J. Crop Prot. **2024, 13 (4): 349-360**

Research Article

Sensitivity and tolerance of quinoa to 22 herbicides registered for other crops

Ehsan Akbari Darabkhani, Goudarz Ahmadvand and Akbar Aliverdi*

Department of Plant Production and Genetics, Faculty of Agriculture, Bu-Ali Sina University, Hamedan, Iran.

Abstract: A pot study was conducted outside the greenhouse at Bu-Ali Sina University, Hamedan, Iran, in 2022. For each of the 22 herbicides tested, a dose-response experiment, applying zero, $^1/_{16}$, $^1/_8$, $^1/_4$, $^1/_2$, and 1 × labeled dose, was conducted. Soil- and foliar-applied herbicides were used after sowing the seeds and at the quinoa's 3-4 leaf stage, respectively. Quinoa had the highest sensitivity to acetochlor and linuron. Using one-eighth of their labeled dose, no seedlings could grow. Approximately 2, 4, and 7% of the labeled dose of acetochlor or 3, 5, and 9% of the labeled dose of linuron were required to reduce 10, 50, and 90% in fresh:dry weight ratio, respectively. The application of $^1/_{16}$, $^1/_8$, and $^1/_4$ × labeled dose of trifluralin, oxyfluorfen, bentazon, phenmedipham + desmedipham + ethofumesate, clomazone, clopyralid, chloridazone, ioxynil, tribenuron-methyl, metribuzin, pendimethalin, nicosulfuron, sulfosulfuron, and bispyribac-sodium caused a 10% reduction in fresh:dry weight ratio of quinoa. To reduce the fresh:dry weight ratio of quinoa by 10%, it needed to use 1.78 and 1.56 times the labeled doses of pinoxaden and clodinafop-propargyl, respectively, and half of the labeled dose of sethoxydim, haloxyfop-r-methyl, triflusulfuron-methyl, and imazethapyr. As a recommendation, the efficacy of selected (pinoxaden and clodinafop-propargyl) and promising herbicides (sethoxydim, haloxyfop-r-methyl, triflusulfuron-methyl, and imazethapyr) should be evaluated under field conditions from the prospects of quinoa yield and weed control.

Keywords: *Chenopodium quinoa*, dose-response, graminicide, Titicaca cultivar

Introduction

Quinoa *Chenopodium quinoa* Willd. is an annual plant belonging to the Amaranthaceae family, which was domesticated thousands of years ago by people living in the Andes Mountains (Peru, Colombia, Ecuador, Chile and Bolivia) (Hinojosa et al., 2018). The oldest archaeological remains of quinoa date back to 5000 BC (Navruz-Varli and Sanlier, 2016). It has high adaptability and tolerance to various environmental stresses such as heat (Hinojosa *et al*., 2018), drought (Fghire *et al*., 2015), salinity (Iqbal *et al*., 2017), ultraviolet radiation (Hilal *et al*., 2004), heavy elements (Bhargava *et al*., 2008), freezing (Jacobsen *et al*., 2005) and flooding (González *et al*., 2009). Moreover, it has exceptional properties and nutritional value (Navruz-Varli and Sanlier, 2016). These advantages of quinoa were so convincing to the United Nations General Assembly that it named 2013 the International Year of Quinoa. Farmers

Handling Editor: Eshagh Keshtkar

*Corresponding authors: a.aliverdi@basu.ac.ir
Received: 02 November 2023, Accepted: 25 December 2024
Published online: 29 December 2024

and agricultural experts around the world were encouraged to cultivate this plant (United Nations, 2013). This action of the United Nations caused the cultivation area of quinoa and its yield to increase by 10.1 and 26.2% from 2012 to 2021, respectively (FAO, 2023).

The seeds of quinoa germinate quickly (6-10 h after imbibition (Makinen *et al*., 2014)), but their seedlings grow slowly in the first two weeks after germination. Therefore, for proper establishment and prevention of quantitative and qualitative reduction in yield, it is necessary to manage and control weeds. For quinoa, the critical period of weed control has been estimated between 16 and 30 days after quinoa emergence (Nurse *et al*., 2016), and in another similar experiment, between 10 and 75 days after quinoa emergence (Merino *et al*., 2019). A previous report shows that the seed yield of quinoa and the seed protein of quinoa can be reduced by 38.8 and 29.4%, respectively, due to lack of weed control throughout the season (Jacobsen *et al*., 2010).

So far, no herbicides have been registered for use in quinoa fields (Abbaspour, 2022). For this reason, weeds in quinoa fields are mainly controlled by mechanical methods like using inter-row cultivators and hand weeding. The effect of some weed cultural control methods has also been investigated in previous studies; for example, the type of cultivar and their allelopathic characteristics (El-Sadek *et al*., 2017), false seedbed (Jacobsen *et al*., 2010), planting date and density (Nurse *et al*., 2016), planting row spacing (Liang *et al*., 2020), intercropping with potato (Jalali *et al*., 2021) and hairy vetch (Buckland *et al*., 2018), and seed inoculation with biofertilizer (Joukar Fathabadi and Kazemeini, 2022). The effectiveness of the mentioned methods is not always sufficient and convincing. Therefore, the low competitiveness of quinoa against weeds, the high costs of mechanical control methods, and the development of the ever-increasing area of quinoa cultivation force us to adopt the most effective and time-efficient method of managing weeds to prevent quantitative-qualitative yield loss of quinoa. Therefore, quick, effective, and economic control of weeds in quinoa fields seems necessary. Herbicides are an integral part of modern agriculture and can meet such a demand, although there are concerns regarding their residues in crops and side effects on non-target organisms (Kudsk, 2008).

So far, 294 herbicides have been discovered and used, of which 260 cases are still produced and available (HRAC, 2024). Recently, some researchers have pursued the need for preliminary screening of herbicides to find the appropriate selective herbicide(s) for use in quinoa fields. Elford (2016) tested 7 herbicides and reported that promising herbicides were pendimethalin, S-metolachlor + benoxacor, which had minor damage to quinoa. Garnica *et al*. (2017) tested 6 herbicides and reported that pethoxamid and S-metolachlor had a high selectivity for quinoa. Pannacci *et al*. (2019) reconfirmed the selectivity of S-metolachlor for quinoa. Merino *et al*. (2020) found none of the tested bentazon and fomesafen to have good selectivity for quinoa unless they were applied in splits. Abbaspour (2022) tested 23 herbicides under field conditions and reported that clethodim and quizalofop-p-tefuryl controlled grassy weeds by 96 and 81% without injury on quinoa, respectively.

The study aimed to screen 22 herbicides (belonging to 11 herbicide groups) to select potential herbicides for use in quinoa fields. Unlike the previous research mentioned above, where only the labeled dose of herbicides has been tested, the present study was conducted as a dose-response experiment to investigate the response of quinoa to different doses of 22 herbicides in semi-field conditions. This is because if quinoa tolerates dose(s) lower than the label dose, it is still considered a promising herbicide since an appropriate safener can eliminate minor plant burns.

Materials and Methods

The study was conducted under semi-field conditions (air temperature and relative humidity were measured between 17-32 °C and

21-34%, respectively) in the summer of 2022 at Bu-Ali Sina University, Hamedan, Iran. The Titicaca cultivar of quinoa was used, which was obtained from the Karaj Seed and Plant Breeding Research Institute. Brown plastic 2-L pots with a square section of 13 × 13 × 13 cm were used for growing the plants. The soil used to prepare the seedbed had a sandy loam texture, which was transferred from the neighboring farm and added into the pots in equal amounts. Soil characteristics include 12.2% clay, 27.2% silt, 60.5% sand, 12.3 dS/m electrical conductivity, 7.6 pH, 1.1% organic matter, 57.2 ppm phosphorus, 368.2 ppm potassium, and 0.1% nitrogen. For POST- and PRE-emergence herbicides, 10 and 100 seeds were planted in each pot, respectively. The seeds were distributed on the soil surface; then 0.5 cm of soil was added. The initial sub-irrigation was conducted from beneath the pots in a leaking manner, while the subsequent irrigations were performed on the surface, applying equal amounts every two or three days. For POST-emergence herbicides, plants were thinned in two stages to maintain five plants per pot.

For each of the 22 herbicides tested in this study (Table 1), a dose-response experiment was conducted as a completely randomized design with four replications. The treatments included the application of 6 rates of each herbicide (zero, $^1/_{16}$, $^1/_8$, $^1/_4$, $^1/_2$, and 1 time the label rate; Table 1). The maximum rate tested was equal to the lowest dose labeled for other crops, which is mentioned on the label. The PRE-emergence herbicides were used immediately after sowing the seeds, and POST-emergence herbicides were used immediately at the 3-4 leaf stage of quinoa. The treatments were applied under open-air conditions by a battery-powered backpack sprayer equipped with an 11002 Even Flat Fan nozzle and calibrated to deliver 230 L ha^{-1} at a pressure of 3 bar.

Four weeks after treatment, the shoots of the plants were removed from the soil surface, fresh weight was immediately weighed, and then dry weight was weighed after two days, placing in the oven at 70 °C. The obtained data were divided by the number of plants in each pot, and the fresh:dry weight ratio was statistically analyzed. The fresh:dry weight ratio of quinoa shows the degree of burning the plant against herbicides. The lowest possible ratio is 1, indicating the entire surface of the shoots is dried. The closer the ratio is to 1, the greater the activity of the herbicide (Rytwo and Tropp, 2001). It should be noted that some of the data related to PRE-emergence herbicides, especially the data related to higher doses, were obtained as zero (no seedlings had grown). Since the result of dividing the fresh weight (zero) by the dry weight (zero) cannot be defined, the ratio in such cases is considered 1 and then analyzed.

Data analysis

The response of the fresh:dry weight ratio of quinoa (Y) to the rates of each herbicide was analyzed using a non-linear regression method via the drc package of the R. Based on the results of the lack-of-fit test (p-value < 0.05), the 4-parameter log-logistic model (Ritz et al., 2015) provided an acceptable fit to the data. Based on the graph of the residuals related to each dose-response curve, their independent, random, and uniform distribution was determined.

$$Y = \frac{C+(D\text{-}C)}{\{1+\exp[B(\log(X)\text{-}\log(ED_{50})]\}}$$

Where, *D* and *C* are the maximum and minimum asymptotes of *Y*, respectively; ED_{50} is where *Y* is halfway between *D* and *C*, donating an effective dose for a 50% reduction in fresh:dry weight of quinoa; and *B* is the slope of the fitted nonlinear-regression line around ED_{50}. Then, the ED_{10} and ED_{90}, denoting an effective dose for 10 and 90% reduction in fresh:dry weight ratio of quinoa, were obtained, respectively. The EDs were estimated at a 95% significance level, and the standard error of each ED was used to compare them (Ritz *et al*., 2015).

Table 1 Herbicides and doses ($^1/_{16}$, $^1/_8$, $^1/_4$, $^1/_2$, & 1 labeled doses) used.

Common name (Group based on 2024 HRAC)	Trade name (Formulation)	Doses (g a.i. ha^{-1})	Method
Clodinafop propargyl (1)	Topic® (8% EC)	4, 8, 16, 32, & 64	POST
Haloxyfop-r-methyl (1)	Galant-Super® (10.8% EC)	5.0, 10.1, 20.2, 40.5, & 81	POST
Pinoxaden (1)	Axial® (5% EC)	0.35, 0.7, 1.4, 2.8, & 5.6	POST
Sethoxydim (1)	Nabu-S® (12.5% EC)	23.4, 46.8, 93.7, 187.5, & 375	POST
Bispyribac-sodium (2)	Nominee® (10% OF)	1.5, 3.1, 6.2,12.5, & 25	POST
Imazethapyr (2)	Pursuit® (10% SL)	6.2, 12.5, 25, 50, & 100	POST
Nicosulfuron (2)	Cruz® (4% SC)	5, 10, 20, 40, & 80	POST
Sulfosulfuron (2)	Aspirus® (75% WG)	1.2, 2.5, 5, 10, & 20	POST
Tribenuron-methyl (2)	Granstar® (75% DF)	0.7, 1.4, 2.8, 5.6, & 11.25	POST
Triflusulfuron-methyl (2)	Safari® (60% DF)	1.1, 2.25, 4.5, 9, & 18	POST
Bentazon (6)	Bazagran® (48% SL)	90, 180, 360, 720, & 1440	POST
Ioxynil (6)	Totryl® (22.5% EC)	28.1, 56.25, 112.5, 225, & 450	POST
Oxyfluorfen (14)	Goal® (24% EC)	22.5, 45, 90, 180, & 360	POST
Clopiralid (4)	Lontrel® (30% SL)	11.25, 22.5, 45, 90, & 180	POST
Chloridazone (5)	Pyramin® (65% DF)	165.5, 325, 650, 1300, & 2600	POST
Metribuzin (5)	Sencor® (70% WP)	43.75, 87.5, 175, 350, & 700	PRE
Linuron (5)	Afhalen® (45% SC)	56.25, 112.5, 225, 450, & 900	PRE
Clomazone (34)	Command® (48% EC)	30, 60, 120, 240, & 480	PRE
Pendimethalin (3)	Stomp® (33% EC)	61.8, 123.75, 247.5, 495, & 990	PRE
Trifluralin (3)	Treflan® (48% EC)	60, 120, 240, 480, & 960	PRE
Acetochlor (15)	Acenit® (50% EC)	125, 250, 500, 1000, & 2000	PRE
Phenmedipham (5) + Desmedipham (5) + Ethofumesate (15)	Bethanal-Progress® (27.4% EC)	51.3, 102.75, 205.5, 411, & 822	POST

Results

The dose-response curves of fresh:dry weight ratio of quinoa to foliar- and soil-applied herbicides are shown in Figs. 1 and 2, respectively. The values of ED_{10}, ED_{50}, and ED_{90} for all herbicides, are estimated in Table 2. The ED_{10}, ED_{50}, and ED_{90} obtained for clodinafop-propargyl, haloxyfop-r-methyl, pinoxaden, sethoxydim, imazethapyr, and triflusulfuron-methyl were more than the maximum rate applied in this study. They were estimated through model extrapolation. Therefore, they are unreliable unless they are tested again with higher rates.

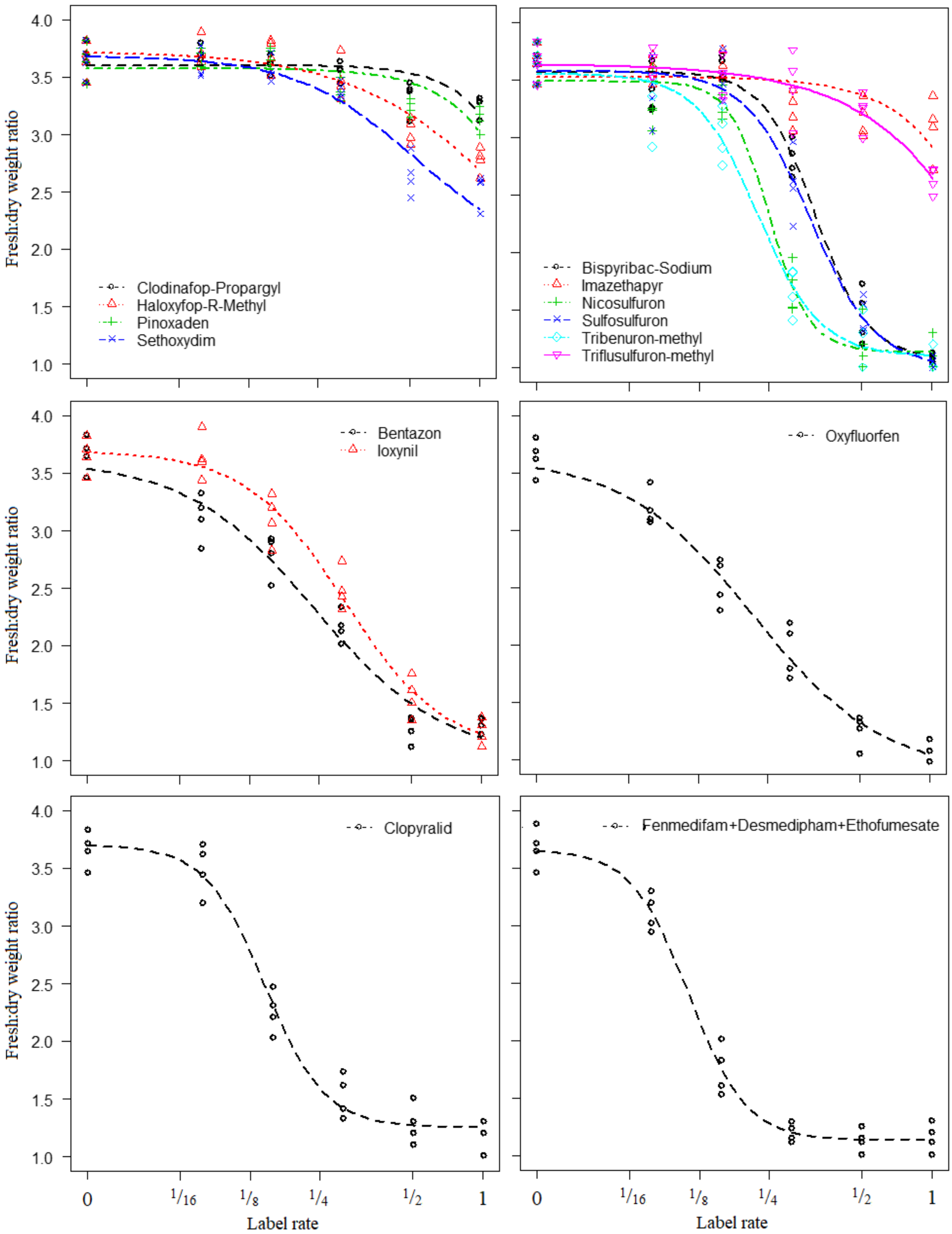

Figure 1 Dose-response curves of the fresh:dry weight ratio of quinoa (shoot) to different doses (labeled dose) of POST-emergence herbicides.

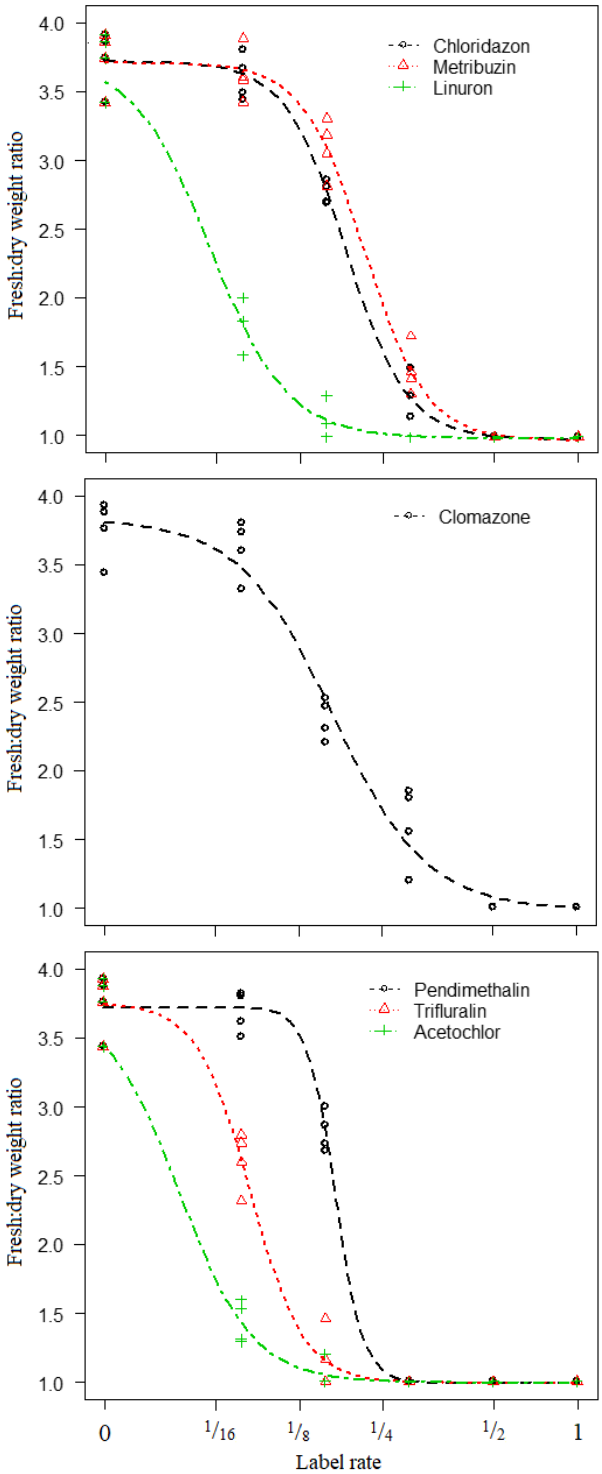

Figure 2 Dose-response curves of the fresh:dry weight ratio of quinoa (shoot) to different doses (labeled dose) of PRE-emergence herbicides.

Table 2 The dose of herbicide required to reduce fresh:dry weight ratio of quinoa (*Chenopodium quinoa*) by 10 (ED_{10}), 50 (ED_{50}) and 90% (ED_{90}).

Herbicide (Group based on HRAC)	ED_{10} (g a.i. ha^{-1})	ED_{50} (g a.i. ha^{-1})	ED_{90} (g a.i. ha^{-1})
Clodinafop propargyl	99.84 (9.60) ^{a}	121.60 (18.56) ^{ab}	131.84 (34.58) ^{a}
Haloxyfop-r-methyl	58.32 (6.48) ^{bc}	128.79 (11.34) ^{b}	144.18 (72.90) ^{ab}
Pinoxaden	111.25 (15.33) ^{a}	124.57 (18.12) ^{a}	130.62 (18.12) ^{a}
Sethoxydim	195.37 (41.05) ^{c}	427.50 (61.25) ^{c}	708.75 (178.10) ^{ab}
Bispyribac-sodium	4.25 (0.22) ^{d}	7.75 (0.50) ^{cd}	13.75 (1.71) ^{c}
Imazethapyr	95.11 (17.41) ^{b}	153.54 (17.24) ^{b}	170.38 (16.03) ^{b}
Nicosulfuron	10.30 (1.43) ^{e}	15.87 (0.99) ^{de}	24.44 (2.13) ^{d}
Sulfosulfuron	2.86 (0.39) ^{de}	5.79 (0.44) ^{d}	11.73 (2.14) ^{c}
Tribenuron-methyl	1.02 (0.15) ^{f}	1.99 (0.13) ^{e}	3.91 (0.58) ^{d}
Triflusulfuron-methyl	15.05 (3.51) ^{b}	28.29 (5.40) ^{b}	30.24 (8.64) ^{b}
Bentazon	67.82 (16.70) ^{gh}	275.61 (35.13) ^{de}	1118.59 (145.60) ^{c}
Ioxynil	39.36 (6.16) ^{f}	15.47 (10.66) ^{d}	338.80 (73.53) ^{c}
Oxyfluorfen	15.08 (3.61) ^{ghi}	62.13 (7.22) ^{e}	255.60 (64.80) ^{c}
Clopiralid	10.87 (1.81) ^{g}	20.66 (9.18) ^{fg}	39.43 (3.42) ^{ef}
Chloridazone	218.14 (13.00) ^{f}	379.60 (10.40) ^{f}	663.01 (49.41) ^{e}
Metribuzin	68.02 (4.91) ^{f}	119.49 (5.39) ^{e}	209.93 (14.00) ^{d}
Linuron	21.33 (5.41) ^{i}	42.93 (2.70) ^{i}	86.41 (9.01) ^{gh}
Clomazone	27.12 (3.40) ^{g}	63.36 (4.56) ^{f}	148.32 (24.00) ^{de}
Pendimethalin	103.75 (13.26) ^{ef}	134.30 (8.02) ^{f}	173.25 (39.60) ^{f}
Trifluralin	39.84 (3.26) ^{h}	64.70 (2.01) ^{h}	105.01 (10.56) ^{g}
Acetochlor	38.60 (24.01) ^{i}	75.20 (20.82) ^{i}	146.22 (15.88) ^{h}
Phenmedipham + Desmedipham + Ethofumesate	39.71 (3.28) ^{g}	74.06 (2.46) ^{g}	138.09 (8.22) ^{f}

The numbers in parentheses are standard errors. In each column, the values with the same letter are not different. The letters have been added to the values as the labeled dose is assumed to be 1.

As it is clear from the dose-response curves, when the labeled dose of bispyribac-sodium, nicosulfuron, sulfosulfuron, tribenuron-methyl, bentazon, ioxynil, oxyfluorfen, and clopyralid was applied, the fresh:dry weight ratio of quinoa was close to 1, which indicates that herbicide injury was complete (100%). When half of the labeled dose of phenmedipham + desmedipham + etofomazite, chloridazone, metribuzin, linuron, clomazone, pendimethalin, trifluralin, and acetochlor was applied, the fresh:dry weight ratio of quinoa was 1 or very close to 1. Meanwhile, when a quarter of the labeled dose of phenmedipham + desmedipham + etofomazite, pendimethalin, trifluralin, and acetochlor was applied, the fresh:dry weight ratio of quinoa was equal to 1, which indicates quinoa is highly sensitive to these four herbicides.

Quinoa was the most sensitive to acetochlor and linuron, so no seedlings grew using one-eighth of the labeled rates. To obtain 10, 50, and 90% injury, it was required 2, 4, and 7% of the labeled dose of acetochlor or 3, 5, and 9% of the labeled dose of linuron, respectively. Also, the results showed that the use of less than a quarter of the labeled dose of acetochlor, linuron, trifluralin, oxyfluorfen, bentazon, phenmedipham + desmedipham + etofomazite, clomazone, clopyralid, chloridazone, ioxynil, tribenuron-methyl, metribuzin, pendimethalin, nicosulfuron, sulfosulfuron, and bispyribac-sodium caused 10% injury to quinoa, showing the high sensitivity of quinoa to the mentioned herbicides. Among the herbicides tested, quinoa had the highest tolerance to pinoxaden and clodinafop-propargyl. It was estimated that 10% injury would be achieved by using 1.78 and 1.56 times the labeled dose, respectively, and for 90% injury, it would be needed to be more than two times the labeled dose of these two herbicides.

Regarding sethoxydim, haloxyfop-r-methyl, triflusulfuron-methyl, and imazethapyr, the results showed that for 10% injury of quinoa, half (sethoxydim) to 1 time the labeled dose (imazethapyr) was needed.

Discussion

Abbaspour (2022) reported more than 75% injury of quinoa with the labeled dose of sulfosulfuron, tribenuron-methyl, and clopyralid. Merino et al. (2020) reported that bentazon at the labeled dose does not have selective quality for application in quinoa fields unless the labeled dose is used as a 2- or 3-split application. Contrary to the report of Abbaspour (2022), reporting a 7% injury to quinoa due to the application of the labeled dose of acetochlor, in the present study, the application of one-eighth of the labeled dose of acetochlor completely prevented the emergence of quinoa seedlings (Fig. 2). This difference in observations can be attributed to two reasons: the difference in experimental conditions (semi-field versus field), the difference in acetochlor formulation in terms of inert ingredients (Acenit® 50% EC in our study versus Surpass 76% EC in Abbaspour's study), or soil type, quinoa variety, and the spray volume applied.

The selection index is used to choose a selective herbicide for a crop; it is defined as the ratio of ED_{10} of herbicide on the crop to ED_{90} of herbicide on the weed (Tind et al., 2009). If the value of the selection index is ≥ 2, the herbicide can be used selectively for the crop (Ghirardello *et al*., 2021). Although no weed was investigated in the present study, the labeled dose of herbicides is recommended based on 90% control of weeds in fields. With such an assumption, the selection index for the herbicides mentioned above for quinoa will be less than 0.25. For this reason, these herbicides cannot be considered for use in quinoa. In addition, among these herbicides, there are herbicides of group B (tribenuron-methyl, nicosulfuron, sulfosulfuron, and bispyribac-sodium), which have residues for the year after application (Melo *et al*., 2016). Due to the high sensitivity of quinoa to very low doses of these herbicides, the cultivation of quinoa might be avoided after wheat (if treated with tribenron-methyl and sulfosulfuron), corn (if treated with nicosulfuron), and rice (if treated with bispyribac-sodium). de Barros-Santos *et al*. (2003) reported that the application of imazaquin and clomazone at 206 days before planting quinoa caused significant injury to quinoa. However, they reported that trifluralin and pendimethalin had no residual effect on quinoa growth. Moreover, due to the significant injury or death of quinoa seedlings caused by the low doses of the mentioned herbicides, exposure of quinoa to spray drift or tank contamination should be of concern to quinoa growers. Therefore, caution should be used when using these herbicides near quinoa fields. However, based on the results obtained, it can be expected that applying the mentioned herbicides to the relevant crops can effectively control volunteer quinoa.

Quinoa had the highest tolerance to pinoxaden and clodinafop-propargyl. Similarly, Abbaspour (2022) observed no injury to quinoa with the application of clodinafop-propargyl at its labeled dose. With the previously mentioned assumption, it seems that the selection index for pinoxaden and clodinafop-propargyl on quinoa is higher than 2. Therefore, they can be considered for use in quinoa fields. Pinoxaden and clodinafop-propargyl are from herbicide group A, which are a graminicide and are usually not lethal on dicotyledonous plants (Zand et al., 2021). Therefore, the reason that quinoa was unaffected by pinoxaden and clodinafop propargyl can be related to the lack of binding of the herbicide to the heteromeric isomer of acetyl coenzyme A carboxylase, which is different from that found in grasses (homomeric). Therefore, the two possible fates that could be followed for these herbicides in quinoa are (1) the decomposition of the herbicide into non-toxic compounds and (2) the incorporation of the herbicide into different parts of the cell without molecular change. The herbicide may be inactivated by binding to an intracellular molecule (e.g., a sugar) or it may move and be deposited from metabolically active areas of the cell to inactive areas (e.g., the cell wall) where it has no effect. In this case, after consuming the cell (plant) by animals or humans, the herbicide is released from the substance attached to it and can cause various diseases. The phenomenon of herbicide incorporation in some group A herbicides has already been reported (Konishi and Sasaki, 1994). For this reason, if residues of these two herbicides do not remain in quinoa due to metabolism (first fate), they can be recommended for use in quinoa fields after carrying field-based tests.

Regarding sethoxydim, haloxyfop-r-methyl, triflusulfuron-methyl, and imazethapyr, the results showed that for 10% injury of quinoa, half (sethoxydim) to about the labeled dose (imazethapyr) was needed. Similarly, Pannacci et al. (2019), who investigated the effect of triflusulfuron-methyl on quinoa yield under field conditions, reported that the injury caused by triflusulfuron-methyl was insignificant. Later, the symptoms of injury disappeared, and the quinoa was recovered. Nevertheless, they reported that the treatment of triflusulfuron-methyl application caused a decrease in the seed yield of quinoa from 1990 to 951 kg ha^{-1}. The reason for this decrease was the ineffectiveness of triflusulfuron-methyl in controlling certain types of weeds in the field, not herbicide injury to quinoa. Although they did not specify the tolerant weed species(s), they listed weeds, including redroot amaranth (*Amaranthus retroflexus*), common purslane (*Portulaca oleracea*), barnyard grass (*Echinochloa crus-galli*), common lambsquarters (*Chenopodium album*), and black nightshade (*Solanum nigrum*). Absence of injury using the labeled amount of sethoxydim and haloxyfop-r-methyl to quinoa was reported by Abbaspour (2022).

In conclusion, this study showed that pinoxaden and clodinafop-propargyl can be used as selective herbicides in quinoa fields due to no injury, provided they are degraded in the plant. Since both are graminicides, another method, such as hand weeding should be taken to control broadleaf weeds in the quinoa field. Although quinoa tolerated doses lower than the labeled dose of sethoxydim, haloxyfop-r-methyl, triflusulfuron-methyl, and imazethapyr, they can be considered as promising herbicides because minor injuries can be removed by using an appropriate herbicide safener. For example, the results of the application of salicylic acid as an herbicide safener to increase the tolerance of corn to the non-selective herbicide sethoxydim have been reported by Shafei *et al*. (2022). It is necessary to evaluate the efficacy of selected (pinoxaden and clodinafop-propargyl) and promising (sethoxydim, haloxyfop-r-methyl, triflusulfuron-methyl, and imazethapyr) herbicides under lambsquarters-infested field conditions. Lambsquarters is a troublesome weed that is a close relative of quinoa.

References

Abbaspoor, M. 2022. Herbicide screening for weed control in quinoa (*Chenopodium quinoa* Willd.). Journal of Plant Production, 29(3): 89-104.

Bhargava, A., Shukla, S., Srivastava, J., Singh, N. and Ohri, D. 2008. *Chenopodium*: a prospective plant for phytoextraction. Acta Physiologiae Plantarum, 1: 111-120.

Buckland, K. R., Reeve, J. R., Creech, J. E. and Durham, S. L. 2018. Managing soil fertility and health for quinoa production and weed control in organic systems. Soil and Tillage Research, 184: 52-61.

de Barros Santos, R. L., Spehar, C. R. and Vivaldi, L. 2003. Quinoa (*Chenopodium quinoa*) reaction to herbicide residue in a Brazilian Savannah soil. Pesquisa Agropecuária Brasileira, 38(6): 771-776.

Elford, E. 2016. Herbicide screening trials for Ontario grown quinoa. Posted on April 26, 2016 at https://onspecialtycrops.ca/2016/04/26/herbicide-screening-trials-for-ontario-grown-quinoa/.

El-Sadek, A., Balah, M., Romani, A., Ieri, F., Vignolini, P., Salem, E., Moselhy, N. and Virtuosi I. 2017. Allelopathic potential of quinoa (*Chenopodium quinoa* Willd.) genotypes on the germination and initial development of some weeds and crops.

Egyptian Journal of Desert Research, 67(1): 25-45.
FAO. 2023. Available online at: https://www.fao.org/faostat/en/#data/QCL.
Fghire, R., Anaya, F., Ali, O. I., Benlhabib, O., Ragab, R. and Wahbi, S. 2015. Physiological and photosynthetic response of quinoa to drought stress. Chilean Journal of Agricultural Research, 75(2): 174-183.
Garnica, I., Lezáun, J. A., Santos, A. and Garnica, J. 2017. Test of tolerance of quinoa (*Chenopodium quinoa*) to herbicides. XVI Congreso de la Sociedad Española de Malherbología, SEMh 2017, Pamplona-Iruña, España, 25-27 octubre, 2017. https://www.cabdirect.org/cabdirect/abstract/20183230960.
Ghirardello, G. A., da Silva Araújo, L., Baccin, L. C., Dotta, M. A., Souza, R. O., A. F. M., Silva, da Silva G. S. and Filho R. V. 2021. Selectivity index of indaziflam to sugarcane cv. IACSP95-5000 in two soil textures. Revista Facultad Nacional de Agronomía Medellín, 74(2): 9531-9539.
González, J. A., Gallardo, M., Hilal, M., Rosa, M. and Prado, F. E. 2009. Physiological responses of quinoa (*Chenopodium quinoa* Willd.) to drought and waterlogging stress: Dry matter partitioning. Botanical Studies, 50(1): 35-42.
HRAC. 2024. Herbicide Resistance Act Committee. Mode of Action Classification. https://hracglobal.com/tools/2024-hrac-global-herbicide-moa-classification.
Hilal, M., Parrado, M. F., Rosa, M., Gallardo, M., Orce, L., Massa, E. M., González, J. A. and Prado, F. E. 2004. Epidermal lignin deposition in quinoa cotyledons in response to UV-B radiation. Photochemistry and Photobiology, 79(2): 205-210.
Hinojosa, L., González, J. A., Barrios-Masias, F. H., Fuentes F. and Murphy, K. M. 2018. Quinoa abiotic stress responses: a review. Plants, 7(4): 106.
Iqbal, S., Basra, S. M. A., Afzal, I. and Wahid, A. 2017. Exploring potential of well adapted quinoa lines for salt tolerance. International Journal of Agriculture and Biology, 19(4): 933-940.
Jacobsen, S. -E., Christiansen, J. L. and Rasmussen, J. 2010. Weed harrowing and inter-row hoeing in organic grown quinoa (*Chenopodium quinoa* Willd.). Outlook on Agriculture, 39(3): 223-227.
Jacobsen, S. -E., Monteros, C., Christiansen, J. L., Bravo, L. A., Corcuera, L. J. and Mujica, A. (2005). Plant responses of quinoa (*Chenopodium quinoa* Willd.) to frost at various phenological stages. European Journal of Agronomy, 12(11): 131-139.
Jalali, M., Eslami, S. V., Mahmoodi, S. and Aien, A. 2021. Effect of weeds control on crop growth and yield in additive quinoa (*Chenopodium quinoa* Willd) and potato (*Solanum tubersum* L.) intercropping. Iranian Journal of Field Crops Research, 18(4): 451-464.
Joukar Fathabadi, R. and Kazemeini, S. A. 2022. Effect of seed biofertilizers inoculation on photosynthesis rate, yield, and competitiveness ability of quinoa (*Chenopodium quinoa* Willd.) with weeds. Journal of Crop Production and Processing, 12(3): 1-15.
Konishi, T. and Sasaki, Y. 1994. Compartmentalization of two forms of Acetyl-CoA carboxylase in plants and the origin of their tolerance toward herbicides. Proceedings of the National Academy of Sciences of the United States of America. pp. 3598-3601.
Kudsk, P. 2008. Optimising herbicide dose: a straightforward approach to reduce the risk of side effects of herbicides. Environmentalist, 28(1): 49-55.
Liang, X., Yang, R. and Leon, R. G. (2020). Growth and yield of quinoa in response to row spacing and weed competition in Eastern Idaho. ASA, CSSA and SSSA International Annual Meetings (2020) VIRTUAL, Phoenix, AZ. https://scisoc.confex.com/scisoc/2020am/meetingapp.cgi/Paper/128241
Makinen, O. E., Hager, A. S. and Arendt, E. K. 2014. Localisation and development of proteolytic activities in quinoa (*Chenopodium quinoa*) seeds during

germination and early seedling growth. Journal of Cereal Science, 60(3): 484-489.

Melo, C. A. D., de Carvalho Dias, R., Mendes, K. F., de Lourdes Pereira Assis, A. C. and dos Reis, M. R. 2016. Herbicides carryover in systems cultivated with vegetable crops. Revista Brasileira de Herbicidas, 15(1): 67-78.

Merino, J., Pedreros, A., Fischer, S. and López, M. D. 2019. Critical period of weed interference on total polyphenol content in quinoa. Chilean Journal of Agricultural Research, 79(3): 405-414.

Merino, J., Pedreros, A., Fischer, S. and López, M. D. 2020. Effect of post-emergence herbicides on stress indicators in quinoa. Chilean Journal of Agricultural Research, 80(1): 21-29.

Navruz-Varli, S. and Sanlier, N. 2016. Nutritional and health benefits of quinoa (*Chenopodium quinoa* Willd.). Journal of Cereal Science, 69: 371-376.

Nurse, R. E., Obeid, K. and Page, E. R. 2016. Optimal planting date, row width, and critical weed-free period for grain amaranth and quinoa grown in Ontario, Canada. Canadian Journal of Plant Science, 96(3): 360-366.

Pannacci, E., Farneselli, M., Ottavini D. and Tei F. 2019. Mechanical and chemical weed control in quinoa. Proceedings of the XLVIII Conference of the Italian Society for Agronomy "Evoluzione e adattamento dei sistemi colturali erbacei" At: Università degli Studi di Perugia - Dipartimento di Scienze Agrarie, Alimentari ed Ambientali - Perugia– Italy. pp. 100-101.

Ritz, C., Kniss, A. R. and Streibig, J. C. 2015. Research methods in weed science: statistic. Weed Science, 63: 166-187.

Rytwo, G. and Tropp, D. 2001. Improved efficiency of a divalent herbicide in the presence of clay, by addition of monovalent organocations. Applied Clay Science, 18: 327-333.

Shafei, A., Rastgoo, M., Izadi, E. and Ghanbari, A. 2022. Evaluation of Induction of Sethoxydim Tolerance in Maize (*Zea mays* L.) using salicylic acid as a safener. Iranian Plant Protection Research, 36(3): 327-337.

Tind, T., Mathiesen, T., Jensen, J. E., Ritz, C. and Streibig, J. 2009. Using a selectivity index to evaluate logarithmic spraying in grass seed crops. Pest management science, 65: 1257-1262.

United Nations. 2013. General assembly launches international year of quinoa, with secretary-general saying extraordinary grain could have significant impact on anti-hunger fight. 20 February 2013. General AssemblyGA/11341. https://press.un.org/en /2013/ga11341.doc.htm.

Zand, E., Keshtkar, E., Mousavi, S. K. and Heydari, A. 2021. Herbicides and their application technology: with the approach of optimizing and reducing consumption. Jihad-e-Danshghi of Mashhad Press.

حساسیت و تحمل کینوآ به ۲۲ علف‌کش ثبت شده برای سایر گیاهان

احسان اکبری دارابخانی، گودرز احمدوند و اکبر علی‌وردی*

گروه مهندسی تولید و ژنتیک گیاهی، دانشکده کشاورزی، دانشگاه بوعلی‌سینا، همدان، ایران.
پست الکترونیکی نویسنده مسئول مکاتبه: a.aliverdi@basu.ac.ir
دریافت: ۱۱ آبان ۱۴۰۲؛ پذیرش: ۵ دی ۱۴۰۳

چکیده: یک مطالعه گلدانی در محیط خارج از گلخانه در دانشگاه بوعلی‌سینا همدان در سال ۱۴۰۱ انجام شد. برای هر کدام از ۲۲ علف‌کش آزمایش شده، یک آزمایش دُز-پاسخ با دُزهای صفر، ۱/۱۶، ۱/۸، ۱/۴، ۱/۲ و ۱ برابر دُز برچسب شده انجام شد. علف‌کش‌های خاک مصرف و شاخ‌وبرگ مصرف به‌ترتیب پس از کاشت بذر و در مرحله ۳-۴ برگی کینوآ به‌کار رفتند. کینوآ بیش‌ترین حساسیت را به علف‌کش‌های استوکلر و لینورون داشت. با کاربرد مقدار یک هشتم برچسب از این دو علف‌کش هیچ گیاهچه‌ای سبز نشد. برای کاهش نسبت وزن تر: خشک به‌ترتیب به ۲، ۴ و ۷ درصد دُز برچسب شده استوکلر یا ۳، ۵ و ۹ درصد دُز برچسب شده لینورون نیاز بود. کاربرد ۱/۱۶، ۱/۸ و ۱/۴ دُز برچسب شده تری‌فلورالین، اکسی‌فلورفن، بنتازون، فن‌مدیفام+دس‌مدیفام + اتوفومازیت، کلومازون، کلوپیرالید، کلریدازون، آیوکسینیل، تری‌بنورون-متیل، متری‌بوزین، پندی‌متالین، نیکوسولفورون، سولفوسولفورون و بیس‌پیرباک-سدیم باعث کاهش ۱۰ درصدی نسبت وزن تر: خشک کینوآ شد. برای کاهش ۱۰ درصدی نسبت وزن تر: خشک کینوآ به‌ترتیب به کاربرد ۱/۷۸ و ۱/۵۶ برابری دُز برچسب شده پینوکسادن و کلودینافوپ پروپارژیل، و نصف دُز برچسب شده سیتوکسیدیم، هالوکسی‌فوپ-آر-متیل، تریفلوسولفورون-متیل و ایمازتاپیر نیاز بود. به‌عنوان یک توصیه، علف‌کش‌های منتخب (پینوکسادن و کلودینافوپ-پروپارژیل) و امیدبخش (ستوکسیدیم، هالوکسی‌فوپ-آر-متیل، ایمازتاپیر و تری-فلوسولفورون-متیل) باید در شرایط مزرعه از نظر عملکرد کینوآ و کنترل علف‌های هرز مورد ارزیابی قرار گیرد.

واژگان کلیدی: باریک‌برگ‌کش، رقم تی‌تی‌کا، دُز-پاسخ، کینوآ