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Optimizing safflower (*Carthamus tinctorius* L.) crop yield and weed suppression through pre-emergence herbicide strategies

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Abstract

Aim: Safflower (*Carthamus tinctorius*) holds significant agricultural and economic value owing to its versatile applications ranging from oil extraction to medicinal and nutritional benefits. Effective weed management is essential throughout its growth stages to optimize yield and quality. This study aimed to optimize safflower yield and suppress weeds through pre-emergence herbicide strategies.

Methodology: Field experiments were conducted during 2019 and 2020 at the Main Agricultural Research Station, University of Agricultural Sciences, Dharwad, Karnataka, India employing a randomized complete block design. Various pre-emergence herbicide treatments were applied and their efficacy was assessed through weed control efficiency and safflower yield attributes.

Results: Sulfentrazone in combination with intercultivation at 30-35 days after sowing (DAS), significantly reduced weed infestation and increased safflower yield compared to the weedy check. Furthermore, the herbicide-treated plots demonstrated higher primary branches, capsules per plant, and test weight, indicating efficient resource utilization by safflower plants. Economic analysis revealed favorable returns and benefit-cost ratios with certain herbicide treatments, particularly sulfentrazone-based strategies. Additionally, weed control efficiency showed a positive correlation with yield attributes, while the number of weeds negatively impacted safflower yield.

Interpretation: Pre-emergence herbicide applications, especially sulfentrazone coupled with intercultivation, offer effective weed suppression and enhanced safflower yield, presenting a cost-effective weed management solution for safflower cultivation.

Keywords: Sulfentrazone, pendimethalin, weed control efficiency, safflower

1. Introduction

Crops and soil are interconnected; subsequently exert mutual effects on one another for effectiveness of its productivity (Padalia *et al.*, 2018) ^[19]. This is because soil gives support in terms of moisture, nutrient and anchorage to crop to grow effectively on the one hand and on the other, crop provides protective cover for soil (Shahi *et al.*, 2023) ^[25], suppresses soil erosion as well as helps to maintain soil nutrient through litter accumulation and decomposition (Bäumler 2015; Pandey *et al.*, 2024) ^[4, 21]. The nutrients in the soil influenced by the available amendments of litter/organic manure and serve as one of the inputs of nutrients in ecosystems (Pant *et al.*, 2017; Padalia *et al.*, 2022; Vibhuti *et al.*, 2020) ^[20, 23, 28]. Agricultural trends in the last five decades have intensive production with increased exercise of commercial seeds, pesticides, fertilizers, etc (Karki *et al.*, 2022; Bargali *et al.*, 2022) ^[2, 16]. The agricultural intensification system has not been implemented properly (Karki *et al.*, 2021) ^[15], for example the use of fertilizers to increase crop yields and pesticides to kill the weeds which is due to limited funds. The use of local resources is one alternative to meet these limitations, namely by utilizing the agricultural residue as a source of energy in the form of organic fertilizer/animal feed/animal bed and herbicides to control the weeds (Bargali *et al.*, 2019; Negi *et al.*, 2023) ^[3, 18].

Safflower (*Carthamus tinctorius*), a member of the Asteraceae family, is an oilseed crop cultivated for its multipurpose benefits. Its vegetable oil, rich in essential nutrients and amino proteins, is a valuable product. Traditionally, safflower was grown for its seeds and its use as a natural dye,

yielding an orange-red pigment from its petals. Additionally, safflower boasts medicinal properties and serves as a source of feed. Safflower leaves, rich in carotene, riboflavin, vitamins A and C, iron, phosphorus, and calcium, are also edible, adding to its versatility and nutritional value (Emongor *et al.*, 2017) ^[10].

Oil of safflower is being extracted from the grains, which are healthier choice, indeed have lower per cent of saturated fatty acids and rich in poly unsaturated fatty acids compared to the palm and canola oil, which is being in the market for so long times. The safflower crop needs lower temperature for growth of roots and development of rosette (daily mean temperature 15-20°C) on the contrary need higher temperature during growth of stem flowering and capsule formation (20-30°C) (FAO, 2023) ^[12]. Effective weed surveillance is crucial during safflower cultivation to maximize seed production. Particularly during the rosette stage, safflower plants have limited competitive ability against weeds, making early weed management essential to prevent severe damage and premature maturation. Various herbicides have been researched and recommended for weed control in safflower fields, targeting both grassy and broadleaf weeds. During 1980, in the USA, principal herbicide used for management of safflower weeds was trifluralin in pre-sowing, as incorporation to the soil (Pannacci *et al.*, 2024) ^[22]. Sulfonylurea herbicides discovery have lead to greater discovery for the control of safflower weeds, chlorsulfuron show less toxicity to safflower as post-emergence application and which might be permitted to eradicate broadleaf weeds, like *Tribulus terrestris* L., common sunflower and *Amaranthus retroflexus* L., which meagerly be managed by soil applied trifluralin, thus fetching safflower production and reduction in harvesting difficulties.

Studies have shown that safflower has a weak competitive ability against weeds, necessitating continuous weed control measures from the early stages of growth to the end of the growing season (Pannacci *et al.*, 2024) ^[22]. Failure to control weeds can lead to substantial yield losses, emphasizing the importance of effective weed management practices for optimal safflower yields. Decline in the produce and yield attributes, such as the capitulum and number of branches and the test weight as weed competition has risen (Budak *et al.*, 2020) ^[6].

The results of a two years study showed that safflower has a weak competitive ability against weeds. Therefore, competitor weeds in safflower fields should be controlled from the beginning of the second week to the end of the growing season. To provide good control in the field, weeds should be controlled by hand weeding several times or by a residual soil herbicide (Budak *et al.*, 2023) ^[7].

Manual hand weeding is not practical due to safflower's thorny nature, making herbicide-based weed management strategies more viable. Cultural practices such as wide-row planting and early cultivation can aid in weed control, but careful attention must be paid to prevent damage to emerging safflower plants.

Pre-emergence herbicides such as S-Metolachlore (Dual Gold), Chlorsulfuron, thiameturon and metsulfuron, as well as post-emergence herbicides like chlorsulfuron, metsulfuron and thiafensulfuron have been observed effective with minimal crop injury. However, perennial weeds such as Canada thistle and perennial sow thistle pose significant challenges and should be managed before safflower cultivation begins (Pannacci *et al.*, 2024) ^[22].

Trifluralin (various brand names), ethalfluralin (Sonalan), Dual/generic S/ metolachlor, Harmony SG (thifensulfuron), sethoxydim (Poast), Select Max (clethodim) and Select/generic clethodim. Pre harvest herbicides: Roundup/generic glyphosate, Valor+ MSO adjuvant (flumioxazin) and Drexel Defol (sodium

chlorate). Post-emergence herbicides that control broadleaf weeds and can be applied successfully to safflower with little or no crop injury include chlorsulfuron, metsulfuron and thiafensulfuron (Budak *et al.*, 2020) ^[6].

Perennial weeds like *Canada thistle* and perennial *Sow thistle* pose significant challenges. It's not advisable to cultivate safflower in fields heavily infested with these types of weeds. If weeds appear before safflower growth, using a light spike tooth or coil spring harrow for harrowing might help control some weeds, though there's a risk of damaging the emerging safflower. In cases where irrigated safflower is planted in wide rows (40 to 45 cm), early cultivation between the rows before stem elongation can effectively eliminate most small weeds. Post-stem elongation, cultivation can be employed to shift soil into the row, covering small weeds within it.

These two weed killers have varied physicochemical acts. Pendimethalin has a high carbon-referenced sediment partition coefficient (Koc) (17,200 L kg⁻¹), with a low leaching potential, whereas sulfentrazone has a low Koc (43 L kg⁻¹), with a high leaching potential (Shaner 2012) ^[26]. Sulfentrazone at minor rates can control common cocklebur, giant foxtail and common ragweed and was improved along with the added metribuzin or cloransulam solutions, without being harming the soybean yield compared with other standard weedicides. Walsh *et al.* (2015) ^[29] studied that sulfentrazone doses @ 104, 139, 15 and 65 g a.i. ha⁻¹ were required to inhibit common ragweed, redroot pigweed, green foxtail and common lambsquarters dry weights by 50%, respectively and also doses of 241, 514, 133 and 721 g a.i. ha⁻¹ of sulfentrazone were needed for 90% decline in aboveground biomass of mentioned weed species, respectively.

Weeds pose a significant challenge to safflower cultivation by competing with the crops for essential resources like nutrients, water, and light, which can result in reduced yields if not adequately controlled. Moreover, weeds can serve as hosts for pests and diseases, exacerbating health issues for safflower plants. The labor-intensive and costly nature of manual weeding further underscores the preference for herbicidal weed management strategies in safflower cultivation. Additionally, the thorny nature of safflower plants complicates weed management efforts, making it even more imperative to rely on effective herbicides.

Pre-emergence herbicides are essential for weed management in safflower because they lessen competition and increase potential yield. Their efficacy depends on appropriate timing, herbicide selection and incorporation techniques. Thus, the aim of this study was to examine how the selected pre-emergence herbicides influence the yield of safflower and weed control during rabi sowing in Dharwad, Karnataka. The findings of this study can be useful to support the authorization for the use of these herbicides in safflower.

2. Materials and methods

2.1 Experimental setup

The field experiments were conducted during rabi 2019 and 2020 at All India Coordinated Research Project on soybean, Main Agricultural Research Station, University of Agricultural Sciences, Dharwad (latitude of 15°29' North and longitude of 74°58' East), Karnataka, India to investigate the best ways to maximize safflower crop yield and suppress weeds using pre-emergence herbicide strategies was conducted on the vertisols, fine clayey soils mixture of sand and silt (coarse sand-7.01, fine sand-12.21, silt- 28.83 and clay-51.95%) having neutral pH-7.1 (1:2.5 soil: water suspension) (Piper, 2002) ^[24], better in Electrical Conductivity (EC) -0.32 dS m⁻¹ (1:2.5 soil: water extract) and

Organic Carbon (OC) of 0.44%. The soil was having the medium, high amount of NPK i.e., 263:30.5:366 kg ha⁻¹, respectively. The Main Agricultural Research Station, Dharwad received 34.6 mm and 37.6 mm of rainfall throughout the crop growing period (November to March) with 4 and 5 rainy days during 2019 and 2020, respectively. The average relative humidity in 2019 and 2020 was 58.6% and 59.2%, respectively which was favorable for crop growth and development. The mean maximum temperature ranged between 27.1-34.1°C and minimum temperature ranged between 15.5-19.4°C. These values fit within the optimal temperature range of 15-32°C that the safflower crop requires (based on mean 2-year data) (Fig. 1).

The safflower was sown with hand dibbling. The fertilizer was applied at the time of sowing (Table 1) as per the package of practices of University of Agricultural Sciences, Dharwad, Karnataka. All the cultural operations have been carried out during the growing season of the crop and herbicide spray was given at definite intervals of the time.

Table 1: Agronomic practices followed in the experiment

Practices	Experiment-1	Experiment-2
Crop	Safflower	Safflower
Sowing date	8-11-2019	12-11-2010
Cultivar	A1	A1
Planting density	55,555.55	55,555.55
Treatment imposition	8-11-2019	12-11-2020
Fertilizers (kg ha⁻¹)		
N	40	40
P2O5	40	40
K2O	12.5	12.5
S	30	30
ZnSO ₄	15	15
Harvest time	20-03-2020	26-03-2021

The knapsack sprayer with flat fan nozzles has been used to apply herbicides. Two controls - the weedy check and the weed-free check were taken into account in the experiment. Table 2 displayed the experiment's treatment details.

Table 2: Treatment details of the experiment conducted during the year 2019 and 2020

Treatment	Treatment details	HRAC group/MoA	Dose (g a. i. ha ⁻¹)
T ₁	Pendimethalin	3 / inhibition of microtubule assembly	1000 (30% EC)
T ₂	Sulfentrazone	14 / inhibiting the protoporphyrinogen oxidase (PPO) enzyme in plants	105 (48% F)
T ₃	Pendimethalin + Sulfentrazone	3 / inhibition of microtubule assembly	1000+105
T ₄	Pendimethalin + Intercultivation at 30-35 DAS	-	1000
T ₅	Sulfentrazone + Intercultivation at 30-35 DAS	-	105
T ₆	Pendimethalin + Sulfentrazone + Intercultivation at 30-35 DAS	-	1000+105
T ₇	Weedy check	-	-
T ₈	Weed free check	-	-

HRAC- Herbicide Resistance Action Committee MoA- Mode of Action

Irrigation (200 m³ ha⁻¹) was given at every treatment imposition in order to activate the herbicide efficacy. In both the experiments, the weed dry weight (g), number of weeds and weed control efficiency (%) was calculated at 30, 60 and at harvest.

$$WCE (\%) = \frac{w_u - w_t}{w_u} \times 100$$

Where,

W_u- weeds in untreated plot, W_t- weeds in treated plot

2.2 Cultivar characters

Cultivar used was A-1 (table 1.) which is the variety suited for

zone 1, 2, 3 and 8, which is highly rainfall dependent. It takes 125-130 days from sowing to harvesting and being recommended to planting time is from September 15th to October 15th.

2.3 Statistical analysis

The study used a randomized complete block design with eight treatments and twelve degrees of freedom as its statistical design. An appropriate statistical analysis of variance (ANOVA) was performed on the gathered data. The effectiveness of the herbicide treatments was assessed for significance level at a 5% probability and statistical differences between treatment means were identified using the F-test. Lastly, R software version 4.3.3 and MS Excel statistical program version 2402 were used for statistical evaluation.

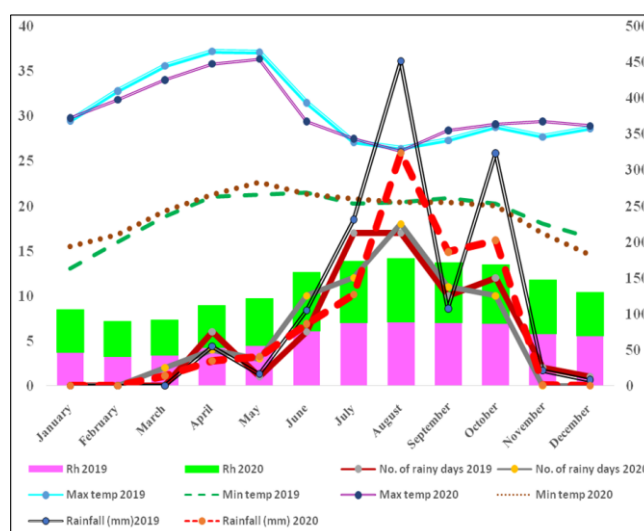


Fig 1: The weather information for 2019 and 2020 at Main Agricultural Research Station, Dharwad

3. Results and Discussion

Corresponding to experiment during 2019 and 2020 the number of weeds is graphically depicted in Fig. 2 indicating significantly lesser number of weeds recorded in the weed free check, among the herbicide treatments, efficacy of herbicide was maximum in T₅ compared with weedy check and was on par with rest of the treatment except weed free check during 30, 60 days after the treatment imposition and even at the harvest.

Reduction of weeds indicates higher mortality of weed due to phytotoxicity imposed by the herbicide on the weeds and might be due to Sulfentrazone did not show rapid loss of herbicide

(Shaner 2012)^[26]. Herbicide efficiency was higher in second year compared to first year (Budak *et al.*, 2020)^[6]. Similarly, sulfentrazone given good weed control efficiency in the study of Budak *et al.*, 2020,^[6] current study aligns with Jha *et al.* (2017)^[14]. Atanasova and Marcheva (2015)^[1] similarly found that pendimethalin demonstrated the highest effectiveness as herbicide. However, they noted that the efficacy of s-metolachlor was constrained due to its strong impact on grass weeds and limited effect on certain broadleaf weeds. The effectiveness of these herbicides on weed control varied with time and application rates.

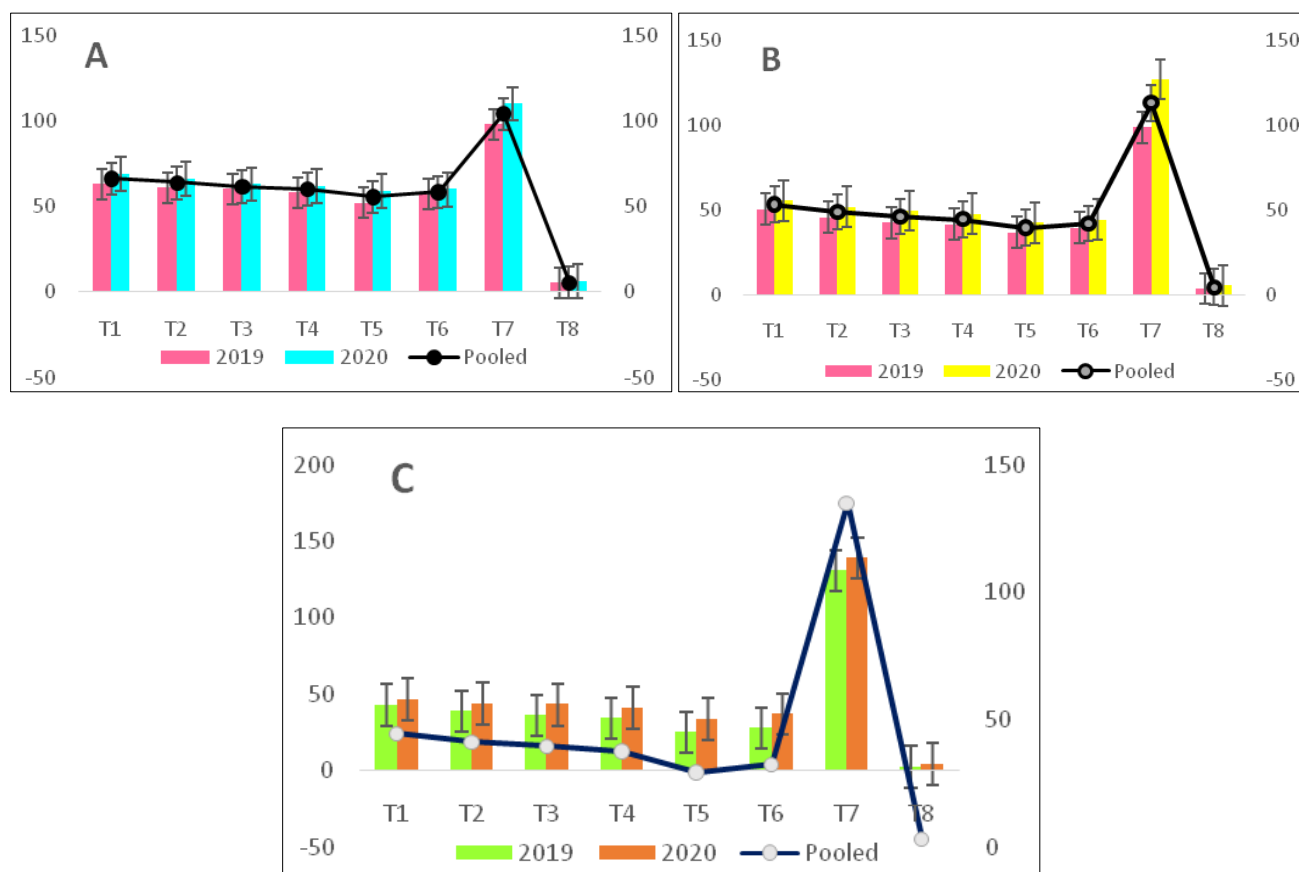


Fig 2: A, B and C indicates the number of weed at 30, 60 and at harvest respectively as influenced herbicides

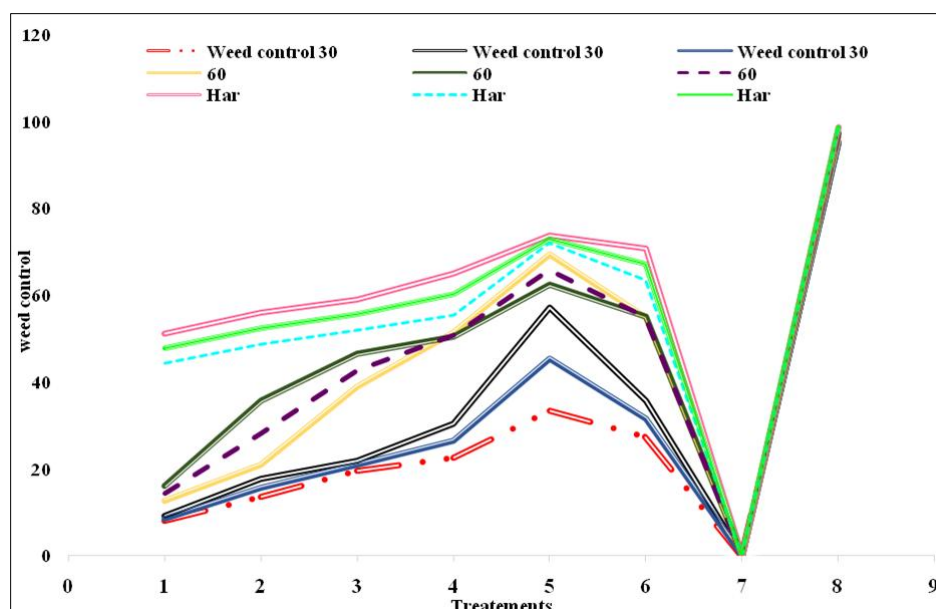


Fig 3: Weed control efficiency during 2019 and 2020, at 30, 60 DAS and at harvest (Har)

Weed control efficiency in experiment 1 and 2 are graphically depicted in Fig. 3 implying that the weed control efficiency was significantly higher in weed free check compared to rest treatments, among the herbicide applied plots, treatment T₅

showed significantly higher mortality rate of weeds compared to rest of the treatments and least control was observed in T₇. Weed control efficiency with pendimethalin was not as effective as sulfentrazone along with the intercultivation.



Fig 4: (A) Treatment showing the management of the weeds (B) Treatment showing the maximum weeds troubling the safflower and (C) Plot of safflower grown in rabi season showing the sparse vegetation

The Fig. 4 (A), (B) and (C) showing the best weed control treatment in comparison with weedy check where we can observe that maximum weed density along with that making the safflower

plant to survive because of the competition, and also showing delayed senescence of certain plants.

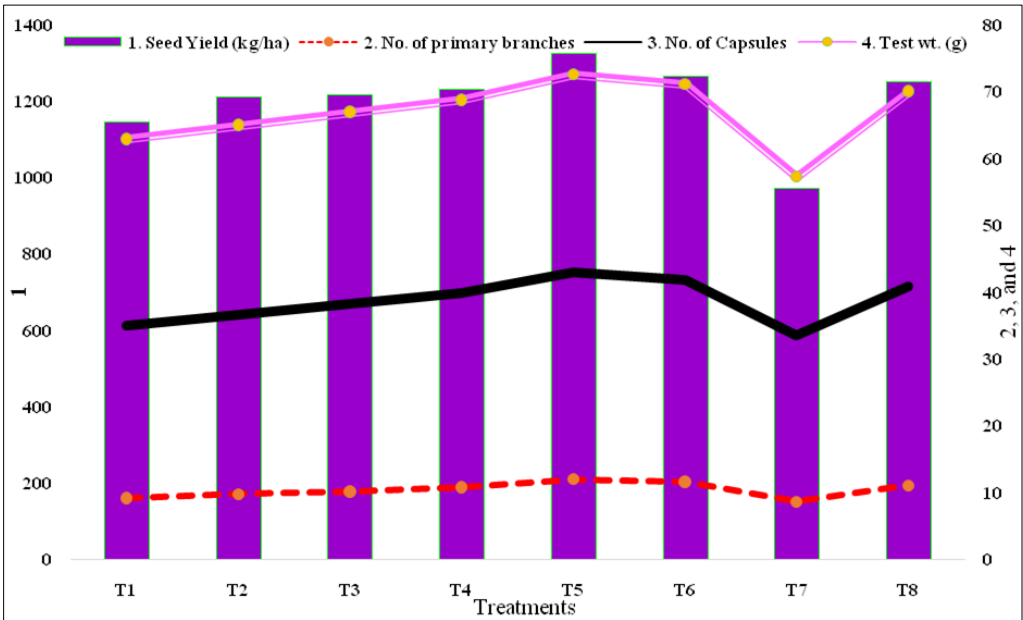


Fig 5: Significance of herbicide on the crop yield and yield attributes (pooled data 2019 and 2020)

Intercultivation alongside Sulfentrazone application at 30-35 DAS notably decreased crop damage and boosted safflower yield, Dayan and Duke (2014) ^[9] noted the similar thing, i.e., increase in the soybean yield might be due to perhaps soybean quickly metabolized sulfentrazone by degradation through oxidative mechanism of the 3-methyl group on the triazolinone ring of the herbicide (Fig. 5). This aligns with previous findings of Hasanuddin *et al.* (2022) ^[13], who observed that combining

pendimethalin at 1 kg ha⁻¹ with sulfentrazone at 0.5 kg ha⁻¹ increased soybean pod count, thereby enhancing yield. This effect may be attributed to the mixture's weed suppression capabilities, fostering improved soybean growth and subsequently higher pod production. Additionally, Buttar *et al.* (2015) ^[8] demonstrated pendimethalin efficacy in controlling broadleaf and grassy weeds, while Belfry *et al.* (2015) ^[5] observed that sulfentrazone application effectively curbed weeds by up to 33%.

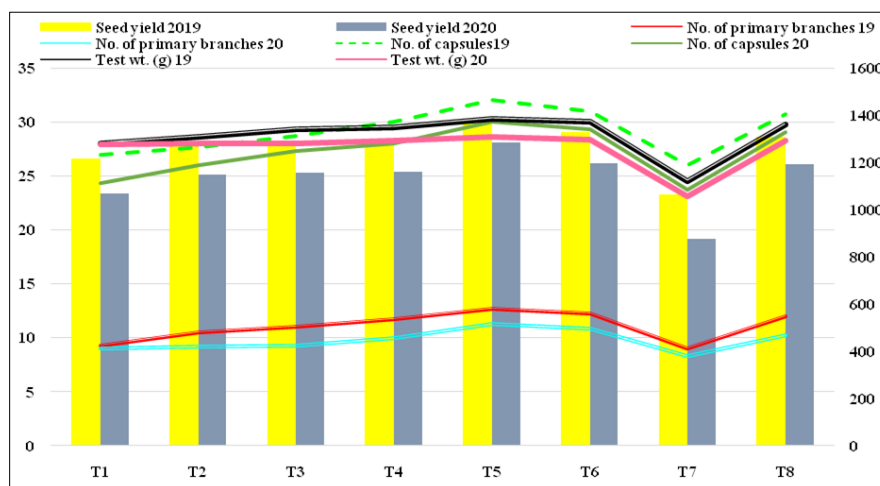


Fig 6: Effect of weed control treatments on yield components during 2019 and 2020

The impact of herbicide application on safflower yield attributes and overall yield is elegantly illustrated in Fig.6. Notably, T₇ exhibited higher crop injury compared to other treatments, while T₈ displayed the least, indicative of the crop's resilience and significant weed reduction throughout the experiments. Treatment T₅ demonstrated a noteworthy increase in primary branches, capsules per plant and test weight, suggesting the herbicide's potent early-stage weed control, thereby minimizing inter-competition and enabling the crop to efficiently utilize available resources. These findings resonate with those of Hasanuddin *et al.* (2022) ^[13], where similar trend in soybean seed weight following the combined application of pendimethalin at one kg ha⁻¹ and sulfentrazone at half kg ha⁻¹ were observed. This synergistic herbicide treatment effectively managed weed growth, potentially enhancing the crop's ability to optimize nutrient uptake, water absorption and sunlight utilization. Furthermore, findings from the research conducted by Atanasova and Marcheiva (2015) ^[11] highlight that the most favorable outcomes in safflower vegetation treatment were achieved with Stomp 330 EC. This herbicide elicited an average increase of 20% in yield,

underscoring its efficacy in optimizing safflower productivity. Weed control efficiency is also influenced by the pH of soil, as some studies indicated that uptake of sulfentrazone by plants hike with declining pH, and hiked pH declines soil adsorption and increase in the cation exchange capacity (Ferrell *et al.*, 2003; Kerr *et al.*, 2004, respectively) ^[11, 17]. The absorption of herbicide is also influenced by the presence of organic matter and it is supported by the study of Tidemann *et al.* (2014) ^[27] where the study evaluated weed management in field pea (*Pisum sativum* L.) using sulfentrazone plus pyroxasulfone and noted that in regions of elevated soil organic matter, higher doses of the weedicide required for maintenance of equivalent management. not only the sulfentrazone or pendimethalin alone have the higher weed control efficiency and increased yield but also due to the Interrow cultivation produced higher yield than the weedy check this aligns with the study of Yau and Haidar (2008) ^[30] revealed that Inter row cultivation under normal sowing, herbicide application, and hand weeding gave higher safflower seed and straw yields than the weedy check.

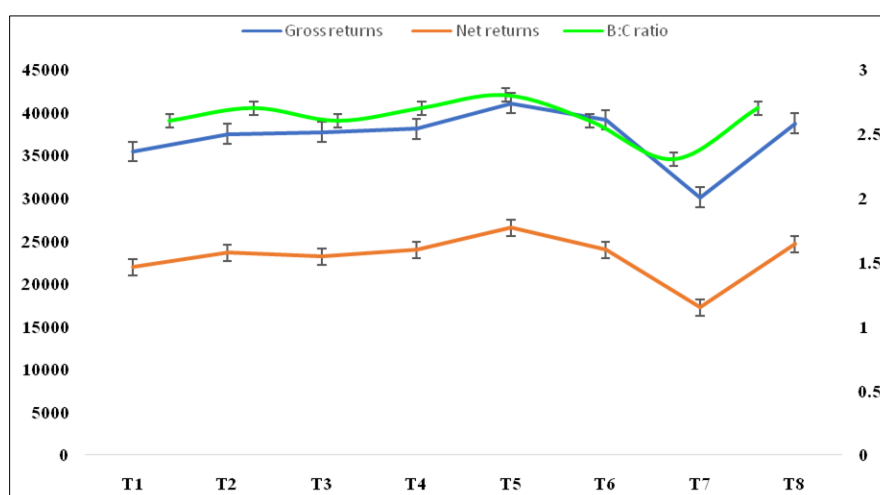


Fig 7: The economics of safflower as influenced by herbicide (pooled)

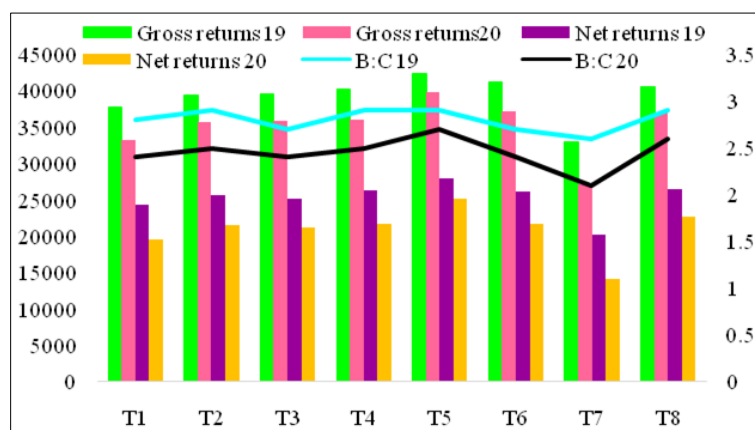


Fig 8: The economics of safflower as influenced by herbicide during 2019 and 2020

Fig. 7 and 8 depicts the returns of safflower as influenced by herbicide treatment, significantly maximum returns were observed with T₅ can be seen on par with T₆, T₈ and T₄, the same trend was followed in net returns along on par with T₂ and T₃, while B:C ratio was significantly higher in T₅ compared to weedy check.

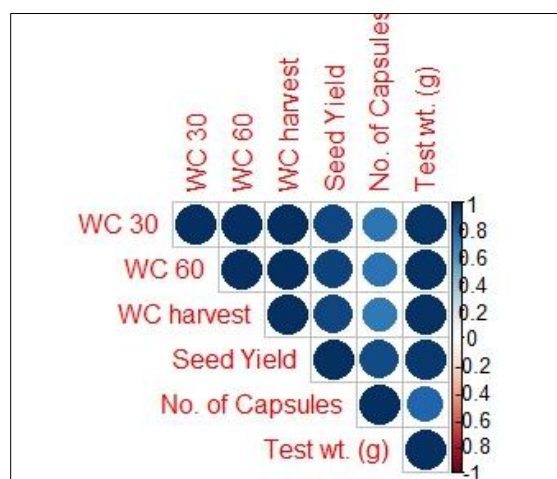


Fig 9: Correlation between weed control efficiency (WCE) and yield attributes

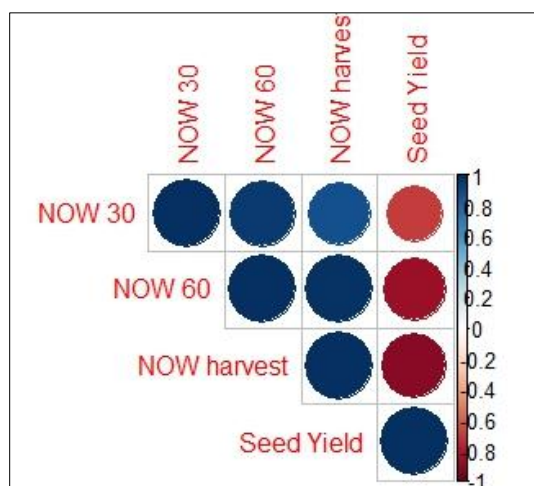


Fig 10: Correlation between number of weeds (NOW at 30 60 and at harvest) and yield

The efficacy of weed control directly influences the enhancement of yield attributes and, ultimately, overall yield. This relationship

is echoed in a study by Atanasova and Marcheva (2015)^[1], which underscores the profound impact of weed infestation, herbicide effectiveness, and climatic conditions on grain yield. Variations observed are largely attributed to shifts in climate patterns. For instance, in 2004, rainfall was irregular, with a mere 2.8 mm recorded in April. Similarly, water supply during March-April 2007 was 60% below the average multiyear data, proving critical for safflower's rosette stage amid dry conditions. Conversely, 2005 experienced relatively favorable climatic conditions, correlating with significantly higher grain yields. Number of weeds and seed yield are negatively correlated, implying that increase in the number of weeds reduces the yield and vice-versa.

4. Conclusion

Selective pre-emergence herbicides are required for chemical weed management in order to prevent weed competition during the early growth stage of safflower. From the above study, it can be concluded that Sulfentrazone at pre-emergent application followed by intercultivation at 30-35 DAS has given excellent results such as higher weed control, superior yield attributes and yield over weedy check and has lowers the cost of cultivation.

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Authors' contribution

G. Somanagouda: Principal Investigator of the project, supervised the research work and monitored preparation of the manuscript; S.S. Nooli, R. Channakeshava and R.B. Jolli: Co-PI of the project, supervised the research work and monitored preparation of the manuscript; Aishwarya Golshetti and Harshiya Banu: helped in preparing the correlation matrix plot in R and also helped preparation of the manuscript.

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Research content: The research content of manuscript is original and has not been published elsewhere.

Ethical approval: The authors have followed and complied with the National/International Guidelines of relevant and appropriate authority for the use of plants or animals or humans in the experimental study.

Conflict of Interest: The authors declare that there is no conflict of interest.

Data availability: Available from the author as well as the report of the project

Consent to publish: All authors agree to publish the paper in Journal of Environmental Biology.

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