ACTA UNIVERSITATIS AGRICULTURAE ET SILVICULTURAE MENDELIANAE BRUNENSIS

Volume 72 7 Number 3-4, 2024

MANAGEMENT OF GLYPHOSATE ISOPROPYLAMINE-RESISTANT GOOSEGRASS (*Eleusine indica*) BIOTYPES THROUGH PRE- AND POST-EMERGENCE HERBICIDES

Koko Tampubolon[1], Edison Purba[2], Mohammad Basyuni[3], Diana Sofia Hanafiah[2]

[1] Research Center for Food Crops, Research Organization for Agriculture and Food, National Research and Innovation Agency, Bogor, West Java 16911, Indonesia

[2] Program Study of Agrotechnology, Faculty of Agriculture, Universitas Sumatera Utara, Padang Bulan, Medan 20155, Indonesia

[3] Department of Forestry, Faculty of Forestry, Universitas Sumatera Utara, Padang Bulan, Medan 20155, Indonesia

Link to this article: https://doi.org/10.11118/actaun.2024.007
Received: 10. 4. 2023, Accepted: 21. 5. 2024

Abstract

The resistance status of *Eleusine indica* to the isopropylamine glyphosate herbicide leads to control losses in oil palm plantations. Appropriate management is needed to reduce the presence of glyphosate-resistant *E. indica*. This study aimed to obtain the recommended sequence or pattern of pre- and post-emergence herbicides in controlling glyphosate-resistant *E. indica* biotypes. This study was conducted in Telaga Sari Village, Sunggal Subdistrict, Deli Serdang District, North Sumatra, Indonesia from January to August 2019. The seeds were used from a confirmed highly glyphosate-resistant biotype of *E. indica* at 1,080 g ai ha^{-1}. This study used the factorial Randomized Block Design with four replications. The first factor was the type of pre- and post-emergence herbicides at 1 l ha^{-1}, respectively. The second factor was *E. indica* biotypes. Parameters were analyzed by ANOVA and subsequently followed by DMRT at $P < 0.05$ with IBM SPSS. Results showed that pre-emergence herbicides were more effective in controlling biotypes of glyphosate-resistant *E. indica* or were classified as excellent than post-emergence at the similar dose. The percentage capability of pre-and post-emergence herbicides in sequence were indaziflam or oxyfluorfen > pendimethalin > propaquizafop > potassium glyphosate > mesotrione. The herbicide performance of propaquizafop was classified as very good compared to other post-emergent herbicides.

Keywords: oil palm plantations, resistant management, pre-emergence, post-emergence, goosegrass

INTRODUCTION

Goosegrass (*Eleusine indica* L. Gearth), a weed in oil palm plantations, has been recorded as resistant to the herbicide isopropylamine (IPA) glyphosate at 65.56% in North Sumatra Province, Indonesia (Tampubolon *et al.*, 2019a). This resistance status indicated the failure of plantation companies to control and prevent the spread of these weed seeds. Plantation companies frequently control these weeds using similar herbicides, namely post-emergence, e.g. glyphosate and paraquat at multiple doses resulting in several species surviving and producing resistant seeds. These seeds mature and then fall to the soil surface and increase the resistant seed bank. On the one hand, oil palm plantations usually control weeds with a 3–4 month rotation, resulting in the next rotation these weeds have grown and produced seeds at a relatively quick period. According to Takano *et al.* (2016), *E. indica* produced seeds at 38 days after germination and the number of seeds increased until the age of 70 days. Munthe *et al.* (2016) added that the *E. indica* seed bank at a soil depth of 0–5 cm had a higher survival rate of 86.25% compared to a soil depth of 5–20 cm from the Pagar Merbau Estate, Deli Serdang District, Indonesia.

The presence of these resistant weeds will be dominant and disadvantageous to oil palm plantations if they are poorly managed. The use of rotation mode of action herbicides has been shown to completely controlled 100% of glyphosate-resistant *E. indica* from oil palm plantations, e.g. monosodium methyl arsenate (Tampubolon *et al.*, 2020). On the other hand, several studies have reported the use of other pre- and post-emergent herbicides in controlling the presence of these resistances. Dalimunthe *et al.* (2015) reported that applying indaziflam herbicide (pre-emergent) at a dose of 25 g ha^{-1} effectively controlled 100% dry weight of glyphosate-resistant *E. indica* biotypes, but was less effective by 27.94% if it used paraquat herbicide (post-emergent) at a dose of 400 g ha^{-1} from Adolina Estate, Serdang Bedagai District, Indonesia. Tampubolon *et al.* (2019b) added that the resistance index of *E. indica* biotypes to glyphosate from several plantation estates decreased by using post-emergence herbicides such as ammonium glufosinate and triclopyr.

The use of herbicides with different modes of action delayed or discontinued the resistance cycle, but there was still a need for several other herbicide modes of action as a reference for oil palm plantations in accepting control treatments for glyphosate-resistant *E. indica* biotypes. This study aimed to obtain an appropriate order or pattern of usage of pre-and post-emergence herbicides in controlling glyphosate-resistant *E. indica* biotypes from several oil palm plantations in North Sumatra, Indonesia.

MATERIALS AND METHODS

Source of Glyphosate-Resistant *E. Indica* Biotypes and Susceptible Population

Seeds of *E. indica* biotypes in this study were from seeds that have been reported to be resistant to isopropylamine glyphosate at a dose of 2 l ha^{-1} from oil palm plantations in North Sumatra (Tampubolon *et al.*, 2019a), then mature seeds were harvested, dried, and re-tested by spraying glyphosate at a dose of 3 l ha^{-1}. Biotypes that had a survival rate greater than 60% or were classified as highly resistant to glyphosate serve as the source of *E. indica* seeds in this study (Tab. I). The glyphosate-susceptible *E. indica* seeds used for comparison were sourced from the soccer field of Medan State Polytechnic with unexposed history to herbicides.

I: *Source locations of glyphosate-resistant E. indica biotypes seeds from oil palm plantations in North Sumatra*

Sample codes	Locations	Districts/cities
EIS	Soccer field of Medan State Polytechnic	Medan City
EIR-01	Afdeling-8, Sawit Seberang Estate	Langkat
EIR-02	Afdeling-9, Sawit Seberang Estate	
EIR-03	Afdeling-1, Bagerpang Estate	Deli Serdang
EIR-06	Afdeling-7, Adolina Estate	Serdang Bedagai
EIR-11	Afdeling-1, Adolina Estate	
EIR-12	Afdeling-2, Rambung Sialang Estate	
EIR-20	Afdeling-3, Rantau Prapat Estate	Labuhanbatu
EIR-22	Afdeling-2, Membang Muda Estate	North Labuhanbatu
EIR-23	Afdeling-2, Sisumut Estate	South Labuhanbatu
EIR-24	Afdeling-2, Sei Daun Estate	
EIR-25	Afdeling-4, Sei Daun Estate	
EIR-26	Pre-nursery, Bukit Udang Estate	Padang Lawas
EIR-27	Afdeling-3, Sei Kebara Estate	
EIR-28	Afdeling-2, Batang Toru Estate	South Tapanuli
EIR-29	Pre-nursery, Hapesong Estate	

Note: EIS (glyphosate-susceptible *E. indica*); EIR (glyphosate-resistant *E. indica*)

Preparation of Sterile Planting Media and Study Design

This study used planting media for seedling trays and pots such as topsoil: chicken manure: and sand with a volume ratio of 1:1:1. The growing medium was sterilized at 100 °C for 3 h (Tampubolon and Purba, 2018). Each pot of each biotype was arranged using a Factorial Randomized Block Design with four replications. The first factor was pre-emergence or post-emergence herbicides and the second factor was glyphosate-resistant *E. indica* biotypes. This study was conducted in farmers' fields in Telaga Sari Village, Sunggal Sub-district, Deli Serdang District, North Sumatra. This study was performed from January to August 2019.

Seed Planting and Pre-Emergence Herbicide Spraying

Seeds of *E. indica* biotypes were counted as 100 seeds from each location. Then sterile planting media was filled into pots with a size of 13.5 cm × 21 cm until three-fourths of the pot. Seeds were sown consistently on the surface of the media, then covered with 1 cm of sterile media. Spraying of pre-emergence herbicides was performed after 1 day of sowing the seeds. Then spray calibration was conducted and the result was 253.97 l ha^{-1}. Pre-emergence herbicides included indaziflam, pendimethalin, and oxyfluorfen at the dose of 500; 336; and 240 g ai ha^{-1}, or equivalent to 1 l ha^{-1}, respectively. The environmental conditions at the spraying of pre-emergence herbicides were recorded such as 29.8 °C temperature; 54% humidity; and 1 011 hPa air pressure.

Seed Germination, Planting and Spraying of Post-Emergence Herbicides

The sterile growing medium was put into seedling trays with a size of 37 cm × 19.5 cm. After *E. indica* had 2–3 leaves, the seedlings were transplanted into pots containing sterile planting media with 10 seedlings pot^{-1} (Tampubolon *et al.*, 2019a). Post-emergence herbicides were sprayed at the 4–6 leaf stage of *E. indica*. The post-emergence herbicides included potassium glyphosate; mesotrione; and propaquizafop at the dose of 660; 50; and 100 g ai ha^{-1}, or equivalent to 1 l ha^{-1}, respectively. Environmental conditions during the spraying of the post-emergence herbicide were also recorded such as the 30 °C temperature, 64% humidity, and 1 011 hPa air pressure.

Parameter Measurement and Data Analysis

Parameters in this study included the number of surviving *E. indica*, the number of tillers, weed toxicity, dry weight, growth reduction, and SPAD total chlorophyll. The level of weed toxicity was observed from changes in leaf color and then scored. Score 0 = green, 1 = yellowish green, 2 = yellowing overall, 3 = brownish yellow, and 4 = brownish and shrink. Measurement of dry weight was performed by oven at 65 ºC for 72 h (Jalaludin *et al.*, 2015). The percentage of growth reduction was calculated using dry weight and then the control level was classified. The control percentage was categorized into 11 groups according to Mohamad *et al.* (2010), including ≤ 0% (non control), 0.01–10.00% (very poor), 10.01–20.00% (poor), 20.01–30.00% (weak-inefficient), 30.01–40.00% (inadequate), 40.01–50.00% (moderately inadequate), 50.01–60.00% (moderate), 60.01–70.00% (unsatisfactory), 70.01–80.00% (unsatisfactory-good), 80.01–90.00% (very good), and 90.01–100.00% (excellent). SPAD total chlorophyll of glyphosate-resistant *E. indica* biotypes from each herbicide type at 3 hours, 1, 3, 5, and 7 days after spraying (DAS). Total chlorophyll was performed on the 2nd leaf from the tip of the shoots (Tampubolon *et al.*, 2019b) using a SPAD 502 plus chlorophyll meter. All parameters were analyzed by ANOVA and the averages were followed by DMRT at $P < 0.05$ with IBM SPSS.

$$E.\ indica\ \text{survival (\%)} = \frac{\Sigma\, E.\ indica\ \text{survive}}{\Sigma\, E.\ indica\ \text{planted}} \times 100\%. \quad (1)$$

$$\text{Weed toxicity (\%)} = \frac{\text{Scores each treatment}}{\text{Highest score}} \times 100\%. \quad (2)$$

$$\text{Weed toxicity (\%)} = \frac{\text{Dry weight of herbicide exposed - unexposed}}{\text{Dry weight unexposed}} \times 100\%. \quad (3)$$

RESULTS

Survival (%)

The pre-emergence herbicides significantly suppressed the survival of glyphosate-resistant *E. indica* biotypes and a susceptible population at 1–2 weeks after spraying (WAS) but had an insignificant effect at 3 MSS (Tab. II). Pre-emergence herbicides suppressed 2 of 15 glyphosate-resistant *E. indica* biotypes (EIR-11 and EIR-29) and susceptible populations (EIS) at 1 WAS, but only suppressed the EIR-29 biotype at 2 WAS. Indaziflam and oxyfluorfen herbicides effectively suppressed all the glyphosate-resistant *E. indica* biotypes and susceptible population up to 100% compared to pendimethalin at 3 WAS. Meanwhile, pendimethalin was only effective in controlling 6 of 15 glyphosate-resistant *E. indica* biotypes, namely EIR-02, EIR-11, EIR-12, EIR-23, EIR-25, and EIR-26. The control of glyphosate-resistant *E. indica* biotypes from oil palm plantations was controlled with pre-emergence herbicides such as indaziflam, oxyfluorfen, and pendimethalin.

The post-emergence herbicides significantly suppressed the survival of glyphosate-resistant *E. indica* biotypes and a susceptible population at 1–3 WAS (Tab. III). Post-emergence herbicides were only suppressive of a susceptible population. Propaquizafop more effectively suppressed 6 of 15 glyphosate-resistant *E. indica* biotypes, namely EIR-20, EIR-22, EIR-23, EIR-26, EIR-27, and EIR-28 by 100% compared to potassium glyphosate and mesotrione at 3 WAS. These results confirm that glyphosate-resistant *E. indica* from oil palm plantations can be controlled using rotational modes of action such as propaquizafop, but are less effective using potassium glyphosate and mesotrione.

II: *Biotypes of glyphosate-resistant Eleusine indica and a susceptible that survived exposure to pre-emergence herbicides at 1–3 weeks after spraying (WAS)*

Pre-emergences	Survival (%)																Average
	EIS	EIR 01	EIR 02	EIR 03	EIR 06	EIR 11	EIR 12	EIR 20	EIR 22	EIR 23	EIR 24	EIR 25	EIR 26	EIR 27	EIR 28	EIR 29	
1 WAS																	
Untreated	29.25	49.25	39.50	50.25	36.75	29.50	37.00	56.75	44.25	43.75	37.50	36.75	45.25	51.25	36.00	28.50	40.72 b
Indaziflam	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00 a
Pendimethalin	0.25	0.50	0.00	2.75	0.00	0.00	0.00	1.00	0.25	0.00	0.25	0.00	0.00	1.25	0.25	1.25	0.48 a
Oxyfluorfen	0.00	0.00	0.00	0.00	0.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03 a
Average	7.38 a	12.44 bc	9.88 ab	13.25 bc	9.31 ab	7.38 a	9.25 ab	14.44 c	11.13 abc	10.94 abc	9.44 ab	9.19 ab	11.31 abc	13.13 bc	9.06 ab	7.44 a	
2 WAS																	
Untreated	68.50	78.75	74.25	73.00	70.00	66.50	71.75	78.50	76.25	75.00	74.50	75.50	64.50	68.50	60.50	50.50	70.41 b
Indaziflam	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00 a
Pendimethalin	0.25	0.75	0.00	2.75	2.00	0.00	0.00	5.75	1.00	0.00	1.25	0.00	0.00	2.00	1.00	3.00	1.23 a
Oxyfluorfen	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00 a
Average	17.19 a-d	19.88 cd	18.56 bcd	18.94 bcd	18.00 bcd	16.63 a-d	17.94 bcd	21.06 d	19.31 bcd	18.75 bcd	18.94 bcd	18.88 bcd	16.13 abc	17.63 bcd	15.38 ab	13.38 a	
3 WAS																	
Untreated	85.00	84.00	81.50	76.25	87.00	83.50	79.50	86.25	88.00	80.75	84.75	80.25	76.00	79.50	76.25	76.75	81.58 c
Indaziflam	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00 a
Pendimethalin	0.25	0.75	0.00	2.75	2.00	0.00	0.00	6.50	1.00	0.00	3.25	0.00	0.00	2.00	1.00	3.25	1.42 b
Oxyfluorfen	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00 a
Average	21.31 ns	21.19 ns	20.38 ns	19.75 ns	22.25 ns	20.88 ns	19.88 ns	23.19 ns	22.25 ns	20.19 ns	22.00 ns	20.06 ns	19.00 ns	20.38 ns	19.31 ns	20.00 ns	

Note: average followed by different letters indicate a significant effect in the DMRT at $P < 0.05$. ns = not significant

III: *Biotypes of glyphosate-resistant Eleusine indica and a susceptible that survived exposure to post-emergence herbicides at 1–3 weeks after spraying (WAS)*

Post-emergences	Survival (%)																Average
	EIS	EIR 01	EIR 02	EIR 03	EIR 06	EIR 11	EIR 12	EIR 20	EIR 22	EIR 23	EIR 24	EIR 25	EIR 26	EIR 27	EIR 28	EIR 29	
1 WAS																	
Untreated	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00 d
Potassium glyphosate	27.50	92.50	95.00	75.00	97.50	100.00	47.50	92.50	100.00	100.00	85.00	100.00	100.00	72.50	55.00	40.00	80.00 b
Mesotrione	52.50	100.00	87.50	92.50	100.00	70.00	100.00	97.50	100.00	100.00	40.00	97.50	100.00	92.50	100.00	90.00	88.75 c
Propaquizafop	7.50	95.00	57.50	17.50	50.00	92.50	7.50	17.50	0.00	0.00	40.00	27.50	0.00	5.00	2.50	5.00	26.56 a
Average	46.88 a	96.88 g	85.00 efg	71.25 b-e	86.88 efg	90.63 fg	63.75 bc	76.88 c-f	75.00 b-f	75.00 b-f	66.25 bcd	81.25 d-g	75.00 b-f	67.50 bcd	64.38 bc	58.75 ab	
2 WAS																	
Untreated	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00 d
Potassium glyphosate	12.50	90.00	90.00	52.50	97.50	100.00	52.50	50.00	100.00	100.00	85.00	100.00	100.00	72.50	52.50	37.50	74.53 b
Mesotrione	25.00	100.00	82.50	90.00	100.00	52.50	100.00	97.50	92.50	100.00	15.00	97.50	100.00	92.50	100.00	95.00	83.75 c
Propaquizafop	2.50	95.00	57.50	15.00	32.50	95.00	7.50	0.00	0.00	0.00	25.00	27.50	0.00	0.00	0.00	5.00	22.66 a
Average	35.00 a	96.25 f	82.50 def	64.38 bcd	82.50 def	86.88 ef	65.00 bcd	61.88 b	73.13 b-e	75.00 b-e	56.25 b	81.25 c-f	75.00 b-e	66.25 bcd	63.13 bc	59.38 b	
3 WAS																	
Untreated	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00 d
Potassium glyphosate	2.50	85.00	90.00	47.50	97.50	100.00	50.00	42.50	100.00	100.00	87.50	100.00	100.00	72.50	50.00	40.00	72.81 b
Mesotrione	5.00	95.00	80.00	90.00	95.00	55.00	100.00	97.50	92.50	97.50	12.50	97.50	100.00	92.50	97.50	92.50	81.25 c
Propaquizafop	0.00	95.00	57.50	15.00	30.00	97.50	7.50	0.00	0.00	0.00	25.00	17.50	0.00	0.00	0.00	5.00	21.88 a
Average	26.88 a	93.75 g	81.88 efg	63.13 b-e	80.63 d-g	88.13 fg	64.38 b-e	60.00 bc	73.13 b-f	74.38 b-f	56.25 b	78.75 c-g	75.00 b-g	66.25 b-e	61.88 bcd	59.38 bc	

Note: average followed by different letters indicate a significant effect in the DMRT at $P < 0.05$

Number of Tillers

Pre- and post-emergence herbicides significantly reduced the number of tillers of glyphosate-resistant *E. indica* biotypes and a susceptible population at 3 WAS (Tab. IV). Pre-emergence herbicides effectively suppressed the number of tillers of 3 biotypes of 15 glyphosate-resistant *E. indica*, namely EIR-12, EIR-23, and EIR-26, as well as a susceptible population at 3 WAS. Indaziflam and oxyfluorfen herbicides effectively suppressed 100% tiller numbers of all glyphosate-resistant *E. indica* biotypes compared to the pendimethalin. Meanwhile, pendimethalin herbicide was only effective in controlling 6 out of 15 glyphosate-resistant *E. indica* biotypes, namely EIR-02, EIR-11, EIR-12, EIR-23, EIR-25, and EIR-26. Post-emergence herbicides were only effective in suppressing the number of tillers in glyphosate-susceptible *E. indica* at 3 WAS. Propaquizafop herbicide was more effective in suppressing tillering of 6 out of 15 glyphosate-resistant *E. indica* biotypes namely EIR-20, EIR-22, EIR-23, EIR-26, EIR-27, and EIR-28 by 100%, followed by mesotrione and potassium glyphosate.

Dry Weight (g) and Growth Reduction (%)

Pre- and post-emergence herbicides significantly inhibited the dry weight of glyphosate-resistant *E. indica* biotypes and a susceptible population at 6 WAS (Tab. V). Pre-emergence herbicides effectively suppressed the dry weight of the EIR-02 biotype at 6 WAS. Indaziflam and oxyfluorfen herbicides effectively suppressed 100% dry weight of all glyphosate-resistant *E. indica* biotypes compared to the pendimethalin. Whereas, pendimethalin herbicide was effective in controlling the dry weight of 6 out of 15 glyphosate-resistant *E. indica* biotypes, namely EIR-02, EIR-11, EIR-12, EIR-23, EIR-25, and EIR-26. Post-emergence herbicides only effectively suppressed the dry weight of a susceptible population at 6 WAS. Propaquizafop herbicide was more effective in suppressing the dry weight of 6 out of 15 glyphosate-resistant *E. indica* biotypes, namely EIR-20, EIR-22, EIR-23, EIR-26, EIR-27, and EIR-28 by 100% than potassium glyphosate and mesotrione.

Growth reduction of glyphosate-resistant E. indica biotypes by exposure to indaziflam and oxyfluorfen herbicides was more effective at 100% while pendimethalin was 90.72% (Fig. 1A). Based on the control rate, these three pre-emergent herbicides were classified as excellent. Growth reduction of all glyphosate-resistant *E. indica* biotypes exposed by propaquizafop herbicide was more effective followed by potassium glyphosate and mesotrione were 81.24; 66.53; and 61.30% (Fig. 1B). Based on the control rate, the propaquizafop herbicide was classified as very good while potassium glyphosate and mesotrione were classified as unsatisfactory.

Weed Toxicity Levels (%)

Post-emergence herbicides significantly toxicized glyphosate-resistant *E. indica* biotypes and a susceptible population at 1-3 WAS (Tab. VI). The post-emergence herbicides were only effective in causing toxicity to the EIR-29 biotype and a susceptible population at 1 WAS, while the susceptible only showed toxicity at 2-3 WAS. The ability of propaquizafop herbicide to cause toxicity of glyphosate-resistant *E. indica* biotypes was higher than potassium glyphosate and mesotrione. It was shown by six biotypes that suffered symptoms of toxicity, namely EIR-20, EIR-22, EIR-23, EIR-26, EIR-27, and EIR-28 at 3 WAS.

SPAD Total Chlorophyll

Post-emergence herbicides significantly suppressed SPAD total chlorophyll of glyphosate-resistant *E. indica* biotypes and a susceptible population from 3 h to 7 DAS (Tab. VII). The post-emergence herbicides were only effective in reducing the SPAD total chlorophyll of the EIR-06 biotype at 3 h after spraying, 1 and 5 DAS. Propaquizafop herbicide was more effective in reducing SPAD total chlorophyll of all glyphosate-resistant *E. indica* biotypes than potassium glyphosate and mesotrione. Propaquizafop herbicide reduced SPAD total chlorophyll of glyphosate-resistant *E. indica* biotypes ranging from 7.50 to 76.92% compared to unsprayed. However, potassium glyphosate and mesotrione herbicides ranged from 7.91 to 51.29; and 8. 21 to 36.70%, respectively. In addition, propaquizafop herbicide reduced SPAD total chlorophyll by 100% in EIR-23, EIR-26, EIR-28, and EIR-29 biotypes at 7 DAS.

DISCUSSION

Effectiveness of Pre-Emergence Herbicides

Pre-emergence herbicides significantly suppressed the survival, the number of tillers, and dry weight of glyphosate-resistant *E. indica* biotypes. Indaziflam and oxyfluorfen herbicides were more effective in controlling glyphosate-resistant *E. indica* biotypes than pendimethalin. Indaziflam at a dose of 500 g ai ha^{-1} controlled all glyphosate-resistant *E. indica* biotype's survival, the number of tillers, and dry weight up to 100%. Therefore, the control level of glyphosate-resistant *E. indica* biotypes using indaziflam herbicide was classified as excellent. It is due to indaziflam that inhibited cellulose biosynthesis by interfering with root growth resulting in glyphosate-resistant *E. indica* biotypes which did not grow radicles after a few days of spraying. These findings are supported by Brabham *et al.* (2014) that indaziflam inhibited cellulose biosynthesis by reducing the formation of ^{14}C-glucose into insoluble cellulose fractions for 1 hour after application, thus inhibiting root growth.

IV: *The number of tillers of glyphosate-resistant E. indica biotypes and a susceptible exposed to pre-and post-emergence herbicides at 3 weeks after spraying*

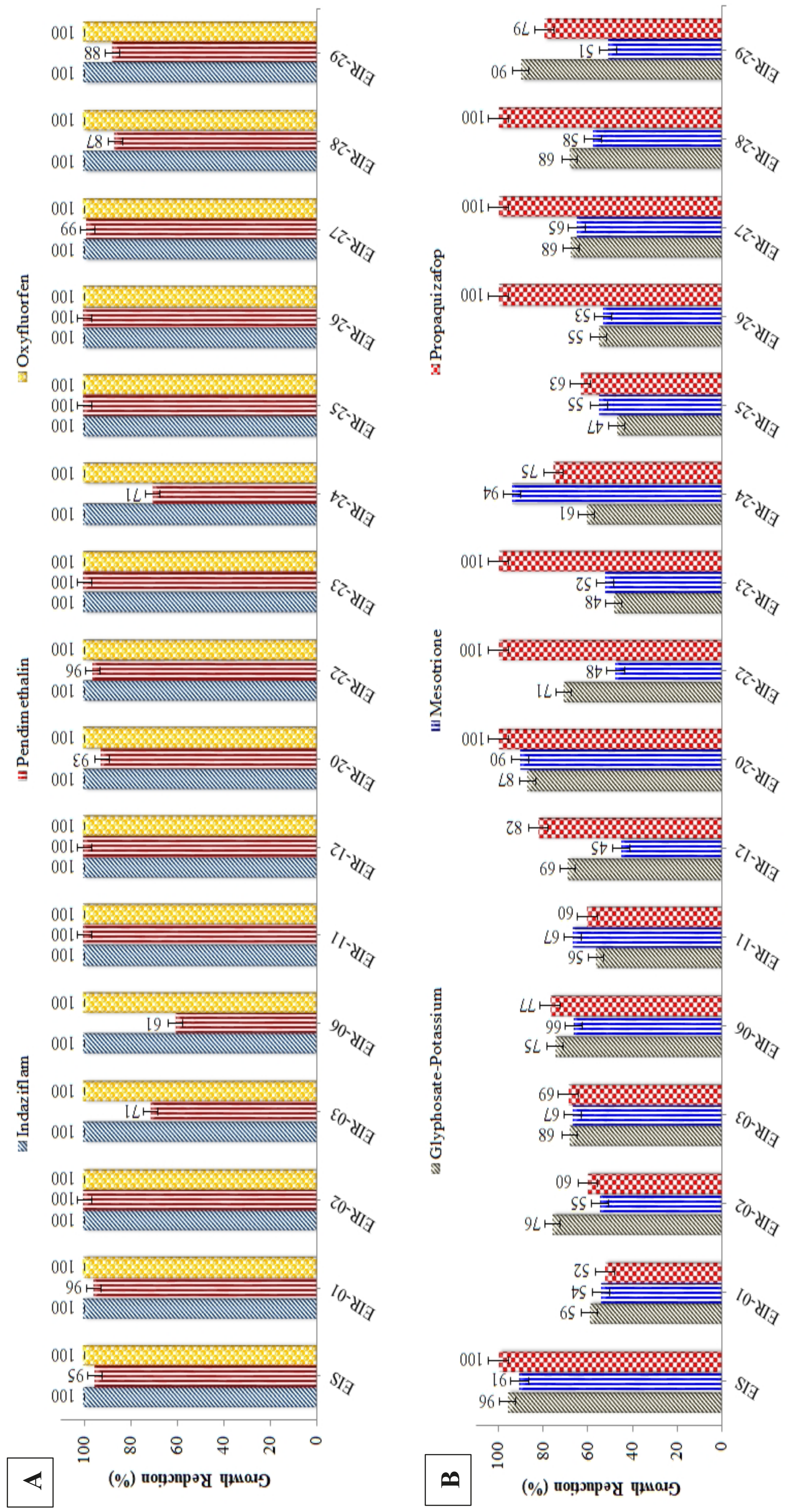
Treatments	Number of tillers																Average
	EIS	EIR 01	EIR 02	EIR 03	EIR 06	EIR 11	EIR 12	EIR 20	EIR 22	EIR 23	EIR 24	EIR 25	EIR 26	EIR 27	EIR 28	EIR 29	
Pre-emergence herbicides																	
Untreated	9.75	10.75	12.75	11.00	16.00	11.75	10.25	12.25	14.50	10.00	16.50	11.25	10.25	10.00	11.25	11.50	11.86 c
Indaziflam	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00 a
Pendimethalin	0.25	1.50	0.00	3.25	4.50	0.00	0.00	4.25	0.75	0.00	2.25	0.00	0.00	1.50	1.50	1.75	1.34 b
Oxyfluorfen	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00 a
Average	2.50 a	3.06 ab	3.19 abc	3.56 abc	5.13 c	2.94 ab	2.56 a	4.13 abc	3.81 abc	2.50 a	4.69 bc	2.81 ab	2.56 a	2.88 ab	3.19 abc	3.31 abc	
Post-emergence herbicides																	
Untreated	12.75	21.50	21.75	21.25	16.75	25.00	21.50	19.75	11.75	16.00	22.75	14.00	16.50	12.75	21.50	20.25	18.48 c
Potassium glyphosate	0.75	11.50	13.25	8.00	1.00	15.25	7.75	2.25	7.25	14.50	12.75	5.50	8.50	5.75	3.50	9.50	7.94 b
Mesotrione	2.25	5.25	4.00	1.00	1.00	8.50	2.50	4.50	9.00	4.75	0.75	2.50	5.75	2.50	0.50	7.25	3.88 a
Propaquizafop	0.00	9.75	5.50	2.25	0.50	16.00	1.75	0.00	0.00	0.00	8.75	4.25	0.00	0.00	0.00	2.25	3.19 a
Average	3.94 a	12.00 g	11.13 fg	8.13 cde	4.81 ab	16.19 h	8.38 def	6.63 a-d	7.00 b-e	8.81 def	11.25 fg	6.56 a-d	7.69 b-e	5.25 abc	6.38 a-d	9.81 efg	

Note: average followed by different letters indicate a significant effect in the DMRT at $P < 0.05$. ns = not significant

V: *The dry weight of glyphosate-resistant E. indica biotypes and a susceptible population under pre-and post-emergence herbicides exposure at 6 weeks after spraying*

Treatments	Dry weight (g)																Average
	EIS	EIR 01	EIR 02	EIR 03	EIR 06	EIR 11	EIR 12	EIR 20	EIR 22	EIR 23	EIR 24	EIR 25	EIR 26	EIR 27	EIR 28	EIR 29	
Pre-emergence herbicides																	
Untreated	13.73	23.62	10.77	16.19	12.62	12.16	14.45	19.72	25.77	14.54	17.83	27.01	20.88	32.54	12.10	18.14	18.25 b
Indaziflam	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00 a
Pendimethalin	0.64	0.99	0.00	4.63	4.95	0.00	0.00	1.48	0.95	0.00	5.25	0.00	0.00	0.42	1.60	2.19	1.44 a
Oxyfluorfen	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00 a
Average	3.59 abc	6.15 a-d	2.69 a	5.20 a-d	4.39 abc	3.04 ab	3.61 abc	5.30 a-d	6.68 bcd	3.63 abc	5.77 a-d	6.75 cd	5.22 a-d	8.24 d	3.43 abc	5.08 a-d	
Post-emergence herbicides																	
Untreated	12.04	22.91	29.75	29.77	30.12	26.00	28.11	37.38	30.97	29.30	29.75	30.36	32.06	29.70	33.46	26.85	28.66 c
Potassium glyphosate	0.49	9.35	7.18	9.51	7.63	11.32	8.72	4.85	9.04	15.10	11.72	16.09	14.36	9.64	10.67	2.70	9.27 b
Mesotrione	1.14	10.49	13.52	9.92	10.15	8.65	15.43	3.57	16.24	14.02	1.86	13.63	15.02	10.42	14.12	13.15	10.71 b
Propaquizafop	0.00	10.91	11.90	9.29	6.98	10.31	5.02	0.00	0.00	0.00	7.35	11.12	0.00	0.00	0.00	5.52	4.90 a
Average	3.42 a	13.42 bc	15.59 cd	14.62 bcd	13.72 bc	14.07 bcd	14.32 bcd	11.45 b	14.06 bcd	14.60 bcd	12.67 bc	17.80 d	15.36 bcd	12.44 bc	14.56 bcd	12.05 bc	

Note: average followed by different letters indicate a significant effect in the DMRT at $P < 0.05$



1: *Growth reduction of glyphosate-resistant E. indica biotypes and a susceptible population exposed by pre-emergence (A) and post-emergence (B) herbicides at 6 weeks after spraying*

VI: *Toxicity rates of glyphosate-resistant E. indica biotypes and a susceptible population exposed to post-emergence herbicides at 1–3 weeks after spraying*

Post-emergence herbicides	Weed toxicity (%)																Average
	EIS	EIR 01	EIR 02	EIR 03	EIR 06	EIR 11	EIR 12	EIR 20	EIR 22	EIR 23	EIR 24	EIR 25	EIR 26	EIR 27	EIR 28	EIR 29	
1 WAS																	
Untreated	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00 c
Potassium glyphosate	41.25	1.88	28.75	46.25	15.63	4.38	40.63	30.63	2.50	0.00	15.63	1.25	0.00	13.75	36.25	48.13	20.43 b
Mesotrione	16.88	0.00	0.00	0.00	0.00	23.75	0.00	0.00	0.00	0.00	49.38	0.00	0.00	0.00	2.50	0.00	5.78 c
Propaquizafop	87.50	3.75	28.75	87.50	26.88	11.88	80.00	51.25	88.75	100.00	51.88	72.50	100.00	70.63	73.13	97.50	64.49 a
Average	36.41 a	1.41 e	14.38 cde	33.44 ab	10.63 de	10.00 de	30.16 abc	20.47 a-d	22.81 a-d	25.00 a-d	29.22 abc	18.44 bcd	25.00 a-d	21.09 a-d	27.97 abc	36.41 a	
2 WAS																	
Untreated	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00 d
Potassium glyphosate	82.50	10.63	9.38	56.25	6.88	0.00	52.50	55.00	10.00	0.00	17.50	0.00	0.00	31.88	45.00	47.50	26.56 b
Mesotrione	50.63	0.00	17.50	11.25	3.13	45.00	0.00	0.63	0.00	0.00	87.50	0.00	0.00	0.00	0.00	5.00	13.79 c
Propaquizafop	97.50	5.00	42.50	85.00	72.50	5.28	77.50	100.00	100.00	100.00	75.00	72.50	100.00	100.00	100.00	95.00	76.74 a
Average	57.66 a	3.91 g	17.34 efg	38.13 bc	20.63 c-g	12.57 fg	32.50 b-e	38.91 bc	27.50 b-f	25.00 c-f	45.00 ab	18.13 d-g	25.00 c-f	32.97 b-e	36.25 bcd	36.88 bc	
3 WAS																	
Untreated	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00 d
Potassium glyphosate	97.50	15.00	10.00	52.50	2.50	0.00	50.00	57.50	0.00	0.00	12.50	0.00	0.00	27.50	50.00	60.00	27.19 b
Mesotrione	95.00	5.00	20.00	10.00	5.00	45.00	0.00	2.50	7.50	2.50	87.50	2.50	0.00	7.50	2.50	7.50	18.75 c
Propaquizafop	100.00	5.00	42.50	85.00	70.00	5.28	92.50	100.00	100.00	100.00	75.00	82.50	100.00	100.00	100.00	95.00	78.30 a
Average	73.13 a	6.25 g	18.13 efg	36.88 b-e	19.38 d-g	12.57 fg	35.63 b-e	40.00 bc	26.88 b-f	25.63 b-f	43.75 b	21.25 c-g	25.00 b-f	33.75 b-e	38.13 bcd	40.63 bc	

Note: average followed by different letters indicate a significant effect in the DMRT at $P < 0.05$

VII: *SPAD total chlorophyll of glyphosate-resistant E. indica biotypes and a susceptible population exposed to post-emergence herbicides from 3 h to 7 days after spraying (DAS)*

Post-emergence herbicides	EIS	EIR 01	EIR 02	EIR 03	EIR 06	EIR 11	EIR 12	EIR 20	EIR 22	EIR 23	EIR 24	EIR 25	EIR 26	EIR 27	EIR 28	EIR 29	Average	%
3 HAS																		
Untreated	30.23	31.40	27.53	35.73	21.98	32.95	30.23	26.23	30.08	32.73	31.45	27.93	30.98	29.65	31.10	33.03	30.20b	-
Potassium glyphosate	27.50	23.20	33.35	31.68	18.03	32.93	31.33	21.25	25.50	27.88	33.30	23.90	26.10	23.48	31.65	33.90	27.81a	7.91
Mesotrione	26.20	23.95	29.90	28.03	22.88	27.28	31.38	23.68	25.20	28.58	30.83	28.35	29.15	27.35	28.83	31.95	27.72a	8.21
Propaquizafop	26.40	25.83	30.18	33.88	15.10	27.98	31.20	23.20	27.18	30.03	30.53	30.43	30.23	28.60	25.53	30.70	27.93a	7.50
Average	27.58cde	26.09 bc	30.24 def	32.33 f	19.49 a	30.28 def	31.03 ef	23.59 b	26.99 cd	29.80 def	31.53 f	27.65 cde	29.11 c-f	27.27 cd	29.28 c-f	32.39 f		
1 DAS																		
Untreated	31.13	30.75	30.35	34.68	22.00	34.55	31.13	28.63	30.73	32.40	33.88	29.75	31.45	29.38	33.80	33.05	31.10c	-
Potassium glyphosate	25.05	26.25	26.95	27.08	13.83	30.43	28.58	20.45	23.43	29.48	30.08	26.78	26.88	29.08	28.88	25.33	26.16b	15.90
Mesotrione	20.40	24.58	19.70	24.10	11.25	24.15	26.00	21.10	24.13	25.50	24.05	24.33	26.35	23.50	27.25	23.63	23.13a	25.65
Propaquizafop	19.50	19.75	28.85	31.83	13.03	26.98	29.80	21.53	28.28	26.13	27.28	26.58	27.13	23.70	25.48	28.85	25.29b	18.68
Average	24.02 bc	25.33bcd	26.46 cde	29.42 e	15.03 a	29.03 e	28.88 e	22.93 b	26.64 cde	28.38 de	28.82 e	26.86 cde	27.95 de	26.41 cde	28.85 e	27.71 de		
3 DAS																		
Untreated	32.73	32.03	31.18	34.83	25.23	35.05	31.55	29.73	31.63	33.78	34.30	29.80	31.18	30.58	35.15	33.65	32.02c	-
Potassium glyphosate	19.90	28.30	25.38	14.38	13.93	30.98	29.90	12.55	27.68	31.35	29.85	28.10	29.75	28.75	22.23	25.48	24.90b	22.23
Mesotrione	16.30	26.03	22.43	17.50	22.43	19.30	25.28	28.13	27.00	26.68	17.45	25.75	24.78	23.43	21.95	15.28	22.48a	29.80
Propaquizafop	6.55	23.88	21.33	25.53	20.05	23.93	27.98	25.13	24.95	23.30	23.08	26.33	24.05	24.83	20.53	27.23	23.04ab	28.05
Average	18.87 a	27.56 cd	25.08 cd	23.06abc	20.41 ab	27.31 cd	28.68 d	23.88bcd	27.81 cd	28.78 d	26.17 cd	27.49 cd	27.44 cd	26.89 cd	24.96 cd	25.41 cd		
5 DAS																		
Untreated	33.50	32.43	32.35	35.50	25.70	35.60	32.38	31.93	32.25	34.35	34.95	30.35	31.63	31.28	35.38	33.95	32.72c	-
Potassium glyphosate	12.15	26.70	17.93	9.85	11.15	28.58	19.70	17.00	25.50	26.80	25.53	26.43	25.35	25.03	22.78	9.50	20.62b	36.97
Mesotrione	12.25	26.18	13.75	18.55	11.60	15.35	22.53	26.18	25.85	26.88	10.15	28.05	23.53	23.95	20.23	26.38	20.71b	36.70
Propaquizafop	3.73	22.08	18.53	14.00	6.00	16.18	19.43	21.08	7.45	5.93	22.40	25.13	18.33	15.53	10.35	12.50	14.91a	54.42
Average	15.41 ab	26.84 d	20.64 bc	19.48 bc	13.61 a	23.93 cd	23.51 cd	24.04 cd	22.76 cd	23.49 cd	23.26 cd	27.49 d	24.71 cd	23.94 cd	22.18 cd	20.58 bc		
7 DAS																		
Untreated	34.25	32.83	33.65	37.20	30.93	36.53	33.25	32.58	30.43	34.88	36.33	30.68	32.03	31.60	36.58	35.10	33.68d	-
Potassium glyphosate	9.10	22.65	11.93	0.30	9.75	29.33	19.03	9.25	24.15	26.23	13.53	24.08	25.58	21.25	11.50	4.83	16.40b	51.29w
Mesotrione	12.78	22.48	29.33	23.58	22.80	17.73	31.50	16.43	26.08	23.28	18.78	23.55	22.80	20.45	22.95	32.78	22.95c	31.84
Propaquizafop	0.65	17.05	27.10	18.50	8.05	21.73	4.25	10.73	0.98	0.00	7.05	7.00	0.00	1.30	0.00	0.00	7.77a	76.92
Average	14.19 a	23.75bcd	25.50 cd	19.89 a-d	17.88 ab	26.33 d	22.01bcd	17.24 ab	20.41 a-d	21.09 a-d	18.92abc	21.33 a-d	20.10 a-d	18.65abc	17.76 ab	18.18abc		

Note: average followed by different letters indicate a significant effect in the DMRT at $P < 0.05$

Alonso *et al.* (2011) stated that the uptake kinetics of indaziflam on mollisols were classified as very fast or greater than 94% at 2 hours after spraying. Sebastian *et al.* (2016) found that the indaziflam herbicide reduced the growth of 6 grasses weeds of indaziflam-susceptible such as *Bromus tectorum, Secale cereale, Bromus japonicus, Aegilops cylindrica, Taeniatherum caput-medusae*, and *Ventenata dubia* were 0.23; 0.56; 0.19; 7.37; 0.36; and 0.44 g ai ha^{-1}, respectively. McCullough *et al.* (2013) added that the indaziflam at 0.07 kg ai ha^{-1} effectively controlled dinitroaniline-resistant *E. indica* by 100% at 3 months after spraying. Tampubolon *et al.* (2019c) reported that indaziflam at 75 g ai ha^{-1} significantly controlled the *E. indica* seed bank by 80.67% compared to the untreated at 4 weeks after application.

Oxyfluorfen herbicide at a dose of 240 g ai ha^{-1} controlled survival, the number of tillers and dry weight up to 100% of all glyphosate-resistant *E. indica* biotypes with the control rate classified as excellent. It was due to oxyfluorfen herbicide inhibited the enzyme protoporphyrinogen oxidase, causing damage to cell membranes and lipid peroxide biotypes of glyphosate-resistant *E. indica* (Monaco *et al.*, 2002). According to Weaver *et al.* (2004) that the oxyfluorfen at 0.33 kg ha^{-1} decreased the shoot dry weight of paraquat-resistant *Conyza canadensis* biotypes at 8 WAS. Umiyati (2016) said that oxyfluorfen at 1 to 3 l ha^{-1} significantly suppressed the dry weight of *Echinochloa colona* and *Phyllanthus debilis* by 100% at 2-6 WAS. Widaryanto and Roviyanti (2017) reported that the oxyfluorfen at 1.5 l ha^{-1} significantly suppressed the dry weight of total weeds by 98.65%. Herrmann *et al.* (2017) found that 0.211 kg ha^{-1} of oxyfluorfen effectively controlled *Chenopodium album* and *Polygonum persicaria* weeds by 100%. Permana *et al.* (2018) also added that oxyfluorfen at 1.5 l ha^{-1} significantly the suppressed dry weight of the weeds by 82.44% at 15 days after planting.

Pendimethalin herbicide at 336 g ai ha^{-1} controlled the survival, the number of tillers, and dry weight of glyphosate-resistant *E. indica* biotypes by 98.58; 88.75; and 90.72%, respectively. There are 6 out of 15 glyphosate-resistant *E. indica* biotypes that could be controlled by pendimethalin herbicide including EIR-02, EIR-11, EIR-12, EIR-23, EIR-25, and EIR-26. Hence, the control rate of glyphosate-resistant *E. indica* biotypes using pendimethalin herbicide was classified as excellent. It was due to pendimethalin inhibited the growth of root and shoot cells of *E. indica*. These findings are supported by Monaco *et al.* (2002) that pendimethalin inhibited cell growth through root fracture and enlargement at the root tip and inhibited the emergence of primary leaves from the coleoptile. Grey *et al.* (2008) stated that the pendimethalin at 0.84 kg ha^{-1} significantly controlled *Urochloa texana* weed by 95% at 4 weeks after planting. Soltani *et al.* (2012) found that the application of pendimethalin herbicide at a dose of 1,080 g ha^{-1} controlled *Amaranthus retroflexus* weed by 73%. Soltani *et al.* (2013) said that the application of pendimethalin herbicide at 1,080 g ha^{-1} controlled *Chenopodium album* weed ranging from 82–97%, reducing density and dry weight by 89% and 97%, respectively. Takano *et al.* (2018) added that the usage of pendimethalin herbicide at 1,250 g ha^{-1} significantly controlled glyphosate-resistant *E. indica* by 100% at 20 DAS.

Effectiveness of Post-Emergence Herbicides

Post-emergence herbicides were significantly effective in suppressing the survival, the number of tillers, toxicity symptoms, SPAD total chlorophyll, and dry weight of glyphosate-resistant *E. indica* biotypes. Propaquizafop herbicide was more effective than potassium glyphosate and mesotrione. Propaquizafop at a dose of 100 g ai ha^{-1} suppressed the survival, the number of tillers, toxicity level, SPAD total chlorophyll, and dry weight of glyphosate-resistant *E. indica* biotypes were 78.12; 84.25; 76.85; 76.92; and 81.24%, respectively. Thus, the control level of glyphosate-resistant *E. indica* biotypes using propaquizafop herbicide was very good. In addition, there were 6 out of 15 glyphosate-resistant *E. indica* biotypes, namely EIR-20, EIR-22, EIR-23, EIR-26, EIR-27, and EIR-28 that could be controlled by propaquizafop up to 100%. It was due to propaquizafop inhibited the acetyl-CoA enzyme by limiting lipid levels resulting in several of the glyphosate-resistant *E. indica* biotypes showing changes in leaf color from green to brownish yellow and shrinking. These findings are supported by the six biotypes that experienced a decrease in SPAD total chlorophyll from 3 to 7 HSS (Tab. VII) leading to 100% toxicity at 2 WAS (Tab. VI). According to Monaco *et al.* (2002), propaquizafop inhibited acetyl-CoA carboxylase which limits lipid levels causing the growth of shoots and roots to be suspended and changes in leaf pigment to quickly at 2 to 4 DAS. Haitas *et al.* (1995) stated that the usage of propaquizafop at 0.20 kg ha^{-1} controlled *Sorghum halepense* weed by 95% at 15 DAS. Zagonel *et al.* (1999) found that the propaquizafop application at 100 g ha^{-1} controlled *Eleusine indica* by 90% at 15 DAS. Panda *et al.* (2015) reported that the propaquizafop application at 75 g ha^{-1} had a weed control efficiency of 62.48% at 15 DAS. Thakare *et al.* (2018) added that spraying propaquizafop at 0.10 kg ha^{-1} had a weed control efficiency of 63.50% at 20 DAS.

Potassium glyphosate herbicide at a dose of 660 g ai ha^{-1} significantly inhibited the survival, the number of tillers, toxicity rate, SPAD total chlorophyll, and dry weight of glyphosate-resistant *E. indica* biotypes were 27.19; 55.07; 22.50; 51.29; and 66.53%, respectively. However, the control level of glyphosate-resistant *E. indica* biotypes using potassium glyphosate was unsatisfactory. It was due to the *E. indica* biotypes in this study being resistant to isopropylamine glyphosate and therefore the capability of potassium glyphosate herbicide used was unsatisfactory. It is evidenced by the increase in the toxicity percentage of *E. indica* biotypes by 19.04 to 22.83% at 1-2 WAS but decreased at 3 WAS (Tab. VI). In addition, the SPAD total chlorophyll content on potassium glyphosate herbicide treatment decreased progressively from 3 hours to 7 DAS (Tab. VII). According to Monaco *et al.* (2002), glyphosate inhibited the enzyme 5-enolpyruvylshikimate-3-phosphate synthase (EPSPS) that occurs in chloroplast tissue and converts shikimate-3-phosphate (S-3-P) into enolpyruvylshikimate-3-phosphate (EPSP) and leads to the production of amino acids, phenylalanine, tyrosine, and tryptophan. Shikimate-3-phosphate (S-3-P) is unable to be converted to EPSP because of unstable S-3-P, therefore it is converted quickly to shikimate which is more stable and accumulates. Golob *et al.* (2008) stated that potassium glyphosate significantly controlled broadleaf and grasses weeds by 83.8% and higher than IPA-glyphosate by 77.5% at 14 DAS. Bentivegna *et al.* (2017) found that spraying potassium glyphosate at a dose of 1.08 kg ha^{-1} controlled the dry weight of *Cynara cardunculus* weed by 94.52% at 30 DAS. Kurniadie *et al.* (2019) reported that potassium glyphosate at 660 g l^{-1} caused 100% destruction of *Imperata cylindrica, Ageratum conyzoides,* and *Setaria plicata* weeds although it was leached by rainfall between 2–4 hours after spraying. Alridiwirsah *et al.* (2020) also added that the potassium glyphosate at 1 l ha^{-1} significantly controlled broadleaf and grasses weeds.

Mesotrione herbicide at a dose of 50 g ai ha^{-1} suppressed the survival, the number of tillers, toxicity symptoms, SPAD total chlorophyll, and dry weight of glyphosate-resistant *E. indica* biotypes were 18.75; 77.21; 13.63; 31.84; and 61.30%, respectively. Therefore, the control rate of glyphosate-resistant *E. indica* biotypes using mesotrione herbicide was unsatisfactory. It was due to mesotrione herbicide being less effective in inhibiting chlorophyll pigments of glyphosate-resistant *E. indica* biotypes in chloroplasts, causing the SPAD total chlorophyll content to increase at 7 DAS (Tab. VII) and the percentage of toxicity was relatively low ranging from 5.78 to 18.75% (Tab. VI). According to Pallet *et al.* (1997) that the mesotrione inhibited the enzyme 4-hydroxyphenyl-pyruvate dioxygenase, which converts 4-hydroxyphenylpyruvate into homogenized. The effect of this enzyme inhibition results in the depletion of plastoquinone (a compound that plays an important role in photosynthetic reduction) that the phytoene desaturase enzyme requires to function successfully, thus leading to the inhibition of pigment production. Armel *et al.* (2003) found that the application of mesotrione herbicide at a dose of 70 g ha^{-1} was only effective in controlling *Ambrosia artemisiifolia* weed by 41%. Takano *et al.* (2018) added that spraying mesotrione at a dose of 120 g ha^{-1} only controlled *Eleusine indica* by 57.5% at 14 DAS and 17.5% at 28 DAS.

This study demonstrated that the capability of pre-emergence was higher compared to the post-emergence herbicides in controlling glyphosate-resistant *E. indica* biotypes from oil palm plantations in North Sumatra. The results also proved that rotation of herbicide mode of action was highly recommended in discontinuing the cycle of glyphosate-resistant *E. indica* biotypes. The implementation of this study recommended rotating the mode of action of herbicides in glyphosate-resistant *E. indica* biotypes using propaquizafop (post-emergence) in the first month and then re-spraying with pre-emergence herbicides such as indaziflam or oxyfluorfen in the subsequent period to reduce the resistant seed bank.

CONCLUSION

Pre-emergence herbicides were more effective in controlling glyphosate-resistant *E. indica* biotypes than post-emergence at the similar dose or 1 l ha^{-1}. The order of percentage capability of pre-and post-emergence herbicides were indaziflam and oxyfluorfen > pendimethalin > propaquizafop > potassium glyphosate > mesotrione. Rotation of propaquizafop herbicide followed by indaziflam or oxyfluorfen effectively suppresses the seedbank distribution of glyphosate-resistant *Eleusine indica* in oil palm plantation.

REFERENCES

ALONSO, D. G., KOSKINEN, W. C., OLIVEIRA JR, R. S., CONSTANTIN, J. and MISLANKAR, S. 2011. Sorption–desorption of indaziflam in selected agricultural soils. *Journal of Agricultural and Food Chemistry*, 59(24): 13096–13101. https://doi.org/10.1021/jf203014g

ALRIDIWIRSAH., TAMPUBOLON, K., SIHOMBING, F. N., SIBURIAN, E., PURBA, Z., WAGINO., SULASTRI, Y. S., MANURUNG, I. R., PRATOMO, B., KARIM, S., SAMOSIR, S. T. S., SUPRIYADI., GUSTIANTY, L. R. and HARAHAP, F. S. 2020. Glyphosate potassium salt dosage efficacy to weed control in guava plants. *Asian Journal of Plant Sciences,* 19(4): 487–494. https://doi.org/10.3923/ajps.2020.487.494

ARMEL, G. R., WILSON, H. P., RICHARDSON, R. J. and HINES, T. E. 2003. Mesotrione alone and in mixtures with glyphosate in glyphosate-resistant corn (*Zea mays*). *Weed Technology*, 17(4): 680–685. https://doi.org/10.1614/WT02-77

BENTIVEGNA, D. J., MOYANO, G. L., DADDARIO, J. F. F. and TUCAT, G. 2017. Determination of optimal doses of glyphosate for controlling weeds at several stages in Southwestern Buenos Aires province (Argentina). *Journal of Plant Protection Research*, 57(4): 347–354. https://doi.org/10.1515/jppr-2017-0047

BRABHAM, C., LEI, L., GU, Y., STORK, J., BARRETT, M. and DEBOLT, S. 2014. Indaziflam herbicidal action: a potent cellulose biosynthesis inhibitor. *Plant Physiology*, 166(3): 1177–1185. https://doi.org/10.1104/pp.114.241950

DALIMUNTHE, S. P., PURBA, E. and MEIRIANI. 2015. Dose response of goosegrass (*Eleusine indica* L. Gaertn) biotype glyphosate-resistance to glyphosate, paraquat, and indaziflam. *Jurnal Online Agroekoteknologi*, 3(2): 625–633.

GOLOB, C. T., WILLIAMS, M. W. and JOHNSTON, W. J. 2008. *Efficacy of a new potassium salt formulation of glyphosate (roundup promax) compared to other formulations of glyphosate*. Washington State University, United States.

GREY, T. L., WEBSTER, T. M. and CULPEPPER, A. S. 2008. Weed control as affected by pendimethalin timing and application method in conservation tillage cotton (*Gossypium hirsutum* L.). *The Journal of Cotton Science*, 12: 318–324.

HAITAS, V. C., KOTOULA-SYKA, E. and ELEFTHEROHORINOS, I. G. 1995. Influence of propaquizafop application rate and time on *Sorghum halepense* (L.) Pers. control and cotton (*Gossypium hirsutum*) yield. *Weed Research*, 35(1): 1–6. https://doi.org/10.1111/j.1365-3180.1995.tb02009.x

HERRMANN, C. M., GOLL, M. A., PHILLIPPO, C. J. and ZANDSTRA, B. H. 2017. Postemergence weed control in onion with bentazon, flumioxazin, and oxyfluorfen. *Weed Technology*, 31(2): 279–290. https://doi.org/10.1017/wet.2016.16

JALALUDIN, A., YU, Q. and POWLES, S. B. 2015. Multiple resistance across glufosinate, glyphosate, paraquat and ACC ase-inhibiting herbicides in an *Eleusine indica* population. *Weed Research*, 55(1): 82–89. https://doi.org/10.1111/wre.12118

KURNIADIE, D., SUMEKAR, Y. and NULKARIM, S. 2019. Effect of rainfall on application of potassium glyphosate herbicide in controlling dominant oil palm weeds. *Kultivasi*, 18(1): 817–826. https://doi.org/10.24198/kltv.v18i1.20988

MCCULLOUGH, P. E., YU, J. and DE BARREDA, D. G. 2013. Efficacy of preemergence herbicides for controlling a dinitroaniline-resistant goosegrass (*Eleusine indica*) in Georgia. *Weed Technology*, 27(4): 639–644. https://doi.org/10.1614/WT-D-13-00060.1

MOHAMAD, R. B., WIBAYA, W., MOHAYIDIN, M. G., PUTEH, A. B., JURAIMI, A. S., AWANG, Y. and LASSIM, M. B. M. 2010. Management of mixed weeds in young oil-palm plantation with selected broad-spectrum herbicides. *Pertanika Journal of Tropical Agricultural Science*, 33(2): 193–203.

MONACO, T. J., WELLER, S. C. and ASHTON, F. M. 2002. *Weed science: principles and practices*. 4th Edition. John Wiley & Sons, Inc, New York. p 685.

MUNTHE, A. S., PURBA, E. and LAHAY, R. R. 2016. Germination seed response of *Eleusine indica* L. Gaertn to depth and buried time. *Jurnal Agroekoteknologi*, 4(4): 2367–2375.

PALLETT, K. E., LITTLE, J. P., VEERASEKARAN, P. and VIVIANI, F. 1997. Inhibition of 4-hydroxyphenylpyruvate dioxygenase: the mode of action of herbicide RPA 201772 (isoxaflutole). *Pesticide Science,* 50, 83–84. https://doi.org/10.1002/(SICI)1096-9063(199705)50:1%3C83::AID-PS554%3E3.0.CO;2-S

PANDA, S., LAL, S., KEWAT, M. L., SHARMA, J. K. and SAINI, M. K. 2015. Weed control in soybean with propaquizafop alone and in mixture with imazethapyr. *Indian Journal of Weed Science*, 47(1): 31–33.

PERMANA, J., WIDARYANTO, E. and WICAKSONO, K. P. 2018. The application of oxyfluorfen and pendimethalin herbicides on shallot (*Allium ascalonicum* L.) *Jurnal Produksi Tanaman*, 6(4): 561–568.

SEBASTIAN, D. J., NISSEN, S. J. and RODRIGUES, J. D. S. 2016. Pre-emergence control of six invasive winter annual grasses with imazapic and indaziflam. *Invasive Plant Science and Management*, 9(4): 308–316. https://doi.org/10.1614/IPSM-D-16-00045.1

SOLTANI, N., NURSE, R. E. and SIKKEMA, P. H. 2012. Weed control in dry bean with pendimethalin plus reduced rates of imazethapyr. *International Research Journal of Agricultural Science and Soil Science*, 2(8): 312–317.

SOLTANI, N., NURSE, R. E., SHROPSHIRE, C. and SIKKEMA, P. H. 2013. Weed control in white bean with pendimethalin applied preplant followed by postemergence broadleaved herbicides. *The Open Plant Science Journal*, 7: 24–30.

TAKANO, H. K., OLIVEIRA JR, R. S., CONSTANTIN, J., SILVA, V. F. V. and MENDES, R. R. 2018. Chemical control of glyphosate-resistant goosegrass. *Planta Daninha*, 36: 1–10. http://dx.doi.org/10.1590/s0100-83582018360100055

TAKANO, H. K., OLIVEIRA, J. R. S., CONSTANTIN, J., BRAZ, G. B. P. and PADOVESE, J. C. 2016. Growth, Development and Seed Production of Goosegrass. *Planta Daninha*, 34(2): 249–258. https://doi.org/10.1590/s0100-83582016340200006

TAMPUBOLON, K. and PURBA, E. 2018. Screening single resistance of *Eleusine indica* on oil palm plantation in Padang Lawas and Tapanuli Selatan Regency Indonesia. *Jurnal Natural*, 18(2): 101–106. https://doi.org/10.24815/jn.v18i2.11223

TAMPUBOLON, K., PURBA, E., BASYUNI, M. and HANAFIAH, D. S. 2019a. Glyphosate resistance of *Eleusine indica* populations from North Sumatra, Indonesia. *Biodiversitas Journal of Biological Diversity*, 20(7), 1910–1916. https://doi.org/10.13057/biodiv/d200717

TAMPUBOLON, K., PURBA, E., BASYUNI, M. and HANAFIAH, D. S. 2019b. Histological, physiological and agronomic characters of glyphosate-resistant *Eleusine indica* biotypes. *International Journal of Agriculture and Biology,* 22(6): 1636–1644. https://doi.org/10.17957/IJAB/15.1245

TAMPUBOLON, P. K., PURBA, E. and MUKHLIS. 2019c. The efficacy indaziflam on weed seedbank vertically on the ultisol soil on palm oil plantations. *IOP Conference Series: Earth and Environmental Science*, 260: 012163.

TAMPUBOLON, K., PURBA, E., BASYUNI, M. and HANAFIAH, D. S. 2020. Application of monosodium methyl arsenate with diuron herbicide to control the characteristics of glyphosate-resistant *Eleusine indica* at oil palm plantations. *Bulgarian Journal of Agricultural Science*, 26(5): 1003–1012.

THAKARE, S. S., CHIRDE, P. N., SHINGRUP P. V., DESHMUKH, J. P., KAKDE, S. U. and GHOLAP, A. N. 2018. Weed management in onion by pre- and post-emergence herbicides. *International Journal of Current Microbiology and Applied Sciences,* (Special Issue-6): 2197–2202.

UMIYATI, U. 2016. Effectivity study of oxyfluorfen 240 g ai l^{-1} herbicide as weed controlling in onion (*Allium ascalonicum* L.). *Kultivasi*, 15(1): 46–51. https://doi.org/10.24198/kltv.v15i1.12003

WEAVER, S., DOWNS, M. and NEUFELD, B. 2004. Response of paraquat-resistant and-susceptible horseweed (*Conyza canadensis*) to diquat, linuron, and oxyfluorfen. *Weed Science*, 52(4): 549–553. https://doi.org/10.1614/WS-03-102R

WIDARYANTO, E. and ROVIYANTI, F. 2017. Efficacy of oxyfluorfen herbicide for weed control in broccoli (*Brassica oleracea* L. var. Italica). *Asian Journal of Crop Science*, 9(2): 28–34. http://dx.doi.org/10.3923/ajcs.2017.28.34

ZAGONEL, J., REGHIN, M. Y. and VENÂNCIO, W. S. 1999. Controle pós-emergente de plantas daninhas em cenoura. *Horticultura Brasileira*, 17(1): 69–71. http://dx.doi.org/10.1590/S0102-05361999000100020

Contact information

Koko Tampubolon: https://orcid.org/0000-0002-7969-5049
Edison Purba: https://orcid.org/0000-0002-9366-2489
Mohammad Basyuni: m.basyuni@usu.ac.id, https://orcid.org/0000-0003-1120-8571
Diana Sofia Hanafiah: https://orcid.org/0000-0002-3642-7386