kg/ha during seedbed preparation.

Two planting methods- bed planting and flat planting were employed. Maize bed planter was used for sowing two rows per bed with a 67.5 cm bed width. Soybean was sown on flat bed using the pora method, maintaining a

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row-to-row spacing of 45 cm and a plant-to-plant spacing of 10 cm. Seed inoculation with *Bradyrhizobium* sp. (LSBR 3) was done. Fertilizer application was done using urea and single super phosphate. The first irrigation was applied at 25 days after sowing (DAS). Weed control measures involved early applications of Stomp 30 EC and propaquizafop 2.5% + imazethapyr 3.75%. Mancozeb 75% WP and Quinalphos 25% EC, were applied to manage pests and diseases. Harvesting was done at 148 DAS in 2022 and 154 DAS in 2023.

Observations recorded for treatment evaluation included plant population, plant height, number of branches, dry matter accumulation, number of pods per plant, grain yield, straw yield, oil and protein yield, and economic indicators such as gross returns, net returns, and benefit-cost ratio. Oil yield and protein yield was calculated using formula-

$$\text{Oil yield (kg/ha)} = \text{Oil \%} \times \text{Dry seed weight}$$

$$\text{Protein yield (kg/ha)} = \text{Protein \%} \times \text{Dry seed weight}$$

Growth analysis revealed that the T2 (Bed planting method with 15 kg/ha HA + 100% RDF) produced highest number of plants/meter square area than other treatments. Fertilizer dose and humic acid application did not affect the plant population on bed planting significantly. Under both the methods of planting, bed planting was significantly

better than flat planting methods. Maximum plant height was recorded in T2 (Bed planting method with 15 kg/ha HA + 100% RDF) under bed planting and T6 (Flat planting with 15 kg HA + 100% RDF) under flat planting methods. Application of humic acid (HA) along with fertilizers, improve the plant height marginally in both the methods of planting. Better soil physical conditions, no water logging, optimum plant nutrition with 100% RDF (Singh *et al.*, 2018) and positive effect of HA at rate 15 kg/ha (Pidurkar *et al.*, 2022) produced relatively taller plants. At 120 days, T2 (Bed planting method with 15 kg/ha HA + 100% RDF) being at par with T1 (Bed planting method with 100% RDF) showed significantly higher number of branches than all other treatments. All the fertility treatments were at par with each other under both bed and flat painting methods. Similar results were recorded by Gunjal *et al.* (2022). Recommended at 100% level and humic acid on bed planting (T2) being at par with T1 (Bed planting method with 100% RDF) was significantly better than all other treatments during harvest (Table 1). Better micro-climate conditions, nutrient availability, humic acid application and full dose of recommended fertilizers under bed planting might be the reason for profuse vegetative growth which led to higher dry matter accumulation in treatment T2 (21.2 g/plant). Kinge *et al.* (2020) also found similar results.

Table 1 Effect of planting methods and fertility levels on growth perimeters of soybean

Symbols	Treatments	Plant Population per one meter row length	Plant height at 120 DAS	No. of branches/plant 120 DAS	DMA (g/plant) at harvest
T1	Bed planting with 100% RDF	18.1	119.7	8.5	20.7
T2	Bed planting with 100% RDF + 15kg HA	18.8	124.0	8.6	21.2
T3	Bed planting with 75% RDF + 15kg HA	18.6	121.7	7.9	19.4
T4	Bed planting with 50% RDF + 15kg HA	17.9	118.0	7.9	19.1
T5	Flat planting with 100% RDF	13.7	104.3	7.7	17.6
T6	Flat planting with 100% RDF + 15kg HA	13.9	109.0	7.7	18.2
T7	Flat planting with 75% RDF + 15kg HA	12.9	106.7	7.4	17.8
T8	Flat planting with 50% RDF + 15kg HA	12.7	106.0	7.4	16.2
	CD (p = 0.05)	1.1	6.8	0.7	0.5

Yield and yield attributes revealed that T2 (Bed planting method with 15 kg/ha HA + 100% RDF) being at par with T3 (Bed planting method with 15 kg HA + 75% RDF) and T1 (Bed planting method with 100% RDF) produced significantly more grain yield and number of pods/plant than all the treatments. All the bed planting treatments were significantly superior than all other flat planting treatments irrespective of fertility treatments.

Higher grain yield under bed planting system might be due to more number of pods and number of seeds per pod as compared to flat planting system. These results were also supported by Kinge *et al.* (2020) and Verma *et al.* (2020). Humic acid application along with 100% RDF recorded significant increase in grain yield under both the methods of planting than 50% RDF + HA. It may be attributed to the positive effect of HA application due to efficient utilization

of moisture and nutrients which resulted in increased grain yield. Highest straw yield was noticed in T2 (Bed planting method with 15 kg/ha HA + 100% RDF) which was at par with T3 (Bed planting method with 15 kg HA + 75% RDF) and proved significantly better than all other treatments (Table 2). Higher straw yield under bed planting system might be due to better plant population and other vegetative parameters as compared to flat planting system. Savita and Girijesh (2019) also reported higher straw yield in

treatments with humic acid application. Application of 100% RDF + 15 kg/ha HA on bed planting produced maximum oil yield under bed planting methods. All the bed planting treatments were significantly superior than flat planting. Application of 100% RDF + 15 kg/ha HA on bed planting produced significantly more protein yield than all other treatments. Raghuvver and Hosmath (2018) also reported higher protein yield in treatments with higher dose of fertilizers.

Table 2 Effect of planting methods and fertility levels on yields and economic analysis of soybean

Symbols	Treatments	Number of pods/plant	Grain yield (kg/ha)	Straw yield (kg/ha)	Oil yield (kg/ha)	Protein yield (kg/ha)	Total cost (Rs)	Gross returns (Rs)	Net returns (Rs)	B:C
T1	Bed planting with 100% RDF	71.7	1800	2616	336	667	37835	82800	44965	1.19
T2	Bed planting with 100% RDF + 15kg HA	72.3	1969	2851	374	753	40835	90574	49739	1.22
T3	Bed planting with 75% RDF + 15kg HA	69.5	1863	2781	350	706	39653	85698	46045	1.16
T4	Bed planting with 50% RDF + 15kg HA	67.0	1740	2547	306	622	38475	80040	41565	1.08
T5	Flat planting with 100% RDF	67.3	1519	2200	274	551	36585	69874	33289	0.91
T6	Flat planting with 100% RDF + 15kg HA	68.7	1538	2290	284	573	39585	70748	31163	0.79
T7	Flat planting with 75% RDF + 15kg HA	68	1419	2062	258	521	38403	65274	26871	0.70
T8	Flat planting with 50% RDF + 15kg HA	66	1375	2007	239	488	37225	63250	26025	0.70
CD (p = 0.05)		3.3	134	217	24	32				

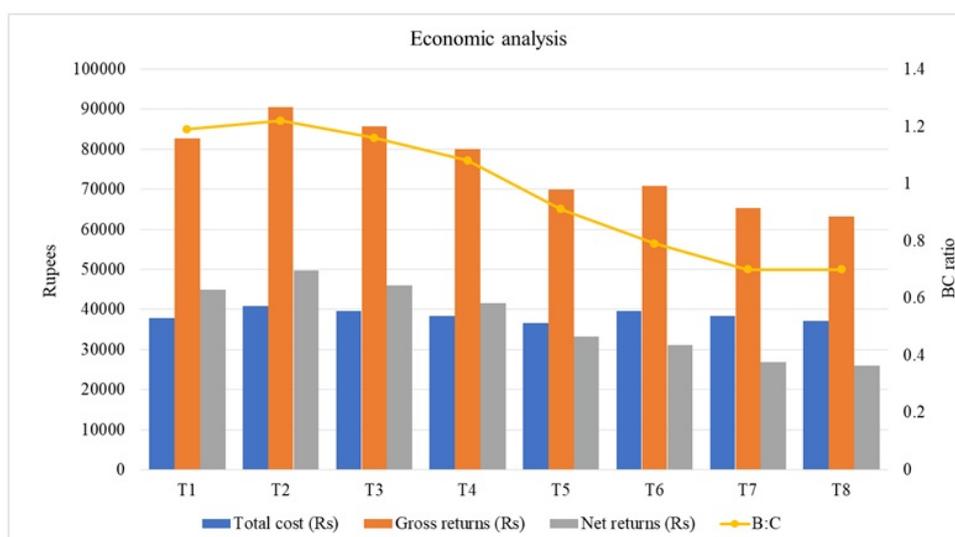


Fig. 1. Effect of planting methods and fertility levels on economic analysis of soybean

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Economic analysis revealed that all the bed planting treatments showed higher net returns and BC ratio than flat planting system. T2 where 100% RDF + humic acid was applied produced maximum net returns of ₹49,739/ha with 1.2 BC ratio. Gunjal *et al.* (2022) also reported highest net return and BC ratio in bed planting system. The results of experiment indicated that for achieving higher productivity of soybean crop, application of 100% RDF + 15 kg/ha HA on bed planting proved beneficial for higher grain yield (1969 kg/ha) which led to higher net returns (₹49,739) and BC ratio (1.2).

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Evaluation of integrated disease management against major diseases of sunflower (*Helianthus annuus* L.)

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ABSTRACT

Integrated disease management strategies favours wider scope for three major diseases such as necrosis, *Alternaria* leaf spot and Powdery mildew that are causing economic losses in sunflower cultivation with reference to Tamil Nadu. For the management of these diseases in an integrated way, four different treatments were imposed on sunflower through a field experiment. Among the treatments tested T1: Seed treatment with salicylic acid @100 ppm; neem oil @ 3% at 30 DAS; foliar spray of zineb (68%) + hexaconazole (4%) WP @ 25 g/ 10 lit at 45 and 60 DAS was found to be significantly effective by recording the maximum seed germination (98.30%), minimum incidence of sunflower necrosis disease (0.81%), *Alternaria* leaf blight (4.6 PDI) and powdery mildew (3.82 PDI) with maximum yield of 1940 kg/ha and benefit cost ratio (2.84). Minimum seed germination of 90.08 % was recorded in Control recorded and maximum incidence of sunflower necrosis disease (5.15 %), *Alternaria* leaf blight (16.2 PDI) and powdery mildew (17.2 PDI) with minimum yield of 1003 kg/ha and BC ratio (0.96).

Keywords: Sunflower, *Alternaria* leaf spot, Necrosis, Powdery mildew, IDM

Sunflower (*Helianthus annuus* L.) ranks third among several vital oilseed crops. Belonging to Asteraceae, sunflower is considered great edible oil, because of poly-unsaturated fatty acid content. Several people in India and worldwide depend on sunflower for dietary purposes. Sunflower is a short-term oilseed crop that is often ready to be harvested in 90-120 days. Its seed oil is high-grade oil rich in vitamins A, E, D, and K and is often used for culinary and medicinal purposes (Joksimovic *et al.*, 2006; Sunil *et al.*, 2023). Sunflower suffers from diseases caused by fungi, bacteria and viruses. Sunflower is the known host of more than 30 pathogens mostly fungi which under certain climatic conditions may impair the normal physiology of the plant, so that yield and oil quality are reduced significantly. Among them necrosis, *Alternaria* leaf spot and Powdery mildew diseases are highly infectious and posing a great problem for sunflowers successful cultivation. *Alternaria* blight caused by *Alternaria helianthi* emerged as a major threat to its cultivation since late 1980's. The disease is known to cause more than 80% of yield loss under severe epiphytotic conditions. It causes leaf and stem lesions, seedling blight and head rot and losses to the tune of up to 80 per cent. Sunflower is most susceptible to *Alternaria helianthi* during anthesis and seed filling stage of growth. However, *Alternaria helianthi* can cause seedling blight which reduce crop stand and can infect both leaves and stems of 10-32 days old plants. The disease symptoms appear more frequently on older leaves than on young and expanding ones (Ahila Devi 2014). It can also infect other

parts such as capitulum, disc and ray florets. The disease is caused by tobacco streak virus (Prasada Rao *et al.*, 2000; Bhat *et al.*, 2002) and it was found to be transmitted by thrips (Harvir Singh, 2005). The disease can cause crop losses to an extent of 100 per cent depending on the cultivar/variety and stage of infection and has become a major limiting factor in sunflower production. Sunflower is susceptible to many diseases mainly caused by fungi. Among these diseases, powdery mildew caused by *Golovinomyces cichoracearum* (DC.), (formerly known as *Erysiphe cichoracearum*), is considered one of the most destructive diseases that could lead to serious and quality yield reductions (Madhusudhan *et al.*, 2017). Powdery mildew severity and its progress rely mainly on favorable conditions like moderate temperatures and high humidity (Sujatha *et al.*, 2018). Its symptoms are very distinctive. White powdery spots, that get bigger as the disease progresses, appear on lower leaves. Several asexual spores are formed, and the mildew can spread to the rest of the plant (Kulkarni *et al.*, 2015)

Salicylic acid is critical in inducing resistance of plants to pathogens as well. According to Vallad and Goodman (2004), exogenous application of Salicylic acid has been proven to induce resistance to diseases caused by both bacteria and fungi in plants. After a pathogen attack, salicylic acid is vital for signalling the initiation of plant defense responses. The mode of action of salicylic acid can enhance defense mechanisms in the plant tissue (Canet *et al.*, 2010). An attempt was made to manage these diseases with integrated schedule of treatments. Cultural and biological strategies are mostly effective at initial stage,

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especially at sowing time. Use of resistant cultivar is also reasonable and easy method for disease management but due to development of new strain among the pathogens, resistant may be break down to become susceptible one. Chemical strategy is very effective but also delicate to environmental pollution, residual effect in grain and killing the non-target organisms Development of fungicide resistance in plant pathogens is a major obstacle of chemical strategy when use continuously. Therefore, due to lesser efficiency of single strategy of disease management, integration of various strategies (IDM) is the foremost need for management of plant disease in near future of agriculture.

Field evaluation trial was conducted during *kharif* and *rabi* seasons of 2023-2024 at Anbil Dharmalingam Agriculture College and Research Institute farm, Trichy. Integrated effect of bio-agents, fungicides and plant extracts as seed treatment and foliar spray was recorded against major diseases of sunflower in field condition. The experiment was conducted using var. CO₂ with four treatments including the farmers practice as a check and five replications with RBD design. A plot size of 4 x 3 m was given for each replication and the seeds were sown with a spacing of 60 x 30 cm. Regular agronomic practices were followed.

The treatment details is as follows; T1: Seed treatment with salicylic acid @100 ppm; neem oil @ 3% at 30 DAS; foliar spray of zineb (68%) + hexaconazole (4%) WP @ 25g/10 l at 45 and 60 DAS.T2: Seed treatment with imidacloprid 17.8 SL 10 ml/kg seed and two sprays of mancozeb 75 WP @ 1 kg/ha during 45 and 60 DAS.T3: Farmers practice (Foliar spray of mancozeb 75 WP @0.1%).

Necrosis incidence (0-5 scale) was calculated using the following formula:

$$\text{Necrosis incidence (\%)} = \frac{\text{Number of necrosis infected plants}}{\text{Total plant population}} \times 100$$

Reaction	Score	Infection %
Immune(I)	0	No infection
Resistant (R)	1	1 – 10% Incidence
MR (Moderately resistant)	2	11 – 25% Incidence
MS (Moderately susceptible)	3	26 – 50% Incidence
S (Susceptible)	4	51 – 75% incidence
HS (Highly susceptible)	5	> 75% incidence

For powdery mildew and *Alternaria* leaf spot assessment, 10 plants in each treatment were randomly

selected for observation of powdery mildew and *Alternaria* leaf spot diseases at fifty per cent seed filling stage by using 0-9 scale and Per cent Disease Index (PDI) was calculated by using the formula given by Wheeler (1969).

0-9 scale for *Alternaria* leaf spot and Powdery mildew diseases of sunflower:

Reaction	Score	Infection %
I	0	No symptoms on the leaf
R	1	1% or less than 1% of the leaf area was damage.
MR	2	1 to 5% leaf area damage
MS	3	11-25% of the leaf area damage
S	4	26-50% of the leaf area damage
HS	5	51% or above of leaf area damage

$$\text{PDI} = \frac{\text{Sum of individual disease ratings}}{\text{Total number of leaves observed X Maximum disease rating}} \times 100$$

Yield of each treatment was recorded separately and were analysed statistically by ANOVA. Further, economics and cost benefit ratio for each treatment was computed.

The results revealed that the treatment T1 (Seed treatment with salicylic acid @100 ppm; neem oil @ 3% at 30 DAS; foliar spray of zineb (68%) + hexaconazole (4%) WP @ 25 g/10 l at 45 and 60 DAS) was found to be significantly effective by recording the maximum seed germination, lesser *Alternaria* leaf blight (4.6 PDI) and powdery mildew (3.82 PDI) scores with maximum yield of 1940 kg/ha and C:B ratio (2.84). while recording necrosis disease, the treatment T2: Seed treatment with imidacloprid 17.8 SL 10 ml/kg seed and two sprays of mancozeb 75 WP @ 1 kg/ha during 45 and 60 DAS has recorded the lowest incidence of 1.61 %, followed by the treatment T1. Farmer practices and use of mancozeb alone recorded the minimum seed germination, maximum incidence of sunflower necrosis disease (5.15 %), *Alternaria* leaf blight (16.2 PDI) and powdery mildew (17.2 PDI) with minimum yield of 1003 kg/ha and C:B ratio (0.96).

The promotive effect of salicylic acid could be attributed to its bioregulator effects on physiological and biochemical processes in plants such as promoting effect of SA is due to increased level of Cell division, cell differentiation and cell elongation within the apical meristem of seedling root, and increment in biosynthesis of organic foods which caused an increase in seedling growth (Delavari *et al.*, 2010).

The data revealed that the treatment salicylic acid combined with *Trichoderma harzianum* resulted a significant reduction of powdery mildew along with a significant increase in yield and vegetative characteristics

such as fresh weight and plant length compared to the control treatment in the two growing seasons. These results also confirmed earlier reports that exogenous application of salicylic acid induces resistance against pathogens including both fungi and bacteria, infecting sunflower plants, and improves the growth of the host plants (Alkahtani *et al.*, 2011). In several crops, salicylic acid can cause pathogenesis-related proteins (PRP) to accumulate, which results in a decrease in disease incidence. Application of salicylic acid and ascorbic acid stimulates the production of tomatin (phytoalexin) in leaves and stems of plants which are toxic to pathogens (Awadella, 2008).

Similar kind of results were reported by Amaresh *et al.* (2002) who evaluated some fungicides under field conditions and found that propiconazole @ 0.1%, hexaconazole @ 0.1% gave good results in controlling the *Alternaria* leaf blight of sunflower and these treatments recorded maximum grain yield, oil content, test weight and least per cent disease intensity. Several workers reported that, propiconazole was found to be effective in reducing powdery mildew severity in various crops. Propiconazole and thiophanate methyl are effective in controlling the Dog wood powdery mildew (Mumbaga *et al.*, 2004). Present results are analogous to previous investigation conducted by Mesta *et al.* (2009), who reported that systemic fungicides such as hexaconazole and propiconazole out of other fungicides showed 72.87 and 76.53 % growth inhibition respectively against *A. helianthi*. They all proposed hexaconazole as the best fungicide against various fungal diseases. Similarly, Venkataramanamma *et al.* (2014) concluded that the fungicidal combination of seed treatment with carbendazim 12% + mancozeb 63% (SAAF) @ 2 g/kg of seed + propiconazole @ 0.1 % spray at 30 and 45 days after sowing will effectively control *Alternaria* leaf blight of sunflower. Our results signify that this fungicide is still efficient against the *Alternaria helianthi*.

Effectiveness of Thiomethoxam 70 WS as a seed treatment and foliar fungicide for management of sunflower necrosis disease was supported by Shirshikar, (2008) who reported that for reducing the necrosis incidence on sunflower, the seed should be treated with thiomethoxam (Cruiser 70 W.S.) at 4 g/kg along with two sprays of the crop with thiomethoxam at 0.05% at 30 and 45 DAS. *Azadirachtin* is also found to be reduce the thrips population, which is the carrier of necrosis virus infected pollen. Over all, in this trial, necrosis incidence was low because thrips population was low in the month of September, because of heavy rains thrips were washed out. Similar reports of Shirshikar (2010) supported the present findings, border crop with 6 rows of sorghum and seed treatment along with three sprayings of imidacloprid recorded low mean necrosis incidence of 10.2 per cent and maximum yield of 1222

kg/ha. Seed treatment with thiamethoxam (4 g/kg seed) along with 2 sprays of thiomethoxam (0.05%) at 30. The results are in agreement with the finding of Pandey *et al.* (2013) who have reported that lowest thrips population and highest bulb yield by applying fipronil. Similarly fipronil and imidacloprid reduced the thrips damage severity and increased the onion bulb yield (Ullah *et al.*, 2010; Gachu *et al.*, 2012).

Bhat *et al.* (2012) also found that seed treatment with thiomethoxam and three sprays of thiomethoxam at 15, 30 and 45 days after sowing along with 3 rows of border crop of sorghum followed by seed treatment with imidacloprid and three sprays of imidacloprid along with 3 rows of border crop sorghum were found best in reducing the sunflower necrosis disease incidence (3.80 and 4.65 per cent respectively, compared to 21.16 per cent in control) and the thrips population (0.56 and 0.70 thrips/plant compared to 4.06 thrips/plant in control). The treatments not only reduced SND infection and thrips population but also increased yield and yield parameters in sunflower cv. Morden. Hiramath *et al.* (2013) found propiconazole was most effective against pea powdery mildew (*E. cichoracearum*) followed by hexaconazole, Difenconazole chemicals. Many fungicides were tested by Karuna *et al.* (2015) on Sunflower powdery mildew disease and concluded that spraying of Difenconazole, Propiconazole and triademorph were equally effective in reducing the disease severity of sunflower powdery mildew and recorded good seed yield when compare to other chemicals such as triadimefon, benlate, wetable sulphur and carbendazim. Several workers reported that, propiconazole was found to be effective in reducing powdery mildew severity in various crops. Linseed powdery mildew caused by *Oidium lini* was successfully managed by Propiconazole (0.1%), (Gohokar *et al.*, 2016).

From the present study, the treatment T1 *viz.*, Seed treatment with salicylic acid @100 ppm; neem oil @ 3% at 30 DAS; foliar spray of zineb (68%) + hexaconazole (4%) WP @ 25 g/10 l at 45 and 60 DAS was found effective when *Alternaria* leaf spot and powdery mildew is a severe problem and the treatment T2 *viz.*, Seed treatment with imidacloprid 17.8 SL 10 ml/kg seed and two sprays of mancozeb 75 WP @ 1 kg/ha during 45 and 60 DAS is effective when necrosis is severe problem. Using these treatments can eventually decrease reliance on the use of any single chemical fungicides in managing plant pathogens of both sensitive and resistant populations, which can, in turn, lead to a reduction in losses of food and eventually the costs of production, which is going to encourage farmers to adopt an integrated approach instead of a fungicide-based one.

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Table 1 Evaluation of integrated disease management against major diseases of sunflower

Treatments	Germination (%)	SND (%)	Leaf spot (PDI)	Powdery mildew (PDI)	Yield (kg/ha)	BC ratio
T1: Seed treatment with salicylic acid @100 ppm; neem oil @ 3% at 30 DAS; foliar spray of zineb (68%) + hexaconazole (4%) WP @ 25 g/ 10 lit at 45 and 60 DAS	98.3 a (89.72)	0.81 a (2.01)	4.6 a (3.11)	3.82 a (5.81)	1940 a	2.84
T2: Seed treatment with imidacloprid 17.8 SL 10 ml/kg seed and two sprays of mancozeb 75 WP @ 1 kg/ha during 45 and 60 DAS	79.8 b (69.28)	1.61 b (4.41)	6.9 b (5.52)	7.41 b (6.90)	1451 b	2.12
T3: Farmers practice (Foliar spray of mancozeb 75 WP @ 0.1 %)	80.9 c (72.37)	4.06 c (7.20)	10.9 c (8.43)	10.95 c (9.18)	1181 c	1.76
T4: Control	83.08 d (79.64)	5.15 d (9.07)	16.2 d (12.85)	17.2 d (14.39)	1003 d	0.96
SE(d)	1.98	0.36	1.32	0.46	49.95	
CD (p=0.05)	2.21	0.90	2.86	0.98	106.46	

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This matter will come below the name(s) of the author(s). Name of the Laboratory/Department, followed by the name of the Institution/Organization/University where the work reported in the paper was carried out shall come below the name(s) of author(s). Complete postal address, which should include city/town, district, and state, followed by PIN (postal) code is to be furnished. In case any author has left the above address, this should be indicated as a footnote.

Abstract

The paragraph should start with the word Abstract (in bold font). The abstract should comprise brief and factual summary or salient points of the contents and the conclusions of the investigation reported in the paper and should refer to any new information therein. As the abstract is an independent entity, it should be able to convey the gist of the paper in a concise manner. It will be seen by many more people than will read the paper. The abstract, as concise as possible, should not exceed 250 words in length. Everything that is important in the paper must be reflected in the abstract. It should provide to the reader very briefly the rationale, objectives or hypothesis, methods, results and conclusions of the study described in the paper. In the abstract, do not deflect the reader with promises such as 'will be discussed' or 'will be explained'. Also do not include reference, figure or table citation. At first mention in the abstract, give complete scientific name for plants and other organisms, the full names of chemicals and the description of soil order/series. Any such names or descriptions from the abstract need not be repeated in the text. It must be remembered that the abstracting journals place a great emphasis on the abstract in the selection of papers for abstracting. If properly prepared, they may reproduce it verbatim.

"Key words" should, follow separately after the last sentence of the abstract. "Key words" indicate the most important materials, operations, or ideas covered in the paper. Key words are used in indexing the articles.

Introduction (To be typed as side-heading, starting from the left-hand margin, a few spaces below the key words)

This section is meant to introduce the subject of the paper. Introduction should be short, concise and indicate the objectives and scope of the investigation. To orient readers, give a brief reference to previous concepts and research. Limit literature references to essential information. When new references are available, do not use old references unless it is of historical importance or a landmark in that field. Emphasis should be given among other things on citing the literature on work done under Indian conditions. Introduction must include: (a) a brief statement of the problem, justifying the need for doing the work or the hypothesis on which the work is based, (b) the findings of others that will be further developed or challenged, and (c) an explanation of the approach to be followed and the objectives of the research described in the paper. If the methods employed in the paper are new, it must be indicated in the introduction section.

Materials and methods (To be typed as side-heading, starting from the left-hand margin, a few spaces below the introduction)

This part of the text should comprise the materials used in the investigation, methods of experiment and analysis adopted. This portion should be self-explanatory and have the requisite information needed for understanding and assessing the results reported subsequently. Enough details should be provided in this section to allow a competent scientist to repeat the experiments, mentally or in fact. The geographical position of soil site or soils used in the experiment or site of field trial should be identified clearly with the help of coordinates (latitude & longitude) and invariably proper classification according to Soil Taxonomy (USDA), must be indicated to the level of Great-group, Suborder or Order as far as possible. Specify the period during which the experiment(s) was conducted. Send the article after completion of the experiment(s) not after a gap of 5 years. Instead of kharif and rabi use rainy and winter season respectively. Please give invariably the botanical names for local crop names like raya, bajra moong, cholam etc. Botanical and zoological names should confirm to the international rules. Give authorities. Go through some of our recent issues and find out the correct names. Give latest correct names from authentic source. For materials, give the appropriate technical specifications and quantities and source or method of preparation. Should a product be identified by trade name, add the name and location of the manufacturer or a major distributor in parenthesis after the first mention of the product. For the name of plant protection chemicals, give popular scientific names (first letter small), not trade names (When trade name is given in addition, capitalize the first letter of the name). Known methods of analysis should be indicated by referring to the original source, avoiding detailed description. Any new technique developed and followed should be described in fair detail. When some specially procured or proprietary materials are used, give their pertinent chemical and physical properties. References for the methods used in the study should be cited. If the techniques are widely familiar, use only their names in that case.

Results and Discussion (To be typed as a side-heading, a few spaces below the matter on "Materials and Methods")

This section should discuss the salient points of observation and critical interpretation thereof in past tense. This should not be descriptive and mere recital of the data presented in the tables and diagrams. Unnecessary details must be avoided but at the same time significant findings and special features should be highlighted. For systematic discussion, this section may be divided into sub-sections under side-heading and/or paragraph side heading. Relate the results to your objectives. While discussing the results, give particular attention to the problem, question or hypothesis presented in the introduction. Explain the principles, relationships, and generalizations that can be supported by the results. Point out any exceptions. Explain how the results relate to previous findings, support, contradict or simply add as data. Use the Discussion section to focus on the meaning of your findings rather than recapitulating them. Scientific speculation is encouraged but it should be reasonable and firmly founded in observations. When results differ from previous results, possible explanations should be given. Controversial issues should be discussed clearly. References to published work should be cited in the text by the name(s) of author(s) as follows: Mukherjee and Mitra (1942) have shown or It has been shown (Mukherjee and Mitra, 1942)..... If there are more than two authors, this should be indicated by et al. after the surname of the first author, e.g., Mukherjee et al. (1938).

Always conclude the article by clearly crystallizing the summary of the results obtained along with their implications in solution of the practical problems or contribution to the advancement of the scientific knowledge.

Acknowledgments (To be typed as given above, as a side-heading, well below the concluding portion of Conclusions)

The author(s) may place on record the help, and cooperation, or financial help received from any source, person or organization. This should be very brief, and omitted, if not necessary.

References (To be typed as above, as side heading below Acknowledgement)

The list of references must include all published work referred to in the text. Type with double line spacing. Do not cite anonymous as author; instead cite the name of the institute, publisher, or editor. References should be arranged alphabetically according to the surnames of the individual authors or first authors. Two or more references by the same author are to be cited chronologically; two or more in the same year by the letters a, b, c, etc. All individually authored articles precede those in which the individual is the first or joint author. Every reference cited in the article should be included in the list of References. This needs rigorous checking of each reference. Names of authors should not be capitalized.

The reference citation should follow the order: author(s), year of publication, title of the paper, periodical (title in full, no abbreviations, italics or underlined), volume (bold or double underlining), starting and ending pages of the paper. Reference to a book includes authors(s), year, title (first letter of each word except preposition, conjunction, and pronouns in capitals and underlined), the edition (if other than first), the publisher, city of publication. If necessary, particular page numbers should be mentioned in the last. Year of publication cited in the text should be checked with that given under References. Year, volume number and page number of each periodical cited under "References" must be checked with the original source. The list of references should be typed as follows:

- Rao C R 1968. *Advances in Statistical Methods in Biometrical Research*, pp.40-45, John Wiley & Sons, New York.
- Kanwar J S and Raychaudhuri S P 1971. *Review of Soil Research in India*, pp 30-36. Indian Society of Soil Science, New Delhi.
- Mukherjee J N 1953. The need for delineating the basic soil and climatic regions of importance to the plant industry. *Journal of the Indian Society of Soil Science*, **1** : 1-6.
- Khan S K, Mohanty S K and Chalam A B, 1986. Integrated management of organic manure and fertilizer nitrogen for rice. *Journal of the Indian Society of Soil Science*, **34** : 505-509.
- Bijay-Singh and Yadvinder-Singh 1997. Green manuring and biological N fixation: North Indian perspective. In: Kanwar J S and Katyal J C (Ed.) *Plant Nutrient Needs, Supply, Efficiency and Policy Issues 2000-2025*. National Academy of Agricultural Sciences, New Delhi, India, pp.29-44.
- Singh S, Pahuja S S and Malik R K 1992. Herbicidal control of water hyacinth and its effect on chemical composition of water (*in*) *Proceedings of Annual Weed Science Conference*, held during 3-4 March 1992 by the Indian Society of Weed Science, at Chaurdhary Charan Singh Haryana Agricultural University, Hisar, 127p.
- AICRP on Soybean 1992. *Proceedings of 23rd Annual Workshop of All-India Co-ordinated Research Project on Soybean*, held during 7-9 May 1992 at University of Agricultural Sciences, Bangalore, Karnataka, National Research Centre for Soybean, Indore, pp.48.
- Devakumar C. 1986. Identification of nitrification retarding principles in neem (*Azadirachta indica* A.Juss.) seeds. Ph D Thesis, Indian Agricultural Research Institute, New Delhi.

Reference to unpublished work should normally be avoided and if unavoidable it may be mentioned only in the text.

Short Communication

Conceptually short communication is a first report on new concept, ideas and methodology which the author(s) would wish to share with the scientific community and that the detailed paper would follow. Short Communication is akin to an advance booking for the report on the findings. Short communications may include short but trend-setting reports of field or laboratory observation(s), preliminary results of long-term projects, or new techniques or those matters on which enough information to warrant its publication as a full length article has still not been generated but the results need to be shared immediately with the scientific community. The style is less formal as compared with the "full-length" article. In the short communications, the sections on abstract, materials and methods, results and discussion, and conclusion are omitted; but the material is put concisely in the same sequence but without formal sections. The other instructions are the same as in the case of the full-length articles.

Tables

Tables should not form more than 20% of the text. Each table should be typed on separate sheet and should have on the top a table number (in Arabic numerals viz. 1, 2, 3 etc.) and a caption or title which should be short, but sufficiently explanatory of the data included in the table. Information in the table should never duplicate that in the text and vice versa. Symbols (asterisks, daggers, etc. or small letters, viz., a, b, etc.) should be used to indicate footnotes to tables. Maximum size of table acceptable is what can be conveniently composed within one full printed page of the journal. Over-sized tables will be rejected out-right. Such tables may be suitably split into two or more small tables.

The data in tables should be corrected to minimum place of decimal so as to make it more meaningful. Do not use full stop with CD, SEm \pm , NS (not C.D., S.E.m \pm , N.S.). Do not put cross-rules inside the table. Tables should be numbered consecutively and their approximate positions indicated in the margin of the manuscript. Tables should not be inserted in the body of the text. Type each table on a separate sheet. Do not use capital letters for the tabular headings, do not underline the words and do not use a full-stop at the end of the heading. All the tables should be tagged with the main body of the text i.e. after references.

Figures

Figures include diagrams and photographs. Laser print outs of line diagrams are acceptable while dot-matrix print outs will be rejected. Alternatively, each illustration can be drawn on white art card or tracing cloth/ paper, using proper stencil. The lines should be bold and of uniform thickness. The numbers and letterings must be stenciled; free-hand drawing will not be accepted. Size of the illustrations as well as numbers, and letterings should be sufficiently large to stand suitable reduction in size. Overall size of the illustrations should be such that on reduction, the size will be the width of single or double column of the printed page of the Journal. Legends, if any, should be included within the illustration. Each illustration should have a number followed by a caption typed/ typeset well below the illustration.

Title of the article and name(s) of the author(s) should be written sufficiently below the caption. The photographs (black and white) should have a glossy finish with sharp contrast between the light and the dark areas. Colour photographs/ figures are not normally accepted. One set of

the original figures must be submitted along with the manuscript, while the second set can be photocopy. The illustrations should be numbered consecutively in the order in which they are mentioned in the text. The position of each figure should be indicated in the margin of the text. The photographs should be securely enclosed with the manuscript after placing them in hard board pouches so that there may not be any crack or fold. Photographs should preferably be 8.5 cm or 17 cm wide or double the size. The captions for all the illustrations (including photographs) should be typed on a separate sheet of paper and placed after the tables.

Expression of Plant Nutrients on Elemental Basis

The amounts and proportions of nutrient elements must be expressed in elemental forms e.g. for ion uptake or in other ways as needed for theoretical purposes. In expressing doses of nitrogen, phosphatic, and potassic fertilizers also these should be in the form of N, P and K, respectively. While these should be expressed in terms of kg/ha for field experiments, for pot culture studies the unit should be in mg/kg soil.

SI Units and Symbols

SI Units (System International d 'Unities or International System of Units) should be used. The SI contains three classes of units: (i) base units, (ii) derived units, and (iii) supplementary units. To denote multiples and sub-multiples of units, standard abbreviations are to be used. Clark's Tables: Science Data Book by Orient Longman, New Delhi (1982) may be consulted.

Some of these units along with the corresponding symbols are reproduced for the sake of convenience.

Names and Symbols of SI Units

Physical Symbol for SI Unit Symbol Remarks quantity physical quantity for SI Unit

Primary Units

length	l	time	t
metre	m	second	s
mass	m	electric current	I
kilogram	kg	ampere	A

Secondary Units

plane angle	radian	rad	Solid angle	steradian	sr
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Unit Symbols

centimetre	cm	microgram	µg
cubic centimetre	cm ³	micron	µm
cubic metre	m ³	micronmol	µmol
day	d	milligram	mg
decisiemens	dS	millilitre	mL
degree-Celsius	°C [= (F-32)x0.556]	minute	min
gram	g	nanometre	nm
hectare	ha	newton	N
hour	h	pascal	Pa
joule J	(= 10 ⁷ erg or 4.19 cal.)	second	s
kelvin	K (= °C + 273)	square centimetre	cm ²
kilogram	kg	square kilometre	km ²

kilometre	km	tonne	t
litre	L	watt	W
megagram	Mg		

Some applications along with symbols

adsorption energy	J/mol (=cal/mol \times 4.19)	leaf area	m ² /kg
cation exchange capacity	cmol (p+)/kg (=m.e./100 g)	nutrient content in plants (drymatter basis)	μ g/g, mg/g or g/kg
Electrolytic conductivity	dS/m (=mmhos/cm)	root density or root length density	m/m ³
evapotranspiration rate	m ³ /m ² /s or m/s	soil bulk density	Mg/m ³ (=g/cm ³)
heat flux	W/m ²	specific heat	J/kg/K
gas diffusion	g/m ² /s or m ³ /m ² /s or m/s	specific surface area of soil	m ² /kg
water flow	kg/m ² /s (or) m ³ /m ² /s (or) m/s	thermal conductivity	W/m/K
gas diffusivity	m ² /s	transpiration rate	mg/m ² /s
hydraulic conductivity ion uptake	m/s	water content of soil	kg/kg or m ³ /m ³
(Per kg of dry plant material)	mol/kg	water tension	kPa (or) MPa

While giving the SI units the first letter should not be in capital i.e cm, not Cm; kg not Kg. There should not be a full stop at the end of the abbreviation: cm, not cm. kg, not kg.; ha, not ha.

In reporting the data, dimensional units, viz., M (mass), L (length), and T (time) should be used as shown under some applications above. Some examples are: 120 kg N/ha; 5 t/ha; 4 dS/m etc.

Special Instructions

- I. In a series or range of measurements, mention the unit only at the end, e.g. 2 to 6 cm², 3, 6, and 9 cm, etc. Similarly use cm², cm³ instead of sq cm and cu m.
- II. Any unfamiliar abbreviation must be identified fully (in parenthesis).
- III. A sentence should not begin with an abbreviation.
- IV. Numeral should be used whenever it is followed by a unit measure or its abbreviations, e.g., 1 g, 3 m, 5 h, 6 months, etc. Otherwise, words should be used for numbers one to nine and numerals for larger ones except in a series of numbers when numerals should be used for all in the series.
- V. Do not abbreviate litre to 'l' or tonne to 't'. Instead, spell out.
- VI. Before the paper is sent, check carefully all data and text for factual, grammatical and typographical errors.
- VII. Do not forget to attach the original signed copy of 'Article Certificate' (without any alteration, overwriting or pasting) signed by all authors.
- VIII. On revision, please answer all the referees' comments point-wise, indicating the modifications made by you on a separate sheet in duplicate.
- IX. If you do not agree with some comments of the referee, modify the article to the extent possible. Give reasons (2 copies on a separate sheet) for your disagreement, with full justification (the article would be examined again).
- X. Rupees should be given as per the new symbol approved by Govt. of India.

Details of the peer review process

Manuscripts are received mainly through e-mails and in rare cases, where the authors do not have internet access, hard copies of the manuscripts may be received and processed. Only after the peer review the manuscripts are accepted for publication. So there is no assured publication on submission. The major steps followed during the peer review process are provided below.

Step 1. Receipt of manuscript and acknowledgement: Once the manuscript is received, the contents will be reviewed by the editor/associate editors to assess the scope of the article for publishing in JOR. If found within the scope of the journal, a Manuscript (MS) number is assigned and the same will be intimated to the authors. If the MS is not within the scope and mandate of JOR, then the article will be rejected and the same is communicated to the authors.

Step 2. Assigning and sending MS to referees: Suitable referees will be selected from the panel of experts and the MS (soft copy) will be sent to them for their comments - a standard format of evaluation is provided to the referees for evaluation along with the standard format of the journal articles and the referees will be given 4-5 week time to give their comments. If the comments are not received, reminders will be sent to the referees for expediting the reviewing process and in case there is still no response, the MS will be sent to alternate referees.

Step 3. Communication of referee comments to authors for revision: Once the referee comments and MS (with suggestions/ corrections) are received from the referees, depending on the suggestions, the same will be communicated to the authors with a request to attend to the comments. Authors will be given stipulated time to respond and based on their request, additional time will be given for attending to all the changes as suggested by referees. If the referees suggest no changes and recommend the MS for publication, then the same will be communicated to the authors and the MS will be taken up for editing purpose for publishing. In case the referees suggest that the article cannot be accepted for JOR, then the same will be communicated to the authors with proper rationale and logic as opined by the referees as well as by the editors.

Step 4. Sending the revised MS to referees: Once the authors send the revised version of the articles, depending on the case (like if major revisions were suggested by referees) the corrected MS will be sent to the referees (who had reviewed the article in the first instance) for their comments and further suggestions regarding the acceptability of publication. If only minor revisions had been suggested by referees, then the editors would look into the issues and decide take a call.

Step 5. Sending the MS to authors for further revision: In case referees suggest further modifications, then the same will be communicated to the authors with a request to incorporate the suggested changes. If the referees suggest acceptance of the MS for publication, then the MS will be accepted for publication in the journal and the same will be communicated to the authors. Rarely, at this stage also MS would be rejected if the referees are not satisfied with the modifications and the reasoning provided by the authors.

Step 6. Second time revised articles received from authors and decision taken: In case the second time revised article satisfies all the queries raised by referees, then the MS will be accepted and if not satisfied the article will be rejected. The accepted MS will be taken for editing process where emphasis will be given to the language, content flow and format of the article.

Then the journal issue will be slated for printing and also the pdf version of the journal issue will be hosted on journal webpage.

Important Instructions

- Data on field experiments have to be at least for a period of 2-3 years
- Papers on pot experiments will be considered for publication only as short communications
- Giving coefficient of variation in the case of field experiments Standard error in the case of laboratory determination is mandatory. For rigorous statistical treatment, journals like Journal of Agricultural Science Cambridge, Experimental Agriculture and Soil Use and Management should serve as eye openers.

SPECIAL ANNOUNCEMENT

In a recently conducted Executive Committee meeting of the Indian Society of Oilseeds Research, it was decided to increase the scope of the Journal of Oilseeds Research by accommodating vibrant aspects of scientific communication. It has been felt that, the horizon of scientific reporting could be expanded by including the following types of articles in addition to the Research Articles, Short Communications and Review Articles that are being published in the journal as of now.

Research accounts (not exceeding 4000 words, with cited references preferably limited to about 40-50 in number): These are the articles that provide an overview of the research work carried out in the author(s)' laboratory, and be based on a body of their published work. The articles must provide appropriate background to the area in a brief introduction so that it could place the author(s)' work in a proper perspective. This could be published from persons who have pursued a research area for a substantial period dotted with publications and thus research account will provide an overall idea of the progress that has been witnessed in the chosen area of research. In this account, author(s) could also narrate the work of others if that had influenced the course of work in authors' lab.

Correspondence (not exceeding 600 words): This includes letters and technical comments that are of general interest to scientists, on the articles or communications published in Journal of Oilseeds Research within the previous four issues. These letters may be reviewed and edited by the editorial committee before publishing.

Technical notes (less than 1500 words and one or two display items): This type of communication may include technical advances such as new methods, protocols or modifications of the existing methods that help in better output or advances in instrumentation.

News (not exceeding 750 words): This type of communication can cover important scientific events or any other news of interest to scientists in general and vegetable oil research in particular.

Meeting reports (less than 1500 words): It can deal with highlights/technical contents of a conference/ symposium/discussion-meeting, etc. conveying to readers the significance of important advances. Reports must

Meeting reports should avoid merely listing brief accounts of topics discussed, and must convey to readers the significance of an important advance. It could also include the major recommendations or strategic plans worked out.

Research News (not exceeding 2000 words and 3 display items): These should provide a semi-technical account of recently published advances or important findings that could be adopted in vegetable oil research.

Opinion (less than 1200 words): These articles may present views on issues related to science and scientific activity.

Commentary (less than 2000 words): This type of articles are expected to be expository essays on issues related directly or indirectly to research and other stake holders involved in vegetable oil sector.

Book reviews (not exceeding 1500 words): Books that provide a clear in depth knowledge on oilseeds or oil yielding plants, production, processing, marketing, etc. may be reviewed critically and the utility of such books could be highlighted.

Historical commentary/notes (limited to about 3000 words): These articles may inform readers about interesting aspects of personalities or institutions of science or about watershed events in the history/development of science. Illustrations and photographs are welcome. Brief items will also be considered.

Education point (limited to about 2000 words): Such articles could highlight the material(s) available in oilseeds to explain different concepts of genetics, plant breeding and modern agriculture practices.

Note that the references and all other formats of reporting shall remain same as it is for the regular articles and as given in Instructions to Authors

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