WEED MANAGEMENT IN RICE-WHEAT CROPPING SYSTEM THROUGH COMBINATION OF PLANT ALLELOPATHIC EXTRACT WITH REDUCED DOSES OF HERBICIDES

Thesis Submitted for the Award of the Degree of

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in

Agronomy

By

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Declaration

I, hereby declare that the presented work in the thesis entitled **"Weed management in Rice-Wheat cropping system through combination of plant allelopathic extract with reduced doses of herbicides"** in fulfilment of the degree of **Doctor of Philosophy (Ph. D.)** is the outcome of research work carried out by me under the supervision of **Prof. (Dr.) Chandra Mohan Mehta**, working as a Professor & Associate Dean in the School of Agriculture, of Lovely Professional University, Punjab, India. In keeping with the general practice of reporting scientific observations, due acknowledgements have been made whenever the work described here has been based on the findings of other investigators. This work has not been submitted in part or in full to any other University or Institute for the award of any degree.

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CERTIFICATE I

This is to certify that the work reported in the Ph. D. thesis entitled "**Weed management in Rice-Wheat cropping system through combination of plant allelopathic extract with reduced doses of herbicides**" submitted in fulfillment of the requirement for the reward of degree of **Doctor of Philosophy (Ph.D.)** in the Department of Agronomy, School of Agriculture, is a research work carried out by **Mr. Diptanu Banik (11916548)**, is a bonafide record of his original work carried out under my supervision and that no part of thesis has been submitted for any other degree, diploma or equivalent course.

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CERTIFICATE II

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Abstract

The present study, entitled "Weed management in Rice-Wheat cropping system through combination of plant allelopathic extract with reduced doses of herbicides", was carried and performed at Lovely Professional University, Phagwara, Punjab, during the rabi-kharif season of 2021-2022 and 2022-2023. In the first phase of the experiment, lab screening was done to find out the best suitable dosage of leaf aqueous extract, and then the pot trial and in the final phase of the experiment, it was laid out in RBD design with 20 treatments and 3 replications. Main treatments were Eucalyptus leaf aqueous extract (5% & 10%), Neem leaf aqueous extract (10% & 15%), and Guava leaf aqueous extract (25% & 30%) with reduced dosage of 50% and 75%. In this experiment, the target was to find out the most suitable potential plant leaf extracts with reduced dosage of herbicide in field conditions to control weeds of the rice-wheat cropping system. Impacts of these treatments have been observed specifically for weeds of the rice-wheat cropping system. In rice & wheat crops, the effect of treatments showed great impacts on the weed population, weed intensity and in weed control efficiency. Results showed that during both cropping years (2021–2022 and 2022–2023), treatment T_1 (Absolute control i.e. no herbicide application) consistently recorded the highest weed population of *Echinochloa crus-galli* at 66.6 and 72.2 plants/m², along with the highest weed intensities of 84.7% and 87.5%, respectively. In contrast, T_2 (100% recommended dose of herbicide) was the most effective treatment in suppressing *Echinochloa crus-galli*, exhibiting the lowest weed populations of 2.6 and 3.7 plants/m² and corresponding weed intensities of 17.3% and 24.9%. T_2 (100% recommended dose of herbicide) also achieved the highest weed control efficiencies of 95.9% and 94.9% in the respective years. However, the lowest weed control efficiency was observed in T_{20} (Guava leaf aqueous extract 30% sole), 67.4% during 2021–2022 and in T_8 (Neem leaf aqueous extract 10% + 75% herbicide), 66.4% during 2022–2023, indicating comparatively poor weed control in these treatments. For *Phalaris minor*, the highest weed population and weed intensity were noted in T_1 (Absolute control i.e. no herbicide application) (41.3% and 56.1%) in both years, with maximum weed control efficiency observed in T_4 (Eucalyptus leaf aqueous extract 5% + 75% herbicide) (88.2%) for 2021–2022 and T_8 (Neem leaf aqueous extract 10% + 75% herbicide) (83.7%) for 2022–2023.

The lowest weed population and weed intensity were found in T_4 (Eucalyptus leaf aqueous extract 5% + 75% herbicide) (5.0 and 6.6) & (11.6% 15.8%), while the lowest weed control efficiency was in T6 (Eucalyptus Leaf Aqueous Extract 10% + 75% herbicide) (47.9 % and 63.8%). For *Anagalis arvensis*, T_1 (Absolute control i.e. no herbicide application) recorded the highest population (47.3 and 45.0) and weed intensity (59.9% and 58.1%) in both years, with maximum weed control efficiencies in T_2 (100% recommended dose of herbicide) (88.7%) and T_7 (Neem leaf aqueous extract 10% + 50% herbicide) (85.1%). The lowest population and intensity were seen in T_3 (Eucalyptus leaf aqueous extract 5% + 50% Herbicide) (5.3, 13.1%) for 2021–2022, and in T_2/T_7 (6.6, 16.8%) for 2022–2023, with the lowest control efficiency in T_4 (58.9%) and T_6 (69.8%), respectively.

Note-For the wheat crop, herbicides used in the field are 2,4 D + Fenoxaprop and rice Crop herbicides used in the field are Bispyribac Sodium + Metsulfuron Methyl 10% + Chlorimuron Mythyl 10%.

Key Words- Herbicide, Leaf aqueous extract

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(A Guru can save us from the pangs of ignorance by applying the balm of knowledge of the Supreme; I offer my salutations to such a Guru)

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Diptanu Banik

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List of abbreviations

Abbreviations	Full name
CD	Critical difference
DAP	Diammonium phosphate
DAS	Days after sowing
DAT	Days after Transplanting
HI	Harvest index
MOP	Muriate of potash
RDF	Recommended dose of fertilizer
pH	Negative logarithm of H^+ ions
EC	Electrical conductivity
OC	Organic carbon
N	Nitrogen
P	Phosphorus
RDH	Recommended Dose of Herbicide
ELE	Eucalyptus leaf extract
NLE	Neem leaf extract
GLE	Guava leaf extract
SE	Standard Error

List of units

Units	**Full name**
%	Percent
cm	Centimeter
g	Gram
Kg/ha	Kilogram per hectare
m^2	Meter square
mg	Milligram
mg/kg	Milligram per kilogram
mg/L	Milligram per liter
ml	Milliliter
ml/kg	Millilitre per kilogram
mM	Millimolar
N	Normality
nm	Nanometer
q/ha	Quintal per hectare
rpm	Revolutions per minute

List of chemical compounds

Chemical formula	**Chemical name**
$CaCO_3$	Calcium carbonate
EDTA	Ethylene diamine tetra acetic acid
FAS	Ferrous Ammonium Sulphate
H_2SO_4	Sulphuric acid
HCl	Hydrochloric acid
H_3PO_4	Phosphoric Acid
HNO_3	Nitric acid
KNO_3	Potassium nitrate
$MgSO_4$	Magnesium sulphate
$Na_2ZnEDTA$	Disodium Zn EDTA
NaCl	Sodium chloride
$NaHCO_3$	Sodium Bicarbonate
$K_2Cr_2O_7$	Potassium Dichromate
$KMnO_4$	Potassium Permanganate

Chapter 1 | INTRODUCTION

Agriculture plays a vital role in providing nutrition, supporting economic growth, and ensuring food security for a growing global population. Among staple crops, wheat (Triticum aestivum L.) and rice (Oryza sativa L.) are the most widely cultivated and serve as primary food sources for millions, supplying essential carbohydrates, proteins, and nutrients. According to FAOSTAT (2021), global wheat production was approximately 770.88 million tonnes from 220.76 million hectares, with an average yield of 34.92 quintals (100 kg) per hectare, while rice production reached about 787.29 million tonnes from 165.25 million hectares, yielding 47.64 quintals (100 kg) per hectare.

India is one of the world's largest producers of both crops, with nearly 12.3 million hectares under the rice–wheat cropping system, about 85% of which lies in the Indo- Gangetic Plains, dominating states such as Punjab, Haryana, Bihar, Uttar Pradesh, and Madhya Pradesh (A. Mahajan & Gupta, 2009). In 2021, India produced approximately 109.59 million tonnes of wheat and 195.43 million tonnes of rice (FAOSTAT, 2021).

In India, specifically in Punjab, wheat and rice are the significant crops and play a pivotal role in ensuring food security, contributing to approximately one-third of the total food grain production. Punjab is a state in India with a geographical area of 5.03 million hectares, out of which 4.23 million hectares are under cultivation. Since the nation's food security plays an important and remarkable role in achieving self- sufficiency in food grains and contributes 60% of the wheat and 40% of the rice to the food security requirement of the nation (*Department of agriculture and farmer welfare, Government of Punjab*, 2023). The state of Punjab holds the highest proportion of its gross cropped area (GCA), approximately 83% and contributes significantly to India's crop production (Gulati et al. 2021).

On the other hand, there are several challenges faced in wheat and rice production, such as soil degradation due to intensive cultivation & excessive use of chemicals to control weeds, insects and diseases, groundwater depletion, climate change, etc. During the wheat front line demonstrations in Punjab, it was overexploitation of groundwater for irrigation was one of the main reasons. Among all these issues, weed management is also becoming a major concern year by year since many of the weeds are developing resistance against the herbicides & application of higher doses of herbicide is a concern. Weeds are significant contributors to yield reduction. Weeds not only reduce the wheat yield by 25 to 30% but also increase the cost of farming, create difficulties in agricultural tasks, and affect crop quality (R. Singh et al., 2016). Over the period of 2008-2018, several weed species have been observed and recorded in association with wheat cultivation in Punjab (Verma, 2021).

Weeds affect agricultural productivity by competing for essential resources and ultimately reducing crop yield by suppressing the overall growth and development of rice and wheat plants. The most common weed species found in wheat-rice fields included species such as *Setaria glauca, Echinochloa colonum, Eleusine indica, Cynodon dactylon, Digitaria spp., Blumea lacera, Enydra fluctuans, Parapholis strigosa, Chenopodium album*, *Echinochloa crus-galli*, *Brachiaria serrata, Euphorbia hirta*, *Brachiaria serrata*, *Digera arvensis, Amaranthus viridis,* *Euphorbia hirta*, *Anagallis arvensis, Rumex dentatus*, & *Medicago denticulate* etc. These weeds were frequently observed in wheat fields, competing with the crops for resources and potentially impacting wheat growth and yield (Hossain *et al.,* 2010). Some weeds have the ability to deplete the soil nutrient pool, which can lead to nutrient deficiencies. In addition, it increases the number of seeds produced that can contaminate the harvested crop. Hence, proper weed control is crucial for maintaining higher yield (Koomen *et al*., 2008).

To prevent yield losses, efficient weed management is important in modern agriculture. The prolific weed growth is affected by various factors including climate change, intensive farming practices and natural disasters, demanding adaption and improved weed management strategies for minimizing the negative effects of weeds on wheat-rice cropping systems (Bhullar *et al.,* 2016).

Various practices are used to regulate or control weeds, but none of them offer complete efficacy. Traditional weed control methods face many challenges that limit their effectiveness and sustainability. In recent years, the use of herbicides has become the solution for weed management in agriculture (G. Mahajan & Chauhan, 2013). Herbicides play an important role in managing weeds in traditional agricultural practices by providing benefits in terms of time and labour savings. It also boosts global food production by controlling weed growth (Shaner, 2014). Also, it is widely applied in agricultural fields due to its high effectiveness and affordability (Mahé *et al.,* 2022). Since the late 1940s, synthetic herbicides have become the primary tool for controlling weeds.

Over the past 40 years, the excessive dependence and improper application of herbicides have caused several issues which cannot be ignored. A number of reports have highlighted the pollution of resources and soil degradation that occurred as a direct result of herbicide misuse (Khaliq et al., 2015). The residues of herbicide chemicals tend to remain in the soil, affecting its quality and disrupting the natural habitat of soil microflora that play vital roles in sustaining soil health and rejuvenating nutrient pools in soil (Zhou *et al.,* 2013),(Jugulam & Shyam, 2019). When herbicides are sprayed near water bodies, they contaminate both surface water and groundwater, posing serious risks to aquatic ecosystems and drinking water sources. Moreover, some herbicides evaporate into the air, which contributes to air pollution and further creates environmental pollution. Consequently, excessive use of chemical herbicides contaminates water sources and disrupts the ecosystem and also harms non-target plants and animals (Kumar *et al.,* 2013).

In recent years, chemical control methods have become less viable due to herbicide resistance development, environmental degradation and health concerns. As a result, there is an urgent need for sustainable & more environmentally friendly weed management strategies that not only boost agricultural productivity but also address these challenges. The negative effects of herbicide use highlight the need for a more balanced and sustainable method to weed management in agriculture (Mahmood *et al.,* 2016). Additionally, the issue of herbicide resistance highlights the necessity of finding alternative approaches to weed management. Integrating plant allelopathic extracts with reduced herbicide doses offers several advantages as a weed management strategy. By combining plant allelopathic extracts with reduced herbicide doses, the overall weed control efficacy can be improved (Pardo-Muras *et al.,* 2020). Also, it helps to decrease the concentration of herbicides applied. Utilization of plant allelopathic extracts in combination with reduced herbicide doses can lead to cost savings for farmers (Jabran *et al.,* 2021).

By utilizing the natural chemical compounds produced by allelopathic plants, the herbicides can work synergistically to suppress weed growth and minimize herbicide reliance (Bhowmik & Inderjit, 2003),(Mushtaq *et al.,* 2010). A wide range of plant species have been identified for their allelopathic effects, such as *Juglans nigra* L. (Strugstad & Despotovski, 2013), *Eucalyptus spp.* (Azizi & Fuji, 2006), *Azadirachta indica* (Salam & Kato-Noguchi, 2010), *Ipomoea tricolor* (Lotina-Hennsen *et al.,* 2013) etc. In the context of field crops, allelopathy offers a range of practical strategies for weed management such as intercropping, crop rotation, cover crops, mulching and utilizing allelopathic water extracts (Khamare *et al.,* 2022).

Considering the potential of different plant extracts for weed management, present study aimed to investigate "Weed management in Rice-Wheat cropping system through combination of plant allelopathic extract with reduced doses of herbicides"

Objectives of the study –

1. To screen the promising bioformulations of leaf extracts in effective control of weeds and their standardization with reduced dosage of herbicides.
2. To evaluate the efficacy of selective bioformulation on weed flora of Rice-Wheat cropping system.
3. To evaluate the impact of bioformulation on growth and yield attributes under Rice-Wheat cropping system.
4. To analyses the economical aspect of bioformulation in Rice-Wheat cropping system.

Chapter 2 | REVIEW OF LITERATURE

2.1. Rice wheat cropping system and its challenges

The rice-wheat cropping system, widely practiced in Asia across 24 million hectares, faces several challenges that threaten its long-term sustainability. Factors such as soil degradation, water scarcity, labour shortages, nutrient imbalances, low soil organic matter, complex weed and insect issues, herbicide-resistant weeds and greenhouse gas emissions pose significant concerns (Nawaz *et al.,* 2019).

After the Green Revolution, the rice-wheat rotation became widespread, facilitated by the introduction of semi-dwarf cultivars and fertilization-responsive varieties for both crops. At that time, weeds were not a major problem because wheat plants had a natural ability to outcompete them. Broadleaf weeds were the primary challengers in wheat fields, but their competitiveness was low, making them relatively easy to manage (Yadav & Malik, 2005). After the introduction of shorter, high-yielding wheat varieties, the types of weeds in the rice-wheat cropping system changed. In the 1970s, both grassy and broadleaf weeds appeared, but since then, grassy weeds, especially *Phalaris minor* (canary grass), have become the main problem. This weed significantly reduces wheat yields, sometimes causing losses of 10% to 65% and even complete crop failure (Chhokar & Sharma, 2008).

In the rice field, too, weeds like *Echinochloa spp.* (barnyardgrass) and *Scirpus spp.* (nutgrass) are commonly found & they cause a great loss to the crop. Weed control in the rice-wheat system demands a multifaceted approach due to the presence of diverse weed species in each crop and the limited options available to effectively manage them without causing harm to the primary crops (Mahajan et al., 2009).

2.2. Weed management strategies

Farmers utilize a range of weed management strategies to effectively control weeds in the rice-wheat crop system. One common method is the application of herbicides. Farmers carefully select and apply herbicides before or after crop emergence to target specific weed species while minimizing harm to the main crops. In addition to chemical control, mechanical methods such as hand weeding and the use of rotary weeders are also employed. In India, weed control has traditionally depended on manual weeding. However, due to increased labour shortage and rising costs, farmers are turning to labour and cost-saving alternatives (Rao & Chauhan, 2015).

Traditional practices also play a vital role, with farmers implementing crop rotation and intercropping to interrupt the weed life cycles and create shading and competition (Kaur *et al.,* 2022). Furthermore, the use of cover crops and mulching serves as a physical barrier, smothering weed growth and inhibiting weed seed germination. Optimizing crop competitiveness through proper spacing, plant density, and balanced nutrient management also helps crops outcompete weeds for resources. By combining these strategies, farmers can effectively manage weeds and ensure the productivity of the rice-wheat cropping system (Kaur *et al.,* 2021).

Traditional methods such as manual hand weeding are labour-intensive, time- consuming and impractical for large-scale farming systems. To address this challenge, farmers employ several strategies. Timely and appropriate herbicide application is a common approach, but it requires careful selection of herbicides that target specific weed species without damaging the rice or wheat crops. Integrated weed management techniques, such as crop rotation with other crops that suppress weed growth, can help break the weed life cycle. Managing weeds is a significant challenge in the rice-wheat cropping system. Employing a combination of integrated weed management techniques, appropriate herbicide application, and mechanical and sustainable practices can help mitigate weed competition and minimize yield losses, ensuring the success of the rice-wheat rotation (Magar *et al.,* 2022).

To mitigate the impact of weeds on rice and wheat crops and the environment, farmers and agricultural experts adopt various strategies. Integrated Weed Management (IWM) combines multiple weed control methods like mechanical cultivation, crop rotation, cover cropping and selective herbicide use. By implementing IWM, farmers minimize weed pressure and reduce the risk of herbicide resistance. Cultural practices such as optimal irrigation management, appropriate plant spacing, and adjusting planting dates also play a crucial role in promoting healthy crop growth, helping crops better compete with weeds. Additionally, precision agriculture technologies, like GPS-guided machinery and remote sensing, allow targeted weed control, reducing herbicide usage and its potential environmental repercussions. Through these combined efforts, farmers can ensure a healthier and more productive agricultural system for future generations, striking a balance between weed management and environmental sustainability (Tudi *et al.,* 2021).

Modern agriculture requires weed management strategies that are adapted to the changing weed dynamics caused by various factors. In recent years, the field of precision agriculture has made remarkable progress, offering a better understanding of how weeds are distributed within fields. This knowledge is essential for increasing the adoption of effective weed management practices (Kumar *et al.,* 2022). One valuable tool that has emerged is spatiotemporal models, which allow us to predict how weed populations develop in specific areas over time. These models can be particularly useful when it comes to planning the targeted use of pre-emergent herbicides. To evaluate integrated weed management strategies, explored both static and spatiotemporal models that depict the distribution of weeds within a field. The research highlights both static and dynamic spatial weed modelling and the strengths and weaknesses of existing techniques. The study also identifies emerging areas of interest for spatial models, including targeted weed treatments, economic analysis, herbicide resistance management, integrated weed management approaches, the dispersal of biocontrol agents and the spread of invasive weed species (Somerville *et al.*, 2020).

2.3. Methods for weed control

Weeds are physically removed or destroyed using tools or by hand in mechanical weed management techniques (Melander *et al.,* 2005). Weeds can be mechanically controlled by hand pulling (hand weeding, for example), using weeding tools (hand hoeing), and using implements (inter-tillage tools, for example). There are different methods of weed control techniques by which we can easily minimize the growth of weeds under field conditions. The different methods are the stale seed-bed technique, in which, before beginning to sow, one or two weed flushes are induced and eliminated. In order to provide optimal conditions for weed seed germination, the stale seed-bed approach involves ploughing the field once or twice with a tiller before rainfall. Tillage operations later eradicate these weed seeds. For this, tools such as cultivators, blade harrows, peg-toothed harrows, and country ploughs may be employed. This method mainly aims at reducing the intensity of weed seeds in soil (Nalayini *et al.,* 2023). Another method is summer ploughing, in which immediately after the receipt of the summer rain, the land is ploughed. This controls the weeds by killing the weeds, which have already emerged. Burying a part of the weed seeds deep into the soil. Exposing a part of the weed seeds to sunlight and birds. Summer ploughing can be done using any tillage tool. Summer ploughing offers other benefits beyond weed control, including lowering erosion, preventing soil-borne insect pests and diseases, and conserving rainwater in situ (Karimipour Fard et al., 2019). Another technique is hand pulling, which involves pushing the emerging weed seedlings into the field or removing them and throwing them out. Wetlands are where this technique is primarily utilised. Although it takes a lot of time and labour, this is the most effective way to eradicate weeds (Yung et al., 2015). Another effective technique is hoeing, which involves using hand tools or equipment pulled by a bullock drawn in the spaces between rows. Cultivators, junior hoes, peg-toothed harrows, rotary weeders, blade harrows (Guntaka), cono-weeders, and Dryland weeders are the tools used for this purpose. Another crucial technique for getting rid of weeds using hand tools is manual weeding. Hand weeding is mostly done by women. In arable crops, manual weeding is often done with a hand hoe, and in plantation crops, using spades. This weed control technique is more expensive, time- consuming, and exhausting. Three to four weeks following seeding, hand weeding should be done. In wetlands, fields are frequently flooded. Weeds can be significantly reduced in rice fields by continuously submerging them. Water submersion down to 5 cm is shown to be sufficient to manage the majority of weeds in rice. Another technique for controlling weeds is mulching. The term "mulch" describes the protective layer of material that covers the soil's surface. Mulching is the process of applying mulch. Mulching is a significant and successful weed-control technique for horticulture crops and gardens. Crop residues, straw, leaves, paper, plastic films, pebbles, and dry soil are among the materials used to make mulch. Mulching reduces weeds because it provides shade and raises the temperature of the soil. Digging is a technique used to eliminate weeds by reaching deeper levels and removing subterranean storage organs. It is used with pick axes or crow bars and is highly effective when dealing with perennial weeds. The least expensive way to manage mature unwanted vegetation in non-cropped areas, such as ditch banks, roadsides and field bunds, is to burn it. Additionally, stacked weeds are disposed away with it. Cultural approaches to weed management to create favourable conditions for the crop, a variety of cultural methods are used, such as tillage, planting, fertilizer application, irrigation, etc. (Gerhards et al., 2022). Although they cannot totally eradicate weeds, cultural approaches can aid in their population reduction. They should therefore be applied in conjunction with other techniques.

One of those techniques is the sowing/planting method, which calls for the use of clean seeds free of weeds. Since the crop has an extra advantage because of its age, transplanting is another procedure that lowers the number of weeds. Reducing weed germination is facilitated by a clean transplanting field (Allmendinger et al., 2022). If the same crop is produced year after year, crop rotation is another technique where the likelihood of certain weeds appearing is increased. Crop rotation can eradicate or at least lessen challenging weed issues. For instance, lowland rice can be incorporated into crop rotation to effectively suppress noxious weeds like Cyperus rotundus. Crop rotation between cotton and sorghum successfully manages Striga. Growing two or more crops on the same plot at the same time is known as intercropping (Singh et al., 2007); that is, intercrops are planted in distinct rows alongside the primary crop. Cotton + Blackgram, for instance. Using chemicals called herbicides to control weeds is part of chemical weed control. The use of another live organism to suppress a weed is known as biological control. The term "bio-agent" refers to the organism that is utilised for control. Insects (predators/parasites) could be the bio-agent used to manage the weed (Uludag et al., 2018). There are various ways to manage weeds. When the same technique is used consistently, tolerant weeds grow. Therefore, in order to improve weed management, two or more approaches must be used. In order to decrease the number of weeds, integrated weed management, or IWM, employs all appropriate methods in a way that works well together. Cultural, physical, biological, and chemical approaches are all included in the IWM. Weeds can be efficiently and affordably controlled by combining two or more of these techniques (Harker & O'Donovan, 2013).

2.4. Advantages of chemical weed control and integrated weed management

Implementing a comprehensive weed control strategy offers numerous advantages in agriculture. It not only ensures higher weed control efficiency but also tilts the competition in favour of crops by minimizing weed interference. This approach prevents the transformation of weeds into perennial nuisances and curbs the development of herbicide-resistant weed strains, safeguarding long-term crop health. Importantly, it eliminates the risk of herbicide residue in both plants and soil, reducing environmental pollution and supporting sustainable farming practices. The cumulative effect of these benefits results in higher net returns for farmers, making this strategy particularly suitable for systems with higher cropping intensity, where weed management plays a pivotal role in optimizing crop yields and overall agricultural sustainability.

2.5. “Herbicide classification and its effect”

Herbicides can be categorized based on their application method, mode of action, mobility, time of application, molecular structure and formulation type (Fonné- Pfister *et al*., 1996). These classifications help in understanding their use, effectiveness and appropriate application in agricultural practices (Varshney *et al*., 2012). Based on the method of application, it can be categorised into two types; soil- applied herbicides (Fluchloralin) and foliage-applied herbicides (glyphosate and paraquat). Further, based on the mode of action, it is categorised as selective herbicides (atrazine) and non-selective herbicides (paraquat). Based on mobility, they can be classified as contact herbicides (paraquat) and translocated or systemic herbicides (glyphosate) (Tresch *et al*., 2008). Moreover, the time of application- based herbicides involved Pre-emergence application and post-emergence application. Furthermore, on the molecular structure-based herbicide, it can distinguish between inorganic and organic compounds (Sherwani *et al*., 2015). Herbicide formulations are prepared by blending the active ingredient with solvents, carriers, surfactants and other additives, ensuring their ease of handling, efficacy and suitability for storage and use.

One of the major issues associated with the continuous and widespread use of chemical herbicides is the development of weed resistance. Depending too heavily on a single herbicide or specific mechanism of action can lead to the emergence of resistant weed varieties (Pandey & Kandel, 2020),(Pradhan *et al*., 2022). It means that certain weeds can evolve to survive the effects of the herbicide. It reduces the herbicide’s efficacy and increases the dependence on more powerful and harmful chemicals (Knezevic *et al*., 2016). Additionally, the labour-intensive nature of many traditional methods, such as hand weeding, makes weed control costly and time- consuming, particularly for large-scale agricultural operations (Kaur et al., 2022).

Growing concerns regarding herbicide resistance, human health risks, and environmental impacts associated with conventional weed control methods have increased demand for alternative approaches. Herbicide resistance is a major challenge associated with traditional weed control methods (Mahmood *et al*., 2016).

Herbicide-resistant weeds can survive and reproduce despite herbicide applications, reducing the effectiveness of these control methods. This phenomenon necessitates the use of higher herbicide doses or alternative herbicides, which can further contribute to environmental concerns and escalate the costs of weed management. According to Pannell *et al.*, (2016), the rise of herbicide-resistant weeds also poses significant threats to the herbicide-tolerant crops. This situation requires us to pay greater attention to the environmental risks associated with alternative methods of weed control (Pannell *et al.*, 2016).

By relying on the natural allelopathic properties of certain plants, the need for higher herbicide doses is reduced, resulting in lower herbicide use and application costs. Additionally, integrating alternative weed control methods, like allelopathy, can help reduce labour costs associated with manual weeding or more intensive weed management practices (Scavo & Mauromicale, 2021).

Allelopathy has emerged as an eco-friendly method for effectively controlling weeds while minimizing environmental concerns (Pradhan *et al.*, 2022). One practical approach involves using allelopathic plant extracts and residues. However, these extracts and residues often provide limited weed suppression compared to preferred labelled herbicides. Various studies suggest that combining lower rates of herbicides with aqueous extracts or residues from various allelopathic plants can significantly reduce herbicide application without compromising crop yields (Alsaadawi *et al.*, 2020). The use of synthetic herbicides may still be necessary to some extent, but incorporating allelopathy as an alternative weed management strategy can help reduce their overall usage while offering environmental benefits.

2.6. Weed management challenges: Impact on rice and wheat yield loss and environmental factors

Weed management directly influences the growth and yield of essential crops. However, it presents several challenges and has significant impacts on both crop productivity and the environment. Crop yield losses due to weed infestations are influenced by various factors, including the timing of weed emergence, the density of weed populations, the specific types of weeds present and the cultivated crops. In Australia, the economic costs of weeds for grain growers are substantial, with an estimated annual cost of AUD 3.3 billion (Llewellyn *et al.*, 2016). Moreover, unchecked weed growth can cause huge losses as it acts as a host for pests and diseases, further damaging the crops. Manual weed control methods can be laborious and costly, especially for large-scale farms, posing practical difficulties in managing weeds. In India, weeds have been responsible for a loss of 2.7 million tons of grain. The situation is particularly alarming in India, where weeds contribute to an annual agricultural production reduction of over USD 11 billion (Gharde *et al.*, 2018). In- depth studies reveal significant crop-specific yield reductions due to weed interference, with estimated losses of 36% in peanut (*Arachis hypogaea* L.), 31% in soybean (*Glycine max* (L.) Merr.), 25% in maize (*Zea mays* L.), and 19% in wheat (*Triticum aestivum* L.). Similarly, in the USA, weeds acquire a staggering USD 33 billion in lost crop production each year (Pimentel *et al.*, 2005). This highlights the global agricultural importance of weed management and the need for effective strategies to address this challenge

2.7. Limitations of chemical weed control & integrated weed management

Using bio-agents for weed control has certain limitations. One significant drawback is the high initial cost associated with their implementation. Additionally, bio-agents often have a small and narrow span of activity, limiting their usefulness to a specific range of weed species. Another challenge is their relatively slow action compared to chemical herbicides, as bio-agents may take time to establish and exert control over weeds. Furthermore, successful bio-agent usage depends on the adaptability of these organisms to the released environment, making it crucial to select appropriate bio- agents for specific ecosystems. Lastly, not all weed species have corresponding bio- agents available, which further restricts their applicability in weed management strategies

2.8. Herbicide use data (Punjab region).

A study conducted by (Shattuck *et al.*, 2023), highlights the pesticide use data, especially the data and revealed that pesticide use in low and lower-middle-income countries had been substantially underestimated, with global pesticide use experiencing a 20% growth in volume over the past decade. Particularly striking was the 153% increase in pesticide use in low-income countries during the same period. The Global pesticide use and trade database insights indicated significant rises in pesticide (Shattuck *et al.*, 2023).

In the context of intensive agriculture, particularly in India, herbicides have been widely applied for effective weed control in various main field crops such as wheat, rice, maize, cotton, sugarcane, potato, onion and pulse crops (P. Kaur *et al.*, 2019). In India, there is a wide range of herbicides available for use in different crops, including in the state of Punjab. More than 60 herbicides have been registered and approved for use in various crops across the country. Specifically, in Punjab, 32 specific herbicide formulations have been recommended and recognized for their effectiveness in weed control in different crops. This diverse range of herbicide options enables farmers in Punjab to effectively manage weeds and protect their crops (Choudhury *et al.*, 2016).

To evaluate the efficacy of different mulching practices and legume intercropping in transplanted pearl millet, a field trial was conducted by Sharon *et al.*, 2023)**.** Different treatments were tested, and the study indicated that intercropping pearl millet with cowpea, combined with the pre-emergence application of Pendimethalin, provided a viable and environmentally sustainable weed management strategy, resulting in improved pearl millet yield compared to the use of polythene mulches (Sharon *et al.*, 2023).

2.9. Harmful effects of herbicide use

Herbicides can have harmful effects on the environment and non-target organisms, such as aquatic life and beneficial insects, leading to ecosystem disruption and biodiversity loss (Tudi *et al.*, 2021). Glyphosate, a widely used herbicide over the past four decades, was initially believed to have negligible impacts on the environment and human health. However, recent global concerns have emerged regarding its potential direct and indirect effects on human health due to excessive usage. In 2017, the World Health Organization classified glyphosate as a carcinogenic substance and subsequently banned its use due to numerous life- threatening side effects on human health (Rawat *et al.*, 2023).

Herbicides also have harmful effects on aquatic life cycles if they are not used properly or enter water bodies in excessive amounts. It is toxic to aquatic organisms, including fish, amphibians, invertebrates, and algae (Mehdizadeh *et al.*, 2021). Different herbicides have varying levels of toxicity, and the effects can range from reduced growth and reproduction to acute toxicity leading to death. Amphibians, with their dual life cycles in both aquatic and terrestrial environments and permeable skin, are easily exposed to chemical contamination. Pesticides can enter their bodies through dermal exposure in both habitats. (Lajmanovich *et al.*, 2015) studied the effectiveness of non-destructive biomarkers in monitoring dermal pesticide exposure in male toads. Results showed the ecological risks of amphibian populations exposed to organophosphate insecticides and herbicides (Lajmanovich *et al.*, 2015). Similarly, (Blahova *et al.*, 2020) evaluated the acute embryotoxicity of atrazine, as well as its degradation products, desisopropylatrazine and desethylatrazine and their combination, on the early life stages of zebrafish using a modified Fish Embryo Acute Toxicity Test. Their findings suggested that higher concentrations, which are not environmentally relevant, pose a potential risk of embryotoxicity for zebrafish (Blahova *et al.*, 2020)**.**

Herbicides also disrupt soil microflora activity. The application leads to a decrease in microbial diversity and alters the abundance of specific microbial groups. This disturbance in soil microflora can affect important ecological processes such as nutrient cycling, organic matter decomposition and plant-microbe interactions. (Lone *et al.*, 2014) examined the effects of six herbicides on soil microbial communities using laboratory microcosms. Results showed a mixed response of the microbial community, with metribuzin negative impact, clodinafop showing a positive effect, and sulphonyl urea herbicides showing no significant effect. Different microbial groups responded differently. The study highlighted the herbicidal impact on soil microbes depends on the specific herbicide, its dose and the microbial group (Lone *et al.*, 2014).

2.10. Weed diversity & herbicide impact in rice-wheat cropping system

Weed infestation is a major yield and production-limiting factor in the rice-wheat cropping system (Sayer *et al.*, 2021),(M. K. Singh *et al.*, 2021). Weeds are basically an unwanted plant that has the ability to compete with desired crops for essential resources such as water, nutrients, sunlight and space. This invasive plant species can be annuals, biennials or perennials and has the potential to reproduce rapidly, spread vigorously and establish dense populations. Weeds negatively affect the crop and limit its productivity. In addition, it also makes the harvesting process challenging (Dass *et al.*, 2017).

Weeds are classified into different categories based on their growth characteristics, including grasses, broadleaf weeds, ferns, herbaceous weeds and woody weeds. Weeds such as Barnyardgrass (*Echinochloa crus-galli*, *Brachiaria serrata, Euphorbia hirta*, *Chenopodium album, Phalaris minor,* etc. are troublesome species and negatively affect the wheat-rice crop cultivation. During a study conducted by (Pisal and Sagarka 2013) in Gujarat, several monocot weeds such as *Echinochloa colonum, Brachiaria serrata* and dicot weeds like *Digera arvensis, Amaranthus viridis, Euphorbia hirta* and *Chenopodium album* were observed (Pisal & Sagarka, 2013). In a study conducted in Punjab by (Kaur and Walia 2015), the experimental field was primarily overspread with the grass weed *Phalaris minor*, along with a few broadleaved weeds such as *Anagallis arvensis, Chenopodium album, Rumex dentatus, Coronopus didymus* and *Medicago denticulate* (T. Kaur *et al*., 2015). Similarly, according to Banerjee et al. 2019), the weed flora in the wheat experimental field at West Bengal was mainly dominated by *Phalaris minor* and *Avena ludoviciana* (Banerjee *et al*., 2019).

To ensure the sustainability and productivity of the agricultural system, weed management plays an important role, specifically in the case of the rice-wheat cropping system (Shahzad *et al*., 2021). Therefore, implementing effective weed management strategies has become a vital component in sustaining food grain production and maintaining the economic viability of the rice-wheat cropping system (Andrew *et al*., 2015).

Phalaris minor, a troublesome weed in wheat crops in the north-western Indo- Gangetic Plains, particularly in Punjab and Haryana regions and become a major challenge for farmers. Phalaris species can be found in various environments, including wild communities and arable lands with sandy or clay soils. Among the 22 recognized species, *Phalaris minor, Phalaris paradoxa,* and *Phalaris brachystachys* are particularly problematic weeds in agricultural systems, especially in wheat fields worldwide (Gherekhloo *et al*., 2021). Unfortunately, the weed has developed resistance to many herbicides, limiting the choice of effective chemical control methods. To address this issue, a study was conducted by (Chaudhary *et al*., 2021) to improve the herbicide efficacy. They examine the different post-emergence herbicides such as fenoxaprop, metsulfuron, clodinafop, sulfosulfuron, iodosulfuron and pinoxaden, effects alone and in combination with metribuzin. The results showed that when metribuzin was mixed with the post-emergence herbicides, it significantly improved weed control. The tank mixtures with metribuzin achieved weed control efficiency ranging from 70% to 89%, compared to only 17% to 54% with the herbicides alone. The metribuzin-based tank-mixed herbicide application not only effectively controlled *Phalaris minor* but also targeted broad-leaved weeds (Chaudhary *et al.*, 2021).

The study conducted by Gealy *et al.* (2019) investigated the effects of barnyard grass (*Echinochloa crus-galli*) on rice cultivation under both flood and alternate-wetting- and-drying irrigation systems. The study evaluated seven different rice genotypes to assess their weed suppression abilities and grain yield potential. Their research findings revealed that barnyardgrass is a challenging weed species in rice fields, impacting both alternate-wetting-and-drying and flood systems. Moreover, the study highlighted a significant grain yield reduction of over 90% in alternate-wetting-and- drying systems, indicating the detrimental impact of the weed species on rice production.

2.11. Herbicide resistance & its impact on the environment

The repeated use of herbicides with the same action mechanisms can select difficult- to-control and herbicide-resistant weeds. It is important to use herbicides with different action mechanisms or combine them with mechanical or cultural practices to prevent these issues (Vencill *et al.*, 2012). Currently, 220 weed species have developed resistance to herbicides, resulting in 404 unique cases of herbicide- resistant weeds worldwide. Herbicide resistance can arise through several mechanisms, such as Target-site resistance, enhanced metabolism, decreased absorption or translocation, Sequestration and Gene amplification/overexpression.

Target-site resistance occurs when mutations occur in the herbicide binding site, typically found within an enzyme. These mutations make it more difficult for the herbicide to bind to the intended target site. For instance, resistance to ALS inhibitors, ACCase inhibitors, dinitroanaline and triazine herbicides can result from target-site resistance. Some common ALS inhibitor-resistant weeds in rice include *Echinochloa crusgalli, Cyperus difformis, Alisma plantago-aquatic*a and *Sagittaria montevidensis*. These weeds have developed resistance to herbicides that inhibit the ALS enzyme, making it challenging to control them effectively in rice fields. In wheat crops, common ALS inhibitor-resistant weeds include species of *Kochia scoparia* (Kochia weed), *Lolium* (ryegrass), *Avena fatua* (wild oat), *Stellaria media* (common chickweed) and *Papaver rhoeas* (corn poppy). These weeds have also exhibited resistance to ALS inhibitor herbicides in wheat fields. However, herbicide resistance can vary geographically, and new cases of resistance may emerge over time (Busi *et al*., 2013).

Similarly, ACCase inhibitor herbicides such as fenoxaprop, diclofop and clodinafop were widely depended upon for grass control, resulting in the selection of 19 grass species resistant to ACCase inhibitors. Currently, over 25 million hectares of cereal crops are infested with ACCase inhibitor-resistant grasses, with *Lolium, Alopecurus, Avena, Setaria* and *Phalaris* species being the most challenging. The resistance in these grasses is attributed to various target-site amino acid substitutions in the acetyl CoA carboxylase (ACCase) gene, leading to an altered and insensitive form of the ACCase enzyme. Additionally, metabolic resistance through cytochrome P450 is prevalent in *Alopecurus myosuroides* and *Lolium rigidum* further contributing to resistance against ACCase inhibitors (Brown *et al*., 2002; Délye *et al*., 2005 Hochberg *et al*., 2009).

Another mechanism is enhanced metabolism, where certain plants possess the ability to metabolize herbicides more efficiently. This allows them to break down the herbicides before they can exert their harmful effects. Decreased absorption and/or translocation is another resistance mechanism, whereby plants limit the movement of herbicides within their tissues, preventing them from reaching their target sites and thus reducing their effectiveness (Caseley *et al*., 2013). Additionally, sequestration is a mechanism in which plants sequester or trap herbicides onto cell walls or within vacuoles, decreasing the concentration of the herbicide at the target site. Furthermore, gene amplification/overexpression involves plants increasing the production of the target enzyme, requiring higher concentrations of herbicides to inhibit the enzyme and induce plant death. These mechanisms collectively contribute to herbicide resistance by altering the herbicide's interaction with the plant, either through modifying the target site, enhancing detoxification processes, impeding herbicide movement, or reducing its concentration at the site of action (Heap, 2014).

The most widespread glyphosate-resistant weed is *Conyza canadensis*, but *Amaranthus palmeri* and *Amaranthus tubercülartus* are economically significant due to their resistance to multiple herbicide sites of action, limiting control options for growers (Feng *et al.*, 2010). Unfortunately, there have been no new herbicides with novel sites of action introduced to the market in over 30 years, forcing growers to depend on existing herbicides used in different ways.

2.12. Effective use of allelopathy in weed management

Allelopathy offers a promising and environmentally friendly alternative for weed control (Sahrir *et al.*, 2022). Jelassi *et al.* (2016) conducted a comprehensive investigation to assess the phytochemical content and allelopathic potential of various organic extracts derived from seeds and pods of three Tunisian Acacia species: *Acacia cyclops*, *Acacia mollissima* and *Acacia cyanophylla*. During their analysis, the team found that the total flavonoid contents in the organic extracts closely ranged from 3.1 to 24 mg RE/100 g/DW. Notably, the n-butanol extracts of Acacia pods exhibited the highest levels of phenol and condensed tannin contents. Regarding allelopathic activity, the ethyl acetate extract obtained from seeds of *A. cyanophylla* demonstrated significant inhibition of the target seeds' germination. The study conducted provides valuable insights into the diverse phytochemical composition of the organic extracts from the examined *Acacia species*. The discovery of mollisside B as a key active compound opens up new possibilities for exploring its potential application as a natural bioherbicide for weed management and sustainable agricultural practices (Jelassi et al., 2016).

Annual ryegrass (*Lolium rigidum*) is a widespread weed that infests a majority of crops. Due to herbicide resistance, it is important to develop alternative methods. In this regard, (Asaduzzaman *et al*.,) conducted a study in 2012 to evaluate the dose- response allelopathic effects of rice through root exudates bioassay using the Equal- Compartment-Agar Method. Their research specifically focused on two different rice genotypes, Quest and M 205 and examined their allelopathic effects on annual ryegrass. The results revealed that rice root exudates had a noticeable inhibitory effect on the growth of annual ryegrass seedlings. These findings highlight the importance of exploring dose-response allelopathic effects of different rice genotypes to effectively manage annual ryegrass (Asaduzzaman *et al.*, 2012).

Similarly, Carrubba *et al*. (2020) conducted a study to explore the potential of plant water extracts for weed control in durum wheat and their impact on yield. The field experiments were carried out in 2014 and 2016, focusing on the herbicidal properties of various plant water extracts on durum wheat. The extracts derived from *Artemisia arborescens, Rhus coriaria, Lantana camara, Thymus vulgaris* and *Euphorbia characias* were tested. Their findings revealed the potential of utilizing plant water extracts for weed management in durum wheat cultivation (Carrubba et al., 2020).

Based mode of action of allelochemical-based herbicides on herbicide-resistant weeds was investigated by Yang *et al.* (2017). A series of allelochemical tricin- derived compounds was evaluated for their herbicidal activities. Among them, a benzothiazine derivative with 4-hydroxyphenyl-pyruvate dioxygenase-inhibiting activity was identified as a target compound. The benzothiazine derivative showed a stronger effect on resistant barnyardgrass than the allelochemical tricin itself. These findings suggest that the benzothiazine derivative effectively inhibited the growth of resistant *Echinochloa crus-galli* by interfering with its photosynthesis system through a mechanism. Therefore, the benzothiazine derivative holds promise as a lead compound for the development of allelochemical-based herbicides targeting resistant weeds.

Table 2.1 Previous works and their findings

Allelopathic plant extracts	**Targeted weed and plant species**	**Findings**	**Reference**
Eucalyptus globulus leaves	*Digitaria sanguinalis* and *Chenopodium album*	Eucalyptus residues as green manure effectively control weed in organic maize-based cropping systems.	(Puig *et al*., 2019)
Ulex europaeus and *Cytisus scoparius*	*Amaranthus retroflexus* and *Digitaria sanguinalis*	The aqueous extracts from the flowering foliage of both shrub species exhibited phytotoxic effects on the target weeds.	(Pardo-Muras *et al*., 2020)

Ocimum basilicum	*Amaranthus spp.* and *Portulaca spp.*	*Ocimum basilicum* effectively control weeds in horticulture orchard fields.	(Mekky *et al.*, 2019)
Eucalyptus species	*Parthenium hysterophorus*	*Eucalyptus* species, particularly *Eucalyptus citriodora,* showed promise for weed control.	(Prajapati *et al.*, 2020)
Passiflora edulis	*Echinochloa crus-galli* and *Monochoria vaginalis*	*Passiflora edulis* as a natural herbicide, offering an eco-friendly alternative to synthetic herbicides and reducing dependence on synthetic herbicides.	(Khanh *et al.*, 2006)
Xanthium occidentale	*Medicago sativa* and *Echinochloa crus-galli*	Both aqueous and methanol extracts significantly inhibited seed germination and root growth of *Medicago sativa* and *Echinochloa crus-galli*	(Chon, 2004)
Artemisia absinthium and *Psidium guajava*	*Parthenium hysterophorus*	Both extracts have the potential to be applied as effective herbicides	Kapoor et al., (2019)
Cupressus sempervirens, Juniperus phoenicea and Tetraclinis articulata	*Lactuca sativa*	The extracts were inhibited root growth and induced phytotoxic effects on the lettuce plants. Visible signs of damage included necrosis and alterations in the plant's physical appearance. The	M'barek et al., (2019)

		extracts also triggered oxidative damage, which resulted in disruptions in membrane permeability and the leakage of electrolytes.	
Cannabis sativa L.	*Sorghum halepense, Lactuca sativa, Stellaria media, Zea mays, Lupinus albus, Ambrosia artemisiifolia, Triticum aestivum, Matricaria recutita, Lepidium sativum, Cyperus rotundus, Brassica napus, Secale cereale, Chenopodium album and Beta vulgaris ssp.*	The study strongly suggested that the allelopathic effects of hemp supported by its a range of chemical compounds, highlight its potential as a valuable source for the development of herbicidal preparations.	Konstantinović et al., (2021)
Sorghum bicolor	*Beta vulgaris* L., *Chenopodium album* L., *Amaranthus retroflexus* L., and *Malva rotundifolia* L	The allelopathic effect of *Sorghum bicolor* was found to effectively suppress weed growth while promoting the growth and productivity of *Vigna Sinensis* L. crops	Sarbout *et al*., (2023)

Sorghum bicolor L. *Morus alba* L., *Echinochloa crusgalli* L. *and Withania somnifera* L.	*Avena fatua* L.) and *Phalaris minor*	Mulberry extract showed the strongest allelopathic effect, completely inhibiting wild oat germination. It, along with barnyard grass and winter cherry extracts, fully suppressed canary grass germination, whereas sorghum exhibited minimal or even stimulatory effects.	Jabran *et al*., (2010)
Amaranthus species	*Lactuca sativa* L.	The findings provided sign of the allelopathic potential of the ethanolic leaf extracts from the studied Amaranthus species.	Carvalho et al., (2019)

2.13. Synergistic effect of allelopathic extract with reduced herbicide dose

Iqbal *et al*. (2010) investigate the response of wheat crop (*Triticum aestivum* L.), and its weeds to different crop water extracts of sorghum, brassica and sunflower in combination with reduced rates of the herbicide Bromoxynil, with 2-methyl-4-chlorophenoxyacetic acid is a powerful, selective phenoxy herbicide (MCPA). The treatment combinations included a mixture of all three crop water extracts combined with the recommended dose of Bromoxynil and MCPA. At 70 days after sowing, the recorded data revealed that the application of water extracts combined with Bromoxynil and MCPA resulted in significant suppression of weed density, weed fresh weight, and weed dry biomass. Their conclusion indicated that the use of allelopathic crop water extracts allows for a reduction of up to 50% in herbicide usage (Iqbal *et al*., 2010).

Alsaadawi (2011) evaluated the herbicidal potential of sunflower residues and their combined effect with herbicides. In their research, different rates of sunflower were incorporated into the soil, along with varying percentages of recommended doses of 2,4-D. The results showed that the combination of the recommended herbicide dose with sunflower residue at 1400 g m-2 exhibited the lowest above-ground weed biomass and weed numbers. In addition, chromatographic analysis revealed the presence of various phenolic compounds in the soil containing sunflower residues, while these compounds were absent in the soil without residues. The study also observed that weed populations started to increase after six weeks of residue decomposition, coinciding with a sharp reduction in phytotoxin concentration in the soil. This approach has the potential to reduce reliance on herbicides for weed control, offering a more sustainable and environmentally friendly alternative (I S Alsaadawi, 2011). In another study, (Alsaadawi et al., 2020) examined the combined effects of allelopathic water extracts and residues with lower herbicide rates in different cropping systems for weed management. The research discusses the positive impact of this approach on soil properties. The findings suggest that utilizing allelopathy in conjunction with reduced herbicide rates shows promise as a sustainable weed management strategy for crop production, with additional benefits for soil health and the environment (Ibrahim S. Alsaadawi *et al.*, 2020).

To address the challenge of widespread resistance in *Phalaris minor* affecting wheat production, Abbas *et al.*, (2018) conducted a two-year field trial to explore the effectiveness of allelopathic crop mulches (sunflower, rice, maize and sorghum) alone and in combination with herbicide mixtures. Their findings revealed that the combined use of mulches and herbicides provided effective control of *Phalaris minor* and effectively reduced its population.

Table 2.2 Work related to herbicidal use with allelopathic mechanisms

Combinations		Targeted weed	Findings	References
Allelopathic plant	**Herbicides use**			
Sorghum, Brassica, Sunflower and Mulberry	Atrazine	*Trianthema portulacastrum* L.	The combination of allelopathic plant water extracts with half and one-third doses of atrazine showed 70-75% suppression of weed density and dry weight.	(Khan *et al*., 2012)
Sorghum	Pendimethalin and S Metolachlor	*Cyperus rotundus* and *Trianthema portulacastrum* L.	1/3rd recommended dose of S-metolachlor and pendimethalin combined with concentrated Sorghum reduced total weed dry weight and cotton yield by effectively control weeds in cotton fields.	(Cheema *et al*., 2003)
Sorghum and	Isoproturon, Bensulfuron,	*Coronopus didymus* L.	The combination	(Razzaq *et al*., 2012)

Sunflower	Metribuzin, phenoxaprop, Mesosulfuron, Idosulfuron,	and *Phalaris minor* L.	of sorghum and sunflower water extracts with metribuzin+ phenoxaprop resulted in the highest number of productive tillers, spikelets per spike, number of grains per spike and grain yield. Moreover, a 70% reduced herbicide dose with allelopathic sorghum and sunflower water extracts effectively control weeds in wheat fields and increased yields.	

Oat, Rapeseed and Sorghum	Bentazone and Imazamox	*Polygonum avicular, Glebionis coronaria, Vaccaria hispanica, Sinapis arvensis, Papaver rhoeas, Chenopodium album, Galium aparine*	Extract-herbicide mixtures reduced herbicide doses holds potential as an effective weed management strategy in faba bean cultivation. However, further research is needed to understand the phytotoxic mechanisms and modes of action of the studied.	(Abdellatif *et al*., 2023)
Ambrosia artemisiifolia and *Xanthium strumarium*	Mesotrione	*Abutilon theophrasti* and *Chenopodium album*	Inhibition of all measured parameters in both weeds when treated with Mesotrione alone and in combination.	(Sarić-Krsmanović *et al*., 2020)

Sorghum, Brassica, Sunflower and Mulberry	Atrazine, Pendimethalin S-Metolachlor, Fenoxaprop-p-ethyl and Clodinafop propargyl.	*Phalaris minor Retz., Avena fatua L., Chenopodium album L., Convolvulus arvensis* L., *Trianthema portulacastrum* L., *Cyperus rotundus L.* and *Echinochloa crus-galli* L.	the combination of sorghum water extract with reduced rates of pre-emergent herbicides pendimethalin and S-Metolachlor provided effective weed control in cotton.	(Cheema *et al*., 2005)
Sorghum and Sunflower	Metribuzin, idosulfuron, mesosulfuron, isoproturon, fenoxaprop and bensulfuron	*Phalaris minor* and *Coronopus didymus* L.	The different combinations of plant water extract with reduced herbicide doses had a significant impact on weed density, dry weed biomass and wheat grain yield.	Razzaq et al., (2010)
Sorghum bicolor L. *Helianthus*	Glyphosate	Purple Nutsedge	The use of a combination of sorghum	(Iqbal *et al.*, 2009)

annuuus L. and *Brassica napus* L.			water extract and half the recommended dose of atrazine has been found to effectively control weeds, achieving similar results as a full dose of atrazine alone	
Sorghum, sunflower and rice	Butachlor, pretilachlor and ethoxysulfuronethyl	*Echinochloa crusgalli, Cyperus iria* and *Dactyloctenum aegyptium*	The water extracts with a lower rate of pre-emergence herbicides can lead to a reduction in herbicide usage by 20-67% while achieving a weed growth reduction of 60-70%	Rehman *et al*., (2010)
Sorghum, Sunflower, and	Halosulfuron and metribuzin	*Cynodon dactylon, Cyperus*	The study assessed various yield	Devedee *et al*., (2022)

Parthenium		*rotundus, Cyperus esculantus, Parthenium hesterophorus, Trianthema portulacastrum, Echinochloa spp. and Digitaria sanguinalis*	attributing characters, displayed positive trends with the use of herbicidal and plant water extract combinations. The microbial population and also after 7 days it did not reduce microbial populations	
Sorghum, sunflower, brassica and rice	Pendimethalin	*Brassica napus* L.	sorghum and rice water extracts combined with pendimethalin exhibited the highest reduction in total weed density after sowing, with reductions of more than 65%	Jabran et al., (2008)

2.14. Previous studies on the combination of allelopathy and herbicides

Various studies have been carried out by researchers to understand the potential synergistic effects of incorporating allelopathic plant extracts with herbicides. (Bhowmik and Inderjit 2003) and (Mushtaq et al. 2010) have proposed that the combination of herbicides with allelopathic conditions can lead to a complementary interaction. This interaction can potentially reduce the need for excessive herbicide usage in managing weeds in field crops. Their findings suggest that incorporating allelopathic conditions, such as the presence of allelopathic plants or their extracts, along with herbicide application, can enhance the overall effectiveness of weed control.

2.15. Weed control efficiency through the combination of allelopathy and herbicides

The combination of allelopathy and herbicides has been found to improve the effectiveness of weed control. The chemical compounds released by allelopathic plants can inhibit various physiological processes in weeds, such as seed germination, root development and nutrient uptake (Khan *et al.*, 2002). The combination of allelopathy and herbicides offers several advantages, such as it can reduce the dependence on high doses of herbicides, leading to decreased chemical usage. Furthermore, allelopathy can provide an alternative mode of action against weeds, helping to alleviate the development of herbicide resistance. Allelopathic substances serve as an effective alternative, natural and biodegradable herbicides offering environmentally friendly solutions for weed control (Vyvyan, 2002).

In cotton and maize crops, the use of a combination of sorghum water extract and half the recommended dose of atrazine has been found to effectively control weeds, achieving similar results as a full dose of atrazine alone (Iqbal *et al.*, 2009).

The study conducted by Masum (2023) explored the potential of allelopathic extracts to control the rapid spread of *Parthenium hysterophorus* L., an invasive weed species in Bangladesh. Their results indicated that certain herbicides, including pretilachlor, pendimethalin, bensulfuron methyl, acetachlor, oxadiazon,and pyrazosulfuron-ethyl, effectively reduced seed germination of *Parthenium* in both puddled and dry sown conditions. The researchers observed a phytotoxic response to weed growth triggered by aqueous extracts of *Oryza sativa* L. var. Boteswar, *Triticum aestivum* L. var. BARI gom-21, *Helianthus annuus* L., *Datura metel*, *Mangifera indica* L., *Delonix regia* and *Acacia nilotica*. Among these extracts, *Delonix regia* showed the most significant inhibition of germination, while *Datura metel* extracts and *Oryza sativa* var. Boteswar straw extracts significantly reduced root and shoot length (Masum, 2023).

Overall, the literature highlights that the rice–wheat cropping system, although highly productive and widely practiced, is increasingly threatened by complex and evolving weed problems, soil and environmental degradation, herbicide resistance, rising labour costs, and ecological risks associated with intensive chemical use. Changes in crop varieties and management practices have altered weed dynamics, with aggressive species such as *Phalaris minor*, *Echinochloa spp.* and *Scirpus spp.* becoming major yield-limiting factors. While chemical herbicides remain effective, their continuous and indiscriminate use has led to resistance development, environmental contamination, disruption of soil microflora and potential risks to human and aquatic health. Mechanical and cultural methods alone are often inadequate, labour-intensive and costly at larger scales. Therefore, the integration of multiple approaches—mechanical, cultural, biological, chemical, and emerging strategies such as allelopathy and precision-based weed modelling— appears to be the most sustainable and economically viable solution. Integrated Weed Management (IWM), supported by advances in spatial modelling and eco- friendly alternatives, offers a balanced pathway to control weeds, protect yields, reduce environmental impact and ensure the long-term sustainability of the rice– wheat cropping system.

Chapter 3

MATERIALS AND METHODS

During the *Rabi*-Kharif season of 2021-2023, an experiment entitled **"Weed management in Rice-Wheat cropping system through combination of plant allelopathic extract with reduced doses of herbicides"** was conducted. The information on the criteria used and techniques adopted for experimental work, for the evaluation of treatments during the entire season of experimental investigation, is mainly described in this chapter.

3.1. Experimental site selection & soil analysis

The experiment was conducted at the research field of Lovely Professional University, Kapurthala district, during the years 2021-2023. The location of the farm is at $31^0$22'31.81" North latitude and $75^0$23'03.02". Punjab falls under sub-tropical region in central plane of state agro climatic zone as per Google map (Fig. 3.1).

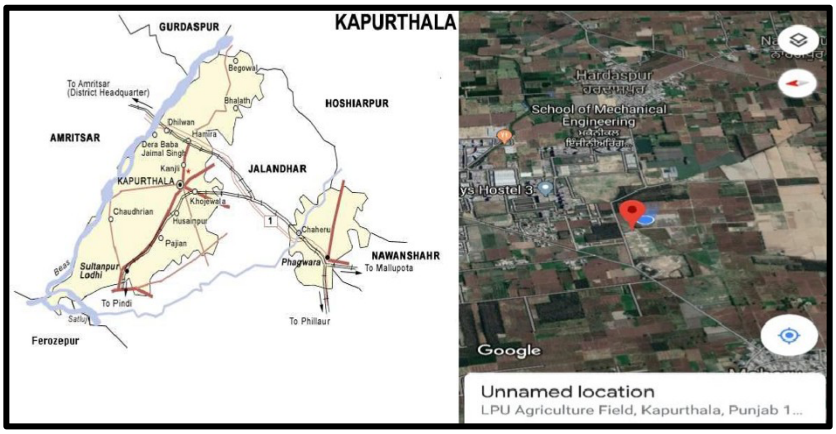


Fig.3.1: Experimental Farm and its location (Source: Google Earth)

The experimental region comes under an area which has cool weather (10-15°C) in the winter season and hot weather (35-45°C) in the summer season. Rainfall mainly occurs in July, August, and September if there is no delay in the southwest monsoon winds. In winter, the temperature goes very low but never goes below 0°C in the month of December and January. The temperature ranges from 35-45°C in April, May and June. The highest temperature normally reaches 45°C during the summer months. Normally, from the last week of June, monsoon rainfall starts and continues until to end of September. The highest amount of rainfall is normally received in July **(Table 3.1)**.

Table 3.1 Meteorological data of growing season

Month	**Temperature (°C)**						**Relative Humidity (%)**			**Rainfall(mm)**		
	Maximum			**Minimum**								
	2021	**2022**	**2023**	**2021**	**2022**	**2023**	**2021**	**2022**	**2023**	**2021**	**2022**	**2023**
January	--	15.97	13.51	--	10.29	8.38	--	69.36	72.18	--	1.15	0
February	--	16.29	22.92	--	9.04	12.21	--	65.59	65.75	--	0.61	0
March	--	26.42	29.77	--	17.84	17.12	--	48.92	50.02	--	0.03	0.135
April	--	38.60	31.16	--	27.67	16.4	--	36.68	35.63	--	0.13	0.92
May	--	39.84	38.06	--	30.32	25.58	--	32.55	32.3	--	0.25	1.68
June	--	--	--	--	--	--	--	--	--	--	--	--
July	39.87	37.22	--	30.51	29.58	--	59.17	64.85	--	5.34	8.25	--
August	40.54	34.45	--	29.58	25.90	--	69.83	69.63	--	4.24	0.90	--
September	39.23	35.61	--	29.13	24.16	--	68.35	67.19	--	3.92	0.36	--
October	33.3	32.0	--	22.45	20.35	--	49.07	49.40	--	0.11	0	--
November	24.36	25.7	--	14.23	13.9	--	50.37	51.43	--	0.01	0	--
December	19.47	24.83	23.45	9.61	10.23	9.82	59.48	80.85	77.6	0.02	0.06	0

Source: Indian Meteorological Department

3.2. Measurement of soil chemical properties

3.2.1. Soil sample collection

Before conducting the investigation, random samples of soil were collected from the field. After scraping the surface, v-shaped cut was made to a depth of 6 inches and about a 1-inch-thick slice of soil was collected from one side of the cut. Similarly, 10 to 12 samples were collected from the field in a zigzag direction. Finally, about 500 g of soil was collected after mixing the soil samples uniformly. The sample was used for analysing the physical and chemical properties of the soil. At harvest, soil samples were again collected and analysed. The soil at the experimental site was sandy loam, fertile, well-tilled, with good drainage and rich in nutrients

3.2.2. Soil pH (Sparks 1996)

Soil samples were analysed for pH using the method of Sparks (1996). Five grams of soil sample were transferred to a 50 ml beaker, and 10 ml of distilled water was added to it. The soil mix was kept in a shaker for 30 minutes. After the homogenization, soil samples were kept aside for 10 minutes, followed by taking a reading of each sample with pre- calibrated pH meter.

3.2.3. Electrical conductivity (Sparks 1996)

Similarly, EC was analyzed by using the sparks method for the analysis of EC. 5 g of soil was transferred to a 50 ml beaker, and 10 ml of distilled water was added to it. Then shake the sample for 30 minutes in a mechanical shaker. After half an hour, take the sample to the pre-calibrated EC electrode and note down the reading of the sample.

3.2.4. Available nitrogen (kg ha^{-1}) (Kjeldahl Method)

Twenty grams of an air-dried soil sample were transferred to a distillation flask of a micro-Kjeldahl distillation assembly. Afterwards, 100 ml of 0.32% $KMnO_4$ and 25 ml of 2.5% NaOH were added to it. In a conical flask (150ml), 10ml of boric acid was added, followed by adding 3-4 drops of mixed indicator. Conical flasks containing boric acid were kept at the bottom of the receiving tube of the distillation assembly. Nearly 100 ml of distillate was collected. The decrease in milli-equivalents of acid as determined by acid-base titration which gives a measure of the nitrogen content of the sample. The boric acid was back-titrated with 0.02N sulphuric acid (H_2SO_4). At the endpoint, the blue colour of the titrated solution just disappeared to pink.

Calculation formula

Nitrogen (%) $=(V-V_b)\times N\times 14.01\times 100\ /\ W$

Where:

- V = volume of acid used in titration (mL)
- Vb = volume of acid used in blank titration (mL)
- N = normality of the standard acid
- 14.01 = atomic mass of nitrogen (g/mol)
- W = weight of the sample (g)

3.2.5. Available phosphorus (Olsen *et al* 1954)

One gram of soil was transferred to a 250 ml conical flask, and 20 ml of 0.5 M $NaHCO_3$ was added to it, followed by keeping the soil mix in an electric shaker for 30 minutes. Then the suspension was filtered through the Whatman No.1 filter paper. Likewise, a blank solution was also prepared. 5 ml of the extract was used for analysis, and 5 ml of 1.5% ammonium molybdate was added to it, followed by adding 10ml of distilled water. 1 ml of stannous chloride was added to the mix, as a result blue colour developed and the reading was taken with the help of a spectrophotometer, at 560nm wavelength.

Calculation formula

Available P (mg/kg) =(a−b) ×V×DF×mcf /W

Where:

- a = concentration of phosphorus in the sample extract (mg/L)
- b = concentration of phosphorus in the blank (mg/L)
- V = volume of extractant used (mL)
- DF = dilution factor (total volume of diluted sample solution divided by aliquot volume)
- mcf = moisture correction factor (to convert to oven-dry basis)
- W = weight of soil sample (g)

3.2.6. Available potassium (Jackson 1973)

Five grams of an air-dried soil sample were transferred into a 150 ml conical flask, and 25 ml of the 1 N ammonium acetate solution was added to it. Then the solution was kept on a mechanical shaker for 5 min. The soil mix was filtered through Whatman No. 1 filter paper. The collected extract was then transferred into a beaker, and 5 ml of that extract was taken for dilution. Samples were analysed in a flame photometer at the wavelength of 766nm.

Calculation formula

Available Potassium (mg/kg) =R×V/W

Where:

- R = concentration of potassium in the extract (mg/L), obtained from flame photometer reading using a standard curve
- V = volume of ammonium acetate extractant used (mL)
- W = weight of soil sample (g)

3.2.7. Organic carbon (Walkley and Black 1934)

One gram of an air-dried soil sample was weighed and transferred into 500ml conical flasks, then 10 ml of 1 N potassium dichromate ($K_2Cr_2O_7$) solution and 20 ml of concentrated H_2SO_4 solution were added to it. The solution was kept for one minute in a mechanical shaker with an RPM range of 180-200. After 30 minutes, the sample was diluted with 200 ml of distilled water + 10 ml of phosphoric acid (H_3PO_4). Then 7-8 drops of diphenylamine indicator were added, after that titration with 0.5 N Ferrous Ammonium Sulphate (FAS) was done. Then the blank solution was prepared similarly. The end titration was indicated by a colour change from purple to green.

Calculation formula

Organic Carbon (%) =(V blank−V sample) ×0.003×100×1.3/W

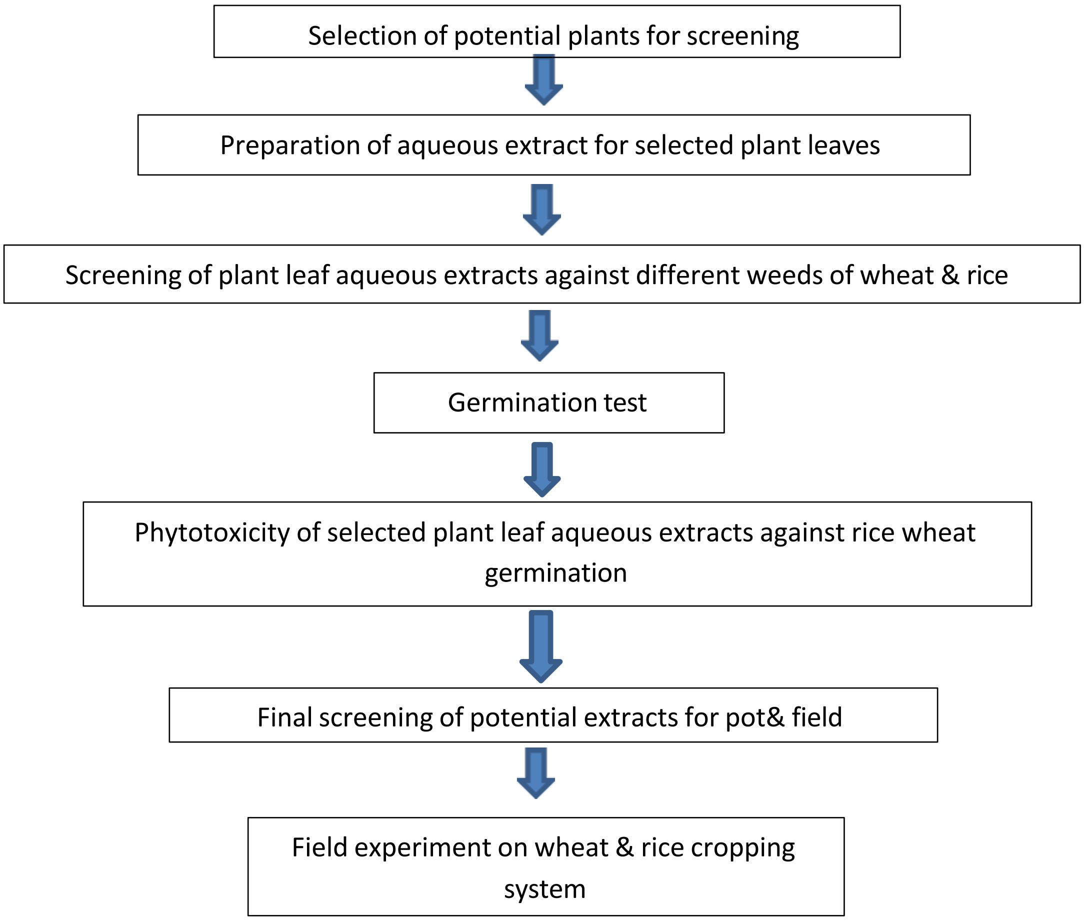
Where:

- V blank = volume of ferrous ammonium sulfate titrant used for the blank (mL)
- V sample = volume of ferrous ammonium sulfate titrant used for the sample (mL)
- W = weight of soil sample (g)

Table 3.2. Chemical properties of the soil

Particulars	Value	Method employed
Electrical conductivity ($dS\ m^{-1}$)	0.802	Conductivity meter method (Sparks 1996)
Soil pH	6.21	Glass electrode pH meter (Sparks 1996)
Organic carbon (%)	1.4	Walkley and Black rapid titration method
Available nitrogen ($kg\ ha^{-1}$)	367.8	Kjeldahl Method (Johann Kjeldahl, 1883)
Available Phosphorus ($kg\ ha^{-1}$)	101.4	0.5 N NaHCO3 extractable Olsen method (Olsen *et al.*, 1954)
Available Potassium ($kg\ ha^{-1}$)	23.7	1N Neutral ammonium acetate (Jackson 1973)

3.3. Screening of leaf extract formulations



3.3.1. Preparation of plant leaf extract for field use

The plant leaf extract was prepared using the following steps:

3.3.1.1 Collection of fresh leaves:

Begin by collecting fresh, healthy leaves from the desired plant. Ensure the leaves are green, disease-free, and not wilted, as the quality of the leaves directly affects the potency of the extract.

3.3.1.2. Cleaning the leaves:

Wash the collected leaves thoroughly using tap water. This step is crucial to remove any dust, dirt, or surface contaminants that might interfere with the quality of the extract.

3.3.1.3. Grinding the leaves:

After cleaning, transfer the leaves to a clean grinder or mortar and pestle. Add a sufficient amount of clean water to facilitate grinding. Grind the leaves thoroughly until a smooth, uniform paste is obtained.

3.3.1.4. Leaf extraction:

The ground leaf mixture was poured into a clean container, and a sieve or muslin cloth was used to strain the liquid. The mixture was gently pressed to extract as much juice as possible. The remaining plant residue was discarded.

3.3.1.5. Filtering the extract:

Leaf extract was filtered using Whatman filter paper to remove fine particulates and ensure a clear solution. This step enhances the purity and consistency of the extract.

3.3.1.6. Storage and field use:

The filtered plant leaf extract is now ready for immediate field application. For best results, use the extract soon after preparation to retain its active properties.

3.3.2. 1st phase of screening

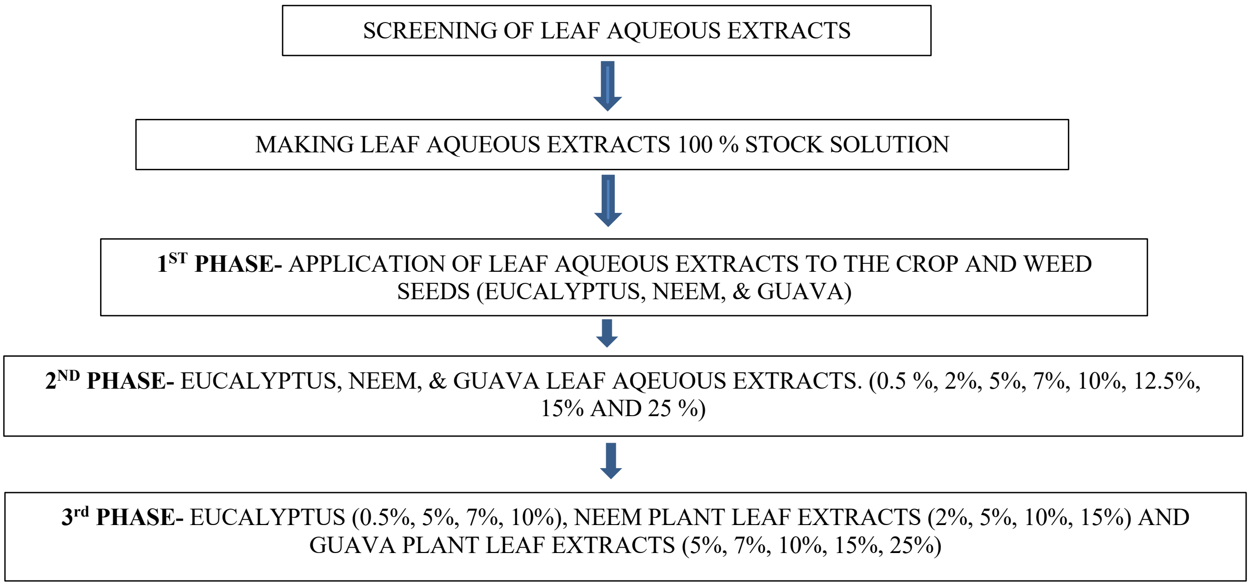
To evaluate the phytotoxicity of the leaf extracts on wheat and rice crops, as well as on weed seeds. An experiment was conducted under lab conditions. In the first phase of screening, the leaf extract formulations have been directly applied to the lab-grown wheat and rice seeds, followed by data analysis. The aqueous extract of each was directly applied to the seeds and seedlings to check its impact on the growth and germination of the seeds. A germination test was also performed in petri dishes with seeds in each petri dish and replications of each treatment. The effect of the plant extract on seeds and germinated seeds was observed in case of any antagonistic response to the crops as well. Eucalyptus, neem, and guava plant extracts have been directly applied to the growing crop seed of wheat-rice in lab conditions. The temperature of the germinator was maintained at 21–25°C, and the humidity was maintained around 70-80%.

3.3.3. 2nd phase of screening

In this phase of screening, the plant extract formulations have been checked in different concentrations to find the best-suited one. To find the effective ones from different concentrations of eucalyptus, neem, and guava leaf extracts. 0.5 %, 2%, 5%, 7%, 10%, 12.5%, 15% and 25 % plant extract has been applied to the grown weed seeds and crop seeds of wheat and rice.

3.3.4. 3rd phase of screening

In this phase of screening, best results from 2nd phase of screening have been taken for further study. The different concentrations of plant extracts that stood out in the 2nd phase have been screened to determine the best-suited concentration of plant leaf extracts for a field trial to control weeds. The plant leaf extracts of eucalyptus (0.5%, 5%, 7%, 10%), neem (2%, 5%, 10%, 15%), and guava (5%, 7%, 10%, 15%, 25%) were applied to the grown weed seeds.



3.4. Pot trial

For further confirmation of the efficacy of the aqueous extract, a pot trial was conducted with 60 pots. 60 pots with 20 treatments, 3 replications have also been done to check the treatment results more efficiently. The data was further analysed. Pots were maintained with the same variety as in the field.

3.5. Cropping site

At the experimental field of Lovely Professional University, Kapurthala found that the land is suitable for cultivation. Normally, a wheat-rice rotation of crop is grown by most of the farmers in this area.

3.6. Experimental details

The experimental design was randomized block design (RBD) with three replications and twenty treatments. Treatment details were properly presented in a table.

Year of experimentation	2021-2022 & 2022-2023
Number of treatments	20
Number of replications	3
Total number of plots	60
Plot size	5m x 3.5m
Irrigation channel	0.5 m
Date of sowing	Rice- Kharif Season Wheat- Rabi Season
Experimental design	Randomized Block Design (RBD)
Crop and variety	Wheat – PBW 550 Rice- PR 126
Estimated area needed	1050 m^2

Table 3.3 Treatment details for field trial

Treatments	Detail
T1	Absolute control
T2	Recommended dosage of herbicide*
T3	Eucalyptus leaf aqueous extract 5% + 50% herbicide*
T4	Eucalyptus leaf aqueous extract 5% + 75% herbicide*
T5	Eucalyptus leaf aqueous extract 10% + 50% herbicide*
T6	Eucalyptus leaf aqueous extract 10% + 75% herbicide*
T7	Neem leaf aqueous extract 10% + 50% herbicide*
T8	Neem leaf aqueous extract 10% + 75% herbicide*
T9	Neem leaf aqueous extract 15% + 50% herbicide*
T10	Neem leaf aqueous extract 15% + 75% herbicide*
T11	Guava leaf aqueous extract 25% + 50% herbicide*
T12	Guava leaf aqueous extract 25% + 75% herbicide*
T13	Guava leaf aqueous extract 30% + 50% herbicide*
T14	Guava leaf aqueous extract 30% + 75% herbicide*
T15	Eucalyptus leaf aqueous extract 5% sole
T16	Eucalyptus leaf aqueous extract 10% sole
T17	Neem leaf aqueous extract 10% sole
T18	Neem leaf aqueous extract 15% sole
T19	Guava leaf aqueous extract 25% sole
T20	Guava leaf aqueous extract 30% sole

***Herbicide used for;**

1. Rice crop - Bispyribac Sodium+Metsulfuron Methyl 10% + Chlorimuron Ethyl 10%)

2. Wheat crop - 2,4 D + Fenoxaprop

3.4 Design and layout

T1 3m 5m	T17	IRRIGATION	T13	T11	IRRIGATION	T16	T2
T4	T10		T5	T8		T9	T14
T6	T12		T17	T18		T3	T7
T2	T15		T20	T14		T19	T5
T11	T16		T12	T1		T13	T4
T19	T8		T3	T9		T6	T17
T5	T20		T15	T7		T18	T10
T13	T18		T19	T2		T12	T11
T3	T14		T6	T4		T8	T1
T17	T9		T16	T10		T15	T20

3.6. Details of crop raising

3.6.1. Agronomical operations done during the growing season

Field and bed preparations for both crops were done according to the seasons. The field was prepared for the rice crop in the first fortnight of July and for the wheat crop in the first fortnight of December**.** Pre-irrigations were given 2-3 days before sowing/transplanting, followed by the first fertilizer application at the time of field preparations. Fertilizer applications and irrigations were done accordingly at the critical stages. Harvesting of the crops was done accordingly after the maturity, that is 2nd fortnight of October for the rice crop and the 1st fortnight of April for the wheat crop.

3.7. Agronomic practices for rice crop

3.7.1. Field preparation & transplanting

Proper tillage operations and levelling of the field were done to improve the irrigation efficiency in the field. The field was ploughed properly, twice with a disc harrow to ensure the proper breakage of the hard surface, followed by planking to ensure better germination. A Randomized Block Design per plot size of 5 x 3.5 m has been selected for the field trial. Field preparation, puddling and transplanting of the crop were done by the first fortnight of July.

For the experimental trial rice variety, PR-126 was selected, and a small plot adjacent to the experimental area was selected for the sowing of rice seed. Afterwards, from a well-grown nursery of 21-day-old plants were uprooted for transplanting at the first fortnight of July in the experimental plot. Plants were transplanted at a distance of 20 × 20 cm, with a row-to- row distance of 20 × 20 cm**.** Depth of the transplanting was 3-4 cm. Transplanting 1-2 plants per hill for better yield was done in the field.

3.7.2. Fertilizer application

Fertilizer application was done as per the recommended doses for rice cultivation in the experimental field. 50% of the nitrogen and the full portion of phosphorus and potash were applied before transplanting as a basal dose, and the rest portion of nitrogen was applied in two fractions, first at the time of tillering and the second at the time of development of ears as top dressing.

3.7.3. Irrigation

Irrigation was given as per the recommendation of the crop. A pre-sowing irrigation was given to the whole field to ensure proper moisture at the time of sowing and germination. After that, the irrigation was given at tillering, ear emergence, flowering and grain filling stage.

3.7.4. Weed control and inter-cultural operation

Weed control measures were used as per the treatments. The proper recommended dosage of herbicide, along with the plant leaf aqueous extracts, was given to the field after 25-30 days of transplanting. Herbicide application and plant leaf extract application according to the treatments were applied in a gap of 1 day (24 hours).

3.7.5. Harvesting and threshing of the crop

Harvesting of the rice crop was done when the colour of the crop became green to yellow and dried. The harvested crops were kept in bundles for further work and sun drying. Threshing was done manually from the harvested crop. Winnowing was done after weighing the crop treatment-wise.

3.8 Observations

Observations were done at different time intervals of the life cycle of crops from a 1 m^2 area of each plot.

3.8.1. Plant height (cm)

Plant height for rice was taken at 30, 60, & 90 days after transplanting.

3.8.2. Chlorophyll index

The chlorophyll index of the rice crop was taken from each treatment using SPAD to understand the chlorophyll index of the crop. Chlorophyll indexing through SPAD has been taken at 30, 60, & 90 days after transplanting.

3.8.3. Tiller number per plant

The tiller numbers of rice crop were noted for each treatment by counting tillers per plant at 60, & 90 days after transplanting.

3.8.4. Effective tiller per plant

The effective tiller numbers of the rice crop were noted for each treatment by counting tillers per plant at 90 days after transplanting.

3.8.5. Panicle length (cm)

The length of the panicles of the rice crop was measured using a measuring scale at the harvesting stage.

3.8.6. Number of spikelets per panicle (SPP)

The number of spikelets per panicle of the rice crop has been counted for a better understanding of grains at the harvesting stage.

3.8.7. Grains per panicle

No. Of grains per panicle of rice crop was counted from the tagged plants of each plot, and then threshed separately, and the data was noted down.

3.8.8. Number of filled grains per panicle

The number of filled grains per panicle of rice crop has also been counted from each treated and tagged plant.

3.8.9. Test weight (g)

After threshing, 1,000 grains of rice were counted from each treatment plot and their weight was recorded.

3.8.10. Straw yield (q/ha)

The straw yield of the rice crop was calculated as the straw weight for the crop that has been harvested from a 1 m^2 area. In the later phase, the data was converted into quintal/ha.

3.8.11. Grain yield (q/ha)

Grain yield for rice crops was taken after harvesting the crop from the field. After threshing and winnowing, the grain weight was taken for every crop, which had been harvested from a 1 m^2 area. In the later phase, the data was converted into quintal/ha.

3.8.12. Harvest index (%)

Harvest index for rice crop was taken by dividing economic yield by total biological yield and multiplying by 100 to express it as a percentage. The formula was given by Donald and Hamblin (1958). The data were taken for both the wheat and rice crops.

$$\text{Harvest index (\%)} = \frac{\text{Grain yield}}{\text{Biological yield}} \times 100$$

3.8.13. Weed population

The number of weeds per square meter area of all the plots of rice crop has been taken at 30, 60, & 90 days after transplanting.

3.8.14. Weed intensity

Weed intensity of the rice crop has been taken before and after the application of treatments.

$$\text{Weed intensity-} \quad \frac{\text{weed population}}{\text{weed+ crop population}} \times 100$$

3.9. Agronomic practices for wheat crop

3.9.1. Field preparation

After the harvesting of rice, the same area was used for a wheat trial. The field was prepared after proper tillage operations. The field was ploughed twice with a disc harrow to ensure the proper breakage of the hard surface, and then followed by planking to ensure better germination. A randomized block design per plot size of 5 x 3.5 m has been selected for the field trial. Field preparation, puddling and transplanting of the crop were done by the first fortnight of December.

3.9.2. Sowing

Wheat variety PBW 550 was sown as per treatment in the first fortnight of December. Seeds were sown at a rate of 100-120 kg/ha. Row-to-row distance was 20 cm.

3.9.3. Fertilizer application

Fertilizer application was done as per the recommended dosage for wheat cultivation in the field. Fertilizer was applied around 50% of the portion of nitrogen and the full portion of phosphorus and potash prior to transplanting as basal dressing, and the rest portion of nitrogen was utilized in two portions, first at the time of tillering and the second at the time of development of spikes as top dressing.

3.9.4. Irrigation

Irrigation was given as per the recommended dose for the crop. A pre-sowing irrigation was given to the whole field to ensure proper moisture at the time of sowing and germination. After that, the irrigations were given at the critical stages of the crop.

3.9.5. Weed control and inter-culture operation

Weed control measures were taken into consideration as per the treatments. The proper recommended dosage of herbicide, as per the treatments along with the plant leaf extract, was given to the field after 25-30 days of sowing. Herbicide application and plant leaf extract application according to the treatments were applied in a gap of 1 day (24 hours).

3.9.6. Harvesting and threshing of the crop

Harvesting of the wheat crop was done when the colour of the wheat crop became green to yellow brown and dried. Threshing was done manually from the harvested crop, and properly kept by weighing them, and then winnowing was done. Observations were recorded.

3.10 Observations

Observations were recorded at different stages of the life cycle of crops from each plot.

3.10.1. Plant height (cm)

Plant height for wheat was taken from each treatment plot. Data was noted at 30, 60, 90 & 120 days after sowing.

3.10.2. Chlorophyll index

The chlorophyll index of the wheat crop was measured using SPAD to understand the chlorophyll index of the crop. The data was collected at 30, 60, 90 & 120 days after sowing.

3.10.3. Tiller numbers m^{-1} row length

The tiller numbers of the wheat crop were noted from each treatment plot by counting tillers per 1-metre row length.

3.10.4. Effective tiller numbers m^{-1} row length

The effective tiller numbers of the wheat crop were noted from each treatment plot by counting tillers per metre row length at 120 days after sowing.

3.10.5. Spike length (cm)

The length of the spikes of the wheat crop was measured and noted from each of the treatment plots. The spike length was taken by measuring the scale.

3.10.6. Number of spikelets per spike

The number of spikelets per spike of the wheat crop has been counted for a better understanding of grains. Spikelets have been counted in the harvesting stage.

3.10.7. Grains per spike

No. of grains per spike of the wheat crop was counted from each treatment plot and then threshed separately, and the data was noted down.

3.10.8. Number of filled grains per spike

The number of filled grains per spike of the wheat crop has also been counted from each treatment plot.

3.10.9. Test weight (g)

After threshing 1000 grains of wheat crop seeds were counted from each treatment plot, and the weight was recorded and expressed for the wheat crop.

3.10.10. Straw yield per plot (q/ha)

Straw yield for the wheat crop was taken after harvesting the crop from the field. After threshing and winnowing, the straw weight was taken for the crop that had been harvested from a 1 m^2 area. In the later phase, the data was converted into quintal/ha.

3.10.11. Grain yield (q/ha)

Grain yield for the wheat crop was taken after harvesting the crop from the field. After threshing and winnowing, the grain weight was taken for every treatment that had been harvested from a 1 m^2 area. In the later phase, the data was converted into quintal/ha.

3.10.12. Harvest Index (%)

Harvest index for wheat crop was taken by dividing economic yield by total biological yield and multiplying by 100 to express it as a percentage. The formula was given by Donald and Hamblin (1958).

$$\text{Harvest Index (\%)} = \frac{\text{Grain yield}}{\text{Biological yield}} \times 100$$

3.10.13. Weed Population

The number of weeds per square meter in the treated plots of wheat crop has been taken at 30, 60, 90 & 120 days after sowing.

3.10.14. Weed Intensity

The weed intensity of the wheat crop was measured before and after the application of treatments.

$$\text{Weed intensity-} \quad \frac{\text{Weed population}}{\text{Weed+ crop population}} \times 100$$

3.11. Economics

3.11.1. Cultivation cost (Rs ha $^{-1}$)

The cost of cultivation was calculated using the different agronomic practices performed on the farm and the inputs used in each particular treatment.

3.11.2. Gross returns (Rs ha $^{-1}$)

To find out the gross return, the prevailing market price was multiplied by the grain yield and the straw yield.

3.11.3. Net return (Rs ha $^{-1}$)

Net return was calculated using the formula: Net return = Gross return – Cost of cultivation.

3.11.4. Benefit: Cost ratio

BC ratio was calculated on the basis of additional cost incurred on applying different inputs & additional output (GY) obtained due to the application of these additional inputs.

$$\text{B:C ratio} = \frac{\text{Net returns (Rs per ha)}}{\text{Total cost of cultivation (Rs per ha)}}$$

3.11.5. Statistical analysis

The data were tabulated treatment-wise across three replications and analysed using the software packages R Studio and OPSTAT. Treatment means were compared using appropriate tests of significance at $P \leq 0.05$.

Chapter 4

RESULTS

4.1. Plant population of rice crop

Plant population is one of the factors that is directly related to the planting geometry, and it refers to the number of plants growing in a specific area. It is a very important aspect of crop management, influencing factors like nutrient uptake, competition and overall yield of the crop. The periodic plant population data **(Table 4.1.1)** were taken 30 days after transplanting (DAT).

In Rice, at 30 DAT (2021), plant population ranged from 9.6 to 12.3 per/m^2. The maximum plant population was recorded at T5, T6 (12.3 per/m^2) which were significantly higher than other treatments followed by T1, T2, T7, T10, T20 (12.0 per/m^2) and at par with T1, T2, T7, T9, T10, T12, T13, T15, T16, T17, & T20 while the minimum plant population was recorded at T4 (9.6 per/m^2) which was significantly lower than other treatments and at par with T3, T8, T11, T14, T17, T18 & T19. **Subsequently,** in the second trial at 30 DAT (2022), plant population ranged from 9.7 to 12.4 per/m^2. The maximum plant population was recorded at T5 (12.4 per/m^2) which was significantly higher than other treatments followed by T6 (12.3 per/m^2) and at par with T1, T2, T6, T7, T9, T10, T12, T13, T15, T16, & T20 while the minimum plant population was recorded at T4 & T18 (9.7 per/m^2) which was significantly lower than other treatments and at par with T3, T8, T11, T14, T17, T19. From the analysis of both years' average data of year **2021 & 2022,** it was observed that the maximum plant population was recorded at T5 (12.52 per/m^2), followed by T6 (12.32 per/m^2), while the minimum plant population was recorded at T4 (9.6 per/m^2). As per the results, there were no significant variations in plant population with different treatment applications. However, plant population may vary depending on the factors such as concentration of the treatments, application method & environmental conditions.

4.1.1. Effect of treatments on plant population of rice (per m^2) at 30 DAT during the years 2021 & 2022

TREATMENTS	2021	2022	AVG.
T1-Absolute control	12.0±0.57	11.5±0.33	11.65
T2-100% RDH*	12.0±0.57	12.1±0.57	12.00
T3-ELE 5% + 50% H*	10.6±0.66	10.5±0.66	10.68
T4-ELE 5% + 75% H*	9.6±0.33	9.7±0.33	9.68
T5-ELE 10% + 50% H*	12.3±0.88	12.4±0.88	12.52
T6-ELE 10% + 75% H*	12.3±0.88	12.0±0.88	12.32
T7-NLE 10% + 50% H*	12.0±0.57	11.0±0.57	11.50
T8-NLE 10% + 75% H*	10.0±0.57	9.5±0.57	9.75
T9-NLE 15% + 50% H*	11.3±0.33	11.6±0.33	11.52
T10-NLE 15% + 75% H*	12.0±0.57	12.0±0.57	12.00
T11-GLE 25% + 50% H*	10.3±0.33	10.4±0.33	10.32
T12-GLE 25% + 75% H*	11.3±0.33	11.3±0.33	11.32
T13-GLE 30% + 50% H*	11.3±0.66	11.1±0.66	11.32
T14-GLE 30% + 75% H*	10.3±0.33	10.5±0.33	10.32
T15-ELE 5%	11.3±0.33	11.2±0.33	11.32
T16-ELE 10%	11.3±0.33	11.4±0.33	11.32
T17-NLE 10%	11.0±1	11.1±1	11.00
T18-NLE 15%	10.0±0	9.7±0	9.85
T19-GLE 25%	10.6±0.33	10.6±0.33	10.68
T20- GLE 30%	12.0±0	12.1±0.33	12.15
CD (P≤0.05)	1.57	1.570	
SE(m ±)	0.549	0.547	

Note-RDH-recommended dose of herbicide, ELE- eucalyptus leaf extract, NLE- neem leaf extract, GLE- guava leaf extract, SE- standard error and CD (P≤0.05)- critical difference, *Bispyribac Sodium + Metsulfuron Methyl 10% + Chlorimuron Ethyl 10%.

4.2. Plant height (cm) of rice crop

Plant height is one of the most important characters on morphological characteristics of a crop. It provides a proper idea of predicting the growth rate and yield of the crop. The existing data showed that the plant height in rice gradually increased with the age of the crop. The periodic plant height data **(Table 4.2.1)** were taken 30, 60, & 90 days after transplanting (DAT). At 30 DAT (2021), plant height ranged from 19.7 cm to 34.3 cm. The maximum plant height was recorded at T16 (34.3 cm), which was significantly higher than other treatments, followed by T15 (33.4 cm) and at par with T3 & T20, while the minimum plant height was recorded at T4 (19.7 cm), which was significantly lower than other treatments and at par with T1, T5, T10, & T11. As compared to T4 (19.7 cm) with T_{16} (34.3 cm) showed a 74.11 % increase in plant height at 30 DAT. **Subsequently,** in the second trial at 30 DAT (2022), plant height ranged from 20.0 cm to 32.9 cm. The maximum plant height was recorded at T3 (32.9 cm) which was significantly higher than other treatments followed by T20 (32.1) and at par with T15, T16 & T20 while the minimum plant height was recorded at T4 (20.0 cm) which was significantly lower than other treatments and at par with T1, T2, T5, T6, T7, T8, T9, T10, T11, T12, T14, T17, T18, & T19. As compared to T4 (20.0 cm) with T3 (32.9 cm) showed a 64.5 % increase in plant height at 30 DAT. From the analysis of both years' average data of year **2021 & 2022,** it was observed that the maximum plant height was recorded at T3 (32.9 cm), followed by T16 (32.2 cm), while the minimum plant height was recorded at T4 (19.8 cm). As compared to T4 (19.8 cm) with T3 (32.9 cm) showed a 66.16 % increase in plant height at 30 DAS.

At 60 DAT 2021, plant height ranged from 33.1 cm to 44.5 cm. The maximum plant height was recorded at T10 (44.5 cm) which was significantly higher than other treatments followed by T20 (44.3 cm) and at par with T3, T4, T7, T9, T11, T15, T19 & T20 while the minimum plant height was recorded at T8 (33.1) which was significantly lower than other treatments and at par with T1, T5, T6, T12, T13, T14, T16, T17 & T18. As compared to T8 (33.1) with T_{10} (44.5 cm) showed a 34.44 % increase in plant height at 60 DAT. **Subsequently,** at 60 DAT (2022), plant height ranged from 31.0 cm to 43.1 cm. The maximum plant height was recorded at T9 (43.1 cm) which was significantly higher than other treatments followed by T10, T20 (42.7 cm) and at par with T3, T4, T7, T10, T11, T15 & T20 while the minimum plant height was recorded at T1 (31.00 cm) which was significantly lower than other treatments and at par with T2, T5, T6, T8, T12, T14, T16, T17, & T18. As compared to T1 (31.00 cm) with T9 (43.1 cm) showed a 39.03 % increase in plant height at 60 DAT. From the analysis of both years' average data of year **2021 & 2022,** it was observed that the maximum plant height was recorded at T10 (43.6 cm), followed by T4 (41.7 cm), while the minimum plant height was recorded at T8 & T16 (32.3 cm). As compared to T8 & T16 (32.3 cm) with T10 (43.6 cm) showed a 32.98 % increase in plant height at 60 DAS.

At 90 DAT 2021, plant height ranged from 44.0 cm to 58.1 cm. The maximum plant height was recorded at T20 (58.1 cm), which was significantly higher than other treatments followed by T15 (57.1 cm) and at par with T2, T4, T5, T6, T8, T11, T12, T13, T14, T15, T16, T17 & T18 while the minimum plant height was recorded at T1 (44.0 cm). As compared to T1 (44.0 cm) with T20 (58.1 cm) showed a 32.05 % increase in plant height at 90 DAT. **Subsequently,** at 90 DAT (2022), plant height ranged from 37.9 cm to 48.9 cm. The maximum plant height was recorded at T2 (48.9 cm) which was significantly higher than other treatments followed by T20 (47.5 cm) and at par with T1, T3, T4, T9 & T20 while the minimum plant height was recorded at T16 (37.9 cm) which was significantly lower than other treatments and at par with T5, T6, T7, T8, T10, T11, T12, T13, T14, T15, T17, T18 & T19. As compared to T16 (37.9 cm) with T2 (48.9 cm) showed a 29.02 % increase in plant height at 90 DAT. From the analysis of both years' average data of year **2021 & 2022, it** was observed that the maximum plant height was recorded at T2 & T20 (52.8 cm), followed by T4 (50.5 cm), while the minimum plant height was recorded at T1 (45.0 cm). As compared to T1 (45.0 cm) with T2 & T20 (52.8 cm) showed a 17.33 % increase in plant height at 90 DAS. Plant height was improved by the use of different leaf extracts, as they might have enhanced the nutrient adsorption rate of the crop. Likewise, the leaf extract of neem leaves is believed to enhance the plant growth of rice crop due to its natural compounds present in its extract, such as azadirachtin, which acts as a growth stimulant. It might have influenced the total absorption, root development, and overall plant growth, contributing to the plant height. Additionally, some studies have suggested that guava leaf extracts can help to improve the growth of the root area, which can lead to improved plant height in field conditions. The root-promoting aspects of guava leaf aqueous extract may be due to the presence of gibberellins, which are mainly plant hormones that regulate growth and development.

4.2.1. Effect of treatments on plant height of rice (cm) at 30, 60,90 DAT during the years 2021 & 2022

TREATMENTS	**30 DAT**			**60 DAT**			**90 DAT**		
	2021	**2022**	**AVG.**	**2021**	**2022**	**AVG.**	**2021**	**2022**	**AVG.**
T1-Absolute control	22.6 ±2.02	23.1±2.16	22.8	36.2±0.59	31.0±1.19	33.6	44.0 ±2.25	46.1±0.83	45.0
T2-100% RDH*	24.8 ±1.87	24.1±1.87	24.4	38.8±1.51	35.7±1.10	37.2	56.7±1.54	48.9±1.65	52.8
T3-ELE 5% + 50% H*	33.0 ±1.52	32.9±1.56	32.9	40.6±2.96	38.5±2.93	39.5	52.1±0.90	44.0±1.04	48.0
T4-ELE 5% + 75% H*	19.7 ±0.40	20.0±0.37	19.8	43.0±2.08	40.4±1.40	41.7	56.4±2.66	44.6±0.43	50.5
T5-ELE 10% + 50% H*	20.5 ±0.28	20.3±0.39	20.4	35.2±0.64	33.6±0.73	34.4	53.4±0.55	41.9±2.66	47.6
T6-ELE 10% + 75% H*	24.3 ±1.37	24.3±0.94	24.3	34.6±0.29	33.1±0.50	33.8	53.5±0.23	40.9±3.14	47.2
T7-NLE 10% + 50% H*	26.0 ±2.18	25.9±1.88	25.9	40.7±0.13	38.3±0.40	39.5	52.5±0.72	40.9±0.55	46.7
T8-NLE 10% + 75% H*	25.0 ±0.57	25.0±0.78	25.0	33.1±1.69	31.5±1.45	32.3	55.1±2.33	39.6±1.77	47.3
T9-NLE 15% + 50% H*	24.6 ±1.50	24.7±1.53	24.6	43.1±1.48	43.1±1.45	43.1	51.6±1.35	43.6±1.33	47.6
T10-NLE 15% + 75% H*	20.5 ±2.05	20.6±2.14	20.5	44.5±0.76	42.7±0.52	43.6	52.6±0.39	42.1±1.11	47.3
T11-GLE 25% + 50% H*	20.3 ±1.56	20.4±1.6	20.3	40.0±0.96	38.7±0.29	39.3	55.7±2.53	40.4±0.97	48.0
T12-GLE 25% + 75% H*	26.6 ±1.2	24.5±1.56	25.5	35.7±3.68	33.5±3.42	34.6	53.7±2.42	39.1±2.51	46.4
T13-GLE 30% + 50% H*	28.7 ±0.63	26.3 ±2.14	27.5	38.1±2.12	35.9±1.95	37.0	53.1±2.32	42.7±1.11	47.9
T14-GLE 30% + 75% H*	26.3 ±2.16	25.0 ±2.61	25.6	35.2±1.60	33.7±2.19	34.4	53.5±1.57	38.3±1.93	45.9
T15-ELE 5%	33.4 ±1.13	29.0 ±3.53	31.2	43.0±1.48	40.2±0.43	41.6	57.1±2.33	42.0±0.32	49.5
T16-ELE 10%	34.3 ±0.72	30.1 ±4.12	32.2	33.5±2.34	31.1±2.44	32.3	54.8±0.99	37.9±1.42	46.3
T17-NLE 10%	26.9 ±1.06	25.0 ±1.76	25.9	35.3±2.84	34.5±2.45	34.9	53.8±2.89	38.5±3.19	46.1
T18-NLE 15%	24.0 ±1.15	23.2 0±1.54	23.6	35.0±0.57	32.6±1.23	33.8	52.9±0.56	41.4±3.85	47.1
T19-GLE 25%	24.3 ±1.01	23.0 ±0.48	23.6	40.6±0.88	38.0±0.15	39.3	51.8±2.90	40.7±0.68	46.2
T20- GLE 30%	33.0 ±1.52	32.1 ±5.07	32.5	44.3±0.88	42.7±0.84	43.5	58.1 ±1.99	47.5±1.14	52.8
CD (P≤0.05)	4.05	6.09		5.13	4.81		5.04	5.49	
SE(m ±)	1.407	2.120		1.788	1.674		1.754	1.91	

Note-RDH-recommended dose of herbicide, ELE- eucalyptus leaf extract, NLE- neem leaf extract, GLE- guava leaf extract, SE-standard error and CD (P≤0.05)- critical difference, *Bispyribac Sodium + Metsulfuron Methyl 10% + Chlorimuron Ethyl 10%.

4.3. Chlorophyll index of rice crop

The periodic chlorophyll index data **(Table 4.3.1)** were taken 30, 60, & 90 days after transplanting (DAT). At 30 DAT 2021, the chlorophyll index ranged from 23.1 to 36.7. The maximum chlorophyll index was recorded at T2 (36.7), which was significantly higher than other treatments, followed by T10 (35.5) and at par with T4, T8, T10, T14 & T19, while the minimum chlorophyll index was recorded at T16 (23.1), which was significantly lower than other treatments and at par with T17. As compared to T16 (23.1) with T2 (36.7) showed a 58.87 % increase in chlorophyll index at 30 DAT. **Subsequently,** in the second trial at 30 DAT (2022), the chlorophyll index ranged from 23.0 to 36.4. The maximum chlorophyll index was recorded at T2 (36.4), which was significantly higher than other treatments, followed by T10 (35.5) and at par with T1, T4, T8, T10, T14, & T19, while the minimum chlorophyll index was recorded at T16 (23.0), which was significantly lower than other treatments and at par with T17. As compared to T16 (23.0) with T2 (36.4) showed a 58.26 % increase in chlorophyll index at 30 DAT. From the analysis of both years' average data of year **2021 & 2022,** it was observed that the maximum chlorophyll index was recorded at T2 (36.5), followed by T10 (35.5), while the minimum chlorophyll index was recorded at T16 (23.0). As compared to T16 (23.0) with T2 (36.5) showed a 58.69 % increase in chlorophyll index at 30 DAT.

At 60 DAT 2021, the chlorophyll index ranged from 23.0 to 36.0. The maximum chlorophyll index was recorded at T2 (36.0) which was significantly higher than other treatments followed by T10 (35.0) and at par with T3, T4, T8, T10, T14 & T19 while the minimum chlorophyll index was recorded at T17 (23.0) which was significantly lower than other treatments and at par with T12, T16, T18, & T20. As compared to T17 (23.0) with T2 (36.0) showed a 56.52 % increase in chlorophyll index at 60 DAT. **Subsequently,** at 60 DAT (2022), the chlorophyll index ranged from 23.4 to 36.0. The maximum chlorophyll index was recorded at T2 (36.0), which was significantly higher than other treatments, followed by T10 (35.7) and at par with T3, T4, T8, T10, & T14 while the minimum chlorophyll index was recorded at T17 (23.4) which was significantly lower than other treatments and at par withT12, T15, T16 & T20. As compared to 17 (23.4) with T2 (36.0) showed a 53.84 % increase in chlorophyll index at 60 DAT. From the analysis of both years' average data of year **2021 & 2022,** it was observed that the maximum chlorophyll index was recorded at T2 (36.0), followed by T10 (35.7), while the minimum chlorophyll index was recorded at T17 (23.0). As compared to T17 (23.0) with T2 (36.0) showed a 56.52 % increase in chlorophyll index at 60 DAT.

At 90 DAT, the chlorophyll index ranged from 11.0 to 19.2. The maximum chlorophyll index was recorded at T5 (19.5), which was significantly higher than other treatments, followed by T14 (19.2) and at par with T2, & T14, while the minimum chlorophyll index was recorded at T17 (11.0). As compared to T17 (11.0) with T5 (19.2) showed a 74.54 % increase in chlorophyll index at 90 DAT. **Subsequently,** at 90 DAT (2022), the chlorophyll index ranged from 11.2 to 19.7. The maximum chlorophyll index was recorded at T5 (19.7), which was significantly higher than other treatments, followed by T10 (19.2) and at par with T10, & T14, while the minimum chlorophyll index was recorded at T17 (11.2). As compared to T17 (11.2) with T5 (19.7) showed a 75.89 % increase in chlorophyll index at 90 DAT. From the analysis of both years' average data of year **2021 & 2022,** it was observed that the maximum chlorophyll index was recorded at T5 (19.6), followed by T14 (19.3), while the minimum chlorophyll index was recorded at T17 (11.1). As compared to T17 (11.2) with T5 (19.6) showed a 76.57 % increase in chlorophyll index at 90 DAT. As per the result, T2- 100% RDH*, T_5-ELE 10% + 50% H* & T_{10}-NLE 15% + 75% H* showed best in chlorophyll index of rice crop. Recommended dosage of herbicide minimizes the weed growth in field conditions, which subsequently improves the chlorophyll synthesis by improving crop health. Other than that, eucalyptus leaf aqueous extract & neem leaf aqueous extract improve the nutrient uptake, control the disease and pest, which can lead to preventing the chlorophyll damage by protecting the tissues, which leads to improved the higher chlorophyll synthesis. As a result, it improves the chlorophyll index.

4.3.1. Effect of treatments on chlorophyll index of rice at 30, 60 DAT during the years 2021 & 2022

TREATMENTS	30 DAT			60 DAT			90 DAT		
	2021	2022	AVG.	2021	2022	AVG.	2021	2022	AVG.
T1-Absolute control	32.0±0.33	32.8±0.78	32.4	30.4±0.58	30.6±0.57	30.5	16.2±0.71	16.9±0.41	16.5
T2-100% RDH*	36.7±0.56	36.4±0.60	36.5	36.0±0.58	36.0±1.07	36.0	18.9±0.86	18.7±0.62	18.8
T3-ELE 5% + 50% H*	30.8±1.60	30.9±2.08	30.8	32.1±1.58	32.4±2.18	32.2	16.6±0.41	16.3±0.59	16.4
T4-ELE 5% + 75% H*	35.1±0.63	35.1±0.66	35.1	34.6±1.92	34.5±1.76	34.5	17.0±0.56	16.8±0.35	16.9
T5-ELE 10% + 50% H*	31.2±3.96	31.4±4.33	31.3	27.8±2.31	27.8±2.43	27.8	19.5±0.59	19.7±0.65	19.6
T6-ELE 10% + 75% H*	30.7±1.07	30.7±1.60	30.7	29.6±1.13	29.3±1.03	29.4	14.4±0.65	13.8±0.65	14.1
T7-NLE 10% + 50% H*	30.7±0.44	30.3±0.06	30.5	31.4±1.61	30.9±1.35	31.1	15.0±0.08	14.9±0.74	14.9
T8-NLE 10% + 75% H*	33.2±1.37	33.7±1.35	33.4	32.3±1.37	32.9±1.82	32.6	15.8±0.26	15.6±0.03	15.7
T9-NLE 15% + 50% H*	29.3±1.49	29.1±0.60	29.2	27.9±1.70	27.7±1.96	27.8	14.2±0.41	13.8±0.17	14.0
T10-NLE 15% + 75% H*	35.5±2.31	35.5±2.22	35.5	35.8±2.39	35.7±1.86	35.7	18.7±0.95	19.2±0.89	18.9
T11-GLE 25% + 50% H*	31.0±0.33	31.8±0.55	31.4	30.9±0.17	31.0±0.60	30.9	15.7±0.29	15.9±0.00	15.8
T12-GLE 25% + 75% H*	27.6±1.03	27.8±1.31	27.7	25.6±1.76	25.5±2.02	25.5	14.7±0.20	14.8±0.24	14.6
T13-GLE 30% + 50% H*	30.0±0.58	30.5±0.46	30.2	28.0±1.15	27.7±0.83	27.8	14.5±0.05	14.5±0.29	14.5
T14-GLE 30% + 75% H*	33.5±2.48	33.3±2.32	33.4	32.9±1.53	32.6±1.05	32.7	19.2±0.41	19.3±0.08	19.2
T15-ELE 5%	28.8±1.20	28.8±0.98	28.8	27.6±1.94	27.4±2.07	27.5	14.7±0.12	14.6±0.17	14.6
T16-ELE 10%	23.1±2.64	23.0±2.25	23.0	23.7±1.93	23.8±1.86	23.7	14.2±0.68	14.3±0.12	14.2
T17-NLE 10%	23.1±0.60	23.1±0.16	23.1	23.0±1.52	23.0±1.41	23.0	11.0±0.26	11.2±0.00	11.1
T18-NLE 15%	29.3±0.44	29.4±0.52	29.3	27.3±1.85	27.8±1.63	27.5	15.0±0.47	14.6±0.50	14.8
T19-GLE 25%	32.6±0.89	31.8±1.10	32.2	31.5±0.96	31.3±1.03	31.4	15.5±0.32	15.3±0.20	15.4
T20- GLE 30%	29.2±1.68	30.0±1.84	29.6	27.1±1.44	27.2±0.86	27.1	15.1±0.62	15.7±0.12	15.4
CD (P≤0.05)	4.37	4.59		4.55	4.57		1.476	1.25	
SE(m ±)	1.520	1.600		1.586	1.592		0.514	0.438	

Note-RDH-recommended dose of herbicide, ELE- eucalyptus leaf extract, NLE- neem leaf extract, GLE- guava leaf extract, SE- standard error and CD (P≤0.05)- critical difference, *Bispyribac Sodium + Metsulfuron Methyl 10% + Chlorimuron Ethyl 10%.

4.4. Tiller number of rice crop

Tiller number is one of the most important characteristics of the yield attribute of a crop. It provides a proper idea of predicting the growth rate and yield of the crop. It is an important factor for assessing any crop's yield potential and overall plant health. The existing data showed that the tiller numbers in rice were different from treatment to treatment, without being affected by the average proven data. The periodic tiller number data **(Table 4.5.1)** was taken 60, 90 and 120 days after transplanting (DAT). At 60 DAT 2021, tiller number ranged from 5.6 to 11.6. The maximum tiller number was recorded at T12 (11.6 per plant) which was significantly higher than other treatments followed by T10 (11.3 per plant) and at par with T2, T4, T7, T10, & T14, while the minimum tiller number was recorded at T6, T15 (5.6 per plant) which was significantly lower than other treatments and at par with T1, T3, T8, T11, T16, & T20. **Subsequently,** in the second trial at 60 DAT (2022), tiller number ranged from 6.0 to 10.0. The maximum tiller number was recorded at T2, T10 (10.0 per plant) which was significantly higher than other treatments followed by T4 (9.7 per plant) and at par with T4, T5, T7, T9, T12, T13, T14, T17 & T18 while the minimum tiller number was recorded at T6, T8 & T15 (6.0 per plant) which was significantly lower than other treatments and at par with T1, T3, T16, T19, & T20. From the analysis of both years' average data of year **2021 & 2022,** it was observed that the maximum tiller number was recorded at T2 (10.5 per plant), followed by T12 (10.4 per plant) while the minimum tiller number was recorded at T6 & T15 (5.8 per plant). As compared to T6 & T15 (5.8 per plant) with T2 (10.5 per plant) showed an 81.03 % increase in tiller number at 60 DAS.

At 90 DAT 2021, tiller number ranged from 5.6 to 11.6. The maximum tiller number was recorded at T12 (11.6 per plant) which was significantly higher than other treatments followed by T10 (11.3 per plant) and at par with T2, T4, T7, T10, &T14, while the minimum tiller number was recorded at T6, T15 (5.6 per plant) which was significantly lower than other treatments and at par with T1, T3, T8, T11, T16, & T20. **Subsequently,** at 90 DAT (2022), tiller number ranged from 6.0 to 10.0. The maximum tiller number was recorded at T2, T10 (10.0 per plant) which was significantly higher than other treatments followed by T4 (9.7 per plant) and at par with T4, T5, T7, T9, T12, T13, T14, T17 & T18 while the minimum tiller number was recorded at T6, T8 & T15 (6.0 per plant) which was significantly lower than other treatments and at par with T1, T3, T16, T19, & T20. From the analysis of both years' average data of year **2021 & 2022,** it was observed that the maximum tiller number was recorded at T2 (10.5 per plant), followed by T12 (10.4 per plant), while the minimum tiller number was recorded at T6 & T15 (5.8 per plant). As compared to T6 & T15 (5.8 per plant), T2 (10.5 per/m^2) showed an 81.03 % increase in tiller number at 90 DAS.

As per the result, T2-100% RDH* & T12-GLE 25% + 75%, H* had the maximum number of tillers in field condition in different stages of the rice crop. The effect of the guava leaf aqueous extract on the number of tillers can vary based on different factors, including concentration, application method and different environmental conditions. However, there is very limited data for the same. Nevertheless, some potential reasons for the same would-be nutrient availability, as guava leaf aqueous extract may contain compounds (Nitrogen, Manganese) which enhance the nutrient uptake in rice crop. Improved nutrient uptake stimulates tillering, ultimately leading to an increase in tiller number.

4.5. Effective tiller number of rice crop

The effective tiller number does have a pivotal role in the determination of the yield attributes of a crop. Effective tillers are the tillers that contribute significantly to the yield of a crop or to the grain production. It's normally excluding nonproductive or sterile tillers. The existing data **(Table 4.5.1)** showed that the effective tiller number gradually showed improvement and stable data after 90 DAT. At 90 DAT 2021, the effective tiller number ranged from 3.3 to 8.3 per plant. The maximum effective tiller number was recorded at T2 (8.3 per plant), which was significantly higher than other treatments, followed by T9 (6.6), while the minimum effective tiller number was recorded at T16 (3.3 per plant) which was significantly lower than other treatments and at par with T1, T3, T5, T8, T15, T17 & T20. **Subsequently,** in the second trial (2022), effective tiller number ranged from 4.7 to 8.0 per plant. The maximum effective tiller number was recorded at T2 (8.0 per plant) which was significantly higher than other treatments followed by T6 (7.7 per plant) and at par with T6 & T9 while the minimum effective tiller number was recorded at T20 (4.7 per plant) which was significantly lower than other treatments and at par with T1, T3, T8, T15, T18 & T19. From the analysis of both years' average data of year **2021 & 2022,** it was observed that the maximum effective tiller number was recorded at T2 (8.2 per plant), followed by T9 (6.8 per plant), while the minimum effective tiller number was recorded at T20 (4.2 per plant).

4.5.1. Effect of treatments on tiller number of rice (per plant) at 60, 90 DAT during the years 2021 & 2022

TREATMENTS	TILLER NUMBER			TILLER NUMBER			EFFECTIVE TILLERS		
	60 DAT			90 DAT			90 DAT		
	2021	2022	AVG.	2021	2022	AVG.	2021	2022	AVG.
T1-Absolute control	7.6±0.88	6.7±0.66	7.1	7.6±0.88	6.7±0.66	7.1	4.0±0.57	5.3±0.33	4.7
T2-100% RDH*	11.0±0.57	10.0±0.57	10.5	11.0±0.57	10.0±0.57	10.5	8.3±0.33	8.0±0.00	8.2
T3-ELE 5% + 50% H*	7.3±0.88	6.7±0.88	7.0	7.3±0.88	6.7±0.88	7.0	4.6±0.66	5.7±0.33	5.2
T4-ELE 5% + 75% H*	11.0±0.57	9.7±0.33	10.3	11.0±0.57	9.7±0.33	10.3	6.0±0.57	6.7±0.33	6.4
T5-ELE 10% + 50% H*	8.3±0.66	8.3±0.88	8.3	8.3±0.66	8.3±0.88	8.3	4.6±0.33	6.3±0.33	5.5
T6-ELE 10% + 75% H*	5.6±0.33	6.0±0.57	5.8	5.6±0.33	6.0±0.57	5.8	5.6±0.33	7.7±0.33	6.7
T7-NLE 10% + 50% H*	9.6±1.85	8.7±0.88	9.1	9.6±1.85	8.7±0.88	9.1	6.3±0.57	6.3±0.33	6.3
T8-NLE 10% + 75% H*	6.3±0.88	6.0±0.57	6.1	6.3±0.88	6.0±0.57	6.1	4.6±0.33	5.7±0.33	5.2
T9-NLE 15% + 50% H*	9.3±1.45	8.3±0.88	8.8	9.3±1.45	8.3±0.88	8.8	6.6±0.33	7.0±0.00	6.8
T10-NLE 15% + 75% H*	11.3±0.88	10.0±0.57	10.6	11.3±0.88	10.0±0.57	10.6	6.3±0.33	6.0±0.00	6.2
T11-GLE 25% + 50% H*	7.0±0.57	8.0±0.57	7.5	7.0±0.57	8.0±0.57	7.5	5.6±0.33	6.7±0.33	6.2
T12-GLE 25% + 75% H*	11.6±0.33	9.3±0.33	10.4	11.6±0.33	9.3±0.33	10.4	6.0±0.00	6.7±0.33	6.4
T13-GLE 30% + 50% H*	8.0±0.57	9.0±0.57	8.5	8.0±0.57	9.0±0.57	8.5	5.0±0.57	6.3±0.33	5.7
T14-GLE 30% + 75% H*	9.6±1.85	8.7±0.88	9.1	9.6±1.85	8.7±0.88	9.1	5.6±0.66	6.3±0.33	6.0
T15-ELE 5%	5.6±0.33	6.0±0	5.8	5.6±0.33	6.0±0	5.8	4.3±0.88	5.3±0.33	4.8
T16-ELE 10%	7.6±0.33	7.7±0.33	7.6	7.6±0.33	7.7±0.33	7.6	3.3±0.33	6.3±0.33	4.8
T17-NLE 10%	9.3±0.33	9.0±0	9.1	9.3±0.33	9.0±0	9.1	4.3±0.33	6.0±0.57	5.2
T18-NLE 15%	9.0±0.57	8.7±1.20	8.8	9.0±0.57	8.7±1.20	8.8	6.0±0.57	5.0±0.57	5.5
T19-GLE 25%	8.0±0.57	7.0±1.52	7.5	8.0±0.57	7.0±1.52	7.5	5.0±1.15	5.0±0.00	5.0
T20- GLE 30%	7.6±0.33	7.3±0.88	7.4	7.6±0.33	7.3±0.88	7.4	3.6±0.33	4.7±0.66	4.2
CD (P≤0.05)	2.32	1.95		2.32	1.95		1.56	1.00	
SE(m ±)	0.808	0.679		0.808	0.679		0.543	0.351	

Note-RDH-recommended dose of herbicide, ELE- eucalyptus leaf extract, NLE- neem leaf extract, GLE- guava leaf extract, SE- standard error and CD (P≤0.05)- critical difference, *Bispyribac Sodium + Metsulfuron Methyl 10% + Chlorimuron Ethyl 10%.

As compared to T20 (4.2 per plant) with T2 (8.2 per plant) showed a 95.23 % increase in effective tiller number at 90 DAT. As per the result, T2- 100% H* showed the best result in the number of effective tillers per plant. 100% of recommended herbicide application can inhibit the growth of weeds in the field. By reducing the weed competition in the field, the treatment allows the rice plants to allocate and absorb more resources towards tillers. The recommended dose of herbicide reduces the competition for essential resources like water, nutrients & light. As a result, tiller formation gets improved, and the effective tiller number is improved.

4.6. *Echinochloa crus-galli* population of rice crop

The periodic *Echinochloa crus-galli* population data **(Table 4.6.1)** were taken at 30, 60, & 90 days after transplanting (DAT). In Rice, at 30 DAT 2021, *Echinochloa crus-galli* population ranged from 40.6 to 76.0 per/m^2. The maximum population of the weed was recorded at T1 (76.0 per/m^2), which was significantly higher than other treatments, followed by T20 (65.0 per/m^2), while the minimum population was recorded at T14 (40.6 per/m^2). As compared to T1 (76.0 per/m^2) with T14 (40.6 per/m^2) showed a 46.57 % decrease in weed population at 30 DAT. **Subsequently,** in the second trial at 30 DAT (2022), weed population ranged from 15.7 to 71.0 per/m^2. The maximum population was recorded at T1 (71.0 per/m^2), which was significantly higher than other treatments, followed by T6 (69.0 per/m^2) and at par with T4, T6 & T16, while the minimum population was recorded at T9 (15.7 per/m^2). As compared to T9 (71.0 per/m^2) with (15.7 per/m^2), T1 showed a 77.88 % decrease in weed population at 30 DAT. From the analysis of both years' average data of year **2021 & 2022**, it was observed that the maximum population of *Echinochloa crus-galli* was in T1 (68.6 per/m^2), followed by T6 (65.5 per/m^2), while the minimum was recorded at T9 (29.8 per/m^2). As compared to T9 (68.6 per/m^2) with T9 (29.8 per/m^2) showed a 56.55 % decrease in *Echinochloa crus-galli* population at 30 DAS.

At 60 DAT 2021, *Echinochloa crus-galli* population ranged from 6.6 to 67.3 per/m^2. The maximum population was recorded at T1 (67.3 per/m^2), which was significantly higher than other treatments, followed by T5 (37.0 per/m^2), while the minimum population was recorded at T2 (6.6 per/m^2), which was significantly lower than other treatments and at par with T4, T6, T10, T12, & T14. As compared to T1 (67.3 per/m^2) with T2 (6.6 per/m^2) showed a 90.19 % decrease in *Echinochloa crus-galli* population at 60 DAT. **Subsequently,** at 60 DAT (2022), *Echinochloa crus-galli* population ranged from 7.3 to 71.7 per/m^2 the maximum population was recorded at T1 (71.7 per/m^2) which was significantly higher than other treatments followed by T5 (36.7 per/m^2) while the minimum population was recorded at T10 (7.3 per/m^2) which was significantly lower than other treatments and at par with T2. As compared to T1 (71.7 per/m^2) with T10 (7.3 per/m^2) showed a 89.81% decrease in *Echinochloa crus-galli* population at 60 DAT. From the analysis of both years' average data of year **2021 & 2022,** the maximum population of *Echinochloa crus-galli* was recorded at T1 (69.5 per/m^2), followed by T18 (29.3 per/m^2), while the minimum population was recorded at T2 (7.3 per/m^2). As compared to T1 (69.5 per/m^2) with T2 (7.3 per/m^2) showed a 89.49 % decrease in *Echinochloa crus-galli* population at 60 DAS.

At 90 DAT 2021, *Echinochloa crus-galli* population ranged from 2.6 to 66.6 per/m^2. The maximum population was recorded at T1 (66.6 per/m^2) which was significantly higher than other treatments followed by T20 (21.6 per/m^2) while the minimum population was recorded at T2 (2.6 per/m^2) which was significantly lower than other treatments and at par with T4, T6, T9, T10, T11, T12 T14, T17 & T18. As compared to T1 (66.6 per/m^2) with T2 (2.6 per/m^2) showed a 96.09 % decrease in *Echinochloa crus-galli* population at 90 DAT. **Subsequently,** at 90 DAT (2022), *Echinochloa crus-galli* population ranged from 3.7 to 72.5 per/m^2. The maximum population was recorded at T1 (72.5 per/m^2), which was significantly higher than other treatments, followed by T8 (24.3 per/m^2), while the minimum population was recorded at T2 (3.7 per/m^2), which was significantly lower than other treatments and at par with T2, T4, T14 & T17. As compared to T1 (72.5 per/m^2) with T2 (3.7 per/m^2) showed a 94.89 % decrease in *Echinochloa crus-galli* population at 90 DAT. From the analysis of both years' average data of year **2021 & 2022,** it was observed that the maximum population of *Echinochloa crus-galli* was recorded in T1 (69.5 per/m^2), followed by T8 (22.3 per/m^2), while the minimum was in T2 (3.1 per/m^2). As compared to T1 (69.5 per/m^2) with T2 (7.3 per/m^2) showed a 89.49 % decrease in *Echinochloa crus-galli* population at 90 DAS.

4.6.1. Effect of treatments on *Echinochloa crusgalli* population of rice (per m^2) at 30, 60, & 90 DAT during the years 2021 & 2022

TREATMENTS	30 DAT			60 DAT			90 DAT		
	2021	2022	AVG.	2021	2022	AVG.	2021	2022	AVG.
T1-Absolute control	76.0±0.57	71.0±1	68.6	67.3±1.45	71.7±0.88	69.5	66.6±1.20	72.5±1.07	69.5
T2-100% RDH*	54.0±13.45	68.3±1.76	61.1	6.6±1.20	8.0±0.57	7.3	2.6±0.66	3.7±23.00	3.1
T3-ELE 5% + 50% H*	53.0±16.46	29.7±0.33	41.3	31.6±9.83	26.0±2.08	28.8	20.0±10.50	22.7±5.71	21.3
T4-ELE 5% + 75% H*	49.0±15.37	70.3±1.20	59.6	11.0±2.64	12.7±1.20	11.8	5.6±2.33	6.0±0.39	5.8
T5-ELE 10% + 50% H*	61.6±2.33	66.7±1.20	64.1	37.0±3.21	36.7±1.20	36.8	18.3±4.66	18.7±0.57	18.5
T6-ELE 10% + 75% H*	62.0±1.52	69.0±0.57	65.5	14.3±1.76	15.0±0.57	14.6	6.6±1.20	8.0±4.70	7.3
T7-NLE 10% + 50% H*	49.0±6.65	68.3±0.88	58.6	22.6±4.25	22.3±0.88	22.4	18.6±1.85	20.3±3.53	19.4
T8-NLE 10% + 75% H*	49.3±9.13	59.7±1.45	54.5	24.6±3.93	23.7±0.66	24.1	20.3±2.90	24.3±0.33	22.3
T9-NLE 15% + 50% H*	44.0±3.05	15.7±0.33	29.8	21.0±3.46	21.0±1.00	21.0	7.0±1.15	10.3±1.20	8.6
T10-NLE 15% + 75% H*	51.0±6.42	47.3±0.66	49.1	8.3±1.76	7.3±0.88	7.8	5.3±2.40	7.0±1.37	6.1
T11-GLE 25% + 50% H*	47.3±7.88	63.3±0.33	55.3	24.0±2.08	24.0±1.52	24.0	12.0±2.51	13.3±5.07	12.6
T12-GLE 25% + 75% H*	64.6±0.66	58.3±0.88	61.4	18.0±0.57	16.7±1.20	17.3	11.0±0.57	9.3±1.44	10.1
T13-GLE 30% + 50% H*	51.6±11.85	38.0±0.57	44.8	24.0±5.13	27.3±0.66	25.6	20.3±5.78	20.3±0.57	20.3
T14-GLE 30% + 75% H*	40.6±13.29	26.7±0.66	33.6	11.3±4.33	12.7±1.45	12.0	4.3±1.20	6.3±2.02	5.3
T15-ELE 5%	48.3±18.98	50.7±0.88	49.5	28.6±5.23	27.7±2.84	28.1	18.6±3.93	16.3±1.46	17.4
T16-ELE 10%	50.0±7.57	70.0±0.57	60.0	25.0±2.30	25.3±0.88	25.1	16.6±2.08	16.7±0.11	16.6
T17-NLE 10%	50.6±16.41	33.7±0.33	42.1	24.3±7.05	21.7±1.76	23.0	6.0±2.30	6.3±0.66	6.1
T18-NLE 15%	55.3±10.13	43.0±0.57	49.1	30.3±5.81	28.3±1.85	29.3	10.3±0.88	10.7±4.66	10.5
T19-GLE 25%	55.0±9.29	60.0±1.52	57.5	25.3±1.20	26.3±1.20	25.8	12.6±0.88	12.7±3.66	12.6
T20- GLE 30%	65.0±4.35	47.0±0.57	56.0	27.6±7.12	30.3±1.54	28.9	21.6±1.20	22.3±15.15	21.9
CD ($P \leq 0.05$)	NA	2.26		5.55	3.96		4.57	3.01	
SE(m ±)	10.47	0.789		1.93	1.378		1.59	1.077	

Note-RDH-recommended dose of herbicide, ELE- eucalyptus leaf extract, NLE- neem leaf extract, GLE- guava leaf extract, SE-standard error and CD ($P \leq 0.05$)- critical difference. *Bispyribac Sodium + Metsulfuron Methyl 10% + Chlorimuron Ethyl 10%.

4.7. Weed intensity of *Echinochloa crus-galli in* rice crop

The periodic *weed intensity of Echinochloa crus-galli* data **(Table 4.7.1)** was taken at 30, 60, & 90 days after transplanting (DAT). In Rice, at 30 DAT 2021, the weed intensity *of Echinochloa crus-galli* ranged from 73.4 % to 86.6 %. The maximum weed intensity *of Echinochloa crus-galli* was recorded at T1 (86.6 %), which was significantly higher than other treatments, followed by T12 (85.0 %), while the minimum weed intensity *of Echinochloa crus-galli* was recorded at T15 (73.4 %). As compared to T1 (86.6 %) with T15 (73.4 %) showed a 15.24 % decrease in weed intensity *of Echinochloa crus-galli at* 30 DAT. **Subsequently,** in the second trial (2022), at 30 DAT weed intensity *of Echinochloa crus-galli* ranged from 57.3 % to 87.9 %. The maximum weed intensity *of Echinochloa crus-galli* was recorded at T4 (87.9 %), which was significantly higher than other treatments, followed by T1 (86.24 %) and at par with T1, T11 & T16, while the minimum weed intensity *of Echinochloa crus-galli* was recorded at T9 (57.3 %). As compared to T4 (87.9 %) with T9 (57.3 %) showed a 34.81 % decrease in weed intensity *of Echinochloa crus-galli* at 30 DAT. From the analysis of both years' average data of year **2021 & 2022,** it was observed that the maximum weed intensity *of Echinochloa crus-galli* was recorded at T1 (86.4 per/m^2), followed by T12 (84.4 per/m^2), while the minimum weed intensity *of Echinochloa crus-galli* was recorded at T3 (77.1 per/m^2). As compared to T1 (86.4 per/m^2) with T3 (77.1 per/m^2) showed a 10.76 % decrease in weed intensity *of Echinochloa crus-galli* at 30 DAS.

At 60 DAT 2021, weed intensity *of Echinochloa crus-galli* ranged from 33.6 % to 85.6 %. The maximum weed intensity *of Echinochloa crus-galli* was recorded at T1 (85.6 %) which was significantly higher than other treatments followed by T18 (75.7 %) and at par with T5, T8, T18, T19 & T20 while the minimum weed intensity *of Echinochloa crus-galli* was recorded at T2 (33.6 %)) which was significantly lower than other treatments and at par with T10. As compared to T1 (85.6 %) with T2 (33.6 %) showed a 60.74 % decrease in weed intensity *of Echinochloa crus-galli at* 60 DAT. **Subsequently,** at 60 DAT (2022), the weed intensity *of Echinochloa crus-galli* ranged from 37.6 % to 84.9 %. The maximum weed intensity *of Echinochloa crus-galli* was recorded at T1 (84.9 %), which was significantly higher than other treatments, followed by T5 (76.9 %), while the minimum weed intensity *of Echinochloa crus-*

galli was recorded at T10 (37.6 %), which was significantly lower than other treatments and at par with T2. As compared to T3 (84.9 %) with T10 (37.6 %) showed a 55.71 % decrease in weed intensity *of Echinochloa crus-galli* at 60 DAT. From the analysis of both years' average data of year **2021 & 2022,** it was observed that the maximum weed intensity *of Echinochloa crus-galli* was recorded at T1 (85.3 per/m^2), followed by T5 (76.2 per/m^2), while the minimum weed intensity *of Echinochloa crus-galli* was recorded at T2 (36.3 per/m^2). As compared to T1 (85.3 per/m^2) with T2 (36.3 per/m^2) showed a 57.44 % decrease in weed intensity *of Echinochloa crus-galli* at 60 DAT.

At 90 DAT 2021, weed intensity *of Echinochloa crus-galli* ranged from 17.3 % to 84.7 %. The maximum weed intensity *of Echinochloa crus-galli* was recorded at T1 (84.7 %), which was significantly higher than other treatments, followed by T8 (67.7 %) while the minimum weed intensity *of Echinochloa crus-galli* was recorded at T2 (17.3 %), which was significantly lower than other treatments and at par with T10, T14, & T17. As compared to T1 (84.7 %) with T2 (17.3 %) showed a 79.57 % decrease in weed intensity *of Echinochloa crus-galli at* 90 DAT. **Subsequently,** at 90 DAT (2022), weed intensity *of Echinochloa crus-galli* ranged from 24.9 % to 87.5 %. The maximum weed intensity *of Echinochloa crus-galli* was recorded at T1 (87.5 %), which was significantly higher than other treatments followed by T3 (70.0 %), while the minimum weed intensity *of Echinochloa crus-galli* was recorded at T2 (24.9%). As compared to T2 (24.9 %) with T1 (87.5 %) showed a 71.54 % decrease in weed intensity *of Echinochloa crus-galli* at 90 DAT. From the analysis of both years' average data of year **2021 & 2022,** it was observed that the maximum weed intensity *of Echinochloa crus-galli* was recorded at T1 (86.1 %), followed by T8 (68.2 %), while the minimum weed intensity *of Echinochloa crus-galli* was recorded at T2 (21.1 %). As compared to T1 (86.1 %) with T2 (21.1 %) showed a 75.49 % decrease in weed intensity *of Echinochloa crus-galli* at 90 DAT.

4.7.1. Effect of treatments on weed intensity of *Echinochloa crus-galli* (%) at 30, 60, 90 DAT during the years 2021 & 2022

TREATMENTS	30 DAT			60 DAT			90 DAT		
	2021	**2022**	**AVG.**	**2021**	**2022**	**AVG.**	**2021**	**2022**	**AVG.**
T1-Absolute control	86.6±0.6	86.2±0.30	86.4	85.6±0.38	84.9±0.19	85.3	84.7±0.51	87.5±0.40	86.1
T2-100% RDH*	79.6±5.64	85.0±0.94	82.3	33.4±0.27	39.2±1.83	36.3	17.3±1.85	24.9±1.76	21.1
T3-ELE 5% + 50% H*	80.6±5.11	73.6±1.09	77.1	70.2±1.55	72.0±1.68	71.1	57.4±1.44	70.0±1.24	63.7
T4-ELE 5% + 75% H*	80.3±6.37	87.9±0.51	84.1	52.3±1.30	55.6±2.26	53.9	33.3±2.14	39.8±2.34	36.5
T5-ELE 10% + 50% H*	83.3±1.02	84.0±0.74	83.7	75.6±2.07	76.9±0.57	76.2	59.9±1.75	56.9±1.96	58.4
T6-ELE 10% + 75% H*	83.4±1.05	84.8±0.84	84.1	56.9±0.78	51.6±0.96	54.3	35.2±1.90	41.3±1.84	38.2
T7-NLE 10% + 50% H*	79.8±2.43	85.0±0.72	82.4	65.6±1.49	62.6±0.42	64.1	61.7±2.28	65.5±1.93	63.6
T8-NLE 10% + 75% H*	82.0±3.84	85.6±0.57	83.8	72.3±1.64	70.2±0.57	71.3	67.7±1.25	68.8±1.08	68.2
T9-NLE 15% + 50% H*	79.4±0.64	57.3±1.07	68.3	64.8±0.96	64.2±0.46	64.5	37.7±1.67	45.8±3.46	41.7
T10-NLE 15% + 75% H*	80.4±2.65	79.8±0.58	80.1	40.2±1.47	37.6±2.78	38.9	28.7±1.75	38.7±1.96	33.7
T11-GLE 25% + 50% H*	81.4±2.56	85.9±0.42	83.7	69.2±1.47	69.1±1.29	69.1	54.9±0.96	54.5±2.33	54.7
T12-GLE 25% + 75% H*	85.0±0.23	83.7±0.47	84.4	60.7±1.36	60.0±1.68	60.4	52.5±0.06	43.7±0.86	48.1
T13-GLE 30% + 50% H*	80.2±4.94	77.0±0.83	78.6	70.2±0.43	69.4±0.52	69.8	60.9±1.67	66.9±0.73	63.9
T14-GLE 30% + 75% H*	77.0±5.20	72.0±0.44	74.5	50.4±3.50	54.7±2.39	52.6	28.8±2.23	36.5±1.22	32.6
T15-ELE 5%	73.4±11.78	81.7±0.45	77.6	70.3±2.52	70.5±2.93	70.4	61.2±6.2.12	58.9±2.53	60.0
T16-ELE 10%	80.9±2.27	86.0±0.27	83.5	68.7±2.48	69.6±0.72	69.2	62.0±1.51	58.0±1.29	60.0
T17-NLE 10%	77.6±9.16	75.4±1.84	76.5	67.9±2.16	62.3±1.87	65.1	30.5±3.12	38.0±4.82	34.3
T18-NLE 15%	83.8±2.69	81.1±0.20	82.5	75.7±2.17	75.1±0.55	75.4	52.5±0.20	52.3±2.46	52.4
T19-GLE 25%	83.0±2.71	84.8±0.60	83.9	73.0±0.69	70.4±0.97	71.7	52.5±1.15	55.2±3.94	53.8
T20- GLE 30%	84.3±0.90	79.2±0.48	81.7	73.1±1.15	72.1±1.08	72.6	65.3±1.99	63.6±1.53	64.4
CD (P≤0.05)	NA	2.16		4.92	4.47		5.08	6.42	
SE(m ±)	4.72	0.754		1.75	1.556		5.40	2.235	

Note-RDH-recommended dose of herbicide, ELE- eucalyptus leaf extract, NLE- neem leaf extract, GLE- guava leaf extract, SE- standard error and CD (P≤0.05)- critical difference. *Bispyribac Sodium + Metsulfuron Methyl 10% + Chlorimuron Ethyl 10%.

4.8. Weed control efficiency *of Echinochloa crus-galli in* rice crop

The periodic weed control efficiency *of Echinochloa crus-galli* data **(Table 4.8.1)** was taken at 30, 60, & 90 days after transplanting (DAT). In Rice, at 30 DAT 2021, weed control efficiency *of Echinochloa crus-galli* ranged from 16.17 % to 47.2 %. The maximum weed control efficiency *of Echinochloa crus-galli* was recorded at T14 (47.2 %), which was significantly higher than other treatments, followed by T9 (43.1 %), while the minimum weed control efficiency *of Echinochloa crus-galli* was recorded at T20 (16.17). **Subsequently,** in the second trial at 30 DAT (2022), weed control efficiency *of Echinochloa crus-galli* ranged from 0.95 % to 77.9. % The maximum weed control efficiency *of Echinochloa crus-galli* was recorded at T9 (77.9 %), which was significantly higher than other treatments, followed by T14 (62.4 %) while the minimum weed control efficiency *of Echinochloa crus-galli* was recorded at T4 (0.95 %) which was significantly lower than other treatments and at par with T2, T6, T7, & T16. From the analysis of both years' average data of year **2021 & 2022,** it was observed that the maximum weed control efficiency *Echinochloa crus-galli* was recorded at T9 (60.5 %), followed by T14 (54.8 %), while the weed control efficiency *of Echinochloa crus-galli* was recorded at T6 (11.4
%).

At 60 DAT 2021, weed control efficiency *of Echinochloa crus-galli* ranged from 45.2 % to 90.1 %. The maximum weed control efficiency *of Echinochloa crus-galli* was recorded at T2 (90.1%) which was significantly higher than other treatments followed by T10 (87.2 %) and at par with T4, T14, T6 & T12, while the minimum weed control efficiency *of Echinochloa crus-galli* was recorded at T5 (45.2 %) which was significantly lower than other treatments and at par with T3, T8, T15, T18 & T20. **Subsequently,** at 60 DAT (2022), weed control efficiency *of Echinochloa crus-galli* ranged from 48.8 % to 89.7 %. The maximum weed control efficiency *of Echinochloa crus-galli* was recorded at T10 (89.7 %), which was significantly higher than other treatments, followed by & at par with T2 (88.8 %), while the minimum weed control efficiency *of Echinochloa crus-galli* was recorded at T5 (48.8. From the analysis of both years' average data of year **2021 & 2022,** it was observed that the maximum weed control efficiency *Echinochloa crus-galli* was recorded at T2 (89.4 %), followed by T10 (88.6 %), while the weed control efficiency *of Echinochloa crus-galli* was recorded at T5 (47.0 %).

4.8.1. Effect of treatments on weed control efficiency of *Echinochloa crus-galli* (%) at 30, 60, 90 DAT during the years 2021 & 2022

TREATMENTS	**30 DAT**			**60 DAT**			**90 DAT**		
	2021	**2022**	**AVG.**	**2021**	**2022**	**AVG.**	**2021**	**2022**	**AVG.**
T1-Absolute control	NA	NA	NA	NA	NA	NA	NA	NA	NA
T2-100% RDH*	29.4±18.67	3.7±1.28	16.6	90.1±1.59	88.8±0.85	89.4	95.9±1.06	94.9±0.44	95.4
T3-ELE 5% + 50% H*	32.5±19.53	58.1±0.92	45.3	53.0±1.56	63.6±3.15	58.3	69.8±2.77	68.7±1.35	69.2
T4-ELE 5% + 75% H*	35.9±20.88	0.9±0.47	18.4	83.4±1.22	82.3±1.54	82.9	91.5±0.88	91.7±0.78	91.6
T5-ELE 10% + 50% H*	20.6±1.54	6.0±1.82	13.3	45.2±0.67	48.8±1.51	47.0	72.7±1.34	74.3±1.66	73.5
T6-ELE 10% + 75% H*	20.1±0.29	2.8±0.78	11.4	78.7±2.44	79.0±0.91	78.9	90.0±1.60	88.9±0.68	89.5
T7-NLE 10% + 50% H*	36.3±9.99	3.7±0.90	20.0	66.3±1.55	68.8±1.08	67.5	72.0±2.42	71.9±1.51	72.0
T8-NLE 10% + 75% H*	36.6±11.62	15.9±1.06	26.2	63.5±1,88	66.9±0.93	65.2	69.4±1.02	66.4±1.75	67.9
T9-NLE 15% + 50% H*	43.1±5.22	77.9±0.68	60.5	68.6±0.88	70.6±1.67	69.6	89.5±1.54	85.6±2.20	87.6
T10-NLE 15% + 75% H*	33.8±9.85	33.2±1.63	33.5	87.5±2.76	89.7±1.36	88.6	92.1±0.75	90.3±0.69	91.2
T11-GLE 25% + 50% H*	38.8±10.85	10.7±1.11	24.7	64.2±1.23	66.5±1.88	65.3	82.1±0.87	81.5±1.91	81.8
T12-GLE 25% + 75% H*	16.5±2.89	17.8±0.83	17.2	73.2±0.82	76.7±1.42	75.0	83.5±0.58	87.1±0.53	85.3
T13-GLE 30% + 50% H*	33.4±15.61	46.4±1.10	39.9	64.4±1.11	61.8±1.31	63.1	69.2±1.11	71.9±0.92	70.6
T14-GLE 30% + 75% H*	47.2±10.14	62.4±0.80	54.8	83.0±1.34	82.3±1.89	82.6	93.4±1.89	91.2±0.50	92.3
T15-ELE 5%	38.6±203.46	28.6±0.43	33.6	57.7±0.89	61.3±4.27	59.5	71.9±1.80	77.5±1.39	74.7
T16-ELE 10%	35.1±10.94	1.3±0.80	18.2	62.9±2.23	64.6±0.83	63.7	75.0±2.97	77.0±0.92	76.0
T17-NLE 10%	34.7±21.53	52.5±0.99	43.6	63.7±1.59	69.7±2.85	66.7	90.9±1.55	91.2±1.59	91.1
T18-NLE 15%	28.6±13.69	39.4±0.42	34.0	54.7±2.11	60.4±2.454	57.6	84.4±1.48	85.3±1.15	84.8
T19-GLE 25%	28.4±13.66	15.5±1.01	22.0	62.3±1.43	63.2±1.95	62.8	80.9±1.68	82.5±2.37	81.7
T20- GLE 30%	16.1±6.28	33.7±1.70	24.9	59.3±1.43	57.6±1.84	58.4	67.4±2.18	69.1±2.65	68.3
CD (P≤0.05)	NA	2.85		5.21	5.47		5.11	4.21	
SE(m ±)	13.55	0.993		1.508	1.904		5.13	1.46	

Note-RDH-recommended dose of herbicide, ELE- eucalyptus leaf extract, NLE- neem leaf extract, GLE- guava leaf extract, SE- standard error and CD (P≤0.05)- critical difference, *Bispyribac Sodium + Metsulfuron Methyl 10% + Chlorimuron Ethyl 10%.

At 90 DAT 2021, weed control efficiency *of Echinochloa crus-galli* ranged from 67.4 % to 95.9 %. The maximum weed control efficiency *of Echinochloa crus-galli* was recorded at T2 (95.9 %) which was significantly higher than other treatments followed by T14 (93.4 %) and at par with T4, T6, T9, T10, T11, T12, T14, T17 & T18 while the minimum weed control efficiency *of Echinochloa crus-galli* was recorded at T20 (67.4 %) which was significantly lower than other treatments and at par with T3, T5, T7, T8, T11, T13, T15, T16 & T19. **Subsequently,** at 90 DAT (2022), weed control efficiency *of Echinochloa crus-galli* ranged from 66.4 % to 94.9 %. The maximum weed control efficiency *of Echinochloa crus-galli* was recorded at T2 (94.9 %) which was significantly higher than other treatments followed by T4 (91.7 %) and at par with T4, T14, & T17 while the minimum weed control efficiency *of Echinochloa crus-galli* was recorded at T8 (66.4 %) which was significantly lower than other treatments and at par with T3 & T20. From the analysis of both years' average data of year **2021 & 2022,** it was observed that the maximum weed control efficiency *Echinochloa crus-galli* was recorded at T2 (95.4 %), followed by T14 (92.3 %), while the weed control efficiency *of Echinochloa crus- galli* was recorded at T18 (20.3 %).

4.9. Panicle length (cm) of rice crop

At the time of harvest 2021, panicle length **(Table 4.11.1)** ranged from 14.2 cm to 21.5 cm. The maximum panicle length was recorded at T2 (21.5 cm) which was significantly higher than other treatments followed by T14 (21.1 cm) and at par with T3, T5, T8, T14, T15, T19, & T20 while the minimum panicle length was recorded at T10 (14.2 cm) which was significantly lower than other treatments and at par with T6, T7, T9, T13, T17 & T18. As compared to T10 (14.2 cm) with T2 (21.5 cm) showed a 51.40 % increase in panicle length at the harvesting stage. **Subsequently,** in the second trial (2022), at the time of harvest, panicle length ranged from 14.1 cm to 21.3 cm. The maximum panicle length was recorded at T2 (21.3 cm) which was significantly higher than other treatments followed by T14 (21.1 cm) and at par with T3, T4, T5, T8, T12, T14, T15, T19 & T20 while the minimum panicle length was recorded at T10 (14.1 cm) which was significantly lower than other treatments and at par with T6, T7, T9, T13, T17 & T18. As compared to T10 (14.1 cm) with T2 (21.3 cm) showed a 51.06 % increase in panicle length at the harvesting stage. From the analysis of both years' average data of year **2021 &**

2022, it was observed that the maximum panicle length was recorded at T2 (21.4 cm), followed by T14 (21.1 cm), while the panicle length was recorded at T10 (14.1 cm). As compared to T10 (14.1 per/m^2) with T2 (21.4 cm) showed a 51.77 % increase in panicle length at the harvesting stage.

4.10. Number of spikelet/panicle

At the time of harvest 2021, the number of spikelet/panicles **(Table 4.11.1)** ranged from 109.3 to 122.7. The maximum number of spikelet/panicle was recorded at T2 (122.7) which was significantly higher than other treatments followed by T4 (119.0) and at par with T6, T8, T14, T16, T17 & T19 while the minimum number of spikelet/panicle was recorded at T1 (109.3) which was significantly lower than other treatments and at par with T3, T5, T6, T7, T9, T10, T11, T12, T13, T14, T15, T16, T17, T18, T19, & T20, As compared to T0 (109.3) with T2 (122.7) showed 12.25 % increase in number of spikelet /panicle at harvesting stage. **Subsequently,** in the second trial (2022), the time of harvest, number of spikelet/panicles ranged from 111.0 to 126.3. The maximum number of spikelet/panicle was recorded at T2 (126.3) which was significantly higher than other treatments followed by T3 (116.3) while the minimum number of spikelet/panicle was recorded at T12 (111.0) which was significantly lower than other treatments and at par with T1, T3, T4, T5, T6, T7, T8, T9, T10, T11, T13, T14, T15, T16, T17, T18, T19 & T20. As compared to T12 (111.0) with T2 (126.3) showed a 13.78 % increase in the number of spikelet/panicle at the harvesting stage. From the analysis of both years' average data of year **2021 & 2022,** it was observed that the maximum spikelet/panicle was recorded at T2 (125.5), followed by T4 & T8 (116.2), while the spikelet/panicle was recorded at T1 (111.0). As compared to T1 (111.0) with T2 (125.5) showed a 13.06 % increase in spikelet/panicle at the harvesting stage.

4.11. Filled grain/panicle

At the time of harvest 2021, the number of filled grain/panicle **(Table 4.11.1)** ranged from 85.0 to 103.0. The maximum number of filled grain/panicle was recorded at T2 (103.0), which was significantly higher than other treatments, followed by T4 (102.2) and at par with T4, T13, T19 & T20, while the minimum number of filled grain/panicle was recorded at T1 (85.0). As compared to T1 (85.0) with T2 (103.0) showed a 21.17 % increase in the number of filled grain/panicle at the harvesting stage. **Subsequently,** in second trial (2022), the time of harvest,

4.11.1. Effect of treatments on panicle length (cm), no. of spikelet/panicle & filled grain/panicle of rice at harvesting stage during the years 2021 & 2022

PANICLE LENGTH				NO. OF SPIKELET/PANICLE			FILLED GRAIN/PANICLE		
TREATMENTS	**2021**	**2022**	**AVG.**	**2021**	**2022**	**AVG.**	**2021**	**2022**	**AVG.**
T1-Absolute control	16.9±1.43	17.13±1.54	17.0	109.3±4.05	112.7±0.88	111.0	85.0±4.35	87.0±4.35	86.0
T2-100% RDH*	21.5±0.54	21.3±0.45	21.4	122.7±2.84	126.3±0.88	124.5	103.0±0.57	106.3±0.66	104.7
T3-ELE 5% + 50% H*	19.5±1.01	19.6±1.36	19.6	113.3±0.88	116.3±0.84	114.8	96.2±2.51	94.1±3.48	95.15
T4-ELE 5% + 75% H*	19.1±1.08	19.4±1.32	19.2	119.0±3.05	113.3±033	116.2	102.3±4.70	103.3±4.05	102.8
T5-ELE 10% + 50% H*	19.9±0.67	20.0±0.95	19.9	113.3±0.88	112.7±0.88	113.0	92.7±2.18	95.0±2.00	93.8
T6-ELE 10% + 75% H*	15.3±0.55	15.1±0.63	15.2	116.0±2.51	115.3±2.84	115.7	95.7±1.20	97.3±1.33	96.5
T7-NLE 10% + 50% H*	15.3±0.86	15.0±0.66	15.1	111.7±0.33	111.7±1.20	111.7	95.7±1.66	97.7±2.18	96.7
T8-NLE 10% + 75% H*	21.0±0.21	20.9±0.26	21.0	116.7±3.66	115.7±2.72	116.2	94.7±2.33	97.0±1.73	95.8
T9-NLE 15% + 50% H*	16.1±0.31	16.0±0.55	16.0	115.0±3.00	111.7±0.88	113.4	96.7±1.45	98.7±0.88	97.7
T10-NLE 15% + 75% H*	14.2±0.46	14.1±0.36	14.1	112.0±0.57	112.0±0.57	112.0	95.7±1.20	98.0±1.15	96.8
T11-GLE 25% + 50% H*	17.4±0.58	17.3±0.52	17.4	112.7±0.33	115.0±3.60	113.8	96.7±1.20	97.0±1.52	96.8
T12-GLE 25% + 75% H*	19.1±1.10	19.1±1.10	19.1	114.7±3.18	111.0±0.57	112.8	96.7±1.20	97.7±1.85	97.2
T13-GLE 30% + 50% H*	14.6±0.33	14.5±0.38	14.6	111.7±0.33	112.3±0.88	112.0	98.0±1.52	98.0±4.16	98.0
T14-GLE 30% + 75% H*	21.1±0.48	21.1±0.41	21.1	116.0±3.00	113.0±1.15	114.5	93.0±2.08	99.3±1.76	96.2
T15-ELE 5%	19.6±0.43	19.4±0.23	19.5	113.7±1.20	115.0±3.05	114.3	97.3±0.88	98.7±1.45	98.0
T16-ELE 10%	17.9±0.40	17.4±0.34	17.7	116.0±2.51	112.0±0.57	114.0	95.3±0.33	97.3±2.60	96.3
T17-NLE 10%	14.3±0.93	14.5±1.15	14.4	115.7±2.90	111.3±0.66	113.5	93.0±1.15	94.0±1.73	93.5
T18-NLE 15%	15.7±0.98	15.6±0.95	15.6	115.0±3.51	112.0±0.57	113.5	92.3±1.20	93.3±0.88	92.8
T19-GLE 25%	19.4±0.49	19.4±0.53	19.4	116.0±3.51	112.7±1.20	114.4	98.7±1.85	96.5±1.45	97.6
T20- GLE 30%	20.4±0.40	20.2±0.64	20.3	112.0±0.57	112.0±0.57	112.0	101.1±0.88	100.0±1.00	100.5
CD (P≤0.05)	2.09	2.34		7.27	4.66		5.81	6.59	
SE(m ±)	0.730	0.816		2.54	1.624		2.023	2.295	

Note-RDH-recommended dose of herbicide, ELE- eucalyptus leaf extract, NLE- neem leaf extract, GLE- guava leaf extract, SE- standard error and CD (P≤0.05)- critical difference, *Bispyribac Sodium + Metsulfuron Methyl 10% + Chlorimuron Ethyl 10%.

number of filled grain/panicle ranged from 87.0 to 106.3. The maximum number of filled grain/panicle was recorded at T20 (106.3) which was significantly higher than other treatments followed by T4 (106.3) and at par with T2, T3, T4, T19 & T20 while the minimum number of filled grain/panicle was recorded at T1 (87.0) which was significantly lower than other treatments and at par with T18. As compared to T1 (87.0) with T20 (106.3) showed a 21.82 % increase in the number of filled grain/panicle at the harvesting stage. From the analysis of both years' average data of year **2021 & 2022,** it was observed that the maximum Spikelet/panicle was recorded at T2 (104.7), followed by T4 (102.8), while the minimum Spikelet/panicle was recorded at T1 (86.0). As compared to T1 (86.0) with T2 (104.7) showed a 21.74 % increase in Spikelet/panicle at the harvesting stage.

4.12. Biological yield (q/ha) of rice crop

At the time of harvest 2021, biological yield **(Table 4.14.1)** ranged from 60.3 q/ha to 104.5 q/ha. The maximum biological yield was recorded at T2 (104.5 q/ha), which was significantly higher than other treatments, followed by T4 (101.3 q/ha) and at par with T4, while the minimum biological yield was recorded at T1 (60.3 q/ha). **Subsequently,** in the second trial (2022), at the time of harvest, biological yield ranged from 50.8 q/ha to 103.3 q/ha. The maximum biological yield was recorded at T2 (103.3 q/ha), which was significantly higher than other treatments, followed by T4 (98.4 q/ha), while the minimum biological yield was recorded at T1 (50.8 q/ha). From the analysis of both years' average data of year **2021 & 2022,** it was observed that the maximum biological yield was recorded at T2 (103.3 q/ha), followed by T4 (99.9 q/ha), while the minimum biological yield was recorded at T1 (55.5 q/ha).

4.13. Straw yield (q/ha) of rice crop

At the time of harvest 2021, straw yield **(Table 4.14.1)** ranged from 38.3 q/ha to 59.0 q/ha. The maximum straw yield weight was recorded at T2 (59.0 q/ha) which was significantly higher than other treatments followed by T13 (58.7 q/ ha) and at par with T4, T10, T11, T12, T13 & T14 while the minimum straw yield was recorded at T1 (38.3 q/ ha) which was significantly lower than other treatments and at par with T9, T17, T19, & T20. **Subsequently,** in the second trial (2022), the time of harvest, straw yield ranged from 33.2 q/ha to 56.1 q/ha. The maximum straw yield was recorded at T2 (56.1 q/ha), which was significantly higher than other treatments

4.14.1. Effect of treatments on biological yield, straw yield, grain yield (q/ha) at harvesting stage during the years 2021 & 2022

BIOLOGICAL YIELD				STRAW YIELD			GRAIN YIELD		
	2021	**2022**	**AVG.**	**2021**	**2022**	**AVG.**	**2021**	**2022**	**AVG.**
T1-Absolute control	60.3±2.85	50.8±2.31	55.5	38.3±2.32	33.2±2.27	35.7	22.0±0.53	17.7±0.20	19.8
T2-100% RDH*	104.5±1.81	103.3±3.40	103.9	59.0±1.66	56.1±3.48	57.5	45.5±0.43	47.2±0.30	46.3
T3-ELE 5% + 50% H*	88.2±1.13	86.6±1.74	87.4	52.5±1.26	49.2±2.18	50.8	35.7±0.66	37.4±0.72	36.5
T4-ELE 5% + 75% H*	101.3±1.02	98.4±0.88	99.9	57.3±1.10	54.4±1.67	55.9	44.0±0.67	44.0±0.78	44.0
T5-ELE 10% + 50% H*	81.8±3.94	88.3±1.75	85.1	46.4±4.87	52.7±2.33	49.5	35.4±1.38	35.7±0.66	35.5
T6-ELE 10% + 75% H*	80.3±3.16	88.5±0.63	84.4	46.4±2.58	51.3±1.61	48.8	33.9±0.58	37.3±0.99	35.6
T7-NLE 10% + 50% H*	82.3±2.40	89.5±0.43	85.9	47.8±2.54	52.4±0.82	50.1	34.5±0.50	37.1±0.58	35.8
T8-NLE 10% + 75% H*	80.5±1.50	90.0±0.99	85.2	48.2±1.64	51.8±1.16	50	32.3±0.14	38.2±0.58	35.2
T9-NLE 15% + 50% H*	74.3±0.76	91.3±1.13	82.8	40.7±0.86	54.4±0.72	47.5	33.6±0.30	36.8±0.69	35.2
T10-NLE 15% + 75% H*	93.2±0.96	92.9±1.23	93.0	53.8±1.93	51.6±0.95	52.7	39.3±1.04	41.3±0.52	40.3
T11-GLE 25% + 50% H*	89.0±1.82	88.8±0.76	88.9	55.1±2.76	49.5±0.50	52.3	33.9±1.03	39.3±0.67	36.6
T12-GLE 25% + 75% H*	90.8±1.39	88.6±1.56	89.7	57.8±1.96	50.6±1.74	54.2	32.9±0.58	38.0±1.24	35.5
T13-GLE 30% + 50% H*	90.5±1.04	87.9±1.33	89.2	58.7±0.78	51.0±1.50	54.9	31.8±0.28	36.9±0.52	34.3
T14-GLE 30% + 75% H*	91.9±0.53	90.9±1.16	91.4	54.5±0.78	51.1±1.06	52.8	37.4±0.29	39.8±0.63	38.6
T15-ELE 5%	81.1±2.34	87.7±1.30	84.4	49.2±2.55	50.7±1.05	59.9	31.8±0.69	37.0±0.72	34.4
T16-ELE 10%	78.7±1.32	86.1±0.97	82.4	46.1±1.62	51.4±1.76	48.8	32.6±0.30	34.7±0.78	33.6
T17-NLE 10%	76.2±0.87	81.8±1.26	79.0	43.4±0.72	49.5±1.46	46.5	32.8±0.57	32.3±0.23	32.5
T18-NLE 15%	77.3±1.59	79.7±2.06	78.5	46.7±1.09	46.7±2.04	46.7	30.7±0.83	33.0±0.53	31.8
T19-GLE 25%	73.3±1.15	82.8±0.58	78.1	44.0±1.89	50.8±0.88	47.4	29.3±0.78	32.1±0.44	30.7
T20- GLE 30%	75.4±1.86	86.3±0.93	80.8	44.1±0.94	52.1±1.69	48.1	31.3±0.92	34.2±0.94	32.8
CD (P≤0.05)	5.47	4.33		5.87	4.82		2.02	1.91	
SE(m)	1.90	1.50		2.04	1.68		0.70	0.66	

Note-RDH-recommended dose of herbicide, ELE- eucalyptus leaf extract, NLE- neem leaf extract, GLE- guava leaf extract, SE-standard error and CD (P≤0.05)- critical difference, *Bispyribac Sodium + Metsulfuron Methyl 10% + Chlorimuron Ethyl 10%.

followed by T4, T9 (54.4 q/ ha) and at par with T4, T5, T7, T8, T9, T10, T16 & T20, while the minimum straw yield was recorded at T1 (33.2 q/ha) which was significantly lower than other treatments. From the analysis of both years' average data of year **2021 & 2022,** it was observed that the maximum straw yield was recorded at T2 (57.5 q/ha), followed by T4 (55.2 q/ha), while the minimum straw yield was recorded at T1 (35.7 q/ha).

4.14. Grain yield (q/ha) of rice crop

At the time of harvest, grain yield **(Table 4.14.1)** ranged from 22.0 q/ha to 45.5 q/ha. The maximum grain yield was recorded at T2 (45.5 q/ha), which was significantly higher than other treatments, followed by T4 (45.3 q/ha) and at par with T4, while the minimum grain yield was recorded at T1 (22.0 q/ha). **Subsequently,** in the second trial (2022), the time of harvest, grain yield ranged from 17.7 q/ha to 47.2 q/ha. The maximum grain yield was recorded at T2 (47.2 q/ha), which was significantly higher than other treatments, followed by T4 (44.0 q/ha), while the minimum grain yield was recorded at T1 (17.7 q/ha), which was significantly lower than other treatments. From the analysis of both years' average data of year **2021 & 2022,** it was observed that the maximum grain yield was recorded at T2 (46.3 q/ha), followed by T4 (44.6 q/ha), while the minimum grain yield was recorded at T1 (19.8 q/ha).

4.15. Test weight (1000 grain) of rice crop

At the time of harvest 2021, test weight **(Table 4.15.1)** ranged from 16.1 g to 27.7 g. The maximum test weight was recorded at T2 (27.7 g), which was significantly higher than other treatments, followed by T4 (26.4 g) and at par with T4, while the minimum test weight was recorded at T18 (16.1 g), which was significantly lower than other treatments and at par with T17. As compared to T18 (16.1 g) with T2 (27.7 g) showed a 72.04 % increase in test weight at the harvesting stage. **Subsequently,** in the second trial (2022), the time of harvest, the test weight ranged from 17.9 g to 26.0 g. The maximum test weight was recorded at T2 (26.0 g) which was significantly higher than other treatments followed by T20 (24.5 g) and at par with T8, T14, T15, & T20 while the minimum test weight was recorded at T17 (17.9 g) which was significantly lower than other treatments and at par with T6, T7, T13 & T18. As compared to

T17 (17.9 g) with T2 (26.0 g) showed a 45.25 % increase in test weight at the harvesting stage. From the analysis of both years' average data of year **2021 & 2022,** it was observed that the maximum test weight was recorded at T2 (26.8 g), followed by T4 (24.6 g), while the test weight was recorded at T17 (17.1 g). As compared to T17 (17.1 g) with T2 (26.8 g) showed a 56.72 % increase in test weight at the harvesting stage.

4.15.1. Effect of treatments on test weight of rice (g) at harvesting stage during the years 2021 & 2022

TREATMENTS	2021	2022	AVG.
T1-Absolute control	20.1±0.39	21.3±1.03	20.7
T2-100% RDH*	27.7±1.04	26.0±0.33	26.8
T3-ELE 5% + 50% H*	22.0±1.04	21.8±0.05	21.9
T4-ELE 5% + 75% H*	26.4±1.10	22.8±0.35	24.6
T5-ELE 10% + 50% H*	23.0±1.12	23.6±0.67	23.3
T6-ELE 10% + 75% H*	19.8±0.43	19.6±0.37	19.7
T7-NLE 10% + 50% H*	19.5±1.08	19.3±1.16	19.4
T8-NLE 10% + 75% H*	23.7±0.43	24.1±0.15	23.9
T9-NLE 15% + 50% H*	21.0±0.26	21.5±0.18	21.2
T10-NLE 15% + 75% H*	20.1±0.54	20.5±0.85	20.3
T11-GLE 25% + 50% H*	20.6±0.32	22.6±0.80	21.6
T12-GLE 25% + 75% H*	21.2±0.23	21.0±0.25	21.1
T13-GLE 30% + 50% H*	18.5±0.55	19.1±0.33	18.8
T14-GLE 30% + 75% H*	24.0±0.41	23.8±0.95	23.9
T15-ELE 5%	22.3±0.55	23.4±1.18	22.8
T16-ELE 10%	24.2±0.66	21.3±0.52	22.7
T17-NLE 10%	16.3±0.52	17.9±1.15	17.1
T18-NLE 15%	16.1±0.60	19.3±1.08	17.7
T19-GLE 25%	25.2±0.45	22.2±0.72	23.7
T20- GLE 30%	23.2±0.55	24.5±1.02	23.8
CD (P≤0.05)	1.97	2.129	
SE(m ±)	0.68	0.741	

Note-RDH-recommended dose of herbicide, ELE- eucalyptus leaf extract, NLE- neem leaf extract, GLE- guava leaf extract, SE- standard error and CD (P≤0.05)- critical difference, *Bispyribac Sodium + Metsulfuron Methyl 10% + Chlorimuron Ethyl 10%.

4.16. Harvest index (%) of rice crop

At the time of harvest 2021, the harvest index **(Table 4.16.1)** ranged from 35 % to 45 %. The maximum harvest index was recorded at T9 (45 %), followed by T2 (44 %), while the minimum harvest index was recorded at T13 (35 %). **Subsequently,** in the second trial (2022), the time of harvest, harvest index ranged from 35 % to 46 %. The maximum harvest index was recorded at T2 (46 %), followed by T4 (45 %), while the minimum harvest index was recorded at T1 (35 %). From the analysis of both years' average data of year **2021 & 2022,** it was observed that the maximum harvest index was recorded at T2 (45%), followed by T4 (44%), while the minimum harvest index was recorded at T1 (36%).

4.16.1. Effect of treatments on harvest index of rice (%) at harvesting stage during the years 2021 & 2022

TREATMENTS	2021	2022	AVG.
T1-Absolute control	37	35	36
T2-100% RDH*	44	46	45
T3-ELE 5% + 50% H*	40	43	41.5
T4-ELE 5% + 75% H*	43	45	44
T5-ELE 10% + 50% H*	43	40	41.5
T6-ELE 10% + 75% H*	42	42	42
T7-NLE 10% + 50% H*	42	41	41.5
T8-NLE 10% + 75% H*	40	42	41
T9-NLE 15% + 50% H*	45	40	42.5
T10-NLE 15% + 75% H*	42	44	43
T11-GLE 25% + 50% H*	38	44	41
T12-GLE 25% + 75% H*	36	43	39.5
T13-GLE 30% + 50% H*	35	42	38.5
T14-GLE 30% + 75% H*	41	44	42.5
T15-ELE 5%	39	42	40.5
T16-ELE 10%	41	40	40.5
T17-NLE 10%	43	40	41.5
T18-NLE 15%	40	41	40.5
T19-GLE 25%	40	39	39.5
T20- GLE 30%	42	40	41
CD ($P \leq 0.05$)	3.95	4.38	
SE(m ±)	1.85	1.70	

Note-RDH-recommended dose of herbicide, ELE- eucalyptus leaf extract, NLE- neem leaf extract, GLE- guava leaf extract, SE- standard error and CD ($P \leq 0.05$)- critical difference, *Bispyribac Sodium + Metsulfuron Methyl 10% + Chlorimuron Ethyl 10%.

4.17. Benefit-Cost ratio rice crop- (B: C ratio)

The crop benefit ratio emphasizes the extent of profit or benefit earned by applying a particular treatment over its cost. It was calculated for the different treatment combinations in both seasons of the wheat crop presented in **Table 4.17.1.** During 2021, the highest benefit-cost ratio was recorded under T2 (1) & T4 (1), followed by T10, T14 (0.7), T3, and T5 (0.6). **Subsequently**, during 2022, the highest benefit cost ratio was recorded under T2 (1.2), followed by T4 (1.1), T10 (1.0), T11 & T14 (0.9).

4.17.1 Effect of treatments on Benefit-Cost ratio of rice (B: C ratio) during the years 2021-2022

Treatments	**Cost of cultivation**	**2021 season**			**2022 season**		
		Gross return	**Net return**	**B: C ratio**	**Gross Return**	**Net Return**	**B: C Ratio**
T1-Absolute control	44050	44880	830	0.1	38639.1	-5410.9	-0.1
T2-100% RDH*	46510	92820	46310	1.0	103037.6	56527.6	1.2
T3-ELE 5% + 50% H*	45779	72828	27049	0.6	81644.2	35865.2	0.8
T4-ELE 5% + 75% H*	46144	92412	46268	1.0	96052	49908	1.1
T5-ELE 10% + 50% H*	45779	72216	26437	0.6	77933.1	32154.1	0.7
T6-ELE 10% + 75% H*	46144	69156	23012	0.5	81425.9	35281.9	0.8
T7-NLE 10% + 50% H*	45779	70380	24601	0.5	80989.3	35210.3	0.8
T8-NLE 10% + 75% H*	46144	65892	19748	0.4	83390.6	37246.6	0.8
T9-NLE 15% + 50% H*	45779	68544	22765	0.5	80334.4	34555.4	0.8
T10-NLE 15% + 75% H*	46144	80172	34028	0.7	90157.9	44013.9	1.0
T11-GLE 25% + 50% H*	45779	69156	23377	0.5	85791.9	40012.9	0.9
T12-GLE 25% + 75% H*	46144	67116	20972	0.5	82954	36810	0.8
T13-GLE 30% + 50% H*	45779	64872	19093	0.4	80552.7	34773.7	0.8
T14-GLE 30% + 75% H*	46144	76296	30152	0.7	86883.4	40739.4	0.9
T15-ELE 5%	45050	64872	19822	0.4	80771	35721	0.8
T16-ELE 10%	45050	66504	21454	0.5	75750.1	30700.1	0.7
T17-NLE 10%	45050	66912	21862	0.5	70510.9	25460.9	0.6
T18-NLE 15%	45050	62628	17578	0.4	72039	26989	0.6
T19-GLE 25%	45050	59772	14722	0.3	70074.3	25024.3	0.6
T20- GLE 30%	45050	63852	18802	0.4	74658.6	29608.6	0.7

Note-RDH-recommended dose of herbicide, ELE- eucalyptus leaf extract, NLE- neem leaf extract, GLE-guava leaf extract, SE- standard error and CD (P≤0.05)- critical difference, *Bispyribac Sodium + Metsulfuron Methyl 10% + Chlorimuron Ethyl 10%.

4.18. Plant population of the wheat crop

Plant population is one of the factors that is directly related to the planting geometry, and it refers to the number of plants growing in a specific area. It is a very important aspect of crop management, influencing factors like nutrient uptake, competition and overall yield of the crop. The periodic plant population data **(Table 4.18.1)** were taken 30 days after sowing (DAS).

4.18.1 Effect of treatments on plant population of wheat (cm) at 30 DAS during the year 2021-2022 & 2022-2023

TREATMENTS	30 DAS		
	2021-2022	**2022-2023**	**AVG.**
T1-Absolute control	32.3±1.14	29.6±0.88	31.0
T2-100% RDH*	34.3±2.02	33.3±0.88	33.8
T3-ELE 5% + 50% H*	27.7±1.45	29.6±0.88	28.7
T4-ELE 5% + 75% H*	32.3±1.85	34.3±1.45	33.3
T5-ELE 10% + 50% H*	31.7±1.45	28.0±0.57	29.8
T6-ELE 10% + 75% H*	37.7±1.76	38.3±1.45	38.0
T7-NLE 10% + 50% H*	29.7±1.45	27.3±0.88	28.5
T8-NLE 10% + 75% H*	33.0±1.52	32.6±1.76	32.8
T9-NLE 15% + 50% H*	31.7±1.20	31.3±0.88	31.5
T10-NLE 15% + 75% H*	26.7±0.88	30.3±1.20	28.5
T11-GLE 25% + 50% H*	33.3±1.20	35.3±1.20	34.3
T12-GLE 25% + 75% H*	36.7±2.02	26.0±1.52	30.3
T13-GLE 30% + 50% H*	35.0±2.64	36.0±2.08	35.5
T14-GLE 30% + 75% H*	30.7 ±2.33	30.3±0.88	30.5
T15-ELE 5%	34.3±0.88	34.0±0.57	34.2
T16-ELE 10%	29.3±1.20	30.6±0.66	30.0
T17-NLE 10%	33.3±1.20	35.0±0.57	34.2
T18-NLE 15%	20.3±2.40	24.0±1.52	23.2
T19-GLE 25%	35.3±2.60	38.3±2.02	36.8
T20- GLE 30%	27.3±1.45	25.3±0.66	26.3
CD (P≤0.05)	4.711	3.288	
SE(m ±)	1.639	1.144	

Note-RDH-recommended dose of herbicide, ELE- eucalyptus leaf extract, NLE- neem leaf extract, GLE- guava leaf extract, SE- standard error and CD (P≤0.05)- critical difference, *2,4 D + Fenoxaprop.

In wheat (2021-2022), at 30 DAS, plant population ranged from 20.3 to 37.7 per/m^2. The maximum plant population was recorded at T6 (37.7 per/m^2), which was significantly higher than other treatments, followed by T12 (36.7 per/m^2) and at par with T2, T8, T11, T13, T15, T17 & T19, while the minimum plant population was recorded at T18 (20.3 per/m^2). As compared to T18 (20.3 per/m^2) with T6 (37.7 per/m^2) showed an 85.71 % increase in plant population at 30 DAS. **Subsequently,** in the second trial at 30 DAS (2022- 2023), plant population ranged from 24.0 to 38.3 per/m^2. The maximum plant population was recorded at T13 and T19 (38.3 per/m^2) which was significantly higher than other treatments followed by T11 (35.3 per/m^2) and at par with T6 & T11 while the minimum plant population was recorded at T12 (24.0 per/m^2) which was significantly lower than other treatments and at par with T18, & T20. As compared to T12 (24.0 per/m^2) with T13 and T19 (38.3 per/m^2) showed a 59.58 % increase in plant population at 30 DAS. From the analysis of both years' average data of year **(2021-2022) & (2022-2023),** it was observed that the maximum plant population was recorded at T6, T19 (36.8 per/m^2), followed by T13 (36.7 per/m^2), while the minimum plant population was recorded at T18 (23.2 per/m^2). As compared to T18 (23.2 per/m^2) with T6, T19 (36.8 per/m^2) showed a 58.62 % increase in plant population at 30 DAS.

4.19. Plant height (cm) of the wheat crop

Plant height is one of the most important characters on morphological characteristics of a crop. It provides a proper idea of predicting the growth rate and yield of the crop. The existing data showed that the plant height in Wheat gradually increased with the age of the crop. The periodic plant height data **(Table 4.19.1)** & **(Table 4.19.2)** were taken 30, 60, 90 and 120 days after sowing (DAS).

At 30 DAS (2021-2022), plant height ranged from 10.6 cm to 17.2 cm. The maximum plant height was recorded at T12 (17.2 cm) which was significantly higher than other treatments followed by T12 (17.2 cm) and at par with T1, T2, T5, T9, T13, T14, T16 & T19 while the minimum plant height was recorded at T20 (10.6 cm) which was significantly lower than other treatments and at par with T4 & T18. As compared to T20 (10.6 cm) with T12 (17.2 cm) showed a 62.26 % increase in plant height at 30 DAS. **Subsequently,** in the second trial at 30 DAS (2022-2023), plant height ranged from 10.7 cm to 17.1 cm. The maximum plant height was recorded at T19 (17.1 cm) which was significantly higher than other treatments followed by T9 (17.0 cm) and at par with T1, T2, T3, T5, T6, T7, T9, T12, T13 & T14 while the minimum plant height was recorded at T20 (10.70 cm) which was significantly lower than other treatments and at par with T4, T15 & T18. As compared to T20 (10.7 cm) with T19 (17.1 cm) showed a 59.81 % increase in plant height at 30 DAS. From the analysis of both years' average data of year **(2021-2022) & (2022-2023),** it was observed that the maximum plant height was recorded at T12 (17.0 cm), followed by T14, T19 (16.8 per/m^2), while the minimum plant height was recorded at T20 (10.6 cm). As compared to T20 (10.6 cm) with T12 (17.0 cm) showed a 60.37 % increase in plant height at 30 DAS.

At 60 DAS (2021-2022), plant height ranged from 15.0 cm to 30.2 cm. The maximum plant height was recorded at T13 (30.2 cm), which was significantly higher than other treatments, followed by T15 (28.4 cm) and at par with T14, while the minimum plant height was recorded at T9 (15.0 cm). As compared to T9 (15.0 cm) with T13 (30.2 cm) showed a 101.3 % increase in plant height at 60 DAS. **Subsequently,** at 60 DAS (2022- 2023), plant height ranged from 13.8 cm to 29.7 cm. The maximum plant height was recorded at T13 (29.7 cm), which was significantly higher than other treatments, followed by T15 (29.1 cm) and at par with T14, T15, T16, T17 & T20, while the minimum plant height was recorded at T9 (13.8 cm). As compared to T9 (13.8 cm) with at T13 (29.7 cm) showed a 115.21 % increase in plant height at 60 DAS. From the analysis of both years' average data of year **(2021-2022) & (2022-2023),** it was observed that the maximum plant height was recorded at T13 (30.0 cm), followed by T15 (28.8 per/m^2), while the minimum plant height was recorded at T9 (14.4 cm). As compared to T9 (14.4 cm) with T13 (30.0 cm) showed an 108 % increase in plant height at 60 DAS.

At 90 DAS (2021-2022), plant height ranged from 56.8 cm to 74.6 cm. The maximum plant height was recorded at T8 (74.6 cm), which was significantly higher than other treatments, followed by T10 (73.7 cm) and at par with T14, while the minimum plant height was recorded at T19 (56.8 cm), which was significantly lower than other treatments and at par with T16. As compared to T19 (56.8 cm) with at T8 (74.6 cm) showed a 31.33 % increase in plant height at 90 DAS. **Subsequently,** at 90 DAS (2022-2023), plant height ranged from 55.6 cm to 75.6 cm. The maximum plant height was recorded at T14 (75.6 cm), which was significantly higher than other treatments, followed by T10 (73.0 cm), while the minimum plant height was recorded at T1 (55.6 cm), which was significantly lower than other treatments and at par with T19. As compared to T1 (55.6 cm) with T14 (75.6 cm) showed a 35.97% increase in plant height at 90 DAS. From the analysis of both years' average data of year **(2021-2022) & (2022-2023),** it was observed that the maximum plant height was recorded at T14 (74.6 cm), followed by T8 (73.4 cm), while the minimum plant height was recorded at T19 (56.6 cm). As compared to T19 (56.6 cm) with T14 (74.6 cm) showed a 31.80 % increase in plant height at 90 DAS.

At 120 DAS (2021-2022), plant height ranged from 61.8 cm to 79.7 cm. The maximum plant height was recorded at T14 (79.7 cm), which was significantly higher than other treatments, followed by T8 (79.4 cm) and at par with T7, while the minimum plant height was recorded at T19 (61.8 cm). As compared to T19 (61.8 cm) with T14 (79.7 cm) showed a 28.96 % increase in plant height at 120 DAS. **Subsequently,** at 120 DAS (2022- 2023), plant height ranged from 61.2 cm to 80.0 cm. The maximum plant height was recorded at T8 (80.0 cm), which was significantly higher than other treatments, followed by T14 (79.3 cm) and at par with T14, while the minimum plant height was recorded at T19 (61.2 cm). As compared to T19 (61.2 cm) with at T8 (80.0 cm) showed a 30.71 % increase in plant height at 120 DAS.

From the analysis of both years' average data of year **(2021-2022) & (2022-2023),** it was observed that the maximum plant height was recorded at T8 (79.7 cm), followed by T14 (79.5 cm), while the minimum plant height was recorded at T19 (61.5 cm). As compared to T19 (61.5 cm) with T8 (79.7 cm) showed a 29.59 % increase in plant height at 120 DAS. The plant height result of a crop indicates a different range across different treatments. There is very limited scientific evidence on the effect of guava leaves and neem leaves aqueous extract on the plant height of wheat crop. Although guava leaves and neem leaf aqueous extract were enriched in beneficial nutrients & compounds that enhance crop growth. Guava leaves aqueous extract is rich in nitrogen, potassium and phosphorus, which are essential nutrients for plant growth. Guava leaves also contain compounds like flavonoids (quercetin, kaempferol and myricetin), tannins and phenolic compounds (gallic acid, catechin & epicatachin), which all have growth-promoting properties. These compounds can help to protect plants from oxidative stress and diseases, which ultimately can enhance plant growth. These results are similar to the results found by Arifin, Poppy & Nurcholis, Waras & Ridwan, Taufik & Faiza, Lucky & Susilowidodo, Raphael & Batubara, Irmanida & Wisastra, Rosalina. (2017).

4.19.1 Effect of treatments on plant height of wheat (cm) at 30, 60 DAS during the year 2021-2022 & 2022-2023

TREATMENTS	30 DAS			60 DAS		
	2021-2022	**2022-2023**	**AVG.**	**2021-2022**	**2022-2023**	**AVG.**
T1-Absolute control	15.2±0.52	16.2±0.54	15.7	19.2±0.43	19.7±1.179	19.5
T2-100% RDH*	15.9±0.54	15.5±0.83	15.7	26.1±1.37	25.9±1.05	26.0
T3-ELE 5% + 50% H*	14.4±0.64	15.1±0.66	14.8	17.5±1.04	17.9±1.88	17.7
T4-ELE 5% + 75% H*	12.2±1.28	11.8±0.75	12.0	20.9±1.13	19.7±1.25	20.3
T5-ELE 10% + 50% H*	15.9±0.17	15.4±0.75	15.7	19.5±0.28	18.0±0.40	18.8
T6-ELE 10% + 75% H*	13.8±1.56	15.0±1.47	14.4	23.2±0.52	21.9±0.92	22.5
T7-NLE 10% + 50% H*	14.2±0.60	15.1±0.61	14.7	19.0±0.57	17.6±0.40	18.3
T8-NLE 10% + 75% H*	13.3±0.66	13.9±1.20	13.6	19.7±0.38	19.8±1.05	19.8
T9-NLE 15% + 50% H*	15.7±0.88	17.0±0.38	16.4	15.0±0.57	13.8±0.23	14.4
T10-NLE 15% + 75% H*	14.6±0.52	14.3±0.52	14.5	25.3±0.17	25.4±0.41	25.4
T11-GLE 25% + 50% H*	14.2±0.69	14.5±0.96	14.4	25.6±0.38	27.2±0.49	26.4
T12-GLE 25% + 75% H*	17.2±0.52	17.1±0.78	17.1	27.2±0.90	26.5±0.53	26.9
T13-GLE 30% + 50% H*	15.7±1.41	14.8±1.03	15.3	30.2±0.67	29.7±0.96	30.0
T14-GLE 30% + 75% H*	17.1±0.43	16.5±0.59	16.8	28.2±0.64	27.7±1.30	28.0
T15-ELE 5%	13.7±1.16	12.2±1.03	13.0	28.4±0.54	29.1±60	28.8
T16-ELE 10%	15.8±0.90	14.2±0.90	15.0	17.4±0.11	28.4±0.58	22.9
T17-NLE 10%	14.3±0.48	14.4±0.65	14.4	25.6±1.02	27.3±0.49	26.5
T18-NLE 15%	12.2±0.25	12.6±0.20	12.4	23.0±1.03	23.1±0.66	23.0
T19-GLE 25%	16.5±0.89	16.8±0.51	16.8	24.3±1.20	21.5±0.57	22.9
T20- GLE 30%	10.6±0.72	10.7±0.47	10.6	24.0±1.15	27.3±0.47	25.7
CD (P≤0.05)	2.405	2.318		2.216	2.477	
SE(m ±)	0.837	0.807		0.771	0.862	

Note-RDH-recommended dose of herbicide, ELE- eucalyptus leaf extract, NLE- neem leaf extract, GLE- guava leaf extract, SE- standard error and CD (P≤0.05)- critical difference, *2,4 D + Fenoxaprop.

4.19.2. Effect of treatments on plant height of wheat (cm) at 90, 120 DAS during the year 2021-2022 & 2022-2023

TREATMENTS	90 DAS			120 DAS		
	2021-2022	**2022-2023**	**AVG.**	**2021-2022**	**2022-2023**	**AVG.**
T1-Absolute control	56.8±0.91	55.6±1.75	58.5	70.3±0.20	63.4±1.39	66.9
T2-100% RDH*	69.4±1.41	65.5±1.36	67.5	74.5±1.76	73.6±0.78	74.1
T3-ELE 5% + 50% H*	72.0±0.97	70.6±0.91	71.3	76.8±0.73	70.6±0.85	73.7
T4-ELE 5% + 75% H*	62.0±0.89	63.9±0.81	63.0	69.9±0.73	71.3±0.55	70.6
T5-ELE 10% + 50% H*	65.2±0.64	65.7±0.71	65.5	75.6±1.56	73.8±1.05	74.7
T6-ELE 10% + 75% H*	67.0±0.75	61.2±0.66	64.1	77.0±0.14	72.6±0.82	74.8
T7-NLE 10% + 50% H*	67.0±0.87	67.9±0.76	67.5	78.2±0.18	77.0±1.04	77.7
T8-NLE 10% + 75% H*	74.6±0.38	75.6±0.43	73.4	79.4±1.00	80.0±0.79	79.7
T9-NLE 15% + 50% H*	65.3±0.54	63.8±0.65	64.5	74.7±0.57	72.7±1.42	73.7
T10-NLE 15% + 75% H*	73.7±0.29	73.0±1.06	73.3	73.1±0.61	71.7±0.85	72.4
T11-GLE 25% + 50% H*	60.9±1.15	61.3±0.63	61.1	68.7±0.12	66.1±0.83	67.4
T12-GLE 25% + 75% H*	65.3±0.46	62.6±0.63	64.0	71.9±0.29	71.0 ±0.75	71.4
T13-GLE 30% + 50% H*	60.7±1.11	62.2±1.18	61.5	69.6±0.81	66.2±1.27	67.9
T14-GLE 30% + 75% H*	73.6±0.84	72.1±1.10	72.8	79.7±0.82	79.3±1.15	79.5
T15-ELE 5%	64.5±1.08	62.8±0.60	63.7	74.9±0.70	72.5±0.63	73.7
T16-ELE 10%	59.2±0.52	60.3±0.46	59.8	66.7±0.61	67.3±1.34	67.0
T17-NLE 10%	62.6±0.90	61.7±0.75	62.2	73.9±0.64	72.3±1.12	73.1
T18-NLE 15%	62.0±0.97	59.9±0.94	60.9	73.4±0.40	71.1±0.95	72.3
T19-GLE 25%	61.2±0.72	56.3±0.32	56.6	61.8±0.35	61.2±1.01	61.5
T20- GLE 30%	60.3±0.55	61.1±0.86	60.7	67.8±1.62	66.3±1.10	67.0
CD (P≤0.05)	2.477	1.996		2.466	1.563	
SE(m ±)	0.862	0.695		0.858	0.544	

Note-RDH-recommended dose of herbicide, ELE- eucalyptus leaf extract, NLE- neem leaf extract, GLE- guava leaf extract, SE- standard error and CD (P≤0.05)- critical difference, *2,4 D + Fenoxaprop.

4.20. Chlorophyll index of wheat crop

Chlorophyll index is the measure of chlorophyll content present in plant leaves. It is a crucial pigment for photosynthesis. Monitoring chlorophyll index in plants can help in assessing the photosynthetic activity and overall health of the crop, from which farmers or researchers get valuable information to optimize fertilizer management to enhance productivity. The periodic chlorophyll index data **(Table 4.20.1) & (Table 4.20.2)** were taken 30, 60, 90 and 120 days after sowing (DAS). At 30 DAS (2021-2022), the chlorophyll index ranged from 31.6 to 36.8. The maximum chlorophyll index was recorded at T18 (36.8) which was significantly higher than other treatments followed by T8, T16 (36.7) and at par with T1, T2, T3, T4, T5, T6, T7, T9, T10, T11, T14, T15, T17, T19 &, while the minimum chlorophyll index was recorded at T13 (31.6) which was significantly lower than other treatments and at par with T1, T2, T3, T4, T6, T7, T9, T10, T11, T12, T15, T17, T19, & T20. As compared to T13 (31.6) with at T18 (36.8) showed a 16.45% increase in chlorophyll index at 30 DAS. **Subsequently,** in the second trial at 30 DAS (2022-2023), the chlorophyll index ranged from 31.7 to 39.1. The maximum chlorophyll index was recorded at T10 (39.1), which was significantly higher than other treatments, followed by T4 (38.3) and at par with T2, T4, T8, T9, T11, T14 & T20, while the minimum chlorophyll index was recorded at T13 (20.3). As compared to T13 (20.3) With T10 (39.1) showed a 92.61 % increase in chlorophyll index at 30 DAS. From the analysis of both years' average data of year **(2021-2022) & (2022-2023),** it was observed that the maximum chlorophyll index was recorded at T4 (36.6), followed by T8 (36.5), while the minimum chlorophyll index was recorded at T13 (26.0). As compared to T13 (26.0) with T4 (36.6) showed a 40.76 % increase in chlorophyll index at 30 DAS.

At 60 DAS (2021-2022), the chlorophyll index ranged from 35.1 to 49.4. The maximum chlorophyll index was recorded at T4 (49.4) which was significantly higher than other treatments followed by T8, T14 (45.2) and at par with T8, & T14, while the minimum chlorophyll index was recorded at T6 (35.1) which was significantly lower than other treatments and at par with T3, T7, T9, T10, T11, T12, T15, T17, T18, T19 & T20. As compared to T6 (35.1) with T2 (49.4) showed a 40.74 % increase in chlorophyll index at 60 DAS. **Subsequently,** at 60 DAS (2022-2023), the chlorophyll index ranged from 37.3 to 45.1. The maximum chlorophyll index was recorded at T14 (45.1) which was significantly higher than other treatments followed by T8, (44.3) and at par with T4, T5, & T8 while the minimum chlorophyll index was recorded at T6 (35.3) which was significantly lower than other treatments and at par with T3, T6, T7, T9, T11, T12, T15, T17, T18, T19 & T20. As compared to T6 (37.3) with T4 (45.1) showed a 20.91 % increase in chlorophyll index at 60 DAS. From the analysis of both years' average data of year **(2021-2022) & (2022-2023),** it was observed that the maximum chlorophyll index was recorded at T4 (46.3) followed by T14 (45.2) while the minimum chlorophyll index was recorded at T6 (36.2). As compared to

T6 (36.2) with T4 (46.3) showed a 27.90 % increase in chlorophyll index at 60 DAS.

At 90 DAS (2021-2022), the chlorophyll index ranged from 33.6 to 46.2. The maximum chlorophyll index was recorded at T19 (46.2) which was significantly higher than other treatments followed by T18 (45.1) and at par with T1, T2, T4, T5, T7, T10, T14, T18 & T20 while the minimum chlorophyll index was recorded at T17 (33.6) which was significantly lower than other treatments and at par with T3, T6, T9, T12, T13, T15, T16, T17 & T19. As compared to T17 (33.6) with T19 (46.2) showed a 37.5 % increase in chlorophyll index at 90 DAS. **Subsequently,** at 90 DAS (2022-2023), the chlorophyll index ranged from 33.6 to 43.7. The maximum chlorophyll index was recorded at T14 (43.7), which was significantly higher than other treatments, followed by T7 (42.5) and at par with T4, T7, T8, T9 & T15, while the minimum chlorophyll index was recorded at T13 (33.6), which was significantly lower than other treatments and at par with T17. As compared to T13 (33.6) with T14 (43.7) showed a 30.05 % increase in chlorophyll index at 90 DAS. From the analysis of both years' average data of year **(2021-2022) & (2022-2023),** it was observed that the maximum chlorophyll index was recorded at T8 (43.9), followed by T14 (42.9), while the minimum chlorophyll index was recorded at T17 (33.8). As compared to T17 (33.8) with T8 (43.9) showed a 29.88 % increase in chlorophyll index at 90 DAS.

At 120 DAS (2021-2022), the chlorophyll index ranged from 16.6 to 23.4. The maximum chlorophyll index was recorded at T8 (23.4), which was significantly higher than other treatments, followed by T4 (22.3), while the minimum chlorophyll index was recorded at T17 (16.6), which was significantly lower than other treatments and at par with T19. As compared to T17 (16.6) with T8 (23.4) showed a 40.84 % increase in chlorophyll index at 120 DAS. **Subsequently,** at 120 DAS (2022-2023), the chlorophyll index ranged from 17.8 to 22.0. The maximum chlorophyll index was recorded at T8 (22.0) which was significantly higher than other treatments followed by T18 (21.8) and at par with T2, T4, T7, while the minimum chlorophyll index was recorded was recorded at T17, T19 (17.8) which was significantly lower than other treatments and at par with T1, T3, T9, T12, T13, T14, T15, & T16. As compared to T17, T19 (17.8) with T8 (22.0) showed a 23.24 % increase in chlorophyll index at 120 DAS. From the analysis of both years' average data of year **(2021- 2022) & (2022-2023),** it was observed that the maximum chlorophyll index was recorded at T8 (22.7), followed by T18 (22.2), while the minimum chlorophyll index was recorded at T17

4.20.1. Effect of treatments on chlorophyll index of wheat at 30, 60 DAS during the year 2021-2022 & 2022-2023

TREATMENTS	30 DAS			60 DAS		
	2021-2022	2022-2023	AVG.	2021-2022	2022-2023	AVG.
T1-Absolute control	33.2±0.16	32.3±0.56	32.8	41.6±1.53	41.2±0.57	41.4
T2-100% RDH*	35.9±1.46	34.7±0.92	35.4	41.2±0.58	41.4±0.88	41.4
T3-ELE 5% + 50% H*	32.4±0.86	33.6±0.78	33.1	35.8±1.79	40.4±0.60	38.1
T4-ELE 5% + 75% H*	34.9±1.85	38.3±0.39	36.6	49.4±4.1	43.0±1.43	46.3
T5-ELE 10% + 50% H*	36.3±1.59	33.5±0.55	34.9	42.1±0.93	42.9±0.70	42.5
T6-ELE 10% + 75% H*	33.7±2.16	30.4±0.66	32.0	35.1±0.85	37.3±1.60	36.2
T7-NLE 10% + 50% H*	34.8±2.1	32.5±0.38	33.7	37.2±1.11	39.3±0.41	38.3
T8-NLE 10% + 75% H*	36.7±0.15	36.3±0.64	36.5	45.2±0.92	44.3±1.21	44.8
T9-NLE 15% + 50% H*	34.3±0.89	34.1±0.51	34.2	37.2±2.52	38.1±1.75	37.7
T10-NLE 15% + 75% H*	35.4±2.61	39.1±0.54	37.3	37.5±1.05	40.3±0.52	38.9
T11-GLE 25% + 50% H*	34.6±2.56	34.1±1.15	34.4	39.7±2.50	39.2±1.80	39.5
T12-GLE 25% + 75% H*	32.2±0.66	32.5±0.59	32.4	37.1±1.20	40.4±1.13	38.8
T13-GLE 30% + 50% H*	31.6±2.48	20.3±8.31	26.0	43.2±1.75	41.8±0.21	42.5
T14-GLE 30% + 75% H*	36.3±0.10	36.5±0.58	36.4	45.2±2.45	45.1±1.70	45.2
T15-ELE 5%	35.4±2.45	31.7±0.86	33.6	38.2±3.15	38.4±1.59	38.3
T16-ELE 10%	36.7±0.72	33.3±1.19	35.0	41.1±0.63	41.4±0.66	41.3
T17-NLE 10%	33.2±2.28	32.0±0.49	32.6	36.5±1.04	39.1±0.93	37.8
T18-NLE 15%	36.8±1.59	32.5±1.18	34.7	36.9±1.38	37.8±0.98	37.4
T19-GLE 25%	34.6±0.64	33.2±1.3	33.9	35.6±0.64	37.5±1.44	36.6
T20- GLE 30%	32.2±1.18	36.2±1.19	34.2	37.4±1.93	39.3±1.09	38.4
CD (P≤0.05)	4.576	5.386		5.394	3.149	
SE(m ±)	1.599	1.874		1.877	1.096	

Note-RDH-recommended dose of herbicide, ELE- eucalyptus leaf extract, NLE- neem leaf extract, GLE- guava leaf extract, SE- standard error and CD (P≤0.05)- critical difference, *2,4 D + Fenoxaprop.

4.20.2. Effect of treatments on chlorophyll index of wheat at 90, 120 DAS during the year 2021-2022 & 2022-2023

TREATMENTS	90 DAS			120 DAS		
	2021-2022	2022-2023	AVG.	2021-2022	2022-2023	AVG.
T1-Absolute control	40.2±0.86	39.9±0.88	40.1	19.7±0.41	19.2±0.63	19.4
T2-100% RDH*	42.1±1.50	38.4±0.57	40.2	20.8±0.57	20.7±0.88	20.8
T3-ELE 5% + 50% H*	37.1±1.43	40.0±0.81	38.6	18.5±0.20	18.7±1.12	18.6
T4-ELE 5% + 75% H*	42.8±1.60	42.3±1.15	42.6	22.3±0.11	21.0±0.81	21.7
T5-ELE 10% + 50% H*	41.6±0.40	40.8±1.04	41.2	21.5±0.51	19.9±0.93	20.7
T6-ELE 10% + 75% H*	38.5±1.73	37.5±0.94	38.0	19.2±0.18	20.1±0.61	19.7
T7-NLE 10% + 50% H*	41.5±1.99	42.5±1.32	42.0	20.7±0.00	20.7±0.54	20.7
T8-NLE 10% + 75% H*	46.2±2.92	41.5±0.64	43.9	23.4±1.13	22.0±0.98	22.7
T9-NLE 15% + 50% H*	37.9±2.98	41.4±0.75	39.7	19.0±0.52	18.8±0.91	18.9
T10-NLE 15% + 75% H*	41.8±1.20	39.3±0.46	40.6	21.4±0.44	20.3±0.83	20.9
T11-GLE 25% + 50% H*	39.9±0.63	37.5±0.63	38.7	20.1±0.53	20.0±0.89	20.1
T12-GLE 25% + 75% H*	36.8±1.51	36.5±0.49	36.7	18.2±0.41	18.3±1.56	18.3
T13-GLE 30% + 50% H*	37.9±1.28	33.6±1.27	35.8	18.9±0.83	19.3±1.15	19.1
T14-GLE 30% + 75% H*	42.1±2.40	43.7±0.81	42.9	21.1±0.31	19.1±1.44	20.1
T15-ELE 5%	36.0±2.74	41.5±0.56	38.8	18.0±0.60	19.1±0.60	18.6
T16-ELE 10%	38.2±3.44	40.8±0.98	39.5	19.0±0.29	19.3±1.23	19.1
T17-NLE 10%	33.6±2.94	33.9±0.92	33.8	16.6±0.26	17.8±1.52	17.2
T18-NLE 15%	45.1±1.60	38.9±1.04	42.0	22.6±0.66	21.8±0.62	22.2
T19-GLE 25%	34.2±4.16	38.7±0.74	36.5	16.8±0.17	17.8±1.87	17.3
T20- GLE 30%	41.0±2.32	40.7±1.30	40.9	20.5±0.26	20.2±0.87	20.3
CD (P≤0.05)	6.312	2.292		1.405	3.055	
SE(m ±)	2.196	0.797		0.489	1.063	

Note-RDH-recommended dose of herbicide, ELE- eucalyptus leaf extract, NLE- neem leaf extract, GLE- guava leaf extract, SE- standard error and CD (P≤0.05)- critical difference, *2,4 D Fenoxaprop.

(17.2). As compared to T17 (17.2) with T8 (22.7) showed a 31.88 % increase in chlorophyll index at 120 DAS. As per the result, neem leaf aqueous and guava leaf aqueous extracts can influence the chlorophyll index of the wheat crop. Neem leaves and guava leaves contain compounds that have antioxidant properties that can protect the chlorophyll molecules from oxidative damage, which is caused by environmental stresses such as high light intensity or temperature fluctuation in field conditions. By protecting the chlorophyll integrity, the extracts help in maintaining the chlorophyll levels, and as a result, the chlorophyll index of wheat crops was improved. Other than that, neem leaves are also rich in pesticidal properties and can inhibit the growth of certain pests and pathogens, which leads to minimize the damage of chlorophyll-containing tissues, allowing for healthier plants with higher chlorophyll content. Guava leaf aqueous extracts may contain compounds that improve the nutrient uptake too including some essential nutrients, which help in chlorophyll synthesis, such as nitrogen and magnesium. By improving nutrient uptake, the extract indirectly promotes chlorophyll production in the crop and improves the chlorophyll index.

4.21. Tiller number of wheat crop

Tiller number is one of the most important characteristics of the yield attribute of a crop. It provides a proper idea of predicting the growth rate and yield of the crop. It is an important factor for assessing any crop's yield potential and overall plant health. The existing data showed that the tiller numbers in Wheat were different from treatment to treatment without being affected by the average proven data. The periodic tiller number **(Table 4.22.1)** was taken at 60, 90 and 120 days after sowing (DAS). At 60 DAS (2021- 2022), tiller number ranged from 87.0 to 130 per/m row. The maximum tiller number was recorded at T2 (130.7 per/m row), followed by T13 (126.0 per/m row), T7 (123.7 per/m row), T8 (120.7 per/m row), T4 (120.7 per/m row), while the minimum tiller number was recorded at T16 (87.0 per/m row), which was significantly lower than other treatments. As compared to T16 (87.0 per/m row) with T2 (130.7 per/m row) showed a 50.22 % increase in tiller number at 60 DAS. **Subsequently,** in the second trial at 60 DAS (2022-2023), tiller number ranged from 83.0 to 132.0. The maximum tiller number was recorded at T2 (132.0 per/m row), which was significantly higher than other treatments, followed by T15 (123.7 per/m row), T5 (120.3 per/m row), T4 (118.0 per/m row), & T13 (116.7 per/m row), while the minimum tiller number was recorded at T16 (83.0 per/m row). As compared to T16 (83.0 per/m row) with T2 (132.0 per/m row) showed a 59.03% increase in tiller number at 60 DAS. From the analysis of both years' average data of year **(2021-2022) & (2022-2023),** it was observed that the maximum tiller number was recorded at T2 (132.0 per/m row) followed by T5 (121.3 per/m row), T4 (119.3 per/m row**)** while the minimum tiller number was recorded at T16 (85 per/m row). As compared to T16 (85 per/m row) with T2 (132.0 per/m row) showed a 55.29 % increase in tiller number at 60 DAS.

At 90 DAS (2021-2022), tiller number ranged from 111.3 to 133.3. The maximum tiller number was recorded at T2 (133.3 per/m row), which was significantly higher than other treatments, followed by T9 (131.0 per/m row), T8, T14, T4, T5, T11, while the minimum tiller number was recorded at T1 (111.3 per/m row), which was significantly lower than other treatments. As compared to T1 (111.3 per/m row) with T2 (133.3 per/m row) showed a 19.76 % increase in tiller number at 90 DAS. **Subsequently,** at 90 DAS (2022-2023), tiller number ranged from 97.0 to 138.0. The maximum tiller number was recorded at T2 (138.0 per/m row) followed by T4, T14, T5, T6, & T15 (123.7 per/m row) while the minimum tiller number was recorded at T10 (97 per/m row). As compared to T10 (97.0 per/m row) with T2 (138.0 per/m row) showed a 42.26% increase in tiller number at 90 DAS. From the analysis of both years' average data of year **(2021-2022) & (2022-2023),** it was observed that the maximum tiller number was recorded at T2 (135.7 per/m row), followed by T4, T5, & T9 (125.3 per/m row**),** while the minimum tiller number was recorded at T10 (105.0 per/m row). As compared to T10 (105.0 per/m row) with T2 (135.7 per/m row) showed a 29.23 % increase in tiller number at 90 DAS.

At 120 DAS (2021-2022), tiller numbers ranged from 102 to 136.7. The maximum tiller number was recorded at T9 (136.7 per/m row) which was significantly higher than other treatments followed by T2 (136.0 per/m row), T8 (130.3 per/m row), T13 (126.7 per/m row), T5 (125.0 per/m row), T4 (124.0 per/m row) while the minimum tiller number was recorded at T17 (102 per/m row) which was significantly lower than other treatments. As compared to T17 (102 per/m row) with T9 (136.9 per/m row) showed a 34.01 % increase in tiller number at 120 DAS. **Subsequently,** at 120 DAS (2022-2023), tiller numbers ranged from 113.0 to 145. The maximum tiller number was recorded at T2 (145 per/m row), followed by T9 (137.3 per/m row), T8 (132 per/m row), T13 (131.3 per/m row), and T10 (129.7 per/m row), while the minimum tiller number was recorded at T17 (113.0 per/m row). As compared to T17 (113.0 per/m row) with T2 (145 per/m row) showed a 28.31% increase in tiller number at 120 DAS. From the analysis of both years average data of year **(2021-2022) & (2022-2023),** it was observed that the maximum tiller number was recorded at T2 (140.5 per/m row) followed by T9(137.0 per/m row), T8(131.2 per/m row), T5 (125.8 per/m row), T4 (126.8 per/m row), & T6 (126.7 per/m row) while the minimum tiller number was recorded at T17 (107.5 per/m row). As compared to T17 (107.5 per/m row) with T2 (140.5 per/m row) showed a 30.69 % increase in tiller number at 120 DAS. As per the result T2-100% RDH, T4-ELE 5% + 75% H, T8-NLE 10% + 75% H & T14-GLE 30% + 75% H showed the maximum number of tillers. The number of tillers might have improved as recommended fertilizer application with different leaf aqueous extracts made a favourable condition for the crop to grow. Other than that, these leaf extracts contain several plant growth-promoting compounds that potentially increase the total growth. Like eucalyptus leaf, aqueous extract contains auxins, a class of plant hormones, which promote cell elongation, root growth and apical dominance. Neem leaf aqueous extract contains nimbin, which stimulates plant growth and yield, and guava leaf aqueous extract is rich in tannins, which improve nutrient uptake. As a result, tiller numbers were improved.

4.22. Effective tiller number

The effective tiller number does have a pivotal role in the determination of the yield attributes of a crop. Effective tillers are the tillers that contribute significantly to the yield of a crop or to grain production. It normally excludes nonproductive or sterile tillers. The existing data **(Table 4.22.1)** showed that the effective tiller number gradually showed improvement and stable data after 120 DAS. At 120 DAS (2021-2022), the effective tiller number ranged from 75.2 to 102.0. The maximum effective tiller number was recorded at T2 (102.0 per/m row), which was significantly higher than other treatments, followed by T3 (99.3 per/m row), T16 (97.0 per/m row), and T13 (95.0 per/m row), while the minimum effective tiller number was recorded at T1 (74.3 per plant) which was significantly lower than other treatments. As compared to T1 (74.3 per/m row) with T2 (102.0 per/m row) showed a 37.28 % increase in effective tiller number at 120 DAS. **Subsequently,** in the second trial (2022-2023), effective tiller number ranged from 76.0 to 103.7. The maximum effective tiller number was recorded at T2 (103.7 per/m row), which was significantly higher than other treatments, followed by T13(101.7 per/m row), T3(101.0 per/m row), and T16 (98.0 per/m row), while the minimum effective tiller number was recorded at T1 (76.0 per/m row). As compared to T1 (76.0 per/m row) with T2 (103.7 per/m row) showed a 36.44 % increase in effective tiller number at 120 DAS. From the analysis of both years average data of year **(2021-2022) & (2022-2023),** it was observed that the maximum effective tiller number was recorded at T2 (102.8 per/m row) followed by T3 (100.2 per/m row), T13 (98.3 per/m row), T16 (97.5 per/m row) while the minimum effective tiller number was recorded at T1 (75.2 per/m row). As compared to T1 (75.2 per/m row) with T2 (102.8 per/m row) showed a 36.70 % increase in effective tiller number at 120 DAS.

4.22.1. Effect of treatments on tiller number & effective tiller numbers of wheat at 60, 90, 120 DAS during the year 2021-2022 & 2022-2023

	TILLER NUMBER									**EFFECTIVE TILLER**		
TREATMENTS	**60 DAS**			**90 DAS**			**120 DAS**			**120 DAS**		
	2021-2022	**2022-2023**	**AVG**	**2021-2022**	**2022-2023**	**AVG.**	**2021-2022**	**2022-2023**	**AVG**	**2021-2022**	**2022-2023**	**AVG**
T1-Absolute control	106.0±4.3	107.3±14.4	106.7	111.3±6.5	111.7±14.1	111.5	117.0±9.0	118.3±10.7	117.7	74.3±9.3	76.0±13.1	75.2
T2-100% RDH*	130.7±15.3	132.0±2.3	131.3	133.3±3.5	138.0±6.0	135.7	136.0±2.3	145.0±12.5	140.5	102.0±1.7	103.7±12.1	102.8
T3-ELE 5% + 50% H*	100.3±12.6	107.3±8.5	103.8	108.0±9.0	112.0±8.3	110.0	112.0±1.0	112.3±12.6	112.2	99.3±11.6	101.0±4.3	100.2
T4-ELE 5% + 75% H*	120.7±10.9	118.0±14.1	119.3	127.0±15.1	130.0±8.0	128.5	124.0±10.0	129.7±6.7	126.8	87.3±13.3	96.0±15.3	91.7
T5-ELE 10% + 50% H*	122.3±19.7	120.3±24.3	121.3	124.3±20.4	124.7±12.2	124.5	125.0±15.0	126.7±1.3	125.8	86.0±3.6	95.0±1.0	90.5
T6-ELE 10% + 75% H*	112.0±10.0	104.7±7.6	108.3	118.3±16.8	123.7±14.1	121.0	122.7±19.6	130.7±12.7	126.7	89.7±17.0	84.0±15.1	86.8
T7-NLE 10% + 50% H*	123.7±24.7	105.0±3.4	114.3	114.3±16.4	107.0±2.0	110.7	113.0±15.3	120.0±6.9	116.5	82.7±14.3	89.0±14.7	85.8
T8-NLE 10% + 75% H*	120.0±6.1	107.3±14.4	113.7	129.3±7.0	110.7±35.5	120.0	130.3±22.2	132.0±23.7	131.2	86.3±11.4	87.7±13.0	87.0
T9-NLE 15% + 50% H*	105.0±15.1	100.0±10.5	102.5	131.0±20.6	119.7±16.3	125.3	136.7±18.0	137.3±5.8	137.0	92.0±13.1	93.3±27.3	92.7
T10-NLE 15% + 75% H*	103.3±4.6	97.0±11.5	100.2	113.0±4.3	97.0±4.3	105.0	121.3±14.3	129.7±7.7	125.5	85.0±13.4	80.7±21.6	82.8
T11-GLE 25% + 50% H*	96.0±10.3	94.7±11.2	95.3	124.7±11.5	100.0±10.1	112.3	122.7±9.6	124.0±2.3	123.3	92.0±7.2	93.0±1.7	92.5
T12-GLE 25% + 75% H*	107.0±3.6	101.0±2.0	104.0	116.3±4.6	119.0±13.2	117.7	113.3±18.0	116.3±4.9	114.8	89.3±11.8	90.0±9.6	89.7
T13-GLE 30% + 50% H*	126.0±19.2	116.7±25.3	121.3	117.7±11.9	120.7±25.9	119.2	126.7±3.5	131.3±9.9	129.0	95.0±2.6	101.7±13.1	98.3
T14-GLE 30% + 75% H*	112.7±14.0	102.0±3.4	107.3	128.3±1.6	126.3±7.7	127.3	113.7±9.8	121.0±17.1	117.3	81.0±7.9	83.0±5.2	82.0
T15-ELE 5%	113.3±16.2	123.7±14.1	118.5	120.0±15.1	123.7±13.1	121.8	122.7±8.1	128.0±16.6	125.3	90.7±14.4	93.3±15.0	92.0
T16-ELE 10%	87.0±21.0	83.0±8.5	85.0	118.0±14.7	110.7±7.4	114.3	118.7±11.3	119.7±10.8	119.2	97.0±1.0	98.0±2.6	97.5
T17-NLE 10%	109.0±26.0	111.0±10.8	110.0	117.7±11.4	115.7±8.6	116.7	102.0±1.7	113.0±15.5	107.5	90.3±10.2	89.0±8.5	89.7
T18-NLE 15%	106.7±7.0	105.0±9.6	105.8	114.0±10.3	114.7±3.5	114.3	121.0±11.2	129.3±3.5	125.2	88.0±11.1	85.7±8.8	86.8
T19-GLE 25%	110.0±11.5	101.3±11.8	105.7	115.0±14.5	114.0±12.0	114.5	114.3±10.8	122.3±6.1	118.3	91.3±10.6	88.7±7.5	90.0
T20- GLE 30%	100.7±6.3	93.7±5.2	97.2	114.3±5.4	115.3±12.8	114.8	122.3±12.1	128.0±4.6	125.2	89.0±11.7	96.0±3.4	92.5
CD (P≤0.05)	**NA**	**NA**		**NA**	**NA**		**NA**	**NA**		**NA**	**NA**	
SE(m ±)	**14.29**	**10.98**		**11.76**	**13.55**		**12.78**	**11.23**		**11.03**	**11.04**	

Note-RDH-recommended dose of herbicide, ELE- eucalyptus leaf extract, NLE- neem leaf extract, GLE- guava leaf extract, SE- standard error and CD (P≤0.05)- critical difference. *2,4 D + Fenoxaprop.

4.23. ***Phalaris minor* population of wheat crop**

It is a weed, which commonly found in wheat crop fields. Its population can negatively impact the total yield of the wheat crop. The periodic *Phalaris minor* population data **(Table 4.23.1) & (Table 4.23.2)** were taken at 30, 60, 90 & 120 days after sowing (DAS). In Wheat, at 30 DAS (2021-2022), *Phalaris minor* population ranged from 20.3 to 40.7 per/m^2. The maximum *Phalaris minor* population was recorded at T1 (40.7 per/m^2) which was significantly higher than other treatments followed by T15 (31.0 per/m^2) while the minimum *Phalaris minor* population was recorded at T6 (20.3 per/m^2) which was significantly lower than other treatments and at par with T2, T4, T5, T7, T8, T9, T12, T17, T19, & T20. As compared to T1 (40.7 per/m^2) with T6 (20.3 per/m^2) showed a 50.12 % decrease in *Phalaris minor* population at 30 DAS. **Subsequently,** in the second trial at 30 DAS (2022-2023), *Phalaris minor* population ranged from 23.0 to 41.3 per/m^2. The maximum *Phalaris minor* population was recorded at T1 (41.3 per/m^2) which was significantly higher than other treatments followed by T12 (36.3 per/m^2) while the minimum *Phalaris minor* population was recorded at T5 & T17 (23.0 per/m^2) which was significantly lower than other treatments and at par with T4, T6, T8, T18, & T19. As compared to T1 (41.3 per/m^2) with T17 (23.0 per/m^2) showed a 44.37 % decrease in *Phalaris minor* population at 30 DAS. From the analysis of both years' average data of year **(2021-2022) & (2022-2023),** it was observed that the maximum *Phalaris minor* population was recorded at T1 (41.0 per/m^2), followed by T11 (31.7 per/m^2), while the minimum *Phalaris minor* population was recorded at T17 (23.3 per/m^2). As compared to T1 (41.0 per/m^2) with T17 (23.3 per/m^2) showed a 43.17 % decrease in *Phalaris minor* population at 30 DAS.

At 60 DAS (2021-2022), *Phalaris minor* population ranged from 8.7 to 41.3 per/m^2. The maximum *Phalaris minor* population was recorded at T1 (41.3 per/m^2), which was significantly higher than other treatments, followed by T6 (21.0 per/m^2), while the minimum *Phalaris minor* population was recorded at T4 (8.7 per/m^2) which was significantly lower than other treatments and at par with T2, T8, T10, & T14. As compared to T1 (41.3 per/m^2) with T4 (8.7 per/m^2) showed a 78.93 % decrease in *Phalaris minor* population at 60 DAS. **Subsequently** at 60 DAS (2022-2023), *Phalaris minor* population ranged from 9.3 to 43.6 per/m^2. The maximum *Phalaris minor* population was recorded at T1 (43.6 per/m^2) which was significantly higher than other treatments followed by T9 (20.6 per/m^2) while the minimum *Phalaris minor* population was recorded at T8 (9.3 per/m^2), which was significantly lower than other treatments and at par with T2 & T4. As compared to T1 (43.6 per/m^2) with T8 (9.3 per/m^2) showed a 78.66% decrease in *Phalaris minor* population at 60 DAS. From the analysis of both years' average data of the year **(2021-2022) & (2022-2023),** it was observed that the maximum *Phalaris minor* population was recorded at T1 (42.5 per/m^2) followed by T9 (20.3 per/m^2), while the minimum *Phalaris minor* population was recorded at T4 (9.3 per/m^2). As compared to T1 (42.5 per/m^2) with T4 (9.3 per/m^2) showed a 78.11 % decrease in *Phalaris minor* population at 60 DAS.

At 90 DAS (2021-2022), *Phalaris minor* population ranged from 6.7 to 43.0 per/m^2. The maximum *Phalaris minor* population was recorded at T1 (43.0 per/m^2), which was significantly higher than other treatments, followed by T6 (22.7 per/m^2), while the minimum *Phalaris minor* population was recorded at T4 (6.7 per/m^2), which was significantly lower than other treatments and at par with T2, T8, & T10. As compared to T1 (43.0 per/m^2) with T4 (6.7 per/m^2) showed an 84.41 % decrease in *Phalaris minor* population at 90 DAS. **Subsequently,** at 90 DAS (2022-2023), *Phalaris minor* population ranged from 6.3 to 42.6 per/m^2. The maximum *Phalaris minor* population was recorded at T1 (42.6 per/m^2), which was significantly higher than other treatments, followed by T9 (16.0 per/m^2), while the minimum *Phalaris minor* population was recorded at T4 (6.3 per/m^2). As compared to T1 (42.6 per/m^2) with T4 (6.3 per/m^2) showed an 85.21 % decrease in *Phalaris minor* population at 90 DAS. From the analysis of both years' average data of year **(2021-2022) & (2022-2023),** it was observed that the maximum *Phalaris minor* population was recorded at T1 (42.8 per/m^2), followed by T6 (19.0 per/m^2), while the minimum *Phalaris minor* population was recorded at T4 (6.5 per/m^2). As compared to T1 (42.8 per/m^2) with T4 (6.5 per/m^2) showed an 84.81 % decrease in *Phalaris minor* population at 90 DAS.

At 120 DAS (2021-2022) the *Phalaris minor* population ranged from 5.0 to 42.3 per/m^2. The maximum *Phalaris minor* population was recorded at T1 (42.3 per/m^2), which was significantly higher than other treatments followed by T6 (22.0 per/m^2), while the minimum *Phalaris minor* population was recorded at T4 (5.0 per/m^2), which was significantly lower than other treatments and at par with T2. As compared to T1 (42.3 per/m^2) with T4 (5.0 per/m^2) showed 87.89 % decrease in *Phalaris minor* population at 120 DAS. **Subsequently,** at 120 DAS (2022-2023), *Phalaris minor* population ranged from 6.6 to 41.3 per/m^2. The maximum *Phalaris minor* population was recorded at T1 (41.3 per/m^2)

4.23.1. Effect of treatments on *Phalaris minor* population (per m^2) of wheat at 30, 60 DAS during the year 2021-2022 & 2022-2023

TREATMENTS	**30 DAS**			**60 DAS**		
	2021-2022	**2022-2023**	**AVG.**	**2021-2022**	**2022-2023**	**AVG.**
T1-Absolute control	40.7±1.20	41.3±2.40	41.0	41.3±1.33	43.6±2.40	42.5
T2-100% RDH*	26.3±1.85	28.6±1.45	27.5	11.0±1.15	10.0±0.57	10.5
T3-ELE 5% + 50% H*	29.0±1.52	30.0±0.57	29.5	15.7±1.20	17.0^{b}±1.52	16.3
T4-ELE 5% + 75% H*	27.0±3.51	26.3±1.45	26.7	8.7±0.88	10.0±0.57	9.3
T5-ELE 10% + 50% H*	25.0±2.08	23.0±2.08	24.0	13.7±0.33	12.0±0.57	12.8
T6-ELE 10% + 75% H*	20.3±0.88	25.3±1.45	22.8	21.0±0.57	16.6±1.45	18.8
T7-NLE 10% + 50% H*	24.3±2.40	27.3±1.45	25.8	13.3±1.76	14.3±1.45	13.8
T8-NLE 10% + 75% H*	23.7±0.88	26.3±1.45	25.0	10.0±0.57	9.3±0.33	9.7
T9-NLE 15% + 50% H*	27.0±2.08	28.3±1.45	27.7	20.0±2.08	20.6±1.20	20.3
T10-NLE 15% + 75% H*	29.0±2.51	30.0±0.57	29.5	11.3±1.45	14.3±1.15	12.8
T11-GLE 25% + 50% H*	30.3±3.84	33.0±1.76	31.7	17.7±1.20	15.6±1.20	16.7
T12-GLE 25% + 75% H*	26.3±1.85	36.3±1.45	31.3	13.7±0.88	14.0±0.57	13.8
T13-GLE 30% + 50% H*	29.7±3.48	28.3±2.08	29.0	16.0±1.52	15.6±0.66	15.8
T14-GLE 30% + 75% H*	27.7±3.18	28.0±1.20	27.8	10.7±1.76	12.0±0.88	11.3
T15-ELE 5%	31.0±2.88	30.6±1.73	30.8	14.7±1.20	14.6±0.57	14.7
T16-ELE 10%	29.3±2.90	28.0±1.73	28.7	16.7±1.85	13.3±0.88	15.0
T17-NLE 10%	23.7±2.60	23.0±1.45	23.3	15.0±2.64	13.0±0.57	14.0
T18-NLE 15%	29.7±2.33	25.6±0.57	27.7	14.0±0.57	15.3±0.88	14.7
T19-GLE 25%	25.0±2.51	26.0±0.57	25.5	16.0±1.15	16.0±1.15	16.0
T20- GLE 30%	24.7±2.33	28.6±1.45	26.7	15.7±0.88	14.3±1.20	15.0
CD (P≤0.05)	6.950	3.720		3.926	2.397	
SE(m ±)	2.418	1.294		1.366	0.834	

Note-RDH-recommended dose of herbicide, ELE- eucalyptus leaf extract, NLE- neem leaf extract, GLE- guava leaf extract, SE- standard error and CD (P≤0.05)- critical difference, *2,4 D + Fenoxaprop.

4.23.2. Effect of treatments on *Phalaris minor* population (per m^2) of wheat at 90, 120 DAS during the year 2021-2022 & 2022-2023

TREATMENTS	90 DAS			120 DAS		
	2021-2022	**2022-2023**	**AVG.**	**2021-2022**	**2022-2023**	**AVG.**
T1-Absolute control	43.0±1.52	42.6±2.33	42.8	42.3±0.57	41.3±1.45	41.8
T2-100% RDH*	7.3±0.88	8.6±0.88	8.0	6.3±0.88	7.0±0.57	6.7
T3-ELE 5% + 50% H*	14.0±0.57	13.3±0.33	13.7	13.3±0.88	10.0±0.57	11.7
T4-ELE 5% + 75% H*	6.7±0.88	6.3±0.33	6.5	5.0±0.57	6.6±0.88	5.8
T5-ELE 10% + 50% H*	13.3±0.88	10.0±0.57	11.7	13.0±0.57	9.0±0.57	11.0
T6-ELE 10% + 75% H*	22.7±1.45	15.3±1.45	19.0	22.0±0.57	15.0±1.15	18.5
T7-NLE 10% + 50% H*	13.3±1.20	12.0±0.57	12.7	13.0±0.57	11.3±0.88	12.2
T8-NLE 10% + 75% H*	9.3±0.88	9.3±0.33	9.3	9.0±0.57	8.6±0.33	8.8
T9-NLE 15% + 50% H*	19.0±2.08	16.0±1.15	17.5	17.7±1.85	13.6±1.20	15.7
T10-NLE 15% + 75% H*	9.7±0.88	10.0±0.57	9.8	9.0±0.57	8.0±0.57	8.5
T11-GLE 25% + 50% H*	17.0±1.00	14.3±0.88	15.7	16.3±1.45	12.3±0.88	14.3
T12-GLE 25% + 75% H*	17.0±1.73	11.6±0.33	14.3	16.0±1.73	10.6±0.66	13.3
T13-GLE 30% + 50% H*	15.3±0.88	10.6±1.20	13.0	15.0±0.57	8.6±0.33	11.8
T14-GLE 30% + 75% H*	10.0±1.52	10.0±0.57	10.0	9.7±0.33	9.3±0.33	9.5
T15-ELE 5%	13.3±0.66	11.0±0.57	12.2	12.7±1.20	9.3±0.33	11.0
T16-ELE 10%	15.0±0.57	13.6±0.88	14.3	14.0±1.15	10.6±0.66	12.3
T17-NLE 10%	13.0±0.57	11.0±0.57	12.0	12.3±0.88	11.3±0.33	11.8
T18-NLE 15%	13.0±1.00	10.6±1.20	11.8	12.0±0.57	11.0±0.57	11.5
T19-GLE 25%	14.3±1.45	13.3±1.20	13.8	13.3±0.88	11.0±0.57	12.2
T20- GLE 30%	13.0±0.57	12.0±1.15	12.5	12.7±0.33	12.0±0.57	12.3
CD (P≤0.05)	3.227	2.272		2.651	2.030	
SE(m ±)	1.123	0.793		0.922	0.706	

Note-RDH-recommended dose of herbicide, ELE- eucalyptus leaf extract, NLE- neem leaf extract, GLE- guava leaf extract, SE- standard error and CD (P≤0.05)- critical difference. *2,4 D + Fenoxaprop.

which was significantly higher than other treatments followed by T6 (15.0 per/m2), while the minimum Phalaris minor population was recorded at T4 (6.6 per/m2), which was significantly lower than other treatments and at par with T2, T8, T10, & T13. As compared to T1 (41.3 per/m2) with T4 (6.6 per/m2) showed an 84.01 % decrease in Phalaris minor population at 120 DAS. From the analysis of both years' average data of year (2021-2022) & (2022-2023), it was observed that the maximum Phalaris minor population was recorded at T1 (41.8 per/m2), followed by T6 (18.5 per/m2), while the minimum Phalaris minor population was recorded at T4 (5.8 per/m2). As compared to T1 (41.8 per/m2) with T4 (5.8 per/m2) showed an 86.12 % decrease in Phalaris minor population at 120 DAS. As per the result, T4- ELE 5% + 75% H was the best among all the other treatments used to control the Phalaris minor population in field conditions. Eucalyptus leaf aqueous extract contains a variety of bioactive compounds that can help to penetrate the weed cell walls and control them. Among all the compounds present in eucalyptus leaves, eucalyptol is the one that has been shown to have strong herbicidal properties. When eucalyptus leaves, aqueous extract is applied to *Phalaris minor,* the eucalyptol can penetrate the cell wall and membrane of the weeds. As a result, it disrupts the cellular process of the weed and causes damage to the tissues, leading to the eventual death of the weed plant. Eucalyptol also affects the hormonal balance of plants, which can inhibit cell elongation and cell division. This can cause stunted growth and reduce biomass production in plants. In addition to that, other bioactive compounds that are present in eucalyptus leaf aqueous extract may also contribute to some herbicidal effects. For example, the presence of tannins in eucalyptus leaf extracts can reduce and inhibit the growth of weeds by disrupting their metabolism and cellular processes.

4.24. *Anagalis arvensis* population in the wheat crop

The periodic *Anagalis arvensis* population data **(Table 4.24.1) & (Table 4.24.2)** was taken at 30, 60, 90 & 120 days after sowing (DAS). In Wheat, at 30 DAS (2021-2022), *Anagalis arvensis* population ranged from 30.0 to 52.0 per/m^2. The maximum *Anagalis arvensis* population was recorded at T1 (52.0 per/m^2) which was significantly higher than other treatments followed by T9, & T13 (44.0 per/m^2) and at par with T9, & T13 while the minimum *Anagalis arvensis* population was recorded at T2 (30.0 per/m^2) which was significantly lower than other treatments and at par with T3, T4, T6, T10, T11, T12, T14, & T18. As compared to T1 (52.0 per/m^2) with T2 (30.0 per/m^2) showed a 42.30 % decrease in *Anagalis arvensis* population at 30 DAS. **Subsequently,** in the second trial at 30 DAS (2022-2023), *Anagalis arvensis* population ranged from 34.6 to 43.0 per/m^2. The maximum *Anagalis arvensis* population was recorded at T1 (43.0 per/m^2) which was significantly higher than other treatments followed by T5 (42.3 per/m^2) and at par with T7, T8, & T20, while the minimum *Anagalis arvensis* population was recorded at T2 (34.6 per/m^2) which was significantly lower than other treatments and at par with T4, T10, T11, T12, T14, T17, T18 & T19. As compared to T1 (43.0 per/m^2) with T2 (34.6 per/m^2) showed a 19.53 % decrease in *Anagalis arvensis* population at 30 DAS. From the analysis of both years' average data of year **(2021-2022) & (2022-2023),** it was observed that the maximum

Anagalis arvensis population was recorded at T1 (47.5 per/m^2), followed by T5 (43.0 per/m^2), while the minimum *Anagalis arvensis* population was recorded at T2 (32.3 per/m^2). As compared to T1 (47.5 per/m^2) with T2 (32.3 per/m^2) showed a 32.00 % decrease in *Anagalis arvensis* population at 30 DAS.

At 60 DAS (2021-2022), *Anagalis arvensis* population ranged from 6.3 to 51.7 per/m^2. The maximum *Anagalis arvensis* population was recorded at T1 (51.7 per/m^2), which was significantly higher than other treatments, followed by T4 (22.0 per/m^2), while the minimum *Anagalis arvensis* population was recorded at T3 (6.3 per/m^2), which was significantly lower than other treatments and at par with T2. As compared to T1 (51.7 per/m^2) with T3 (6.3 per/m^2) showed an 87.81 % decrease in *Anagalis arvensis* population at 60 DAS. **Subsequently,** at 60 DAS (2022-2023), *Anagalis arvensis* population ranged from 10.0 to 43.3 per/m^2. The maximum *Anagalis arvensis* population was recorded at T1 (43.3 per/m^2) which was significantly higher than other treatments followed by T6 (23.0 per/m^2) while the minimum *Anagalis arvensis* population was recorded at T7 and T15 (10.0 per/m^2) which was significantly lower than other treatments and at par with T2, T3, T4, T13, & T16. As compared to T1 (43.3 per/m^2) with T7 and T15 (10.0 per/m^2) showed a 76.90 % decrease in *Anagalis arvensis* population at 60 DAS. From the analysis of both years average data of the year **(2021-2022) & (2022-2023),** it was observed that the maximum *Anagalis arvensis* population was recorded at T1 (47.5 per/m^2), followed by T6 (20.2 per/m^2), while the minimum *Anagalis arvensis* population was recorded at T3 (9.2 per/m^2). As compared to T1 (47.5 per/m^2) with T3 (9.2 per/m^2) showed an 80.63 % decrease in *Anagalis arvensis* population at 60 DAS.

At 90 DAS (2021-2022), *Anagalis arvensis* population ranged from 6.0 to 48.3 per/m^2. The maximum *Anagalis arvensis* population was recorded at T1 (48.3 per/m^2), which was significantly higher than other treatments, followed by T4 (20.3 per/m^2), while the minimum *Anagalis arvensis* population was recorded at T3 (6.0 per/m^2), which was significantly lower than other treatments and at par with T2. As compared to T1 (48.3 per/m^2) with T3 (6.0 per/m^2) showed a 87.57 % decrease in *Anagalis arvensis* population at 90 DAS. **Subsequently,** at 90 DAS (2022-2023), *Anagalis arvensis* population ranged from 8.3 to 45.0 per/m^2. The maximum *Anagalis arvensis* population was recorded at T1 (45.0 per/m^2), which was significantly higher than other treatments, followed by T6 (18.0 per/m^2)

while the minimum *Anagalis arvensis* population was recorded at T2 and T7 (8.3 per/m^2) which was significantly lower than other treatments and at par with T4, T8, T13 & T16. As compared to T2 and T7 (8.3 per/m^2) with T1 (45.0 per/m^2) showed an 81.55 % increase in *Anagalis arvensis* population at 90 DAS. From the analysis of both years' average data of year **(2021-2022) & (2022-2023),** it was observed that the maximum *Anagalis arvensis* population was recorded at T1 (46.7 per/m^2), followed by T6 (17.2 per/m^2), while the minimum *Anagalis arvensis* population was recorded at T2 (8.0 per/m^2). As compared to T1 (46.7 per/m^2) with T2 (8.0 per/m^2) showed an 82.86 % decrease in *Anagalis arvensis* population at 90 DAS.

At 120 DAS (2021-2022), *Anagalis arvensis* population ranged from 5.3 to 47.3 per/m^2. The maximum *Anagalis arvensis* population was recorded at T1 (47.3 per/m^2), which was significantly higher than other treatments, followed by T4 (19.3 per/m^2), while the minimum *Anagalis arvensis* population was recorded at T3 (5.3 per/m^2), which was significantly lower than other treatments and at par with T3. As compared to T1 (47.3 per/m^2) with T3 (5.3 per/m^2) showed an 88.79 % decrease in *Anagalis arvensis* population at 120 DAS. **Subsequently,** at 120 DAS (2022-2023), *Anagalis arvensis* population ranged from 6.6 to 45.0 per/m^2. The maximum *Anagalis arvensis* population was recorded at T1 (45.0 per/m^2), which was significantly higher than other treatments followed by T6 (13.6 per/m^2), while the minimum *Anagalis arvensis* population was recorded at T2 and T7 (6.6 per/m^2), which was significantly lower than other treatments and at par with T3, & T8. As compared to T1 (45.0 per/m^2) with T2 and T7 (6.6 per/m^2) showed an 85.33 % increase in *Anagalis arvensis* population at 1200 DAS. From the analysis of both years' average data of year **(2021-2022) & (2022-2023),** it was observed that the maximum *Anagalis arvensis* population was recorded at T1 (47.0 per/m^2), followed by T4 (17.0 per/m^2), while the minimum *Anagalis arvensis* population was recorded at T2 (6.7 per/m^2). As compared to T1 (47.0 per/m^2) with T2 (6.7 per/m^2) showed an 85.74 % decrease in *Anagalis arvensis* population at 120 DAS. As per the result, the best treatments were the ones with reduced dosage of herbicide in combination with eucalyptus & neem leaf aqueous extracts. Studies showed that neem leaves could be effective in controlling weed species by affecting their growth. The active ingredients in neem leaves, such as azadirachtin, salannin and meliantriol have been found to be toxic to weed species and can inhibit the growth of weeds. Other than that, eucalyptus leaves contain allelochemicals such as terpinoids, phenolics and flavonoids.

These properties show weed control properties against species like *Anagalis arvensis.* These properties inhibit the weeds' germination, growth and development by reducing root and shoot growth and disrupting the physiological processes like photosynthesis. Specifically, the allelochemicals present in eucalyptus leaf aqueous extract can disrupt the hormonal balance within weeds, inhibit enzyme activity and disrupt cell membrane integrity, ultimately leading to weed suppression. Furthermore, eucalyptus leaf aqueous extract releases allelopathic compounds to the soil by the decomposition of weeds for further inhibiting weed growth and providing long-lasting weed control effects.

4.24.1. Effect of treatments on *Anagalis arvensis* population (per m^2) in wheat at 30, 60 DAS during the year 2021-2022 & 2022-2023

TREATMENTS	**30 DAS**			**60 DAS**		
	2021-2022	**2022-2023**	**AVG**	**2021-2022**	**2022-2023**	**AVG**
T1-Absolute control	52.0±2.30	43.0±1.73	47.5	51.7±3.18	43.3±2.96	47.5
T2-100% RDH*	30.0±3.21	34.6±0.88	32.3	8.3±0.66	10.6±0.33	9.5
T3-ELE 5% + 50% H*	37.0±1.52	39.0±2.08	38.0	6.3±0.88	12.0±1.15	9.2
T4-ELE 5% + 75% H*	30.7±1.20	36.6±1.20	33.7	22.0±1.52	11.0±0.57	16.5
T5-ELE 10% + 50% H*	43.7±1.85	42.3±1.45	43.0	17.7±0.88	14.0±1.15	15.8
T6-ELE 10% + 75% H*	37.3±2.33	39.0±1.15	38.2	17.3±0.66	23.0±1.73	20.2
T7-NLE 10% + 50% H*	42.0±1.15	39.6±2.02	40.8	14.3±0.88	10.0±0.57	12.2
T8-NLE 10% + 75% H*	42.0±4.58	42.0±1.15	42.0	15.0±3.64	13.6±0.66	14.3
T9-NLE 15% + 50% H*	44.0±1.52	38.6±0.88	41.3	18.3±0.33	16.0±1.15	17.2
T10-NLE 15% + 75% H*	36.7±1.33	37.6±1.33	37.2	17.0±0.57	17.3±0.88	17.2
T11-GLE 25% + 50% H*	38.3±3.93	36.6±1.76	37.5	15.7±1.20	15.0±1.15	15.3
T12-GLE 25% + 75% H*	34.0±2.51	38.6±0.88	36.3	16.3±1.20	13.3±0.88	14.8
T13-GLE 30% + 50% H*	44.0±5.03	38.6±1.20	41.3	15.0±1.00	11.6±0.66	13.3
T14-GLE 30% + 75% H*	32.0±1.52	37.3±0.88	34.7	14.7±2.33	16.0±1.15	15.3
T15-ELE 5%	42.7±2.40	39.0±0.57	40.8	13.3±1.20	10.0±0.57	11.7
T16-ELE 10%	42.7±3.38	38.6±0.88	40.7	15.0e±2.64	11.0±0.57	13.0
T17-NLE 10%	42.0±4.16	37.0±1.15	39.5	16.7±1.45	16.0±0.57	16.3
T18-NLE 15%	36.7±2.02	36.3±1.20	36.5	17.7±0.88	16.0±1.15	16.8
T19-GLE 25%	39.3±2.60	37.3±0.88	38.3	18.3±0.33	15.3±0.88	16.8
T20- GLE 30%	42.3±1.45	39.6±1.45	41.0	17.0±0.57	13.3±0.88	15.2
CD (P≤0.05)	8.040	3.793		4.276	2.305	
SE(m ±)	2.798	1.320		1.488	0.802	

Note-RDH-recommended dose of herbicide, ELE- eucalyptus leaf extract, NLE- neem leaf extract, GLE- guava leaf extract, SE- standard error and CD (P≤0.05)- critical difference, *2,4 D + Fenoxaprop.

4.24.2. Effect of treatments on *Anagalis arvensis* population (per m^2) in wheat at 30, 60 DAS during the year 2021-2022 & 2022-2023

TREATMENTS	**90 DAS**			**120 DAS**		
	2021-2022	**2022-2023**	**AVG.**	**2021-2022**	**2022-2023**	**AVG.**
T1-Absolute control	48.3±3.38	45.0±2.51	46.7	47.3±2.60	45.0±2.08	47.0
T2-100% RDH*	7.7±0.88	8.3±0.88	8.0	5.3±0.33	6.6±0.66	6.7
T3-ELE 5% + 50% H*	6.0e±0.57	10.6±0.88	8.3	5.7±0.33	7.6±0.66	7.0
T4-ELE 5% + 75% H*	20.3±0.33	9.0±0.57	14.7	19.3±0.33	8.6±0.33	17.0
T5-ELE 10% + 50% H*	17.3±0.88	13.0±1.15	15.2	17.0±0.57	11.0±0.57	16.1
T6-ELE 10% + 75% H*	16.3±0.33	18.0±1.15	17.2	16.0±1.52	13.6±1.45	16.6
T7-NLE 10% + 50% H*	13.3±0.66	8.3±0.33	10.8	12.7±0.66	6.6±0.33	11.8
T8-NLE 10% + 75% H*	13.0±1.00	10.0±0.57	11.5	12.7±0.88	7.3±0.33	12.1
T9-NLE 15% + 50% H*	16.7±0.88	11.3±0.88	14.0	16.0±0.57	11.0±0.57	15.0
T10-NLE 15% + 75% H*	16.7±0.88	13.0±0.57	14.8	15.3±0.33	11.3±0.33	15.1
T11-GLE 25% + 50% H*	15.7±0.88	11.3±0.88	13.5	14.0±0.57	12.3±0.33	13.8
T12-GLE 25% + 75% H*	15.7±1.85	12.3±0.88	14.0	15.0±0.57	12.3±0.66	14.5
T13-GLE 30% + 50% H*	14.7±0.66	10.3±0.88	12.5	14.0±1.00	9.6±0.33	13.3
T14-GLE 30% + 75% H*	14.0±0.57	13.0±0.57	13.5	13.3±1.45	11.0±0.57	13.4
T15-ELE 5%	12.7±0.66	11.0±0.57	11.8	11.7±0.88	9.3±0.33	11.8
T16-ELE 10%	14.0±1.52	10.3±0.88	12.2	13.7±0.66	10.3±0.33	12.9
T17-NLE 10%	16.3±1.85	16.0±1.15	16.2	13.7±1.45	13.3±0.88	14.9
T18-NLE 15%	17.0±0.57	14.6±0.88	15.8	16.7±0.88	12.3±0.88	16.3
T19-GLE 25%	16.7±0.33	13.0±1.00	14.8	16.3±1.20	11.3±0.88	15.6
T20- GLE 30%	16.3±0.88	13.3±0.33	14.8	15.7±0.88	10.3±0.88	15.3
CD (P≤0.05)	3.482	2.021		3.025	2.000	
SE(m ±)	1.212	0.703		1.053	0.696	

Note-RDH-recommended dose of herbicide, ELE- eucalyptus leaf extract, NLE- neem leaf extract, GLE- guava leaf extract, SE- standard error and CD (P≤0.05)- critical difference, *2,4 D + Fenoxaprop.

4.25. Effect of weed intensity on wheat crop

The periodic weed intensity *of Phalaris minor* data **(Table 4.25.1) & (Table 4.25.2)** was taken at 30, 60, 90 & 120 days after sowing (DAS). In Wheat, at 30 DAS (2021-2022), weed intensity *of Phalaris minor* ranged from 35.0 % to 59.5 %. The maximum weed intensity *of Phalaris minor* was recorded at T18 (59.5 %) which was significantly higher than other treatments followed by T1 (51.7 %) and at par with T1, & T10 while the minimum weed intensity *of Phalaris minor* was recorded at T6 (35.0 %) which was significantly lower than other treatments and at par with T8, T12, T17 & T19. As compared to T18 (59.5 %) with T6 (35.0 %) showed a 41.17 % decrease in weed intensity *of Phalaris minor at* 30 DAS. **Subsequently,** in the second trial at 30 DAS (2022-2023), weed intensity *of Phalaris minor* ranged from 39.5 % to 60.2 %. The maximum weed intensity *of Phalaris minor* was recorded at T12 (60.2 %), which was significantly higher than other treatments, followed by T1 (58.1 %) and at par with T1 while the minimum weed intensity *of Phalaris minor* was recorded at T17 (39.5 %) which was significantly lower than other treatments and at par with T6, T13, & T19. As compared to T12 (60.2 %) with T17 (39.5 %) showed a 34.38 % decrease in weed intensity *of Phalaris minor* at 30 DAS. From the analysis of both years' average data of year **(2021-2022) & (2022-2023),** it was observed that the maximum weed intensity *of Phalaris minor* was recorded at T1 (56.9 %), followed by T18 (54.6 %), while the minimum weed intensity *of Phalaris minor* was recorded at T6 (38.2 %). As compared to T1 (56.9 %), T6 (38.2 %) showed a 32.86 % decrease in weed intensity *of Phalaris minor* at 30 DAS.

At 60 DAS (2021-2022), weed intensity *of Phalaris minor* ranged from 20.7 % to 53.9 %. The maximum weed intensity *of Phalaris minor* was recorded at T1 (53.9 %) which was significantly higher than other treatments, followed by T6 (43.0 %) while the minimum weed intensity *of Phalaris minor* was recorded at T4 (20.7 %) which was significantly lower than other treatments and at par with T2, T5, T8, T10, T12, & T14. As compared to T1 (53.9 %) with T4 (20.7 %) showed a 61.59 % decrease in weed intensity *of Phalaris minor at* 60 DAS. **Subsequently,** at 60 DAS (2022-2023), weed intensity *of Phalaris minor* ranged from 20.7 % to 57.6 %. The maximum weed intensity *of Phalaris minor* was recorded at T1 (57.6 %), which was significantly higher than other treatments, followed by T9 (40.7 %), while the minimum weed intensity *of Phalaris minor* was recorded at T8 (22.5 %), which was significantly lower than other treatments and at par with T2, T4, T5, & T14. As compared to T1 (57.6 %) with T8 (20.7 %) showed a 64.06 % decrease in weed intensity *of Phalaris minor* at 60 DAS. From the analysis of both years' average data of year **(2021-2022) & (2022-2023),** it was observed that the maximum weed intensity *of Phalaris minor* was recorded at T1 (55.8 %), followed by T9 (41.0 %), while the minimum weed intensity *of Phalaris minor* was recorded at T4 (22.3 %). As compared to T1 (55.8 %) with T4 (22.3 %) showed a 60.03 % decrease in weed intensity *of Phalaris minor* at 60 DAS.

At 90 DAS (2021-2022), the weed intensity *of Phalaris minor* ranged from 14.9 % to 58.4 %. The maximum weed intensity *of Phalaris minor* was recorded at T1 (58.4 %), which was significantly higher than other treatments, followed by T6 (41.5 %), while the minimum weed intensity *of Phalaris minor* was recorded at T4 (14.9 %), which was significantly lower than other treatments and at par with T2, & T10. As compared to T1 (58.4 %) with T4 (14.9 %) showed a 74.48 % decrease in weed intensity *of Phalaris minor at* 90 DAS. **Subsequently,** at 90 DAS (2022-2023), the weed intensity *of Phalaris minor* ranged from 15.1 % to 56.0 %. The maximum weed intensity *of Phalaris minor* was recorded at T1 (56.0 %), which was significantly higher than other treatments, followed by T11 (32.3 %), while the minimum weed intensity *of Phalaris minor* was recorded at T4 (15.1 %). As compared to T1 (56.0 %) with T4 (15.1 %) showed 73.0 % decrease in weed intensity *of Phalaris minor* at 90 DAS From the analysis of both years average data of year **(2021-2022) & (2022-2023),** it was observed that the maximum weed intensity *of Phalaris minor* was recorded at T1 (57.3 %) followed by T6 (36.3 %) while the minimum weed intensity *of Phalaris minor* was recorded at T4 (15.0 %). As compared to T1 (57.3 %) with T4 (15.0 %) showed a 73.82 % decrease in weed intensity *of Phalaris minor* at 90 DAS.

At 120 DAS (2021-2022), the weed intensity *of Phalaris minor* ranged from 11.6 % to 58.4 %. The maximum weed intensity *of Phalaris minor* was recorded at T1 (58.4 %), which was significantly higher than other treatments, followed by T6 (40.8 %), while the minimum weed intensity *of Phalaris minor* was recorded at T4 (11.6 %), which was significantly lower than other treatments and at par with T2. As compared to T1 (58.4 %) with T4 (11.6 %) showed an 80.13 % decrease in weed intensity *of Phalaris minor at* 120 DAS. **Subsequently,** at 120 DAS (2022-2023), the weed intensity *of Phalaris minor* ranged from 15.8 % to 56.1 %. The maximum weed intensity *of Phalaris minor* was recorded at T1 (56.1 %), which was significantly higher than other treatments, followed by T6 (29.5 %), while the minimum weed intensity *of Phalaris minor* was recorded at T4 (15.8 %), which was significantly lower than other treatments and at par with T2. As compared to T1 (56.1 %) with T4 (15.8 %) showed a 71.83 % increase in weed intensity of Phalaris minor at 90 DAS. From the analysis of both years' average data of year (2021-2022) & (2022-2023), it was observed that the maximum weed intensity of Phalaris minor was recorded at T1 (57.3 %), followed by T6 (35.2 %), while the minimum weed intensity of Phalaris minor was recorded at T4 (13.8 %). As compared to T1 (57.3 %) with T4 (13.8 %) showed a 75.91 %

4.25.1. Effect of treatments on weed intensity of *Phalaris minor* population (%) of wheat at 30, 60 DAS during the year 2021-2022 & 2022-2023

TREATMENTS	**30 DAS**			**60 DAS**		
	2021-2022	**2022-2023**	**AVG.**	**2021-2022**	**2022-2023**	**AVG.**
T1-Absolute control	55.7±1.79	58.1±1.23	56.9	53.9±1.71	57.6±0.58	55.8
T2-100% RDH*	43.4±3.06	46.2±1.80	44.8	23.4±0.58	23.2±1.32	23.4
T3-ELE 5% + 50% H*	51.1±0.74	50.2±1.01	50.7	34.2±1.95	34.3±2.05	34.3
T4-ELE 5% + 75% H*	45.2±4.16	43.4±2.36	44.3	20.7±1.10	23.8±1.51	22.3
T5-ELE 10% + 50% H*	44.0±1.38	44.9±1.88	44.5	27.4±1.08	23.0±0.76	25.3
T6-ELE 10% + 75% H*	35.0±0.07	41.3±2.71	38.2	43.0±2.12	36.6±2.44	39.9
T7-NLE 10% + 50% H*	44.9±1.91	49.9±1.35	47.4	29.0±3.94	28.9±1.39	29.0
T8-NLE 10% + 75% H*	41.7±0.27	44.6±2.64	43.2	23.2±1.17	22.5±0.34	22.9
T9-NLE 15% + 50% H*	45.9±2.06	47.4±0.58	46.7	41.2±2.13	40.7±1.43	41.0
T10-NLE 15% + 75% H*	51.9±1.97	49.7±1.55	50.8	26.6±3.61	33.0±1.67	29.8
T11-GLE 25% + 50% H*	47.3±2.54	48.3±0.61	47.8	35.8±3.13	35.5±1.93	35.7
T12-GLE 25% + 75% H*	41.8±2.91	60.2±1.23	51.0	27.6±1.15	29.3±1.76	28.5
T13-GLE 30% + 50% H*	45.7±4.22	42.4±1.87	44.1	31.9±1.09	31.0±1.37	31.5
T14-GLE 30% + 75% H*	47.2±4.30	47.9±2.49	47.6	23.9±3.71	26.1±1.36	25.0
T15-ELE 5%	47.2±2.96	47.4±1.37	47.3	32.3±0.30	28.3±0.66	30.3
T16-ELE 10%	49.7±3.49	47.6±1.62	48.7	37.0±3.67	29.8±1.40	33.4
T17-NLE 10%	41.3±2.74	39.5±2.2	40.4	29.2±3.57	28.0±1.29	28.7
T18-NLE 15%	59.5±0.93	49.6±0.31	54.6	32.4±2.79	34.8±1.91	33.7
T19-GLE 25%	41.4±4.05	40.4±1.12	41.0	32.5±0.82	34.5±2.52	33.6
T20- GLE 30%	47.3±3.17	53.0±1.52	50.2	36.1±1.64	33.5±2.55	34.9
CD (P≤0.05)	7.762	3.763		6.947	3.656	
SE(m ±)	2.701	1.309		2.417	1.272	

Note-RDH-recommended dose of herbicide, ELE- eucalyptus leaf extract, NLE- neem leaf extract, GLE- guava leaf extract, SE- standard error and CD (P≤0.05)- critical difference, *2,4 D + Fenoxaprop.

decrease in weed intensity of Phalaris minor at 120 DAS. Weed intensity is directly related to the number of weeds & crop plants present in the field condition, meaning the population of weeds & plants in different stages of the crop. Therefore, as per the result, treatments with eucalyptus leaf aqueous extract (T4-ELE 5% + 75% H) showed the minimum weed intensity, which means the best in weed control.

4.25.2. Effect of treatments on weed intensity of *Phalaris minor* population (%) of wheat at 90, 120 DAS during the year 2021-2022 & 2022-2023

TREATMENTS	**90 DAS**			**120 DAS**		
	2021-2022	**2022-2023**	**AVG.**	**2021-2022**	**2022-2023**	**AVG.**
T1-Absolute control	58.4±1.22	56.0±0.98	57.3	58.4±0.35	56.1±1.52	57.3
T2-100% RDH*	18.0±2.12	21.2±1.34	19.7	15.9±1.38	18.4±2.02	17.2
T3-ELE 5% + 50% H*	28.2±1.98	30.3±2.05	29.3	27.1±0.27	22.8±1.08	25.0
T4-ELE 5% + 75% H*	14.9±2.09	15.1±1.15	15.0	11.6±2.25	15.8±1.56	13.8
T5-ELE 10% + 50% H*	32.2±2.79	22.7±0.76	27.5	31.6±1.11	22.1±2.69	26.9
T6-ELE 10% + 75% H*	41.5±4.20	31.1±2.44	36.3	40.8±0.76	29.5±3.30	35.2
T7-NLE 10% + 50% H*	30.1±1.99	25.1±1.39	27.6	29.7±2.47	25.6±1.74	27.7
T8-NLE 10% + 75% H*	22.3±1.36	22.4±0.33	22.4	21.7±1.21	21.0±0.23	21.4
T9-NLE 15% + 50% H*	35.1±4.35	30.9±1.43	33.0	33.5±0.91	28.3±1.14	30.9
T10-NLE 15% + 75% H*	20.4±2.09	23.6±1.67	22.1	19.3±1.08	21.0±1.60	20.2
T11-GLE 25% + 50% H*	33.3±1.66	32.3±1.93	32.8	32.3±1.82	28.4±2.10	30.4
T12-GLE 25% + 75% H*	32.3±0.81	24.6±1.76	28.5	31.0±2.07	28.3±0.93	29.7
T13-GLE 30% + 50% H*	30.2±0.34	22.7±1.78	26.5	29.8±0.77	22.2±1.40	26.0
T14-GLE 30% + 75% H*	27.7±3.38	22.4±1.36	25.1	27.3±1.42	25.3±0.85	26.3
T15-ELE 5%	29.0±0.86	24.6±0.65	26.8	27.9±0.35	21.2±2.15	24.6
T16-ELE 10%	31.9±0.70	31.0±1.40	31.5	30.4±1.65	24.6±2.18	27.5
T17-NLE 10%	26.8±0.84	25.8±1.29	26.3	25.8±0.96	25.2±0.88	25.5
T18-NLE 15%	27.4±1.90	27.0±1.91	27.2	25.9±1.27	25.3±0.37	25.6
T19-GLE 25%	29.3±1.74	29.9±2.52	29.6	27.9±0.18	24.6±1.81	26.3
T20- GLE 30%	27.4±2.05	27.6±2.55	27.5	26.8±2.47	27.2±0.71	27.0
CD (P≤0.05)	6.222	3.663		5.372	3.871	
SE(m ±)	2.165	1.275		1.869	1.347	

Note-RDH-recommended dose of herbicide, ELE- eucalyptus leaf extract, NLE- neem leaf extract, GLE- guava leaf extract, SE- standard error and CD (P≤0.05)- critical difference, *2,4 D + Fenoxaprop.

4.26. Weed intensity of *Anagalis arvensis* in the wheat crop

The periodic weed intensity *of Anagalis arvensis* data **(Table 4.26.1) & (Table 4.26.2) was** taken at 30, 60, 90 & 120 days after sowing (DAS). In wheat, at 30 DAS (2021-2022), weed intensity *of Anagalis arvensis* ranged from 46.4 % to 64.4 %. The maximum weed intensity *of Anagalis arvensis* was recorded at T18 (64.4 %) which was significantly higher than other treatments followed by T1 (61.5 %) and at par with T1, T7, T9, T16, & T20 while the minimum weed intensity *of Anagalis arvensis* was recorded at T2 (46.4 %) which was significantly lower than other treatments and at par with T4, T6, T12, T14, & T19. As compared to T18 (64.4 %) with T2 (46.4 %) showed a 27.95 % decrease in weed intensity *of Anagalis arvensis at* 30 DAS. **Subsequently,** in the second trial at 30 DAS (2022-2023), weed intensity *of Anagalis arvensis* ranged from 49.4 % to 61.7 %. The maximum weed intensity *of Anagalis arvensis* was recorded at T12 (61.7 %) which was significantly higher than other treatments followed by T20 (61.0 %) at par with T1, T5, T7, T18 & T20 while the minimum weed intensity *of Anagalis arvensis* was recorded at T19 (49.4 %) which was significantly lower than other treatments and at par with T2, T4, T6, T11, T13 & T17. As compared to T19 (49.4 %) with T12 (61.7 %) showed a 19.9 % decrease in weed intensity *of Anagalis arvensi s* at 30 DAS. From the analysis of both years' average data of year **(2021- 2022) & (2022-2023),** it was observed that the maximum weed intensity *of Anagalis arvensis* was recorded at T18 (61.8 %), followed by T1 (60.4 %), while the minimum weed intensity *of Anagalis arvensis* was recorded at T2 (52.8 %). As compared to T18 (61.8 %) with T2 (52.8 %) showed a 14.56 % decrease in weed intensity *of Anagalis arvensis* at 30 DAS.

At 60 DAS (2021-2022), the weed intensity *of Anagalis arvensis* ranged from 17.2 % to 59.3 %. The maximum weed intensity *of Anagalis arvensis* was recorded at T1 (59.3 %), which was significantly higher than other treatments, followed by T4 (39.9 %), while the minimum weed intensity *of Anagalis arvensis* was recorded at T3 (17.2 %), which was significantly lower than other treatments and at par with T2. As compared to T1 (59.3 %) with T3 (17.2 %) showed a 70.99 % decrease in weed intensity *of Anagalis ardencies at* 60 DAS. **Subsequently,** at 60 DAS (2022-2023), the weed intensity *of Anagalis arvensis* ranged from 21.2 % to 57.4 %. The maximum weed intensity *of Anagalis arvensis* was recorded at T1 (57.4 %), which was significantly higher than other treatments, followed by

T6 (44.4 %), while the minimum weed intensity *of Anagalis arvensis* was recorded at T15 (21.2 %), which was significantly lower than other treatments and at par with T2 & T7. As compared to T1 (57.4 %) with T15 (21.2 %) showed a 63.06 % decrease in weed intensity *of Anagalis arvensis at* 60 DAS. From the analysis of both years' average data of year **(2021-2022) & (2022-2023),** it was observed that the maximum weed intensity *of Anagalis arvensis* was recorded at T1 (58.4 %), followed by T6 (41.4 %), while the minimum weed intensity *of Anagalis arvensis* was recorded at T2 (21.7 %). As compared to T1 (58.4 %) with T2 (21.7 %) showed a 62.84 % decrease in weed intensity *of Anagalis arvensis* at 60 DAS.

At 90 DAS (2021-2022), the weed intensity *of Anagalis arvensis* ranged from 14.5 % to 61.1 %. The maximum weed intensity *of Anagalis arvensis* was recorded at T1 (61.1 %), which was significantly higher than other treatments, followed by T5 (38.0 %), while the minimum weed intensity *of Anagalis arvensis* was recorded at T3 (14.5 %), which was significantly lower than other treatments and at par with T2. As compared to T1 (61.1 %) with T3 (14.5 %) showed a 76.26 % decrease in weed intensity *of Anagalis arvensis at* 90 DAS. **Subsequently,** at 90 DAS (2022-2023), the weed intensity *of Anagalis arvensis* ranged from 19.2 % to 58.4 %. The maximum weed intensity *of Anagalis arvensis* was recorded at T1 (58.4 %), which was significantly higher than other treatments, followed by T5 (38.0 %), while the minimum weed intensity *of Anagalis arvensis* was recorded at T7 (19.2 %), which was significantly lower than other treatments and at par with T2 & T4. As compared to T1 (58.4 %) with T7 (19.2 %) showed a 67.12 % decrease in weed intensity *of Anagalis arvensis at* 90 DAS. From the analysis of both years' average data of year **(2021- 2022) & (2022-2023),** it was observed that the maximum weed intensity *of Anagalis arvensis* was recorded at T1 (59%), followed by T6 (36.2 %), while the minimum weed intensity *of Anagalis arvensis* was recorded at T2 (19.4 %). As compared to T1 (59.8 %) with T2 (19.4 %) showed a 67.55 % decrease in weed intensity *of Anagalis arvensis* at 90 DAS.

At 120 DAS (2021-2022), the weed intensity *of Anagalis arvensis* ranged from 13.1 % to 59.5 %. The maximum weed intensity *of Anagalis arvensis* was recorded at T1 (59.5 %), which was significantly higher than other treatments, followed by T5 (37.2 %), while the minimum weed intensity *of Anagalis arvensis* was recorded at T3 (13.1 %), which was significantly lower than other treatments and at par with T2. As compared to T1 (59.9 %)

with T3 (13.1 %) showed a 77.98 % decrease in weed intensity *of Anagalis arvensis at* 120 DAS. **Subsequently,** at 120 DAS (2022-2023), the weed intensity *of Anagalis arvensis* ranged from 16.8 % to 58.1 %. The maximum weed intensity *of Anagalis arvensis* was recorded at T1 (58.1 %), which was significantly higher than other treatments followed by T12 (31.3 %) while the minimum weed intensity *of Anagalis arvensis* was recorded at T7 (16.8 %), which was significantly lower than other treatments and at par with T2, T3, T4 & T8. As compared to T1 (58.1 %) with T7 (16.8 %) showed a 71.08 % decrease in weed intensity *of Anagalis arvensis at* 120 DAS.

4.26.1. Effect of treatments on weed intensity of *Anagalis arvensis* population (%) of wheat at 30, 60 DAS during the year 2021-2022 & 2022-2023

TREATMENTS	30 DAS			60 DAS		
	2021-2022	**2022-2023**	**AVG.**	**2021-2022**	**2022-2023**	**AVG.**
T1-Absolute control	61.6±0.98	59.1±1.40	60.4	59.3±0.60	57.4±1.26	58.4
T2-100% RDH*	46.4±3.88	50.9±1.22	52.8	19.0±1.82	24.4±0.34	21.7
T3-ELE 5% + 50% H*	57.2±0.60	56.7±0.60	58.2	17.2±1.36	27.0±2.26	22.2
T4-ELE 5% + 75% H*	48.7±0.65	51.6±1.82	53.9	39.9±2.48	25.6±1.44	32.8
T5-ELE 10% + 50% H*	57.9±1.73	60.1±1.11	58.5	32.8±0.90	25.8±1.46	29.3
T6-ELE 10% + 75% H*	49.7±0.63	52.0±0.72	54.4	38.4±1.65	44.4±2.24	41.4
T7-NLE 10% + 50% H*	58.6±1.58	59.1±1.60	58.9	30.6±2.27	22.2±0.85	26.4
T8-NLE 10% + 75% H*	55.7±1.79	56.3±0.65	57.4	30.8±3.9	29.9±0.52	30.4
T9-NLE 15% + 50% H*	58.1±0.94	55.2±1.25	58.6	39.3±1.48	34.7±2.19	37.1
T10-NLE 15% + 75% H*	57.8±0.28	55.3±1.51	58.5	35.2±1.93	37.3±1.52	36.3
T11-GLE 25% + 50% H*	53.2±3.28	50.8±2.04	56.2	33.1±3.13	34.5±2.18	33.9
T12-GLE 25% + 75% H*	48.0±1.23	61.7±1.97	53.6	31.3±1.40	28.3±1.46	29.8
T13-GLE 30% + 50% H*	55.4±4.81	50.2±1.12	57.3	30.7±2.04	25.1±0.76	27.9
T14-GLE 30% + 75% H*	51.1±2.50	55.1±1.12	55.1	30.1±402	31.9±1.38	31.0
T15-ELE 5%	55.3±2.05	53.4±0.79	57.2	30.4±3.33	21.2±1.12	25.9
T16-ELE 10%	59.0±2.71	55.7±0.69	59.1	34.3±4.70	25.9±0.97	30.2
T17-NLE 10%	55.4±3.10	51.3±1.18	57.3	31.8±2.94	32.4±0.80	32.2
T18-NLE 15%	64.4±3.07	58.3±2.01	61.8	37.7±3.08	35.7±2.36	36.8
T19-GLE 25%	52.7±1.83	49.4±1.27	55.9	35.7±0.00	33.6±2.10	34.7
T20- GLE 30%	60.7±1.81	61.0±1.15	60.0	38.1±1.72	32.0±2.30	35.1
CD (P≤0.05)	6.512	3.887		7.269	3.524	
SE(m ±)	2.266	1.352		2.529	1.226	

Note-RDH-recommended dose of herbicide, ELE- eucalyptus leaf extract, NLE- neem leaf extract, GLE- guava leaf extract, SE- standard error and CD (P≤0.05)- critical difference, *2,4 D + Fenoxaprop.

From the analysis of both years' average data of the year **(2021-2022) & (2022-2023),** it was observed that the maximum weed intensity *of Anagalis arvensis* was recorded at T1 (58.9 %), followed by T14 (31.9 %), while the minimum weed intensity *of Anagalis arvensis* was recorded at T2 (15.6 %). As compared to T1 (58.9 %) with T2 (15.6 %) showed a 73.51 % decrease in weed intensity *of Anagalis arvensis* at 120 DAS. According to the results, T_3- ELE 5% + 50% H & T_7-NLE 10% + 50% H showed the minimum weed intensity, which means these treatments had the minimum count of weeds in their respective trial plots. This might be because of the leaf aqueous extract concentration used to control weeds. These aqueous extracts contain herbicidal allelochemicals, which inhibit the growth of weeds by disrupting their cellular processes. As a result, weed intensity gets lower.

4.26.2. Effect of treatments on weed intensity of *Anagalis arvensis* population (%) of wheat at 90, 120 DAS during the year 2021-2022 & 2022-2023

TREATMENTS	**90 DAS**			**120 DAS**		
	2021-2022	**2022-2023**	**AVG.**	**2021-2022**	**2022-2023**	**AVG.**
T1-Absolute control	61.1±1.90	58.4±0.63	59.8	59.5±1.60	58.1±0.22	58.9
T2-100% RDH*	18.6±1.89	20.0±1.61	19.4	13.5±0.54	17.6±1.44	15.6
T3-ELE 5% + 50% H*	14.5±2.26	24.8±1.95	19.7	13.1±0.82	18.5±1.34	15.9
T4-ELE 5% + 75% H*	34.9±0.87	21.9±1.53	28.4	34.1±0.40	19.5±0.91	26.9
T5-ELE 10% + 50% H*	38.0±0.77	24.4±1.53	31.3	37.2±1.62	25.7±1.02	31.5
T6-ELE 10% + 75% H*	33.8±2.16	38.5±1.89	36.2	32.6±1.75	27.5±1.35	30.1
T7-NLE 10% + 50% H*	30.3±2.65	19.2±0.78	24.8	29.2±0.40	16.8±1.06	23.1
T8-NLE 10% + 75% H*	28.6±1.67	23.8±0.93	26.2	28.0±1.22	18.3±1.12	23.2
T9-NLE 15% + 50% H*	32.2±2.28	27.4±1.89	29.8	31.7±1.10	24.2±0.21	28.0
T10-NLE 15% + 75% H*	30.6±0.32	30.9±1.22	30.8	29.7±1.03	27.4±0.93	28.6
T11-GLE 25% + 50% H*	31.5±1.39	28.5±1.81	30.0	31.5±2.63	28.4±0.66	30.0
T12-GLE 25% + 75% H*	30.5±1.31	26.7±1.51	28.6	30.9±0.83	31.3±1.53	31.1
T13-GLE 30% + 50% H*	29.3±0.38	22.9±1.32	26.1	30.5±1.01	24.1±0.42	27.4
T14-GLE 30% + 75% H*	35.2±0.99	27.6±0.21	31.5	35.2±2.93	28.5±2.32	31.9
T15-ELE 5%	28.1±2.36	22.9±1.09	25.5	25.6±1.01	21.2±0.35	23.5
T16-ELE 10%	30.3±2.48	24.7±1.87	27.6	29.6±0.82	24.0±0.67	26.9
T17-NLE 10%	31.4±2.77	32.4±1.95	31.9	28.5±2.39	28.3±0.84	28.4
T18-NLE 15%	33.1±0.54	33.8±1.82	33.5	33.5±1.36	27.5±1.76	30.6
T19-GLE 25%	32.6±0.65	30.0±2.43	31.4	32.1±1.49	25.1±0.46	28.6
T20- GLE 30%	32.0±0.36	32.0±1.48	32.1	31.9±1.69	24.3±0.90	28.1
CD (P≤0.05)	4.937	3.362		4.222	3.191	
SE(m ±)	1.718	1.170		1.469	1.110	

Note-RDH-recommended dose of herbicide, ELE- eucalyptus leaf extract, NLE- neem leaf extract, GLE- guava leaf extract, SE- standard error and CD (P≤0.05)- critical difference, *2,4 D + Fenoxaprop.

4.27. Weed control efficiency of *Phalaris minor in* wheat crop

The periodic weed control efficiency *of Phalaris minor* data **(Table 4.27.1) & (Table 4.27.2)** was taken at 30, 60, 90 & 120 days after sowing (DAS). In Wheat, at 30 DAS (2021-2022), weed control efficiency *of Phalaris minor* ranged from 23.9 % to 49.9 %. The maximum weed control efficiency *of Phalaris minor* was recorded at T6 (49.9 %) which was significantly higher than other treatments followed by T8, & T17 (41.6 %) and at par with T2, T4, T5, T7, T9, T12, T19, T20 while the minimum weed control efficiency *of Phalaris minor* was recorded at T15 (23.9 %) which was significantly lower than other treatments and at par with T2, T3, T4, T5, T7, T9, T10, T11, T12, T13, T14 T16, T18, T19& T20. **Subsequently,** in the second trial at 30 DAS (2021-2022), weed control efficiency *of Phalaris minor* ranged from 11.7 % to 43.7 %. The maximum weed control efficiency *of Phalaris minor* was recorded at T5 (43.7 %) which was significantly higher than other treatments followed by T17 (43.6 %) and at par with T6, T17, T18, & T19 while the minimum weed control efficiency *of Phalaris minor* was recorded at T12 (11.7 %) which was significantly lower than other treatments and at par with T11. From the analysis of both years' average data of year **(2021-2022) & (2022-2023),** it was observed that the maximum weed control efficiency *of Phalaris* was recorded at T6 (44.0 %), followed by T17 (42.6 %), while the minimum weed control efficiency *of Phalaris* was recorded at T11 (22.4 %).

At 60 DAS (2021-2022), weed control efficiency *of Phalaris minor* ranged from 49.0 % to 79.0 %. The maximum weed control efficiency *of Phalaris minor* was recorded at T4 (79.0 %) which was significantly higher than other treatments followed by T8, T17 (75.8 %) and at par with T2, T8, T10, & T14 while the minimum weed control efficiency *of Phalaris minor* was recorded at T6 (49.0 %) which was significantly lower than other treatments and at par with T9, & T11. **Subsequently,** at 60 DAS (2022-2023), weed control efficiency *of Phalaris minor* ranged from 52.6 % to 78.5 %. The maximum weed control efficiency *of Phalaris minor* was recorded at T8 (78.5 %), which was significantly higher than other treatments, followed by T4 (76.8 %) and at par with T2 & T4, while the minimum weed control efficiency *of Phalaris minor* was recorded at T9 (52.6 %). From the analysis of both years' average data of year **(2021-2022) & (2022-2023),** it was observed that the maximum weed control efficiency *of Phalaris* was recorded at T4 (77.9 %), followed by T8 (77.2 per/m^2), while the minimum weed control efficiency *of Phalaris* was recorded at T9 (52.2 %).

At 90 DAS (2021-2022), weed control efficiency *of Phalaris minor* ranged from 46.9 % to 84.3 %. The maximum weed control efficiency *of Phalaris minor* was recorded at T4 (84.3 %), which was significantly higher than other treatments, followed by T2 (83.0 %) and at par with T2, T8, & T10, while the minimum weed control efficiency *of Phalaris minor* was recorded at T6 (46.9 %). **Subsequently,** at 90 DAS (2022-2023), weed control efficiency *of Phalaris minor* ranged from 62.5 % to 85.1 %. The maximum weed control efficiency *of Phalaris minor* was recorded at T4 (85.1 %), which was significantly higher than other treatments, followed by T2 (79.3 %), while the minimum weed control efficiency *of Phalaris minor* was recorded at T9 (62.5 %), which was significantly lower than other treatments and at par with T6 & T11. From the analysis of both years' average data of year **(2021-2022) & (2022-2023),** it was observed that the maximum weed control efficiency *of Phalaris* was recorded at T4 (84.7 %), followed by T2 (81.2 %), while the minimum weed control efficiency *of Phalaris* was recorded at T6 (55.5 %).

At 120 DAS (2021-2022), weed control efficiency *of Phalaris minor* ranged from 47.9 % to 88.2 %. The maximum weed control efficiency *of Phalaris minor* was recorded at T4 (88.2 %), which was significantly higher than other treatments, followed by T2 (85.1 %) and at par with T2, while the minimum weed control efficiency *of Phalaris minor* was recorded at T6 (47.9 %). **Subsequently,** at 120 DAS (2022-2023), weed control efficiency *of Phalaris minor* ranged from 63.8 % to 83.7 %. The maximum weed control efficiency *of Phalaris minor* was recorded at T4 (83.7 %), which was significantly higher than other treatments, followed by T2 (82.9 %) and at par with T2 & T10, while the minimum weed control efficiency *of Phalaris minor* was recorded at T6 (63.8 %) which was significantly lower than other treatments and at par with T9. From the analysis of both years' average data of year **(2021-2022) & (2022-2023),** it was observed that the maximum weed control efficiency *of Phalaris* was recorded at T4 (85.9 %), followed by T2 (84.0 %), while the minimum weed control efficiency *of Phalaris* was recorded at T6 (55.8 %). As per the result, T_4-ELE 5% + 75%, H was best among all the treatments. As the weed population and intensity were also minimal in the same treatment, it is obvious that this treatment showed the best weed control efficiency. Studies showed that eucalyptus leaf aqueous extract could exhibit allelopathic effects, which can inhibit the seed germination, seedling growth and overall weed biomass. Specific concentration of these extracts may lead to a result that is more impactful in controlling *phalaris minor.* Potentially reducing its population density and competitive ability against crops. It has been studied that eucalyptus leaf aqueous extract is enriched with bioactive compound eucalyptol, which is also known as 1,8-cineole. It possesses high herbicidal properties due to its ability to disrupt the physiological and biochemical processes of plants. One of the primary modes of action of eucalyptol is its ability to penetrate the cuticle of the plant leaves and enter the plant tissues. Once it is inside the cell, it can reduce the cellular processes and key metabolic processes such as photosynthesis and respiration. This ultimately reduces the growth and eventually death of the plant.

4.27.1. Effect of treatments on weed control efficiency *of Phalaris minor* (%) of wheat at 30, 60 DAS during the year 2021-2022 & 2022-2023

TREATMENTS	30 DAS			60 DAS		
	2021-2022	2022-2023	AVG.	2021-2022	2022-2023	AVG.
T1-Absolute control						
T2-100% RDH*	34.9±6.22	29.8±6.80	32.4	73.3±3.00	76.8±2.66	75.1
T3-ELE 5% + 50% H*	28.3±5.74	26.7±5.44	27.6	62.2±1.71	61.1±2.02	61.7
T4-ELE 5% + 75% H*	33.2±10.18	35.6±6.19	34.4	79.0±2.18	76.8±2.55	77.9
T5-ELE 10% + 50% H*	38.6±4.48	43.7±6.97	41.1	66.9±0.96	72.3±1.82	69.6
T6-ELE 10% + 75% H*	49.9±2.54	38.0±6.08	44.0	49.0±2.85	61.6±3.74	55.3
T7-NLE 10% + 50% H*	39.8±7.49	33.2±6.35	36.5	67.9±3.58	67.0±3.12	67.5
T8-NLE 10% + 75% H*	41.6±3.63	35.6±6.19	38.6	75.8±0.83	78.5±0.89	77.2
T9-NLE 15% + 50% H*	33.3±6.26	30.7±6.46	32.1	51.8±3.49	52.6±1.46	52.2
T10-NLE 15% + 75% H*	28.4±7.17	26.8±5.70	27.6	72.7±2.69	67.0±2.09	69.9
T11-GLE 25% + 50% H*	25.2±10.15	19.6±5.14	22.4	57.3±1.57	64.0±2.42	60.7
T12-GLE 25% + 75% H*	34.9±6.22	11.7±4.63	23.4	67.0±1.53	67.8±2.81	67.4
T13-GLE 30% + 50% H*	26.8±9.76	30.7±6.46	28.8	61.1±4.58	64.0±2.42	62.6
T14-GLE 30% + 75% H*	32.3±5.79	31.5±7.53	31.9	74.1±4.61	72.2±2.92	73.1
T15-ELE 5%	23.9±5.66	25.0±6.87	24.5	64.6±1.78	66.3±1.39	65.5
T16-ELE 10%	27.7±7.94	31.4±7.18	29.6	59.3±5.61	69.4±0.88	64.4
T17-NLE 10%	41.6±7.12	43.6±6.54	42.6	63.3±7.26	70.0±1.92	66.7
T18-NLE 15%	26.6±7.72	37.1±6.41	31.9	66.1±1.79	64.8±0.90	65.5
T19-GLE 25%	38.2±7.57	36.7±3.41	37.5	61.2±3.13	63.1±2.95	62.2
T20- GLE 30%	39.6±3.92	29.8±6.80	34.7	61.9±3.22	67.2±0.99	64.6
CD (P≤0.05)	17.066	7.426		9.587	4.223	
SE(m ±)	6.068	2.579		3.329	1.466	

Note-RDH-recommended dose of herbicide, ELE- eucalyptus leaf extract, NLE- neem leaf extract, GLE- guava leaf extract, SE- standard error and CD (P≤0.05)- critical difference, *2,4 D + Fenoxaprop.

4.27.2. Effect of treatments on weed control efficiency *of Phalaris minor* (%) of wheat at 90, 120 DAS during the year 2021-2022 & 2022-2023

TREATMENTS	90 DAS			120 DAS		
	2021-2022	**2022-2023**	AVG.	**2021-2022**	**2022-2023**	AVG.
T1-Absolute control						
T2-100% RDH*	83.0±1.43	79.3±3.12	81.2	85.1±1.87	82.9±1.98	84.0
T3-ELE 5% + 50% H*	67.3±1.97	68.4±2.65	67.9	68.3±3.03	75.8±0.56	72.1
T4-ELE 5% + 75% H*	84.3±2.46	85.1±0.78	84.7	88.2±1.44	83.7±2.49	85.9
T5-ELE 10% + 50% H*	68.8±2.79	76.4±1.87	72.6	69.2±2.52	78.2±0.65	73.7
T6-ELE 10% + 75% H*	46.9±5.12	64.1±2.09	55.5	47.9±2.86	63.8±1.54	55.8
T7-NLE 10% + 50% H*	68.9±3.01	71.7±2.08	70.3	69.2±2.14	72.3±3.08	70.8
T8-NLE 10% + 75% H*	78.2±2.51	78.0±1.07	78.1	78.7±1.34	78.9±1.48	78.8
T9-NLE 15% + 50% H*	55.7±5.19	62.5±1.31	59.1	58.1±5.07	67.0±1.72	62.6
T10-NLE 15% + 75% H*	77.5±2.28	76.5±0.65	77.0	78.6±1.90	80.5±1.84	79.6
T11-GLE 25% + 50% H*	60.4±2.37	66.3±1.31	63.4	61.2±4.48	70.2±1.01	65.7
T12-GLE 25% + 75% H*	60.1±5.30	72.4±2.10	66.3	61.9±5.24	74.2±0.83	68.1
T13-GLE 30% + 50% H*	64.2±2.83	75.0±2.02	69.6	64.5±1.84	79.0±0.49	71.8
T14-GLE 30% + 75% H*	76.8±3.34	76.2±2.69	76.5	77.1±1.32	77.3±1.15	77.2
T15-ELE 5%	69.0±1.20	74.1±0.69	71.6	70.1±2.49	77.4±0.33	73.8
T16-ELE 10%	65.0±2.34	67.9±0.67	66.5	66.7±3.69	74.1±1.89	70.4
T17-NLE 10%	69.6±2.34	74.1±0.69	71.9	70.8±2.22	72.4±1.70	71.6
T18-NLE 15%	69.5±3.28	75.0±2.02	72.3	71.7±0.95	73.4±0.48	72.5
T19-GLE 25%	66.5±4.02	68.8±1.26	67.7	68.6±1.32	73.4±0.48	71.0
T20- GLE 30%	69.8±0.49	71.9±1.54	70.9	70.0±1.51	70.9±1.35	70.5
CD (P≤0.05)	7.587	4.362		6.637	4.339	
SE(m ±)	2.635	1.515		2.305	1.507	

Note-RDH-recommended dose of herbicide, ELE- eucalyptus leaf extract, NLE- neem leaf extract, GLE- guava leaf extract, SE- standard error and CD (P≤0.05)- critical difference, *2,4 D + Fenoxaprop.

4.28. Weed control efficiency of *Anagalis arvensis* of wheat crop

The periodic weed control efficiency *of Anagalis arvensis* data **(Table 4.28.1) & (Table 4.28.2)** were taken at 30, 60, 90 & 120 days after sowing (DAS). In Wheat, at 30 DAS (2021-2022), weed control efficiency *of Anagalis arvensis* ranged from 15.3 % to 41.8%. The maximum weed control efficiency *of Anagalis arvensis* was recorded at T2 (41.8 %) which was significantly higher than other treatments followed by T4 (40.6 %) and at par with T3, T4, T6, T10, T12, T14 & T18 while the minimum weed control efficiency *of*

Anagalis arvensis was recorded at T9 (15.3 %) which was significantly lower than other treatments and at par withT3, T5, T7, T6, T8, T10, T11, T17, T18, T19 T13, T15, T16, & T20. **Subsequently,** in the second trial at 30 DAS (2021-2022), weed control efficiency *of Anagalis arvensis* ranged from 3.0 % to 20.3 %. The maximum weed control efficiency *of Anagalis arvensis* was recorded at T2 (20.3 %) which was significantly higher than other treatments followed by T18 (16.7 %) and at par with T4, T10, T11, T14, T17, T18 & T19, while the minimum weed control efficiency *of Anagalis arvensis* was recorded at T5 (3.0 %) which was significantly lower than other treatments and at par with, T8. From the analysis of both years' average data of year **(2021-2022) & (2022-2023),** it was observed that the maximum weed control efficiency *of Anagalis arvensis* was recorded at T2 (31.1 %), followed by T4 (28.2 %), while the minimum weed control efficiency *of Anagalis arvensis* was recorded at T5 (9.4 %).

At 60 DAS (2021-2022), weed control efficiency *of Anagalis arvensis* ranged from 56.7 % to 87.8 %. The maximum weed control efficiency *of Anagalis arvensis* was recorded at T3 (87.8 %), which was significantly higher than other treatments followed by T2 (83.8%) and at par with T2, while the minimum weed control efficiency *of Anagalis arvensis* was recorded at T4 (56.7 %), which was significantly lower than other treatments and at par with T9 & T19. **Subsequently,** at 60 DAS (2022-2023), weed control efficiency *of Anagalis arvensis* ranged from 45.8 % to 76.6 %. The maximum weed control efficiency *of Anagalis arvensis* was recorded at T2 (76.6 %), which was significantly higher than other treatments followed by T16 (75.9 %) and at par with T4, T7, T15 & T16, while the minimum weed control efficiency *of Anagalis arvensis* was recorded at T6 (45.8 %). From the analysis of both years' average data of year **(2021-2022) & (2022-2023),** it was observed that the maximum weed control efficiency *of Anagalis arvensis* was recorded at T2 (80.2 %), followed by T3 (79.6 %**),** while the minimum weed control efficiency *of Anagalis arvensis* was recorded at T6 (56.1 %).

At 90 DAS (2021-2022), weed control efficiency *of Anagalis arvensis* ranged from 57.5 % to 87.3 %. The maximum weed control efficiency *of Anagalis arvensis* was recorded at T3 (87.3 %), which was significantly higher than other treatments followed by T2 (84.0 %) and at par with T2, while the minimum weed control efficiency *of Anagalis arvensis* was recorded at T4 (57.5 %). **Subsequently,** at 90 DAS (2022-2023), weed control efficiency *of*

Anagalis arvensis ranged from 59.9 % to 81.3 %. The maximum weed control efficiency *of Anagalis arvensis* was recorded at T2, T7 (81.3 %), which was significantly higher than other treatments, followed by T4 (79.8 %) and at par with T4, while the minimum weed control efficiency *of Anagalis arvensis* was recorded at T6 (59.9 %). From the analysis of both years' average data of year **(2021-2022) & (2022-2023),** it was observed that the maximum weed control efficiency *of Anagalis arvensis* was recorded at T2 (82.7 %), followed by T3 (81.8 %), while the minimum weed control efficiency *of Anagalis arvensis* was recorded at T6 (62.9 %).

4.28.1. Effect of treatments on weed control efficiency of *Anagalis arvensis* (%) of wheat at 30, 60 DAS during the year 2021-2022 & 2022-2023

TREATMENTS	**30 DAS**			**60 DAS**		
	2021-2022	**2022-2023**	**AVG.**	**2021-2022**	**2022-2023**	**AVG.**
T1-Absolute control						
T2-100% RDH*	41.8±7.85	20.3±4.01	31.1	83.8±1.14	76.6±0.45	80.2
T3-ELE 5% + 50% H*	28.±5.90	10.7±2.98	19.6	87.8±1.05	71.4±0.03	79.6
T4-ELE 5% + 75% H*	40.6±4.73	15.7±4.84	28.2	56.7±5.23	75.7±1.92	66.3
T5-ELE 10% + 50% H*	15.6±5.81	3.0±0.83	9.4	65.7±1.59	66.8±0.22	66.3
T6-ELE 10% + 75% H*	27.5±7.65	10.6±0.75	19.1	66.3±1.65	45.8±0.56	56.1
T7-NLE 10% + 50% H*	18.8±4.94	9.2±2.51	14.0	71.9±3.00	75.7±1.92	73.8
T8-NLE 10% + 75% H*	19.0±9.05	3.8±0.75	11.4	71.2±3.95	69.1±0.11	70.2
T9-NLE 15% + 50% H*	15.3±1.32	11.4±1.10	13.4	64.2±2.51	62.3±0.45	63.3
T10-NLE 15% + 75% H*	29.2±4.24	13.6±3.40	21.4	66.8±2.37	60.0±0.56	63.5
T11-GLE 25% + 50% H*	25.8±8.53	15.7±6.16	20.8	69.3±3.51	64.6±0.34	67.0
T12-GLE 25% + 75% H*	34.0±7.65	11.2±4.38	22.6	68.2±2.49	69.1±011	68.7
T13-GLE 30% + 50% H*	15.7±7.34	11.2±4.54	13.5	70.8±1.77	73.7±0.11	72.3
T14-GLE 30% + 75% H*	37.9±5.71	14.3±3.78	26.1	70.8±5.94	65.5±1.13	68.2
T15-ELE 5%	17.9±3.20	10.5±3.44	14.2	74.1±2.38	75.7±1.92	74.9
T16-ELE 10%	18.0±4.50	11.2±4.38	14.6	71.2±3.95	75.9±0.22	73.6
T17-NLE 10%	19.4±6.28	15.0±4.86	17.2	67.5±3.55	64.6±0.34	66.1
T18-NLE 15%	29.4±3.26	16.7±2.62	23.1	65.3±3.53	62.3±0.45	63.9
T19-GLE 25%	23.8±6.88	14.3±3.71	19.1	64.3±1.46	66.2±0.45	65.3
T20- GLE 30%	18.1±5.20	9.1±1.44	13.7	66.7±2.94	69.1±0.11	68.0
CD (P≤0.05)	15.581	8.430		7.907	2.274	
SE(m ±)	5.410	2.927		2.746	0.790	

Note-RDH-recommended dose of herbicide, ELE- eucalyptus leaf extract, NLE- neem leaf extract, GLE- guava leaf extract, SE- standard error and CD (P≤0.05)- critical difference, *2,4 D + Fenoxaprop.

At 120 DAS (2021-2022), weed control efficiency *of Anagalis arvensis* ranged from 58.9 % to 88.7 %. The maximum weed control efficiency *of Anagalis arvensis* was recorded at T2 (88.7 %), which was significantly higher than other treatments followed by T3 (87.9 %) and at par with T3, while the minimum weed control efficiency *of Anagalis arvensis* was recorded at T4 (58.9 %), which was significantly lower than other treatments and at par with T5. **Subsequently,** at 120 DAS (2022-2023), weed control efficiency *of Anagalis arvensis* ranged from 69.8 % to 85.1 %. The maximum weed control efficiency *of Anagalis arvensis* was recorded at T7 (85.1 %) which was significantly higher than other treatments followed by T2 (84.9 %) and at par with T2, T3 & T8 while the minimum weed control efficiency *of Anagalis arvensis* was recorded at T6 (69.8 %) which was significantly lower than other treatments and at par with T11, T12, T17 & T18. From the analysis of both years' average data of year **(2021-2022) & (2022-2023),** it was observed that the maximum weed control efficiency *of Anagalis arvensis* was recorded at T2 (86.9 %), followed by T3 (85.4 %**),** while the minimum weed control efficiency *of Anagalis arvensis* was recorded at T6 (67.9 %).

4.28.2. Effect of treatments on weed control efficiency of *Anagalis arvensis* (%) of wheat at 90, 120 DAS during the year 2021-2022 & 2022-2023

TREATMENTS	**90 DAS**			**120 DAS**		
	2021-2022	**2022-2023**	**AVG.**	**2021-2022**	**2022-2023**	**AVG.**
T1-Absolute control						
T2-100% RDH*	84.0±1.84	81.3±2.31	82.7	88.7±0.31	84.9±2.25	86.9
T3-ELE 5% + 50% H*	87.3±1.83	76.2±1.52	81.8	87.9±0.98	82.9±1.44	85.4
T4-ELE 5% + 75% H*	57.5±3.06	79.8±1.84	68.7	58.9±2.32	80.6±1.35	69.8
T5-ELE 10% + 50% H*	63.6±3.70	71.1±1.65	67.4	63.8±2.85	75.5±0.31	69.7
T6-ELE 10% + 75% H*	65.8±2.52	59.9±1.63	62.9	66.0±3.41	69.8±1.88	67.9
T7-NLE 10% + 50% H*	72.2±2.02	81.3±1.56	76.8	73.0±1.99	85.1±1.17	79.1
T8-NLE 10% + 75% H*	73.1±0.39	77.7±0.84	75.4	73.2±0.60	83.5±1.54	78.4
T9-NLE 15% + 50% H*	65.3±1.99	74.8±0.94	70.1	65.9±3.63	75.5±0.31	70.7
T10-NLE 15% + 75% H*	64.9±4.05	71.0±0.99	68.0	67.4±1.88	74.7±1.19	71.1
T11-GLE 25% + 50% H*	67.0±3.74	74.8±0.94	71.0	70.3±0.40	72.4±1.28	71.4
T12-GLE 25% + 75% H*	67.5±3.62	72.6±0.91	70.1	68.1±1.55	72.4±2.26	70.3
T13-GLE 30% + 50% H*	69.5±0.78	77.0±0.99	73.3	70.2±2.37	78.4±1.44	74.3
T14-GLE 30% + 75% H*	70.6±2.86	71.0±0.99	70.8	71.8±2.37	75.5±0.31	73.7
T15-ELE 5%	73.7±0.53	75.3±2.13	74.6	75.0±3.18	79.2±0.68	77.1
T16-ELE 10%	70.9±2.93	77.0±0.99	74.0	70.8±2.95	76.9±0.76	73.9
T17-NLE 10%	65.6±5.20	64.4±1.61	65.1	71.0±2.80	70.4±0.87	70.7
T18-NLE 15%	64.3±3.47	67.3±1.17	65.9	64.7±1.63	72.6±0.92	68.7
T19-GLE 25%	65.2±1.92	71.1±0.61	68.2	65.0±4.01	74.8±0.98	70.0
T20- GLE 30%	66.1±1.23	70.2±0.88	68.2	66.5±3.65	77.1±1.05	71.8
CD (P≤0.05)	6.126	3.327		5.683	3.446	
SE(m ±)	2.127	1.155		1.973	1.197	

Note-RDH-recommended dose of herbicide, ELE- eucalyptus leaf extract, NLE- neem leaf extract, GLE- guava leaf extract, SE- standard error and CD (P≤0.05)- critical difference, *2,4 D + Fenoxaprop.

4.29. Spike length (cm) of wheat crop

At the time of harvest (2021-2022), spike length **(Table 4.31.1)** ranged from 8.1 cm to 12.3 cm. The maximum spike length was recorded at T3 (12.3 cm), which was significantly higher than other treatments, followed by T2, T10 (11.2 cm), while the minimum spike length was recorded at T15 (8.1 cm), which was significantly lower than other treatments and at par with T16. As compared to T15 (8.1 cm) with T3 (12.3 cm) showed a 51.85 % increase in spike length at the harvesting stage. **Subsequently,** in the second trial (2022-2023), the time of harvest, spike length ranged from 7.9 cm to 8.7 cm. The maximum spike length was recorded at T8 (8.7 cm), which was significantly higher than other treatments, followed by T4, T10, & T11 (8.6 cm), while the minimum spike length was recorded at T5 (7.9 cm). From the analysis of both years' average data of year (2021-2022) & (2022-2023), it was observed that the maximum spike length was recorded at T3 (10.1 cm), followed by T10 (9.9 cm), while the minimum spike length was recorded at T16 (8.2 cm). As compared to T16 (8.2 cm) with T3 (10.1 cm) showed a 23.17 % increase in spike length at the harvesting stage. As compared to T5 (7.9 cm) with T8 (8.73 cm) showed a 10.12 % increase in spike length at the harvesting stage. As per the results, the best treatment was T_3-ELE 5% + 50% H, followed by T_2-100 % RDH. These treatments showed that spike length was improved by the use of leaf aqueous extracts. As the recommended dose of fertilizer and herbicide can improve the growth of crop plants, it certainly improved the spike length. Furthermore, eucalyptus leaf aqueous extract improves the nutrient uptake of the crop, which stimulates the spike elongation by reducing stress responses that ultimately improve the spike length. In addition, eucalyptus leaf aqueous extract provides a favourable condition for crop plants by inhibiting the growth of weed plants.

4.30. Number of spikelet/spike of wheat crop

At the time of harvest (2021-2022), the number of spikelet/spike **(Table 4.31.1)** ranged from 10.3 to 14.0. The maximum number of spikelet/spike was recorded at T2, T4 and T16 (14.0) which was significantly higher than other treatments followed by T13 and T14 (13.3) and at par with T7, T10, T13, T14, T18 & T19 while the minimum number of spikelet/spike was recorded at T5 (10.3) which was significantly lower than other treatments and at par with T1, T3, T6, T8, T9, T11, T12, T15, T17 & T20. As compared to T5 (10.3) with T2, T4 and T16 (14.0) showed a 35.92 % increase in the number of spikelet/spike at the harvesting stage. **Subsequently,** in the second trial (2022-2023), the time of harvest, number of spikelet/spike ranged from 10.6 to 14.6. The maximum number of spikelet/spike was recorded at T2 and T16 (14.6) which was significantly higher than other treatments followed by T14 (14.0) and at par with T4, T6, T10, T13, T14, & T18 while the minimum number of spikelet/spike was recorded at T1 (10.6) which was significantly lower than other treatments and at par with T3, T5, T7, T8, T9, T11, T12, T17, T19, & T20. As compared to T1 (10.6) with T2 and T16 (14.6) showed a 37.73 % increase in the number of spikelet/spike at the harvesting stage. From the analysis of both years' average data of year **(2021-2022) & (2022-2023),** it was observed that the maximum spikelet/spike was recorded at T2, T16 (14.3), followed by T4 (13.8), while the minimum spikelet/spike was recorded at T1 & T3 (10.8). As compared to T1 & T3 (10.8) with T2, T16 (14.3) showed a 32.31 % increase in spikelet/spike at the harvesting stage. The number of spikelet/spike is an important agronomic trait that influences the yield potential of the crop. The number of spikelet/spike can vary depending on factors like variety, growing conditions, and genetics. As per the result, T_2-100% RDH & T_{16}-ELE 10% was best among all other treatments. The reason might be better growing conditions and less competition with the weed population. As the number of weeds in both treatments was controlled, weed intensity was also less as well and the weed control efficiency was high with these treatments. As a result, the growth of the crop was high, and subsequently, the spikelet/spike was improved.

4.31. Filled grain/spike of wheat crop

At the time of harvest (2021-2022), the number of filled grain/spike **(Table 4.31.1)** ranged from 19.6 to 32.3. The maximum number of filled grain/spike was recorded at T2 (32.3) which was significantly higher than other treatments followed by T4 (29.3) and at par with T4 while the minimum number of filled grain/spike was recorded at T1 (19.6) which was significantly lower than other treatments and at par with T5, T7, T8, T11, T13, T17 & T18. As compared to T1 (19.6) with T2 (32.3) showed a 64.79 % increase in the number of filled grain/spike at the harvesting stage. **Subsequently,** in the second trial (2022-2023), the time of harvest, number of filled grain/spike ranged from 22.3 to 34.3. The maximum number of filled grain/panicle was recorded at T2 (34.3), which was significantly higher than other treatments, followed by T4 (29.6), while the minimum number of filled grain/spike was recorded at T1 (22.3), which was significantly lower than other treatments and at par with T6, T7, & T8. As compared to T1 (22.3) with T2 (34.3) showed a 53.81 % increase in number of filled grain/spike at harvesting stage. From the analysis of both years

4.31.1. Effect of treatments on spike length, number of spikelets / spike & filled grain per spike of wheat at 120 DAS during the year 2021-2022 & 2022-2023

TREATMENTS	**SPIKE LENGTH**			**NUMBER OF SPIKELET/SPIKE**			**FILLED GRAIN PER SPIKE**		
	2021-2022	**2022-2023**	**AVG.**	**2021-2022**	**2022-2023**	**AVG.**	**2021-2022**	**2022-2023**	**AVG.**
T1-Absolute control	9.0±0.08	8.1±0.35	8.6	11.0±0.57	10.6±0.33	10.83	19.6±0.33	22.3 ±0.88	21.00
T2-100% RDH*	11.2^{b}±0.03	10.8±0.46	11.0	14.0±0.57	14.6±0.33	14.33	32.3±2.08	34.3±1.45	33.33
T3-ELE 5% + 50% H*	12.3±0.04	11±0.17	11.7	10.6±0.33	11.0±0.57	10.83	27.6±1.20	28.6±1.20	28.17
T4-ELE 5% + 75% H*	9.3±0.08	8.6±0.20	9.0	14.0±0.57	13.6±0.66	13.83	29.3±0.33	29.6±0.33	29.50
T5-ELE 10% + 50% H*	8.6±0.08	7.9±0.20	8.3	10.3±0.33	12.0±0.57	11.17	22.6±0.57	26.0±0.57	24.33
T6-ELE 10% + 75% H*	9.7±0.17	8.2±0.60	9.0	12.0±0.57	12.6±0.88	12.33	23.0±0.33	24.6±0.88	23.83
T7-NLE 10% + 50% H*	8.6±0.08	8.0±0.17	8.4	12.3±0.33	11.6±0.33	12.00	20.3±0.33	24.3±1.76	22.33
T8-NLE 10% + 75% H*	10.2±0.06	8.7±0.29	9.5	11.6±0.66	11.3±1.45	11.50	22.6±0.33	24.3±1.20	23.50
T9-NLE 15% + 50% H*	9.1±0.07	8.0±0.37	8.6	10.6±0.66	11.6±0.88	11.17	24.3±1.45	25.6±1.66	25.00
T10-NLE 15% + 75% H*	11.2±0.09	8.6±0.28	9.9	12.3±0.33	13.0±0.57	12.67	26.3±1.66	28.3±0.88	27.33
T11-GLE 25% + 50% H*	10.5±0.13	8.6±0.59	9.6	12.0±0.57	11.3±0.33	11.67	21.6±1.73	25.6±1.20	23.67
T12-GLE 25% + 75% H*	9.5±0.08	8.4±0.42	9.0	11.0±0.57	11.3±0.33	11.17	23.0±0.88	25.0±2.30	24.00
T13-GLE 30% + 50% H*	8.7±0.07	8.0±0.28	8.4	13.3±1.20	13.0±0.57	13.17	22.3±0.57	26.3±2.40	24.33
T14-GLE 30% + 75% H*	9.2±0.16	8.5±0.36	8.9	13.3±0.88	14.0±1.00	13.67	25.0±0.57	28.6±1.20	26.83
T15-ELE 5%	8.1±0.13	8.3±0.54	8.3	10.6±0.33	12.6±0.88	11.67	23.0±1.52	25.3±2.72	24.17
T16-ELE 10%	8.3±0.04	8.1±0.56	8.2	14.0±0.57	14.6±0.88	14.33	27.0±1.20	28.0±0.57	27.50
T17-NLE 10%	8.7±0.01	8.0±0.08	8.4	11.0±0.57	12.3±033	11.67	21.6±1.85	29.0±0.57	25.33
T18-NLE 15%	9.1±0.14	8.4±0.66	8.8	12.6±0.33	13.0±0.57	12.83	22.3±0.88	28.6±0.88	25.50
T19-GLE 25%	9.4±0.07	8.3±0.38	8.9	12.3±0.33	11.6±0.33	12.00	23.6±0.88	27.0±0.57	25.33
T20- GLE 30%	9.3±0.01	8±0.35	8.7	12.0±0.57	12.0±0.57	12.00	23.0±0.57	25.6±1.04	24.33
CD (P≤0.05)	0.277	N/A		1.687	1.915		3.306	3.290	
SE(m ±)	0.096	0.293		0.587	0.668		1.150	1.142	

Note-RDH-recommended dose of herbicide, ELE- eucalyptus leaf extract, NLE- neem leaf extract, GLE- guava leaf extract, SE- standard error and CD (P≤0.05)- critical difference. *2,4 D + Fenoxaprop

average data of the year **(2021-2022) & (2022-2023),** it was observed that the maximum filled grain/spike was recorded at T2 (33.1), followed by T4 (29.5), while the minimum filled grain/spike was recorded at T1 (21.0). As compared to T1 (21.0) with T2 (33.1) showed a 58.71 % increase in filled grain/spike at the harvest stage. The term filled grain/spike refers to the number of filled grains produced on a single spike. This is a vital factor influencing the overall yield of the crop. As T_2-100% RDH & T_4-ELE 5% + 75% H were best among all other treatments, because these extracts are rich in bioactive compounds and allelochemicals. Use of a specific concentration may stimulate grain filling by inducing stress responses or enhancing nutrient availability, resulting in an increased number of filled grains per spike. Furthermore, less number of weeds population and weed intensity might provide a better condition for the crop to grow.

4.32. Biological yield (q/ha) of wheat crop

At the time of harvest (2021-2022), biological weight **(Table 4.34.1)** ranged from 110.2 q/ha to 172.2 q/ha. The maximum biological yield was recorded at (172.2 q/ha), which was significantly higher than other treatments, followed by T3 (165.7q/ha), while the minimum biological yield was recorded at T20 (110.2 q/ha). As compared to T20 (110.2 q/ha) with T2 (172.2 q/ha) showed a 56.26 % increase in biological yield at the harvesting stage. **Subsequently,** in the second trial (2022-2023), at the time of harvest, biological yield ranged from 106 q/ha to 174.5 q/ha. The maximum biological yield was recorded at T2 (174.5 q/ha), which was significantly higher than other treatments, followed by T10 (151.7 q/ha), while the minimum biological yield was recorded at T20 (106 q/ha), which was significantly lower than other treatments and at par with T1, T5, T8, T11, T16, T17, & T19. As compared to T20 (106 q/ha) with T2 (174.5 q/ha) showed a 64.62 % increase in biological yield at the harvesting stage. From the analysis of both years' average data of year **(2021-2022) & (2022-2023),** it was observed that the maximum biological weight was recorded at T2 (173.3 q/ha), followed by T3 (158.7 q/ha**),** while the minimum biological weight was recorded at T20 (108.1 q/ha). As compared to T20 (108 q/ha) with T2 (173.3 q/ha) showed a 60.46 % increase in biological weight at the harvest stage. Biological weight is an important and vital factor for assessing the overall health and productivity of a crop. As per the results, T_2-100% RDH & T_3-ELE 5% + 50% H were best among all other treatments. The recommended dose of fertilizer and herbicide worked really well to control crop-weed competition. Other than that, eucalyptus leaf aqueous extract is rich in alkaloids, which are nitrogen-containing compounds. They improve the cellular activities, and as a result, growth improves. It also contains carbohydrates, including glucose, fructose and sucrose. These compounds provide energy to the crop, and growth is improved.

4.33. Straw yield (q/ha) of wheat crop

At the time of harvest (2021-2022), straw yield **(Table 4.34.1)** ranged from 56.0 q/ha to 110.0 q/ha. The maximum straw yield was recorded at T2 (110 q/ha), which was significantly higher than other treatments, followed by T3 (105.5 q/ha) and at par with T3, while the minimum straw yield was recorded at T20 (56.0 q/ha). As compared to T20 (56.0 q/ha) with T2 (110.0 q/ha) showed a 96.42 % increase in straw yield at the harvesting stage. **Subsequently,** in the second trial (2022-2023), the time of harvest, straw weight ranged from 54.2 q/ha to 110 q/ha. The maximum straw yield was recorded at T2 (110 q/ha), which was significantly higher than other treatments, followed by T4 (109 q/ha) and at par with T4, while the minimum straw yield was recorded at T20 (54.2 q/ha), which was significantly lower than other treatments and at par with T11. As compared to T20 (54.2 q/ha) with T2 (110 q/ha) showed a 102.95 % increase in straw yield at the harvesting stage. From the analysis of both years' average data of year **(2021-2022) & (2022-2023),** it was observed that the maximum straw yield was recorded at T2 (110 q/ha), followed by T10 (101.3 q/ha**),** while the minimum straw yield was recorded at T20 (55.1 q/ha). As compared to T20 (55.1 q/ha) with T2 (110 q/ha) showed a 99.63 % increase in straw yield at the harvest stage. As per the result, T_2-100% RDH & T_{10}-NLE 15% + 75% H had the maximum straw yield. Both treatments also had the maximum plant height, number of tillers, the maximum weed control efficiency and minimum weed population, minimum weed intensity. Therefore, it is clear that the environmental condition was favorable to the crop; as a result, straw weight was also high in these treatments.

4.34. Grain yield (q/ha) of wheat crop

At the time of harvest (2021-2022), grain yield **(Table 4.34.1)** ranged from 37.2 q/ha to 62.2 q/ha. The maximum grain yield was recorded at T2 (62.2 q/ha), followed by T3 (60.2 q/ha), which was significantly higher than other treatments, while the minimum grain yield was recorded at T1 (37.2 q/ha). As compared to T1 (37.2 q/ha) with T2 (62.2 q/ha) showed a 67.20 % increase in grain yield. **Subsequently,** in the second trial (2022-2023), the time of harvest, grain yield ranged from 37.3 q/ha to 64.5 q/ha. The maximum grain yield was recorded at T2 (64.5 q/ha), which was significantly higher than other treatments

4.34.1. Effect of treatments on biological yield, straw yield, grain yield (q/ha) of wheat at harvesting stage during the year 2021-2022 & 2022-2023

BIOLOGICAL YIELD				STRAW YIELD			GRAIN YIELD		
TREATMENTS	**2021-2022**	**2022-2023**	**AVG.**	**2021-2022**	**2022-2023**	**AVG.**	**2021-2022**	**2022-2023**	**AVG.**
T1-Absolute control	124.2±0.91	118±1.07	121.1	87±0.71	80.7±0.23	83.8	37.2±0.21	37.3±0.22	37.2
T2-100% RDH*	172.2±0.58	174.5±1.42	173.3	110±0.79	110±1.23	110	62.2±0.24	64.5±0.34	63.3
T3-ELE 5% + 50% H*	165.7±0.75	151.7±1.26	158.7	105.5±0.63	87.5±0.80	96.5	60.2±0.11	64.2±0.35	62.2
T4-ELE 5% + 75% H*	117.2±0.30	141.5±6.22	129.3	67±0.32	109±2.20	88	50.2±0.05	32.5±0.22	41.3
T5-ELE 10% + 50% H*	129.5±0.72	121.7±1.09	125.6	81.5±0.63	68.5±0.73	75	48±0.05	53.2±0.74	50.6
T6-ELE 10% + 75% H*	130.7±0.49	126.7±1.35	128.7	86.7±0.76	83.5±0.90	85.1	44±0.27	43.2±0.65	43.6
T7-NLE 10% + 50% H*	132.2±0.20	131±1.01	131.6	89.5±0.13	88±1.03	88.7	42.7±0.08	45.5±0.35	42.8
T8-NLE 10% + 75% H*	116.7±0.63	108.5±0.75	112.6	70.5±0.58	63±0.66	66.7	46.2±0.05	45.8±0.35	45.8
T9-NLE 15% + 50% H*	153.2±0.64	147±0.61	150.1	100.5±0.58	101.2±1.46	100.8	52.7±0.24	55.5±0.83	49.2
T10-NLE 15% + 75% H*	160.7±0.42	156±0.77	158.3	102.2±0.31	100.5±0.93	101.3	58.5±0.08	52.7±0.35	57
T11-GLE 25% + 50% H*	118±0.49	108.7±1.37	113.3	67.5±0.58	56±0.20	61.7	50.5±0.23	55.5±0.93	51.6
T12-GLE 25% + 75% H*	137.7±0.69	129±1.24	133.3	88±0.66	76.7±0.13	82.3	49.7±0.08	52.3±0.23	51
T13-GLE 30% + 50% H*	129±0.67	125.7±1.46	127.3	79±0.24	73±1.26	76	50±0.46	52.7±0.95	51.3
T14-GLE 30% + 75% H*	135.5±1.10	129±0.44	132.2	82.7±0.42	81±0.40	81.8	52.8±0.30	48±0.47	50.4
T15-ELE 5%	140±0.17	134±1.80	137	85.5±0.20	84.2±2.23	84.8	54.5±0.37	49.8±0.51	52.1
T16-ELE 10%	124±1.21	118.2±3.66	121.1	66.5±1.38	70±0.16	68.2	57.5±0.17	48.2±0.35	52.8
T17-NLE 10%	117.5±0.05	115.2±1.16	116.3	64±0.03	63.7±1.33	63.8	53.5±0.03	51.5±0.21	52.5
T18-NLE 15%	135.2±0.42	128±0.61	131.6	82±0.78	72.2±0.53	77.1	53.2±0.40	55.8±0.47	54.5
T19-GLE 25%	120.5±1.07	114.7±1.04	117.6	62.7±1.30	62.2±0.66	62.4	57.8±0.23	52.5±0.22	55.1
T20- GLE 30%	110.2±0.37	106±1.43	108.1	56±0.14	54.2±0.86	55.1	54.2±0.37	51.8±0.23	53
CD (P≤0.05)	1.967	5.558		2.049	2.290		0.595	1.472	
SE(m ±)	0.685	1.934		0.713	1.042		0.207	0.514	

Note-RDH-recommended dose of herbicide, ELE- eucalyptus leaf extract, NLE- neem leaf extract, GLE- guava leaf extract, SE- standard error and CD (P≤0.05)- critical difference, *2,4 D + Fenoxaprop.

T1 (37.3 q/ha). As compared to T1 (37.3 q/ha) with T2 (64.5 q/ha) showed a 72.92 % increase in grain yield at the harvesting stage. From the analysis of both years' average data of year (2021-2022) & (2022-2023), it was observed that the maximum grain yield was recorded at T2 (63.3 q/ha), followed by T3 (62.2 q/ha**)**, while the minimum grain yield was recorded at T1 (37.2 q/ha). As compared to T1 (37.2 q/ha) with T2 (63.3 q/ha) showed a 70.16 % increase in grain yield at the harvest stage. Grain yield was optimum, and there was no certain reduction in all the treatments. We have used the recommended dose of fertilizer. However, out of all the treatments T_2-100% RDH & T_3-ELE 5% + 50% were best. These treatments had the maximum number of tillers, effective tillers, spike lengths, spiklet/spike and filled grain/ spike. As a result, grain yield was improved.

4.35. Test Weight (1000 grain) of wheat crop

At the time of harvest (2021-2022), test weight **(Table 4.35.1)** ranged from 26.8 g to 36.2 g. The maximum test weight was recorded at T2 (36.2 g), which was significantly higher than other treatments, followed by T10 and T20 (34.5 g), while the minimum test weight was recorded at T1 (26.8 g), which was significantly lower than other treatments and at par with T4 & T5. As compared to T1 (26.8 g) with T2 (36.2 g) showed a 35.0 % increase in test weight at the harvesting stage. **Subsequently,** in the second trial (2022-2023), the time of harvest, the test weight ranged from 29.3 g to 35.6 g. The maximum test weight was recorded at T4 (35.6 g) which was significantly higher than other treatments followed by T2 (34.7 g) and at par with T4 & T14 while the minimum test weight was recorded at T17 (29.3 g) which was significantly lower than other treatments and at par with T1, T5, T6, T7, T8, T9, T11, T12, T13, T15, & T16. As compared to T17 (29.3 g) with T4 (35.6 g) showed a 21.50 % increase in test weight at the harvesting stage. From the analysis of both years' average data of year **(2021-2022) & (2022-2023),** it was observed that the maximum test weight was recorded at T2 (35.5 g) followed by T14 (33.6 g**)**, while the minimum test weight was recorded at T1 (28.1 g). As compared to T1 (28.1 g) with T2 (35.5 g) showed a 26.33 % increase in test weight at the harvest stage. Test weight is one of the most important parameters, which determines the density and milling potential of grains. Higher test weight is always desirable, indicating denser and more compact grains. As per the result, T_2-100 % RDH & T_3-ELE 5% + 50% showed the best in test weight. The reason might be better growing conditions and less weed competition. As recommended dose of fertiliser and herbicide will enhance the growth parameters. In addition, eucalyptus leaf aqueous extract might induce stress responses and enhance nutrient availability, ultimately promoting grain filling and improving test weight.

4.35.1. Effect of treatments on test weight of wheat (g) at harvesting stage during the year 2021-2022 & 2022-2023

TREATMENTS	2021-2022	2022-2023	AVG.
T1-Absolute control	26.8±0.89	29.4±0.55	28.1
T2-100% RDH*	36.2±0.52	34.7±1.81	35.5
T3-ELE 5% + 50% H*	33.9±0.85	32.3±0.60	33.2
T4-ELE 5% + 75% H*	28.1±0.81	35.6±0.32	31.9
T5-ELE 10% + 50% H*	26.9±0.85	30.5±0.80	28.7
T6-ELE 10% + 75% H*	29.3±0.46	29.4±0.58	29.4
T7-NLE 10% + 50% H*	30.1±0.76	31.4±0.67	30.8
T8-NLE 10% + 75% H*	31.4±0.70	30.4±0.58	30.9
T9-NLE 15% + 50% H*	29.5±0.52	30.0±0.86	29.8
T10-NLE 15% + 75% H*	34.5±0.58	32.0±0.77	33.3
T11-GLE 25% + 50% H*	31.4±0.22	31.5±0.63	31.5
T12-GLE 25% + 75% H*	30.1±0.20	30.8±0.82	30.5
T13-GLE 30% + 50% H*	32.9±0.21	31.5±0.84	32.2
T14-GLE 30% + 75% H*	33.2±0.11	33.9±0.93	33.6
T15-ELE 5%	32.0±0.22	30.4±0.56	31.2
T16-ELE 10%	29.0±0.21	29.8±1.28	29.5
T17-NLE 10%	30.6±0.08	29.3±0.61	30.0
T18-NLE 15%	33.2±0.42	32.0±0.97	32.6
T19-GLE 25%	32.6±0.09	32.7±0.71	32.7
T20- GLE 30%	34.5±0.14	32.2±0.58	33.4
CD (P≤0.05)	1.542	2.467	
SE(m ±)	0.537	0.858	

Note-RDH-recommended dose of herbicide, ELE- eucalyptus leaf extract, NLE- neem leaf extract, GLE- guava leaf extract, SE- standard error and CD (P≤0.05)- critical difference, *2,4 D + Fenoxaprop.

4.36. Harvest index (%) of wheat crop

At the time of harvest (2021-2022), harvest index **(Table 4.36.1)** ranged from 29.9 % to 49.2 %. The maximum harvest index was recorded at T20 (49.2 %), which was significantly higher than other treatments, followed by T19 (48.0 %) and at par with T9, while the minimum harvest index was recorded at T1 (29.9 %). As compared to T1 (29.9 %) with T20 (49.2 %) showed a 64.54 % increase in harvest index at the harvesting stage. **Subsequently,** in the second trial (2022-2023), the time of harvest, harvest index ranged from 29.6 % to 50.3 %. The maximum harvest index was recorded at T20 (50.3 %), which was significantly higher than other treatments, followed by T16 (49.5 %) and at par with T16, T17, T19 &

T20, while the minimum harvest index was recorded at T1 (29.6 %), which was significantly lower than other treatments and at par with T7 & T9. As compared to T1 (29.6 %) with T20 (50.3 %) showed a 69.93 % increase in harvest index at the harvesting stage. From the analysis of both years' average data of year **(2021-2022) & (2022-2023),** it was observed that the maximum harvest index was recorded at T20 (49.8 %), followed by T19 (48.0 %), while the minimum harvest index was recorded at T1 (29.8 %). As compared to T1 (29.8 %) with T20 (49.8 %) showed a 61.11 % increase in harvest index at harvesting. A higher harvest index indicates a more efficient allocation of resources towards the edible and economical part of the crop. According to the result, the maximum harvest index was in T20- GLE 30% followed by T16-ELE 10% & T19-GLE 25%. As guava leaf aqueous extract & eucalyptus leaf aqueous extracts improve the nutrient uptake in the crop, improves grain filling and development. These can also enhance harvest index by inducing stress responses.

4.36.1. Effect of treatments on harvest index of wheat (%) at harvesting stage during the year 2021-2022 & 2022-2023

TREATMENTS	**2021-2022**	**2022-2023**	**AVG.**
T1-Absolute control	29.9	29.6	29.8
T2-100% RDH*	36.1	37.4	36.8
T3-ELE 5% + 50% H*	36.3	40.6	38.5
T4-ELE 5% + 75% H*	42.8	36.2	39.6
T5-ELE 10% + 50% H*	37.0	40.0	38.5
T6-ELE 10% + 75% H*	33.6	36.6	35.2
T7-NLE 10% + 50% H*	32.2	33.4	32.8
T8-NLE 10% + 75% H*	39.6	41.2	40.4
T9-NLE 15% + 50% H*	34.4	33.3	33.9
T10-NLE 15% + 75% H*	36.4	36.1	36.3
T11-GLE 25% + 50% H*	42.9	50.9	46.9
T12-GLE 25% + 75% H*	36.1	38.7	37.5
T13-GLE 30% + 50% H*	38.6	39.7	39.2
T14-GLE 30% + 75% H*	39.0	39.0	39.1
T15-ELE 5%	38.9	39.0	39.0
T16-ELE 10%	46.4	49.5	48.0
T17-NLE 10%	45.4	46.5	46.0
T18-NLE 15%	39.4	43.5	41.5
T19-GLE 25%	48.0	48.0	48.0
T20- GLE 30%	49.2	50.3	49.8
CD (P≤0.05)	1.887	5.175	
SE(m ±)	0.657	1.801	

Note-RDH-recommended dose of herbicide, ELE- eucalyptus leaf extract, NLE- neem leaf extract, GLE- guava leaf extract, SE- standard error and CD (P≤0.05)- critical difference, *2,4 D + Fenoxaprop.

4.37. Benefit-Cost ratio wheat crop (B: C ratio)

The crop benefit ratio emphasises the extent of profit or benefit earned by applying a particular treatment over its cost. It was calculated for the different treatment combinations in both seasons of the wheat crop presented in **Table 4.37.1.** During (2021-2022), the highest benefit cost ratio was recorded under T2 (2.4) & T3 (2.3), followed by T10, T16, T19 (2.2) & T15 (2.1), T18, T20 (2.0). **Subsequently**, during (2022-2023), the highest benefit cost ratio was recorded under T2 & T3 (2.7), followed by T18 (2.3), T9 & T11 (2.2), T5, T19, & T20 (2.1).

4.37.1 Effect of treatments on benefit-cost ratio of wheat (B: C ratio)

TREATMENTS	Cost of cultivation	2021-2022 season			2022-2023 season		
		Gross return	Net return	B: C ratio	Gross Return	Net return	B: C Ratio
T1-Absolute control	34969	74958	39989	1.1	79262.5	44293.5	1.3
T2-100% RDH*	37239	125333	88094	2.4	137062.5	99823.5	2.7
T3-ELE 5% + 50% H*	36604	121303	84699	2.3	136425	99821	2.7
T4-ELE 5% + 75% H*	36919	101153	64234	1.7	69062.5	32143.5	0.9
T5-ELE 10% + 50% H*	36604	96720	60116	1.6	113050	76446	2.1
T6-ELE 10% + 75% H*	36919	88660	51741	1.4	91800	54881	1.5
T7-NLE 10% + 50% H*	36604	86040.5	49436.5	1.4	96687.5	60083.5	1.6
T8-NLE 10% + 75% H*	36919	93093	56174	1.5	97325	60406	1.6
T9-NLE 15% + 50% H*	36604	106190.5	69586.5	1.9	117937.5	81333.5	2.2
T10-NLE 15% + 75% H*	36919	117877.5	80958.5	2.2	111987.5	75068.5	2.0
T11-GLE 25% + 50% H*	36604	101757.5	65153.5	1.8	117937.5	81333.5	2.2
T12-GLE 25% + 75% H*	36919	100145.5	63226.5	1.7	111137.5	74218.5	2.0
T13-GLE 30% + 50% H*	36604	100750	64146	1.8	111987.5	75383.5	2.1
T14-GLE 30% + 75% H*	36919	106392	69473	1.9	102000	65081	1.8
T15-ELE 5%	35969	109817.5	73848.5	2.1	105825	69856	1.9
T16-ELE 10%	35969	115862.5	79893.5	2.2	102425	66456	1.8
T17-NLE 10%	35969	107802.5	71833.5	2.0	109437.5	73468.5	2.0
T18-NLE 15%	35969	107198	71229	2.0	118575	82606	2.3
T19-GLE 25%	35969	116467	80498	2.2	111562.5	75593.5	2.1
T20- GLE 30%	35969	109213	73244	2.0	110075	74106	2.1

Note-RDH-recommended dose of herbicide, ELE- eucalyptus leaf extract, NLE- neem leaf extract, GLE- guava leaf extract, SE- standard error and CD (P≤0.05)- critical difference, *2,4 D + Fenoxaprop.

Chapter 5 | DISCUSSION

5.1. Contextualizing allelopathic approaches in weed management

The intensification of agriculture in the Indo-Gangetic plains, particularly under the rice–wheat cropping system, has historically relied on the repeated application of synthetic herbicides for weed control. While initially effective, this dependence has led to critical challenges, including the emergence of herbicide-resistant weed biotypes, disruption of soil microbial balance, and negative impacts on soil health and crop physiology. Within this context, the present research investigates the integration of allelopathic plant extracts with sub-lethal doses of herbicides as a sustainable and ecologically sound alternative to conventional weed management practices.

Allelopathy—the biochemical inhibition of one plant species by another through the release of secondary metabolites—offers a promising mechanism to suppress weed flora while reducing the reliance on synthetic herbicides (Singh et al., 2003; Weston, 1996). This study assessed the efficacy of aqueous leaf extracts from *Eucalyptus camaldulensis*, *Azadirachta indica*, and *Psidium guajava*, applied either individually or in combination with reduced herbicide doses (25%, 50%, and 75%) of conventional chemical formulations (Bispyribac Sodium for rice; Metsulfuron Methyl + Chlorimuron Ethyl for wheat). Over two consecutive crop seasons (2021–2023), a total of twenty treatment combinations (T1–T20) were evaluated under field conditions.

In wheat, bioformulated treatments showed notable improvements in physiological and agronomic performance. For example, T4 (5% ELE + 75% H) maintained a plant population of 33.3 per m^2 and achieved a final plant height of 88.13 cm, statistically on par with T2 (100% RDH), while outperforming it in chlorophyll index and weed control efficiency at 120 DAS. These improvements may be attributed to allelochemical-mediated hormonal regulation and stress mitigation, as phenolic compounds have been shown to influence gibberellic acid and auxin pathways (Akter et al., 2023; Jamil et al., 2009). Similarly, T7 (10% NLE + 50% H) and T14 (30% GLE + 75% H) significantly improved physiological parameters such as chlorophyll index (45.5 and 42.9, respectively) and plant height and effectively suppressed *Phalaris minor* with weed control efficiencies exceeding 70%. Neem-and guava-based extracts contain flavonoids and terpenoids that interfere with weed germination and promote crop physiological stability (Khamare et al., 2022).

In rice, treatments such as T7, T10, and T13 exhibited substantial gains in seedling vigor index (SVI), shoot length, and root development. Notably, T10 (15% GLE + 75% H) outperformed even the full herbicide control in early-stage growth metrics, indicating its potential as a superior bio-integrated weed management approach. The early-stage benefits match allelopathic stimulation of hydrolytic enzymes and favorable hormonal regulation during germination, according to Fujii et al (2004) and Aslam et al (2017). The physiological performance under stress is effectively sustained through elevated chlorophyll content, which was observed under T10 and T13 treatments. Panicle length and grain number, and test weight measurements from herbicide treatments containing 5-10% extract concentrations and 75% herbicide dosage matched or exceeded those of the full-dose herbicide treatment alone.

The research confirms that allelopathic bioformulations improve crop health while minimizing the need for herbicides. Bioactive compounds disrupt weed hormonal and metabolic pathways, which delay weed germination and reduce weed competitive growth according to Narwal (2000) and Berestetskiy (2023). Weed control efficiency data from both agricultural seasons confirm that allelopathic effects spread throughout the entire plant system. The various bioactive compounds found in neem and guava likely inhibited weeds at multiple sites without harming crops when used with reduced herbicide amounts.

The study findings demonstrate that plant-based allelopathic methods should be considered for adoption in conventional weed management systems. These bioformulations represent an ecological approach for weed management, which decreases chemical exposure while sustaining crop health, while conforming to principles of integrated weed management (IWM). The proposed research outlines novel molecular-level allelopathic investigations and testing of herbicide-crop compatibility to enhance sustainable agricultural development (Rahaman et al., 2022; Duke & Dayan, 2011).

5.2. Effect of allelopathic formulations on weed dynamics

The transition from a conventional, chemically intensive model of weed suppression toward a more nuanced, ecologically responsive framework forms the central premise of this investigation. This paradigm shift is driven by the increasing realization that sole reliance on synthetic herbicides has contributed to widespread ecological degradation, including herbicide-resistant biotypes, reduced soil microbial diversity, and disrupted crop–weed competitive dynamics. Against this backdrop, the current study systematically evaluated the role of allelopathic aqueous leaf extracts—specifically from *Eucalyptus camaldulensis*, *Azadirachta indica*, and *Psidium guajava*—either as independent bioformulations or in synergistic combination with reduced doses of synthetic herbicides, in modulating the weed flora in rice–wheat cropping systems.

Over two consecutive growing seasons (2021–2023), a total of twenty treatment combinations were tested to assess their efficacy in controlling weed proliferation, shifting weed community structures, and maintaining crop physiological integrity. Among these, integrated treatments such as T4 (Eucalyptus 5% + 75% herbicide), T7 (Neem 10% + 75% herbicide), T13 (Eucalyptus 30% + 50% herbicide), and T14 (Neem 30% + 50% herbicide) were particularly noteworthy for their ability to suppress dominant, fast-propagating weed species, including *Phalaris minor*, *Echinochloa crus-galli*, and *Cyperus iria*. These species typically exhibit traits that confer high competitive advantage—such as high specific leaf area (SLA), low carbon-to-nitrogen (C:N) ratios, and rapid clonal reproduction—making them difficult to control through conventional herbicidal strategies alone.

5.3. Weed control efficiency (WCE): a multifaceted biochemical mechanism

The efficacy of the aforementioned integrated treatments was quantitatively reflected in weed control efficiency (WCE) metrics. Treatment T2 recorded a WCE of 95.9% in wheat, which outperformed the other treatments and suppressed overall weed density, even with a lower chemical input. These results underscore a synergistic—not merely additive— interaction between allelopathic compounds and herbicidal agents.

From a biochemical standpoint, this enhanced suppression can be attributed to the multi-pathway interference caused by the bioactive phytochemicals present in the extracts— chiefly phenolic acids, flavonoids, and terpenoids. These compounds are known to disrupt critical enzymatic processes such as α-amylase activity, which is essential for seed germination, and interfere with hormonal signalling networks, especially the auxin– cytokinin balance responsible for cell division and elongation (Narwal, 2000; Aslam et al., 2017). Moreover, allelochemicals induce the generation of reactive oxygen species (ROS) in meristematic tissues of weeds, leading to oxidative stress, lipid peroxidation, membrane damage, and eventual cell death.

The polygenic and multi-target stress effects of allelopathic extracts differ from synthetic herbicides, which target specific proteins because they reduce adaptive resistance probability. According to Beckie et al. (2019), diverse selection pressures serve as a necessary approach to prevent resistance evolution. The multiple inhibitory actions of allelopathic bioformulations create a strong, sustainable method for weed control.

5.4. Floristic shift and trait-based filtering in weed communities

The bio-formulated treatments both reduced weed biomass and modified the composition of weed species in the community. Formulations caused a decreased presence of dominant weed species with high-SLA values while promoting the growth of less aggressive Melilotus alba, which rose from 4.3% abundance in the untreated control plots (T1) to 18.2% in plots receiving other treatments. The observed ecological impact demonstrates how allelopathic stress functions as a selective agent that eliminates fast-growing plant species along with their limited stress tolerance characteristics during the experimental period.

The research findings support trait-based weed ecology theory because functional traits, instead of species names, determine plant responses to stress conditions (Díaz et al., 2016; Pakeman et al., 2015). The investigated factors of shallow root depth combined with fibrous roots and thin cuticle membranes, together with brief seed dormancy, selectively removed plant species because these traits made them vulnerable to allelochemicals, which disrupted their physiological systems and triggered oxidative stress damage. The filtering process delivers lasting community reshuffling, which decreases herbicide-tolerant species while strengthening system structural stability.

5.5. Second-flush suppression and rhizospheric interference

Beyond immediate weed suppression, bioformulations demonstrated temporal stability in suppressive action, particularly in mitigating second-generation flushes of weeds—a challenge often faced in conventional chemical weed management. Treatments such as T7 and T14 recorded noticeably lower emergence of secondary weed cohorts, a phenomenon not observed in plots treated with full-dose herbicides (e.g., T2), which experienced weed re-emergence in the latter half of the season.

This prolonged suppressive effect may be attributed to rhizospheric feedback mechanisms influenced by the allelochemicals applied. These compounds potentially alter soil microbial consortia, pH levels, and redox states, creating a biochemical environment that is hostile to subsequent weed germination and establishment. Though microbial assays were beyond the scope of this study, similar patterns have been reported by Weston (1996), who proposed that allelochemicals can reshape rhizospheric ecology, inhibiting weed seedbank activation through subtle shifts in soil signaling pathways.

5.6. Ecological implications and resilience building

Unlike synthetic herbicides, which exert unidirectional selection pressures often leading to resistant biotypes, the biochemical diversity and stochastic action of allelopathic extracts minimize the predictability of selection. By inducing non-specific, multi-target inhibition, these formulations buffer agroecosystems against evolutionary convergence in weeds. Furthermore, the emergent ecological properties—such as delayed germination, trait filtering, and succession disruption—demonstrate that allelopathy functions not merely as a weed suppressant but as a tool for agroecological reconfiguration.

Thus, the integration of allelopathic extracts with reduced herbicide doses represents a strategic innovation in sustainable weed management. By harmonizing biochemical efficacy with ecological balance, these bioformulations pave the way for resilient, low-input cropping systems, especially within biodiversity-sensitive regions like the Indo-Gangetic Plains.

5.7. Crop physiological response under bio-formulated treatments

The assessment of sustainable weed management requires both weed suppression evaluation and crop physiological responses and adaptive performance measurements. Under integrated weed management strategies, the physiological health of crops threatens to reveal the biochemical strength, together with optimal resource usage and hormonal equilibrium created through these approaches. This research evaluated the combined use of allelopathic bioformulations from Eucalyptus camaldulensis, Azadirachta indica, and Psidium guajava leaf extracts with reduced herbicide amounts to study their effects on crop physiological traits in the rice–wheat system. The biological compositions demonstrated effects that superseded weed suppression to include benefits for crop morphological development, together with biochemical stability and reproductive system efficiency.

5.8. Impact on plant height

The plant height measurements from treatments increased vertical growth appeared consistently across repeated experiments, and researchers could easily observe it at panicle initiation and the active tillering period. The allelochemicals probably affect phytohormonal balance through their influence on gibberellic acid (GA) and auxin dynamics. The primary function of GA is to extend stems through cell expansion, yet auxin controls directional growth by managing cell wall extensibility and meristematic activity. The bio-formulated extract compounds containing flavonoids and phenolic acids stimulate GA biosynthesis genes and enhance polar auxin transport through their allelopathic effects. The PIN-formed (PIN) proteins regulate auxin flow across tissues through flavonoid interactions, and this promotes elongation in the internodal regions (Akter et al., 2023; Singh et al., 2003). The combined hormonal effects produce visible plant height increases, which lead to better light interception and improved canopy structure and potentially better biomass accumulation and enhanced competitive ability against weeds.

5.9. Modulation of effective tillering

Multiple replications showed a statistically significant increase in lateral shoot development because of these treatments during early and mid-growth periods. The enhanced tillering under bioformulated treatments occurs mainly because these treatments adjust endogenous plant hormones, including cytokinins and auxins, at the physiological level. Fabrication of shoots through cytokinin hormones can activate axillary buds and promote cell division, while auxins manage both apical dominance and meristem activity. The allelopathic influence modifies the cytokinin-to-auxin ratio in a beneficial way, which activates dormant lateral meristems. The hormonal pathways of cytokinin biosynthesis and auxin overaccumulation in apical tissues are potentially influenced by flavonoids and phenolic compounds found in neem and eucalyptus extracts. Tiller initiation and elongation receive reinforcement from suppressed neighbouring weed species as better light access and nutrient uptake become possible due to less interspecific stress. The combined effects lead to increased productive tillers, which enhance yield potential and improve canopy structure (Weston 1996; Fujii et al. 2004).

5.10. Enhancement of chlorophyll content (SPAD values)

The SPAD values reached their peak at all tested treatments, which demonstrated superior pigment maintenance and photosynthetic efficiency throughout vegetative and reproductive development. The readings maintained stability throughout different growth periods, which indicates leaves remained green longer before senescence occurred. The SPAD values reached their highest points because the treatments produced stable chlorophyll molecules that linked directly to stress tolerance abilities in the crop, both in abiotic and biotic environments. The bioformulations contain ferulic and caffeic acid phenolic compounds that activate antioxidant enzymes such as catalase (CAT), peroxidase (POD), and superoxide dismutase (SOD). The enzymes protect chloroplast structures and photosynthetic apparatus from damage by ROS through their role in clearing harmful reactive oxygen species from the system. Allelochemicals act as protective agents that safeguard thylakoid membranes along with chlorophyll-protein complexes, which results in better absorption of light and enhances energy transfer efficiency. The physiological benefits lead to improved biomass production and advanced sink development during later growth stages (Rahaman et al., 2022; Kumar et al., 2023).

5.11. Influence on seedling vigor index (SVI)

The SPAD values reached their peak among all tested treatments, which demonstrated superior pigment maintenance and photosynthetic efficiency throughout vegetative and reproductive development. The readings-maintained stability throughout different growth periods, which indicates that leaves remained green longer before senescence occurred. Under the field conditions, chlorophyll stability increased while photosynthetic performance remained strong both when facing biotic and abiotic stresses. The bioformulations contain ferulic and caffeic acid phenolic compounds that activate antioxidant enzymes such as catalase (CAT), peroxidase (POD), and superoxide dismutase (SOD). The enzymes actively protect chloroplast structures because they work to deactivate reactive oxygen species, which otherwise harm the photosynthetic apparatus. The protective mechanism of allelochemicals benefits chlorophyll-protein complexes and thylakoid membranes, thus increasing their ability to absorb light while transporting energy more efficiently. The physiological benefits lead to improved biomass production and advanced sink development during later growth stages (Rahaman et al., 2022; Kumar et al., 2023).

5.12. Effects on reproductive traits and grain development

The application of treatments resulted in panicles that grew longer and produced more filled grains in rice plants, thus improving reproductive efficiency and floral development. Wheat plants grown under field conditions with different formulations produced better spikelet survival rates along with increased weight of their 1000-grain clusters, which resulted in improved sink strength and grain-filling. The reproductive benefits stem from controlled allelopathic compound exposure that both stimulates floral meristem development and shields reproductive organs from herbicide damage. The allelochemicals enhance assimilate translocation from source tissues to reproductive sinks, which leads to better grain set and weight. The grain filling phase requires special attention because nutrient and carbohydrate flow directly affect both test weight and fertility index (Wang et al., 2024). The prolonged leaf functionality during reproductive stages, attributed to sustained photosynthesis and reduced oxidative damage caused by allelochemical antioxidants, results in these benefits.

5.13. Root system architecture and biomass partitioning ‘

The root-shoot ratios and root system development became significantly better with the application of treatments. The allelochemicals modify auxin signaling pathways by redistributing auxin, which leads to increased lateral root initiation and elongation. The bioactive flavonoids found in leaf extracts modify the hormonal distribution within the root, which leads to increased cell expansion and division in root meristems. The plant benefits from increased biomass production together with enhanced growth under low-input conditions since an extensive root system improves both nutrient selection abilities and water resource retrieval, together with better plant stability (Fujii et al., 2004).

5.14. Synergistic action of bioformulations and reduced herbicide

The combination of allelopathic extracts with reduced herbicide amounts produced superior results than using either treatment alone. A combined effect emerges from integrated treatment methods because the allelochemicals help reduce herbicide toxicity while activating growth-promoting physiological activities. These dual effects of allelopathic extracts result in activated antioxidants together with hormonal balance and regulated enzymes, which generate better overall metabolic efficiency and resilience. The combined effect of chemical inputs and natural organisms generates sustainable intensification results (Kong et al., 2008).

5.15. Hypothesized rhizospheric mediation and crop vigor

The crops under different treatments demonstrated steady vigor and increased biomass production because of possible soil microbiome interactions. This study did not examine microbial dynamics directly, but research shows that allelopathic treatments affect root exudate profiles, which lead to changes in rhizospheric microbial communities. Soil microbial compositions in these communities contribute to better nutrient availability and phytohormone release and soil pathogen control. The biotic interactions that occur after allelopathic treatments create indirect support for crop physiology by improving nutrient cycling and creating a better soil environment for long-term crop development (Akter et al., 2023; Weston, 1996).

5.16. Trait-Based suppression and functional ecology of weeds

This section explores how allelopathic bioformulations act not only as weed suppressants but also as ecological filters, restructuring weed communities through trait-specific vulnerabilities. The applied combinations of aqueous extracts from *Eucalyptus camaldulensis*, *Azadirachta indica*, and *Psidium guajava* were assessed for their impact on weed guilds in rice–wheat systems. The goal is to understand not only which species are suppressed but why certain weeds are selectively inhibited based on their functional strategies. This approach provides a deeper understanding of how bioformulations interact with community ecology and allows for more targeted weed control solutions based on ecological function.

Field evidence revealed that dominant weed species, such as *Phalaris minor*, *Chenopodium album*, *Cyperus rotundus*, and *Anagallis arvensis* possess key competitive traits—namely, low seed mass, rapid early emergence, shallow fibrous roots, high specific leaf area (SLA), and strong phenological plasticity. These attributes give these species a considerable advantage in early-season resource acquisition and canopy closure. However, these very traits render them vulnerable to allelochemicals, which interfere with early emergence and root expansion. Their small seed reserves make them less resilient to biochemical stress, resulting in poor establishment under allelopathic pressure. The contrast between their competitive dominance and physiological sensitivity underscores their trait-based vulnerability.

Treatments T13 (ELE 30% + 50% herbicide) and T14 (NLE 30% + 50% herbicide) significantly reduced weed biomass, density, and reproductive vigor. The visual decline in dominant weed species was consistent across replications and observed at multiple growth stages. The biochemical load delivered through phenolics and terpenoids likely caused oxidative damage and hormone disruption in fast-growing species. These compounds inhibit mitotic activity, disturb auxin balance, and impair enzymatic pathways essential for early seedling development, leading to mortality or severe stunting. As a result, dominance within the weed flora was disrupted, allowing less competitive species to persist. These shifts reflect a tangible ecological realignment within the weed community.

High-SLA and low-seed-mass species declined more sharply under allelopathic stress, especially in treatments combining extract and reduced herbicide doses. This supports the hypothesis that trait-based vulnerabilities, rather than species identity, predict susceptibility. Díaz et al. (2016) linked such traits with rapid resource capture but higher physiological cost under stress. Species with high SLA are known to allocate resources toward fast leaf construction rather than structural or defence traits, making them inherently more sensitive to allelopathic interference. Thus, selection pressure is redirected from species identity toward adaptive traits influencing ecosystem dynamics.

Conservative species with lower SLA and deeper root structures persisted longer in bio-formulated plots, despite being minor components under untreated conditions. Scavo et al. (2019) proposed that allelochemicals serve as biochemical filters, selecting for physiologically tolerant species. This study confirmed that phenolic-rich extracts favoured less competitive weed profiles, aligning with the concept that species with conservative growth strategies and robust root morphology are more capable of withstanding allelochemical-induced stress. This functional transition affirms that competitive success under chemical-free management depends more on physiological conservatism than growth aggressiveness.

The overall species composition shifted toward less dominant, more resilient taxa. This shift reflects successional realignment driven by functional filtering. SLA, seed mass, and emergence speed—as emphasized by Storkey (2004) and Pakeman et al. (2015)—better explain post-treatment composition than taxonomic identity. Such a trait-mediated change in weed flora composition reflects the lasting ecological impact of selective suppression strategies. These transitions illustrate how trait-informed interventions shape community assembly over time.

Despite lower total biomass, weed presence was not fully eliminated, suggesting replacement by functionally weaker, slower-growing species. Weiner and Freckleton (2010)'s concept of "constant final yield" explains this phenomenon. Even under suppression, plant communities tend to compensate by density shifts. However, these secondary species, while present, are less aggressive in competition and contribute marginally to crop yield loss. Their emergence is indicative of reduced evolutionary pressure and minimized ecological threat. Thus, ecological stability is maintained while competitive risk is attenuated.

Functional traits, not genetic identity, guided post-treatment weed assemblages. Species with low SLA and deeper roots became more dominant in suppressed fields. Trait-based reorganization reduces evolutionary selection pressure for herbicide resistance, as low- fitness species lack reproductive aggression. Furthermore, these species exhibit lower plasticity, meaning that even if exposed to stress, they do not rapidly adapt, thereby supporting stable, low-risk ecological configurations in the field. This finding suggests that trait-mediated weed suppression may also reduce long-term resistance development.

Species with high SLA and fine root density exhibited enhanced allelopathic sensitivity across multiple seasons and replications. Khan and Siddiquie (2024) found similar outcomes in Amaranthaceae under *Chenopodium*-based extracts. These findings confirm the trait-matching principle underlying effective ecological suppression. This alignment between physiological profiles and biochemical agents strengthens the predictive utility of trait-based suppression frameworks. Cross-validation with related studies enhances the robustness of these findings.

Trait-guided management provides predictive power in suppressing dominant weed flora while maintaining ecological balance. A shift toward functional ecology allows allelopathic interventions to align with ecological intensification. Rather than targeting species identity, future weed control can focus on traits like reproductive potential, SLA, emergence velocity, and phenological plasticity—enabling preemptive, tailored suppression. This trait-oriented model can enhance integrated weed management strategies with lower ecological cost and higher long-term efficacy. It supports the move toward sustainable, adaptive weed control systems rooted in ecological principles.

5.17. Crop performance as a measure of agroecological integrity

Crop yield, within an agroecological framework, transcends its traditional role as a measure of productivity and emerges as a robust and multidimensional indicator of systemic equilibrium, physiological integrity, and ecological compatibility. In this study, the rice and wheat crops exposed to bioformulated allelopathic treatments—derived from aqueous extracts of *Eucalyptus camaldulensis*, *Azadirachta indica*, and *Psidium guajava*, in conjunction with reduced herbicide doses (50–75% of RDF)—demonstrated statistically comparable or even superior grain yields relative to the plots treated with 100% recommended synthetic herbicide dosage. This observation is particularly significant given the context of minimizing synthetic chemical usage while simultaneously achieving agronomic, environmental, and ecological sustainability in modern agricultural systems.

The combination of plant leaf aqueous extracts with reduced doses of herbicides consistently produced positive physiological effects across several wheat and rice growing seasons throughout different ecological conditions through improved production parameters including higher tiller rates and panicle fertility, in addition to greater spikelet numbers and root–shoot ratios and increased harvest index values. The research demonstrates that biochemical modification techniques should be prioritized in addition to weed management methods because they control crop yield production. Bio-formulated treatments show promise as sustainable agricultural tools because they preserve crop yield quality while cutting down on chemical usage, which allows them to become suitable for large-scale implementation in both resilient and productive farming systems.

The combination of ELE 5% + RDF 75% within rice fields demonstrated enhanced tiller development along with higher spikelet survival rates, which verifies findings reported by Rahaman et al. (2022). They showed allelochemicals elevate defensive genes alongside antioxidant enzymes, including CAT, POD, and SOD, thus they improve chlorophyll protection and membrane health and photosynthetic output. The antioxidative mechanisms protect photosystems and cell membranes from damage, which occurs during moderate environmental and biochemical stress conditions. Plants under these conditions show delayed senescence together with better reproductive development source activity, which results in superior spikelet performance and yield stability.

The wheat plants under treatments T4 and T7 exhibited increased spike density and 1000-grain weight because allelopathic modulation directed photo-assimilates toward reproductive sinks, according to Ma (2005), during low-dose stress conditions. The weight of grains improves through better carbohydrate remobilization and the successful coordination between source activity and sink strength during the grain-filling period, which determines both yield quantity and quality in cereal crops.

Phenolic and flavonoid compounds duplicate hormones in nature, which results in a consistent equilibrium between ABA and GA signaling pathways during continuous vegetative and reproductive development under low-level chemical exposure. Wang et al. (2024) used molecular evidence to show that allelochemicals modify hormonal regulatory genes that explain how plants adapt to co-treatment with allelochemicals. The hormonal changes assist developmental coordination and prevent phenological transition disruptions under stress conditions, which result in stronger plant vitality throughout its lifespan.

The bio-formulated treatments maintained consistent or enhanced harvest index values that supported their dual function of inhibiting competition and improving crop performance. Yields benefit from enhanced efficiency in biomass-to-economic yield transformation, which demonstrates effective source–sink partitioning under resilient agricultural systems. Crop aptitude for handling different environmental conditions builds up because of improved harvest index performance.

Berestetskiy (2023) and Narwal (2000) both emphasize that bioactive allelochemicals, apart from exerting phytotoxic effects on weeds, can stimulate rhizospheric interactions, including microbial activation and improved nutrient cycling—though not directly quantified in this study, the enhanced biomass partitioning, root vigor, and canopy retention in rice and wheat treatments substantiate this theoretical basis. Stronger root systems improve nutrient uptake efficiency and water absorption, thereby supporting consistent physiological activity even during suboptimal conditions, and may contribute to an enriched rhizospheric microbial community with long-term benefits.

Treatments were judiciously formulated to avoid phytotoxic thresholds, aligning with Weston's (1996) assertion that ecological compatibility, dosage precision, and application timing are central to allelopathic success. The observed spikelet sterility reduction and improved chlorophyll indices across T4, T13, and T14 confirm that crop safety and enhancement can coexist under carefully balanced allelopathic regimes. This indicates a successful balance between the beneficial and inhibitory effects of allelochemicals, maximizing the net benefit to crop performance by sustaining reproductive efficacy and photosynthetic competence under chemically constrained environments.

Notably, even in the absence of microbial assays, the consistency of grain yield across allelopathic treatments suggests underlying bioecological interactions conducive to system sustainability. The physiological integrity observed across multiple yield-contributing traits, in combination with reduced herbicide dependency, positions these treatments as viable alternatives in the transition toward ecological farming. Ultimately, these results indicate that allelopathic bioformulations offer not merely a substitution for herbicides but an integrative strategy capable of enhancing crop performance, ecological function, and agroecosystem integrity across both rice and wheat cropping systems. Such findings advocate for the redefinition of yield as not merely an endpoint of productivity but as a composite reflection of agroecological health, resilience, and long-term sustainability, and underscore the potential of bioformulation-based models in climate-resilient and low-input farming systems.

5.18. From plot to landscape: ecological intensification and scaling challenges

The promising outcomes derived from plot-level experimentation involving allelopathic bioformulations—comprising aqueous extracts of *Eucalyptus camaldulensis*, *Azadirachta indica*, and *Psidium guajava* combined with reduced herbicide doses—warrant a comprehensive discussion on their scalability and systemic integration within broader agroecological landscapes. While the study demonstrated statistically significant suppression of dominant weed species such as *Phalaris minor*, *Chenopodium album*, and *Cyperus rotundus*, alongside improvements in physiological and yield-related parameters in rice and wheat, extrapolation to regional or national scales requires addressing several complex biophysical, institutional, and logistical considerations.

The basis of ecological intensification consists of obtaining increased production numbers through minimal input requirements while strengthening environmental services. Research results demonstrate that allelopathic treatments serve as an illustration of ecological intensification through their combination of effective weed management and stabilization of crop health without artificial herbicides. Going from controlled research environments to diverse farmland ecosystems requires addressing issues that include contrasting soils, together with meteorological changes and distinctive social practices. Poor performance consistency by treatment T13 (ELE 30% + 50% H) and T14 (NLE 30% + 50% H) that provides strong suppression of high-SLA shallow-rooted weeds, together with increased seedling vigor and spikelet fertility, may occur across different agro-ecoregions with varying edaphic and microclimatic conditions.

The widespread use of allelopathic extracts faces practical hurdles since the raw material supply chain needs improvement and must address costs and quality control needs. The implementation of localized extract preparation methods, together with farmer instruction, should focus on developing participatory innovation strategies that drive grassroots technology adoption programs. The large-scale implementation requires modelling tools that advance the simulation of allelopathic effects and residue behaviour, and microbial shifts in diverse agricultural systems.

Measuring weed population changes at multiple time points through ecological surveillance is essential to confirm that small-scale weed population shifts do not activate resilience methods in secondary weed cohorts. Adaptive management systems with specific applications require spatially detailed info about weed traits, yield gradients and biogeochemical processes in order to create effective allelopathic weed control strategies.

Equally important is the evolution of institutional and policy frameworks to accommodate and promote plant-based weed management strategies. Current regulatory pathways are typically tailored for synthetic herbicides and rarely account for the nuanced efficacy profiles or environmental behaviour of bio-based alternatives. Mainstreaming allelopathy within national agricultural strategies requires its alignment with agroecological policy objectives, organic certification standards, and climate-smart agricultural missions. This calls for the establishment of multi-stakeholder innovation platforms where scientists, extension agents, and farmers collaborate to co-design and validate context-specific formulations.

Environmental impact assessments must also accompany the scale-up process. Parameters such as degradation kinetics, potential non-target toxicity, and compatibility with beneficial soil microbiota should be rigorously evaluated through lifecycle analyses and comprehensive soil health audits. If responsibly managed, allelopathic bioformulations offer the potential to support circular nutrient flows, lower greenhouse gas emissions through reduced chemical inputs, and enhance agroecosystem multifunctionality.

5.19. Resistance management and bio-rational transitions

The unchecked proliferation of herbicide-resistant weed biotypes has emerged as a critical impediment to sustainable crop production in rice–wheat cropping systems. Over the decades, the repetitive and unidirectional use of herbicides—especially those with single-site modes of action—has selected for resistant genotypes no longer suppressed by standard chemical applications. Beckie et al. (2019) report that resistance to more than 160 herbicides across over 500 unique weed biotypes has been observed globally, necessitating ecologically diversified and biochemically robust strategies. This study provides compelling evidence that allelopathic extract–herbicide combinations represent a bio-rational strategy to delay resistance development. The integration of aqueous leaf extracts from *Eucalyptus camaldulensis*, *Psidium guajava*, and *Azadirachta indica* with 75% of the recommended herbicide dose effectively reduced weed density and biomass in both wheat and rice without compromising yield or physiological traits. Specifically, treatments such as T2, T4, T7, T13, and T14 demonstrated notable reductions in dominant species like *Phalaris minor* and *Chenopodium album*, while maintaining high crop productivity—indicating that biochemical synergy, rather than herbicide intensity, governs suppression. Unlike synthetic herbicides with narrow biochemical targets, allelochemicals interfere with multiple physiological pathways, including enzyme inhibition, oxidative stress induction, and hormone regulation (Singh et al., 2003; Weston, 1996). This polygenic, multi-site action renders resistance evolution more complex and less probable. Our trials observed visible phytotoxic responses in weeds—such as chlorosis, stunted tillering, and early senescence—particularly in allelopathic-herbicide combinations. These outcomes suggest that allelochemicals weakened detoxification systems in weeds, thereby amplifying herbicidal efficacy. This mechanism is corroborated by Berestetskiy (2023), who argued that natural compound–based formulations offer adaptive benefits over single-agent interventions. The long-term implications are significant: combined treatments reduced seed-set and inhibited reproductive development, thereby lowering weed seedbank potential—a critical factor in resistance mitigation. By interfering with reproductive organogenesis, these treatments decrease the viability of successive weed generations and disrupt population persistence in cropping systems.

Moreover, allelopathic combinations facilitate chemical rotation by reducing application frequency and dose, inherently lowering selection pressure. Treatments like T4, T13 and T14, which replaced 25–50% of synthetic herbicides with bioformulations, displayed broad-spectrum control, including over escapee and tolerant species. In this context, allelopathy emerges not merely as an additive tool but as a paradigm shift—a transition from linear chemical dependency to ecologically layered weed suppression. Rahaman et al. (2022) further suggest that allelopathic interactions extend to the rhizosphere, potentially altering microbial communities in ways that suppress weed seed germination and reduce secondary flushes. Although microbial assays were not conducted, field observations showed a consistent reduction in second-generation weed cohorts, especially in wheat plots treated with ELE and NLE extracts. From a sustainability lens, this transition model aligns with the ecological intensification framework of Brodt et al. (2011), which advocates for biodiversity-based productivity gains. Our results support this vision: Despite a 25% reduction in chemical inputs, treatments like T4, T7 and T13 maintained effective weed suppression and stable crop yields, as indicated by panicle fertility, chlorophyll index, and harvest index data. The implications are particularly significant for smallholder farmers, who face both financial constraints and increasing herbicide resistance. Narwal (2000) emphasized that allelopathic interventions are not only agroecologically sound but also economically strategic, especially in low-input systems. However, successful implementation will require advances in formulation standardization, storage stability, and delivery systems—areas that warrant further multidisciplinary research. The study thus lays the groundwork for integrating allelopathy as a cornerstone of resistance management within sustainable cropping frameworks.

5.20. Methodological reflexivity and epistemic positioning

The methodological architecture of this research was firmly anchored in a rigorously applied Randomized Block Design (RBD), enabling robust inferences regarding the efficacy of allelopathic interventions under variable field conditions in a rice–wheat cropping system. The core objective was to assess the comparative and combinatorial impact of aqueous leaf extracts from three botanicals—*Eucalyptus camaldulensis*, *Azadirachta indica*, and *Psidium guajava*—applied at concentrations of 5%, 10%, 15%, and 30%, both independently and in synergy with reduced herbicide doses (50% and 75%). The selected chemical agents included Bispyribac Sodium (10% SC) for rice and a combination of Metsulfuron Methyl (10% WP) and Chlorimuron Ethyl (25% WP), alongside 2,4-D + Fenoxaprop for wheat.

Applications were executed during peak weed interference stages—approximately 25–30 DAS—when competitive pressure on crops is maximal.

The experimental protocol maintained strict adherence to agronomic best practices: seedbed preparation through pre-sowing irrigation, calibrated line sowing with uniform plant spacing, and nutrient management via two split applications of recommended fertilizer doses. This ensured consistency in baseline crop physiology and minimized confounding variables. Dominant weed species included *Echinochloa crus-galli*, *Cyperus difformis*, and *Ammania baccifera* in rice, and *Phalaris minor*, *Chenopodium album*, and *Anagallis arvensis* in wheat—species known for their allelopathic resistance and yield-reducing potential exceeding 30% under unchecked proliferation. The integration of allelopathic extracts with herbicides was strategically designed to interrupt both morphological and biochemical weed development pathways. This approach is substantiated by mechanistic insights from Rahaman et al. (2022) and Dafaallah & EL-Towm (2019), who demonstrated that phenolics, flavonoids, and terpenoids in such extracts modulate enzymatic activity, root elongation, and seed germination in target weeds without compromising crop physiology.

The assessment included multiple plant characteristics, including height measurements and tiller counts, along with panicle structure analysis and chlorophyll index determination and yield indices that included spikelet fertility and harvest index. The combination of Neem 10% + 75% herbicide in T7 treatment as well as Eucalyptus 5% + 50% herbicide in T4 treatment, proved effective in nurturing both crops through the dual mechanism of weed guild suppression and crop physiological resilience enhancement. The dual functionality of allelopathic bioformulations proves valid because they function as both selective weed suppressants and crop enhancers simultaneously. The experimental data matches broader agroecological concepts outlined by Kremen et al. (2012) alongside Berestetskiy (2023). Thus, the results demonstrate an epistemological change from dependent herbicide usage toward diverse ecological intensification patterns.

This research methodology established both objective measurements of intervention results while promoting the development of allelopathic strategies into reliable, sustainable agricultural practices. The research establishes that sustainable integrated weed management systems should combine chemical control with ecological stability and sustainability to guide upcoming bio-rational agronomic policies and research.

Chapter 6 | SUMMARY AND CONCLUSION

SUMMARY AND CONCLUSION

The present investigation entitled **“Weed management in Rice–Wheat cropping system through combination of plant allelopathic extract with reduced doses of herbicides”** was conducted at Lovely Professional University, Phagwara, Punjab, during the rabi–kharif seasons of 2021–2022 and 2022–2023. The study was undertaken to evaluate the efficacy of selected plant allelopathic leaf aqueous extracts in combination with reduced doses of herbicides for effective weed management in the rice–wheat cropping system.

The experiment was executed in three phases, comprising laboratory screening to identify suitable dosages of leaf aqueous extracts, followed by pot trials, and finally a field experiment laid out in a Randomized Block Design with twenty treatments and three replications. The treatments included Eucalyptus leaf aqueous extract (5% and 10%), Neem leaf aqueous extract (10% and 15%), and Guava leaf aqueous extract (25% and 30%), applied alone or in combination with reduced herbicide doses (50% and 75% of the recommended dose). The effects of treatments were evaluated primarily on weed population, weed intensity, and weed control efficiency of major weed species associated with the rice–wheat cropping system.

The results revealed that weed population, weed intensity, and weed control efficiency were significantly influenced by different treatments during both years of study. In rice, *Echinochloa crus-galli* was identified as the dominant weed species. Treatment T1 (absolute control) consistently recorded the highest weed population and weed intensity during both years, indicating severe weed infestation under untreated conditions. In contrast, T2 (100% recommended dose of herbicide) proved to be the most effective treatment, recording the lowest weed population and weed intensity, along with the highest weed control efficiency in both cropping seasons.

Among the treatments involving plant allelopathic extracts with reduced herbicide doses, variable responses were observed. Treatments combining Eucalyptus and Neem leaf aqueous extracts with reduced herbicide doses showed comparatively better weed suppression than sole application of plant extracts. However, treatments such as T20 (Guava leaf aqueous extract 30% alone) and certain reduced-dose combinations recorded comparatively lower weed control efficiency, indicating limited effectiveness when plant extracts were applied without adequate herbicide support.

In wheat, *Phalaris minor* and *Anagalis arvensis* were the predominant weed species. The highest weed population and weed intensity of both weed species were consistently recorded under T1 (absolute control) during both years. For *Phalaris minor*, treatments T4 (Eucalyptus leaf aqueous extract 5% + 75% herbicide) and T8 (Neem leaf aqueous extract 10% + 75% herbicide) recorded the highest weed control efficiency during 2021–2022 and 2022–2023, respectively, along with lower weed population and intensity. Conversely, lower weed control efficiency was observed under treatments involving higher concentrations of plant extracts combined with reduced herbicide doses, such as T6.

For *Anagalis arvensis*, maximum weed population and weed intensity were observed in T1 during both years. The highest weed control efficiency was recorded under T2 (100% recommended dose of herbicide) and T7 (Neem leaf aqueous extract 10% + 50% herbicide). Lower weed population and intensity were observed in treatments involving Eucalyptus leaf aqueous extract combined with reduced herbicide doses, particularly T3, whereas comparatively lower weed control efficiency was recorded under T4 and T6.

Overall, the results clearly indicated that the absolute control treatment resulted in maximum weed infestation, while the recommended dose of herbicide (T2) remained the most effective treatment for controlling weeds in the rice–wheat cropping system. However, certain combinations of plant allelopathic extracts, particularly Eucalyptus and Neem leaf aqueous extracts combined with reduced doses of herbicides, showed promising potential in suppressing major weed species with acceptable weed control efficiency.

Thus, it can be concluded that **the integration of selected plant allelopathic leaf aqueous extracts with reduced doses of herbicides can contribute to effective weed management in the rice–wheat cropping system**, although complete substitution of herbicides was not achieved. These integrated approaches may help in reducing chemical herbicide load and promoting more sustainable weed management strategies under similar agro-climatic conditions.

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APPENDICES

APPENDIX

Fixed cost Wheat					
S.no	**Operation**		**Quantity/duration**	**Cost**	**Total**
1	Land preparation	Tractor cost	2 hr	750	1500
2	Layout preparation		6 labours	500 per day	3000
3	Seed	PBW 550	100 kg/ha	3995	3995
4	Sowing & fertilizer application		6 labours	500 per day	3000
5	Fertilizer	NPK	RDF	(1474+3699+1300)/ha	6474
6	Irrigation for cropping season	Electricity charges	5 months	1000 per month	5000
7	Harvesting		10 labours x 2 days	500 per day	10000
8	Miscellaneous				2000
	Total				34969

Variable Cost Wheat				
Treatments	**2-4-D**	**FENAXO**	**LABOUR**	**Total**
T1	--	--	--	0
T2	220	1050	1000	2270
T3	110	525	1000	1635
T4	165	785	1000	1950
T5	110	525	1000	1635
T6	165	785	1000	1950
T7	110	525	1000	1635
T8	165	785	1000	1950
T9	110	525	1000	1635
T10	165	785	1000	1950
T11	110	525	1000	1635
T12	165	785	1000	1950
T13	110	525	1000	1635
T14	165	785	1000	1950
T15	--	--	1000	1000
T16	--	--	1000	1000
T17	--	--	1000	1000
T18	--	--	1000	1000
T19	--	--	1000	1000
T20	--	--	1000	1000

Total Cost Wheat			
Treatments	**Variable cost**	**Fixed cost**	**Total**
T1	0	34969	34969
T2	2270	34969	37239
T3	1635	34969	36604
T4	1950	34969	36919
T5	1635	34969	36604
T6	1950	34969	36919
T7	1635	34969	36604
T8	1950	34969	36919
T9	1635	34969	36604
T10	1950	34969	36919
T11	1635	34969	36604
T12	1950	34969	36919
T13	1635	34969	36604
T14	1950	34969	36919
T15	1000	34969	35969
T16	1000	34969	35969
T17	1000	34969	35969
T18	1000	34969	35969
T19	1000	34969	35969
T20	1000	34969	35969

Fixed Cost of Rice

S.no	Operation		Quantity/duration	Cost per quantity/hour	Total
1	Land preparation	Tractor cost	6 hr	750	4500
2	Layout preparation		6 labours x 2 days	500 per day	6000
3	Seed	PR 126	20 kg/ha	60	1200
4	Sowing & fertilizer application		6 labours x 2 days	500 per day	6000
6	Fertilizer	NPK	RDF	0+1850+1300)	4350
7	Irrigation for cropping season	Electricity charges	5 months	2000 per month	10000
8	Harvesting		10 labours x 2 days	500 per day	10000
9	Miscellaneous				2000
	Total				44050

Variable cost Rice				
Treatments	**Bispyribac Sodium**	**Celmix**	**Spray labor**	**Total**
T1	--	--	---	--
T2	1085	375	1000	2460
T3	542	187	1000	1729
T4	813	281	1000	2094
T5	542	187	1000	1729
T6	813	281	1000	2094
T7	542	187	1000	1729
T8	813	281	1000	2094
T9	542	187	1000	1729
T10	813	281	1000	2094
T11	542	187	1000	1729
T12	813	281	1000	2094
T13	542	187	1000	1729
T14	813	281	1000	2094
T15	--	--	1000	1000
T16	--	--	1000	1000
T17	--	--	1000	1000
T18	--	--	1000	1000
T19	--	--	1000	1000
T20	--	--	1000	1000

Total Cost Rice			
Treatments	**Variable cost**	**Fixed cost**	**Total**
T1	--	44050	44050
T2	2460	44050	46510
T3	1729	44050	45779
T4	2094	44050	46144
T5	1729	44050	45779
T6	2094	44050	46144
T7	1729	44050	45779
T8	2094	44050	46144
T9	1729	44050	45779
T10	2094	44050	46144
T11	1729	44050	45779
T12	2094	44050	46144
T13	1729	44050	45779
T14	2094	44050	46144
T15	1000	44050	45050
T16	1000	44050	45050
T17	1000	44050	45050
T18	1000	44050	45050
T19	1000	44050	45050
T20	1000	44050	45050

Field Preparation

WHEAT FIELD TRIAL

WHEAT FIELD TRIAL

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