



RESEARCH ARTICLE

Response of selected corn (*Zea mays* L.) varieties and inbreed lines to the glyphosate herbicide

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Abstract

Corn (*Zea mays* L.) is the world's main food commodity after wheat and rice. One of the crucial problems in corn cultivation is weed disturbances that can reduce yields by 30–80 %. The current reliable weed control technology is the use of herbicides and the most widely used herbicides are herbicides with the active ingredient glyphosate. However, the glyphosate herbicide can kill all crops, including corn that is affected by this herbicide. There has been a lot of research on the diversity of maize varieties in terms of susceptibility to this broad-spectrum glyphosate herbicide. Some have found that there are significant differences in herbicide tolerance between some varieties of corn. This difference in response is caused by a difference in the activity level of the EPSP synthase (5-enolpyruvylshikimate-3-phosphate synthase) enzyme, which is the target component of the glyphosate herbicide. This research was conducted on grain corn hybrid, namely the R1001 and R1137 lines, the ADV Jago variety and corn genetically engineered NK 212s variety. The results of this study show that all normal maize (lines and varieties), which are not genetically modified maize, that are exposed to this herbicide, regardless of the concentration, will die within 6–7 days. The death of corn is caused by the damage of EPSP synthase enzyme in the shikimate pathway in the biosynthesis of aromatic amino acids so that proteins and secondary metabolite compounds such as phenolics and flavonoids as well as growth hormone (auxin) will not be formed. This death is shown by stunted plant height, leaf length and leaf width, plant stress level and plant death. The EPSP synthase enzymes in this ordinary corn plant which can be replaced by EPSP synthase enzyme which cannot be damaged by the herbicide glyphosate so that corn plants exposed to this herbicide will not be disturbed in their growth and development as shown by the genetically engineered hybrid corn in this experiment. The native EPSP synthase enzyme in conventional maize is replaced by a glyphosate-tolerant EPSP synthase enzyme that is not inhibited by the herbicide glyphosate. Consequently, genetically engineered hybrid maize exposed to glyphosate exhibits normal growth and development, as demonstrated in the present experiment.

Keywords: corn; EPSP enzyme; glyphosate; herbicide; response

Introduction

Corn (*Zea mays* L.) is the third most important food crop in the world after rice and wheat. The countries that produce the corn in the largest quantities are the United States, China, Brazil, Argentina, India, Ukraine, Mexico and Indonesia, with production volumes of 381.78 million t, 252.1 million t, 81.91 million t, 39.92 million t, 31.6 million t, 28.07 million t, 27.8 million t, 23.04 million t in 2021 (1).

It is not only used as a food, but also as a raw material for the animal feed industry and other purposes such as the food industry (oil, flour and sweetener) and cosmetics. The need for corn continues to increase, but sometimes farmers have obstacles in the application of good cultivation technology so that production

capabilities cannot be maximised. One of the problems faced by farmers is the limited workforce, especially in weed control, which is very significant in reducing corn production by 20–70 % (2, 3).

The common weed control technology to deal with labour shortages is to spray herbicides. The herbicides that are commonly known to farmers are herbicides with the active ingredient glyphosate. Weed control technology in corn with herbicides made from the active ingredient glyphosate is the easiest, fastest and a technology preferred by farmers because it can provide maximum results as this active ingredient will kill all types of weeds so that corn plants can grow without weed disturbed and can produce optimally. However, the disadvantage of herbicides with the active ingredient

glyphosate is that they will kill all non-genetically modified (GM) types of plants that have green leaves, including corn, if exposed to this herbicide (4).

To date, genetic engineering technology for corn plants has been able to overcome the problem of corn damage due to exposure to herbicides with the active ingredient glyphosate, commonly known as genetic modified herbicide resistant (GMHR) (5–7).

Therefore, the efforts to produce corn varieties that can survive and produce optimally despite exposure to herbicides with the active ingredient glyphosate can be done by genetically modifying the enzyme in the maize plant tissue. The enzyme can be transferred from the *Agrobacterium* sp. strain CP5. Genetically modified herbicide resistant maize was first released in the United States of America in 1998 (8) and was subsequently widely developed in the United States and then distributed in Argentina, Brazil, Canada, South Africa, Philippines, Mexico and several other countries in the early 2000s. Currently, GMHR maize has been widely developed in some countries such as America, Latin America, parts of Africa and Asia (9, 10).

In Indonesia, research about genetic modified corn has also begun to be carried out about 10 years ago. It was reported that as many as 30 bacterial isolates had been selected for resistance to glyphosate and paraquat herbicides and obtained 1 herbicide-resistant isolate with a concentration of 4000 ppm glyphosate and 1600 ppm paraquat (11).

The results of this study can provide recommendations for future research on determining the lower and upper limits of glyphosate herbicide doses that may inhibit the growth of normal corn plants or even kill them. To date, no studies have investigated the effects of using specific herbicide dosage levels on the growth and development of normal corn plants compared to those that already carry the EPSP (5-enolpyruvylshikimate-3-phosphate synthase) enzyme up to its lethal threshold.

To find out how maize plants respond to glyphosate herbicides, what is the lowest dose of glyphosate herbicide that can kill normal maize plants and genetically modified herbicide resistant (GMHR) maize, as well as how the mechanism of glyphosate herbicides kills maize plants, these experiments were conducted in the field and in greenhouses so that comprehensive information about the capabilities of several existing maize varieties and inbred lines by evaluating agronomy aspects. To determine the response of maize plants to glyphosate herbicides, identify the lowest dose of glyphosate capable of killing conventional maize and genetically modified herbicide-resistant (GMHR) maize and understand the mechanism by which glyphosate kills maize plants, field and greenhouse experiments were conducted. These experiments provided comprehensive information on the performance of several maize varieties and inbred lines based on the evaluation of agronomic traits.

Materials and Methods

A total of four genetic resources of corn plants used in this study consisted of 2 inbred lines, namely R 1001 and R 1335 obtained from PT Restu Agropo Jayamas (RAJA) and 2 hybrid corn variety, namely ADV Jago and NK 212s (the genetic modified herbicide resistant / GMHR maize). NK 212s was used as a check genotype corn to respond the herbicide treatments. The herbicide with the active

ingredient glyphosate used is Round up 480 SL which contains 48 % glyphosate active ingredient which is the solution form that is easily soluble in water and obtained from an agricultural store.

This experiment was conducted in 2 stages; the first one was carried out in the field. Each genotype of corn were planted in a plot of 1.4 m x 2.4 m. Planting distance was 70 cm x 40 cm with 1 seed per hole. There were 5 levels of herbicide concentration, namely 0 (control), 50, 100, 150 and 300 mL/16 L of water or 0, 1.1, 2.2, 3.3 and 6.6 g glyphosate/L round up in 16 L of water, which were applied to plants aged 31 days.

The second experiment was carried out in the greenhouse to test an even lower herbicide concentration carried out in a greenhouse with 5 levels of herbicide concentration, namely 0 (control), 0.25, 0.50, 0.75 and 1.00 g/L in 16 L of water. The corn seed was planted in the seed in the seedling tray, one seed per hole of the tray. Herbicide treatments were applied to 8 days old plants.

The main reason for applying the herbicide to the two different growth stages of maize crop was to compare the response of the young trial crops (on day 8 after planting) and the mature maize plants (31 days after planting) that have been in the rapid growth phase to the herbicide application.

Data collection

These two studies were conducted using the factorial randomised block design (RBD) method with two factors with 3 replications. Observations of growth variables were carried out at plant age 31 days (before treatment), 36 (5 days after treatment) and 43 days (12 days after treatment) in the field experiment and at plant age 8 days (before treatment), 13 days (5 days after treatment) and 15 days (7 days after treatment). Some of the variables observed in this study are plant height, leaf length and leaf width as well as plant stress level scores and percentage of dead plants (12). The variables of plant height, stem diameter, leaf length and leaf width were measured using a meter (m) and calliper in 3 plants per plot.

To determine plant stress levels, three plants were randomly sampled from each plot and give score of 0–9. Give a score of 0 if it looks like the plant is growing normally, score 3 if the plant shows a change in leaf colour from green to yellow, score 5 if the leaves of the plant are not only yellowing but also turn to brown and show a slight wrinkle and score 7 if most the leaves have started to turn brown and wrinkled, score 9 if the leaves of the plant are completely brown and curled and also dry to death, using European Weed Research Council (EWRC) rating scale.

Data analysis

The data was analysed using Minitab software version 20 to calculate analysis of variance (ANOVA) and Tukey least significant difference (LSD) for advanced analysis.

Results

The results of the research reported in this paper include field research data such as changes in plant height, stem diameter, leaf length, leaf width and percentage of dead plants and the greenhouse experimental data consisting of the changes of plant height, leaf length and plant stress level.

Increase in plant height

The increase in height of corn plants is a growth variable that can be measured as a result of the occurrence of various normal

physiological processes so that crops will continue to grow until it reaches optimal height of corn plants (13). The increase in height of corn plants from field experiments and experiments in the greenhouse are shown in Fig. 1.

The results of the measurement of the increase in height of corn plants tested in the field (Fig. 1) revealed that all corn varieties that were not sprayed with herbicides (control) showed an increase in plant height between 60–90 cm, during 7 days after treatment, while corn that received herbicide treatment, at all levels of herbicides, does not experience an increase in plant height (0 cm) except for NK 212s variety. Even though exposed to herbicides with all concentrations, NK 212s still grows with an increase in height reaching between 60 and 70 cm.

This result is the same as in the greenhouse experiments on R 1001 and R 1337, that although the concentration of herbicides is reduced to 0.25–1.00 mL/16 L of water, after 7 days of herbicide exposure, the increase in plant height is less than 3 cm. In contrast to corn plants that do not receive herbicide treatment (control), they continue to grow which is characterised by an increase in plant height of about 3.6–4.6 cm in 7 days. This confirms that the retardation of plant growth is not due to high herbicide concentrations (50–300 mL/16 L of water) and low herbicide concentrations (0.25–1.0 mL/16 L of water) but due to the presence of herbicides in plant tissues that have chlorophyll.

Increase in stem diameter

During the growth period of corn plants, the increase in plant diameter is also one of the variables that describes normal growth to reach the optimal diameter in supporting plant growth and development. An illustration of the increase in plant diameter from field experiments are shown in Fig. 2.

The results of measurements on the increase in corn stem diameter tested in the field showed that all control corn varieties had an increase in plant stem diameter between about 3–5 cm during 7 days after herbicide application depending on the variety. Meanwhile, ADV Jago, R 1001 and R 1337, which received herbicide treatment, at all herbicide levels, did not experience an increase in plant stem diameter (0 cm) after 7 days from the time of herbicide spray. Only NK 212s variety continues to grow with an increase in stem diameter reaching between 2 and 4 cm, despite exposure to herbicides at all concentrations.

Increased in leaf length

Leaf length is also an important variable in determining the growth speed of plants because with long leaves, the photosynthesis process will take place more optimally with the leaves that are compact. The results of measuring the increase in the length of corn leaves from field experiments and experiments in the greenhouse are shown in Fig. 3.

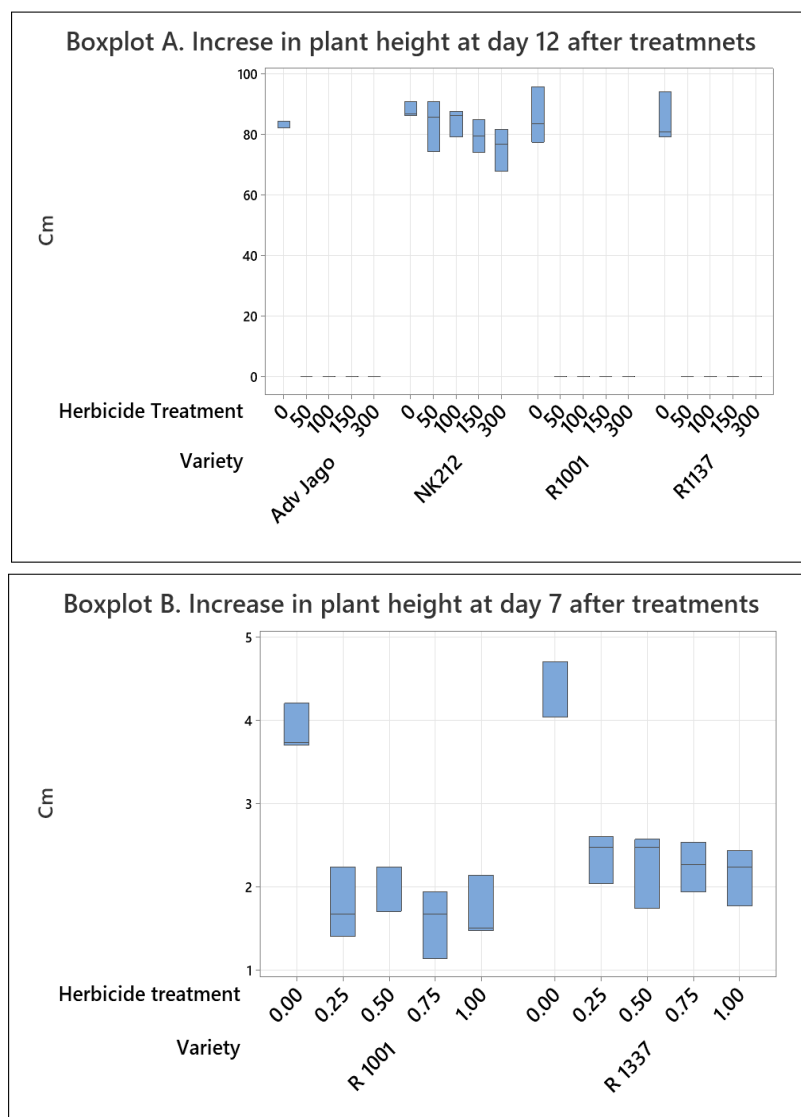


Fig. 1. Increase in plant height of the maize in the field experiment (Boxplot A) and maize in the greenhouse experiment (Boxplot B).

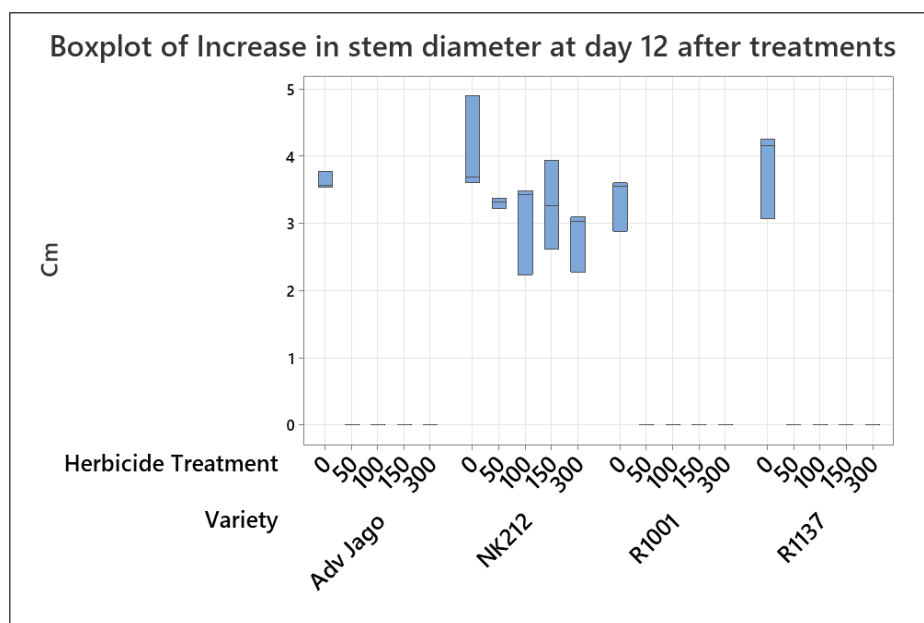


Fig. 2. Increase in stem diameter of the maize in the field experiment.

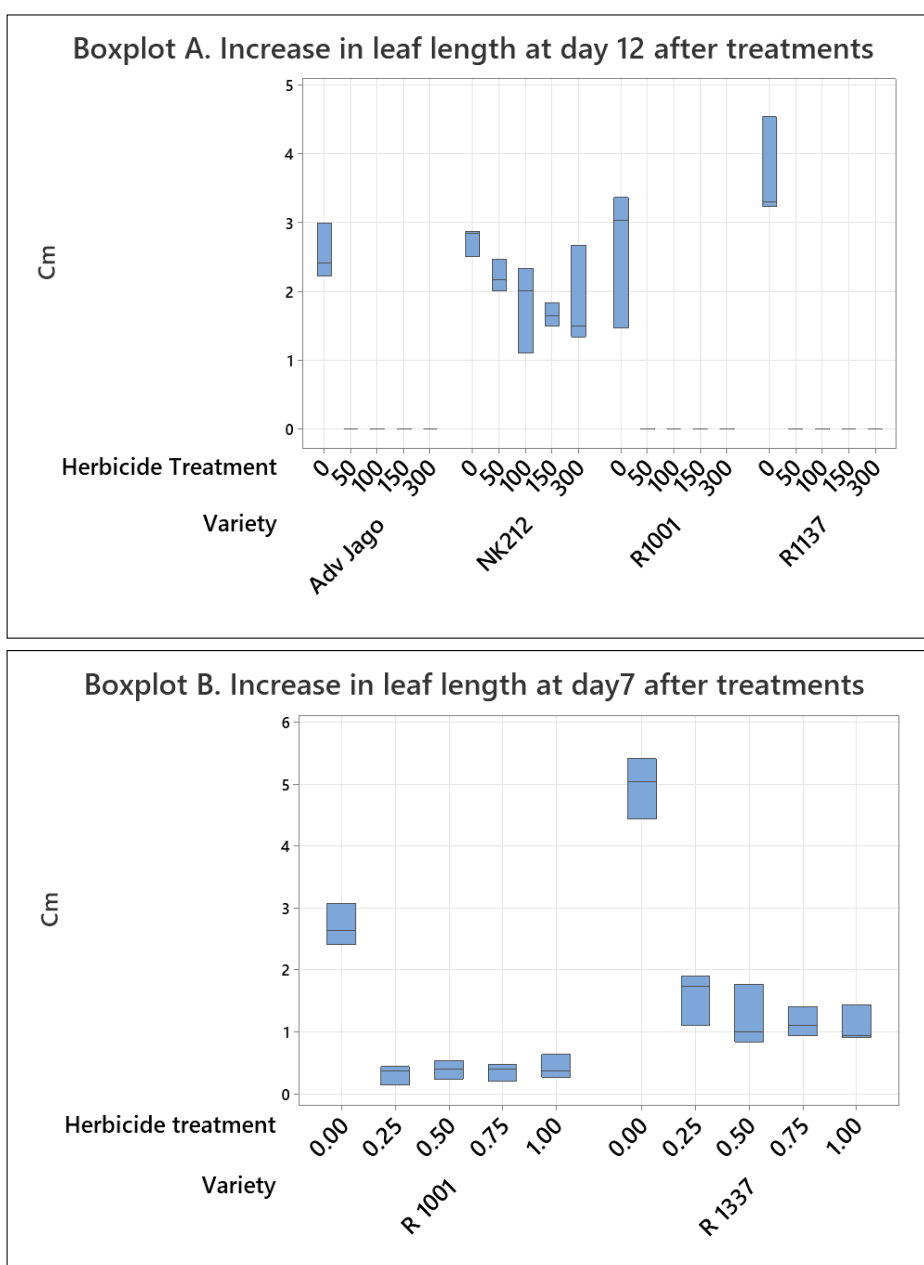


Fig. 3. Increase in leaf length of the maize in the field experiment (Boxplot A) and maize in the greenhouse experiment (Boxplot B).

It can be seen, from Fig. 3, that all control corn varieties have an increase in leaf growth between 1.5–4.5 cm depending on the variety for 7 days after herbicide application. The addition of leaf length also occurred in NK 212s which received herbicide treatment with various concentration levels. Meanwhile, ADV Jago corn, R 1001 and R 1337, which received herbicide treatment, at all herbicide levels, did not experience an increase in leaf length after receiving herbicide application. Similar to corn plants in the experiment in the greenhouse, all control plants still experienced an increase in leaf length between 2.5 and 5 cm more than 3 cm for R 1001 and between 3.5 cm and 4.5 cm for R 1337 while those that received herbicide treatment experienced an increase in leaf length just less than 1 cm for R 1001 and less than 2 cm for R 1337.

Increase in leaf width

Leaf width is also an important variable in determining the growth speed of plants because with wide leaves, the photosynthesis process will take place more optimally compared to narrow leaves. The change in the width of plant leaves from field experiment are illustrated in Fig. 4.

As same as plant height, stem diameter and leaf length variables, the increase in the width of the control corn leaves still increased (between 0.5 and 3 cm) because it was not exposed to herbicides. Meanwhile, ADV Jago, R 1001 and R 1337 which are exposed to all levels of herbicide do not experience an increase in leaf width (0 cm), which means that leaf growth is stop growing even to death. Only the NK 212s variety that, despite being exposed to herbicides at all levels, still experienced an increase in leaf width (between 1.5 and 3.5 cm) or still experienced leaf growth. It also confirms that normal plant growth is still taking place in all control crops and NK212s corn.

Plant stress levels

Plant stress level is a growth variable that gives an overview of physiological disorders in the plant as shown by changes in leaf colour and physical appearance such as shrinking and drying of the plant. The average level of plant stress of the greenhouse experiment, recorded in the form of scoring in this experiment is shown in Fig. 5.

The experiment results of the greenhouse experiment showed that the two inbred lines of control corn did not experience stress (stress score 0). Meanwhile, the stress level of corn plants continues to increase after receiving treatment with glyphosate herbicide and on the 5th day has reached a stress score of around 2–3 while on the seventh day the observation of the stress score of the two types of corn has reached more than 8 to close to 9. This shows that plant stress levels against the herbicide glyphosate stated increase several days after herbicide drift and have reached a peak and are leading to plant death in the 7th day.

Plant death

The rate of plant mortality can be indicated by the percentage of plants that die as a result of herbicide treatment at some level (herbicide concentration). The results of the calculation of plant mortality in this field experiment are shown in Fig. 6.

The results of the calculation of the percentage of the dead plants after the 7th day herbicide spray (Fig. 6 Boxplot A) showed that the majority (100 %) of ADV Jago, R 1001 and R 1337 died after receiving glyphosate herbicide treatment at all test levels and only NK 212s and all control corn (not herbicide applied) were almost completely normal growing. Although there is NK 212s that has received herbicide treatment, this plant does not die. If depicted in graphic form, the dead percentage for 7 days between the five herbicide concentrations tested from corn that received herbicide treatment of 50, 100, 150 and 300 mL/16 L of water, the percentage of plant mortality continued to increase until on the fifth day it reached more than 80 % of dead plants and on the 7th day after treatment the total number (100 %) of dead plants was recorded. This illustrates that NK 212s corn, which is genetically engineered corn, already has a resistance gene to the herbicide glyphosate so that it does not cause the plant to die, while what causes corn plants that do not have the resistance gene to die is not due to concentration but because of the presence of the glyphosate herbicide in plant tissues.

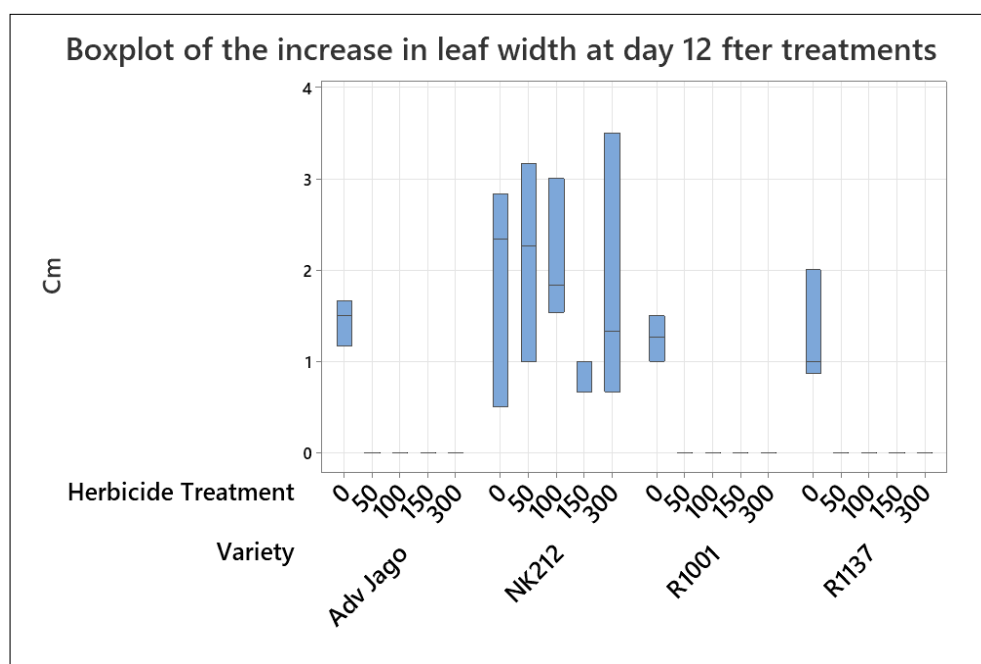


Fig. 4. The change of the leaf width of the maize in the field experiment.



Fig. 5. Average score of the maize plant stress before and after treatments of the experiment.

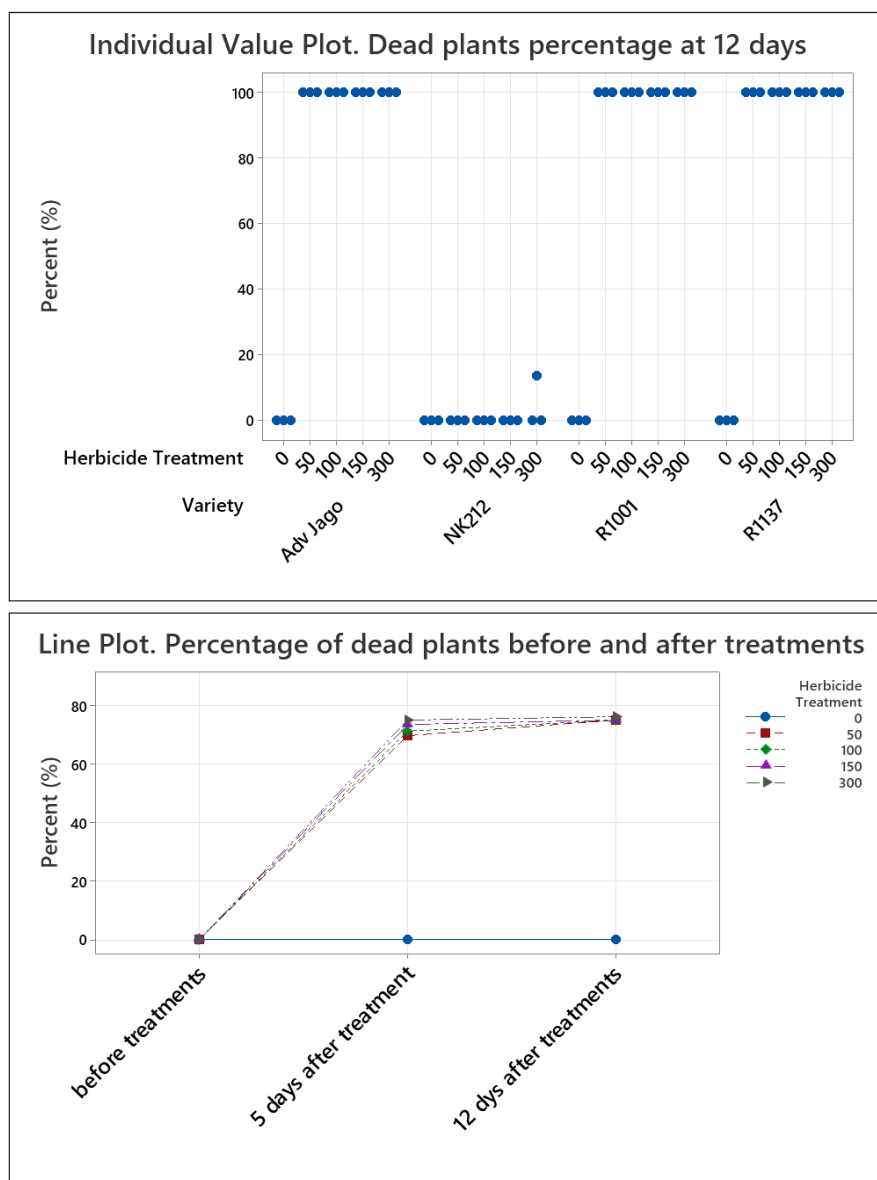


Fig. 6. Percentage of dead plant 12 days after herbicide treatment of the experiment maize in the field test (Individual value plot) and trend of the dead plant at 5 and 12 days after treatment in the field test (Line plot).

Discussion

The results of the calculation of ANOVA from field research data and experiments in greenhouses showed that the variety, concentration of glyphosate herbicide and its interactions had a very real effect on all corn observation variables, namely plant height, stem diameter, leaf length, leaf width, plant stress level and plant mortality rate. The results of the ANOVA test and follow-up tests from this experiment are shown in Tables 1 and 2.

The results of the follow-up analysis of the variety treatment showed that only the NK 212s variety had a good increase in plant height (82 cm) in contrast significantly to the other 3 varieties, namely R 1001 only increased by 17.1 cm, followed by R 1337 increased by 16.9 cm and ADV Jago increased by 16.6 cm.

Similar to the variable plant height, increase in stem diameter, leaf length and leaf width for all four types of corn, only NK 212 has the largest increase that is statistically different compared to the other three types of corn, which are 3.3 cm in addition to stem diameter, 2.3 cm increase in leaf length and 1.8 cm increase in leaf width. The ADV Jago variety is the variety that has experienced the smallest increase (stem diameter 0.7 cm, leaf length 0.5 cm and leaf width 0.3 cm) which are not significantly different from R 1001 and R 1337.

The results of the Tukey LSD analysis of the treatment of glyphosate herbicide concentration showed that all types of corn that did not receive herbicide treatment (control) had the highest increase in observation variables (plant height increased by 85.1 cm; stem diameter increased by 3.7 cm; leaf length increased by 2.9 cm; and leaf width increased by 1.5 cm) which are statistically different compared to herbicide treatment at all concentration levels. The lowest increase in plant height, stem diameter, leaf length and leaf width in herbicide treatment was 300 mL/16 L of water (plant height increased by 18.8 cm; stem diameter increased by 0.7 cm; leaf length increased by 0.3 cm; and leaf width increased by 1.3 cm) which did not differ significantly from the concentration of 50, 100 and 150 mL/16 L of water.

The percentage of dead plant variable, also gives a similar picture to other variables, namely the NK 212s variety has almost no dead plants (0.9 %) while, the other three corn are significantly different because all plants die after 7 days of glyphosate herbicide treatment (100 %).

It was not different from the experiment in the greenhouse on maize that did not have the glyphosate herbicide resistance gene (inbred lines R 1001 and R 1337) those receiving herbicide treatment responded significantly different to them that got

Table 1. Increase in plant height, stem diameter, leaf length, leaf width and percentage of death plant of maize field experiment at day 127 after herbicide treatment

Factor	Level of factor	Increase in plant height (cm)		Increase in stem diameter (cm)		Increase in leaf length (cm)		Increase in leaf width (cm)		Percentage of death plant (%)	
Variety	ADV Jago	16.6	b	0.7	b	0.5	b	0.3	b	80.0	a
	NK 212	82.0	a	3.3	a	2.1	a	1.8	a	0.9	b
	R 1001	17.1	b	0.7	b	0.5	b	0.3	b	80.0	a
	R 1337	16.9	b	0.8	b	0.7	b	0.3	b	80.0	a
Herbicide	0	85.1	A	3.7	A	2.9	A	1.5	A	0.0	B
	50	20.9	B	0.8	B	0.6	B	0.5	B	75.0	A
	100	21.0	B	0.8	B	0.5	B	0.5	B	75.0	A
	150	19.8	B	0.8	B	0.4	B	0.2	B	75.0	A
	300	18.8	B	0.7	B	0.5	B	0.5	B	76.1	A
Interaction	ADV Jago x 0	82.8	LM	3.6	LM	2.5	M	1.4	Ns	0.0	N
	ADV Jago x 50	0.0	N	0.0	O	0.0	O	0.0	Ns	100.0	L
	ADV Jago x 100	0.0	N	0.0	O	0.0	O	0.0	Ns	100.0	L
	ADV Jago x 150	0.0	N	0.0	O	0.0	O	0.0	Ns	100.0	L
	ADV Jago x 300	0.0	N	0.0	O	0.0	O	0.0	ns	100.0	L
	NK 212 x 0	87.8	L	4.1	L	2.7	M	1.9	ns	0.0	N
	NK 212 x 50	83.5	LM	3.3	MN	2.2	MN	2.1	ns	0.0	N
	NK 212 x 100	84.2	LM	3.0	N	1.8	N	2.1	ns	0.0	N
	NK 212 x 150	79.3	LM	3.3	MN	1.7	N	0.9	ns	0.0	N
	NK 212 X 300	75.3	LM	2.8	N	1.8	N	1.8	ns	4.5	M
	R 1001 x 0	85.4	LM	3.3	MN	2.6	M	1.3	ns	0.0	N
	R 1001 x 50	0.0	N	0.0	O	0.0	O	0.0	ns	100.0	L
	R 1001 x 100	0.0	N	0.0	O	0.0	O	0.0	ns	100.0	L
	R 1001 x 150	0.0	N	0.0	O	0.0	O	0.0	ns	100.0	L
	R 1001 x 300	0.0	N	0.0	O	0.0	O	0.0	ns	100.0	L
	R 1337 x 0	84.6	LM	3.8	L	3.7	L	1.3	ns	0.0	N
	R 1337 x 50	0.0	N	0.0	O	0.0	O	0.0	ns	100.0	L
	R 1337 x 100	0.0	N	0.0	O	0.0	O	0.0	ns	100.0	L
	R 1337 x 150	0.0	N	0.0	O	0.0	O	0.0	ns	100.0	L
	R 1337 X 300	0.0	N	0.0	O	0.0	O	0.0	ns	100.0	L

Numbers followed by different letters mean statistically significant difference with $p \leq 0.05$;

Letter “a” means the highest value range among the tested varieties; Letter “b” means the smallest value range among the tested varieties;

Letter “A” means the highest value range among the herbicide treatments; Letter “B” means the smallest value range among the herbicide treatments;

Letter “L” means the highest value range among the combination treatments; Letter “M” means smaller value range than letter “L” among the herbicide treatments; Letter “N” means smaller value range than letter “M” among the herbicide treatments; Letter “O” means the smallest value range among the combination treatments;

Letter “ns” means there is not statistically significant different with $p \leq 0.05$;

Table 2. Increase in plant height, leaf length and average of stress plant score of greenhouse maize experiment at day 7 after herbicide treatment

Factor	Level of factor	Increase in plant height (cm)		Increase in leaf length (cm)		Increase in score of plant stress	
Variety	R 1001	2.2	b	0.8	b	6.8	ns
	R 1337	2.7	a	2.0	a	6.8	ns
Herbicide	0	4.1	A	3.8	A	0.0	B
	0.25	2.1	B	0.9	B	8.4	A
	0.50	2.1	B	0.8	B	8.4	A
	0.75	1.9	B	0.8	B	8.4	A
	1.00	1.9	B	0.8	B	8.6	A
Interaction	R 1001 x 0	4.3	ns	2.7	L	0.0	ns
	R 1001 x 0.25	2.4	ns	0.3	N	8.3	ns
	R 1001 x 0.50	2.3	ns	0.4	N	8.3	ns
	R 1001 x 0.75	2.2	ns	0.4	N	8.6	ns
	R 1001 x 1.00	2.1	ns	0.4	N	8.6	ns
	R 1337 x 0	3.9	ns	3.0	L	0.0	ns
	R 1337 x 0.25	1.8	ns	1.6	MN	8.6	ns
	R 1337 x 0.50	1.9	ns	1.2	MN	8.6	ns
	R 1337 x 0.75	1.6	ns	1.1	MN	8.3	ns
	R 1337 X 1.00	1.7	ns	1.1	MN	8.7	ns

Numbers followed by different letters mean statistically significant difference with $p \leq 0.05$;

Letter “a” means the highest value range among the tested varieties; Letter “b” means the smallest value range among the tested varieties;

Letter “A” means the highest value range among the herbicide treatments; Letter “B” means the smallest value range among the herbicide treatments;

Letter “L” means the highest value range among the combination treatments; Letter “M” means smaller value range than letter “L” among the herbicide treatments; Letter “N” means the smallest value range among the combination treatments;

Letter “ns” means there is not statistically significant different with $p \leq 0.05$;

herbicide drift in all variables (plant height increased by 4.1 cm and leaf length increased by 3.8 cm). The highest herbicide concentration, 300 mL/16 L of water, was the one that exerted the greatest influence (plant height increased by 1.9 cm, leaf length increased by 0.8 cm and leaf width increased by 0.3 cm) which did not differ significantly from the concentrations of 0.50 and 0.75 mL/16 L of water, as a result of treatment with glyphosate herbicide concentration.

Meanwhile, the results of the follow-up statistical analysis of the interaction between variety and herbicide treatment confirmed that the NK 212s variety that was not given herbicide application (NK 212s x 0) was the best plant height (87.8 cm) which was not significantly different from the other three types of corn that did not receive herbicide treatment (R 1001 x 0 herbicide received an increase in plant height of 85.4 cm, R 1337 x 0 got an increase in height of 84.6 cm and ADV Jago x 0 got an increase of 82.5 cm) and it is also not significantly different from the combination of NK 212s which received herbicide treatment at all concentration levels, but it is very different from the treatment of combination varieties (ADV Jago, R 1001 and R 1337) which received herbicide treatment at all concentration levels.

Similarly, the results of follow-up tests on the interaction of variety and herbicide interaction data in the greenhouse experiment showed that there was no significance difference between the two types of corn that did not receive herbicide treatment, but it was significantly different from corn that received herbicide treatment in the variable of the increase in leaf length.

From the aspect of plant stress levels, it is known that only differences in herbicide concentrations significantly affect plant stress levels. It can be seen that 0 mL/16 L of water does not cause plant stress, while herbicide concentration of 50 mL/16 L of water raises the plant's stress score by 8.4 and the concentration of 100

mL/ 16 L of water raises the plant's stress score by 8.4, also 150 mL/ 16 L of water raises the plant's stress score by 8.4, lastly the concentration of 300 mL/ 16 L of water caused a plant stress score of 8.6, while the varieties and interactions did not differ markedly.

From the discussion above, it can be seen that the response of corn that already has a resistance gene to the herbicide glyphosate, namely NK 212s, does not experience growth disturbances even though it is treated with herbicides with the lowest concentration of 50 mL/16 L of water to the highest concentration (300 mL/16 L of water). This confirms the exact results from previous studies where there was no real effect of the herbicide dose of potassium glyphosate 660 g/L on the growth and yield of herbicide-tolerant corn crops (14, 15).

Meanwhile, corn that does not have the enzyme EPSP which is resistant to glyphosate herbicide will experience plant growth disorders because the metabolic process in plant tissues is disrupted, namely the inhibition of the work of the enzyme EPSP synthase in the shikimate pathway in corn plant tissues (10, 16). With up-to date technologies, GMHR corn can be created and tested by using artificial gene transfer or genome editing soaking in glyphosate solution (17–20). Therefore, the integration of transferring resistance EPSP genes to national superior varieties of corn that have been widely developed in various regions in Indonesia needs to be carried out so that farmers' constraints in terms of limited capital in controlling weeds can be overcome.

Although there is a debate about the safety of using genetically modified organisms (GMOs), including corn in Indonesia, there are currently many GMHRs in Indonesia and Séralini (21) reported that PT Monsanto has conducted GMHR food safety research and the results of the study confirm that GMHR commercial corn hybrids that have been circulating in the market are safe and nutritious food just like other non-GM corn (22, 23).

By adopting the use of GMHR maize, it was estimated that the use of glyphosate herbicides with high concentrations would be further reduced so that it would be more environmentally friendly (24).

However, long-term food safety research needs to be conducted on the consumption of GMHR maize which may cause intestinal, liver and kidney disorders as well as hormonal disorders that may result from overexpression of EPSP transgenic in corn associated with phenolic acid metabolites.

Conclusion

The results of this study prove that NK 212s corn is a very tolerant variety to glyphosate herbicide compared to ADV Jago and R 1001 and R 1337 corn. The high tolerance level is because NK 212s corn is genetically modified herbicide resistant (GMHR) corn that already has a gene for resistance to glyphosate. In the future, corn development needs to be carried out so that efforts to increase corn production can be achieved with relatively low farming costs.

Genetically engineered corn research must have begun in Indonesia to be able to produce genetic modified herbicide resistant (GMHR) corn that is high yielding and tolerant to pest attacks and main corn diseases.

Even the smallest concentration of glyphosate herbicide (0.25 mL/16 L of water) can kill ordinary (non-GMHR) corn varieties. That means the use of herbicides with the active ingredient glyphosate in order to control weeds in corn cultivation does not require excessive application rates so that cultivation costs are lower and further reduce environmental pollution.

The way the herbicide glyphosate works is by damaging the EPSP enzyme in plant tissues so that all physiological processes in the webs and plant cells are disrupted. The existence of this herbicide, even though it is very small, is able to enter plant cells, it is able to interfere with the formation of proteins and aromatic compounds that are indispensable for plants in forming body building materials and photosynthesis and respiration processes, including disrupting the process of forming plant growth hormones such as auxin, so that plant growth will stop and die.

In addition, it is also concluded that long-term food safety research needs to be carried out on the development of GMHR maize in Indonesia in order to prevent public health disturbances.

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Authors' contributions

EYH, ESM and RH contributed to the conceptualisation and design of the study, literature review, data processing and preparation of the original draft manuscript. YMB and DS coordinated the research process and contributed to data collection. AW performed the data analysis and assisted in the interpretation of the results. SR participated in the literature review and supported manuscript

revision. MDL contributed to the study design, performed the statistical analysis and critically reviewed the manuscript. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: The authors do not have any conflict of interest to declare.

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