Boosting the effectiveness of nicosulfuron-atrazine-propisochlor with adjuvants for weed management in maize

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Abstract

Adjuvants are critical in enhancing herbicide efficacy, resulting in reduced herbicide application cost, less environmental pollution, and more sustainable weed management. To check the role of adjuvants (alkyl ether sulphate sodium salt, rapsoel methyl ester, fatty alcohol ethoxylate, and ammonium sulphate) in improving the efficacy of nicosulfuron-atrazine-propisochlor (NAP), a repeated warehouse experiment was conducted to optimize the NAP at 100% and 75% of the recommended label dose and adjuvants combinations against five different types of weeds and maize plants. NAP at a reduced dose (75% label dose) plus rapsoel methylester at 400 ml ha^{-1} provided 100% and 97% control of *Trianthema portulacastrum* and *Dactyloctenium aegyptium*. While NAP at reduced dose plus alkyl ether sulphate sodium salt 400 ml ha^{-1} provided 91%, 86%, and 87% control of *Amaranthus viridis*, *Echinochloa colona* and *Cyperus rotundus*, respectively. The addition of adjuvants did not cause any phytotoxic effect on maize growth and grain yield. All tested adjuvants enhanced the NAP efficacy, however, change in efficacy depended on the adjuvant added and the type of weed species. Hence, tested adjuvants can be used to reduce herbicide doses up to 25%, representing a promising strategy to reduce herbicide input to cope with increasing herbicide-resistance development and environmental pollution to ensure sustainable weed control in maize.

Abbreviations

AHAS: acetohydroxyacid synthase
ALS: acetolactate synthase
EO: ethyl oxide
HSD: honestly significant difference
NAP: nicosulfuron-atrazine-propisochlor
WCE: weed control efficiency

Introduction

Maize (*Zea mays* L.) is a staple food, exerting cultural, economic, environmental, and nutritional influences worldwide. Beyond its role as a major crop for global food security, maize has demand for use in animal feed and ethanol production for biofuel (Tanumihardjo *et al.*, 2020). Global maize production is continuously increasing due to increasing demand and supported by technological advances, enhanced yields, and expanded cultivation areas. Maize currently holds the top position among cereals in terms of production volume and the most widely cultivated and traded crop in the next decade (Erenstein *et al.*, 2022).

Weeds cause severe yield losses in maize, vary depending on weed infestation duration, density and type of weeds, uncontrolled weed can cause up to 100% yield (Abbas *et al.*, 2017a; Chauhan, 2020). Weeds are more aggressive and versatile than crop plants and hence are found in large numbers in diverse environmental conditions (Abbas *et al.*, 2025). Their large adaptability enables them to grow in multiple flushes and survive under extreme of climate, ecological and biotic stresses (Abbas *et al.*, 2025). Hence, the use of post-emergence herbicides has increased (Radheshyam *et al.*, 2021). Instead of various non-chemical weed control strategies introduced in recent years, the chemical weed control is still the most commonly used control option (Abbas *et al.*, 2024; Abbas *et al.*, 2025), that is facing various challenges associated with resistance development in weeds and environmental pollution hazards (Abbas *et al.*, 2017b; Matloob *et al.*, 2020). Indiscriminate use of herbicides causing problems such as water and environment pollution, herbicide resistance development in weeds, herbicide hormesis, higher cost for weed control and observed residual/toxic effects of herbicide on soil fertility and productivity (Abbas at al., 2017b; Nadeem *et al.*, 2017b). Use of herbicide at reduced dose can be done under specific situations as it will increase net income for farmers, reduce potential phytotoxic effects and damage to current and succeeding susceptible crops, and minimize risk to degrade the environment (Duke, 2020). One of the most important strategies to cope with these challenges is the facilitation of reduced herbicide input (Bunchek *et al.*, 2020; (Abbas *et al.*, 2025).

The incorporation of adjuvants with herbicides as tank mixtures is a potential method to reduce herbicide input, thereby reducing herbicide selection pressure without compromising weed control efficacy. This strategy is effective against herbicide-resistant weeds, serving both to enhance their control and to reduce resistance development (Palma-Bautista *et al.*, 2020). Adjuvants enhanced herbicide efficacy by increasing plant surface wettability and herbicide absorption on the plant surface and then into their cells (Akhter *et al.*, 2017). Adjuvants help: i) to increase the foliar activity of herbicide and decrease the surface tension of the droplets, due to which herbicide retention on leaves increase (Pacanoski *et al.*, 2015), ii) to improve the plant surface retention and for penetration of the plant cuticles (Mirgorodskaya *et al.*, 2020), to reduce the herbicide dose by 10-25% in maize fields (Nadeem *et al.*, 2016). Different pre-emergence and post-emergence herbicides have been widely used for control of weeds in maize (Nadeem *et al.*, 2016; Radheshyam *et al.*, 2021). Herbicide mixtures are gaining importance due to their role in widening the weed control spectrum, enhancing efficacy, and reducing herbicide selection pressure to manage herbicide resistance (Barbieri *et al.*, 2023). Considering the role of herbicides mixtures in maize weed control, a pre-mixed herbicide nicosulfuron-atrazine-propisochlor has been recently introduced. Nicosulfuron is rapidly absorbed through the plant leaves and then translocated by the both xylem and phloem. It inhibits the normal functioning of an enzyme called acetolactate synthase (ALS), also called acetohydroxyacid synthase (AHAS), having a key role in the biosynthesis of the branched-chain amino acids isoleucine, leucine, and valine and it is effective against major annual broadleaf weeds with minimum effect on grasses (Bagale *et al.*, 2023). Atrazine is a member of the triazine group, which is highly effective against broadleaf weeds (Sardrood and Goltapeh, 2018). Propisochlor belongs to the chloroacetanilide group, which is a selective herbicide absorbed by shoots in germinating plants, it inhibits protein synthesis and cell division. It is very effective to control annual grasses and broadleaf weeds in maize (Xie *et al.*, 2018).

Trianthema portulacastrum, *Amaranthus viridis*, *Dactyloctenium aegyptium*, *Echinochloa colona* and *Cyprus rotundus* are major maize weeds (Rashid *et al.*, 2020). Managing these weeds has become complicated and challenging due to the development of herbicide resistance and its associated environmental pollution concerns. Therefore, a repeated wirehouse study was conducted to evaluate the comparative performance of adjuvants to reduce herbicide and find out the best adjuvant for novel herbicide mixture (nicosulfuron-atrazine-propisochlor) to control broad leaved (*T. portulacastrum* and *A.viridis*), narrow leaved (*D. aegyptium* and *E. colona*) and sedge (*C. rotundus*) in maize.

Materials and methods

Experimental materials and cultivation conditions

The experiments were conducted in the glasshouse of the College of Agriculture, University of Sargodha, located at 32.13 °N, 72.68 °E and 193 m altitude in 2022, and 2023 seasons. Weed seeds were collected from maize field a year before sowing (respectively, 2021 and 2022) and kept at room temperature. Seeds of broad leaved, narrow leaved, sedge, and maize commercial hybrid DK-919 were sown in glasshouse potting soil in 46 × 39 cm trays. Fifteen seeds of each weed type and maize were planted in the potting soil, seeded pots were placed in a glasshouse and watered with tap water. After the germination, weed and maize plants were thinned to 12 plants per tray to take a uniform stand. Water was applied as needed till the maturity. The glasshouse temperature was maintained between 25-30°C. Plants were monitored regularly to assess growth and any signs of abiotic stress. The experiment continued until both the maize and weed plants reached maturity.

Herbicide treatments

Treatments were applied when maize plants were at the 3 to 4-leaf growth stage and weeds were at the 3-5 leaf growth stage. Herbicide mixture of nicosulfuron-atra-

Table 1 - Effect of herbicide alone and in combination with different adjuvants on weed density and WCE of different weeds (pooled data from repeated experiments).

	Weed density (WCE)				
Treatments	***Trianthema partula casturm***	***Amaranthus viridis***	***Dactyloctenium aegyptium***	***Echinochloa colona***	***Cyperus rotundus***
T_0	12 a	12a	12 a	12 a	12 a
T_1	0.00 e (100%)	0.00 h (100%)	0.32 f (97%)	0.00 g (100)	1.2 f (90%)
T_2	4 b (67%)	4.12 b (66%)	3.50 b (71%)	4.7 b (61%)	4.5 b (63%)
T_3	0.14 e (99%)	1.12 g (91%)	0.53 f (96%)	1.67 f (86%)	1.52 f (87%)
T_4	0.00 e (100%)	1.8 f (85%)	0.41 f (97%)	2.21 e (82%)e	1.92 e (84%)
T_5	0.66 d (95%)	2.09 f (83%)	1.7 d (86%)	2.29 e (81%)	2.04 e (83%)
T_6	1.00 c (92%)	3.7 c (69%)	2.4 c (80%)	3.94 c (67%)	3.1 c (74%)
T_7	0.33 de (97%)	3.2 d (73%)	2.55 c (79%)	3.72 c (69%)c	2.56 d (79%)
T_8	0.00 e (100%)	3.4 cd (72%)	1.67 d (86%)	3.94 b (67%)cd	2.23 de (81%)
T_9	0.00 e (100%)	2.5 e (79%)	1.17 e (90%)	3.21 d (73%)	1.99 e (84%)

T_0: Weedy check, T_1: Nicosulfuron-atrazine-propisochlor @740g a.i. ha^{-1} (NAP at 100%), T2 : Nicosulfuron-atrazine-propisochlor @555g a.i. ha^{-1} (NAP at 75%), T_3: NAP at 75% + alkyl ether sulphate sodium salt @ 400 ml ha^{-1}, T_4 : NAP at 75% + rapsoel methyl ester 400 ml ha^{-1}, T_5: NAP at 75% + fatty alcohol ethoxylate @ 200 ml ha^{-1}, T_6: NAP at 75% + ammonium sulphate (2%), T_7: NAP at 75% + ammonium sulphate (3%), T_8: NAP at 75% + ammonium sulphate (4%), T_9: NAP at 75% + ammonium sulphate (5%). In a column, means sharing different letters statistically vary from one another based on Tukey's HSD test ($p < 0.05$).

zine-propisochlor (NAP) containing nicosulfuron 2%, atrazine 20% and propisochlor 15% as oil dispersion was used. Adjuvants were mixed with herbicide before application. All herbicide treatments including T_0: Weedy check, T_1: NAP @740g a.i. ha^{-1} (NAP at 100%), T_2: NAP @ 555g a.i. (active ingredient) ha^{-1} (NAP at 75%), T_3: NAP at 75% + alkyl ether sulphate sodium salt @ 400 ml ha^{-1}, T_4: NAP at 75% + rapsoel methyl ester 400 ml ha^{-1}, T_5: NAP at 75% + fatty alcohol ethoxylate @ 200 ml ha^{-1}, T_6: NAP at 75% + ammonium sulphate (2%), T_7: NAP at 75% + ammonium sulphate (3%), T_8: NAP at 75% + ammonium sulphate (4%) and T_9: NAP at 75% + ammonium sulphate (5%) were applied as post emergence application. The treatments were sprayed using a CO_2 pressurized back pack sprayer attached with TeeJet 8003VS nozzle at 30 psi pressure set apart 50 cm above plant high that sprayed about 187 L ha^{-1}. All the treatments were replicated four times and arranged in completely randomized design with factorial arrangements of herbicides and adjuvant combinations.

Traits recorded and data collection

Weed Density, the weed count was recorded 14 days after spray from every tray and mean values were expressed as plants per tray. For weed and maize dry matter estimation, weeds from each tray were collected, shade-dried and then dried in oven at 80 oC for 72 hours.

Weed control efficiency (WCE) was calculated as per the formula given below

$$\text{Weed control efficiency (\%)} = \frac{\text{(Weed density in controlled pot- Weed density in treated pot)}}{\text{(Weed density in controlled pot)} \times 100}$$

Crop damage was visually estimated 14 days after spray on a scale of 0 (no damage) to 20 (complete desiccation) (Pratt *et al.*, 2003). Maize dry weight, 1000-grain weight and grain yield was calculated using digital electric weighing balance.

Statistical analysis

The experiment was conducted twice using a completely randomized design with four replications. Data from repeated experiments were pooled due to the lack of significant differences among the repetitions. Analysis of variance (ANOVA) was run on the data (Steel *et al.*, 1997). using the computer package Statistix 8.1 (Analytical software, Statistix; Tallahassee, FL, USA, 1985-2003) to test the effect of NAP with adjuvants on weeds and maize plants. Significant main effects are reported in tables. HSD Tukey's test was applied at 5% probability level to test the significance of treatment means.

Results and Discussion

Weed density and WCE (%)

Weed density and WCE varied significantly among the treatments, as shown in Table 1. Adjuvants significantly increased the herbicide efficacy as compared to herbicide application without adjuvants. Among the herbicide treatments, maximum control of *T. portulacastrum* (100%) and *D. aegyptium* (97%) was obtained by NAP @ 555 g a.i. ha^{-1} with addition of rapsoel methyl ester 400 ml ha^{-1}, it was followed by the NAP @ 555g a.i. ha^{-1} + alkyl ether sulphate sodium salt @ 400 ml ha^{-1}. For *A. viridis*, *E. colona*, and *C. rotundus* maximum control (91%, 86%, and 87%, respectively) was obtained with the application of NAP @ 555 g a.i. ha^{-1} + alkyl ether sulphate sodium salt ha1@ 400 ml ha^{-1} and followed by NAP @ 555 g a.i. ha^{-1} with addition of rapsoel methyl

Table 2 - Effect of herbicide alone and in combination with different adjuvants on weed dry weight (g pot-1) of different weeds (pooled data from repeated experiments

	Weed dry weight (% weight reduction)				
Treatments	***Trianthema partulacasturm***	***Amaranthus viridis***	***Dactyloctenium aegyptium***	***Echinochloa colona***	***Cyperus rotundus***
T_0	60 a (0%)	74 a (0%)	52 a (0%)	61 a (0%)	45 a (0%)
T_1	0 e (100%)	0 e (100%)	2.17 e (96%)	0 d (100%)	2.45 e (82%)
T_2	36 b (40%)	33 b (55.40%)	37 b (28.8%)	42 b (31.1%)	28 bc (37.7%)
T_3	18 d (70%)	17 d (77.0%)	27 cd (48.0%)	26 c (57.3%)	19 cd (57.7%)
T_4	0 e (100%)	16 d (78.3%)	26 d (50%)	28 c (54.0%)	17 d (62.2%)
T_5	21 d (65%)	19 d (74.3%)	25 d (51.9%)	24 c (60.6%)	20 cd (55.5%)
T_6	26 c (56.6%)	34 b (54.0%)	32 bcd (38.4%)	31 c (49.1%)	30 b (33.3%)
T_7	27 c (55%)	31 bc (58.1%)	35 bc (32.6%)	33 bc (45.9%)	25 bcd (44.4%)
T_8	0 e (100%)	28 c (62.1%)	30 bcd (42.3%)	27 c (55.7%)	27 bc (40%)
T_9	0 e (100%)	30 bc (59.4%)	29 bcd (44.2%)	29 c (52.4%)	26 bcd (42.2%)

T_0: Weedy check, T_1: Nicosulfuron-atrazine-propisochlor @740g a.i. ha^{-1} (NAP at 100%), T_2 : Nicosulfuron-atrazine-propisochlor @555g a.i. ha^{-1} (NAP at 75%), T_3: NAP at 75% + alkyl ether sulphate sodium salt @ 400 ml ha^{-1}, T4 : NAP at 75% + rapsoel methyl ester 400 ml ha^{-1}, T5: NAP at 75% + fatty alcohol ethoxylate @ 200 ml ha^{-1}, T6: NAP at 75% + ammonium sulphate (2%), T7: NAP at 75% + ammonium sulphate (3%), T8: NAP at 75% + ammonium sulphate (4%), T9: NAP at 75% + ammonium sulphate (5%). In a column, means sharing different letters statistically vary from one another based on Tukey's HSD test ($p < 0.05$).

ester 400 ml ha^{-1}. The application of NAP @ 555g a.i. ha^{-1} without adjuvant achieved 61-71% weed control efficacy against *T. portulacastrum*, *A. viridis*, *D. aegyptium*, *E. colona* and *C. rotundus*. The addition of adjuvants helped enhance herbicide efficacy to 69-100%.

Weed dry weight

The application of NAP with adjuvants caused significant reduction in weed dry weight, with varied reductions depending on the adjuvant used (Table 2). The application of NAP @ 555g a.i. ha^{-1} (NAP at 75%) with adjuvants resulted in greater reduction in dry weight of *T. portulacastrum* (55-100%), *A. viridis* (54-78%), *D. aegyptium* (32-52%), *E. colona* (33-52%) and *C. rotundus* (33-62%) compared to treatments without adjuvants (29-55%). For *T. portulacastrum* application of NAP @ 555g a.i. ha^{-1} with rapsoel methyl ester 400 ml ha^{-1} caused 100% reduction in dry weight which was statistical at par with recommended dose of herbicide without adjuvant. For other weed species including *A. viridis*, *D. aegyptium* and *C. rotundus* same herbicide adjuvant combination yielded better results. However, for *E. colona* the application of NAP @ 555g a.i. ha^{-1} plus alkyl ether sulphate sodium salt @ 400 ml ha^{-1} caused more reduction in weed dry weight as compared to other adjuvants. Overall results revealed that, addition of rapsoel methyl ester and alkyl ether sulphate sodium salt @ 400 ml ha^{-1} as adjuvant found more effective in reducing weed dry weight as compared to fatty alcohol ethoxylate @ 200 ml ha^{-1} and ammonium sulphate at 2, 3, 4 and 5%.

Maize damage, growth and yield

Results regarding maize crop damage revealed that addition of adjuvants including alkyl ether sulphate sodium salt, rapsoel methylester, fatty alcohol ethoxylate and ammonium sulphate with NAP caused non-significant effect on maize damage. Similarly, results about maize dry weight revealed no significant effect of NAP alone or in combination with adjuvant on maize dry weight (Table 3). Cob length, seeds per cob and maize grain weight per plant were also significantly affected by different herbicide adjuvant application. The untreated maize plants in control treatment achieved increased values of the following traits: cob length (18.21 cm), seeds per cob (435.43) and grain yield (83.2 g $plant^{-1}$). The minimum cob length (17.49 cm), seeds per cob (413.32) and grain yield (74.3 $plant^{-1}$) were achieved in pots treated with NAP at 75% + ammonium sulphate (5%). The application of herbicide with different adjuvants (alkyl ether sulphate sodium salt, rapsoel methyl ester, fatty alcohol ethoxylate and ammonium sulphate) caused no detrimental impact on cob length, seeds per cob, and grain yield of maize, except for NAP at 75% concentration combined with 4% ammonium sulfate, which led to a reduction in cob length.

It is clear from the above mentioned results that there is a significant increase in weed control potential of NAP with adjuvants in autumn maize, proving better weed control efficacy in comparison to no adjuvant. Herbicide plus adjuvants mixtures did negatively influence the maize growth and yield, except NAP at 75% + ammonium sulphate (5%) application (Table 3). Different adjuvants showed different potential to enhance herbicide efficacy. Different studies support the ideology of herbicide implication along with adjuvants, which increased the weed control percentage as well as lessen the laborious and challenging target to controlling

Table 3 - Effect of herbicide alone and in combination with different adjuvants on crop damage and dry weight of maize (pooled data from repeated experiments).

Treatments	Crop damage	Dry weight (g plant^{-1})	Cob length (cm)	Seeds cob^{-1}	Grain weight (g plant^{-1})
T_0	0 b	7.24 ^{NS}	18.21 a	435.4 a	83.2 a
T_1	4 a	6.68	18.13	422.5 bcd	79.2 ab
T_2	4 a	7.20	18.20 a	424.5 bcd	80.3 ab
T_3	4 a	6.91	18.14 a	422.3 cd	79.2 ab
T_4	5 a	6.84	18.16 a	420.3 cd	80.1 ab
T_5	4 a	6.92	18.17 a	429.4 ab	79.0 ab
T_6	5 a	6.61	18.14 a	426.5 bc	80.7 ab
T_7	5 a	7.92	18.09 ab	424.2 bcd	81.4 a
T_8	5 a	6.27	17.94 b	419.2 de	77.0 ab
T_9	6 a	6.56	17.49 c	413.3 e	74.3 b

T_0: Weedy check, T_1: Nicosulfuron-atrazine-propisochlor @740g a.i. ha^{-1} (NAP at 100%), T_2 : Nicosulfuron-atrazine-propisochlor @555g a.i. ha^{-1} (NAP at 75%), T_3: NAP at 75% + alkyl ether sulphate sodium salt @ 400 ml ha^{-1}, T_4 : NAP at 75% + rapsoel methyl ester 400 ml ha^{-1}, T_5: NAP at 75% + fatty alcohol ethoxylate @ 200 ml ha^{-1}, T_6: NAP at 75% + ammonium sulphate (2%), T_7: NAP at 75% + ammonium sulphate (3%), T_8: NAP at 75% + ammonium sulphate (4%), T_9: NAP at 75% + ammonium sulphate (5%). In a column, means sharing different letters statistically vary from one another on the basis of Tukey's HSD test ($p < 0.05$).

weeds manually (Nadeem *et al.*, 2016; Ferreira *et al.*, 2020). However, it is a fact that adjuvants combination performs differently when mixed with herbicides so it is a basic need to make selection of a right adjuvant for a perfect combination to gain the positive results when mixed with the herbicide (Idziak *et al.*, 2023; Ferreira *et al.*, 2020).

Surfactants with high ethyl oxide (EO) concentration can enhance cuticle hydration at a given relative humidity level. The enhanced hydration state of the cuticle caused by high EO surfactants increases the diffusion of water-soluble herbicides over the cuticle (Zeisler-Diehl *et al.*, 2022). Thus, surfactants with high EO concentration increase the absorption of hydrophilic herbicides the greatest, whereas surfactants with low EO content aid the absorption of lipophilic herbicides. Surfactant molecules are primarily composed of a lipophilic (hydrophobic) long chain hydrocarbon (alkyl) group and a hydrophilic (lipophobic) polar group. Adjuvants have both lipophilic (oil-loving) and hydrophilic (water-loving) qualities, allowing them to interact with both lipophilic plant surfaces and herbicides, as well as hydrophilic herbs and water (Javaid *et al.*, 2012; Nadeem *et al.*, 2016; Tanveer *et al.*, 2018). Previously, alkyl ether sulphate sodium salt has been successfully used to enhance efficacy of various herbicides against different weed species (Javaid *et al.*, 2012; Tanveer *et al.*, 2018). Furthermore, the addition of rapeseed methyl ester and fatty alcohol ethoxylate as adjuvants increased the efficacy of post-emergence herbicides (sulfosulfuron and mesosulfuron methyl) against wheat weeds (Abbas *et al.*, 2018).

Ammonium sulfate, employed as an adjuvant, has also proved to be effective in overcoming diminished herbicidal action due to opposition with another ingredient in the spray formulation (Travlos *et al.*, 2017). The addition of ammonium sulfate to the herbicide solution neutralized the resistance. In a spray formulation containing calcium and sodium ions, adding ammonium sulfate reduces their influence on herbicide absorption. For example, glyphosate's efficiency can be diminished when mixed with water with a high concentration of calcium ions (Chahal *et al.*, 2012). Calcium ions bond to glyphosate and render the pesticide molecule useless. When ammonium sulfate is introduced to the mixture, the calcium ion bonds to the sulfate ions in it and forms a salt (calcium sulfate), rather than attaching to the herbicide resulting an increased efficacy of glyphosate herbicide (Devkota and Johnson, 2019; Duke, 2020). All mixtures were not the same for every weed, so the selection is always done based on supportive research or experimentation that which herbicide and adjuvant combination suits the most among different conditions, targeting the right sites with increased penetrative ability and active nature resulting increased efficacy for optimum control (Abbas *et al.*, 2018; Duke, 2020).

The findings provide evidence favoring the modern concept of adjuvants usage along with their positive impacts when combined with herbicides in a calculated dosage, increasing herbicide efficacy against different summer weeds. The potential of adjuvants to increase efficacy or reduce herbicide input without compromising weed control efficiency can be potentially used to cope with the increasing challenge of herbicide resistance development. As reduced herbicide input decreases the herbicide selection pressure, which is a desirable factor to avoid the development of resistance development in weeds (Palma-Bautista *et al.*, 2020).

Further, it will also help to reduce the use of chemical pesticides as human health, ecosystem biodiversity, and agriculture sustainability are badly affected by such synthetic chemicals (Abbas *et al.*, 2025). Under challenges possessed by climate change and the increasing issue of herbicide resistance, modern strategies are crucial to ensure the precise use of herbicides with better weed control efficacy (Abbas *et al.*, 2025). More research regarding the study of perfect combinations for adjuvants and herbicides against different weeds in various crops to cope with increasing weed infestation and food security issues. Developing an effective weed control method that sustains agricultural productivity and conserves resources, with a forward-thinking approach capable of revolutionizing the world economically and socially, is the need of the hour.

Conclusions

In conclusion, adjuvants including (alkyl ether sulphate sodium salt, rapsoel methylester, fatty alcohol ethoxylate and ammonium sulphate) can increase the efficacy of NAP to control broad leaved (*T. portulacastrum* and *A.viridis*) narrow leaved (*D. aegyptium* and *E. colona*) and sedge (*C. rotundus*) in maize. Each adjuvant exhibited varying responses depending on the weed species and the type of herbicide used at 75% of its recommended dose. When paired with an adjuvant, the herbicide provided weed control comparable to that achieved with the recommended dose. Addition of adjuvants did not cause detrimental impact on maize growth and yield.

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Author Contributions

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by TA and NF. The first draft of the manuscript was written by TA. Review and editing was done by AM, BAK, NF, MAN, SIA, JG and TA. NF contributed as senior author. All authors read, helped to shape research and manuscript, and approved the final manuscript.

Conflict of interest

Authors state no conflict of interest

Data Availability Statement

The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request

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