

Comparative Efficacy, Cost-Efficiency, and Phytotoxicity of Premium and Generic Glufosinate-Ammonium Formulations for *Paspalum conjugatum* Control

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ABSTRACT

This study compared weed-control efficacy, biomass responses, phytotoxicity, and cost-efficiency of premium and generic glufosinate-ammonium commercial programmes for *Paspalum conjugatum* under local conditions. A randomised complete block design with three independent blocks was used. Five treatments were evaluated: untreated control; premium programme (Tepat®, 5.66% w/w glufosinate-ammonium) at 6 and 12 L/ha; and generic programme (Vista 15, 13.5% w/w glufosinate-ammonium) at 3 and 6 L/ha. For weed assessments, three tray subsamples within each treatment-by-block unit were averaged before inferential analysis ($n = 3$ independent block means). Equal active-ingredient doses could not be verified because product-density data were unavailable; therefore, comparisons refer to commercial application programmes rather than equivalent active-ingredient doses. Weed-control efficacy was assessed for six weeks, fresh and dry biomass at 42 days after treatment, and *Brassica juncea* served as a sensitive indicator of off-target phytotoxicity. All herbicide programmes achieved approximately 97-98% weed control at three weeks and significantly reduced biomass relative to the untreated control. No statistically significant difference in final weed-control performance was detected between premium and generic programmes; this should not be interpreted as biological equivalence. All herbicide programmes caused severe phytotoxicity to *B. juncea* by day 7. Partial-budgeting analysis showed that generic programmes reduced treatment costs by RM60-RM120/ha, equivalent to estimated annual savings of RM180,000-RM360,000 for 3,000 ha. These results support considering biological performance, crop safety, and treatment cost when selecting glufosinate-ammonium programmes.

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1. INTRODUCTION

Herbicides are major components of chemical weed management and are used to prevent or disrupt normal plant growth and development (Mesnage et al., 2021). Glufosinate-ammonium is a non-selective, broad-spectrum herbicide with a rapid mode of action and is an important option in diversified weed-management programmes (Takano & Dayan, 2020). Commercial products containing the same active ingredient may differ in active-ingredient concentration and in co-formulants such as surfactants and solvents, which can influence spray properties and biological activity (Maldonado-Reina et al., 2022).

Throughout this manuscript, the comparison is made between commercial application programmes, with each product applied at the rates tested in this experiment. Because product-density data were unavailable, equal

active-ingredient doses could not be verified. The results should therefore be interpreted as comparisons between the products as sold and applied rather than as comparisons at equivalent active-ingredient doses.

The primary purpose of this investigation was to provide empirical evidence through a comparative evaluation of selected premium and generic glufosinate-ammonium commercial application programmes. The study assessed control of *Paspalum conjugatum*, a stoloniferous perennial grass that competes aggressively with crops for light, water, and nutrients (Hirani et al., 2024). Four outcomes were evaluated: visual weed-control efficacy, biomass response, non-target crop phytotoxicity, and cost-efficiency. The study was intended to support practical herbicide selection by considering biological performance together with economic implications (Das et al., 2024).

A significant gap still exists in the current literature regarding the field-level performance of specific herbicide categories under localised conditions. Existing research often focuses on the general effectiveness of the active ingredient itself, providing limited comparative data on how specific commercial formulations differ in practice. Consequently, there is also a notable lack of local comparative data detailing the crop injury risks, quantitative biomass suppression, and long-term cost-benefit ratios between branded and generic products. This study addresses this knowledge gap by moving beyond broad molecular analysis to provide empirical field-level data, allowing more precise understanding of formulation performance, and economic viability in real-world agricultural settings.

2. LITERATURE REVIEW

2.1 Impact of Weeds on Agricultural Productivity

Herbicides are essential agrochemicals applied to prevent or disrupt normal plant development (Mesnage et al., 2021). Weeds are defined as unwanted plants that compete with cultivated crops for essential resources such as light, water, and nutrients (Moond et al., 2023). This competition is a perennial challenge that reduces crop yield, increases management costs, and interferes with farm operations (Moond et al., 2023). Early-season weed infestation is particularly detrimental as weeds compete with young crops during the critical establishment period (Hirani et al., 2024). If left uncontrolled, weed infestations can result in a total yield loss of 100% (Chauhan, 2020). Furthermore, contamination of harvested grains with weed seeds can reduce grain quality and market value, leading to lower income for farmers (Little et al., 2021). Weeds often demand more water than many crops, and dense growth can increase dry biomass and fuel load, contributing to fire risks under dry conditions (Pagadala et al., 2024; Singh et al., 2022). Consequently, properties with severe weed infestations may suffer from decreased land value due to increased production risks and restoration costs (El-Beltagi et al., 2022).

2.2 Characteristics of *Paspalum conjugatum* and *Brassica juncea*

Paspalum conjugatum, known as buffalo or carabao grass, is a vigorous, creeping perennial grass with long stolons and has been extensively introduced beyond its native range (CABI, n.d.). Its leaf anatomy and photosynthetic characteristics are consistent with C4 plants, making it resilient to high temperatures and well-adapted to tropical environments (Zhou et al., 2026). Its growth under contrasting soil-moisture regimes has also been investigated, indicating its relevance under variable moisture conditions

(Yanos, 2022).

Brassica juncea (brown mustard) belongs to the Brassicaceae family and is an important edible oilseed crop (Rai et al., 2022). This species is highly sensitive to temperature stress, which can decrease photosynthetic rates and reduce water availability (Lee et al., 2020). Due to its rapid germination, uniform growth, and high susceptibility to chemical stress, *Brassica juncea* is an ideal sensitive crop indicator for assessing herbicide phytotoxicity (Bakshi et al., 2021).

2.3 Glufosinate-Ammonium: Mode of Action and Resistance

Glufosinate-ammonium is a non-selective, post-emergent, broad-spectrum herbicide (Qian et al., 2025). It is currently the only herbicide that targets the glutamine synthetase (GS) enzyme (Takano & Dayan, 2020). By inhibiting GS, the herbicide prevents the conversion of ammonium and glutamate into glutamine, leading to a toxic accumulation of ammonia within plant cells (Takano & Dayan, 2020). This process collapses photosynthesis, causes the formation of reactive oxygen species (ROS), and results in rapid cell death (Qian et al., 2025; Takano & Dayan, 2020).

Herbicide resistance is the inherited ability of a weed population to survive and reproduce after exposure to a herbicide dose that would normally be lethal (Arasan et al., 2025). Repeated use of the same mode of action may select for resistant biotypes, making long-term management more difficult (Ofosu et al., 2023).

2.4 Herbicide Formulations: Premium vs. Generic

Commercial glufosinate-ammonium products containing the same active ingredient may differ in active-ingredient concentration, surfactants, solvents, and other co-formulants. These formulation components can influence spray properties, deposition, penetration, and the speed or consistency of biological activity (Maldonado-Reina et al., 2022). Previous work in oil palm has shown that premium and generic glufosinate-ammonium products can both provide effective weed control at their commercial application rates, although performance may vary among products and weed communities (Jabit et al., 2022).

Adjuvants are products added to herbicide mixtures to modify physical properties and enhance activity, such as improving the penetration of the herbicide through the leaf cuticle (Bell et al., 2019). Surfactants specifically reduce the surface tension of spray droplets, allowing them to spread out as a thin film and increase contact with plant tissue (Maldonado-Reina et al., 2022).

2.5 Identification of the Research Gap

Effective herbicide programs are known to improve farm

profitability, while less effective selections increase production risks (Das et al., 2024). Despite the availability of both premium and generic glufosinate-ammonium formulations, there is a lack of comparative data evaluating their efficacy, biomass reduction, non-target crop injury (phytotoxicity), and cost-efficiency under local agricultural conditions. This study addresses this gap by providing empirical evidence to support evidence-based herbicide selections.

3. MATERIALS AND METHODS

3.1 Preparation of Materials

Samples of *Paspalum conjugatum* were collected from areas around Universiti Malaysia Sarawak (UNIMAS), specifically near the Faculty of Resource Science and Technology (FRST). Seeds of the model crop *Brassica juncea* were obtained from a commercial supplier. Two glufosinate-ammonium herbicide formulations were evaluated: a premium product containing 5.66% w/w glufosinate-ammonium and a generic product containing 13.5% w/w glufosinate-ammonium. Because product-density data were unavailable, equal active-ingredient doses per hectare could not be verified; therefore, the study compares the commercial application programmes at the rates tested. The product labels are shown in Figures 1 and 2, and key product information is summarised in Table 1.



Figure 1. Premium glufosinate-ammonium herbicide (Tepat®).



Figure 2. Generic glufosinate-ammonium herbicide (Vista 15).

Table 1. Product information for the premium and generic glufosinate-ammonium herbicides.

Item	Premium herbicide	Generic herbicide
Product Name	Tepat®	Vista 15
Manufacturer	D-BASE (BASF Malaysia)	Halex (M) Sdn. Bhd. (as stated on the label: distributed by Halex (M) Sdn. Bhd.)
Active ingredient (a.i.)	Glufosinate-ammonium (5.66% w/w)	Glufosinate-ammonium (13.5% w/w)

3.2 Plant Cultivation and Soil Preparation

B. juncea seeds were sown in trays before being transplanted into 10x12 inch polybags and watered daily. For *P. conjugatum*, stolons were selected during their active vegetative growth stage (3 to 6 weeks) using a zig-zag method. The selected stolons measured around 10 to 15 cm long with multiple intact nodes.

The experimental soil for the weed study consisted of a 3:2:1 ratio of soil, clay, and sand, which was filled into 45 sowing trays. For the crop, a commercial 4-in-1 garden soil mix (topsoil, peat, cocopeat, and perlite) was used in 15 polybags. Irrigation was performed based on visual and touch assessments of soil moisture, with crop watering scheduled for early morning and late evening to optimise absorption.

3.3 Experimental Design and Treatments

Both the weed and crop experiments followed a Randomised Complete Block Design (RCBD) with five treatments and three independent blocks ($n = 3$). For the weed experiment, each treatment-by-block unit comprised three tray subsamples, giving 45 trays in total; the three subsamples within a block were averaged to obtain one block-level value before inferential analysis. The crop experiment comprised one polybag per treatment in each block, giving 15 polybags in total. The treatments were:

- T1: Control (Water only).
- T2: Premium herbicide at a recommended rate of 6 L/ha.
- T3: Premium herbicide at a higher rate of 12 L/ha.
- T4: Generic herbicide at a recommended rate of 3 L/ha.
- T5: Generic herbicide at a higher rate of 6 L/ha.

Herbicides were applied in the early morning using a 1.5 L pressure sprayer at a walking speed of approximately 69.46 m/min to ensure even canopy coverage.

3.4 Parameter Measurement

- Weed Control Efficacy: Visual weed control was evaluated weekly for six weeks after treatment (WAT) using a 0-100% scale adapted from the Canadian Weed Science Society (CWSS, 2018), as summarised in Table 2.

Table 2. Weed-control rating scale adapted from the Canadian Weed Science Society (CWSS, 2018).

Weed Control (%)	Visual Symptoms	Category
0–20	Green to pale yellow	Very low control
21–40	Yellowish	Low control
41–60	Dark yellow	Moderate control
61–80	Brown	Good control
81–100	Dried and dark brown/dead	Excellent control

- Phytotoxicity: Crop injury was assessed on days 1, 3, 5, 7, and 14 using a study-specific 1-5 visual injury scale adapted from EPPO PP 1/135(4) (EPPO, 2014), as shown in Table 3.

Table 3. Study-specific phytotoxicity rating scale adapted from EPPO PP 1/135(4) (EPPO, 2014).

Score	Description
1	No visible phytotoxicity; normal leaf colour and shape; normal crop growth.
2	Mild phytotoxicity; 5-20% of foliage showing abnormal colour and/or shape, with slight growth abnormality.
3	Moderate phytotoxicity; >20-50% of foliage showing abnormal colour and/or shape, with clear growth abnormality.
4	Severe phytotoxicity; >50-75% of foliage showing abnormal colour and/or shape, with marked growth suppression.
5	Very severe phytotoxicity; >75-100% of foliage affected, with severe deformation, necrosis, growth cessation, or plant death.

Modified scoring index adapted from EPPO PP 1/135(4) guidelines for phytotoxicity assessment (EPPO, 2014).

- **Biomass Reduction and Tissue Moisture Content:** Weeds were harvested 42 days after treatment and weighed immediately to determine fresh weight, then oven-dried at 60°C for 72 hours to determine dry weight. Tissue moisture content was calculated for each experimental unit as [(fresh weight - dry weight) / fresh weight] x 100. This biomass-derived percentage is distinct from the visual weed-control efficacy rating.
- **Cost Efficiency:** The economic comparison was conducted as a deterministic partial-budgeting analysis of the commercial application programmes. Herbicide retail prices were combined with a fixed operational overhead of RM76/ha covering labour, water, and transport. Machinery depreciation, equipment maintenance, fuel, repeated applications, and other operational costs were excluded. For this analysis, cost efficiency was expressed as the percentage cost saving of a generic programme relative to its paired premium programme.

Total treatment cost (RM/ha) = [herbicide price (RM/L) x application rate (L/ha)] + operational overhead (RM/ha)

Cost saving (RM/ha) = $C_p - C_g$

Cost efficiency (%) = $[(C_p - C_g) / C_p] \times 100$

Annual saving (RM/year) = $(C_p - C_g) \times A$

where C_p is the total cost of the paired premium programme (RM/ha), C_g is the total cost of the comparable generic programme (RM/ha), and A is the annual treated area (3,000 ha). The lower-rate programmes were compared as T2 versus T4, and the higher-rate programmes as T3 versus T5.

3.5 Preparation of Herbicide

The spray volume was determined by measuring flow rate, spray width, and walking speed. The amount of herbicide per tank was calculated based on the treatment rate, tank

3.6 Statistical Analysis

All recorded data were analysed using SAS statistical software. Treatment means for weed-control efficacy, fresh weight, dry weight, and tissue moisture content were compared at a 5% significance level using analysis of variance (ANOVA) followed by Tukey's test. For the weed experiment, the three tray subsamples within each treatment-by-block unit were averaged before analysis; therefore, the independent sample size was three block means per treatment ($n = 3$), not nine tray subsamples. Ordinal phytotoxicity scores were analysed using the Kruskal-Wallis test followed by Dunn's post-hoc test. Each crop treatment also had three independent block observations ($n = 3$). Owing to the limited replication, statistical power was low and the possibility of a Type II error must be considered when interpreting non-significant results. Accordingly, absence of statistical significance should not be interpreted as evidence of biological equivalence between treatments.

4. RESULTS AND DISCUSSION

4.1 Effect of Treatment with Glufosinate-Ammonium on Weed Control Efficacy (%) for *Paspalum conjugatum*

Statistical evaluation indicated that all glufosinate-ammonium treatments provided highly significant suppression of *Paspalum conjugatum* compared with the untreated control. At one week after treatment (WAT), efficacy ranged from 62.33% to 76.00% and increased to more than 85% by the second week. Peak weed control occurred at 3 WAT, when the premium programme at 6 L/ha reached 98.00% and the other herbicide programmes reached 97.33-97.67%. A minor decline was observed by the sixth week (92.00-96.33%). No statistically significant difference in weed-control efficacy was detected among the premium and generic herbicide programmes throughout the observation period. These comparisons refer to the commercial application programmes tested, and the non-significant results do not establish biological equivalence. The 3-WAT comparison is illustrated in Figure 3.

Table 4. Weed-control efficacy (%) of *Paspalum conjugatum* over six weeks after treatment.

Treatment t	Weed Control Efficacy (%) on Week After Treatment					
	1	2	3	4	5	6
T1	7.67 ± 0.33 ^b	5.67 ± 0.33 ^b	6.33 ± 0.33 ^b	8.33 ± 1.21 ^b	10.00 ± 1.53 ^b	10.33 ± 1.45 ^b
T2	67.00 ± 4.04 ^a	85.00 ± 0.58 ^a	98.00 ± 0 ^a	97.00 ± 0 ^a	97.00 ± 0 ^a	96.00 ± 0 ^a
T3	65.00 ± 5.86 ^a	86.33 ± 0.33 ^a	97.67 ± 0.33 ^a	97.33 ± 0.33 ^a	97.33 ± 0.33 ^a	96.33 ± 0.88 ^a
T4	62.33 ± 2.33 ^a	85.00 ± 0 ^a	97.33 ± 0.33 ^a	96.33 ± 1.21 ^a	94.33 ± 0.88 ^a	92.00 ± 2.08 ^a

Treatment	Weed Control Efficacy (%) on Week After Treatment					
T5	76.00 ± 4.51 ^a	86.67 ± 0.33 ^a	97.33 ± 0.33 ^a	96.00 ± 0 ^a	95.33 ± 0.33 ^a	93.00 ± 0.58 ^a

Data are means ± standard error of three independent block means (n = 3); each weed block mean was derived from three tray subsamples. Means followed by the same letter within a column are not significantly different according to Tukey's test at p < 0.05. WAT = weeks after treatment; T1 = untreated control; T2 = premium 6 L/ha; T3 = premium 12 L/ha; T4 = generic 3 L/ha; T5 = generic 6 L/ha; GA = glufosinate-ammonium.

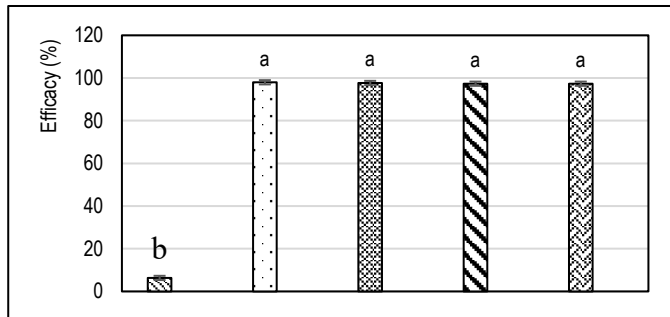


Figure 3. Weed-control efficacy of *Paspalum conjugatum* at 3 WAT following premium and generic glufosinate-ammonium programmes.

Note: Bars with the same letter are not significantly different according to Tukey's test at p < 0.05, T1 = untreated control; T2 = premium 6 L/ha; T3 = premium 12 L/ha; T4 = generic 3 L/ha; T5 = generic 6 L/ha; GA = glufosinate-ammonium.

4.2 Fresh Weight, Dry Weight, and Tissue Moisture Content (%) of *Paspalum conjugatum*

Glufosinate-ammonium treatment significantly reduced biomass accumulation relative to the untreated control. The untreated control recorded a mean fresh weight of 82.28 g and a dry weight of 65.01 g, whereas herbicide-treated units had fresh weights of 36.71-46.02 g and dry weights of 33.91-40.40 g. Tissue moisture content, calculated separately for each experimental unit from fresh and dry weight, was 35.61% in the untreated control and 5.26-12.14% in herbicide-treated units. The visual weed-control efficacy metric reported in Section 4.1 is therefore distinct from this biomass-derived tissue moisture measurement. No statistically significant differences in fresh weight, dry weight, or tissue moisture content were detected among the four herbicide programmes under the conditions of this experiment.

Table 5. Fresh weight, dry weight, and tissue moisture content of *Paspalum conjugatum* at 42 days after treatment.

Treatment	Fresh Weight (g)	Dry Weight (g)	Tissue Moisture Content (%)
T1	82.28 ± 8.01 ^a	65.01 ± 0.94 ^a	35.61 ± 5.71 ^a
T2	46.02 ± 2.97 ^b	40.40 ± 2.39 ^b	12.14 ± 0.89 ^b
T3	39.96 ± 3.22 ^b	35.37 ± 1.79 ^b	11.05 ± 2.88 ^b
T4	40.93 ± 1.21 ^b	38.80 ± 1.68 ^b	5.26 ± 2.21 ^b
T5	36.71 ± 0.23 ^b	33.91 ± 0.27 ^b	7.63 ± 0.41 ^b

Data are means ± standard error of three independent block means (n = 3); each weed block mean was derived from three tray subsamples. Means followed by the

same letter within a column are not significantly different according to Tukey's test at p < 0.05. T1 = untreated control; T2 = premium 6 L/ha; T3 = premium 12 L/ha; T4 = generic 3 L/ha; T5 = generic 6 L/ha; GA = glufosinate-ammonium.

Fresh weight was significantly reduced by glufosinate-ammonium application. The untreated control recorded 82.28 g, whereas herbicide-treated units ranged from 36.71 g to 46.02 g. The premium programme at 6 L/ha recorded 46.02 g and the generic programme at 3 L/ha recorded 40.93 g. However, all herbicide treatments shared the same Tukey grouping, indicating that no statistically significant difference in fresh biomass was detected among the four herbicide programmes. Fresh-weight treatment means are shown in Figure 4.

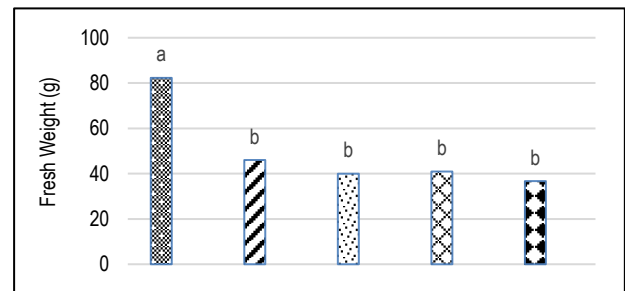


Figure 4. Fresh weight of *Paspalum conjugatum* following application of premium and generic glufosinate-ammonium programmes.

Note: Bars with the same letter are not significantly different according to Tukey's test at p < 0.05, T1 = untreated control; T2 = premium 6 L/ha; T3 = premium 12 L/ha; T4 = generic 3 L/ha; T5 = generic 6 L/ha; GA = glufosinate-ammonium.

Dry-weight results were consistent with the fresh-weight findings. The untreated control recorded 65.01 g, whereas herbicide-treated units ranged from 33.91 g to 40.40 g. The reduction in dry matter is consistent with inhibition of glutamine synthetase and subsequent disruption of nitrogen metabolism and photosynthesis by glufosinate-ammonium (Takano & Dayan, 2020). The herbicide programmes shared the same Tukey grouping, so no statistically significant difference in dry biomass was detected among the premium and generic programmes. Dry-weight treatment means are shown in Figure 5.

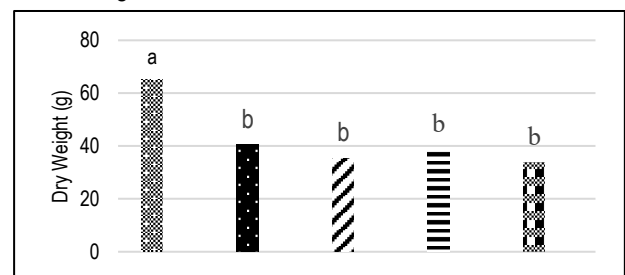


Figure 5. Dry weight of *Paspalum conjugatum* following application of premium and generic glufosinate-ammonium programmes, T1 = untreated control; T2 = premium 6 L/ha; T3 = premium 12 L/ha; T4 = generic 3 L/ha; T5 = generic 6 L/ha; GA = glufosinate-ammonium.

Note: Bars with the same letter are not significantly different according to Tukey's test at p < 0.05.

Tissue moisture content was significantly lower in herbicide-treated units than in the untreated control. The untreated control recorded 35.61%, whereas the herbicide programmes ranged from 5.26% to 12.14%. This variable was calculated from fresh and dry weight for each experimental unit and should not be interpreted as the visual weed-control efficacy percentage reported in Section 4.1. Although numerical differences occurred among herbicide programmes, they shared the same Tukey grouping and no statistically significant difference was detected. Tissue moisture content is shown in Figure 6.

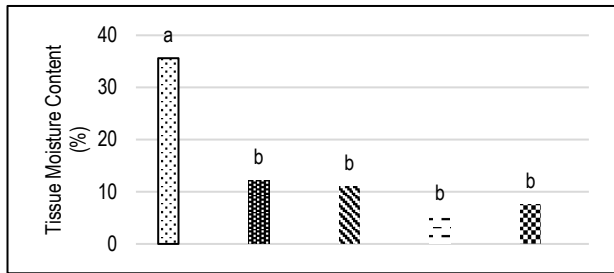


Figure 6. Tissue moisture content of *Paspalum conjugatum* following application of premium and generic glufosinate-ammonium programmes, T1 = untreated control; T2 = premium 6 L/ha; T3 = premium 12 L/ha; T4 = generic 3 L/ha; T5 = generic 6 L/ha; GA = glufosinate-ammonium.

Note: Bars with the same letter are not significantly different according to Tukey's test at $p < 0.05$.

4.3 Phytotoxicity Effect toward Treatment for *Brassica juncea*

The assessment of *Brassica juncea* confirmed that direct contact with glufosinate-ammonium caused severe injury to the non-target crop. All herbicide treatments reached the maximum injury score of 5.00 by day 7. The premium programmes reached this score by day 3, whereas the generic programmes recorded a mean score of 3.33 on day 3 and 4.33 on day 5. This faster visible injury response may be associated with differences in active-ingredient concentration, surfactant systems, or other co-formulants; however, formulation composition and the underlying mechanism were not experimentally characterised in this study (Maldonado-Reina et al., 2022). Both products should therefore be applied using directed spray techniques and drift-reducing measures to avoid injury to susceptible non-target foliage (Jomantas et al., 2023).

Table 6. Phytotoxicity scores of *Brassica juncea* after glufosinate-ammonium application.

Treatment	Days After Treatment (DAT)				
	1	3	5	7	14
T1	1.00 ± 0 ^a	1.00 ± 0 ^c	1.00 ± 0 ^b	1.00 ± 0 ^b	1.00 ± 0 ^b
T2	1.00 ± 0 ^a	5.00 ± 0 ^a	5.00 ± 0 ^a	5.00 ± 0 ^a	5.00 ± 0 ^a
T3	1.00 ± 0 ^a	5.00 ± 0 ^a	5.00 ± 0 ^a	5.00 ± 0 ^a	5.00 ± 0 ^a

Treatment	Days After Treatment (DAT)				
	1	3	5	7	14
T4	1.00 ± 0 ^a	3.33 ± 0.33 ^b	4.33 ± 0.33 ^a	5.00 ± 0 ^a	5.00 ± 0 ^a
T5	1.00 ± 0 ^a	3.33 ± 0.33 ^b	4.33 ± 0.33 ^a	5.00 ± 0 ^a	5.00 ± 0 ^a

Data are means ± standard error ($n = 3$). Means followed by the same letter within a column are not significantly different at $p < 0.05$ based on Dunn's post-hoc test following Kruskal-Wallis analysis. T1 = untreated control; T2 = premium 6 L/ha; T3 = premium 12 L/ha; T4 = generic 3 L/ha; T5 = generic 6 L/ha; GA = glufosinate-ammonium.

4.4 Cost Efficiency (Partial Budgeting Comparison) between the Premium and Generic Commercial Application Programmes of Glufosinate-Ammonium

The partial-budgeting comparison showed clear cost differences between the commercial programmes. Chemical costs were RM90.00/ha and RM180.00/ha for the premium programmes and RM30.00/ha and RM60.00/ha for the generic programmes. After adding the common operational overhead of RM76.00/ha, T2 cost RM166.00/ha compared with RM106.00/ha for the paired T4 programme, giving a saving of RM60.00/ha (36.14%) or RM180,000 per year across 3,000 ha. The higher-rate comparison, T3 versus T5, gave a saving of RM120.00/ha (46.88%) or RM360,000 per year. These deterministic estimates support consideration of treatment cost alongside biological performance; no inferential statistical test was applied to the cost calculations. This analysis is a partial-budgeting comparison for one application round. It includes herbicide retail price and a fixed RM76.00/ha overhead for labour, water, and transport, but excludes machinery depreciation, equipment maintenance, fuel, repeated applications, and other operational costs. The annual estimates assume 3,000 ha treated once per year and should not be interpreted as a comprehensive economic evaluation.

Table 7. Estimated operational overhead costs.

Operational Cost (Overhead)	Cost (RM/ha)
Labour	65
Water	6
Transport	5
Total	76.00

Table 8. Paired treatment-cost and cost-efficiency comparison of premium and generic glufosinate-ammonium programmes.

Comparison	Premium total cost (RM/ha)	Generic total cost (RM/ha)	Cost saving (RM/ha)	Cost efficiency (%)	Annual treated area (ha)	Estimated annual saving (RM/year)
T2 vs T4	166.00	106.00	60.00	36.14	3,000	180,000.00
T3 vs T5	256.00	136.00	120.00	46.88	3,000	360,000.00

Note: Paired comparisons are T2 versus T4 (premium 6 L/ha versus generic 3 L/ha) and T3 versus T5 (premium 12 L/ha versus generic 6 L/ha). Costs are for one treatment round using the 2026 prices applied in this study and a common operational overhead of RM76/ha. Cost efficiency (%) is the percentage saving relative to the paired premium programme. Estimated annual savings assume an annual treated area of 3,000 ha.

Estimated annual saving was calculated from the paired premium-versus-generic cost difference per hectare multiplied by the assumed annual treated area.

Example: T2 versus T4 = (RM166/ha - RM106/ha) x 3,000 ha = RM180,000/year.

For T3 versus T5 = (RM256/ha - RM136/ha) x 3,000 ha = RM360,000/year.

4.5 Discussion

The absence of statistically significant differences between the premium and generic programmes may reflect several factors. Both products contain glufosinate-ammonium and act by inhibiting glutamine synthetase (Takano & Dayan, 2020). Under the rates and conditions tested, the response may have approached a level at which additional product concentration or formulation differences produced little detectable change in final visual control. In addition, with only three independent blocks per treatment, statistical power was limited and small but real differences may have gone undetected. The absence of statistical significance should therefore not be interpreted as proof of biological equivalence (Section 3.6).

The programmes differed in the timing of visible crop injury. The premium programmes reached the maximum *Brassica juncea* injury score earlier than the generic programmes. This difference may be associated with active-ingredient concentration, surfactant systems, or other co-formulants that influence spray behaviour and penetration, but the formulation composition and mechanism were not directly tested (Maldonado-Reina et al., 2022; Bell et al., 2019). Importantly, no statistically significant difference in final weed-control efficacy was detected between the programmes at 3 WAT. Thus, the present data support a difference in the timing of visible injury, not a demonstrated difference in final weed-control performance or statistical equivalence.

Within the conditions of this experiment, final weed-control performance did not statistically distinguish the tested premium and generic programmes. This finding should be interpreted cautiously because of the limited replication. Regardless of formulation category, repeated reliance on glufosinate-ammonium imposes the same mode-of-action selection pressure; rotation and diversification of weed-management practices remain important for resistance management (Ofosu et al., 2023; Takano & Dayan, 2020). Directed spraying and drift-control measures are also necessary with both products to protect non-target vegetation (Jomantas et al., 2023).

The results are broadly consistent with the limited comparative evidence on premium and generic glufosinate-ammonium products. Jabit et al. (2022) reported effective

weed control from both product categories in oil palm. Studies of commercial plant-protection products also show that co-formulant profiles can differ among marketed products containing the same active ingredient (Maldonado-Reina et al., 2022). In the present study, any mechanistic role of co-formulants remains hypothetical because formulation composition was not experimentally characterised.

The field-level results also have economic implications. In the partial-budgeting analysis, T4 (generic 3 L/ha) reduced total treatment cost from RM166.00/ha for T2 (premium 6 L/ha) to RM106.00/ha, a saving of RM60.00/ha or RM180,000 per year for an assumed 3,000 ha. The higher-rate comparison (T3 versus T5) produced an estimated saving of RM120.00/ha or RM360,000 per year. Because machinery depreciation, equipment maintenance, fuel, repeated applications, and other costs were excluded, these figures are indicative rather than comprehensive. They show the potential economic advantage of the tested generic programmes while the biological comparison remains subject to the study's limited statistical power (Das et al., 2024).

Several limitations of this study should be acknowledged. First, the experiment used only three replicates per treatment, which limited statistical power and increased the risk of Type II error; the absence of significant differences therefore does not establish biological equivalence. Second, equal active ingredient doses could not be verified because product density data were unavailable, so the findings apply to the commercial application programmes as sold rather than to the active ingredient per se. Third, the trial was conducted at a single location over a single season under semi-controlled conditions, and phytotoxicity was assessed on a single sensitive indicator species (*B. juncea*); extrapolation to field conditions, other crops, and repeated-use scenarios should be made with caution.

5. CONCLUSION

This study evaluated weed-control efficacy, biomass response, non-target phytotoxicity, and cost-efficiency of premium and generic glufosinate-ammonium commercial application programmes for *Paspalum conjugatum*. All herbicide programmes provided high visual weed control and significantly reduced fresh and dry biomass relative to the untreated control. No statistically significant difference in final weed-control performance was detected among the premium and generic programmes under the experimental conditions. Because the experiment had three independent blocks per treatment ($n = 3$), this non-significant result should not be interpreted as proof of biological equivalence. Tissue moisture content, a biomass-derived metric distinct from visual weed-control efficacy, was also lower in herbicide-

treated units than in the untreated control. Direct exposure caused severe phytotoxicity to *Brassica juncea*, confirming the need for directed spraying and drift-control measures. In the partial-budgeting analysis, the paired generic programmes reduced estimated treatment costs by RM60-RM120/ha, corresponding to RM180,000-RM360,000 per year for an assumed 3,000-ha treated area. Overall, herbicide selection should consider weed-control performance, crop safety, formulation characteristics, and treatment cost.

6. RECOMMENDATION

Future studies should evaluate premium and generic glufosinate-ammonium formulations under field conditions across different crop production systems to verify the consistency of the findings obtained under controlled experiments. Since this study compared commercial application rates rather than equivalent active ingredient doses, future research should standardise active ingredient concentrations to better distinguish formulation effects. Long-term evaluations involving repeated herbicide applications are also recommended to investigate weed regrowth, potential resistance development, environmental impacts, and residue persistence. Additional crop species with varying levels of herbicide tolerance should be included to provide broader information on phytotoxicity risk. From a practical perspective, glufosinate-ammonium should be applied according to the manufacturer's recommendations using directed spraying, appropriate nozzles, and drift-control measures to minimise crop injury and maximise weed-control efficacy. Finally, future economic analyses should incorporate labour, machinery, fuel, and long-term production costs to provide a more comprehensive assessment of herbicide cost-effectiveness for commercial farming operations.

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Conflict Of Interest Statement

The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this manuscript.

Declaration Of Generative Ai And Ai-Assisted Technologies

During the preparation of this manuscript, the author used ChatGPT (OpenAI), Gemini, Gemini Notebook, and Anara AI to assist with improving the language, grammar, sentence structure, and overall readability of the manuscript. The AI tool was also used to provide suggestions for organizing and refining the presentation of ideas. All scientific content, data analysis, interpretation of results, and conclusions were independently reviewed, verified, and approved by the author. The author accepts full responsibility for the accuracy, originality, and integrity of the content presented in this manuscript.

Author Contribution Statement

Angelita Anak Jackson Bara: Conceptualization; Methodology; Investigation; Data Curation, Formal Analysis; Visualization, Writing, Original Draft; Writing, Review and Editing.

Kamalul Adham Bin Che Ruzlan: Supervision; Conceptualization; Methodology; Validation; Writing, Review and Editing, Project Administration.

Data Availability Statement

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

Ethics Declaration Statement

This study did not involve human participants or animals. Therefore, ethical approval and informed consent were not applicable.

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