Research Article

Effect of Different Herbicides and Plant Extracts on Yield and Yield Components of Canola Cultivars

Meher Ali*, Ijaz Ahmad Khan, Zahid Hussain, Muhammad Saddique and Rashid Anwar

Department of Weed Science and Botany, Faculty of Crop Protection Sciences, University of Agriculture, Peshawar-Pakistan.

Abstract | A field trial was conducted during the Rabi season of 2023 at the Agriculture Research Institute Tarnab (ARI) Peshawar to evaluate the effects of different herbicides and plant extracts on the yield and yield components of canola cultivars. The experiment was laid out in a Randomized Complete Block Design (RCBD) with a split-plot arrangement, comprising three canola cultivars (CB-11, CB-15, and CB-16) assigned to main plots, and six weed control treatments including Stomp 330 EC and Dual Gold 960 EC as PRE herbicides, sorghum extract (20 L ha^{-1}) and eucalyptus extract (18 L ha^{-1}) as foliar sprays, hand weeding done once each at 30 and 60 days after transplanting (DAT), and a weedy check, were allocated to the subplots. The weed and crop parameters measured were weed density, fresh and dry weed biomasses, plant height, siliquae length, 1000-seed weight, biological yield, harvest index, and seed yield. The results indicated that weed control treatments significantly influenced both the weeds and canola growth parameters. Hand weeding at 30 and 60 DAT resulted in the lowest weed density (43 m^{-2}, fresh biomass (1585 kg ha^{-1}), and dry biomass (883 kg ha^{-1}). This treatment also led to a significant increases in plant height (165.3 cm), siliqua length (8.0 cm), 1000-seed weight (4.2 g), biological yield (5004 kg ha^{-1}), and seed yield (1654 kg ha^{-1}). Hand weeding was closely followed by Stomp 330 EC herbicide with a seed yield of 1498 kg ha^{-1}. Dual Gold 960 EC and sorghum extract treatments yielded 1413 kg ha^{-1} and 1405 kg ha^{-1}, respectively. The weedy check plots exhibited the highest weed population and the lowest canola yield. The maximum harvest index (37.4%) was observed in the weedy check, followed by Stomp 330 EC (33.6%) and hand weeding (33.0%). The study concludes that manual weeding at 30 and 60 DAT, in combination with allelopathic plant extracts, is an effective and environmentally friendly practice for weed control in canola crop.

Received | March 21 2025; **Accepted** | Aug 29, 2025; Published | December 26, 2025
***Correspondence** | Meher Ali, Department of Weed Science and Botany, University of Agriculture, Peshawar-Pakistan. **Email:** meherali21505@gmail.com
Citation | Ali, M., I.A. Khan, Z. Hussain, M. Saddique and R. Anwar. 2025. Effect of different herbicides and plant extracts on yield and yield components of canola cultivars. Sarhad Jurnal of Agriculture, 41(5): 228-237.
DOI | https://dx.doi.org/10.17582/journal.sja/2025/41.5.228.237
Keywords | Canola, Cultivars, Extracts, Herbicides, Weeds, Yield.

Introduction

Canola (*Brassica napus* L.), a member of the Brassicaceae family, is an important oilseed crop grown worldwide. The "canola" cultivars have reduced erucic acid and glucosinolate levels. Typically planted in the fall, canola grows through winter and resumes in spring (Assefa *et al*., 2018). In Pakistan, the canola yield remains lower (<812 kg ha^{-1}) as compared to that of 2000 kg in Australia and 3200 kg ha^{-1} in Canada due to marginal land, poor fertility, weed competition, and inadequate crop nutrition (Reddy, 2014). Canola is cultivated across all provinces of Pakistan under both irrigated and rainfed conditions (Hussain *et al*., 2023). It is grown over 0.026 m ha, with an annual production of 0.102 m tons (AARI, 2020-21). In KP, rapeseed is grown on 0.0235 m ha, producing 0.0112 m tons with an average yield of 575 kg ha^{-1} (MINFAL, 2022).

Weed interference poses a significant challenge to agricultural productivity in Pakistan, causing yield losses of 25-45% (Shah *et al*., 2003). Weeds compete with crops for essential resources such as water, light, nutrients, and space. Additionally, weeds from the Brassicaceae family can negatively impact the quality of canola products (Salisbury *et al*., 2018). Weed management in conventional canola is challenging due to expensive tillage and herbicide use (Gulzar *et al*., 2012), and weeds from the mustard family can degrade oil quality (Beckie *et al*., 2014). Weeds can reduce canola crop yield and seed quality (Marwat *et al*., 2005). Canola, a slow-growing crop, faces severe competition with weeds, particularly during early growth stages. Effective weed management, especially during early growth, is crucial for enhancing seed output (Blackshaw *et al*., 2002).

Weed control in canola relies on cultural, biological, chemical, and physical methods. While hand weeding is common, labor shortages and costs make it impractical, leading to increased herbicide use, particularly post-emergence types (Harker and O'Donovan, 2013). Broad-spectrum herbicides are effective against weeds like wild radish and shepherd's purse (Grey *et al*., 2006), but frequent use can lead to resistance, posing economic risks (Heap, 2019). An integrated weed management approach, combining herbicidal and non-herbicidal methods, is vital for sustainable canola production (Harker and O'Donovan, 2013). Sorghum and eucalyptus extracts were selected due to their allelopathic potential. Sorghum contains sorgoleone, a potent allelochemical that suppresses weed root development, while eucalyptus is rich in 1,8-cineole, known to inhibit weed germination (Khanh *et al*., 2005; Jabran *et al*., 2015). Biological control methods involving microbes and insects are gaining traction in sustainable weed management. For instance, soil microbes like Trichoderma and Bacillus have shown potential to suppress weed seed germination (Xu *et al*., 2021), while insects such as Aphthona spp. have been successfully used against broadleaf weeds (Smith *et al*., 2020).

This study was aimed at evaluating the effect of plant extracts and herbicides on canola yield and related traits, identifying the most effective weed control combination, and exploring the interactions between canola cultivars and weed management treatments to optimize production and sustainability of canola crop.

Materials and Methods

Site description

The field trial was conducted during Rabi season 2023 at the Agriculture Research Institute (ARI) Tarnab, situated in the east of Peshawar, having the latitude of 34.0050° N, longitude of 71.6981° E and elevation of approx. 308–310 m above sea level. The experimental site's soil and climatic conditions were representatives of the region's typical canola-growing environment. Standard soil preparation practices were followed, and the field was fertilized with phosphates @ 20 and 80 kg ha^{1} before sowing. Irrigation was applied as needed throughout the growing season.

Experimental design and treatments

The experiment was laid out in a Randomized Complete Block Design (RCBD) with a split-plot arrangement, replicated three times.

Main plots: Three canola cultivars
CB-11 (NARC Canola)
CB-15 (Khanpur Canola)
CB-16 (Faisal Canola)

Sub-plots: Six weed control treatments
Stomp 330 EC (pendimethalin at 2.50 kg a.i. ha^{-1}, PRE)
Dual Gold 60 EC (s-metolachlor at 1.25 kg a.i. ha^{-1}, PRE)
Sorghum extract (20 L ha^{-1} foliar spray) 5 days after emergence (DAE)
Eucalyptus extract (18 L ha^{-1} foliar spray) 5 (DAE)
Hand weeding at 30 and 60 DAT (i.e. two times in whole season)

Weedy check (control)

Each sub-plot measured 5 m long × 4.5 m wide and consisted of six rows spaced 75 cm between rows. Canola was sown using a planting machine/hand drill, and standard agronomic practices were followed until maturity.

Weed Management applications

The herbicides i.e. Stomp 330 EC (pendimethalin) and Dual Gold 60 EC (s-metolachlor) were applied before weed emergence as PRE. The extracts of sorghum and eucalyptus extracts were applied as foliar sprays (i.e. as post-emergence or POE). Hand weeding was conducted once each at 30 and 60 DAT in the relevant experimental plots.

Data collection

The following parameters were recorded: Weed density was assessed by counting weeds in three randomly placed 50 cm × 50 cm quadrats per plot and converted to weeds m^{-2}. Weed biomass: Fresh and dry weights (after oven-drying) of collected weeds. Crop parameters: Plant height and siliqua length (measured from 10 randomly selected plants). 1000-seed weight (calculated from seed samples). Seed yield and biological yield (recorded at harvest and converted to kg ha^{-1}). Harvest index: Calculated as (seed yield / biological yield) × 100.

Statistical analysis

Field data of each parameter were analyzed using the statistical software Statistix 2.0 suitable for the relevant ANOVA. The significant means were subjected to the Fisher Protected LSD test (Steel *et al*., 1997).

Results and Discussion

Weed density (m^{-2})

Weed density was significantly affected by the canola cultivars, weed management treatments, and their interactions (Table 1). Among the weed management treatments, hand weeding was the most effective method, reducing weed density to 43 m^{-2}, followed by Stomp 330 EC (74), while the highest density was observed in the weedy check (172 m^{-2}). Among the canola cultivars, the plots of CB-11 had the highest weed density (111.8), whereas CB-16 had the lowest weed density (92.8 m^{-2}). The main effects are presented in Table 1, while the interaction effect is shown in Figure 1 below. The combination of CB-11 cultivar with weedy check resulted in the highest weed density (187), while CB-16 under hand weeding recorded the lowest (37.5 m^{-2}). These results emphasized the importance of integrating effective weed management strategies with suitable cultivars. Among the weed control treatments, hand weeding significantly reduced weed density, which is aligning with the previous findings of Ali *et al*. (2011) while the results of Stomp 330 EC residual weed suppression was in line with the results of Harker *et al*. (2012). Allelopathic plant extracts, including sorghum and eucalyptus, offer potential sustainable weed control alternatives (Khanh *et al*., 2005).

Table 1: *Effect of different weed control practices on weed density (m^{-2}) in canola cultivars*

Treatments	Canola cultivars			Means
	CB-11	CB-15	CB-16	
Stomp 330 EC	82.7 a	72.7 b	66.6 c	74 e
Dual gold 960 EC	90.1 d	83.5 e	75.9 g	83 d
Sorghum extract	135.7 e	128.4 f	112.5 h	125 b
Eucalyptus extract	129.0 i	118.8 j	106.8 k	118 c
Hand weeding	46.8 j	45.0 k	37.5 l	43 f
Weedy check	187 m	172.5 m	157.5 n	172 a
Cultivars means	111.8 a	103.4 b	92.8 c	

LSD $_{(0.05)}$ Cultivars= 1.4071, LSD $_{(0.05)}$ Treatments=3.1721, LSD $_{(0.05)}$ Interaction=5.1964

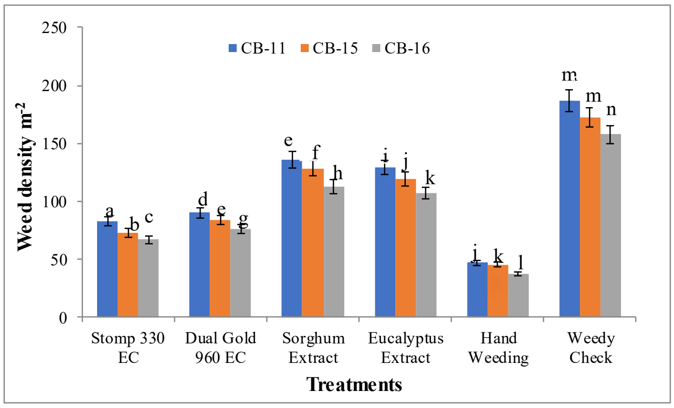

Figure 1: *Interaction effect of canola and weed control practices on weed density*

Fresh weed biomass (kg ha^{-1})

The analysis revealed that weed management practices, canola cultivars, and their interactions significantly affected fresh weed biomass. As shown in Table 2, the lowest biomass was observed with Dual Gold 960 EC (1233 kg ha^{-1}) and hand weeding (1094 kg ha^{-1}), while the highest was in the control (1585 kg ha^{-1}). Among cultivars, CB-15 exhibited the lowest biomass (1211 kg ha^{-1}), whereas CB-11 had the highest (1305 kg ha^{-1}). The interaction between treatments and cultivars showed that hand weeding with CB-16 resulted in the lowest biomass (1008 kg ha^{-1}), whereas the control with CB-11 had the highest (1626 kg ha^{-1}). Fresh weed biomass was significantly reduced by weed management techniques, particularly hand weeding and herbicide applications. Among the weed control strategies, hand weeding effectively minimized weed competition, aligning with the findings of Kumar and Singh, (2010). The herbicides, Dual Gold 960 EC and Stomp 330 EC substantially reduced weed biomass by inhibiting weed emergence. The results were consistent with those of Blackshaw *et al.* (2002). The significant reduction in weed biomass in CB-15 could be attributed to the rapid early growth of the cultivar seedlings that suppressed weeds. Integrating herbicides, hand weeding, and allelopathic plant extracts can enhance weed suppression, as the result is also supported by Farooq *et al.* (2011) and Chauhan *et al.* (2012).

Table 2: *Effect of weed management strategies on weed fresh biomass (kg ha^{-1}) in canola cultivars*

Treatments	Cultivars			Treatments means
	CB-11	CB-15	CB-16	
Stomp 330 EC	1304 ef	1224 fgh	1193 ghi	1240 c
Dual gold 960 EC	1315 ef	1220 fgh	1164 hi	1233 c
Sorghum extract	1435 cd	1382 de	1184 ghi	1334 b
Eucalyptus extract	1275 fg	1275 fg	1197 ghi	1249 c
Hand weding	1155 hi	1120 i	1008 j	1094 d
Weedy check	1626 a	1608 ab	1520 bc	1585 a
Cultivars means	1352 a	1305 b	1211 c	

LSD$_{0.05}$ Cultivars = 30.91, LSD$_{0.05}$ Treatments = 28.377, LSD$_{0.05}$ Interaction = 53.605

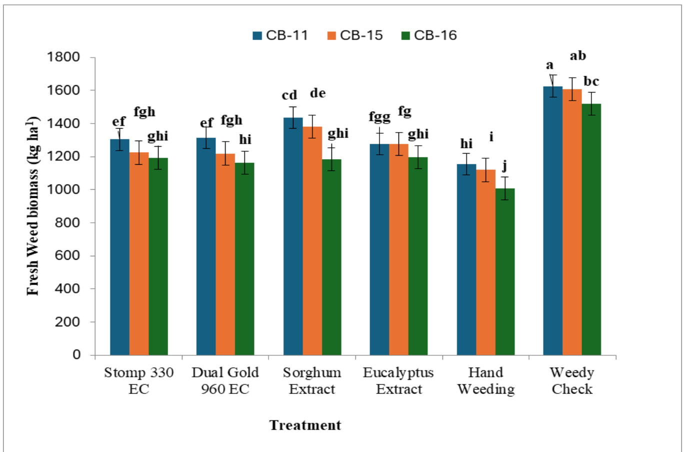

Figure 2: *Interaction of canola cultivars & weed control practices on weed fresh biomass*

Dry weed biomass (kg ha^{-1})

Weed dry biomass was significantly affected by weed management practices, canola cultivars, and their interactions (Table 3). Hand weeding recorded the lowest biomass (419 kg ha^{-1}), followed by Dual Gold (524 kg ha^{-1}), while the highest was in the weedy check (883 kg ha^{-1}). Among cultivars, CB-16 had the lowest biomass (565 kg ha^{-1}) and CB-11 the highest (630 kg ha^{-1}). The interaction effect (Figure 3) showed that hand weeding with CB-16 had the lowest biomass (381 kg ha^{-1}), whereas the control in interaction with CB-11 had the highest dry weed biomass (920 kg ha^{-1}). The weed management techniques, particularly herbicides and hand weeding, effectively reduced weed dry biomass by suppressing weed growth. CB-11's higher biomass suggests lower competitiveness, leading to greater weed infestation. Similar findings were reported by Chauhan *et al.* (2012), where hand weeding declined weed biomass by 85%. Blackshaw *et al.* (2001) also opined that herbicides can reduce weed biomass by 90%. Additionally, the plant extracts such as neem and eucalyptus have shown eco-friendly weed control potentially reducing weed biomass by 70% (Cheema and Khaliq, 2000).

Table 3: *Effect of various weed management practices on weed dry biomass (kg ha^{-1}) in canola*

Treatments	Canola Cultivars			Treatments Means
	CB-11	CB-15	CB-16	
Stomp 330 EC	575 a	543 b	527 c	548 d
Dual Gold 960 EC	549 d	534 e	489 fg	524 e
Sorghum Extract	684 f	655 fgh	588 hi	642 b
Eucalyptus Extract	596 gh	578 jk	563 k	579 c
Hand Weeding	456 ij	420 jk	381 l	419 f
Weedy Check	920 m	888 n	843 o	883 a
Cultivars Means	630 a	603 b	565 c	

LSD$_{0.05}$ Cultivars = 7.7794, LSD$_{0.05}$ Treatments = 11.469, LSD$_{0.05}$ Interaction =19.635

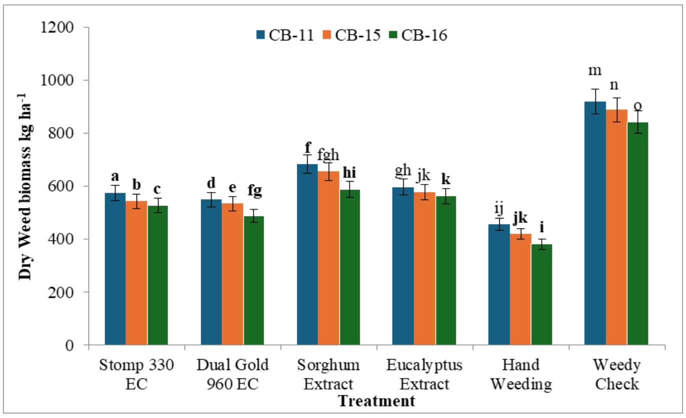

Figure 3: *Interaction effect of canola cultivars × treatments on dry weed biomass.*

Plant height (cm)

Weed control treatments and canola cultivars significantly affected the plant height (Table 4) while the interaction effect was non significant. Among the treatments, the hand weeding resulted in the tallest plants (165.33 cm), while the weedy check had the shortest (150.72 cm). Among cultivars, CB-16 had the tallest plants (159.92 cm), and the interaction showed that hand weeding with CB-16 produced the tallest plants (167.17 cm), while the weedy check with CB-15 had the shortest (149.08 cm). The interaction showed that hand weeding with CB-16 produced the tallest plants (167.17 cm), while the weedy check with CB-15 had the shortest (149.08 cm). Weed management strategies improved plant height by reducing weed competition for nutrients, water, and light. Hand weeding and herbicides effectively suppressed weeds that ultimately enhanced the plant growth and yield (Zaman *et al*., 2019; Gulzar *et al*., 2018). Plant extracts like neem also contributed to weed suppression and improved plant height (Saeed *et al*., 2017).

Table 4: *Effect of various weed management strategies on plant height (cm) of canola cultivars*

Treatments	Canola cultivars			Treat-ments means
	CB-11	CB-15	CB-16	
Stomp 330 EC	160.08	158.08	160.92	159.69 b
Dual gold 960 EC	158.5	158.08	162.17	159.58 b
Sorghum extract	156.08	155.08	159.5	156.89 c
Eucalyptus extract	154.83	154.25	156.92	155.33 c
Hand weeding	165.08	163.75	167.17	165.33 a
Weedy check	150.25	149.08	152.83	150.72 d
Cultivars means	157.47 b	156.39 c	159.92 a	

$LSD_{0.05}$ Cultivars = 0.9268, $LSD_{0.05}$ Treatments = 1.5830, $LSD_{0.05}$ Interaction = 2.7419

Siliqua length (cm)

Statistical analysis revealed significant differences in siliqua length across weed management treatments, canola cultivars, and their interactions (Table 5). Hand weeding resulted in the longest siliques (8.0 cm), followed by Stomp 330 EC (7.9 cm) and Dual Gold 960 EC (7.8 cm), while the weedy check had the shortest (5.9 cm). Among cultivars, CB-16 had the longest siliquae (7.4 cm), while CB-11 (7.1 cm) and CB-15 (7.2 cm) had slightly shorter lengths. The interaction (Figure 4) showed that hand weeding with CB-16 produced the longest siliquae (8.2 cm), while the weedy check with CB-11 and CB-15 had the shortest (5.9 cm). A similar study by Ali *et al*. (2016) found that hand weeding significantly increases siliqua length by reducing weed competition and improving resource availability. Cheema *et al*. (2004) reported that selective herbicides suppress weeds effectively, enhancing crop growth. Likewise, Jabran *et al*. (2010) observed that allelopathic plant extracts, such as sunflower and sorghum, improve siliqua development by reducing weed pressure.

Table 5: *Effect of different weed control practices on siliqua length of canola cultivars*

Treatments	Canola cultivars			Treatments means
	CB-11	CB-15	CB-16	
Stomp 330 EC	7.8 de	7.9 c	8.1 b	7.9 b
Dual Gold 960 EC	7.7 e	7.8 de	7.9 c	7.8 c
Sorghum Extract	6.8 h	6.8 h	7 g	6.9 e
Eucalyptus Extract	6.8 h	6.9 h	7.1 f	6.9 d
Hand Weeding	7.8 d	7.9 c	8.2 a	8.0 a
Weedy Check	5.9 j	5.9 j	6.1 i	5.9 f
Cultivars Means	7.1 c	7.2 b	7.4 a	

$LSD_{0.05}$ Cultivars = 0.0382, $LSD_{0.05}$ Treatments = 0.0411, $LSD_{0.05}$ Interaction = 0.0712

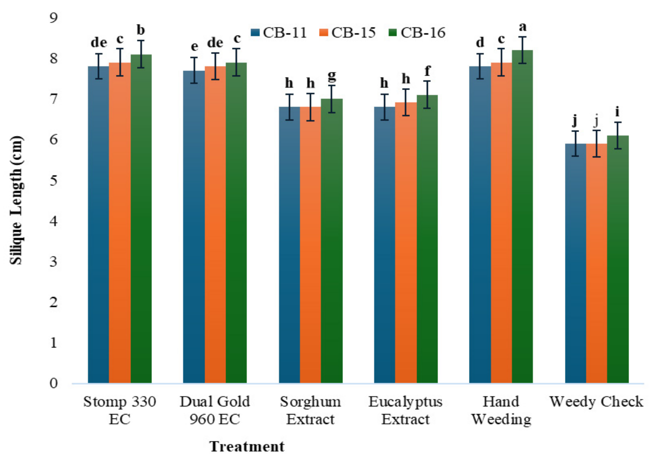

Figure 4: *Interaction of canola cultivars and treatments on siliqua length (cm)*

1000 seed weight (g)

Statistical analysis showed that weed management practices, canola cultivars, and their interaction significantly influenced 1000-seed weight (Table 6). Hand weeding resulted in the highest seed weight (4.2 g), followed by Stomp 330 EC and Dual Gold 960 EC (4.0 g); while, weedy check had the lowest (3.1 g). Among cultivars, CB-16 had the highest seed weight (3.9 g), and CB-11 the lowest (3.5 g). The interaction (Figure 5) revealed that hand weeding with CB-16 produced the highest seed weight (4.3 g), whereas the weedy check with CB-11 had the lowest (2.9 g). A similar study by Asghari *et al.* (2014) found that hand weeding significantly increases 1000-seed weight by reducing weed competition and enhancing nutrient availability. Aziz *et al.* (2013) reported that foliar application of plant extracts, such as seaweed, improves seed weight by enhancing nutrient uptake and stress tolerance. Selective herbicides also contribute to increased seed weight by effectively reducing weed pressure.

Table 6: *Impact of weed management practices on 1000 seed weight (g) of canola cultivars*

Treatments	Canola cultivars			Treatments means
	CB-11	CB-15	CB-16	
Stomp 330 EC	3.9 g	4.0 e	4.2 b	4.0 b
Dual gold 960 EC	3.8 h	4.0 f	4.1 c	4.0 b
Sorghum extract	3.2 m	3.4 k	3.7 i	3.4 d
Eucalyptus extract	3.3 l	3.5 j	3.8 g	3.5 c
Hand weeding	4.1 d	4.2 b	4.3 a	4.2 a
Weedy check	2.9 o	3.1 n	3.2 m	3.1 e
Cultivars means	3.5 c	3.7 b	3.9 a	

$LSD_{0.05}$ Cultivars = 9.836, $LSD_{0.05}$ Treatments = 6.93, $LSD_{0.05}$ Interaction = 0.0120

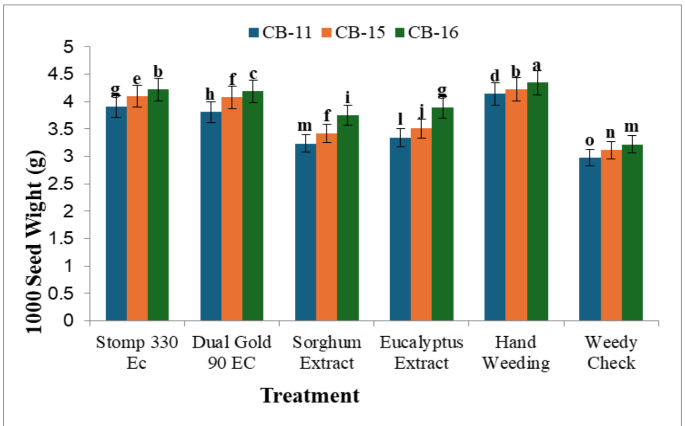

Figure 5: *Interaction effect of canola cultivars x treatments on 1000 seed weight*

Biological yield (kg ha^{-1})

Statistical analysis showed that weed control measures and canola varieties significantly affected biological yield, while their interaction was statistically insignificant (Table 7). Hand weeding produced the highest yield (5004 kg ha^{-1}), followed by Stomp 330 EC (4453 kg ha^{-1}), while the weedy check had the lowest (3440 kg ha^{-1}). Among cultivars, CB-16 had the highest yield (4426 kg ha^{-1}), while CB-15 had the lowest (4191 kg ha^{-1}). The interaction (Figure 6) showed that hand weeding with CB-15 yielded the highest (5200 kg ha^{-1}). The lower yield in weedy check plots was due to weed competition for nutrients, light, and space. Chauhan and Johnson (2010) found that hand weeding significantly increases biological yield by reducing weed interference. Amiri *et al.* (2019) reported that herbicides enhance yield by minimizing weed pressure, though excessive use may lead to resistance. Additionally, Mahajan *et al.* (2016) suggested that botanical extracts like neem may offer natural weed control, potentially increasing biological yield, though further research is needed.

Table 7: *Impact of weed management practices on biological yield (kg ha^{-1}) of canola cultivars*

Treatments	Canola cultivars			Treatments means
	CB-11	CB-15	CB-16	
Stomp 330 EC	4480 e	4240 hi	4640 d	4453 b
Dual gold 960 EC	4320 g	4160 j	4480 e	4320 c
Sorghum extract	4266 h	4240 hi	4400 f	4302 d
Eucalyptus extract	4160 j	4213 i	4320 g	4231 e
Hand weeding	4960 b	4853 c	5200 a	5004 a
Weedy check	3360 m	3440 l	3520 k	3440 f
Cultivars means	4257 b	4191 c	4426 a	

$LSD_{0.05}$ Cultivars = 26.657, $LSD_{0.05}$ Treatments = 29.272, $LSD_{0.05}$ Interaction = 29.272

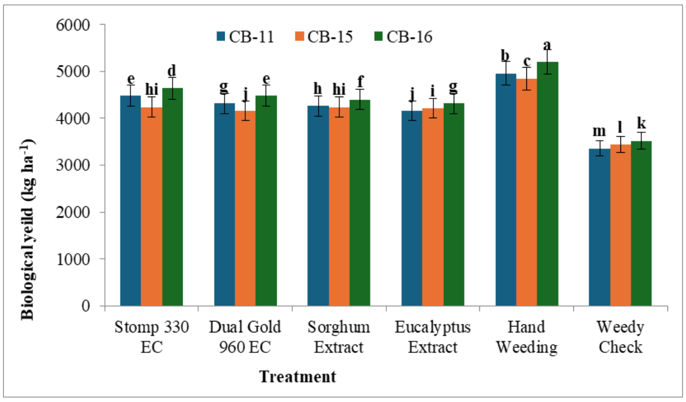

Figure 6: *Interaction of canola cultivars x treatments on biological yield of canola*

Seed yield (kg ha^{-1})

The data analysis indicated a significant impact of weed management practices, canola cultivars, and their interaction on seed yield (Table 8). Hand weeding produced the highest yield (1656 kg ha^{-1}), followed by Stomp 330 EC (1498 kg ha^{-1}), while the weedy check had the lowest (1288 kg ha^{-1}). Among cultivars, CB-16 had the highest yield (1509 kg ha^{-1}), while

CB-15 had the lowest (1382 kg ha^{-1}). The interaction (Figure 7) showed that hand weeding with CB-16 resulted in the highest yield (1760 kg ha^{-1}), whereas the weedy check with CB-15 had the lowest (1264 kg ha^{-1}). The superior yield in hand-weeded plots was due to reduced competition for nutrients, promoting optimal growth and seed development. Ghamari *et al.* (2015) found that hand weeding increased canola yield by 10–15%. Rashid *et al.* (2018) reported that proper herbicide application significantly boosts seed yield by controlling weeds. Additionally, Bajwa *et al.* (2017) suggested that certain plant extracts may act as bio-herbicides, indirectly influencing canola yield.

Table 8: *Impact of various weed control strategies on seed yield (kg ha^{-1}) of canola cultivars*

Treatments	Canola cultivars			Treatments means
	CB-11	CB-15	CB-16	
Stomp 330 EC	1490 c	1408 d	1597 b	1498 b
Dual gold 960 EC	1413 d	1336 e	1490 c	1413 c
Sorghum extract	1408 d	1341 e	1466 c	1405 c
Eucalyptus extract	1320 e	1341 e	1418 d	1360 d
Hand weeding	1605 b	1602 b	1760 a	1656 a
Weedy check	1280 f	1264 f	1322 e	1288 e
Cultivars means	1419 a	1382 c	1509 a	

$LSD_{0.05}$ Cultivars = 6.8334, $LSD_{0.05}$ Treatments = 21.714, $LSD_{0.05}$ Interaction = 37.609

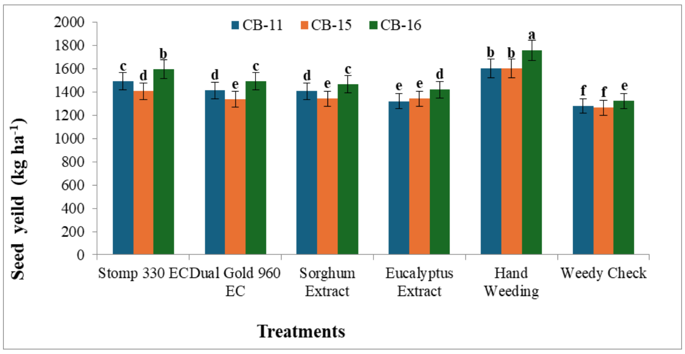

Figure 7: *Interaction effect of canola cultivars x treatments on seed yield*

Harvest index (HI)

The analysis revealed that canola cultivars, weed control treatments, and their interaction significantly influenced the harvest index (HI). The weedy check had the highest HI (37.4%), followed by Stomp 330 EC (33.6%), while Eucalyptus Extract plots had the lowest (32.1%). Among cultivars, CB-16 had the highest HI (34.2%). Interaction data (Figure 8) showed Stomp 330 EC with the highest HI (34.4%) and Eucalyptus Extract with CB-11 the lowest (31.7%). Effective weed management through herbicides, plant extracts, and hand weeding significantly impacted HI. Rizwan *et al.* (2015) reported that hand weeding reduced weed competition, improving HI, while Chauhan *et al.* (2010) found herbicides effective in lowering weed biomass and enhancing HI. Cheema *et al.* (2004) highlighted the allelopathic potential of plant extracts in weed suppression, though further research is needed. From a practical standpoint, hand weeding at 30 and 60 DAT, despite its higher labor demand, proved to be more cost-effective than chemical options due to increased yield and reduced herbicide costs (Zaman *et al.*, 2019).

Table 9: *Impact of weed control strategies on harvest index (HI) of canola cultivars*

Treatments	Canola cultivars			Treat-ments means
	CB-11	CB-15	CB-16	
Stomp 330 EC	33.2 de	33.2 de	34.4 c	33.6 b
Dual gold 960 EC	32.7 efg	32.1 gh	33.2 de	32.6 c
Sorghum extract	32.9 ef	31.6 h	33.3 de	32.6 c
Eucalyptus extract	31.7 h	31.8 h	32.8 efg	32.1 d
Hand weeding	32.3 fgh	33.0 ef	33.8 cd	33.0 c
Weedy check	38.0 a	36.7 b	37.5 a	37.4 a
Cultivars means	33.5 b	33.0 c	34.2 a	

$LSD_{0.05}$ Cultivars = 0.2327, $LSD_{0.05}$ Treatments = 0.4793, $LSD_{0.05}$ Interaction = 0.8302

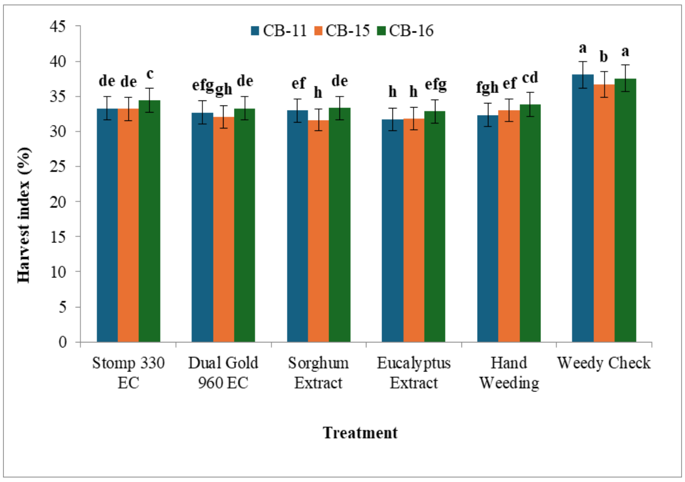

Figure 8: *Interaction of canola cultivars and treatments harvest index (HI)*

Conclusions and Recommendations

This study demonstrated that effective weed management and canola cultivars can significantly improve the canola yield and growth parameters. Among the tested strategies, hand-weeding, Stomp

330 EC, and Dual Gold 960 EC were the most effective individual treatments in reducing the weed populations, while sorghum extract also improved canola growth and yield to some extent. Hand-weeding and sorghum extract treatments led to a notable increase in biological and seed yield, with CB-16 Faisal performing as the best-yielding cultivar. Herbicide application and hand-weeding also resulted in the highest net returns for farmers. Therefore, for effective weed control and improved productivity, the individual use of Stomp 330 EC or Dual Gold 960 EC herbicides is recommended, along with manual weeding for optimal crop development. In areas with labor shortages, plant extracts can serve as an alternative, particularly for small-scale farmers. Additionally, CB-16 Faisal is recommended for cultivation due to its superior yield performance.

Acknowledgements

I am thankful to the ARI Tarnab for providing me the logistic support to conduct the experiment successfully.

Novelty Statement

This study uniquely evaluates the comparative efficacy of pre-emergence herbicides and allelopathic plant extracts (sorghum and eucalyptus) alongside manual weeding across multiple canola cultivars under the agro-climatic conditions of Peshawar, Pakistan. Unlike previous studies, it integrates both synthetic and biological weed control approaches in a single factorial design and identifies cultivar-specific responses. The results offer novel insights into sustainable, location-specific weed management practices that enhance canola yield while reducing chemical dependence.

Author's Contribution

Meher Ali: Conducted the research, curated and investigated the data, prepared visualizations, and wrote the original draft.
Ijaz Ahmad Khan: Conceptualized and supervised the research.
Zahid Hussain: Performed formal analysis and managed the software.
Muhammad Saddique: Developed the methodology, provided resources, and reviewed and edited the manuscript.
Rashid Anwar: Assisted in data collection, experimental setup, and contributed to the review and refinement of the manuscript.

Generative AI and AI-assisted technology statement
The authors declare that no generative artificial intelligence (AI) or AI-assisted technologies were used in this manuscript.

Conflict of interest
The authors have no conflict of interest.

References

AARI, 2020-2021. Ayub Agriculture Research Institute, https://aari.punjab.gov.pk/rapeseed oilseed. pp. 246-252.
Ali, K. and K. Jabran. 2016. Impact of different weed management practices on weed dynamics, growth, yield and quality of canola (*Brassica napus* L.). Pak. J. Weed Sci. Res., 22(2): 279-291.
Ali, K., S.K. Khalil, S.M. Raza, A.Z. Khan. 2011. "Effect of herbicides and hand weeding on the performance of canola." Afri. J. Biotechnol., 10(68): 15357-15363.
Amiri, H. and H. Torabi. 2019. Allelopathic effects of aqueous extracts of canola (*Brassica napus* L.) on seed germination and seedling growth of weeds. Agric. Sci. Tech., 21(1): 167-176.
Assefa, Y.P., V.Q. Prasad, V.V. Foster, C. Wright, Y. Young, S. Bradley, P. Stamm, M.A. Ciampitti. 2018. Major Management Factors Determining Spring and Winter Canola Yield in North America. Crop Sci., 7(58): 2875-2880. https://doi.org/10.2135/cropsci2017.02.0079
Asghari A., C.C. Baskin, J. Baskin, M.A. Zare Chahouki, S.M. Hojjati, F.N. Khajoei and H. Shirmardi. 2014. The effect of herbicides on germination and seedling growth of canola (*Brassica napus* L.). J. Plant Prot. Res., 54(2): 130-136.
Aziz, E., S.F. Hendawy, E.A. Omer and M.M. Rady. 2013. Response of canola plants to foliar application with bio stimulants under different irrigation regimes. *Inter. J. Agric. Bio.,* 15(5): 979-985.
Bajwa, A.A., A. Nawaz, H.H. Ali, T.A. Chattha, B.S. Chauhan and S.W. Adkins. 2017. Potential Use of Allelopathy for Weed Management in Cropping Systems. *Crop Prot.,* 95: 21-33.

https://doi.org/10.1016/j.cropro.2016.08.021

Beckie, H.J. and L.M. Hall. 2014. Weed management in canola. "Weed Techn." pp 287-295.

Blackshaw, R.E., L.J. Molnar and H.H. Janzen. 2001. Nitrogen fertilizer timing and application method affect weed growth and competition with spring wheat. Weed Sci., 49(5): 594-598.

Blackshaw, R.E., G. Semach and H.H. Janzen. 2002. The fertilizer application method affects nitrogen uptake in weeds and wheat. Weed Sci., 50(3): 634-641. https://doi.org/10.1614/0043-1745(2002)050[0634:FAMANU]2.0.CO;2

Blackshaw, R.E. and K.N. Harker. 2002. Effect of herbicides on weed control and canola (*Brassica napus L.*) yield. Weed Tech., 16(3): 512-518

Chaudhry, S., U. Hussain, M.J. Iqbal. 2011. Effect of different herbicides on weed control and yield of canola (*Brassica napus* L.). J. Agric. Res., 49(4): 483-490.

Cheema, Z.A. and A. Khaliq. 2000. Use of sorghum allelopathic properties to control weeds in irrigated wheat in a semi-arid region of Punjab. *Agric. Eco. Enviro*., 79(2-3): 105-112. https://doi.org/10.1016/S0167-8809(99)00140-1

Cheema, Z.A., A. Khaliq and S. Saeed. 2004. Weed control in maize (*Zea mays L.*) through sorghum allelopathy. J. Sustain. Agri., 23(4): 73-86. http://dx.doi.org/10.1300/J064v23n04_07

Cheema, Z.A., A. Khaliq and H.S. Saeed. 2004. Weed control in canola (*Brassica napus* L.) with allelopathic sorghum and sunflower water extracts. Inter. J. Agric. Bio. 6(4): 652-656.

Chauhan, B.S. and D.E. Johnson. 2010. The role of seed ecology in improving weed management strategies in the tropics. *Advan. Agro.*, 105: 221-262. https://doi.org/10.1016/S0065-2113(10)05006-6

Chauhan, B.S., G. Mahajan, V. Sardana, J. Timsina and M.L. Jat. 2012. Productivity and sustainability of the rice-wheat cropping system in the Indo-Gangetic plains of the Indian subcontinent: Problems, opportunities and strategies. Advan. Agro., 117: 315-369. https://doi.org/10.1016/B978-0-12-394278-4.00006-4

Chauhan, B.S., G. Gill and C. Preston. 2012. Influence of environmental factors on seed germination and seedling emergence of three horn bedstraw (*Galium tricornutum*). Weed Sci., 60(1): 37-43.

Farooq, M., K. Jabran, Z.A. Cheema, A. Wahid and K.H.M. Siddique. 2011. The role of allelopathy in agricultural pest management. *Pest Manage. Sci. 67*(5): 493-506. https://doi.org/10.1002/ps.2091

Ghamari, H., M. Oveisi and E. Zand. 2015. The Effect of Different Weed Control Methods on Grain Yield and Yield Components of Canola (*Brassica napus* L.). J. Plant Prot. Res., 55(1): 78-85.

Grey, T., P. Raymer and D. Bridges. 2006. Herbicide-Resistant Canola (*Brassica napus* L.) Response and Weed Control with Postemergence Herbicides. Weed Tech., 20: 551-557. https://doi.org/10.1614/WT-05-061R.1

Gulzar, A. and M. Inam-ul-Haq. 2012. Impact of weeds on canola (*Brassica napus* L.) yield and quality. Aust. J. Crop Sci., 49(7): 348-354.

Gulzar, S., A.N. Shah, M.O. Ullah and J.U. Din. 2018. Effect of different weed control methods on the growth and yield of canola (*Brassica napus* L.). J. Agric. Res., 56(4): 437-446.

Harker, K.N., J.T.O. Donovan and H.J. Beckie. 2012. Herbicide-tolerant canola: weed control and yield comparisons. Weed Tech., 26(3): 359-364.

Harker, K.N. and J.T.O. Donovan. 2013. Recent weed control, weed management and integrated weed management. Weed Tech., 27(8): 1–110. https://doi.org/10.1614/WT-D-12-00109.1

Heap, I., 2019. International survey of herbicide-resistant weeds. http://www. weedscience.org.

Hussain, M., M.A. Khan, S. Ali, and U. Ashraf. 2023. Canola production in Pakistan: Challenges and opportunities. J. of Agri. Sci. Tech., 20(3): 537-554.

Jabran, K., Z.A. Cheema, M. Farooq and M. Hussain. 2010. Lower doses of pendimethalin mixed with allelopathic crop water extracts for weed management in canola (*Brassica napus* L.). Int. J. Agric. Biol., 12(3): 335-340.

Jabran, K., G. Mahajan, V. Sardana and B.S. Chauhan. 2015. Allelopathy for weed control in agricultural systems. Crop Protect., 72: 57-65. https://doi.org/10.1016/j.cropro.2015.03.004

Khanh, T.D., I.M. Chung, T.D. Xuan and S. Tawata. 2005. The exploitation of crop allelopathy in sustainable agricultural production. J. Agro. Crop Sci., 191(3): 172-184. https://doi.org/10.1111/j.1439-037X.2005.00172.x

Kumar, S., and R. Singh. 2010. Effect of hand weeding on weed control in canola (*Brassica napus* L.). *India. J. Weed Sci., 42*(1, 2): 112-115.

Mahajan, G. and B.S. Chauhan. 2016. Ecological management of weeds in canola (*Brassica napus* L.) using crop competition, allelopathy and herbicides. Crop Prot., 88: 7-13.

Marwat, K.B., B. Gul, M. Saeed, Z. Hussain and N.I. Khan. 2005. Efficacy of different pre and post-emergence herbicides for weed management in canola in higher altitudes. Pak. J. Weed Sci. Res., 11(3- 4): 165-170.

MINFAL. 2022. Ministry of Food, Agriculture and Research Government of Pakistan.

Rashid, M.H.A., U. Ashraf, I. Hussain, A. Wahid and Z. Ahmad. 2018. Effect of Herbicides on Yield and Yield Components of Canola (*Brassica napus* L.). *J. Agric, Sci. Technol.,* 20: 901-910.

Reddy, S.R. 2014. Rapeseed and mustard. In: Agronomy of field crops. Kalyani publishers. India. pp. 245-264.

Rizwan, M., S. Ali, T. Abbas, M. Zia-ur-Rehman, F. Hannan, C. Keller and M.I. Al-Wabel. 2015. Cadmium minimization in wheat: a critical review. Ecotoxicol. Environ. Safe., 112: 1-15.

Saeed, U., M.B. Khan and I.A. Khan. 2017. Comparative efficacy of various weed management strategies in canola (*Brassica napus* L.). Sarhad J. Agric., 33(2): 207-214.

Salisbury, P.A., T.D. Potter, A.M. Gurum, R.J. Mailer and W.M. Williams. 2018. Potential impact of weedy Brassicaceae on oil and meal quality of oilseed rape (*canola*) in Australia. Weed Res., 58(3): 122-196. https://doi.org/10.1111/wre.12296

Shah, W.A., M.A. Khan, N. Khan, M.A. Zarkoon and J. Bakht. 2003. Effect of weed management at various growth stages on the yield and yield components of wheat (*Triticum aestivum* L.). Pak. J. Weed Sci. Res., 9(1-2): 41-48.

Smith, J.A., K.E. Brown and T.L. Davis. 2020. Herbicide resistance in Brassica napus: Mechanisms, management and future prospects. Weed Sci., 68(4): 351–360. https://doi.org/10.1017/wsc.2020.42

Steel, R.G.D., J.H. Torrie and D. Dickey. 1997. Principles and procedures of statistics: a biometrical approach. 3rd Ed. McGraw Hill Inc. New York. pp. 400-428.

Xu, L., J. Chen, Z. Li and X. Wang. 2021. Biological weed control using beneficial soil microbes: A sustainable alternative. Appl. Soil Ecol., 158: 103779. https://doi.org/10.1016/j.apsoil.2020.103779

Zaman, G., M.A. Khan, R. Ahmad and S.A. Shah. 2019. Comparative efficiency of hand weeding and herbicides on weed control and yield of canola (*Brassica napus* L.). Pak. J. Weed Sci. Res., 25(2):157–166.