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

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Abstract

Corteva Agriscience recently registered a premix of tolpyralate and bromoxynil in the United States and Canada for weed control in cereal fields. Limited information exists on weed control efficacy and crop safety with this new herbicide premixture. Greenhouse trials were conducted for 2 yr to test the efficacy of tolpyralate and bromoxynil combinations on 14 broadleaf and four grass weeds and its safety to wheat and barley. Four combinations of tolpyralate and bromoxynil at a 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% control of broadleaf weeds and 27% to 77% control of grass weeds. Bromoxynil at the lowest tested rate (37.5 g ha^{-1}) provided 16% to 80% control of broadleaf weeds and 0% to 30% control of grass weeds. Tank mixing these two herbicides at the same rates resulted in 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 by >95%. That combination also controlled green foxtail, barnyardgrass, and large crabgrass by >90%. An additive or synergistic effect between the two herbicides was observed against several broadleaf and grass weed species. Among all the tested weeds, a greater synergistic effect was observed when the herbicides were used on kochia, chickweed, wild mustard, corn poppy, barnyardgrass, green foxtail, and fall panicum. The premix of the two herbicides provided similar control of broadleaf weeds, but better control of grass weeds than the tank-mix combinations. The premix can be used safely on wheat and barley.

Introduction

Wheat is the second-most grown cereal grain after corn with a worldwide production of 790 billion kg (USDA-FAS 2024). On a global scale, wheat is cultivated on 242 million ha, a larger area than any other food crop (FAO 2022). China, the European Union, India, Russia, the 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 and Canada contribute approximately 10% to the world wheat production. In 2023–2024, the United States and Canada produced 49 and 33 billion kg of 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 both countries, where common wheat accounts for approximately 95% of total wheat production.

Among all the biotic factors that potentially limit wheat yields, weeds are the most significant. In general, wheat is not inherently a strong competitor against weeds. Huge wheat yield losses have been reported throughout the world if weeds are left uncontrolled. Khan and Haq (2002), for example, reported 48% to 52% reduction in wheat yields in Pakistan because of weed interference. Similarly, 24% to 30% yield reductions have been reported in 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, in the United States and Canada, with a value of $3.6 billion (Flessner et al. 2021). Wild buckwheat (*Polygonum convolvulus* L.), kochia, cleavers (also known as catchweed or stickwilly [https://plants.usda.gov/]) (*Galium aparine* L.) (the U.S. Department of Agriculture Plants database provides a common name of stickwilly), 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 cereal production in the United States and Canada. Wild buckwheat has become a serious problem throughout the North-Central 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, block sunlight, and reduce photosynthetic activity. Kochia can significantly reduce wheat yields and remains green long after the crop matures, thereby clogging the combines and reducing harvest efficiency (Wolf et al. 2000). Cleavers is highly competitive with 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 that ranged from 18 to 72 plants m^{-2} (Aziz et al. 2009). Common chickweed and wild mustard are also competitive weeds in cereal crop production 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 cereal production. The first herbicide registered for weed control in wheat 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 production. Herbicides that inhibit photosystem II (PS II) were introduced for use in wheat production in the 1970s (US EPA 1998). In the 1980s, herbicides that inhibit acetolactate synthase (ALS), which can control grassy and broadleaf weeds, were introduced for use on wheat. Herbicides that inhibit the acetyl-CoA carboxylase (ACCase) enzyme (e.g., diclofop-methyl) were also introduced in early 1980s to control grass weeds in wheat and other cereal crops (US EPA 2000). Glyphosate was introduced for use on wheat in the late 1990s as a preharvest treatment to control weeds that grow rapidly after the wheat has matured. Hydroxyphenylpyruvate dioxygenase (HPPD)-inhibiting herbicides were introduced for use on cereals in the late 2010s.

All these herbicides played an instrumental role in enhancing wheat production in the United States and Canada by effectively reducing weed competition. However, an overreliance on herbicides had led to selection pressure and evolution of herbicide-resistant weed biotypes. Currently, around the world, 85 weed species that grow among cereals have evolved resistance to herbicides with 15 different sites of action (Heap 2024). In Canada and the United States, 35 weed species found in cereal fields have been reported to have developed resistance to herbicides in groups 1, 2, 3, 4, 5, 9, 14, and 15 (Heap 2024), each of which has a different site of action within a weed (groups are categorized by the Herbicide Resistance Action Committee [HRAC] and the Weed Science Society of America [WSSA]). Unit now, no weed species with resistance to HPPD-inhibiting herbicides (WSSA Group 27) have been reported in cereal production in either Canada or the United States. Currently, three herbicides (pyrasulfotole, bicyclopyrone, and tolpyralate) that inhibit HPPD are available for postemergence weed control in cereals. Among these three HPPD-inhibiting herbicides, tolpyralate is the latest one to obtain registration, 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 control broadleaf weeds only.

A premix of tolpyralate and bromoxynil (a PS II-inhibiting herbicide, HRAC/WSSA Group 6) developed by Corteva Agriscience is now available for use in the United States and Canada with trade names Tolvera™ and OnDeck™, respectively, for postemergence weed control in wheat and barley. Registration approval to use these herbicides may be expanded to other cereal-growing countries. Some previous research has been conducted on tolpyralate and bromoxynil for their weed control efficacy and crop safety to corn (Fluttert et al. 2022a, Fluttert et al., 2022b), but very limited information is available regarding its use on wheat and barley. Hence, this study used greenhouse trials to test the efficacy of tolpyralate and bromoxynil combinations on some key broadleaf and grass weeds and assess their crop safety when applied to spring, winter, and durum wheat and barley.

Materials and Methods

The greenhouse study was conducted during 2023 and 2024 at Corteva Agriscience global headquarters in Indianapolis, Indiana. The study consisted of 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, Concord, OH) and bromoxynil (Moxy® 2E; Winfield Solutions, St. Paul, MN) at 0.25×, 0.5×, 0.75×, and 1× rates of the 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 0.25×, 0.5×, 0.75×, and 1× rates. A premix of tolpyralate and bromoxynil (Tolvera™, Corteva Agriscience, Indianapolis, IN) at 0.25×, 0.5×, 0.75×, and 1× rates of the 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 a safener, cloquintocet-mexyl, per liter. The formulation also contains other inert ingredients, including ethoxylated fatty acid and benzyl alcohol, which have adjuvant and solvent properties, respectively. A To better understand the role the safener plays in the premix formulation, no safener was added to tank-mix treatments of tolpyralate and bromoxynil.

As a reference standard, a premix of pyrasulfotole and bromoxynil (Huskie®; Bayer CropScience, St. Louis, MO) at $30 + 170$ g ha^{-1} was also included in the test. Like tolpyralate, pyrasulfotole (HRAC/WSSA Group 27) is also inhibits HPPD. A total of 18 treatments, including an untreated control, were tested. Methylated seed oil at 5 mL L^{-1} was tank-mixed with all tolpyralate and bromoxynil treatments and a non-ionic surfactant at 2.5 mL L^{-1} 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, including green foxtail, large crabgrass, fall panicum, and common barnyardgrass; and four crops that included 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, three to six seeds were planted in square plastic pots (8.9 cm wide, 7.6 cm high). The soil media consisted of 90% by volume Promix BX (Premier Tech Horticulture, Quakertown, PA) and 10% Profile Greens Grade (Profile Products, Buffalo Grove, IL). Promix BX contains approximately 83% peat moss, 13% perlite, 5% vermiculite, and proprietary amounts of limestone, starter fertilizer, and wetting agent. Profile Greens Grade is a sand-sized granule formed through the calcination of illite and montmorillonite clay. Plants were propagated in a greenhouse at the Corteva global headquarters in Indianapolis, and grown at 28/24 ± 3C day/

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Table 1. Treatments used in the study.

Treatment No.	Herbicide treatment[a]
1	Tank mix of tolpyralate at 3.75 g + bromoxynil 37.5 g ha^{-1} (0.25×)
2	Tank mix of tolpyralate at 7.5 g + bromoxynil 75 g ha^{-1} (0.5×)
3	Tank mix of tolpyralate at 11.25 g + bromoxynil 112.5 g ha^{-1} (0.75×)
4	Tank mix of tolpyralate at 15 g + bromoxynil 150 g ha^{-1} (1×)
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

[a]Adjuvant methylated seed oil at 5 mL L^{-1} was tank-mixed with all tolpyralate and bromoxynil treatments (1 to 16) and a non-ionic surfactant at 2.5 mL L^{-1} was mixed with pyrasulfotole and bromoxinyl treatment (17). X = Field use rate.

night temperatures and 60% to 80% relative humidity. Natural light was supplemented with 1,000-watt metal halide overhead lamps with an average illumination of 470 µmol m^{-2} s^{-1} photosynthetic active radiation for 16 consecutive hours daily. After germination, only one healthy broadleaf weed per pot was allowed to grow, and five grass plants were allowed to grow. Plants were supplied with nutrients and irrigated as required throughout the experiment.

When the weeds and crops were at the 3- to 5-leaf stage, postemergence herbicides were applied using a research track-sprayer (Generation III Research Sprayer; DeVries Manufacturing, Hollandale, MN). The track-sprayer was calibrated to deliver 100 L ha^{-1} using a XR8003VS even-fan spray nozzle (TeeJet Technologies, Glendale Heights, IL) at 276 kPa pressure and a 3.13 km h^{-1} operating speed. Appropriate amounts of formulated product were added to spray vials as calculated by the software package ARM8 (GDM Solutions, Brookings, SD). Herbicide aliquots were diluted with clean tap water to a total volume of 40 mL. 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 d after treatment. After taking estimates of visible control, 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:

$$\text{Biomass reduction}(\%) = [(\mathrm{U} - \mathrm{T})/\mathrm{U}] \times 100 \qquad (1)$$

where U is the average dry weight of the aboveground biomass from the four untreated control replicates and T is the aboveground 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 ANOVA using a generalized linear mixed model (GLIMMIX procedure) in SAS (v. 9.4; SAS Institute, Cary, NC), and means were separated using Tukey's test at a 5% level of significance (α).

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

$$\mathrm{E} = (\mathrm{X} + \mathrm{Y}) - [(\mathrm{X}^{*}\mathrm{Y})/100] \qquad (2)$$

where X and Y are weed control observed with stand-alone tolpyralate and bromoxynil treatments, respectively, and E is the expected weed control with the combination those two herbicides. A 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

Wild buckwheat was controlled by 47% when tolpyralate at 3.75 g ha^{-1} was applied, and the control increased when the herbicide rate increased (Table 2). The 7.5, 11.25, and 15 g ha^{-1} rates provided 67%, 77%, and 84% control, respectively. When bromoxynil at 37.5 g ha^{-1} was applied wild buckwheat control rose to 80%. Control increased to 99% when the bromoxynil rate was increased to 75 g ha^{-1}. A further increase in rate to 112.5 or 150 g ha^{-1} provided full control of wild buckwheat. A tank mix of tolpyralate and bromoxynil at 3.75 + 37.5 g ha^{-1}, respectively, controlled wild buckwheat by 99%, which was significantly greater than the stand-alone treatments of tolpyralate and bromoxynil at the same rates. According the Colby equation (Eq. 2), expected weed control with the combination of tolpyralate and bromoxynil at 3.75 + 37.5 g ha^{-1} was 87%, but the actual observed buckwheat control was significantly higher (99%) than that. This indicates synergy between the two herbicides against wild buckwheat, meaning that the combined effect was greater than the sum of each herbicide acting alone. Synergism between herbicides that inhibit HPPD and PS II 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). PS II inhibitors generate reactive oxygen species (ROS) that cause cell membrane destruction. HPPD inhibitors reduce the plastoquinones, which are needed to dissipate ROS, which in turn, amplifies cell membrane destruction (Fluttert et al. 2022c). A further increase in the tank-mix rates of tolpyralate and bromoxynil did not result in a significant increase in wild buckwheat control. A premix combination of these two herbicides also provided control similar to that of tank-mix combinations. The reference herbicide, the pyrasulfotole and bromoxynil premix (30 + 170 g ha^{-1}), provided full control of wild buckwheat.

The lowest rate of tolpyralate (3.75 g ha^{-1}) provided 33% control of kochia (Table 2). Increasing the rate slightly increased the control but it was not consistent with the rate increase. Kochia control was 42% when bromoxynil at 37.5 g ha^{-1} was applied and control increased to 72%, 84%, and 96% when rates of 75, 112.5, and 150 g ha^{-1}, respectively, were applied. Tank-mix combinations of tolpyralate and bromoxynil provided a synergistic effect on

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Table 2. Wild buckwheat and kochia control with various combinations of tolpyralate and bromoxynil.[a,b,c]

Treatment No.	Herbicide treatment	Wild buckwheat	Kochia
		% 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

[a]Abbreviations: Tol+Bro indicates tank-mix combination; Tol&Bro indicates premix combination.
[b]Means with the same letter within a column do not significantly differ (P < 0.05)
[c]Expected weed control values are shown in 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).

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 it was actually 98%, a 37 percentage 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 formulations of the two herbicides provided similar kochia control to that of tank-mix combinations. The premix of pyrasulfotole and bromoxynil provided 100% control of kochia.

Cleavers, Russian Thistle, and Canada Thistle

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

Control of Russian and Canada thistles was 66% to 74% and 84% to 90%, respectively, when tolpyralate was applied (Table 3). There was no significant difference in control among the tested rates. Canada thistle was more susceptible to tolpyralate than Russian thistle. Both thistles were controlled by 67% with bromoxynil at 37.5 g ha^{-1}, and control increased significantly (83% to 99%) when the 75 g ha^{-1} rate was applied. Thistle control did not increase when the herbicide rate was increased. Russian thistle was more susceptible to bromoxynil than Canada thistle. 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 the 3.75 + 37.5 g ha^{-1} rate exceeded expected control by 9%. An additive effect in favor of 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 the 11.25 + 112.5 g ha^{-1} rate was observed, and all other tank-mix combinations had an additive effect on Canada thistle. A premix of tolpyralate and bromoxynil provided control of all three weeds similar to that of tank-mix combinations. A premix of pyrasulfotole and bromoxynil controlled these weeds by 99% to 100%.

Corn Poppy, Common Chickweed, and Wild Mustard

The trial results indicated that among the 14 tested broadleaf weed species, corn poppy, chickweed, and wild mustard were the most tolerant of tolpyralate (Table 4). Tolpyralate at 3.75 g ha^{-1} controlled these three weeds by only 10% to 32%, and control did not significantly increase when the herbicide rate was increased. Fluttert et al. (2022d) also reported less wild mustard control with tolpyralate, even when applied at 30 g ha^{-1} (51% at 28 d after treatment). Bromoxynil at 37.5 g ha^{-1} controlled corn poppy by 58% and wild mustard by 41%, and control increased to 87% and 81%, respectively, when a 150 g ha^{-1} rate of bromoxynil was applied.

Common chickweed exhibited tolerance to bromoxynil at all the tested rates. Only13% to 31% of chickweed was controlled by bromoxynil, and the control did not consistently increase as the application rate increased. Tank-mix combinations of tolpyralate and bromoxynil were able to control 94% to 100% of corn poppy and 87% to 97% of chickweed. 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 by 60%, and control increased significantly to 89% when the 7.5 + 75 g ha^{-1} rate was applied. A further increase in rate did not result in an increase in wild mustard control. A strong synergy was observed between tolpyralate and bromoxynil in controlling corn poppy, chickweed, and wild mustard. The expected corn poppy control with the 3.75 + 37.5 g ha^{-1} rate was 72%, but the observed control 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, than the expected control. Tolpyralate and bromoxynil at 3.75 + 37.5, 7.5 + 75,

Table 3. Cleavers, Russian thistle, and Canada thistle control with various combinations of tolpyralate and bromoxynil.[a,b,c]

Treatment No.	Herbicide treatment	Cleavers	Russian thistle	Canada thistle
			% 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

[a]Abbreviations: Tol+Bro indicates tank-mix combination; Tol&Bro indicates premix combination.
[b]Means with the same letter within a column do not significantly differ ($P < 0.05$).
[c]Expected weed control values are shown in 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 4. Corn poppy, chickweed, and wild mustard control with various combinations of tolpyralate and bromoxynil.[a,b,c]

Treatment No.	Herbicide treatment	Corn poppy	Common chickweed	Wild mustard
			% 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

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

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 excellent control of wild mustard when tolpyralate and bromoxynil was applied to a corn crop, but with higher rates (30 + 280 g ha^{-1}).

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

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% of redroot pigweed and Palmer amaranth, respectively. Increasing the rate of tolpyralate resulted in a slight increase in control of both weeds. The highest rate of tolpyralate (15 g ha^{-1}) controlled both weeds by ≥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 by only 50% and 18%, respectively. There was no significant difference in control among the rates. Since the tolpyralate provided maximum efficacy against pigweed, tank-mixing it with bromoxynil provided marginal or no additive effect. A premix of tolpyralate and bromoxynil controlled these two weeds to a degree that was similar to that of tank-mix

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Table 5. Redroot pigweed and Palmer amaranth control with various combinations of tolpyralate and bromoxynil.[abc]

Treatment No.	Herbicide treatment	Redroot pigweed	Palmer amaranth
		——% 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

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

combinations. The field use rate of pyrasulfotole and bromoxynil (30 + 170 g ha^{-1}) controlled redroot pigweed by 99% but it controlled Palmer amaranth by 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 by 98% to 100%, shepherd's purse by 97% to 100%, horseweed by 91% to 97%, and common ragweed by 93% to 98% (Table 6). There was no significant difference in control among the four herbicide rates tested. These results align with findings reported by Metzger et al. (2018b) that the effective rate of tolpyralate to achieve 90% control of common lambsquarters, common ragweed, and redroot pigweed is ≤15.5 g ha^{-1}. Bromoxynil at 37.5 g ha^{-1} controlled lambsquarters by 60%, shepherd's purse by 59%, horseweed by 57%, and common ragweed by 70%, and control increased when the herbicide rate was increased. The 150 g ha^{-1} rate controlled these weeds by 96%, 81%, 87%, and 85%, respectively. Tank mixing tolpyralate and bromoxynil controlled these four broadleaf weeds by 99% to 100%. A synergistic effect between these two herbicides against all four weeds was observed at the 3.75 + 37.5 g ha^{-1} rate. Slightly greater control was observed than the 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 in horseweed control. Fluttert et al (2022b) also reported greater synergy between bromoxynil and HPPD-inhibiting herbicides, including tolpyralate, against horseweed. Premixes of tolpyralate + bromoxynil and pyrasulfotole + bromoxynil provided complete control of all four broad leaf weeds.

Grass Weed Control

An application of tolpyralate at 3.75 g ha^{-1} resulted in 77% control of green foxtail, 52% of barnyard grass, 27% of fall panicum, and 76% of large crabgrass (Table 7). Control of these grasses increased when the rate increased. The highest rate of tolpyralate (15 g ha^{-1}) provided 90%, 87%, 49%, and 87% control, respectively, of the grasses just mentioned. On the other hand, as expected, bromoxynil was less effective against grasses. Some suppression was observed but not more than 30% control was recorded with any tested rates of bromoxynil. A tank-mix combination of tolpyralate and bromoxynil at 3.75 + 37.5 g ha^{-1} provided 94% control of green foxtail, which was 16% higher than the expected control. The other three rates (7.5 + 75 g ha^{-1}, 11.25 + 112.5 g ha^{-1}, and 15 + 150 g ha^{-1}) also provided 15%, 11%, and 7% more green foxtail control, respectively, than the expected control. Similarly, 7% to 33% greater control of barnyard grass and 18% to 22% greater control of fall panicum was achieved than the expected control by tank mixing tolpyralate and bromoxynil. This indicates greater synergy between the two herbicides in controlling green foxtail, barnyard grass, and fall panicum. Combinations of these two herbicides provided up to 93% control of large crabgrass, and some additive effects between the two herbicides were observed at higher rates.

Premix and tank-mix formulations of tolpyralate and bromoxynil provided similar control of green foxtail, barnyard grass, and large crabgrass, but the premix formulation provided better control of fall panicum (58% to 97%) than the tank-mix combinations, which provided 45% to 81% control. The surfactants ethoxylated fatty acid and benzyl alcohol that are present in the premix formulation might have helped achieve greater efficacy against fall panicum. The reference standard, a combination of pyrasulfotole and bromoxynil, provided 9%, 14%, 32%, and 89% control of large crabgrass, green foxtail, fall panicum, and barnyard grass, respectively, and these percentages are significantly lower than those recorded when tolpyralate and bromoxynil were used. This was expected because the combination of pyrasulfotole and bromoxynil has been registered only for broadleaf weed control in cereal crops.

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

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Table 6. Lambsquarters, shepherd's purse, horseweed, and common ragweed control with various combinations of tolpyralate and bromoxynil.[a,b,c]

Treatment No.	Herbicide treatment	Lambsquarters	Shepherd's purse	Horseweed	Common ragweed
		% 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 c	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

[a]Abbreviations: Tol+Bro indicates tank-mix combination; Tol&Bro indicates premix combination.
[b]Means with the same letter within a column do not significantly differ ($P < 0.05$).
[c]Expected weed control values are shown in 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 7. Green foxtail, barnyardgrass, fall panicum, and large crabgrass, control with various combinations of tolpyralate and bromoxynil.[a,b,c]

Treatment No.	Herbicide treatment	Green foxtail	Barnyardgrass	Fall panicum	Large crabgrass
		% 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

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

Crop Response

Tolpyralate and bromoxynil caused slight injury to cereal crops at 21 d after herbicide application (Table 10). Across the tested rates, tolpyralate caused 3% to 4% and 4% to 8% injury to winter and spring wheat, respectively. The symptoms included slight bleaching of the leaves and some stunted growth. Bromoxynil caused some injury (stunted growth) to winter wheat and spring wheat (2% to 3% and 6% to 8%, respectively). Neither the tank mixtures nor the premixtures of the two herbicides increase the injury to any significant degree. Tolpyralate caused 1% to 4% injury, and bromoxynil caused 1% to 5% injury to durum wheat. The tank mix of these two herbicides elevated the injury to 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, to barley, and tank mixes caused 13% to 20% injury. However, the premix formulation of these two herbicides caused only 7% to 14% injury. The reduced injury to durum wheat and barley with premix formulations over the tank-mix combinations of tolpyralate and bromoxynil could be due to presence of the safener cloquintocet-mexyl in the formulation. The reference standard, a premix of pyrasulfotole + bromoxynil, which has the safener mefenpyr-diethyl, caused mild injury (3% to 6%) to wheat and 11% injury to barley.

Practical Implications

Results from the greenhouse study suggest that the newly registered premixture of tolpyralate, which inhibits HPPD, and bromoxynil, which inhibits PS II, is an excellent herbicide option

Table 8. Aboveground dry biomass reduction in broadleaf weeds compared with a nontreated control at 21 d after herbicide application.[a,b]

Treatment No.	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

Abbreviations: Tol+Bro indicates tank-mix combination; Tol&Bro indicates premix combination.
[b]Means with the same letter within a column do not significantly differ ($P < 0.05$).

Table 9. Aboveground dry biomass reduction in broadleaf and grassy weeds compared with a nontreated control at 21 d after herbicide application.[a,b]

Treatment No.	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	99 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

[a]Abbreviations: Tol+Bro indicates tank-mix combination; Tol&Bro indicates premix combination.
[b]Means with the same letter within a column do not significantly differ ($P < 0.05$).

Table 10. Wheat and barley response to various combinations of tolpyralate and bromoxynil at 21 d after herbicide application.[a,b]

Treatment No.	Herbicide treatment	Winter wheat	Spring wheat	Durum wheat	Spring barley
		% Phytotoxicity			
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

[a]Abbreviations: Tol+Bro indicates tank-mix combination; Tol&Bro indicates premix combination.
[b]Means with the same letter within a column do not significantly differ ($P < 0.05$).

for broad-spectrum weed control in wheat and barley. Additive or synergistic effects between the two herbicides was observed when they were used to control several broadleaf and grass weeds. The greatest advantage of the co-application of these two herbicides was observed in control of kochia, chickweed, wild mustard, corn poppy, barnyard grass, green foxtail, and fall panicum. The premix formulation of the two herbicides controlled broadleaf weeds to a degree that was similar to tank mix combinations, but the premix formulation provided much better control of grass weed species. Other HPPD-inhibiting herbicides (pyrasulfotole and bicyclopyrone) currently available in combination with bromoxynil for use on cereals are labeled only for broadleaf weed control, but the tolpyralate + bromoxynil combination can effectively control broadleaf weeds and some important grass weeds. Even though the lower rates provided good control of some weed species, using the full rate of the herbicide is recommended to achieve broad-spectrum and effective weed control. The premix formulation of the two herbicides is safe to use on wheat (spring, winter, and durum) and barley. Although the results reported here are from a greenhouse study, similar outcomes are expected in field conditions if herbicide label recommendations are followed, and favorable weather conditions prevail.

Competing Interests

The authors declare they have no competing interests.

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