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ORIGINAL PAPER

Natural Plant By-Products and Mulching Materials to Suppress Weeds and Improve Sugar Beet (*Beta vulgaris* L.) Yield and Quality

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Abstract

To reduce the use of herbicides in agriculture, there is an urgent need to look for cost-effective and environmentally friendly non-chemical methods to control weeds in field crops. Plant by-products could be exploited directly as plant residues or indirectly as plant extracts for weed control. Thus, the objective of this study was to evaluate the effectiveness of several plant wastes and extracts in controlling weeds of sugar beet (*Beta vulgaris* subsp. *vulgaris*) with enhancing yield and quality. Three weed control groups of twelve practices were examined. The first weed control group included three aqueous extract concentrations (15, 20, and 25%) of *Plectranthus amboinicus* L. The second weed control group involved six soil mulching plant materials [rice (*Oryza sativa* L.) straw, wheat (*Triticum aestivum* L.) hay, peanut (*Arachis hypogaea* L.) straw, mango (*Mangifera indica* L.) leaves, flax (*Linum usitatissimum* L.) meal, and soybean (*Glycine max* (L.) Merr.) meal], while the third group comprised of desmedipham/ethofumesate/lenacil/phenmedipham (DELP) herbicide 1.5 L ha^{-1} [desmedipham 70.5 g active ingredient (ai) ha^{-1} + ethomesufate 112.5 g ai ha^{-1} + lenacil 40.5 g ai ha^{-1} + phenmedipham 90 g ai ha^{-1}], hoeing, and unweeded check. During a 2-year field trial (2019/20 and 2020/21), the 12 weed control treatments arranged in a randomized complete block design (RCBD) and replicated three times. Compared to the recommended applications (hoeing and herbicide), reduction averages of both seasons for total weeds biomass were 46.3–54.2%, 37.3–46.4%, and 23.0–34.4% due to rice straw, wheat hay, and mango leaves, respectively. Root and sugar yields of sugar beet divulged the highest values with hoeing in both seasons statistically equaling ($P \geq 0.05$) rice straw and wheat hay for root yield and wheat hay for sugar yield in the first season. Except flax meal, all weeded treatments in the first season as well as mango leaves, wheat hay, peanut straw, and hoeing in the second one caused significant ($P \leq 0.05$) reductions in sodium content of beet juice. Wheat hay, mango leaves, and hoeing in both seasons, in addition to rice straw, peanut straw, and herbicide in the first season, were the most efficient practices for improving sucrose % and extractable sugar %. Compared to hoeing, reductions in net return were –286.7 and –320.0 (\$ ha^{-1}) by percentage of 6.5 and 7.2, due to mulching soil by rice straw and wheat hay, respectively. Recycling the plant by-products such as wheat hay, rice straw, peanut straw, or mango leaves in the form of soil mulch could serve as safe and eco-friendly tools in weed control programs of sugar beet. The beneficial effect of mulching extended to enhance root and sugar yields with low impurities. Since the plant wastes are available in the farm, better revenues will be gained for sugar beet growers. Further investigations related to the use of plant extracts as natural herbicide should be performed to reach acceptable levels for weed control.

Keywords Allelopathy · Integrated weed management · Non-chemical methods · Sugar productivity · Sugar quality index · Waste recycling

1 Introduction

Sugar beet (*Beta vulgaris* L.) ranks as the second most important sugar crop worldwide after sugar cane. (*Saccharum officinarum* L.) (Brar et al. 2015). Sugar beet is a temperate crop and its root contains a high amount of sucrose (Paul et al. 2019). It is still one of the main sources for sucrose extraction where approximately 30% for human

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consumption sugar of the world is contributed by the sugar beet crop (Bairagi et al. 2013). The total global cultivated acreage of about 4.4 Mt produces approximately 253 Mt of sugar beet roots that provides ~ 30% of the gross world's requirements of white sugar (FAO 2022). However, sugar beet production worldwide is frequently faced ecological challenges (Abd El-Mageed et al. 2022; Makhlouf et al. 2022) and biotic stresses such as weeds. Since sugar beet is highly sensitive to weed competition during the initial growth stages, effective weed control should be implemented (Jalali and Salehi 2013; Marwitz et al. 2014). Sugar beet plants must be free of weeds until 46 to 54 days after emergence to prevent yield loss over 5%, while the presence of weeds caused decrease in root yield by 60–99% (Dogan and Adem 2018). Accordingly, weed management should be paid attention with application of new methods are required in order to identify the best weed control timing and to minimize costs. Herbicides application can result in low crop interference with weeds (Saudy 2014; Saudy and Mubarak 2015; El-Metwally and Saudy 2021b; Saudy et al. 2021b). The spectrum of herbicides used in sugar beet is rather narrow and further restrictions are expected in the near future (Jursík and Holec 2019). Also, no single chemical herbicide can control all weeds in sugar beet fields. Moreover, herbicides led to rapid selection of many resistant weed populations (Heap 2018). Thus, continuous dependence on herbicides application should be reduced and alternative tools of weed control should be adopted (Saudy and El-Metwally 2009; Saudy and El-Bagoury 2014; Saudy 2015; Papapanagiotou et al. 2019).

Therefore, alternative non-chemical weed control options should be evaluated.to choose the best one. As a conventional tactic, hoeing is a clean mechanical method for eliminating weeds in in row crops which achieve high weed control efficiency (Abd El Lateef et al. 2021; Saudy and El-Metwally 2022). However, hoeing is still hard and costly due to it requires high effort and labor expense. In farms that are organically managed, exploiting the agricultural wastes is regarded as a useful act for nutrients recycling with clean environment and production of healthy plants (Abd-Elrahman et al. 2022; Elgala et al. 2022). Plant wastes represent a serious source of carbon dioxide emissions. Recycling the agricultural wastes as soil mulching or natural plant extract could be exploited in weed management programs.

Several benefits could be gained by application of soil mulching. Mulching has been increasingly practiced improving crop yield by enhancing precipitation use efficiency (Awodoyin and Ogunyemi 2005; Mubarak et al. 2021), conserving soil moisture (Zhao et al. 2009; Salem et al. 2021) and regulating soil temperature (Kader et al. 2019). Moreover, Wang and Xing (2016) reported that the soil water content, yield and fertilizer use efficiency in the mulching treatment were significantly higher than that of non–mulching one. Increment in crop productivity with applying straw mulch is largely attributed to maintain soil moisture (Gan et al. 2013), decreasing soil bulk density (Hassan et al. 2007) and activating plant root system (Huang et al. 2012). Concerning weed problems, straw mulch could be used as an efficient tactic of reducing weed emergence and growth (El-Metwally et al. 2022). Decreases in weed population and dry biomass with improving weed control efficiency were observed owing to organic materials application (Yadav et al. 2015; Saudy et al. 2021c). Thus, various crop yields were increased by about 80–135% as a result of mulch application (El-Metwally and El-Wakeel 2019). Mulching the soil by rice straw caused 48.9% increase in potato tuber yield (Bhullar et al. 2015). Since soil mulches, i.e., peanut straw and herbicide are similar for inhibiting weed growth and increasing the marketable yield, water use efficiency, and economic returns, the farmers are advised to use soil mulching instead of herbicides as a clean and eco-friendly method for weed control (El-Metwally et al. 2022).

The use of eco-friendly natural plant compounds is a promising approach to replace, partially at least, synthetic herbicides in weed management programs. For shrinking the dependence on the synthetic pesticides and maintaining the agroecosystems, allelopathy phenomenon as an ecologically safe method could be exploited in weed control with improving crop yields (Hegab et al. 2008, Saudy et al. 2022). Allelopathic effect could be regarded as a sustainable pattern for biologically weed management (Arora et al. 2015) by liberating chemical compounds from different plant organs influencing adversely the growth of other plants (Delcour et al. 2015). Owing to the integration with aqueous plant water extracts, herbicide addition rate could be lowered with achieving distinctive efficacious weed control (Khan et al. 2012).

Since weeds are great consumer for soil water and nutrients, numerous attempts have been adopted to combat weeds in the economic field crops. Moreover, using mulches of allelopathic crops is an important tool to suppress weed flora and improve crop yield. However, the role of different mulches in suppressing weed flora and improving the root yield and quality of sugar beet has infrequently been investigated. The current research hypothesized that using various plant wastes in the form of mulching or aqueous extracts will have better efficiencies for controlling weeds than conventional methods, hence improving sugar beet yield and quality. Therefore, this study aimed to assess the effect of diversified mulch types and aqueous extract concentrations of *Plectranthus amboinicus* L. compared to the common practices (herbicide or hoeing) on weed growth, sugar beet yield and quality keeping in mind the economic feasibility.

2 Material and Methods

2.1 Site Description

During the winter seasons of 2019/20 and 2020/21, two field experiments were conducted at the Experimental Farm, National Research Centre El-Behaira Governorate, Egypt (30.30° N, 30.18° E and 21 m above sea level) (see Fig. 1). The experimental soil was sandy and the mechanical and chemical analysis of the soil are presented in Table 1. Based on the soil taxonomy (IUSS Working Group WRB 2015), the soil is order Entisols and suborder Psamments. The site is classified as an arid zone with cool winters and non-significant precipitation. As an average of the two seasons, the mean values of daily air temperature, wind speed, relative humidity, precipitation, and solar

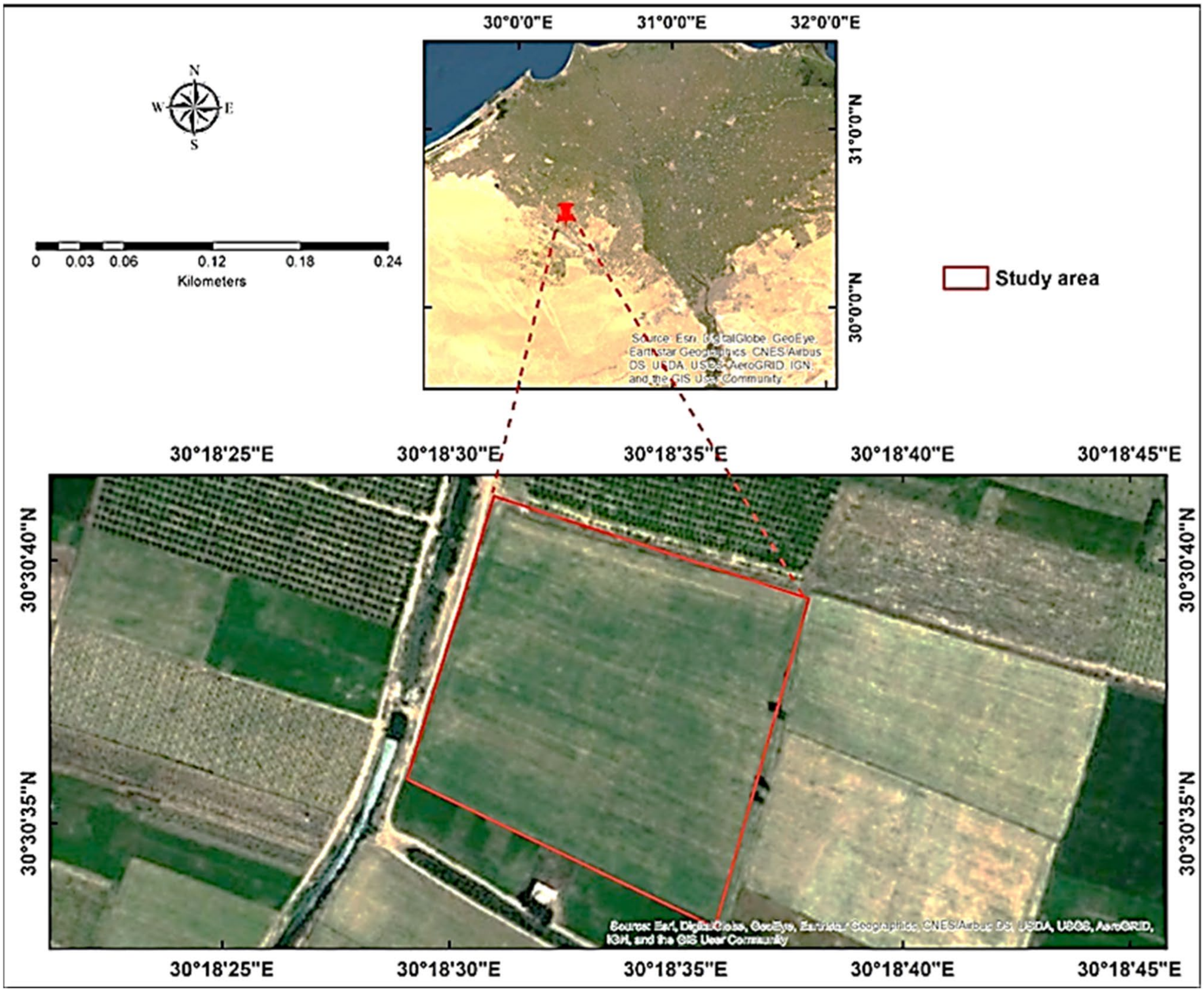

Fig. 1 Location of the study area at the Experimental Farm, National Research Centre El-Behaira Governorate, Egypt

Table 1 Initial mechanical and chemical analysis of experimental soil

Particles distributions %			pH	EC (dS m^{-1})	Organic matter %	$CaCo_3$ %	Nutrient (mg L^{-1})		
Sand	Silt	Clay					N	P	K
90.4 ± 0.3	3.1 ± 0.1	6.5 ± 0.2	7.8 ± 0.1	0.35 ± 0.02	0.13 ± 0.02	1.44 ± 0.08	8.14 ± 0.02	3.22 ± 0.04	21.3 ± 0.3

pH acidity, *EC* electrical conductivity, *$CaCo_3$* calcium carbonate, *N* nitrogen, *P* phosphorus, *K* potassium. Values are the mean of 3 replicates ± standard errors.

radiation were 18.5 °C, 2.62 m s^{-1}, 61.6%, 0.41 mm, and 18.3 MJ m^{-2} day^{-1}, respectively. In the previous growing seasons, maize (*Zea mays* L.) was the crop grown on the soil of the experimental field. The prevailing weeds at the experimental site through the two growing seasons were broad-leaved weeds, i.e. wild radish (*Raphanus raphanistrum* L), sweet clover (*Melilotus indica* L.), wild beet (*Beta vulgaris* L.), and greater ammi (*Ammi majus* L.), as well as grasses, i.e., wild oat (*Avena fatua* L.) and ryegrass (*Lolium temulentum* L.).

2.2 Crop Establishment and Management

Soil was prepared at a tillage depth of 30 cm with incorporating the ordinary calcium superphosphate (15.5% P_2O_5, 61.2 g P kg^{-1}) at a rate of 74.0 kg P ha^{-1}. Nitrogen fertilizer was applied at a rate of 240.0 kg N ha^{-1} as ammonium nitrate (33.5% N) in 5 equal portions, 30, 45, 60, 75, and 90 days after sowing (DAS). Potassium fertilizer was added at a rate of 60.0 kg K ha^{-1} as potassium sulfate (48% K_2O, 398.4 g kg^{-1}) in 3 equal portions, 60, 75, and 90 DAS. Trickle irrigation system was set up consisting of control head (media and screen filters, pressure gauges, and control valves), main and sub-main lines (main line is PVC of 75.0-mm diameter up to 6.0 bar pressure, 41.0-m length, and sub-main line is PVC pipe of 50.0-mm diameter up to 6.0 bar pressure) as well as lateral lines are polyethylene tubes of 16-mm diameter (with built in emitters), 30.0-cm emitter spacing, and manufacturing emitter discharge 4.0 L h^{-1}, at operating pressure of 1.0 bar.

Sugar beet cultivar Baraka (multi germ) was sown manually in hills 25 cm apart at a rate of 4.8 kg ha^{-1} in rows on the 21st and 29th of October in 2019/20 and 2020/21 seasons, respectively. Seeds were drilled on one side of the ridge in hills 25 cm apart. For obtaining one plant per hill, plants were thinned twice at 30 and 50 DAS.

2.3 Plant Materials and Experimental Design

The experiment included 12 treatments represented in three concentrations of aqueous **e**xtract of *Plectranthus amboinicus* L. six soil mulching plant materials, in addition to three check treatments (herbicide and hoeing as positive checks and unweeded as negative check). The experimental design was randomized complete block design (RCBD) in four replicates. The experimental unit included 5 ridges, 70 cm apart and 3.0 m length, occupying an area of 10.5 m^2. In the second season (2020/21), new plots were established in an adjacent but different area of the same site to avoid any residual effects of the fertilizer on the studied parameters and to actually repeat the experiment in time. Details of the treatments could be briefly described as follow:

Aqueous Extract *P. amboinicus* L. leaves were collected from Egyptian gardens, washed with tap water, then with distilled water to eliminate dust. After air drying in the shade, the dried leaves were finely powdered by an electric mill. The dry powdered leaves (1500 g) were transferred to labeled beakers to which 6 L of distilled water were added and allowed to soak for 48 h. Then the produced extract was collected and filtered through a very fine mesh and pushed through the mesh carefully for complete extraction. The produced extract was at a 25% concentration. Part of the extract remained as it was (2 L of 25%) and the remaining extract was diluted with distilled water, to concentrations of 15 and 20% for each extract. The process of extraction was repeated according to need to ensure that the extracts were fresh. The analysis described by Srisawat et al. (2010) proved that *P. amboinicus* L. extract contained total phenols (29.5 mg g^{-1}) and total flavonoids (11.2 mg g^{-1}) on dry weight base. The prepared aqueous extract solution with different concentrations was sprayed at a rate of 480 L ha^{-1}. Extract spraying was applied two times at 15 and 30 DAS.

Mulching Materials Plant wastes used as soil mulching were rice straw (3.0 ton ha^{-1}), wheat hay (2.0 ton ha^{-1}), peanut straw (3.0 ton ha^{-1}), mango leaves (3.0 ton ha^{-1}), flax meal (1.5 ton ha^{-1}), and soybean meal (1.5 ton ha^{-1}) applied at 21 DAS. Each mulch type applied as a layer of about 4–6 cm thickness, covering the whole plot surface area and surrounding the sugar beet plants.

Herbicide A mixture product Betanal MaxxPro® herbicide (Desmedipham/Ethofumesate/Lenacil/Phenmedipham 47:75:27:60 g L^{-1}, abbreviated as DELP), Bayer CropScience, Cambridge, was sprayed as post–emergence, 30 DAS (at the age of 3–6 true leaves of sugar beet plants). Since the maximum recommended field application rate for the prepackage four–herbicide mixture (Betanal MaxxPro®) is 1.5 L ha^{-1}, then, the application rates for all active ingredients were the following: desmedipham 70.5 g ai ha^{-1} + ethomesufate 112.5 g ai ha^{-1} + lenacil 40.5 g ai ha^{-1} + phenmedipham 90 g ai ha^{-1}. Such herbicide controls many annual weeds in sugar beet, since it inhibits photosynthesis, cell, and respiration suppressing the assimilation ability of the target weeds (May and Wilson 2006).

Hoeing Hand hoeing thrice at 20, 40 and 65 DAS was performed.

Unweeded In plots of unweeded treatment the weeds left to grow freely until the harvest.

Both of aqueous extract and herbicide were separately sprayed using Cooper Pegler CP3 Classic 20lt Professional Knapsack Sprayer fitted with a flat−fan nozzle and calibrated to deliver 480 L water ha^{-1}.

2.4 Data Collection

2.4.1 Weed Biomass

Four 0.25 m^2 (0.5 m × 0.5 m) wooden quadrats were placed in each plot in area with uniform weed flora and away from the margins. Using the quadrats with a size of 1 m^2, weeds were hand pulled in each plot at 90 DAS and separating them by species and placing them in numbered paper bags. Thereafter, weed samples were air-dried (for 12 days) and oven-dried (at 70° C until constant weight). Moreover, the weed samples were then weighed to determine the dry weed biomass per unit area.

2.4.2 Agronomic Traits

At 90 DAS, leaf greenness expressed in SPAD value of the uppermost fully expanded leaf was determined by chlorophyll meter (SPAD–502Plus) according to Süß et al. (2015). Moreover, a sample of ten plant was taken from each experimental unit to estimate leaves fresh weight, root fresh weight, root length and root diameter. At harvest (on May 15 and May 20 in 2019/20 and 2020/21 seasons, respectively) whole plants of each experimental unit were uprooted to estimate root yield ha^{-1}.

2.4.3 Sugar Yield and Quality Traits

Twenty roots from each plot were randomly taken to determine root quality and technological characteristics at Quality Control Laboratory, El-Nubaria Sugar Factory, El-Behera, Egypt. Sucrose % was determined using Saccharometer according to the method described in AOAC (2012). According to Cooke and Scott (1993) impurities (potassium (K), sodium (Na), and alpha amino nitrogen (α-amino N) were estimated. Sugar lost to molasses % (Eq. 1) and alkalinity coefficient (Eq. 2) were calculated as described by Deviller (1988). Extractable sugar % was computed by Eq. 3 (Dexter et al. 1967). Moreover, juice purity using Eq. 4 was estimated (Cooke and Scott 1993). After that, sugar yield ha^{-1} was calculated using Eq. 5 as reported by Deviller (1988).

$$\text{Sugar lost to molasses\%} = 0.14(\text{Na} + \text{K}) + 0.25(\alpha - \text{amino N}) + 0.5 \tag{1}$$

$$\text{Alkalinity coefficient} = \frac{(\text{K\%} + \text{Na \%})}{\alpha} - \text{amino N\%} \tag{2}$$

$$\text{Extractable sugar \%} = \text{Sucrose \%} - \text{sugar lost to molasses\%} - 0.6 \tag{3}$$

$$\text{Juice purity \%} = (\text{Extractable sugar\%}/\text{sucrose \%}) \times 100 \tag{4}$$

$$\text{Sugar yield}\left(\text{tha}^{-1}\right) = \text{Root yield }\left(\text{tha}^{-1}\right) \times \text{extractable sugar\%} \tag{5}$$

2.4.4 Economic Profitability

According to Cimmyt (1988), the economic evaluation was estimated by calculating the cost of cultivation for different agro–inputs, i.e., labors, fertilizers, irrigation, mulching, insect control, harvesting, and other necessary materials. Returns of each treatment were calculated (\$ ha^{-1}) on the basis of local market prices using Eqs. 6 and 7 as follows:

$$\text{Gross return} = \text{Root yield} \times \text{price of root yield } (\$\text{ha}^{-1}) \tag{6}$$

$$\begin{aligned}\text{Net return} &= \text{Gross returns} \\ &\quad - \text{fixed and variable cost of crop production} \\ &\quad (\$\text{ ha}^{-1})\end{aligned} \tag{7}$$

The average prices were taken from the local market where the price of one ton of sugar beet root was 66.67 (\$); and the fixed costs of cultivation were 1066.67 (\$ ha^{-1}).

2.5 Statistical Analysis

The obtained data of the two seasons were subjected to the analysis of variance (ANOVA) according to Casella (2008), using Costat software program, Version 6.303 (2004), CoHort Software, Monterey. Years and weed control treatments were considered as fixed effects while replications (blocks) were considered as random effects. Means separation was performed only when the *F*-test indicated significant ($P \leq 0.05$) differences among the treatments, based on Duncan's multiple range test.

Sugar beet root yield data (t ha^{-1}) were correlated with total weed dry weight data (g m^{-2}). According to the following linear model, correlation was performed at a significance level of a = 0.05 using STATGRAPHICS Centurion XVI:

$$y = a + bx \tag{8}$$

where y is sugar beet root yield data, x is total weed dry weight data, a is the intercept, and b is the slope of the regression line.

3 Results

3.1 Weed Biomass

All applied treatments showed distinctive elimination for sugar beet weeds compared to weedy check (unweeded) in both 2019/20 and 2020/21 seasons. Generally, the maximum reductions in different broad-leaved and grass weed species (Table 2) and total weeds (Fig. 2) were

Table 2 Biomass of broad-leaved and grass weeds (g m^{-2}) infested sugar beet as affected by weed control treatments in 2019/20 and 2020/21 seasons

Treatment	Broad-leaved				Grass	
	Raphanus raphanistrum L	*Melilotus indica* L	*Beta vulgaris* L	*Ammi majus* L	*Avena fatua* L	*Lolium temulentum* L
2019/20						
*P. amb.*25	46.1 ± 2.8c	50.3 ± 2.8d	34.1 ± 2.3d	66.2 ± 3.5c	94.0 ± 2.3c	46.0 ± 1.1b
*P. amb.*20	50.1 ± 2.8bc	60.0 ± 2.8c	51.1 ± 2.9c	70.0 ± 2.8c	100.8 ± 5.3bc	51.0 ± 3.4b
*P. amb.*15	55.1 ± 2.9b	69.0 ± 5.2b	63.1 ± 1.7b	90.0 ± 5.7b	109.7 ± 5.2b	50.0 ± 2.8b
Rice straw	6.1 ± 1.2f	3.1 ± 0.1 h	1.1 ± 0.1i	7.2 ± 0.6 g	16.7 ± 1.5 fg	9.0 ± 0.5 fg
Wheat hay	8.1 ± 0.6ef	4.1 ± 0.1gh	2.9 ± 0.2hi	10.2 ± 1.2 g	14.4 ± 1.3 fg	7.0 ± 0.5 g
Peanut straw	15.2 ± 1.0e	11.3 ± 1.1 g	10.1 ± 1.2f	23.2 ± 1.8ef	30.2 ± 1.8e	16.0 ± 1.1de
Mango leaves	11.1 ± 1.1ef	8.1 ± 0.1gh	7.2 ± 0.1 fg	10.3 ± 1.3 g	10.0 ± 0.5 g	8.9 ± 0.6 fg
Soybean meal	30.1 ± 2.8d	20.2 ± 1.1f	17.1 ± 1.2e	40.1 ± 2.9d	50.3 ± 3.0d	21.0 ± 1.1 cd
Flax meal	30.0 ± 2.8d	27.1 ± 1.2e	14.9 ± 1.1e	30.3 ± 3.0e	50.4 ± 3.1d	25.0 ± 1.7c
DELP	13.3 ± 0.9ef	8.9 ± 1.1gh	8.3 ± 1.3 fg	25.7 ± 0.9ef	28.8 ± 1.6e	14.0 ± 1.7ef
Hoeing	10.2 ± 1.2ef	7.5 ± 0.5gh	5.6 ± 0.3gh	20.3 ± 0.7f	24.0 ± 1.1ef	12.4 ± 1.3efg
Unweeded	155.1 ± 2.8a	110.2 ± 2.8a	94.7 ± 2.7a	210.3 ± 5.9a	263.4 ± 11.5a	131.7 ± 6.1a
2020/21						
*P. amb.*25	50.3 ± 3.0b	50.0 ± 2.8b	40.0 ± 2.8b	70.0 ± 2.8c	104.5 ± 2.6c	52.2 ± 1.2c
*P. amb.*20	60.0 ± 2.8b	50.0 ± 1.1b	35.7 ± 1.1b	90.0 ± 2.8b	110.2 ± 5.8bc	55.1 ± 2.8bc
*P. amb.*15	62.0 ± 2.8b	53.0 ± 1.7b	38.2 ± 1.7b	100.0 ± 5.7b	114.5 ± 8.3b	57.2 ± 1.2b
Rice straw	5.0 ± 0.5d	5.0 ± 0.5f	3.0 ± 0.5f	8.3 ± 0.7 g	21.2 ± 2.4 g	10.0 ± 1.1 g
Wheat hay	7.0 ± 0.5d	6.0 ± 0.5f	4.0 ± 0.5ef	10.4 ± 1.1 fg	25.2 ± 2.0 fg	12.0 ± 1.1 fg
Peanut straw	17.0 ± 1.1d	13.0 ± 1.1e	10.0 ± 1.1de	27.9 ± 1.1e	32.3 ± 2.4ef	20.0 ± 1.1e
Mango leaves	10.0 ± 1.1d	8.0 ± 0.5ef	7.0 ± 1.1def	15.2 ± 1.1efg	27.2 ± 1.0efg	14.0 ± 1.1f
Soybean meal	30.0 ± 2.8d	29.0 ± 2.6c	20.0 ± 1.7c	50.4 ± 2.3d	50.1 ± 2.8d	35.0 ± 1.7d
Flax meal	35.0 ± 1.7c	23.0 ± 1.7d	17.0 ± 1.7c	60.1 ± 2.8 cd	50.9 ± 1.7d	35.0 ± 1.1d
DELP	15.0 ± 1.1c	14.0 ± 1.1e	11.0 ± 1.1d	20.3 ± 1.9efg	34.5 ± 2.3e	15.0 ± 1.1f
Hoeing	18.0 ± 1.7d	10.0 ± 1.1ef	6.0 ± 0.5def	22.4 ± 1.3ef	28.6 ± 1.7efg	13.0 ± 0.5 fg
Unweeded	150.0 ± 11.5a	140.0 ± 5.7a	110.0 ± 5.7a	220.1 ± 11.5a	295.0 ± 8.6a	140.3 ± 2.8a

*P. amb.*15, *P. amb.*20, and *P. amb.*25: *Plectranthus amboinicus* L. leaves extract at concentrations of 15, 20 and 25%, respectively. DELP herbicide: desmedipham 70.5 g ai ha^{-1} + ethomesufate 112.5 g ai ha^{-1} + lenacil 40.5 g ai ha^{-1} + phenmedipham 90 g ai ha^{-1}. Values are the mean of 3 replicates ± standard errors. Different letters within columns refers that there are significant variations at 0.05 level of probability. Means were separated based on Duncan's multiple range test ($P \leq 0.05$)

recorded with rice straw, wheat hay and mango leaves. Compared to the recommended applications (hoeing and DELP, reduction averages of both seasons for total weeds biomass were 46.3–54.2%, 37.3–46.4%, and 23.0–34.4% due to rice straw, wheat hay, and mango leaves, respectively.

Despite aqueous extract of *P. amboinicus* L. gave less reduction in weed biomass than mulching, all extraction concentrations surpassed the weedy check and reduced total weed biomass by 57.4, 61.2 and 65.2% with the concentrations of 15, 20, and 25%, respectively.

3.2 Sugar Beet Growth and Yields

Sugar beet growth parameters measured at 90 DAS (Table 3) and yields (Table 4) significantly affected by weed control treatments in 2019/20 and 2020/21 seasons. Wheat hay showed the maximum leaves fresh weigh plant $^{-1}$ in both seasons. Also, wheat hay along rice straw, peanut straw, and hoeing in both seasons, in addition to mango leaves in the first season exhibited the maximum increases in SPAD value. Except the extract concentration treatments in both seasons and soybean meal or flax meal in the second season, the other weeded treatments were similar for enhancing root fresh weight surpassing the unweeded. Hoeing in both seasons as well as rice straw, wheat hay, and DELP herbicide in the second season showed the longest roots of sugar beet. The widest roots expressed in root diameter were observed with DELP herbicide and wheat hay in both seasons, in addition to peanut straw in the second season.

All weeded practices surpassed the unweeded for improving root and sugar yields in both seasons. Root

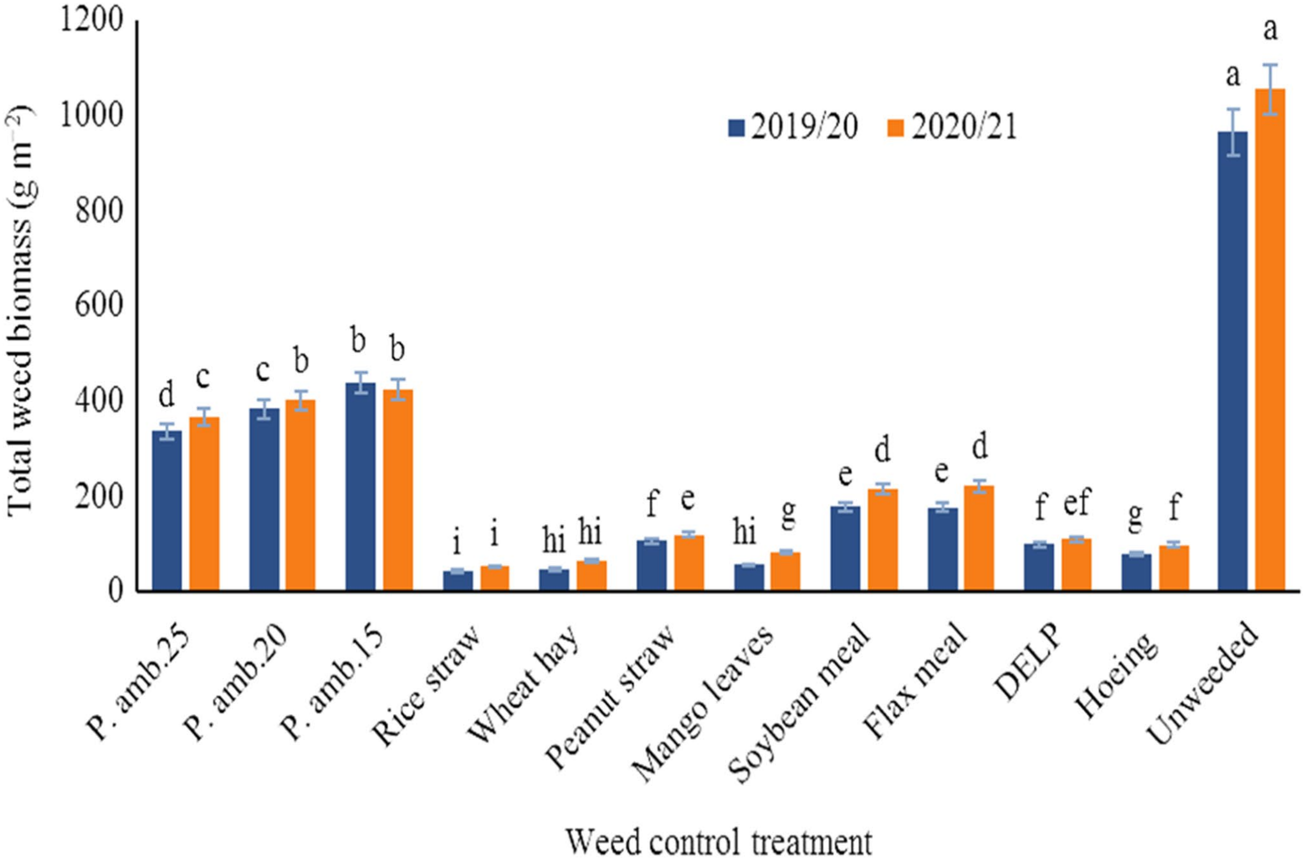

Fig. 2 Biomass of total weeds infested sugar beet as affected by weed control treatments in 2019/20 and 2020/21 seasons. *P. amb.*15, *P. amb.*20, and *P. amb.*25: *Plectranthus amboinicus* L. leaves extract at concentrations of 15, 20 and 25%, respectively. DELP herbicide: desmedipham 70.5 g ai ha^{-1} + ethomesufate 112.5 g ai ha^{-1} + lenacil 40.5 g ai ha^{-1} + phenmedipham 90 g ai ha.$^{-1}$. Values are the mean of 3 replicates ± standard errors. Different letters within columns refers that there are significant variations at 0.05 level of probability. Means were separated based on Duncan's multiple range test ($P \leq 0.05$)

and sugar yields of sugar beet divulged the highest values with hoeing in both seasons statistically equaling rice straw and wheat hay for root yield and wheat hay for sugar yield in the first season. Furthermore, the other mulching materials, especially peanut straw and mango leaves, came in the second order for achieving distinctive enhancements in root and sugar yield.

According to the results of the linear regression analysis performed, weed competition affected sugar beet root yield. Negative and strong correlation was observed between root yield data and total weed dry weight (Fig. 3; $n = 36$; $y = 83.763–0.0553 \times x$; $p \leq 0.001$; $R = -0.947$; $R^2 = 0.8977$).

3.3 Sugar Impurities

Except α-amino N in the second season, all other impurities significantly affected by weed control treatments in both seasons (Table 5). Potassium showed the maximum concentration with flax meal, soybean meal, and wheat hay in the first season and with wheat hay, *P. amb.*25, *P. amb.*20, and hoeing in the second one. Except flax meal, all weed control treatments in the first season as well as mango leaves, wheat hay, peanut straw and hoeing in the second season caused significant reductions in sodium content. The highest α-amino N content was obtained with flax meal in the first season. Hoeing and *P. amb.*20 recorded the maximum alkalinity coefficient in the first and second seasons, respectively.

3.4 Juice Quality

Wheat hay, mango leaves, and hoeing in both seasons, in addition to rice straw, peanut straw, and DELP herbicide in the first season were the most efficient practices for improving sucrose % and extractable sugar % (Table 6). Hoeing, DELP herbicide, and mango leaves (in both seasons); and wheat hay, rice straw, peanut straw *P. amb.*25, and *P. amb.*20 (in 2019/20 season) as well as flax meal (in 2020/21 season) gave the best juice purity %. The highest values of sugar lost

Table 3 Sugar beet growth parameters as affected by weed control treatments after 90 days from sowing in 2019/20 and 2020/21 seasons

Treatment	Leaves plant $^{-1}$		Root		
	Fresh weight (kg)	SPAD value	Fresh weight (kg)	Length (cm)	Diameter (cm)
2019/20					
*P. amb.*25	0.61 ± 0.029e	43.90 ± 0.58b	0.71 ± 0.035d	23.50 ± 1.15ef	7.00 ± 0.29ef
*P. amb.*20	0.49 ± 0.023f	43.60 ± 0.58bc	0.62 ± 0.012d	23.00 ± 1.15f	6.60 ± 0.23 fg
*P. amb.*15	0.47 ± 0.023f	42.30 ± 0.58c	0.59 ± 0.029d	22.70 ± 1.15f	6.10 ± 0.23 g
Rice straw	0.84 ± 0.023c	47.50 ± 0.58a	1.01 ± 0.058bc	27.70 ± 1.15b	8.50 ± 0.29d
Wheat hay	1.33 ± 0.075a	47.57 ± 0.58a	1.15 ± 0.087ab	26.60 ± 1.15bc	9.80 ± 0.35ab
Peanut straw	1.21 ± 0.058b	46.70 ± 0.40a	1.22 ± 0.058a	26.10 ± 1.15bcd	9.50 ± 0.29bc
Mango leaves	0.78 ± 0.046 cd	46.50 ± 0.29a	1.14 ± 0.081ab	25.20 ± 1.15cde	9.50 ± 0.29bc
Soybean meal	0.75 ± 0.029d	42.40 ± 0.23c	0.89 ± 0.052c	23.70 ± 1.15ef	8.73 ± 0.41d
Flax meal	0.71 ± 0.058d	42.60 ± 0.35bc	0.91 ± 0.040c	24.10 ± 1.15def	7.60 ± 0.35e
DELP	1.18 ± 0.103b	43.20 ± 0.58bc	1.10 ± 0.058ab	27.20 ± 1.15bc	10.30 ± 0.17a
Hoeing	0.78 ± 0.049 cd	47.30 ± 0.17a	1.24 ± 0.058a	30.50 ± 1.15a	8.90 ± 0.23 cd
Unweeded	0.26 ± 0.020 g	40.10 ± 0.58d	0.31 ± 0.029e	19.0 ± 1.15 g	4.90 ± 0.17 h
2020/21					
*P. amb.*25	0.59 ± 0.052e	41.30 ± 0.58 cd	0.67 ± 0.040bc	22.10 ± 1.16c	6.90 ± 0.173 fg
*P. amb.*20	0.44 ± 0.023f	40.90 ± 0.52 cd	0.61 ± 0.058bc	21.70 ± 1.16c	6.30 ± 0.173gh
*P. amb.*15	0.41 ± 0.023f	40.20 ± 0.12de	0.57 ± 0.040c	20.30 ± 1.16c	5.70 ± 0.231 h
Rice straw	0.81 ± 0.058bc	46.50 ± 0.28a	0.98 ± 0.046a	26.90 ± 1.16ab	8.30 ± 0.173 cd
Wheat hay	0.99 ± 0.052a	45.93 ± 0.55a	1.01 ± 0.058a	26.2 ± 1.16ab	9.50 ± 0.289a
Peanut straw	0.90 ± 0.058b	45.30 ± 0.17ab	0.76 ± 0.28abc	25.40 ± 1.16b	9.10 ± 0.289ab
Mango leaves	0.75 ± 0.029 cd	44.20 ± 0.58b	0.97 ± 0.040a	25.00 ± 1.16b	8.70 ± 0.231bc
Soybean meal	0.71 ± 0.029d	41.70 ± 0.58 cd	0.85 ± 0.028abc	21.70 ± 1.16c	8.00 ± 0.289de
Flax meal	0.67 ± 0.040de	41.90 ± 0.58c	0.87 ± 0.040ab	22.10 ± 1.16c	7.40 ± 0.231ef
DELP	0.89 ± 0.052b	42.30 ± 0.58c	0.97 ± 0.040a	26.70 ± 1.16ab	9.70 ± 0.231a
Hoeing	0.76 ± 0.035 cd	46.10 ± 0.58a	1.03 ± 0.058a	28.70 ± 1.16a	7.97 ± 0.203de
Unweeded	0.24 ± 0.018 g	38.90 ± 0.58e	0.29 ± 0.023d	17.00 ± 1.16d	4.20 ± 0.115i

*P. amb.*15, *P. amb.*20, and *P. amb.*25: *Plectranthus amboinicus* L. leaves extract at concentrations of 15, 20 and 25%, respectively. DELP herbicide: desmedipham 70.5 g ai ha^{-1} + ethomesufate 112.5 g ai ha^{-1} + lenacil 40.5 g ai ha^{-1} + phenmedipham 90 g ai ha^{-1}. Values are the mean of 3 replicates ± standard errors. Different letters within columns refers that there are significant variations at 0.05 level of probability. Means were separated based on Duncan's multiple range test ($P \leq 0.05$).

to molasses % were obtained with flax meal and soybean meal in the first season as well as unweeded, hoeing, wheat hay, *P. amb.*25, and *P. amb.*15 in the second season.

3.5 Economic Profitability

The economic analysis divulged that there were higher increases in gross return, net return and total cost owing to the weeded practices than the unweeded (Table 7). Hoeing exhibited the maximum gross and net returns, while soybean meal or flax meal manifested the maximum costs. Rice straw followed by wheat hay were the closest to the hoeing in achieving the highest revenues. Compared to hoeing, reductions in net return amounted to –286.7 and –320.0 ($ ha^{-1}) by percentage of 6.5 and 7.2, due to mulching soil by rice straw and wheat hay, respectively.

4 Discussion

In order to maintain adequate growth factor, i.e. water, and nutrients for crop growth, reasons of loss of growth requirements should be precluded. Since weeds are considered one of the major competitors for environmental factors, they should be combated (El-Metwally and Saudy 2021a). There is no doubt that weeds exemplify emphatic biotic stress toward crop plants, particularly at early growth stages. Accordingly, application of practices which can suppress weed growth early is a crucial act in this situation. The current investigation suggests sundry safe weed control patterns which may have different mechanisms for quenching weeds in sugar beet. Controlling weeds in sugar beet fields depends mainly on the use of mechanical and chemical methods. In this respect, classical weed control methods i.e. hoeing (as

Table 4 Sugar beet root and sugar yields as affected by weed control treatments in 2019/20 and 2020/21 seasons

Treatment	Root yield (t ha^{-1})		Sugar yield (t ha^{-1})	
	2019/20	2020/21	2019/20	2020/21
*P. amb.*25	53.0 ± 1.7 h	52.7 ± 1.1f	8.33 ± 0.29e	8.51 ± 0.289e
*P. amb.*20	58.1 ± 1.1 g	56.3 ± 1.1e	8.96 ± 0.29e	9.04 ± 0.29e
*P. amb.*15	61.7 ± 1.1f	57.1 ± 1.1e	8.63 ± 0.49e	8.89 ± 0.44e
Rice straw	84.5 ± 1.1a	83.2 ± 1.1b	14.71 ± 0.58bc	13.89 ± 0.58bc
Wheat hay	84.0 ± 1.1ab	82.7 ± 1.1b	15.63 ± 0.58ab	14.87 ± 0.58b
Peanut straw	80.9 ± 1.1bc	80.0 ± 1.1bc	14.75 ± 0.58bc	13.26 ± 0.56c
Mango leaves	78.9 ± 1.1 cd	79.1 ± 1.1c	14.39 ± 0.29c	14.81 ± 0.58b
Soybean meal	69.8 ± 1.1e	70.1 ± 1.1d	10.05 ± 0.29d	10.85 ± 0.29d
Flax meal	72.5 ± 1.1e	71.4 ± 1.1d	10.53 ± 0.29d	11.17 ± 0.29d
DELP	77.0 ± 0.5d	78.0 ± 1.1c	14.08 ± 0.58c	13.26 ± 0.58c
Hoeing	87.2 ± 1.1a	86.7 ± 1.1a	16.55 ± 0.58a	16.89 ± 0.58a
Unweeded	32.4 ± 1.1i	34.7 ± 0.5 g	4.48 ± 0.28f	4.54 ± 0.29f

*P. amb.*15, *P. amb.*20, and *P. amb.*25: *Plectranthus amboinicus* L. leaves extract at concentrations of 15, 20 and 25%, respectively. DELP herbicide: desmedipham 70.5 g ai ha^{-1} + ethomesufate 112.5 g ai ha^{-1} + lenacil 40.5 g ai ha^{-1} + phenmedipham 90 g ai ha^{-1}. Values are the mean of 3 replicates ± standard errors. Different letters within columns refers that there are significant variations at 0.05 level of probability. Means were separated based on Duncan's multiple range test ($P \leq 0.05$).

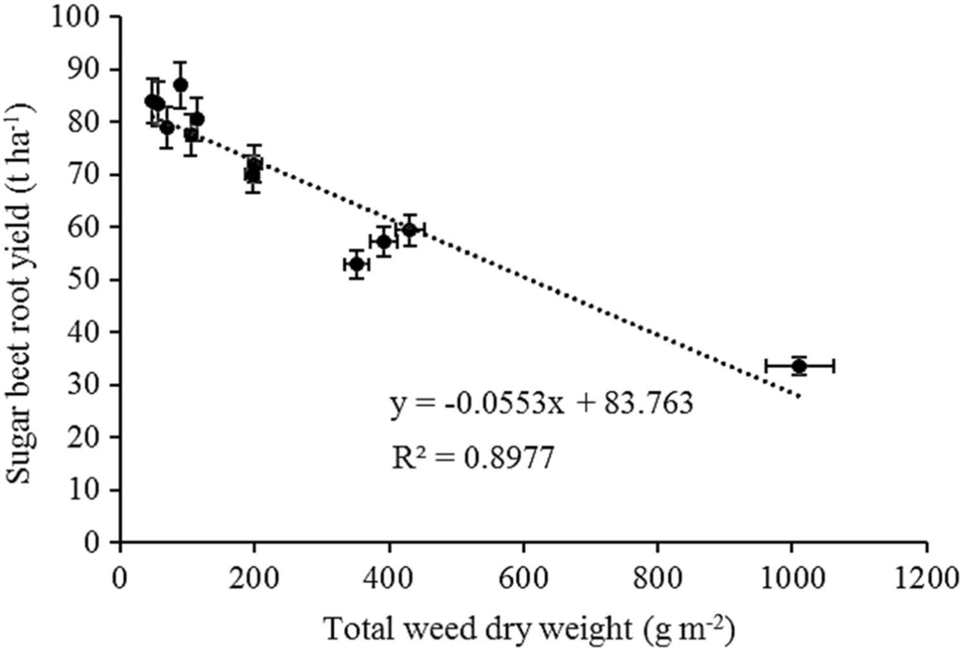

Fig. 3 Linear regression analysis performed over the two experimental seasons (2019/20 and 2020/21) between sugar beet root yield data and total weed dry weight data

a mechanical method) and DELP herbicide (as a chemical one) were so effective for reducing weed biomass. Herein, weeds are teared and/or uprooted by hoeing, reducing their competitiveness against crop plants (Saudy 2013). Owing to potentiality of hoeing in eliminating the hazard impacts of weeds, ecological resources became more available and effectively utilized by the crop (Saudy et al. 2021b). Besides its efficient role in weed control (El-Metwally et al. 2022), hoeing improves soil structure, aeration, water penetration, and the availability of some nutrients for crop plants. Also, hoeing was effective because multiple mechanical operations were performed (Gazoulis et al. 2021; Kanatas and Gazoulis 2022). Consequently, sugar beet growth, agronomic traits, and quality were improved. Hoeing caused 89.0 and 90.4% reductions in weed density and weed dry weight, respectively, with 68.8% increase in root yield of sugar beet (Abd El Lateef et al. 2021). Also, nutrient availability and utilization by crop plants were enhanced with hoeing treatment

Table 5 Sugar beet sugar impurities as affected by weed control treatments in 2019/20 and 2020/21 seasons

	Potassium (meq/100 g beet)	Sodium (meq/100 g beet)	α-amino N (meq/100 g beet)	Alkalinity coefficient
2019/20				
*P. amb.*25	4.65 ± 0.115 cd	1.79 ± 0.058 cd	1.95 ± 0.058e	3.30 ± 0.115c
*P. amb.*20	4.81 ± 0.115c	1.83 ± 0.058c	2.15 ± 0.058d	3.10 ± 0.115 cd
*P. amb.*15	4.95 ± 0.115bc	1.87 ± 0.058c	2.28 ± 0.058c	2.98 ± 0.110 cd
Rice straw	4.66 ± 0.115 cd	1.78 ± 0.052 cd	2.26 ± 0.058c	2.85 ± 0.115de
Wheat hay	5.03 ± 0.115abc	1.80 ± 0.058 cd	1.81 ± 0.058f	3.77 ± 0.115b
Peanut straw	4.32 ± 0.115de	1.46 ± 0.058e	1.83 ± 0.058f	3.12 ± 0.115 cd
Mango leaves	4.69 ± 0.115c	1.78 ± 0.058 cd	2.06 ± 0.058d	3.14 ± 0.115 cd
Soybean meal	5.21 ± 0.115ab	3.37 ± 0.058b	2.59 ± 0.058b	2.39 ± 0.115f
Flax meal	5.36 ± 0.115a	3.52 ± 0.058a	3.50 ± 0.058a	2.54 ± 0.115ef
DELP	4.26 ± 0.115e	1.42 ± 0.058e	1.71 ± 0.058 g	3.32 ± 0.115c
Hoeing	4.68 ± 0.115 cd	1.70 ± 0.058d	1.48 ± 0.058 g	4.31 ± 0.115a
Unweeded	4.78 ± 0.115c	1.70 ± 0.058d	1.64 ± 0.058 h	3.95 ± 0.115b
2020/21				
*P. amb.*25	4.80 ± 1.01ab	3.40 ± 0.12a	4.32 ± 0.058a	1.67 ± 0.115bc
*P. amb.*20	4.64 ± 0.12abc	3.00 ± 0.12b	3.43 ± 0.058a	2.23 ± 0.115a
*P. amb.*15	3.91 ± 0.12bcde	3.06 ± 0.12ab	5.26 ± 0.058a	1.33 ± 0.058efg
Rice straw	4.16 ± 0.09bcde	3.03 ± 0.12ab	4.05 ± 0.058a	1.78 ± 0.028b
Wheat hay	5.32 ± 0.12a	2.66 ± 0.12c	4.74 ± 0.058a	1.68 ± 0.115bc
Peanut straw	3.19 ± 0.11e	2.41 ± 0.12c	3.29 ± 0.058a	1.70 ± 0.058bc
Mango leaves	4.25 ± 0.12bcd	1.70 ± 0.12d	4.85 ± 0.058a	1.23 ± 0.058 fg
Soybean meal	4.05 ± 0.12bcde	3.22 ± 0.12ab	4.82 ± 0.058a	1.51 ± 0.115cde
Flax meal	3.57 ± 0.12de	3.08 ± 0.12ab	4.16 ± 0.058a	1.60 ± 0.058bcd
DELP	3.78 ± 0.12cde	3.11 ± 0.12ab	5.94 ± 0.058a	1.16 ± 0.058 g
Hoeing	4.66 ± 0.12abc	2.39 ± 0.12c	4.88 ± 0.058a	1.44 ± 0.058def
Unweeded	3.91 ± 0.12bcde	3.06 ± 0.12ab	5.26 ± 0.058a	1.33 ± 0.058efg

*P. amb.*15, *P. amb.*20, and *P. amb.*25: *Plectranthus amboinicus* L. leaves extract at concentrations of 15, 20, and 25%, respectively. DELP herbicide: desmedipham 70.5 g ai ha^{-1} + ethomesufate 112.5 g ai ha^{-1} + lenacil 40.5 g ai ha^{-1} + phenmedipham 90 g ai ha^{-1}. Values are the mean of 3 replicates ± standard errors. Different letters within columns refers that there are significant variations at 0.05 level of probability. Means were separated based on Duncan's multiple range test ($P \leq 0.05$).

(Saudy et al. 2020). However, despite hoeing still being a conventional weed control in row crops, manual labor has become scarce and expensive (Saudy et al. 2021a).

DELP herbicide caused reductions of 90.2, 88.9, and 89.7% (averages of the two seasons) in dry weight of broad leaf, grass, and total weeds, respectively. In this regard, application of acetolactate synthase (ALS) inhibiting herbicides achieved excellent efficacy on common sugar beet weeds (Gotze et al 2018). Furthermore, Jursík et al. (2020) recorded that DELP herbicide completely controlled *Amaranthus retroflexus* L., *Echinochloa crus-galli* L., and *Chenopodium album* L. in sugar beet.

Findings of the current work clarified that using different plant wastes as soil covering achieved significantly reduction in weed biomass. It should be mentioned that in widely spaced row crops such as sugar beet, severe weed competition occurs. In this situation, the allowable penetrated sunlight to the soil surface increases, along with increased crop-weed competition for soil minerals, soil moisture, and CO_2, and it becomes more available to weeds. This promotes the weeds to grow better and dramatically spread. Conversely, blocking light to reach the soil surface by mulching directly reduced subsequent germination and suppressed weed growth (Monaco et al. 2002). Due to blocking light penetration, straw mulch prevented the seed germination and inhibited the emerged weed seedlings growth (Chang et al. 2016). Weed density in straw-mulched field was less than that of non-mulched one (Sinkevičienė et al. 2009). Furthermore, several plant residues decreased weed competition because of their allelopathic potentiality (Anzalone et al. 2010). The negative impacts of weeds could be dwindled by employing the allelopathic potential of crops using mulches (Riaz Marral et al. 2020). Significant increase in relative water content and photosynthesis efficiency and decrease in weed competition were obtained with using of soil mulching (Abd El-Mageed et al. 2016; El-Metwally et al. 2022).

Table 6 Sugar beet root and sugar quality as affected by weed control treatments in 2019/20 and 2020/21 seasons

	Sucrose %	Extractable sugar %	Juice purity %	Sugar lost to molasses %
2019/20				
*P. amb.*25	17.20 ± 0.58bc	15.71 ± 0.58b	86.23 ± 1.15abc	1.89 ± 0.058cde
*P. amb.*20	17.90 ± 0.58b	15.42 ± 0.58bc	86.15 ± 1.15abc	1.88 ± 0.058cdef
*P. amb.*15	17.10 ± 0.58bc	14.42 ± 0.58bc	84.66 ± 0.94 cd	1.98 ± 0.058c
Rice straw	19.98 ± 0.58a	17.41 ± 0.58a	87.14 ± 1.15abc	1.97 ± 0.058c
Wheat hay	20.12 ± 0.58a	18.61 ± 0.58a	88.12 ± 1.15ab	1.91 ± 0.058 cd
Peanut straw	20.60 ± 0.58a	18.23 ± 0.58a	88.50 ± 1.15ab	1.74 ± 0.035ef
Mango leaves	21.14 ± 0.58a	18.24 ± 0.58a	86.27 ± 1.15abc	2.30 ± 0.058b
Soybean meal	17.58 ± 0.58bc	14.40 ± 0.58bc	81.91 ± 1.15d	2.58 ± 0.058a
Flax meal	17.71 ± 0. 61b	14.52 ± 0.58bc	81.85 ± 1.15d	2.52 ± 0.058a
DELP	20.60 ± 0.59a	18.28v0.58a	88.74 ± 1.15a	1.72 ± 0.058f
Hoeing	21.34 ± 0.58a	18.98 ± 0.58a	88.94 ± 1.15a	1.76 ± 0.058def
Unweeded	16.26 ± 0.58c	13.84 ± 0.58c	85.12 ± 1.15bcd	1.82 ± 0.058cdef
2020/21				
*P. amb.*25	16.14 ± 0.56c	12.95 ± 0.58bc	80.24 ± 1.15bc	2.59 ± 0.058abc
*P. amb.*20	16.06 ± 0.56c	13.03 ± 0.58bc	81.13 ± 1.15bc	2.43 ± 0.058c
*P. amb.*15	15.86 ± 0.56c	12.47 ± 0.58c	78.13 ± 1.15c	2.79 ± 0.058a
Rice straw	16.70 ± 0.56bc	13.91 ± 0.88bc	81.31 ± 1.15bc	2.52 ± 0.058bc
Wheat hay	17.98 ± 0.56ab	14.58 ± 0.58ab	81.09 ± 1.15bc	2.63 ± 0.123abc
Peanut straw	16.58 ± 0.56bc	13.48 ± 0.58bc	81.30 ± 1.15bc	2.50 ± 0.058bc
Mango leaves	18.72 ± 0.56a	16.02 ± 0.58a	85.58 ± 1.15a	2.10 ± 0.058de
Soybean meal	15.48 ± 0.56c	12.66 ± 0.58bc	81.78 ± 1.15bc	2.22 ± 0.058d
Flax meal	15.64 ± 0.56c	13.07 ± 0.58bc	83.57 ± 1.15ab	1.97 ± 0.058e
DELP	17.00 ± 0.56bc	13.95 ± 0.58bc	82.06 ± 1.15abc	2.45 ± 0.058c
Hoeing	19.48 ± 0.56a	16.17 ± 0.58a	83.01 ± 1.15ab	2.71 ± 0.058ab
Unweeded	13.08 ± 0.56d	9.69 ± 0.58d	74.08 ± 1.15d	2.78 ± 0.052a

*P. amb.*15, *P. amb.*20, and *P. amb.*25: *Plectranthus amboinicus* L. leaves extract at concentrations of 15, 20, and 25%, respectively. DELP herbicide: desmedipham 70.5 g ai ha^{-1} + ethomesufate 112.5 g ai ha^{-1} + lenacil 40.5 g ai ha^{-1} + phenmedipham 90 g ai ha^{-1}. Values are the mean of 3 replicates ± standard errors. Different letters within columns refers that there are significant variations at 0.05 level of probability. Means were separated based on Duncan's multiple range test ($P \leq 0.05$).

Table 7 Profitability of sugar beet cultivated under different weed control treatments (average of 2019/20 and 2020/21 seasons)

Treatment	Average root yield (t ha^{-1})	Gross return ($ ha^{-1})	Treatment cost ($ ha^{-1})	Total cost ($ ha^{-1})	Net return ($ ha^{-1})
*P. amb.*25	52.85	3523.82	150.00	1216.67	2307.15
*P. amb.*20	57.20	3813.52	150.00	1216.67	2596.85
*P. amb.*15	59.40	3960.20	150.00	1216.67	2743.53
Rice straw	83.85	5590.27	400.00	1466.67	4123.61
Wheat hay	83.35	5556.94	400.00	1466.67	4090.27
Peanut straw	80.45	5363.60	400.00	1466.67	3896.93
Mango leaves	79.00	5266.93	400.00	1466.67	3800.26
Soybean meal	69.95	4663.56	500.00	1566.67	3096.89
Flax meal	71.95	4796.91	500.00	1566.67	3230.24
DELP	77.50	5166.93	100.00	1166.67	4000.26
Hoeing	86.95	5796.96	320.00	1386.67	4410.29
Unweeded	33.55	2236.68	00.00	1066.67	1170.01

*P. amb.*15, *P. amb.*20, and *P. amb.*25: *Plectranthus amboinicus* L. leaves extract at concentrations of 15, 20 and 25%, respectively. DELP herbicide: desmedipham 70.5 g ai ha^{-1} + ethomesufate 112.5 g ai ha^{-1} + lenacil 40.5 g ai ha^{-1} + phenmedipham 90 g ai ha^{-1}. Values are the mean of 3 replicates ± standard errors

Therefore, sugar beet growth and yield and sugar quality were improved owing to mulching application.

As an attempt to exploit the allelopathy phenomenon, the current research proved that the aqueous extract of *P. amboinicus* L. particularly at a high rate (25%), involved significant amount of phenolics, thus it displayed reasonable prorated repressive impact on weeds associated sugar beet plants. Various types of phenolic compounds such as syringic acid, chlorogenic acid, ferulic acid, vanillic acid, p-coumaric acid, protocatechuic acid, caffeic acid, benzoic acid, and gallic acid are typified by allelopathic properties (Hassan et al. 2012). Owing to existence of phenolics, aqueous water extracts and plant residues mulch may contribute in decreasing weed infestation (Farooq et al. 2017; Naeem et al. 2022). Allelochemicals can disrupt the metabolism processes of recipient plants such as photosynthesis, cell division, respiration and protein synthesis (Duke and Dayan 2006). Allelopathic chemicals cause physiological injuries due to unrestrained production and the accumulation of reactive oxygen species, ROS (Bogatek and Gniazdowska 2007). ROS causes cell structure disintegration by lipids peroxidation, DNA and proteins impairment, and enzyme inertia (Wang et al. 2017). Accordingly, allelochemicals can demoralize the growth of weeds through photosynthesis inhibition, free radical production, chlorophyll deterioration, deactivation of enzymatic systems, and cell membrane turmoil of the target plants (Ghanizadeh et al. 2014). However, still, the efficacy of natural plant extracts for weed control requires more improvements.

Despite hoeing was the superior practice for obtaining the maximum benefits of sugar beet cultivation, soil mulching materials especially rice straw and wheat hay, should not be neglected. In this respect, besides mulching as a clean method, it achieved benefits higher than herbicide application. Also, in addition to the financial interests returning the agricultural wastes in the form of mulching achieves another advantage related to lowering greenhouse emissions. Economically and environmentally sustainable weed control alternatives, such as non-synthetic or natural mulch, can provide many benefits, including weed suppression and delayed weed seedling emergence (Abouziena et al. 2015; El-Metwally and El-Wakeel 2019). Distinctive improvement in yield and quality was achieved using soil mulches particularly peanut mulch. (El-Metwally et al. 2022).

5 Conclusions

The current study revealed that different soil mulching materials significantly differed in their potentiality to suppress weed growth and enhance yield and quality of sugar beet. The results proved that exploiting the plant by-products as mulching showed several advantages via suppressing the growth of various weed types, increasing sugar beet yield potential and quality with high revenues. Accordingly, using wheat hay, rice straw, peanut straw, or mango leaves as safe and eco-friendly methods to control weeds is promising in sugar beet cultivation. Instead of herbicides, the allelopathic effect of *Plectranthus amboinicus* L. aqueous extract could be incorporated into weed management strategies as an additional, more cost-effective and eco-friendly method that will help to save the environment. However, the use of natural plant extracts, such as *Plectranthus amboinicus* L. in weed control still requires further investigations with the aim of increasing their efficiency to persuade the farmers to use them as a tool for weed control.

*P. amb.*15, *P. amb.*20, and *P. amb.*25: *Plectranthus amboinicus* L. leaves extract at concentrations of 15, 20 and 25%, respectively. DELP herbicide: desmedipham 70.5 g ai ha^{-1} + ethomesufate 112.5 g ai ha^{-1} + lenacil 40.5 g ai ha^{-1} + phenmedipham 90 g ai ha^{-1}. Values are the mean of 3 replicates ± standard errors. Different letters within columns refers that there are significant variations at 0.05 level of probability. Means were separated based on Duncan's multiple range test ($P \leq 0.05$).

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Declarations

Conflict of Interest The authors declare no competing interests.

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