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Short title: Tolpyralate and bromoxynil premix

Weed control and crop safety with premixed tolpyralate and bromoxynil in cereals

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Abstract

Recently a premix of tolpyralate and bromoxynil was registered in the USA and Canada by Corteva Agriscience for weed control in cereals. Limited information exists on weed control efficacy and crop safety with this new herbicide pre-mixture. Greenhouse trials were conducted for two years to test the efficacy of tolpyralate and bromoxynil combinations on 14 broadleaf and 4 grass weeds and crop safety in wheat and barley. Four combinations of tolpyralate and bromoxynil at 1:10 ratio (3.75 + 37.5, 7.5+ 75, 11.25 + 112.5, and 15 + 150 g ai ha^{-1}) as a tank-mix and premix were tested. Stand-alone treatments of tolpyralate and bromoxynil were also included in this study. The lowest tested rate of tolpyralate (3.75 g ha^{-1}) provided 10 to 98% and 27 to 77% control of broadleaf and grass weeds, respectively. Bromoxynil at the lowest tested rate (37.5 g ha^{-1}) provided 16 to 80% and 0 to 30% control of broadleaf and grass weeds, respectively. Tank-mixing these two herbicides at the same rates had improved broadleaf (60 to 100%) and grass (45 to 94%) weed control. The minimum recommended field use rate of tolpyralate +bromoxynil (15 + 150 g ha^{-1}) controlled all the broadleaf weeds >95%. This combination also controlled green foxtail, barnyardgrass and large crabgrass >90%. Additive or synergistic effect between the two herbicides was observed on several broadleaf and grass weed species. Among all the tested weeds, greater synergistic effect was observed on kochia, chickweed, wild mustard, corn poppy, barnyardgrass, green foxtail, and fall panicum. The premix of the two herbicides provided similar broadleaf control, but better grass weed control compared to the tank-mix combinations. Premix was safe on wheat and barley.

Nomenclature: tolpyralate; bromoxynil; barnyardgrass, *Echinochloa crus-galli* (L.) Beauv.; chickweed, *Stellaria media* L.; corn poppy, *Papaver rhoeas L.;* fall panicum, *Panicum dichotomiflorum Michx*.; green foxtail, *Setaria viridis L.*; kochia, *Bassia scoparia L.*; large crabgrass, *Digitaria sanguinalis* L.; wild mustard, *Sinapis arvensis* L.; barley, *Hordeum vulgare* L.; wheat, *Triticum aestivum* L.

Keywords: HPPD inhibiting herbicide, PSII-inhibiting herbicide, synergy

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Introduction

Wheat is the second most cereal grain after corn with a production of 790 billion kg worldwide (USDA-FAS 2024). Globally, it is being cultivated on a larger area than any other food crop with over 242 million hectares (FAO 2022). China, European Union, India, Russia, United States, Canada, Pakistan, Australia, Ukraine, and Turkey are the top 10 wheat producing regions with a contribution of about 85% of the global production (USDA-FAS 2024). The United States (U.S.) and Canada contribute approximately 10% to the world wheat production. In 2023-24, U.S and Canada produced 49 and 33 billion kg wheat, respectively (USDA-FAS 2024). Among several wheat species, common wheat and durum wheat (*Triticum durum* Desf.) are the two most widely cultivated species in U.S. and Canada where the common wheat accounts for approximately 95% of the total wheat production.

Among all the biotic factors that potentially limit wheat yields, weeds are the most significant ones. In general, wheat is not inherently a strong competitor against weeds. Huge wheat yield losses have been reported throughout the world if the weeds were left uncontrolled. Khan and Haq (2002) reported 48 to 52% reduction in wheat yields from Pakistan because of weed interference. Similarly, 24 to 30% yield reductions were reported from India (Kurchania et al. 2002). Ten years of research trial data (2007 to 2017) revealed that on average 23.5% and 19.5% yield losses are expected from weed competition in winter and spring wheat, respectively across the United States and Canada which accounts for $3.6 billion in value (Flessner et al. 2021). Wild buckwheat (*Polygonum convolvulus* L.), kochia, cleavers/catchweed (*Galium aparine* L.), wild mustard, Canada thistle (*Cirsium arvense* L.), Russian thistle (*Salsola kali* L.), common lambsquarters (*Chenopodium album* L.), shepherd's purse (*Capsella bursa-pastoris* L.) and redroot pigweed (*Amaranthus retroflexus* L.) are some important broadleaf weeds in cereals in the U.S. and Canada. Wild buckwheat has become a serious problem throughout the north central region of the United States and the prairie provinces of Canada (Fabricius and Nalewaja 1968). When growing in stands of cereal crops, its climbing nature allows it to overshadow the plants and block the sunlight and reduce photosynthetic activity. Kochia can reduce wheat yields significantly and remains green long after crop maturity, thereby clogging the combines and reducing harvest efficiency (Wolf et al. 2000). Cleavers is highly competitive in wheat. It can cause large yield reductions, interfere with harvesting, and cause crop lodging. Wheat grain yield loss up to 32% was reported with cleavers density ranging from 18 to 72 plants m^{-2} (Aziz et al.

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2009). Common chickweed and wild mustard are also very competitive weeds in cereal crops and can cause significant yield losses (Soltani et al. 2019; Zargar et al. 2021).

For decades, postemergence herbicides have been reliable tools for weed control in cereals. The first herbicide registered for use in wheat for weed control in the United States was 2,4-D, which was followed by MCPA. These herbicides have been widely used for broadleaf weed control since their introduction in the 1940s and 1950s, respectively. After MCPA, in the late 1960s, dicamba was another broadleaf weed herbicide registered for use in wheat. Photosystem II inhibiting herbicides were introduced in wheat in the 1970s (EPA-NSCEP, 1998). In the 1980s, acetolactate synthase (ALS) inhibiting herbicides were introduced to wheat, which can control grassy and broadleaf weeds. Acetyl-CoA carboxylase enzyme inhibiting herbicides (diclofop-methyl) were also introduced in early 1980s to control grass weeds in wheat and other cereal crops (EPA, 2000). Glyphosate was introduced in wheat in the late 1990s as a pre-harvest treatment to control weeds that grow rapidly after the wheat has matured. Hydroxyphenylpyruvate dioxygenase-(HPPD) inhibiting herbicides were introduced to cereals in the late 2010s.

All these herbicides played an instrumental role for enhancing wheat production in the U.S. and Canada by effectively reducing weed competition. However, over reliance on herbicides had led to selection pressure and evolution of herbicide resistant weed biotypes. Currently, 85 weed species in cereals have evolved resistance to herbicides with 15 different sites of action worldwide (Heap 2024). In the U.S. and Canada, 35 weed species in cereals have been reported to have resistance to different herbicide site of action including Weed Science Society of America (WSSA) groups 1, 2, 3, 4, 5, 9, 14, and 15 (Heap 2024). Till date, no weed species resistant to HPPD inhibiting herbicides (WSSA group 27) have been reported in cereals from U.S. and Canada. Currently, three HPPD inhibiting herbicides namely pyrasulfotole, bicyclopyrone and tolpyralate are available for postemergence weed control in cereals. Among these three HPPD inhibiting herbicides, tolpyralate is the latest one to get registered and it belongs to the benzoylpyrazole family. Tolpyralate can control both broadleaf weeds and grasses (Jhala et al. 2023; Tsukamoto et al. 2021) whereas the other two herbicides can only control broadleaf weeds.

A premix of tolpyralate and bromoxynil (PSII inhibiting herbicide, HRAC/WSSA group 6) developed by Corteva Agriscience is now available in the U.S. and Canada with trade names

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Tolvera™ and OnDeck™, respectively, for postemergence weed control in wheat and barley. There is a possibility for expansion of registration to other cereal growing countries. Some previous research has been conducted on tolpyralate and bromoxynil for weed control efficacy and crop safety in corn (Fluttert et al. 2022a and 2022b) but very limited information is available in wheat and barley Hence, greenhouse trials were conducted to test efficacy of tolpyralate and bromoxynil combinations on some key broadleaf and grass weeds in cereals and crop safety in wheat (spring, winter, and durum) and barley.

Materials and Methods

The greenhouse study was conducted during 2023 and 2024 at Corteva Agriscience global headquarters, Indianapolis, IN, USA. The study included two experimental runs, and the design was a randomized complete block design with four replications. The treatments include tank-mix combination of tolpyralate (Shieldex®, ISK Biosciences Corporation, 740 Auburn Road, Concord, OH 44077, USA) and bromoxynil (Moxy® 2E, Winfield Solutions, LLC, St. Paul, MN, USA) at 0.25x, 0.5x, 0.75x and 1x rates of minimum field use rate (Table 1). The minimum recommended field use rate of tolpyralate and bromoxynil combination in cereals is 15 g and 150 g ha^{-1}, respectively (1:10 ratio). Treatments also included stand-alone tolpyralate and bromoxynil at 0.25x, 0.5x, 0.75x and 1x rates. Premix of tolpyralate and bromoxynil (Tolvera™, Corteva Agriscience, Indianapolis, IN, USA) at 0.25x, 0.5x, 0.75x and 1x rates of minimum field use rate were also included. The premix is an emulsifiable concentrate formulation that contains 186.6 g of bromoxynil, 18.66 g of tolpyralate and 4.67 g of safener cloquintocet-mexyl per litre. The formulation also contains other inert ingredients like ethoxylated fatty acid and benzyl alcohol which have adjuvant and solvent properties. To get better understanding on role of safener in the pre-mix formulation, no safener was added to tank-mix treatments of tolpyralate and bromoxynil.

As a reference standard, premix of pyrasulfotole and bromoxynil (Huskie®, Bayer CropScience, St. Louis, MO, USA) at 30 + 170 g ha^{-1} was also included in the test. Like tolpyralate, pyrasulfotole is also a HPPD inhibiting herbicide (WSSA group 27). Total 18 treatments, including an untreated control, were tested. Methylated seed oil at 0.5% v/v was tank-mixed with all tolpyralate and bromoxynil treatments and a non-ionic surfactant at 0.25% v/v was mixed with pyrasulfotole and bromoxynil treatment.

Fourteen broadleaf weeds, including wild buckwheat, kochia, wild mustard, cleavers/ catchweed, Russian thistle/common saltwort, common lambsquarters, redroot pigweed, Palmer amaranth (*Amaranthus palmeri* S. Watson), shepherd's purse, Canada thistle, corn poppy, horseweed (*Conyza canadensis* L.), common chickweed, common ragweed (*Ambrosia artemisiifolia* L.); four grass weeds such as green foxtail, large crabgrass, fall panicum, common barnyardgrass and four crops including winter wheat, spring wheat, durum wheat and spring barley were tested in this study. Seeds were sourced from multiple vendors across the United States. Depending on species and germination percentage, 3 to 6 seeds were planted in square plastic pots with 8.9 cm width and 7.6 cm height. The soil media used was composed of 90% by volume Promix BX (Premier Tech Horticulture, Quakertown, PA) and 10% Profile Greens Grade (Profile Products LLC, Buffalo Grove, IL). Promix BX contains approximately 83% Sphagnum Peat Moss, 13% Perlite, 5% vermiculite, proprietary amounts of limestone, starter fertilizer, and wetting agent. Profile Greens Grade is a sand-sized granule formed from calcining illite and montmorillonite clay. Plant material was propagated in a greenhouse at the Corteva global headquarters (Indianapolis, Indiana, USA) and was grown at 28/24 ± 3C day/night temperatures and 60 to 80% relative humidity. Natural light was supplemented with 1000-watt metal halide overhead lamps with an average illumination of 470 μmol m^{-2} s^{-1} photosynthetic active radiation for 16 consecutive hoursdailyy. After germination, only one healthy plant per pot was allowed to grow for all broadleaf weeds and 5 plants were allowed for grasses. Plants were supplied with nutrients and irrigated as and when required throughout the experiment.

When the weeds and crops were at 3-5 leaf stage, herbicide treatments were sprayed as a postemergence application using a research track-sprayer (Generation III Research Sprayer manufactured by DeVries Manufacturing in Hollandale, MN, USA). The track sprayer was calibrated to deliver 100 L ha^{-1} utilizing Teejet XR8003VS even fan spray nozzle at 276 kPa pressure and 3.13 km hr^{-1} operating speed. Appropriate amounts of formulated product were added to spray vials as calculated by the software package ARM8 (Gylling Data Management Inc.). Herbicide aliquots were diluted with clean tap water to a total volume of 40 millilitres. After the herbicide applications, plants were moved back to the greenhouse and were randomized.

Percent visible control of weeds and phytotoxicity assessments in crops were made on a scale of 0 to 100% (where 0 was no control and 100 was complete plant death) at 21 days after treatment (DAT). After taking visible control ratings, plants were harvested at ground level and placed in paper bags. Those samples were oven-dried at 60 ± 2 C until stable dry weights were achieved. All the aboveground dry biomass values were converted into percent biomass reduction compared to the untreated control plants using the following equation:

Biomass reduction (%) = [(U-T)/U] x 100 ………………… [1]

Where U is the average dry weight of the aboveground biomass from the four untreated control replicates and T is the above ground biomass of an individual treated replicate.

Data from two experimental runs were pooled because there was no significant interaction between treatment and year. Weed control and weed dry biomass data were subjected to analysis of variance using a generalized linear mixed model (GLIMMIX procedure) in SAS version 9.4 (SAS Institute Inc., 100 SAS Campus Drive, Cary, North Carolina, USA, 27513) and means were separated using Tukey's test at 5% level of significance (α).

Expected weed control for each tolpyralate and bromoxynil tank-mix combination was calculated with the following Colby's Equation (Colby 1967) by using the visible observed values

$$E = (X + Y) - [(X * Y) / 100]$$

where X and Y are weed control observed with stand-alone tolpyralate and bromoxynil treatments, respectively and E is expected weed control with combination those two herbicides. Two-sided t-test was used to compare the observed values and calculated expected values for weed control.

Results and Discussion

Broadleaf weed control:

Wild buckwheat and kochia:

Tolpyralate at 3.75 g ha^{-1} controlled wild buckwheat 47% and the control increased with increase in the rate (Table 2). The rates at 7.5, 11.25, and 15 g ha^{-1} provided 67, 77 and 84%

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control, respectively. Bromoxynil at 37.5 g ha^{-1} controlled wild buckwheat 80%. Increasing the rate to 75 g ha^{-1} increased the control significantly (99%). Further increase in rate to 112.5 or 150 g ha^{-1} provided full control of wild buckwheat. Tank-mix of tolpyralate and bromoxynil at 3.75 + 37.5 g ha^{-1} rate controlled wild buckwheat 99% which was significantly higher than that of stand-alone treatments of tolpyralate and bromoxynil at the same rates. As per the Colby equation, the expected weed control with the combination of tolpyralate and bromoxynil at 3.75 + 37.5 g ha^{-1} was 87%, but the actual observed buck wheat control was significantly higher (99%) than the expected value. This indicates synergy between the two herbicides on wild buckwheat meaning the combined effect was greater than the sum of each herbicide acting alone. Synergism between HPPD inhibiting herbicides and PSII inhibiting herbicides has been well documented (Abendroth et al. 2006; Walsh et al. 2012). The synergism between these two herbicides arises from their complementary modes of action. The HPPD inhibitors deplete plastoquinones, which allow increased binding of a PS II inhibitors to the D1 protein (Jhala et al. 2023). PSII inhibitors generate reactive oxygen species (ROS) which cause cell membrane destruction. HPPD inhibitors reduce the plastoquinones, which are needed to dissipate ROS and that amplifies cell membrane destruction (Fluttert et al. 2022c). Further increase in the tank-mix rates of tolpyralate and bromoxynil didn't increase wild buckwheat control significantly. Premix combination of these two herbicides also provided control similar to that of tank-mix combinations. The reference herbicide, premix of pyrasulfotole and bromoxynil (30 + 170 g ha^{-1}) provided full control of wild buckwheat.

The lowest rate of tolpyralate (3.75 g ha^{-1}) controlled kochia 33% (Table 2). Increasing the rate slightly increased the control but it was not consistent with increase in the rate. Bromoxynil at 37.5 g ha^{-1} controlled kochia 42% and it was increased to 72, 84 and 96% with 75, 112.5 and 150 g ha^{-1} rates, respectively. Tank-mix combinations of tolpyralate and bromoxynil provided synergistic effect on kochia control (Table 2). The expected kochia control with the combination of tolpyralate and bromoxynil at 3.75 + 37.5 g ha^{-1} was 61%, but the achieved control was 98% which was a 37 percent point advantage. Likewise, significantly higher kochia control was observed with 7.5 + 75 and 11.25 + 112.5 g ha^{-1} rates compared to the expected weed control (99% vs 87% and 100% vs 92%, respectively). Premix formulation of two herbicides provided similar kochia control to that of tank-mix combinations. Premix of pyrasulfotole and bromoxynil controlled kochia 100%.

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Cleavers, Russian thistle, and Canada thistle

Tolpyralate at 3.75 g ha^{-1} controlled cleavers 84% and the control increased to 91% with 15 g ha^{-1} rate (Table 3). Bromoxynil at 37.5 g ha^{-1} controlled cleavers 65% and the control increased significantly until 112.5 g ha^{-1} (92%). Tank-mix of tolpyralate and bromoxynil provided 99 to 100% control of cleavers. Synergy was observed between tolpyralate and bromoxynil at 3.75 + 37.5 g ha^{-1} rate, and an additive effect was observed in the remaining tank-mix combinations. The expected cleavers control with 3.75 + 37.5 g ha^{-1} rate was 94% whereas the observed control was 100%.

Tolpyralate controlled Russian and Canada thistles 66 to 74% and 84 to 90%, respectively (Table 3). There was no significant difference in control among the tested rates. Between these two thistles, Canada thistle was more susceptible to tolpyralate. Bromoxynil at 37.5 g ha^{-1} controlled both thistles 67% and the control increased significantly with 75 g ha^{-1} rate (83 to 99%). Further increase in rate, did not increase thistle control. Between the two thistles, Russian thistle was more susceptible to bromoxynil. All tank-mix combinations of tolpyralate and bromoxynil provided 100% control of Russian thistle. A synergy was observed at lower rate tank-mix combination of these two herbicides. The observed Russian thistle control with 3.75 + 37.5 g ha^{-1} rate exceeded expected control by 9%. An additive effect on Russian thistle control was observed with all remaining combinations of tolpyralate and bromoxynil. Tank-mix combinations of these two herbicides provided 97 to 100% control of Canada thistle. A slight synergy between these two herbicides at 11.25 + 112.5 g ha^{-1} rate was observed and all other tank-mix combinations showed additive effect on Canada thistle. Pre-mix of tolpyralate and bromoxynil provided control of all three weeds similar to tank-mix combinations. Pre-mix of pyrasulfotole and bromoxynil controlled these weeds 99 to 100%.

Corn poppy, common chickweed, and wild mustard

The trial results indicated that corn poppy, chickweed and wild mustard were the most tolerant species to the HPPD-inhibiting herbicide tolpyralate among the tested 14 broadleaf weed species (Table 4). Tolpyralate at 3.75 g ha^{-1} controlled these three weeds 10 to 32% and the control didn't significantly increase with increase in the rate. Fluttert et al. (2022d) also reported less wild mustard control with tolpyralate even at 30 g ha^{-1} rate (51% at 28 DAT). Bromoxynil at 37.5 g ha^{-1} controlled corn poppy and wild mustard 58 and 41%, respectively, and the control

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increased to 87 and 81%, respectively, with a 150 g ha^{-1} rate. Compared to corn poppy and wild mustard, common chick weed showed tolerance to bromoxynil at all the tested rates. Bromoxynil controlled chickweed 13 to 31% and the control did not increase consistently with the application rate. Tank-mix combinations of tolpyralate and bromoxynil controlled corn poppy and chickweed 94 to 100% and 87 to 97%, respectively. There was no significant difference among the rates. The lowest tested rate of tolpyralate and bromoxynil (3.75 + 37.5 g ha^{-1}) controlled wild mustard 60% and the control significantly increased to 89% with the 7.5 + 75 g ha^{-1} rate (89%). Further increase in rate didn't increase wild mustard control significantly. Greater synergy between tolpyralate and bromoxynil for the control of corn poppy, chickweed and wild mustard was observed. The expected corn poppy control with 3.75 + 37.5 g ha^{-1} rate was 72% but the observed control with this rate was 94% which was 22% higher than the expected control. Similarly, synergy was observed with the next two rates. The 7.5 + 75 and 11.25 + 112.5 g ha^{-1} rates provided 18 and 11% greater corn poppy control, respectively, compared to expected control. Tolpyralate and bromoxynil at 3.75 + 37.5, 7.5 + 75, 11.25 + 112.5 and 15 + 150 g ha^{-1} rates provided 45, 61, 57 and 53% higher chickweed control, respectively over the expected control. Similarly, tank-mixing these two herbicides achieved 10 to 20% greater wild mustard control. Fluttert et al (2022a) also reported an excellent control of wild mustard with tolpyralate and bromoxynil in corn but with higher rates (30 + 280 g ha^{-1}).

Pre-mix of tolpyralate + bromoxynil controlled corn poppy and wild mustard similar to that of tank-mix combinations. However, the 3.75 + 37.5 g ha^{-1} rate of the premix provided significantly higher wild mustard control (80%) compared to tank-mix combination (60%). This can be attributed to the surfactants present in the premix. The reference herbicide pyrasulfotole and bromoxynil fully controlled all three broadleaf weeds.

Pigweeds (Redroot pigweed and Palmer amaranth):

Tolpyralate provided good control of Amaranthus species (Table 5). The lowest tested rate (3.75 g ha^{-1}) controlled 91% and 85% control of redroot pigweed and Palmer amaranth, respectively. Increasing the rate of tolpyralate slightly increased control of both weeds. The highest rate of tolpyralate (15 g ha^{-1}) controlled them ≥ 95%. Metzger et al. (2018a) also reported >90% control of redroot pigweed with 30 g ha^{-1} of tolpyralate. The other herbicide bromoxynil controlled redroot pigweed and Palmer amaranth only up to 50% and 18%, respectively. There was no significant difference in control among the rates. Since the tolpyralate provided maximum efficacy on pigweeds, tank-mixing it with bromoxynil provided marginal or no additive effect. Pre-mix of tolpyralate and bromoxynil controlled these two weeds similar to that of tank-mix combinations. Field use rate of pyrasulfotole and bromoxynil (30 + 170 g ha^{-1}) controlled redroot pigweed 99% but it controlled Palmer amaranth only 59% which is significantly lower than that of tolpyralate + bromoxynil.

Common lambsquarters, shepherd's purse, horseweed, and common ragweed

The HPPD inhibiting herbicide tolpyralate controlled common lambsquarters, shepherd's purse, horseweed and common ragweed 98 to 100%, 97 to 100%, 91 to 97% and 93 to 98%, respectively (Table 6). There was no significant difference in control among the tested four rates. These results align with findings of Metzger et al. (2018b), who reported effective rate of tolpyralate as ≤15.5 g ha^{-1} to achieve 90% control of common lambsquarters, common ragweed and redroot pigweed. Bromoxynil at 37.5 g ha^{-1} controlled these four weeds 60%, 59%, 57% and 70%, respectively, and the control increased with rate increase. The 150 g ha^{-1} rate controlled them 96%, 81%, 87% and 85%, respectively. Tank-mixing tolpyralate and bromoxynil controlled these four broadleaf weeds 99 to 100%. Synergistic effect between these two herbicides on all four weeds was observed at the 3.75 + 37.5 g ha^{-1} rate. Slightly higher control was observed than expected control at that tank-mix rate. Synergy at the next two rates (7.5 + 75 and 11.25 + 112.5 g ha^{-1}) was also observed for horseweed control. Fluttert et al (2022b) also reported greater synergy between bromoxynil and HPPD inhibiting herbicides, including tolpyralate on horseweed. Pre-mixes of tolpyralate + bromoxynil and pyrasulfotole + bromoxynil provided complete control of all four broad leaf weeds.

Grass weed control

Tolpyralate at 3.75 g ha^{-1} controlled green foxtail, barnyard grass, fall panicum and large crabgrass 77%, 52%, 27% and 76%, respectively (Table 7). The control increased with increase in the rate. The highest rate of tolpyralate (15 g ha^{-1}) provided 90%, 87%, 49% and 87% control, respectively. On the other hand, as expected, bromoxynil was less effective on grasses. Some suppression was observed but not more than 30% grass control was recorded with any tested rates of bromoxynil. Tank-mix combination of tolpyralate and bromoxynil at 3.75 + 37.5 g ha^{-1} controlled green foxtail 94% which was 16% higher than the expected control. The other three

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rates also provided 15%, 11%, and 7% more green foxtail control, respectively, compared to the expected control. Similarly, 7% to 33% and 18% to 22% higher barnyard grass and fall panicum control, respectively, were achieved than the expected control by tank-mixing tolpyralate and bromoxynil. This indicates greater synergy between the two herbicides for controlling green foxtail, barnyard grass and fall panicum. Combinations of these two herbicides controlled large crabgrass up to 93%, where some additive effects between the two herbicides were observed at higher rates.

Pre-mix formulation of tolpyralate and bromoxynil controlled green foxtail, barnyard grass and large crabgrass similar to tank-mix combinations of the two herbicides. However, the pre-mix formulation provided better fall panicum control (58 to 97%) than the tank-mix combinations (45 to 81%). The surfactants, like ethoxylated fatty acid and benzyl alcohol, present in the pre-mix formulation might have helped achieve greater efficacy on the fall panicum. The reference standard pyrasulfotole and bromoxynil provided 9%, 14%, 32% and 89% control of large crabgrass, green foxtail, fall panicum and barnyard grass, respectively which was significantly lower than that of tolpyralate and bromoxynil. This was expected as the herbicide has been registered only for broadleaf weed control in cereals.

The reductions in above ground dry biomass for all the 18 weed species due to herbicide treatments compared to untreated control were in line with visible observed values (Tables 8 and 9).

Crop response

Tolpyralate and bromoxynil caused slight injury on cereal crops at 21 days after herbicide application (Table 10). Across the tested rates, tolpyralate caused 3 to 4% and 4 to 8% injury on winter and spring wheat, respectively. The symptoms included slight bleaching of the leaves and some stunted growth. Bromoxynil caused some injury (stunted growth) in winter wheat and spring wheat (2 to 3% and 6 to 8%, respectively). Tank-mix or premix of the two herbicides didn't increase the injury significantly. In durum wheat, tolpyralate caused 1 to 4% injury and bromoxynil caused 1 to 5% injury. Tank-mixing these two herbicides slightly elevated the injury (5 to 9%) whereas the premix caused only 2 to 4% injury. Similarly, tolpyralate and bromoxynil caused 5 to 12% and 4 to 15% injury, respectively in spring barley and their tank-mixes caused 13 to 20% injury. However, the premix formulation of these two herbicides caused only 7 to

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14% injury. The reduced injury with premix formulation compared to the tank-mix combinations of tolpyralate and bromoxynil in durum wheat and spring barley could be due to the safener cloquintocet-mexyl present in the formulation. The reference standard pyrasulfotole + bromoxynil premix, which has safener mefenpyr-diethyl, caused mild injury on wheat (3 to 6%) and spring barley (11%).

Practical implications

Results from the greenhouse study suggest that the newly registered premix of HPPD inhibiting herbicide tolpyralate and PSII inhibitor bromoxynil is an excellent herbicide option for broad spectrum weed control in wheat and barley. Additive or synergistic effect between the two herbicides was observed for control of several broadleaf and grass weeds. The greatest advantage of the co-application of these two herbicides was observed in kochia, chickweed, wild mustard, corn poppy, barnyard grass, green foxtail, and fall panicum. The premix formulation of the two herbicides controlled broadleaf weeds similar to tank-mix combinations, but the grass weed control was much better than tank-mixes. Currently available other HPPD inhibiting herbicides (pyrasulfotole and bicyclopyrone) in combination with bromoxynil in cereals are only labelled for broadleaf weed control, but the tolpyralate + bromoxynil can effectively control broadleaf weeds and as well as some important grass weeds. Even though the lower rates provided good control of some weed species, full rate of the herbicide is recommended for broad spectrum and effective weed control. The premix formulation of the two herbicides is safe on wheat (spring, winter, and durum) and barley. Although the results are from a greenhouse study, similar outcomes are expected in field conditions if label recommendations are followed, and favorable weather conditions prevail.

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Table 1. List of the treatments used in the study.

Treatment#	Herbicide Treatment*
1	Tank-mix of tolpyralate at 3.75 g + bromoxynil 37.5 g ha^{-1} (0.25 X)
2	Tank-mix of tolpyralate at 7.5 g + bromoxynil 75 g ha^{-1} (0.5 X)
3	Tank-mix of tolpyralate at 11.25 g + bromoxynil 112.5 g ha^{-1} (0.75 X)
4	Tank-mix of tolpyralate at 15 g + bromoxynil 150 g ha^{-1} (1 X)
5	Tolpyralate at 3.75 g ha^{-1}
6	Tolpyralate at 7.5 g ha^{-1}
7	Tolpyralate at 11.25 g ha^{-1}
8	Tolpyralate at 15 g ha^{-1}
9	Bromoxynil at 37.5 g ha^{-1}
10	Bromoxynil at 75 g ha^{-1}
11	Bromoxynil at 112.5 g ha^{-1}
12	Bromoxynil at 150 g ha^{-1}
13	Premix of tolpyralate & bromoxynil at 3.75 + 37.5 g ha^{-1}
14	Premix of tolpyralate & bromoxynil at 7.5 + 75 g ha^{-1}
15	Premix of tolpyralate & bromoxynil at 11.25 + 112.5 g ha^{-1}
16	Premix of tolpyralate & bromoxynil at 15 + 150 g ha^{-1}
17	Premix of pyrasulfotole & bromoxynil at 30 + 170 g ha^{-1}
18	Untreated Control

*Adjuvant methylated seed oil at 0.5% v/v was tank-mixed with all tolpyralate and bromoxynil treatments (1 to 16) and a non-ionic surfactant at 0.25% v/v was mixed with pyrasulfotole and bromoxinyl treatment (17). X = Field use rate.

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Table 2. Wild buckwheat and kochia control with different combinations of tolpyralate and bromoxynil.

Trt #	Herbicide Treatment	Wild buckwheat			Kochia		
		……………Weed control %.........................					
1	Tol+Bro @ 3.75+37.5 g ha^{-1}	99	a	(87)**	98	a	(61)***
2	Tol+Bro @ 7.5+75 g ha^{-1}	100	a	(99)	99	a	(87)*
3	Tol+Bro @ 11.25+112.5 g ha-1	100	a	(99)	100	a	(92)**
4	Tol+Bro @ 15+150 g ha^{-1}	100	a	(100)	100	a	(99)
5	Tolpyralate @ 3.75 g ha^{-1}	47	d		33	g	
6	Tolpyralate @ 7.5 g ha^{-1}	67	c		59	de	
7	Tolpyralate @ 11.25 g ha^{-1}	77	bc		51	ef	
8	Tolpyralate @ 15 g ha^{-1}	84	b		45	fg	
9	Bromoxynil @ 37.5 g ha^{-1}	80	b		42	fg	
10	Bromoxynil @ 75 g ha^{-1}	99	a		72	cd	
11	Bromoxynil @ 112.5 g ha^{-1}	98	a		84	bc	
12	Bromoxynil @ 150 g ha^{-1}	100	a		96	ab	
13	Tol&Bro @ 3.75+37.5 g ha^{-1}	97	a		96	ab	
14	Tol&Bro @ 7.5+75 g ha^{-1}	100	a		100	a	
15	Tol&Bro @ 11.25+112.5 g ha^{-1}	100	a		100	a	
16	Tol&Bro @ 15+150 g ha^{-1}	100	a		100	a	
17	Pyra&Bro @ 30+170 g ha^{-1}	100	a		100	a	

Tol+Bro indicates tank-mix combination and Tol&Bro indicates pre-mix combination.
Means with the same letter within a column do not significantly differ ($P< 0.05$)
Expected weed control values are given in the parentheses. Asterisks (*) indicate significant differences between observed and expected values based on a two-tailed t-test (*$P < 0.05$, **$P < 0.01$, ***$P < 0.001$).

Table 3. Cleavers, Russian thistle, and Canada thistle control with different combinations of tolpyralate and bromoxynil.

Trt #	Herbicide Treatment	Cleavers			Russian thistle			Canada thistle		
		……………Weed control %.........................								
1	Tol+Bro @ 3.75+37.5 g ha^{-1}	100	a	(94)**	100	a	(91)**	97	ab	(96)
2	Tol+Bro @ 7.5+75 g ha^{-1}	99	ab	(97)	100	a	(99)	99	a	(97)
3	Tol+Bro @ 11.25+112.5 g ha^{-1}	100	a	(99)	100	a	(100)	100	a	(97)*
4	Tol+Bro @ 15+150 g ha^{-1}	100	a	(99)	100	a	(100)	99	a	(99)
5	Tolpyralate @ 3.75 g ha^{-1}	84	de		73	b		88	bc	
6	Tolpyralate @ 7.5 g ha^{-1}	90	cd		66	b		85	c	
7	Tolpyralate @ 11.25 g ha^{-1}	91	cd		73	b		84	c	
8	Tolpyralate @ 15 g ha^{-1}	91	abcd		74	b		90	abc	
9	Bromoxynil @ 37.5 g ha^{-1}	65	f		67	b		67	d	
10	Bromoxynil @ 75 g ha^{-1}	79	e		99	a		83	c	
11	Bromoxynil @ 112.5 g ha^{-1}	92	abcd		100	a		80	c	
12	Bromoxynil @ 150 g ha^{-1}	91	bcd		100	a		84	c	
13	Tol&Bro @ 3.75+37.5 g ha^{-1}	97	abc		100	a		98	a	
14	Tol&Bro @ 7.5+75 g ha^{-1}	100	a		100	a		99	a	
15	Tol&Bro @ 11.25+112.5 g ha^{-1}	100	a		100	a		100	a	
16	Tol&Bro @ 15+150 g ha^{-1}	100	a		100	a		100	a	
17	Pyra&Bro @ 30+170 g ha^{-1}	100	a		100	a		99	a	

Tol+Bro indicates tank-mix combination and Tol&Bro indicates pre-mix combination.
Means with the same letter within a column do not significantly differ (P< 0.05)
Expected weed control values are given in the parentheses. Asterisks (*) indicate significant differences between observed and expected values based on a two-tailed t-test (*P < 0.05, **P < 0.01, ***P < 0.001).

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Table 4. Corn poppy, chickweed and wild mustard control with different combinations of tolpyralate and bromoxynil.

Trt #	Herbicide Treatment	Corn poppy			Common chickweed			Wild mustard		
		……………..……………Weed control %...								
1	Tol+Bro @ 3.75+37.5 g ha^{-1}	94	ab	(72)**	87	ab	(42)***	60	e	(48)
2	Tol+Bro @ 7.5+75 g ha^{-1}	97	ab	(79)**	92	ab	(31)***	89	abc	(76)
3	Tol+Bro @ 11.25+112.5 g ha^{-1}	100	a	(89)**	95	ab	(38)***	93	ab	(73)**
4	Tol+Bro @ 15+150 g ha^{-1}	99	a	(99)	97	a	(44)**	98	ab	(88)**
5	Tolpyralate @ 3.75 g ha^{-1}	32	e		21	cde		10	g	
6	Tolpyralate @ 7.5 g ha^{-1}	36	e		19	de		13	g	
7	Tolpyralate @ 11.25 g ha^{-1}	39	e		26	cde		14	g	
8	Tolpyralate @ 15 g ha^{-1}	35	e		35	c		25	g	
9	Bromoxynil @ 37.5 g ha^{-1}	58	d		31	cd		41	f	
10	Bromoxynil @ 75 g ha^{-1}	73	c		17	de		72	cde	
11	Bromoxynil @ 112.5 g ha^{-1}	83	bc		18	de		68	de	
12	Bromoxynil @ 150 g ha^{-1}	87	ab		13	e		82	abcd	
13	Tol&Bro @ 3.75+37.5 g ha^{-1}	92	ab		78	b		80	bcd	
14	Tol&Bro @ 7.5+75 g ha^{-1}	100	a		91	ab		98	ab	
15	Tol&Bro @ 11.25+112.5 g ha^{-1}	100	a		95	a		97	ab	
16	Tol&Bro @ 15+150 g ha^{-1}	100	a		99	a		100	a	
17	Pyra&Bro @ 30+170 g ha^{-1}	99	a		100	a		100	a	

Tol+Bro indicates tank-mix combination and Tol&Bro indicates pre-mix combination.
Means with the same letter within a column do not significantly differ ($P< 0.05$)
Expected weed control values are given in the parentheses. Asterisks (*) indicate significant differences between observed and expected values based on a two-tailed t-test (*$P < 0.05$, **$P < 0.01$, ***$P < 0.001$).

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Table 5. Redroot pigweed and Palmer amaranth control with different combinations of tolpyralate and bromoxynil.

Trt #	Herbicide Treatment	Redroot pigweed			Palmer amaranth		
		……..……………Weed control %................................					
1	Tol+Bro @ 3.75+37.5 g ha^{-1}	88	a	(94)	86	a	(86)
2	Tol+Bro @ 7.5+75 g ha^{-1}	89	a	(97)	96	a	(86)
3	Tol+Bro @ 11.25+112.5 g ha^{-1}	96	a	(98)	99	a	(99)
4	Tol+Bro @ 15+150 g ha^{-1}	100	a	(99)	100	a	(96)
5	Tolpyralate @ 3.75 g ha^{-1}	91	a		85	a	
6	Tolpyralate @ 7.5 g ha^{-1}	95	a		88	a	
7	Tolpyralate @ 11.25 g ha^{-1}	97	a		98	a	
8	Tolpyralate @ 15 g ha^{-1}	98	a		95	a	
9	Bromoxynil @ 37.5 g ha^{-1}	40	b		16	c	
10	Bromoxynil @ 75 g ha^{-1}	39	b		14	c	
11	Bromoxynil @ 112.5 g ha^{-1}	50	b		12	c	
12	Bromoxynil @ 150 g ha^{-1}	50	b		18	c	
13	Tol&Bro @ 3.75+37.5 g ha^{-1}	92	a		85	a	
14	Tol&Bro @ 7.5+75 g ha^{-1}	99	a		95	a	
15	Tol&Bro @ 11.25+112.5 g ha^{-1}	99	a		100	a	
16	Tol&Bro @ 15+150 g ha^{-1}	100	a		100	a	
17	Pyra&Bro @ 30+170 g ha^{-1}	99	a		59	b	

Tol+Bro indicates tank-mix combination and Tol&Bro indicates pre-mix combination.

Means with the same letter within a column do not significantly differ ($P < 0.05$)

Expected weed control values are given in the parentheses. Asterisks (*) indicate significant differences between observed and expected values based on a two-tailed t-test (*$P < 0.05$, **$P < 0.01$, ***$P < 0.001$).

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Table 6. Lambsquarters, shepherd's purse, horseweed and common ragweed control with different combinations of tolpyralate and bromoxynil.

Trt #	Herbicide Treatment	Lambsquarters			Shepherd's purse			Horseweed			Common ragweed		
		……………………………………..Weed control %..											
1	Tol+Bro @ 3.75+37.5 g ha^{-1}	100	a	(99)**	100	a	(99)**	99	a	(96)*	100	a	(98)*
2	Tol+Bro @ 7.5+75 g ha^{-1}	100	a	(100)	100	a	(100)	100	a	(98)**	100	a	(99)
3	Tol+Bro @ 11.25+112.5 g ha^{-1}	100	a	(100)	100	a	(100)	100	a	(99)*	100	a	(100)
4	Tol+Bro @ 15+150 g ha^{-1}	100	a	(100)	100	a	(100)	99	a	(100)	100	a	(100)
5	Tolpyralate @ 3.75 g ha^{-1}	98	a		97	a		91	bc		93	ab	
6	Tolpyralate @ 7.5 g ha^{-1}	98	a		99	a		93	abc		97	a	
7	Tolpyralate @ 11.25 g ha^{-1}	100	a		100	a		95	ab		99	a	
8	Tolpyralate @ 15 g ha^{-1}	99	a		100	a		97	ab		98	a	
9	Bromoxynil @ 37.5 g ha^{-1}	60	c		59	d		57	f		70	d	
10	Bromoxynil @ 75 g ha^{-1}	85	b		73	c		77	e		76	d	
11	Bromoxynil @ 112.5 g ha^{-1}	95	a		76	c		83	d		84	c	
12	Bromoxynil @ 150 g ha^{-1}	96	a		81	b		87	cd		85	bc	
13	Tol&Bro @ 3.75+37.5 g ha^{-1}	100	a		100	a		97	ab		100	a	
14	Tol&Bro @ 7.5+75 g ha^{-1}	100	a		100	a		100	a		100	a	
15	Tol&Bro @ 11.25+112.5 g ha^{-1}	100	a		100	a		100	a		100	a	
16	Tol&Bro @ 15+150 g ha^{-1}	100	a		100	a		100	a		100	a	
17	Pyra&Bro @ 30+170 g ha^{-1}	100	a		100	a		100	a		100	a	

Tol+Bro indicates tank-mix combination and Tol&Bro indicates pre-mix combination.
Means with the same letter within a column do not significantly differ ($P < 0.05$)
Expected weed control values are given in the parentheses. Asterisks (*) indicate significant differences between observed and expected values based on a two-tailed t-test (*$P < 0.05$, **$P < 0.01$, ***$P < 0.001$).

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Table 7. Green foxtail, barnyardgrass, fall panicum and large crabgrass, control with different combinations of tolpyralate and bromoxynil.

Trt #	Herbicide Treatment	Green foxtail			Barnyardgrass			Fall panicum			Large crabgrass		
		……………………………………..Weed control %..											
1	Tol+Bro @ 3.75+37.5 g ha^{-1}	94	ab	(78)***	89	bcd	(56)***	45	ef	(50)	73	e	(73)
2	Tol+Bro @ 7.5+75 g ha^{-1}	98	a	(83)***	95	ab	(73)***	63	c	(55)	82	cde	(85)
3	Tol+Bro @ 11.25+112.5 g ha^{-1}	98	a	(87)**	97	a	(84)**	76	b	(54)**	88	abc	(85)
4	Tol+Bro @ 15+150 g ha^{-1}	98	a	(91)**	97	a	(90)***	81	b	(63)**	93	ab	(88)
5	Tolpyralate @ 3.75 g ha^{-1}	77	e		52	f		27	h		76	de	
6	Tolpyralate @ 7.5 g ha^{-1}	81	de		67	e		38	fg		85	bcd	
7	Tolpyralate @ 11.25 g ha^{-1}	85	cd		82	d		33	gh		85	bcd	
8	Tolpyralate @ 15 g ha^{-1}	90	bc		87	cd		49	de		87	abc	
9	Bromoxynil @ 37.5 g ha^{-1}	3	h		9	i		30	gh		0	f	
10	Bromoxynil @ 75 g ha^{-1}	6	gh		18	gh		28	gh		0	f	
11	Bromoxynil @ 112.5 g ha^{-1}	9	fg		13	hi		31	gh		3	f	
12	Bromoxynil @ 150 g ha^{-1}	16	f		20	g		27	h		3	f	
13	Tol&Bro @ 3.75+37.5 g ha^{-1}	94	ab		93	abc		58	cd		79	cde	
14	Tol&Bro @ 7.5+75 g ha^{-1}	99	a		97	a		92	a		93	ab	
15	Tol&Bro @ 11.25+112.5 g ha^{-1}	99	a		98	a		96	a		95	a	
16	Tol&Bro @ 15+150 g ha^{-1}	100	a		97	a		97	a		96	a	
17	Pyra&Bro @ 30+170 g ha^{-1}	14	f		89	bcd		32	gh		9	f	

Tol+Bro indicates tank-mix combination and Tol&Bro indicates pre-mix combination.
Means with the same letter within a column do not significantly differ ($P < 0.05$)
Expected weed control values are given in the parentheses. Asterisks (*) indicate significant differences between observed and expected values based on a two-tailed t-test (*$P < 0.05$, **$P < 0.01$, ***$P < 0.001$).

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Table 8. Above ground dry biomass reduction in broadleaf weeds compared to non-treated control at 21 days after herbicide application.

Trt #	Herbicide Treatment	Wild buckwheat	Kochia	Cleavers	Russian thistle	Canada thistle	Corn poppy	Common chickweed	Wild mustard	Redroot pigweed
		……………………………………………………%						dry		weight reduction………………………………………………………..
1	Tol+Bro @ 3.75+37.5 g ha^{-1}	100 a	99 a	100 a	100 a	97 ab	95 ab	85 bc	55 cd	88 a
2	Tol+Bro @ 7.5+75 g ha^{-1}	100 a	99 a	99 a	100 a	99 a	97 ab	89 abc	76 abc	89 a
3	Tol+Bro @ 11.25+112.5 g ha^{-1}	100 a	100 a	100 a	100 a	100 a	100 a	96 ab	90 a	95 a
4	Tol+Bro @ 15+150 g ha^{-1}	100 a	100 a	100 a	100 a	99 a	99 ab	97 ab	94 a	98 a
5	Tolpyralate @ 3.75 g ha^{-1}	54 c	30 f	76 d	75 b	86 bc	33 f	27 efg	2 e	93 a
6	Tolpyralate @ 7.5 g ha^{-1}	76 b	63 d	84 cd	67 bc	84 c	30 f	27 efg	5 e	95 a
7	Tolpyralate @ 11.25 g ha^{-1}	84 b	58 d	88 c	74 bc	81 c	47 e	41 de	12 e	97 a
8	Tolpyralate @ 15 g ha^{-1}	81 b	55 de	89 c	74 bc	86 bc	45 e	47 d	13 e	97 a
9	Bromoxynil @ 37.5 g ha^{-1}	81 b	46 e	56 e	66 c	67 d	65 d	34 ef	35 d	46 c
10	Bromoxynil @ 75 g ha^{-1}	99 a	74 c	78 d	99 a	81 c	78 c	22 fg	62 c	45 c
11	Bromoxynil @ 112.5 g ha^{-1}	98 a	83 bc	90 bc	100 a	82 c	87 bc	28 efg	59 c	58 b
12	Bromoxynil @ 150 g ha^{-1}	100 a	92 ab	92 abc	100 a	86 bc	91 ab	20 g	66 bc	62 b
13	Tol&Bro @ 3.75+37.5 g ha^{-1}	97 a	97 a	98 ab	100 a	97 ab	94 ab	78 c	55 cd	92 a
14	Tol&Bro @ 7.5+75 g ha^{-1}	100 a	100 a	100 a	100 a	99 a	100 a	91 abc	86 ab	98 a
15	Tol&Bro @ 11.25+112.5 g ha^{-1}	100 a	100 a	100 a	100 a	100 a	100 a	94 ab	89 a	98 a
16	Tol&Bro @ 15+150 g ha^{-1}	100 a	100 a	100 a	100 a	100 a	100 a	99 a	99 a	99 a
17	Pyra&Bro @ 30+170 g ha^{-1}	100 a	100 a	100 a	100 a	99 a	98 ab	99 a	98 a	99 a

Tol+Bro indicates tank-mix combination and Tol&Bro indicates pre-mix combination.

Means with the same letter within a column do not significantly differ (P< 0.05)

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Table 9. Above ground dry biomass reduction in broadleaf and grassy weeds compared to non-treated control at 21 days after herbicide application.

Trt #	Herbicide Treatment	Palmer amaranth	Common lambsquarters	Shepherd's purse	Horseweed	Common ragweed	Green foxtail	Barnyard grass	Fall panicum	Large crabgrass
		…..…………………………………………………% dry weight reduction…………………………………………………………..								
1	Tol+Bro @ 3.75+37.5 g ha^{-1}	89 ab	99 a	100 a	100 a	100 a	92 ab	94 ab	49 e	69 e
2	Tol+Bro @ 7.5+75 g ha^{-1}	97 ab	99 a	100 a	99 a	100 a	98 a	98 ab	62 d	84 cd
3	Tol+Bro @ 11.25+112.5 g ha^{-1}	99 a	99 a	100 a	100 a	100 a	98 a	99 a	77 c	93 ab
4	Tol+Bro @ 15+150 g ha^{-1}	100 a	99 a	100 a	99 a	100 a	98 a	99 a	82 bc	94 ab
5	Tolpyralate @ 3.75 g ha^{-1}	87 ab	98 a	98 a	85 c	98 a	76 e	61 d	28 f	70 e
6	Tolpyralate @ 7.5 g ha^{-1}	87 ab	98 a	99 a	88 c	99 a	80 ef	79 c	31 f	81 d
7	Tolpyralate @ 11.25 g ha^{-1}	97 ab	99 a	100 a	90 c	99 a	83 cd	89 b	36 f	84 cd
8	Tolpyralate @ 15 g ha^{-1}	96 ab	99 a	100 a	90 bc	99 a	89 bc	91 ab	36 f	88 bcd
9	Bromoxynil @ 37.5 g ha^{-1}	11 e	58 c	65 d	59 e	71 b	5 hi	11 f	17 g	7 f
10	Bromoxynil @ 75 g ha^{-1}	14 e	90 b	82 c	77 d	70 b	12 g	22 e	14 gh	8 f
11	Bromoxynil @ 112.5 g ha^{-1}	11 e	96 a	83 bc	85 c	91 a	13 g	23 e	15 gh	8 f
12	Bromoxynil @ 150 g ha^{-1}	14 e	95 ab	89 b	88 c	91 a	11 gh	24 e	5 h	5 f
13	Tol&Bro @ 3.75+37.5 g ha^{-1}	80 bc	100 a	100 a	97 ab	100 a	94 ab	96 ab	50 e	71 e
14	Tol&Bro @ 7.5+75 g ha^{-1}	95 ab	100 a	100 a	99 a	100 a	98 a	99 a	87 abc	90 abc
15	Tol&Bro @ 11.25+112.5 g ha^{-1}	99 a	99 a	100 a	100 a	100 a	99 a	99 a	96 a	94 ab
16	Tol&Bro @ 15+150 g ha^{-1}	99 a	100 a	100 a	100 a	100 a	100 a	99 a	96 a	9 ab
17	Pyra&Bro @ 30+170 g ha^{-1}	63 d	100 a	100 a	100 a	100 a	2 i	94 ab	28 f	8 f

Tol+Bro indicates tank-mix combination and Tol&Bro indicates pre-mix combination.

Means with the same letter within a column do not significantly differ ($P< 0.05$)

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Table 10. Wheat and barley response to different combinations of tolpyralate and bromoxynil at 21 days after herbicide application.

Trt #	Herbicide Treatment	Winter wheat		Spring wheat		Durum Wheat		Spring barley	
		…………………………Phyto toxicity %.................................							
1	Tol+Bro @ 3.75+37.5 g ha^{-1}	1	c	2	d	5	bcd	13	bcd
2	Tol+Bro @ 7.5+75 g ha^{-1}	3	bc	5	bcd	7	abc	13	bcd
3	Tol+Bro @ 11.25+112.5 g ha^{-1}	3	abc	7	abc	9	ab	13	bc
4	Tol+Bro @ 15+150 g ha^{-1}	6	a	9	abc	10	a	20	a
5	Tolpyralate @ 3.75 g ha^{-1}	3	bc	4	cd	4	bcd	5	ef
6	Tolpyralate @ 7.5 g ha^{-1}	3	bc	7	abcd	1	d	11	bcd
7	Tolpyralate @ 11.25 g ha^{-1}	4	abc	8	abc	2	d	12	bcd
8	Tolpyralate @ 15 g ha^{-1}	4	abc	6	abcd	1	d	9	bcdef
9	Bromoxynil @ 37.5 g ha^{-1}	3	bc	8	abc	3	cd	4	f
10	Bromoxynil @ 75 g ha^{-1}	2	bc	6	abcd	5	bcd	12	bcd
11	Bromoxynil @ 112.5 g ha^{-1}	3	bc	8	abc	1	d	8	cdef
12	Bromoxynil @ 150 g ha^{-1}	3	bc	7	abc	4	cd	15	ab
13	Tol&Bro @ 3.75+37.5 g ha^{-1}	5	ab	10	a	4	cd	14	ab
14	Tol&Bro @ 7.5+75 g ha^{-1}	4	ab	10	ab	4	bcd	7	def
15	Tol&Bro @ 11.25+112.5 g ha^{-1}	3	bc	7	abc	2	d	11	bcde
16	Tol&Bro @ 15+150 g ha^{-1}	3	bc	5	bcd	4	bcd	12	bcd
17	Pyra&Bro @ 30+170 g ha^{-1}	5	ab	6	abcd	3	cd	11	bcde

Tol+Bro indicates tank-mix combination and Tol&Bro indicates pre-mix combination.
Means with the same letter within a column do not significantly differ ($P< 0.05$)

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The authors declare none

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