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台灣中南部水田雜草對除草劑之抗性判斷流程

Valuation process of herbicide-resistant weeds in paddy field in the central and southern Taiwan

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摘要

千金子(*Leptochloa chinensis*)、稗草(*Echinochloa crus-galli*)、芒稷(*Echinochloa colona*)、尖瓣花(*Sphenoclea zeylanica*)及鴨舌草(*Monochoria vaginalis*)是水稻田中常見且較難防治的雜草，一般傳統農法防治雜草的主要方式為施用化學除草劑，但隨著除草劑之選汰壓力(selection pressure)上升，逐漸使雜草對除草劑產生抗性。本研究利用台灣中南部水田中疑似對除草劑具有抗性之雜草收集系，經栽培後繁殖種子，並進行發芽能力測試、ALS抑制型除草劑混劑Apiro Forte之普篩試驗、及數種作用機制除草劑之劑量反應分析，以判斷是否可能產生單一(single)、交叉(cross)、及多重(multiple)抗性。根據log-logistic model所進行之非線性回歸分析(nonlinear regression analysis)結果，可判斷出千金子收集系RS(I)-15 對丁基拉草(butachlor)具有單一抗性，RS(I)-14 則對丁基拉草、及派伏利(pyriftalid)具有多重抗性，其對丁基拉草具有低度或中度抗性，而對派伏利則具有中度或高度抗性。研究發現稗草收集系BG(II)-13 對派伏利具有單一抗性；BG(II)-8 對免速隆(bensulfuron-methyl)、平速爛(penoxsulam)及派伏利三種ALS抑制劑具有交叉抗性，並對免速隆具有中度或高度抗性，對平速爛及派伏利均具有高度抗性。根據多重抗性分析，可知BG(II)-8 亦對丁基拉草、樂滅草(oxadiazon)、及派伏利具有多重抗性，其對丁基拉草具有低度抗性，對樂滅草、及派伏利均具有高度抗性；另BG(II)-17 對丁基拉草及派伏利亦具有多重抗性；顯示上述僅稗草收集系出現交叉抗性，而千金子及稗草抗性收集系對丁基拉草、樂滅草、及派伏利均具有不同程度之多重抗性。本研究進一步分析Apiro Forte混劑對千金子及稗草產生藥效之原因，發現Apiro Forte混劑對二雜草物種之效果皆大於二種單劑，尤其免速隆之藥效會因加入派伏利而增強。台灣國內普遍缺少除草劑抗性雜草判斷之研究資料，因此本論文期能建立完整標準作業流程(standard operating procedures)，用以判斷除草劑抗性雜草之抗性種類及程度。

Abstract

Barnyardgrass (*Echinochloa crus-galli*), ceylon sphenoclea (*Sphenoclea zeylanica*), jungle rice (*Echinochloa colona*), red sprangle-top (*Leptochloa chinensis*), and sheathed monochoria (*Monochoria vaginalis*) are common and most troublesome weeds in rice (*Oryza sativa* L.) paddy fields. Application of chemical herbicides is an important strategy for traditional weed control in crop field. However, the continued use of these herbicides increases selection pressure which resulted in the evolution of resistant weeds. This study collects weed accessions which were suspected resistant to herbicides used in the central and southern Taiwan. A series of tests to determine seed germination abilities were made after collection of the seeds propagated from suspected herbicide-resistant weed accessions. Then, the screening test against the Apiro Forte, a mixture of two acetolactate synthase (ALS) inhibitors, with different binding sites, and the dose-response analysis to herbicides with different action mechanisms were also conducted. Finally, resistance valuation of all accessions of both species, red sprangle-top and barnyardgrass, including single, cross, and multiple resistance were confirmed.

According to the results calculated by using a nonlinear regression analysis based on a log-logistic model, red sprangle-top accession RS(I)-15 showed a single resistance to butachlor. RS(I)-14 showed a multiple resistance to butachlor and pyriftalid; with a low or moderate resistance to butachlor, and a moderate or high resistance to pyriftalid. For the barnyard grass, accession BG(II)-13 showed a single resistance to pyriftalid. BG(II)-8

showed a cross resistance to bensulfuron-methyl, penoxsulam, and pyriftalid; with a moderate or high resistance to bensulfuron-methyl, and a high resistance to both penoxsulam and pyriftalid. On the other hand, multiple resistance was also found in BG(II)-8, with a low resistance to butachlor, and a high resistance to both oxadiazon and pyriftalid. According to the descriptions mentioned above, this study reveals that the cross resistance merely developed in barnyard grass accessions, but the multiple resistance appeared in both barnyard grass and red sprangle-top accessions, though with differential extents to herbiceds including butachlor, oxadiazon, and pyriftalid.

Due to the lacks of researches related to herbicide resistant weed valuation in Taiwan, this study contributes to the establishment of the standard operating procedures for determining the types and extent of herbicide resistance in weeds.

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第一章、 緒言

水稻(*Oryza sativa* L.)為台灣重要的糧食作物，其栽培面積約為 22 萬公頃，產量約為 156 萬公噸(糙米)，產值高達 367 億元(行政院農業委員會農業 110 年統計資料)，可知稻米產業對台灣糧食供給層面影響巨大，且在經濟層面亦具有舉足輕重的地位。水稻栽培過程中常面對諸多環境因子影響，其中雜草與水稻初期生長競爭養分可能降低水稻產量(Ahmed et al., 2020)，而千金子(*Leptochloa chinensis*, red sprangle-top)、稗草(*Echinochloa crus-galli*, barnyard grass)、芒稷(*Echinochloa colona*, jungle rice)、尖瓣花(*Sphenoclea zeylanica*, ceylon sphenoclea)及鴨舌草(*Monochoria vaginalis*, sheathed monochoria)被認為是水稻田中常見且難以防治的雜草，其與水稻競爭亦會顯著降低水稻產量(Mercado et al., 1990; Bajwa et al., 2015; Peerzada et al., 2016; Yu et al., 2017; Widianto et al., 2022)。一般傳統農業防治雜草的主要方式為施用除草劑，但隨著除草劑之選汰壓力(selection pressure)上升，逐漸使雜草對除草劑產生抗性。

根據美國雜草學會(Weed Science Society of America, WSSA)的國際間除草劑抗性雜草調查報告，在 1970 年發現歐洲千里光(*Senecio vulgaris* L.)是第一個對三氮阱系類化合物(triazines)具有抗性的雜草，截至 2022 年，全世界已報導 513 個案例，包括 267 個雙子葉植物(dicots)及 246 個單子葉植物(monocots)。統計至 2021 年，對乙醯乳酸合成酶

(acetolactate synthase, ALS)抑制劑產生抗性之雜草物種共有 170 個；對光系統II (photosystem II)抑制型除草劑產生抗性之雜草物種則共有 87 個；對 5-烯醇丙酮酸莽草酸-3-磷酸鹽合成酶(5-enoyl-pyruvyl shikimate 3-phosphate synthase)抑制劑產生抗性之雜草物種則共有 56 個(Heap, 2022)。世界各地迅速出現除草劑抗性雜草，不僅威脅全球糧食安全，也造成經濟損失(Délye et al., 2013)，雜草入侵可導致全球作物平均減產達 34% (Oerke, 2006)，而在美國，每年雜草造成作物減產之損失大約 264 億美元(Pimentel et al., 2000)。

台灣在農作物生產過程中亦普遍使用除草劑以防治雜草，之後逐漸產生對除草劑具有抗性之生物型，根據國際除草劑抗性雜草資料庫(International herbicide-resistant weed database)報導，台灣早先在 1980 年發現野茼蒿(*Conyza sumatrensis*)對巴拉刈(paraquat)具有抗性，之後在 2002 年，發現華九頭獅子草對嘉磷塞(glyphosate)具有抗性(Yuan et al., 2002)。而在 2017 年，發現牛筋草(*Eleusine indica*)可藉由提升穀胱苷肽 S-轉移酶(glutathione S-transferase)之活性，代謝降解ACCase抑制劑伏寄普(fluazifop)，使牛筋草對伏寄普產生非目標位置抗性(Lin et al., 2017; Wang et al., 2017)。有鑑於台灣對除草劑抗性研究資料較少，亦缺乏完整之除草劑抗性判斷流程，因此本研究參考WSSA之抗性雜草定義，且與先正達(Syngenta)屏東試驗站合作，設計除草劑抗性判斷流程，使後續研究人員可依循此流程判斷抗性雜草。

第二章、 前人研究

一、除草劑抗性與耐性之定義

在國際除草劑抗性雜草調查(International survey of herbicide-resistant weeds, http://www.weedscience.org)網站中，在除草劑控制該雜草物種的推薦劑量施用下，這些抗性生物型(resistant biotype)可以正常存活下來。雜草抗性生物型是進化過程的結果，在一個物種中之個體經過適應特定的除草劑選汰壓力之後，其抗性族群(population)將會增加。當雜草族群暴露於除草劑施用下，其中有一種或多種植物具有天然抗性時，則出現感性個體死亡，但抗性個體得以生存和繁殖。於重複使用除草劑後，原本最初出現於田間的孤立植物、或小塊出現的抗性雜草可以迅速傳播，從而取得族群和土壤種子庫的主導地位(王，2021)。雖然除草劑抗性雜草之研究眾多，但對於耐性及抗性雜草之定義並無統一定義。

依照WSSA於 1998 年定義之除草劑抗性(herbicide resistance)，係指雜草族群經特定劑量除草劑處理後，此劑量可有效防除對藥劑敏感的野生型(wild type)植株，而族群中仍能存活與繁殖的植株則被定義為抗性生物型，此抗性為自然發生且可遺傳於子代。而植物對除草劑產生之抗性，可能來自自然發生、或是藉由遺傳工程技術誘導而導致、或是藉

由組織培養及誘變(mutagenesis)等方式從變異個體(variants)中選拔(王，2021)。

雜草之除草劑抗性可分成單一抗性(single resistance)、交叉抗性(cross resistance)及多重抗性(multiple resistance)三個種類(WSSA)。單一抗性係指一雜草生物型，僅對一種除草劑具有抗性；交叉抗性係指一雜草生物型，針對相同作用機制、而分子結構類型不同之二個以上除草劑具有抗性，稱之為交叉抗性；多重抗性係指一雜草生物型，對不同作用機制之數種除草劑，同時具有抗性的特質。多重抗性產生之原因可能是田間重複施用單一種除草劑之後，先選汰出除草劑單一抗性生物型，之後再重複施用另一種不同作用機制之除草劑，經選汰後所得之多重抗性生物型(王，2021)。而根據WSSA定義之除草劑耐性(herbicide tolerance)，係指雜草物種經除草劑處理後，此植物物種表現出存活及繁殖的固有能力(inherent ability)，亦顯示植物對除草劑耐性的產生未經選汰、或遺傳工程操作，純屬自然產生耐性(王，2021)。

本研究試驗材料均以田間採集疑似具有除草劑抗性之植株子代進行劑量反應試驗，此材料應為田間選汰壓力下產生之抗性或耐性生物型，為方便說明及討論，本論文將耐性視為抗性之一部分，論文中主要以抗性(resistant)及感性(susceptible)二者劃分雜草收集系對藥劑之敏感

程度。

二、全球除草劑抗性雜草概況

在農作物生產上，除草劑為有效且經濟的雜草管理方法，取代過往人工、獸力及機械除草，但隨之而來除草劑面臨安全性、環境保護議題以及演化出除草劑抗性雜草等挑戰(Heap, 2014)。除草劑於 1940 年代末期被快速與廣泛應用於田間，而在長年多次施用同一種除草劑之後，開始出現除草劑抗性雜草的報導(Clay, 2021)，於 1957 年發現節節草(*Commelina diffusa* Burm. f.)對生長素型除草劑 2,4-D具有抗性(Hilton, 1957)；於 1963 年發現野生胡蘿蔔(*Daucus carota* L.)對生長素型除草劑具有抗性(Whitehead and Switzer, 1963)；於 1970 年發現歐洲千里光對三氮阱系類化合物(triazines)具有抗性(Ryan, 1970)；而在 1982 年之後，隨著乙醯乳酸合成酶抑制劑(acetolactate synthase inhibitor, ALS inhibitor)及乙醯輔酶A羧化酵素抑制劑(acetyl coenzyme A carboxylase inhibitor)被引入市場，除草劑抗性雜草的類型(types)及程度(extent)逐漸增加(Powles and Holtum, 1994)。目前已有超過 20 種作用機制之除草劑被應用於田間，但仍有部分除草劑作用機制尚未明瞭(Duke et al., 2018)。

以下為本次試驗使用之除草劑種類及抗性案例。

(一)乙醯乳酸合成酶抑制劑(ALS inhibitor)

乙醯乳酸合成酶為植物生合成三種支鏈胺基酸(branched-chain amino acids)路徑上第一個關鍵酵素，若受到ALS抑制劑影響，將會使纈胺酸(valine)、白胺酸(leucine)、及異白胺酸(isoleucine)生合成受阻，最後導致植株萎黃枯死(Endo et al., 2013)。而ALS抑制劑具有用量極低、廣效性(broad-spectrum efficacy)及哺乳類低毒性等優點，因此被廣泛使用防除雜草(Singh et al., 2018)。

ALS抑制型除草劑以化學結構共分為硫醯尿素類(sulfonylureas, SUs)、三唑嘧啶類(triazolopyrimidines, TPs)、咪唑啉酮類(imidazolinones, IMIs)、硫代苯甲醯胺類(pyrimidinyl-thiobenzoates, PTBs)、及磺醯胺基羰基三唑啉酮類(sulfonyl-aminocarbonyl triazolinones, SCTs)等五種類型(Fang et al., 2019)。

Whitcomb (1999)指出部分ALS抑制劑具有較長時間的殘留活性，可能導致田間快速產生抗性雜草。根據國際除草劑抗性雜草調查，截至 2022 年 6 月，對ALS抑制劑具有抗性雜草案例高達 170 個，分別有 105 個雙子葉植物及 65 個單子葉植物。澳洲於 1980 年代廣泛使用ALS抑制劑 chlorsulfuron，防除小麥田中的硬直黑麥草 (*Lolium rigidum*) (Llewellyn and Powles, 2001)，在 1982 年發現對diclofop-methyl (ACCase 抑制劑) 具有抗性的硬直黑麥草族群，後續試驗發現此族群對

chlorsulfuron及metsulfuron-methyl亦具有抗性(Heap and Knight, 1990)。在 2021 年，於愛爾蘭(Ireland)發現大穗看麥娘(*Alopecurus myosuroides*)及義大利黑麥草(*Lolium multiflorum*)對ALS及ACCase抑制劑皆具有交叉及多重抗性，而此二種雜草對除草劑之抗性程度差異可能與突變率(mutation rate)、雜合性程度(level of heterozygosity)及除草劑用量(herbicide rates)有關(Vijayarajan et al., 2021)

(二)原紫質原氧化酶抑制劑(PPO inhibitor)

原紫質原氧化酶(protoporphyrinogen oxidase, PPO)抑制劑藉由抑制PPO的活性導致原紫質IX (protoporphyrin IX)在細胞質中累積，而當原紫質IX吸收光能後會與氧進行反應，產生大量活化氧族(reactive oxygen species, ROSs)，最後破壞細胞膜，使細胞及胞器快速乾燥和分解(Duke et al., 1991)。PPO抑制劑具有低施用量、廣效性、環境友善及對哺乳動物低毒性等多種優勢，因而被廣泛使用(Wang et al., 2017)。

在過去 60 年出現許多種類的PPO抑制劑，包括聯苯醚類(diphenyl ethers)、噁二唑類(*N*-phenyl-oxadiazolones)、三唑啉酮類(*N*-phenyl-triazolinones)及苯基醯亞胺類(*N*-phenyl-imides)(Zhao et al., 2020)。

根據國際除草劑抗性雜草調查，截至 2022 年 6 月對PPO抑制劑具有抗性雜草案例共有 14 個，分別有 10 個雙子葉植物及 4 個單子葉植

物。在 2001 年，研究者發現糙果莧(*Amaranthus tuberculatus*)對PPO抑制劑具有抗性(Shoup et al., 2003)，而在 2019 年，研究者發現糙果莧及長芒莧(*Amaranthus palmeri*)均對PPO抑制劑產生抗性(Lillie et al., 2019)。

(三)極長鏈脂肪酸生合成抑制劑(VLCFAs biosynthesis inhibitor)

極長鏈脂肪酸(very long-chain fatty acid, VLCFA)生合成抑制劑會抑制植物體內VLCFA的生合成，而VLCFA為蠟質、木栓質(suberin)、角質(cutin)的前驅物(precursors)，可形成葉片的角質層(cuticle)，並有助於植物進行脂質生合成等生化反應(Trenkamp et al., 2004)。

除草劑抗性執行委員會(herbicide resistance action committee, HRAC)將VLCFAs抑制劑分為氯化乙醯胺類(α-chloroacetamides)、硫乙醯胺類(α-thioacetamides)、氧乙醯胺類(α-oxyacetamides)、環氧乙烷類(oxiranes)、異噁唑啉類(isoxazolines)、azolyl-carboxamides、苯呋喃類(benzofuranes)及硫代胺基甲酸鹽類(thiocarbamates)。

根據國際除草劑抗性雜草調查，截至 2022 年 6 月對極長鏈脂肪酸生合成抑制劑具有抗性雜草案例共有 13 個，分別有 2 個雙子葉植物及 11 個單子葉植物。在 1993 年於中國發現對丁基拉草具有抗性之稗草，在1998年於泰國亦發現對丁基拉草具有抗性之稗草(Talbert and Burgos,

2007)。目前並無確切證據表明稗草對丁基拉草之抗性機制，但間接證據指出提高醯胺水解酶(amide hydrolase)的活性可能增強代謝丁基拉草(Juliano et al., 2010)。

三、抗性機制

Gaines et al. (2020)將雜草對除草劑之抗性機制分為目標位置抗性(target-site resistance, TSR)及非目標位置抗性 (nontarget-site resistance, NTSR)二大類，目標位置抗性係指目標位置之酵素蛋白之編碼基因發生突變，影響除草劑分子在催化結構域(catalytic domains)或其附近之結合，或在除草劑進入區域結合。這些基因突變大多數是特異性的單核苷酸多型性(single nucleotide polymorphism, SNPs)，但也已經進化出一個以上密碼子(codon)、或整個密碼子缺失的多型性(王，2021)。

非目標位置抗性則包括減少吸收(uptake)、轉運(translocation)，或是增加封存(sequestration)及代謝降解(metabolic degradation)等方式，使除草劑無法到達其作用部位，或是使其代謝失去生物活性。此外，若除草劑使植物產生ROSs造成氧化逆境(oxidative stress)，亦可藉由提升抗氧化系統活性以獲得部分緩解效果(Gaines et al., 2020)，以下分別列出雜草對ALS、PPO及VLCFAs抑制劑之抗性機制。

(一)目標位置抗性(TSR)

1. 乙醯乳酸合成酶抑制劑(ALS inhibitor)

在ALS酵素上發生胺基酸置換將使ALS抑制劑無法有效結合在基質進入酵素反應的通道上(McCourt et al., 2006)，而在ALS酵素蛋白第 122、197 及 205 個或其他胺基酸位置發生置換，可能使稗草對不同種類的ALS抑制劑產生不同程度之交叉抗性(Riar et al., 2013;Yu and Powles, 2013; Fang et al., 2019; Amaro-Blanco et al., 2021)。

2. 原紫質原氧化酶抑制劑(PPO inhibitor)

Salas et al. (2016)發現長芒莧(*Amaranthus palmeri*)的原紫質原氧化酶中出現基因缺失，因而使其對PPO抑制劑產生抗性。另外，其他研究者發現在原紫質原氧化酶上第 128、212 及 399 個胺基酸位置上發生置換，亦可賦予雜草對PPO抑制劑產生抗性(Giacomini et al., 2017; Bi et al., 2019; Rangani et al., 2019)。Lillie et al. (2019)亦發現糙果莧為PPO第 210 個胺基酸位置之甘胺酸(glycine)缺失導致，長芒莧則同時在PPO第 210 個胺基酸位置之甘胺酸缺失及第 128 個位置精胺酸(arginine)置換成甘胺酸，因而對PPO抑制劑產生抗性。

(二)非目標位置抗性(NTSR)

1. 乙醯乳酸合成酶抑制劑(ALS inhibitor)

研究者指出硬雀麥(*Bromus rigidus*)、稗草、水稗(*Echinochloa phyllopogon*)、長芒莧、糙果莧、看麥娘(*Alopecurus aequalis*)可藉由細胞色素P450 單加氧酶(cytochrome P450 monooxygenase)代謝解毒乙醯乳酸合成酶抑制劑，使其產生抗性(Owen et al., 2011; Riar et al., 2012; Iwakami et al., 2014; Nakka et al., 2017; Shergill et al., 2018; Zhao et al., 2018)，且許多研究均證實在施用ALS抑制劑後，細胞色素P450 的基因出現過表現或上調的情形(Jugulam and Shyam, 2019)。此外，穀胱苷肽S- 轉移酶 (glutathione S-transferase, GST)、葡萄糖基轉移酶 (glucosyltransferase, GT) 及 ABC 運輸蛋白 (ATP-binding cassette transporter, ABC transporter)等酵素亦參與代謝解毒ALS抑制劑，賦予雜草對ALS抑制劑產生非目標位置抗性(Zhao et al., 2017; Liu et al., 2018; Duhoux et al., 2015; Yang et al., 2016)。

2. 原紫質原氧化酶抑制劑(PPO inhibitor)

研究者指出糙果莧可藉由細胞色素P450 代謝解毒除草劑，使其對PPO抑制劑產生抗性，研究者亦發現長芒莧可藉由細胞色素P450 及穀胱苷肽S-轉移酶賦予其對PPO抑制劑產生抗性(Obenland et al., 2019; Varanasi et al., 2018; Varanasi et al., 2019)。

3. 極長鏈脂肪酸生合成抑制劑(VLCFAs biosynthesis inhibitor)

有關雜草對丁基拉草之抗性研究多為非目標位置抗性，前人研究指出雜草可藉由提高醯胺水解酶、α-澱粉酶(α-amylase)、水解酶(hydrolase)及蛋白酶(protease)等活性，或是累積植物防禦素(phytoalexin)等，賦予雜草對丁基拉草產生抗性(Baltazar, 2017; Liu et al., 2021)。另外亦有研究者指出雜草可藉由提高細胞色素P450、穀胱苷肽S-轉移酶之活性，抑或是減少除草劑吸收及轉運、增加降解速率等，使雜草對丁基拉草產生抗性(Dimaano et al., 2020; Wang et al., 2020; Hwang et al., 2022)。

第三章、 材料與方法

一、除草劑抗性判斷流程

本研究參考除草劑抗性行動委員會(Herbicide Resistance Action Committee, HRAC) 訂定之除草劑抗性雜草判定標準(https://hracglobal.com/herbicide-resistance/confirming-resistance)，並加以整理後調查田間疑似具有除草劑抗性的雜草，擬訂以下判斷流程圖(Figure 1)。本研究於 2020 年水稻二期作及 2021 年水稻一期作期間前往台灣中南部各處水田調查點(Supplementary 1A, B)進行田野調查，合計一、二期作分別有 18 及 28 個調查點，紀錄農民田間用藥經歷包括施用除草劑種類、施用時機及用量(Supplementary 2, 3)。

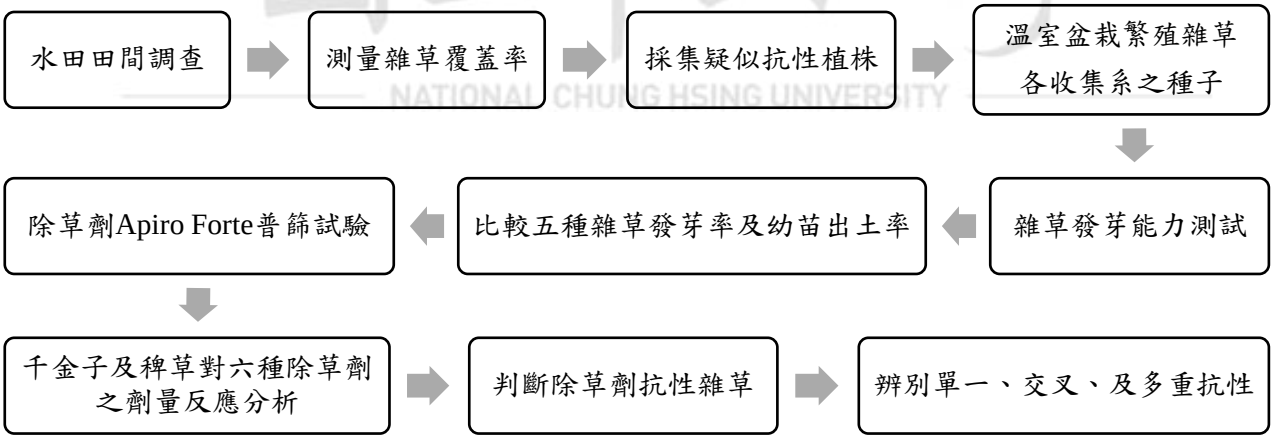


Figure 1. Herbicide-resistance valuation process of weeds in paddy field.

同時測量水田雜草生長情形，包含雜草覆蓋率及三大類雜草之出現頻度，以及在田間採集於施用除草劑後仍未死亡之雜草幼苗，保留植株周圍半徑 5 公分及深度 10-15 公分之土塊，置於塑膠袋中保持通風並維持適當土壤濕度，之後移植至中興大學溫室內盆栽生長並以調查點進行編號(Supplementary 4)，待雜草植株生長成熟後套袋收集其種子，收穫種子後去除其他雜質，最後置於玻璃發芽皿內並放在通風乾燥陰涼處保存。

本研究針對目標雜草物種進行發芽能力測試，發現千金子及稗草在發芽皿濾紙中的發芽率顯著高於其他雜草物種(Supplementary 5)，後續在溫室環境條件下，千金子及稗草播種於栽培介質中之幼苗出土率顯著提升，可配合後續劑量反應試驗所需之大量幼苗材料，因此僅以千金子及稗草二雜草物種進行試驗。本研究先以 10 倍推薦用量之Apiro Forte進行普篩試驗，期能得到二物種對於Apiro Forte較具抗性之收集系。

針對千金子及稗草各收集系在 1-2 及 3-4 葉齡(Supplementary 6)進行九種劑量濃度之劑量反應分析試驗，可得到收集系間對藥劑的差異性反應表現，本試驗使用不同作用機制之Apiro Forte、免速隆、派伏利、平速爛、樂滅草及丁基拉草六種除草劑(Figure 2)，分別於以下介紹：

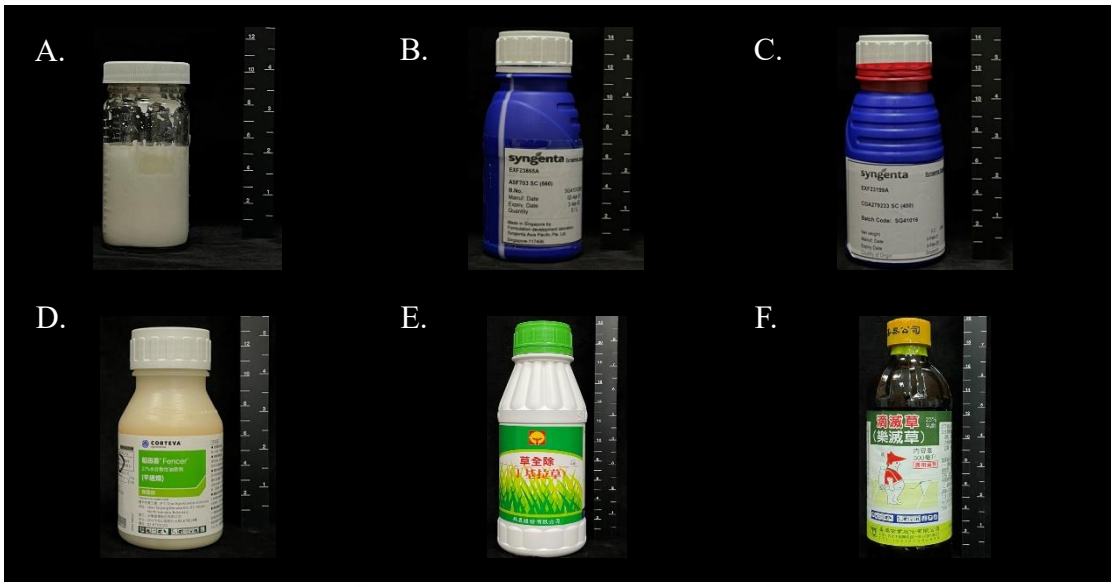


Figure 2. Six herbicides with different action mechanisms including ALS inhibition (Apiro Forte, A), ALS inhibition (bensulfuron-methyl, B), ALS inhibition (pyriftalid, C), ALS inhibition (penoxsulam, D), VLCFA biosynthesis inhibition (butachlor, E), and PPO inhibition (oxadiazon, F).

1. Apiro Forte (bensulfuron-methyl+pyriftalid)：為先正達公司擬在台灣上市之水田用除草劑，劑型是水懸劑(suspension concentrate)，分別含有 33.6%之免速隆(bensulfuron-methyl)及 66.4%派伏利(pyriftalid)之單劑成分，兩者皆為ALS抑制型除草劑，其作用機制是抑制劑結合在基質進入反應位置的通道上，以阻擋反應進行，抑制ALS酵素蛋白活性，進而使植株無法生合成白胺酸(leucine)、纈胺酸(valine)及異白胺酸(isoleucine)等三種支鏈胺基酸(branched-chain amino acids) (Zhou et al., 2007)。此混劑中所含免速隆及派伏利分別屬於ALS抑制劑中硫醯尿素類(sulfonylureas)及硫代苯甲酸嘧啶類(pyrimidinyl benzoates)。

2. 免速隆[bensulfuron-methyl；methyl a-(4,6-dimethoxypyrimidin-2-ylcarbamoylsulfamoyl)-o-toluate)]：為先正達公司特別生產供試驗用之除草劑，劑型是水懸劑，含 56.0%重量百分濃度之免速隆成分。作用機制為抑制ALS酵素蛋白活性。

3. 派伏利 [Pyriftalid, 7-(4,6-dimethoxypyrimidin-2-yl)sulfanyl-3-methyl-H-2-benzofuran-1-one]：為先正達公司特別生產供試驗用之除草劑，劑型是水懸劑，含 40.0%重量百分濃度之派伏利成分。作用機制為抑制ALS酵素蛋白活性。

4. 平速爛 {penoxsulam ； 3-(2,2-difluoroethoxy)-*N*-(5,8-dimethoxy[1,2,4] triazolo[1,5-c]pyrimidin-2-yl)-a,a,a-trifluorotoluene-2-sulfonamide}：商品名為稻田喜，由台灣道禮股份有限公司生產而成，劑型為水分散性油懸劑(oil dispersion)，外觀呈黃色液體狀。作用機制為抑制ALS酵素蛋白活性，屬於三唑嘧啶類(triazolopyrimidines)。

5. 丁基拉草 (butachlor ； *N*-butoxymethyl-2-chloro-2',6'-diethylacetanilide)：商品名為草全除，由興農股份有限公司銷售，劑型為乳劑(emulsifiable concentrate)，外觀呈琥珀色液體狀。作用機制為抑制極長鏈脂肪酸(very long chain fatty acids, VLCFAs)生合成(Baltazar, 2017)，屬於氯化乙醯胺類(*α*-chloroacetamides)。

6. 樂滅草 (oxadiazon ； 5-tert-butyl-3-(2,4-dichloro-5-isopropoxyphenyl)-1,3,4-oxadiazol-2(3H)-one)：商品名為滴滅草，由嘉泰企業股份有限公司生產，劑型為乳劑，外觀呈褐色液體狀。作用機制為抑制植體中原紫質原氧化酶的活性(Matringe et al., 1989)，屬於噁二唑類(*N*-phenyl-oxadiazolones)。

於施用藥劑後 28 及 35 天測量幼苗之傷害指數(injury index)、存活率(survival rate)、鮮重(fresh weight)及乾重(dry weight)等四個性狀，其數值代入對數邏輯模式(log-logistic model)後可得半數有效劑量(herbicide dosage causing 50% of plant response, ED_{50})值，再將收集系彼此間之ED_{50} 值經統計檢定，可判斷是否為除草劑抗性雜草，並判斷其抗性程度及抗性行為，包括單一(single)、交叉(cross)或多重(multiple)抗性。

傷害指數係將 1-2 葉齡千金子及稗草對藥劑之傷害程度劃分為六個等級，0 代表植株健康不受藥劑傷害；1 代表植株新葉開始黃化或紅化；2 代表植株地上部 25%黃化或紅化且生長停滯；3 代表植株地上部 50%黃化或紅化；4 代表植株地上部 50%黃化或紅化；5 代表植株所有葉片皆已黃化或紅化，呈現枯死狀態(Figure 3)。

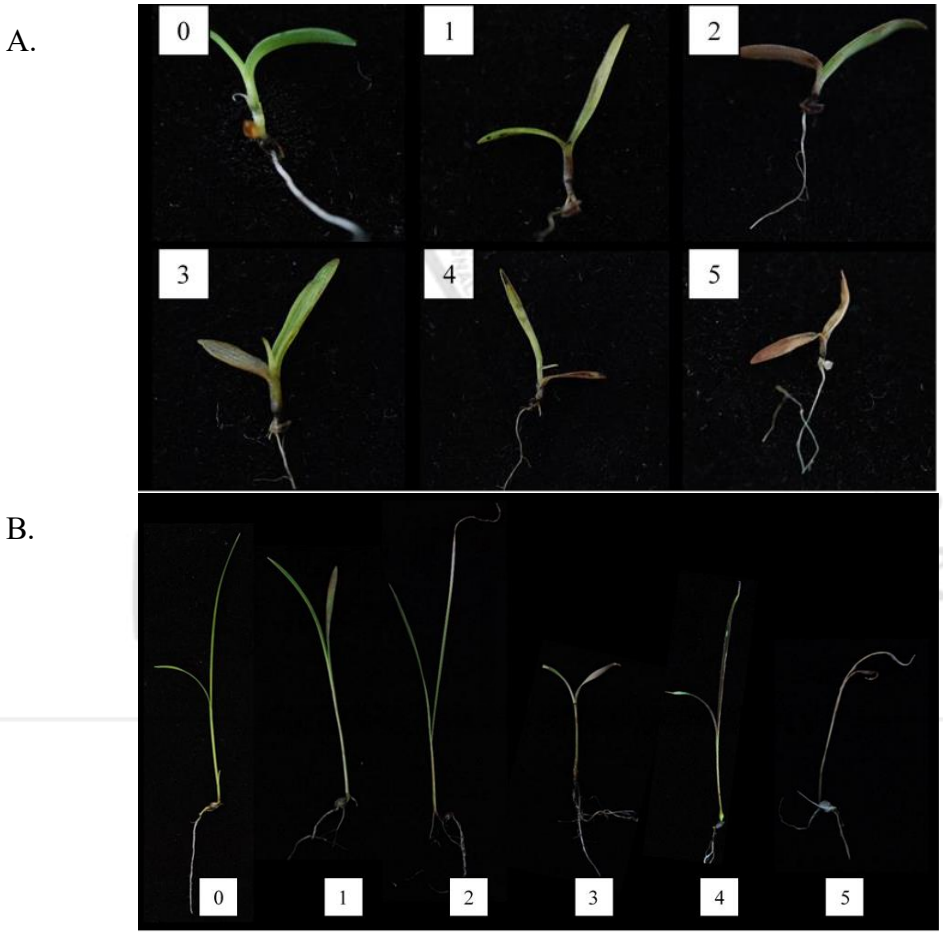


Figure 3. Injury index (0-5) of red sprangle-top (A) and barnyard grass (B) treated with various dosages of Apiro Forte. According to the apparent symptoms, injury indices can be divided to six levels; 0 indicates weeds without herbicidal injury, 1 indicates weeds with new leaf turning yellow (or red), 2 indicates weeds with 25% turning yellow and growth stop in aerial part, 3 indicates weeds with 50% turning yellow in aerial part, 4 indicates weeds with 75% turning yellow in aerial part, and 5 indicates weeds killed by herbicide.

二、台灣中南部水田雜草覆蓋率及三大類雜草出現頻度

本研究在台灣中南部水田一、二期作水田施用藥劑後 7-14 天前往調查地點(location)，以 50×50 公分之方框隨機放置於田區八個不同調查點(investigation point)，每個調查點面積為 2,500 平方公分，目視評估雜草覆蓋率(式 1)及三大類雜草出現頻度(式 2)，最後將各調查地點所得之數值以 ANOVA 進行分析，若有顯著差異(P-value < 0.05)，再以 Fisher's protected LSD 檢定，比較各調查地點之雜草覆蓋率及三大類雜草出現頻度之差異。

$$\text{雜草覆蓋率(\%)}=\frac{\text{雜草總覆蓋面積}}{\text{調查點面積}(2{,}500\ \text{cm}^2)} \qquad \text{(式 1)}$$

$$\text{三大類雜草出現頻度(\%)}=\frac{\text{禾本科、莎草科或闊葉草類之雜草覆蓋面積}}{\text{雜草總覆蓋面積}} \qquad \text{(式 2)}$$

三、台灣中南部水田五種主要雜草之發芽率與幼苗出土率測試

(一) 比較五種雜草發芽率

將千金子、稗草、芒稷、尖瓣花及鴨舌草各 40 粒種子播種於直徑 14 公分發芽皿中的濕潤濾紙上(Figure 4)，然後放入生長箱中，溫度設置為 25℃，進行全日照處理，光強度為 43 μmol·m^{-2}·s^{-1}，相對溼度為 63%。若種子成功萌芽，則在 14 天後調查其發芽率，並以ANOVA進行分析，若有顯著差異(P-value < 0.05)，再以Fisher's protected LSD檢定，比較五種雜草之發芽率差異(Supplementary 5)。

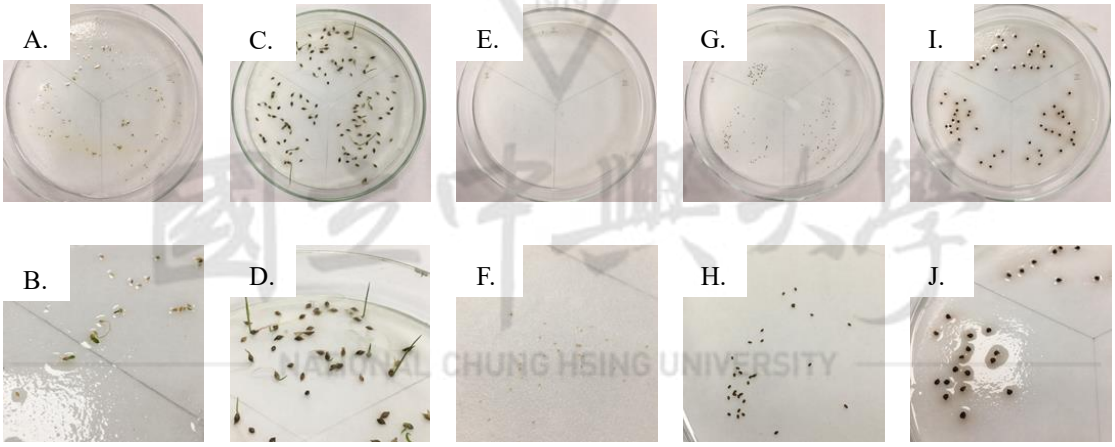


Figure 4. Germination of five weeds including *Leptochloa chinensis* (千金子, A, B), *Echinochloa crus-galli* (稗草, C, D), *Sphenoclea zeylanica* (尖瓣花, E, F), *Monochoria vagina* (鴨舌草, G, H), and *Echinochloa colona* (芒稷, I, J). Forty seeds were placed on moistured filter paper (dia. 14 cm) in Petri dishes. Dishes were placed in the incubator with temperature at 25℃ and full photoperiod under light intensity of 43 μmol·m^{-2}·s^{-1}. These pictures were captured 14 days after imbibition.

(二)發芽皿濾紙發芽率與穴植盤栽培介質的幼苗出土率差異比較

1. 發芽皿濾紙測試

發芽率測試以千金子及稗草二種雜草進行，每種雜草測試三次，每次重複三遍，播種之種子粒數為 40 粒。播種前，種子先用 0.1%次氯酸鈉消毒處理，再用一次水浸泡 10 分鐘。最後將 40 粒種子放置在直徑 14 公分發芽皿中的濕潤濾紙上(Figure 4A, B, C, D)。然後放入生長箱中，溫度設置為 25℃，進行全日照處理，光強度為 43 μmol·m^{-2}·s^{-1}，相對溼度為 63%。若種子成功萌芽，則在 14 天後測其發芽率，並以ANOVA進行分析，若有顯著差異(P-value < 0.05)，再以Fisher's protected LSD檢定，比較千金子及稗草各收集系發芽率差異。

2. 栽培介質測試

栽培介質之幼苗出土率測試亦先以千金子及稗草二種雜草進行，每種雜草測試三次，每次重複三遍，播種之種子粒數為 10 粒。播種前，種子先用 0.1%次氯酸鈉消毒處理，再用一次水浸泡 10 分鐘。最後將 10 粒種子放置在穴植盤中的栽培介質上，栽培介質為福壽實業生產之固根土 1 號(Figure 5)。然後放置於溫室環境條件下，平均溫度介於 19.5-26.5℃，加裝輔助燈具，光強度為 62 μmol·m^{-2}·s^{-1}，相對溼度為 55%。若種子成功萌芽，則在 14 天後調查其幼苗出土率，並以ANOVA進行

分析，若有顯著差異(P-value＜0.05)，再以Fisher's protected LSD檢定，比較千金子及稗草各收集系幼苗出土率差異。

後續亦比較千金子及稗草所有供試收集系分別在發芽皿濾紙及栽培介質中的平均發芽率及幼苗出土率，將二種栽培條件下的平均發芽率及幼苗出土率以ANOVA進行分析，若有顯著差異(P-value＜0.05)，再以Fisher's protected LSD檢定，比較二種栽培條件下千金子及稗草發芽能力差異。

Figure 5. Seeds of *Leptochloa chinensis* and *Echinochloa crus-galli* were sown in the plug trays in the glasshouse, and each cell had 10 seeds of the tested weed (A). Seedling emergence of both *Leptochloa chinensis* (B) and *Echinochloa crus-galli* (C) was measured after 14 and 28 days after imbibition, respectively.

3. 比較五種雜草的幼苗出土率差異

將千金子、稗草、芒稷、尖瓣花及鴨舌草之種子各取 10 粒種子播種在穴植盤中的栽培介質上，然後放置於溫室環境條件下，在 14 天後調查五種雜草之幼苗出土率，並以ANOVA進行分析，若有顯著差異(P-

value < 0.05)，再以Fisher's protected LSD檢定，比較五種雜草幼苗出土率之差異。

4. 千金子及稗草收集系之間的幼苗出土率變化

千金子及稗草種子延長浸潤後觀察時間至 28 天，觀察二雜草物種幼苗出土率之變化，在 28 天後調查千金子及稗草幼苗出土率，並以ANOVA進行分析，若有顯著差異(P-value < 0.05)，再以Fisher's protected LSD檢定，比較千金子及稗草各收集系幼苗出土率之差異。

四、千金子及稗草對 Apiro Forte 抗性之普篩試驗

本研究使用先正達公司擬上市之除草劑Apiro Forte，田間推薦用量為 0.333 L/ha，經換算施用於田間之水深 4 公分之田水中其有效成分濃度為 0.550 ppm (mg/L) (Supplementary 7)。於千金子及稗草種子發芽後，移植 10 株千金子及稗草幼苗至植穴中，待植株生長至 1-2 葉齡後，連同植穴一併放入塑膠杯中，之後施用 50 mL之 10 倍推薦用量Apiro Forte (5.50 ppm)，藥劑水平面略高於介質表面，每週觀察調查傷害指數及存活率，並補充水分至介質表面，試驗持續進行 28 天，進行三重複，試驗進行三次。最後將傷害指數及存活率數值以ANOVA進行分析，若有顯著差異(P-value < 0.05)，再以Fisher's protected LSD檢定，比較千金子及稗草收集系彼此間對 10 倍推薦用量Apiro Forte之抗性表現差異。

五、千金子及稗草之劑量反應分析試驗

本研究使用Apiro Forte、免速隆、派伏利、平速爛、樂滅草及丁基拉草等六種常見水田除草劑，模擬除草劑於水田施用情形，分別以九種劑量濃度，包括對照組(CK)、0.0001、0.001、0.01、0.1、1、10、100 及 1,000 倍推薦用量，對千金子六個收集系與稗草四個收集系在 1-2 及 3-4 葉齡進行試驗，千金子及稗草各收集系間之生長性狀一致，施用藥劑後放置於溫室環境條件下，待施用藥劑後 28 及 35 天兩個不同生育時期之藥害性狀趨於穩定，再測量其傷害指數、存活率、鮮重及乾重等數值，並比較收集系彼此間對藥劑之抗感程度。

(一)劑量反應分析

本研究將千金子及稗草所有供試收集系播種於穴苗盤中，待其發芽後分別移植 3 株幼苗至單一植穴中，移植過程需謹慎夾取幼苗之種子部分，避免對根部造成損傷，之後放置於溫室待其分別生長至 1-2 及 3-4 葉齡以進行藥劑處理。根據六種藥劑在田水濃度之換算結果，分別配置九種劑量濃度(Table 1)。之後將有 3 株幼苗之植穴放入塑膠杯中，並加入 50 mL之藥劑，使藥劑水平面略高於介質表面，每週補充水分至介質表面，採三真重複，且試驗進行三次。於施用藥劑後 28 天及 35 天調查傷害指數、存活率、鮮重及乾重等性狀，且將數值經過統計分析後比較各收集系彼此間及不同生育時期之抗性差異。

Table 1. Nine dosages of six herbicides with different action mechanisms in dose-response experiments.

Herbicides	Recommended dosage (ppm, w/v)*	Dosages (ppm) (w/v)
Apiro Forte	0.550	0, 5.5×10^{-5}, 5.5×10^{-4}, 5.5×10^{-3}, 5.5×10^{-2}, 5.5×10^{-1}, 5.5, 5.5×10^{1}, 5.5×10^{2}
Bensulfuron-methyl	0.185	0, 1.85×10^{-5}, 1.85×10^{-4}, 1.85×10^{-3}, 1.85×10^{-2}, 1.85×10^{-1}, 1.85, 1.85×10^{1}, 1.85×10^{2}
Butachlor	4.840	0, 4.84×10^{-4}, 4.84×10^{-3}, 4.84×10^{-2}, 4.84×10^{-1}, 4.84, 4.84×10^{1}, 4.84×10^{2}, 4.84×10^{3}
Oxadiazon	2.145	0, 2.145×10^{-4}, 2.145×10^{-3}, 2.145×10^{-2}, 2.145×10^{-1}, 2.145, 2.145×10^{1}, 2.145×10^{2}, 2.145×10^{3}
Penoxsulam	0.068	0, 6.8×10^{-6}, 6.8×10^{-5}, 6.8×10^{-4}, 6.8×10^{-3}, 6.8×10^{-2}, 6.8×10^{-1}, 6.8, 6.8×10^{1}
Pyriftalid	0.365	0, 3.65×10^{-5}, 3.65×10^{-4}, 3.65×10^{-3}, 3.65×10^{-2}, 3.65×10^{-1}, 3.65, 3.65×10^{1}, 3.65×10^{2}

* Theoretical concentration based on the recommended dosage of bensulfuron-methyl, penoxsulam, and pyriftalid applied in paddy water.

本研究採三次獨立試驗，將傷害指數、存活率、鮮重及乾重等性狀的數值利用Seefeldt et al. (1995)提出的非線性迴歸之對數邏輯模式(log-logistic model) (式 3)分析Apiro Forte、免速隆、丁基拉草、樂滅草、平速爛及派伏利等六種除草劑之反應。D代表無施用除草劑之植株平均反應，為反應上限；C代表最高劑量下植株平均反應，為反應下限，反應下限不一定是 0；b為劑量為I時的曲線斜率，b越大代表斜率較陡峭；I為植株特定性狀達某一程度之劑量。由於存活率、鮮重及乾重相對百分率資料範圍介於 0-100%之間，若數值並非集中在 30-70%範圍內則需要經過反正弦函數的轉換，使得其變方為均一，並將轉換後的數值帶入模式後可得ED_{50} 值(林，1997)。

$$y = f(x) = C + \frac{D - C}{1 + \exp\{b[\log(x) - \log(I)]\}} \qquad (式\ 3)$$

將抑制千金子及稗草幼苗生長、造成傷害藥效或引起 50%致死率之藥劑濃度稱之為 ED_{50} 值。比較(1)千金子及稗草收集系彼此間對藥劑之抗性差異與(2)不同生育時期下千金子及稗草收集系對藥劑之反應表現。將千金子及稗草收集系在 1-2 及 3-4 葉齡對各藥劑之 ED_{50} 值以 ANOVA 進行分析，若有顯著差異($P\text{-value} < 0.05$)，再以 Fisher's protected LSD 檢定，比較千金子及稗草收集系彼此間以及不同生育時期下是否

存在抗性差異，並選出抗性及感性收集系，將抗性收集系之 ED_{50} 值與感性收集系相除可得抗性指數(resistance index, RI)。Beckie and Tardif (2012)將抗性程度劃分為四種，分別為無抗性(not resistant) (RI < 2)、低度抗性(low resistance) (RI = 2-5)、中度抗性(moderate resistance) (RI = 6-10)及高度抗性(high resistance) (RI > 10)。

六、抗性行為判斷

後續亦針對千金子及稗草抗感性收集系對Apiro Forte、免速隆、派伏利、平速爛、丁基拉草及樂滅草六種藥劑之反應，包含傷害指數、存活率、鮮重及乾重等性狀，判斷抗性收集系對除草劑之抗性行為是單一、交叉或多重抗性。

(一) 單一抗性

將 1-2 及 3-4 葉齡千金子及稗草分別對六種藥劑之劑量反應表現，包括傷害指數、存活率、鮮重及乾重等數值帶入非線性迴歸之對數邏輯模式(式 3)分析後，可得四個劑量反應分析圖及 ED_{50} 值，後者以ANOVA進行分析，若有顯著差異(P-value < 0.05)，再以LSD檢定，比較千金子及稗草收集系彼此間以及不同生育時期下是否存在抗性差異。最後將 3-4 葉齡千金子及稗草對藥劑之反應具有顯著差異之收集系分別以R代

表抗性，S代表感性，統整千金子及稗草所有供試收集系中對六種藥劑之具有抗感性之收集系。

(二)交叉抗性

1. 千金子及稗草對ALS抑制劑之交叉抗性

本研究比較 3-4 葉齡千金子及稗草對免速隆、平速爛與派伏利三種ALS抑制劑之反應，主要以傷害指數及存活率此二種性狀之ED_{50} 值比較千金子及稗草所有供試收集系之整體表現，後續進一步比較具有抗性及感性之收集系對免速隆、平速爛與派伏利之ED_{50} 值，以ANOVA進行分析，若有顯著差異(P-value < 0.05)，再以LSD檢定，最後將抗性與感性收集系之ED_{50} 值相除可得抗性指數，並判斷抗性收集系對藥劑之交叉抗性程度差異。

2. Apiro Forte混劑對千金子及稗草產生協同藥效之原因

觀察 3-4 葉齡千金子及稗草收集系整體在施用Apiro Forte、免速隆及派伏利之傷害指數及存活率劑量反應分析曲線，可以界定千金子及稗草對此三種除草劑之ED_{50} 值範圍，而比較ED_{50} 值範圍可知千金子及稗草對Apiro Forte混劑、以及免速隆及派伏利單劑之藥效表現差異是否涉及協同作用(synergism)。

3. 多重抗性

本研究比較 3-4 葉齡千金子及稗草對丁基拉草、樂滅草及派伏利等三種不同作用機制除草劑之反應，主要以傷害指數及存活率此二種性狀之ED_{50} 值比較千金子及稗草所有供試收集系之整體表現，後續進一步比較具有抗性及感性之收集系對丁基拉草、樂滅草及派伏利之ED_{50}值，以ANOVA進行分析，若有顯著差異(P-value < 0.05)，再以LSD檢定，最後將抗性與感性收集系之ED_{50} 值相除可得抗性指數，並判斷抗性收集系對藥劑之多重抗性程度差異。

七、統計分析

本研究之試驗包含水田雜草覆蓋率、三大類雜草出現頻度、五種雜草發芽率及幼苗出土率測試，以及Apiro Forte抗性之普篩試驗及劑量反應分析試驗，均將所得之數值以ANOVA進行分析，若有顯著差異(P-value < 0.05)，再以Fisher's Protected LSD檢定是否具有顯著差異，除雜草覆蓋率及三大類雜草出現頻度之外，其他試驗皆採三次獨立試驗。

第四章、 結果與討論

一、台灣中南部水田雜草覆蓋率及三大類雜草之出現頻度

(一) 一期作(調查時間 2021.03-04)

1. 雜草覆蓋率

本研究於台灣中南部水田一期作時，分別在 3、4 月於水稻插秧後調查 18 個調查點之雜草覆蓋率，雜草平均覆蓋率介於 0.0 - 88.1%之間(Table 2)，經Fisher's protected LSD檢定後可知，18 個調查點的雜草平均覆蓋率之間具有顯著差異。表示台灣中南部各地區水田中雜草的覆蓋程度較不一致。結果可依雜草覆蓋率區分為 50%以上、20~50%、5~20%、及小於 5%等四群。爾後再依各區收集之疑似抗性雜草之劑量反應分析，判斷用藥差異、雜草覆蓋率、及抗性雜草出現率之間的關係。

Table 2. Coverage rate of weeds in paddy field in central and southern Taiwan during crop season I (Investigation period: 2021.03-04).

Location	Average coverage rate (%)	Location	Average coverage rate (%)
1	0.4 [a*]	11	2.5 [a]
2	1.6 [a]	12	88.1 [c]
3	3.9 [a]	13	0.6 [a]
4	1.8 [a]	14	4.5 [ab]
5	2.3 [a]	15	11.1 [ab]
6	0.0 [a]	16	20.1 [b]
7	0.1 [a]	17	20.0 [b]
8	0.1 [a]	18	1.6 [a]
9	20.9 [b]		
10	7.5 [ab]		
P-value			< 0.001
$LSD_{0.05}$			16.0

[*] Values followed by the same letter mean no significant difference at the 5% level using Fisher's protected LSD test.

2. 三大類雜草出現頻度

將觀測之田間五種目標雜草分為禾草類、莎草類及闊葉草類雜草等三大類，並計算其在各類雜草覆蓋率中所佔之比例。由 18 個調查點的三大類草相出現頻度可知，稗草、千金子、螢蘭、鴨舌草及尖瓣花等出現頻度並不一致(Table 3)，經Fisher's protected LSD檢定後具有顯著差異，表示 18 個調查點之三大類草相出現頻度並不相同。

田間雜草總覆蓋率達 50%以上之調查點僅只有調查點 12，雜草總覆蓋率為 88.1% (Table 2)，其中調查點 12 之禾草類雜草佔雜草總覆蓋率為 95.0%，而闊葉草類佔 5.0% (Table 3)，其田區係於整地後使用 32%

Table 3. Frequency of paddy weeds in central and southern Taiwan during crop season I (Investigation period: 2021.03-04).

Location	Grasses				Sedges			Broad-leaf weeds			
	Barnyard grass (% of grasses)	Red sprangle-top (% of grasses)	Other weeds (% of grasses)	Total grasses (% of coverage)	Rush-like bulrush (% of sedges)	Other weeds (% of sedges)	Total sedges (% of coverage)	Sheathed monochoria (% of broad-leaf weeds)	Ceylon sphenoclea (% of broad-leaf weeds)	Other weeds (% of broad-leaf weeds)	Total broad-leaf weeds (% of coverage)
1	100.0	0.0	0.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	92.5	7.5	0.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	0.0	0.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0	0.0	0.0
4	100.0	0.0	0.0	20.0	0.0	25.0	80.0	0.0	0.0	0.0	0.0
5	100.0	0.0	0.0	93.8	0.0	50.0	6.2	0.0	0.0	0.0	0.0
6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	100.0
8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	100.0
9	50.0	0.0	50.0	2.5	0.0	100.0	97.5	0.0	0.0	0.0	0.0
10	0.0	0.0	0.0	0.0	0.0	100.0	96.0	0.0	0.0	100.0	4.0
11	0.0	0.0	0.0	0.0	0.0	100.0	100.0	0.0	0.0	0.0	0.0
12	100.0	0.0	0.0	95.0	0.0	0.0	0.0	0.0	0.0	100.0	5.0
13	100.0	0.0	0.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14	100.0	0.0	0.0	14.0	0.0	0.0	0.0	0.0	0.0	100.0	86.0
15	25.0	75.0	0.0	64.2	0.0	0.0	0.0	0.0	0.0	100.0	35.8
16	66.7	0.0	33.3	60.0	0.0	0.0	0.0	0.0	0.0	100.0	40.0
17	100.0	0.0	0.0	14.3	100.0	0.0	7.1	17.5	82.5	0.0	78.6
18	100.0	0.0	0.0	30.0	0.0	0.0	0.0	0.0	0.0	100.0	70.0
P-value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	<0.001
$LSD_{0.05}$	32.5	13.9	13.3	35.9	23.9	26.4	34.1	6.1	11.6	33.9	36.1

丁基拉草乳劑及插秧後使用 5%丁基拉草粒劑，仍無法有效控制雜草以降低雜草覆蓋率(Supplementary 1)。

田間雜草總覆蓋率介於 20~50%之調查點包括 9、16 及 17 等三點，三個調查點的三大類草相出現頻度較不一致，但皆出現稗草且其占禾草類雜草之比例達 50%以上(Table 3)。而三個調查點之用藥經歷相似，調查點 9 使用丁拉免速隆(秧後)，調查點 16 及 17 則使用 60%丁基拉草乳劑(整地後) (Supplementary 1)。

田間雜草覆蓋率介於 5~20%之間的調查點，僅有調查點 10 及 15 (Table 2)，其中調查點 10 之莎草類雜草覆蓋率超過 50%；而調查點 15 之禾草類雜草覆蓋率超過 50% (Table 3)。然而調查點 10 及 15 分別施用丁拉免速隆(秧後)及 60%丁基拉草乳劑(整地時)，兩個調查點幾乎無共同用藥經歷(Supplementary 1)。

田間雜草總覆蓋率在 5%以下之調查點包括 1、2、3、4、5、6、7、8、11、13、14 及 18 (Table 2)，其中調查點 1、2、5 及 13 之禾草類雜草佔雜草總覆蓋率 50%以上，且稗草發生頻度較高(> 90%)；而調查點 3、4、及 11 之莎草類雜草佔雜草總覆蓋率 50%以上；調查點 7、8、14 及 18 之闊葉類雜草佔雜草總覆蓋率 50%以上(Table 3)。12 個調查點之共同用藥較多的是丁基拉草(整地時)佔 5/6 (Supplementary 1)。其中調

查點 6 之雜草總覆蓋率為 0%，於插秧後施用滅芬免速隆。

根據以上一期作調查結果可知，田間覆蓋率介於 5~20%及低於 5%以下之田區較常出現禾草類雜草，其中又以稗草之出現頻度較高，田間用藥經歷為丁基拉草或免速隆混劑，表示田區可能出現對兩種藥劑具有抗性之稗草植株。

(二) 二期作(調查時間 2020.08-12)

1. 雜草覆蓋率

本研究於台灣中南部水田二期作時，分別在 8~12 月於水稻插秧後調查 27 個調查點的雜草覆蓋率，雜草平均覆蓋率介於 0.0 - 84.4%之間(Table 4)，經Fisher's protected LSD檢定後可知，27 個調查點的雜草平均覆蓋率之間具有顯著差異。表示台灣中南部各地區水田中雜草的覆蓋程度較不一致。

Table 4. Coverage rate of weeds in paddy field in central and southern Taiwan during crop season II (Investigation period: 2020.08-09).

Location	Average coverage rate (%)	Location	Average coverage rate (%)
1	4.3 [ab]	16	9.1 [ab]
2	0.5 [a]	17	27.3 [c]
3	1.0 [ab]	18	84.4 [e]
4	6.9 [ab]	19	15.0 [abc]
5	37.6 [c]	20	61.3 [d]
6	16.9 [bc]	21	18.1 [bc]
7	4.1 [ab]	22	5.6 [ab]
8	25.6 [c]	23	10.0 [ab]
9	2.9 [a]	24	24.4 [b]
10	0.0 [a]	25	42.5 [c]
11	0.3 [a]	26	3.8 [a]
12	0.0 [a]	27	3.8 [a]
13	4.4 [ab]		
14	0.3 [a]		
15	3.4 [ab]		
P-value			< 0.001
$LSD_{0.05}$			16.0

[*] Values followed by the same letter mean no significant difference at the 5% level using Fisher's protected LSD test.

2. 三大類雜草出現頻度

將觀測之田間五種目標雜草草相分為禾草類、莎草類及闊葉類雜草等三大類，並記錄其在雜草平均覆蓋率中所佔之比例。27 個調查點的三大類草相頻度可知，稗草、千金子、螢蘭、鴨舌草及尖瓣花等出現頻度並不一致(Table 5)，經Fisher's protected LSD檢定後具有顯著差異，表示 27 個調查點之三大類草相出現頻度並不相同。

Table 5. Frequency of paddy weeds in central and southern Taiwan during crop season II (Investigation period: 2020.08-09).

Location	Grasses				Sedges			Broad-leaf weeds			
	Barnyard grass (% of grasses)	Red sprangle-top (% of grasses)	Other weeds (% of grasses)	Total grasses (% of coverage)	Rush-like bulrush (% of sedges)	Other weeds (% of sedges)	Total sedges (% of coverage)	Sheathed monochoria (% of broad-leaf weeds)	Ceylon sphenoclea (% of broad-leaf weeds)	Other weeds (% of broad-leaf weeds)	Total broad-leaf weeds (% of coverage)
1	50.0	50.0	0.0	14.3	0.0	0.0	0.0	39.3	0.0	60.7	85.7
2	0.0	100.0	0.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	0.0	0.0	100.0	10.0	0.0	100.0	10.0	100.0	0.0	0.0	80.0
4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	40.0	60.0	0.0	100.0
5	0.0	83.3	16.7	59.4	0.0	0.0	0.0	91.7	8.3	0.0	40.6
6	0.0	100.0	0.0	12.5	0.0	50.0	20.0	8.3	75.0	16.7	67.5
7	0.0	0.0	0.0	0.0	100.0	0.0	59.8	100.0	0.0	0.0	40.2
8	100.0	0.0	0.0	82.1	0.0	0.0	0.0	0.0	100.0	0.0	17.9
9	0.0	0.0	0.0	0.0	100.0	0.0	83.3	0.0	100.0	0.0	16.7
10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	0.0	100.0
12	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
13	100.0	0.0	0.0	80.0	0.0	100.0	20.0	0.0	0.0	0.0	0.0
14	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	100.0
15	0.0	0.0	0.0	0.0	0.0	100.0	66.7	0.0	0.0	100.0	33.3
16	0.0	0.0	0.0	0.0	0.0	0.0	0.0	60.0	0.0	40.0	100.0
17	66.7	0.0	33.3	18.7	0.0	100.0	12.50	80.6	0.0	19.4	68.8
18	74.1	10.4	15.5	87.5	0.0	100.0	12.5	0.0	0.0	0.0	0.0

Location	Grasses				Sedges			Broad-leaf weeds			
	Barnyard grass (% of grasses)	Red sprangle-top (% of grasses)	Other weeds (% of grasses)	Total grasses (% of coverage)	Rush-like bulrush (% of sedges)	Other weeds (% of sedges)	Total sedges (% of coverage)	Sheathed monochoria (% of broad-leaf weeds)	Ceylon sphenoclea (% of broad-leaf weeds)	Other weeds (% of broad-leaf weeds)	Total broad-leaf weeds (% of coverage)
19	0.0	100.0	0.0	50.0	0.0	100.0	20.0	0.0	0.0	100.0	30.0
20	60.0	40.0	0.0	51.3	0.0	0.0	0.0	0.0	100.0	0.0	48.7
21	0.0	0.0	100.0	22.5	0.0	0.0	0.0	10.0	70.0	20.0	77.5
22	0.0	0.0	0.0	0.0	0.0	0.0	0.0	25.0	75.0	0.0	100.0
23	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	0.0	100.0
24	0.0	100.0	0.0	15.0	0.0	0.0	0.0	0.0	99.4	0.6	85.0
25	0.0	18.6	81.4	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
26	0.0	50.0	50.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
27	0.0	100.0	0.0	12.5	85.7	14.3	87.5	0.0	0.0	0.0	0.0
P-value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
$LSD_{0.05}$	22.8	29.0	21.0	36.8	21.3	25.2	31.2	28.0	30.1	25.4	40.4

田間雜草總覆蓋率達 50%以上之調查點 18 及 20，雜草總覆蓋率分別為 84.4%與 61.2% (Table 4)，其中調查點 18 之禾草類雜草佔雜草總覆蓋率為 87.5%，莎草類佔 12.5%；調查點 20 之禾草類雜草佔雜草總覆蓋率為 51.2%，闊葉類雜草佔雜草總覆蓋率為 48.8% (Table 5)，二試區之共同點是秧後使用丁基賽伏草，而調查點 20 分別使用丁拉免速隆(秧後)及丁拉依速隆(秧前)，可能有助於減少覆蓋率(Supplementary 2)。

田間雜草總覆蓋率介於 20~50%之調查點 5、6、8、17、19、21、22、24、及 25 合計 9 點，其中禾草類雜草佔雜草總覆蓋率 50%以上之調查點 5、8、及 25 (Table 4)，而九個調查點之共同用藥經歷，包括較常施用之丁基拉草(秧前)佔 2/3 比例(Supplementary 2)。闊葉類雜草佔雜草總覆蓋率 50%以上之調查點 6、17、21、22、及 24。

田間雜草覆蓋率介於 5~20%之間的調查點，則包括調查點 1、4、7、13、16、23、及 26，合計 7 點，其中禾草類雜草覆蓋率超過 50%，有調查點 13 及 26；而闊葉草覆蓋率超過 50%以上者有 1、4、16、23 (Table 5)。然而七個調查點幾乎無共同用藥經歷(Supplementary 2)。

田間雜草總覆蓋率在 5%以下之調查點 2、3、9、10、11、12、14、15、及 27，其中只有調查點 2 之禾草類雜草佔雜草總覆蓋率 50%以上；而調查點 9、15、及 27 之莎草類雜草佔雜草總覆蓋率 50%以上；調查點 3、11、及 14 之闊葉類雜草佔雜草總覆蓋率 50%以上。九個調查點

之共同用藥較多的是丁基拉草(秧前)佔 4/9 及Apiro Forte (秧前)佔 3/9 (Supplementary 2)。其中調查點 10、12 雜草總覆蓋率為 0%，其共同用藥為丁基拉草(秧前)。

根據以上二期作田野調查結果可知，田間覆蓋率介於 5~20%及低於 5%以下之田區其三大類雜草出現頻度較不一致，且田間用藥經歷亦不相同，表示各調查點之雜草覆蓋率、草相變化及用藥經歷之關聯性較低。

(三) 兩期作之比較

1. 雜草覆蓋率

將台灣中南部一期作及二期作水田中的雜草平均覆蓋率進行比較，發現一期作 18 個調查點的雜草平均覆蓋率為 10.4%，而二期作 27 個調查點的雜草平均覆蓋率為 15.3% (Table 6)，兩期作間的雜草平均覆蓋率經Fisher's protected LSD檢定後並未達顯著差異，可推測在慣行化學除草劑控制環境下兩期作之間的雜草發生程度較相同。由於雜草覆蓋率大小涉及諸多因素，包括田間試區之除草劑實際用量、藥劑分布均勻程度、殘留量變化、灌排水狀況、雜草族群對於除草劑之敏感度(sensitivity)，土壤種子庫(seed bank)豐瘠、及草相分布等，故覆蓋率大小與是否存在可能之抗性雜草物種(species)與生物型(biotype)，尚待進一步分析。

Table 6. Comparison of weed coverage rate between two crop seasons (Investigation period: 2021.03-04 & 2020.08-09) at paddy field in central and southern Taiwan.

Crop season I		Crop season II			
Location	Average coverage rate (%)	Location	Average coverage rate (%)	P-value	$LSD_{0.05}$
1	0.4	1	4.3		
2	1.6	2	0.5		
3	3.9	3	1.0		
4	1.8	4	6.9		
5	2.3	5	37.6		
6	0.0	6	16.9		
7	0.1	7	4.1		
8	0.1	8	25.6		
9	20.9	9	2.9		
10	7.5	10	0.0		
11	2.5	11	0.3		
12	88.1	12	0.0		
13	0.6	13	4.4		
14	4.5	14	0.3		
15	11.1	15	3.4		
16	20.1	16	9.1		
17	20.0	17	27.3		
18	1.6	18	84.4		
		19	15.0		
		20	61.3		
		21	18.1		
		22	5.6		
		23	10.0		
		24	24.4		
		25	42.5		
		26	3.8		
		27	3.8		
Mean ± SD	10.4 ± 20.7	Mean ± SD	15.3 ± 20.5	0.44	ND

2. 禾草類雜草出現頻度

將台灣中南部一期作及二期作水田中的禾草類雜草出現頻度進行比較，一期作禾草類雜草佔總覆蓋率之比例為 38.5%，而二期作禾草類雜草佔比為 30.2% (Table 7)，兩期作之禾草類雜草佔總覆蓋率之比例經 Fisher's protected LSD檢定後並未達顯著差異，表示兩期作間水田出現禾草類雜草的情形較一致。

Table 7. Relative coverage percentage of grass weeds as compared with total weeds at paddy field in central and southern Taiwan during two crop seasons (Investigation period: 2021.03-04 & 2020.08-09).

Crop I		Crop II			
Location	Total grasses (% of coverage)	Location	Total grasses (% of coverage)	P-value	$LSD_{0.05}$
1	100.0	1	14.3		
2	100.0	2	100.0		
3	0.0	3	10.0		
4	20.0	4	0.0		
5	93.8	5	59.4		
6	0.0	6	12.5		
7	0.0	7	0.0		
8	0.0	8	82.1		
9	2.5	9	0.0		
10	0.0	10	0.0		
11	0.0	11	0.0		
12	95.0	12	0.0		
13	100.0	13	80.0		
14	14.0	14	0.0		
15	64.2	15	0.0		
16	60.0	16	0.0		
17	14.3	17	18.7		
18	30.0	18	87.5		
		19	50.0		
		20	51.3		

Location	Crop I Total grasses (% of coverage)	Location	Crop II Total grasses (% of coverage)	P-value	$LSD_{0.05}$
		21	22.5		
		22	0.0		
		23	0.0		
		24	15.0		
		25	100.0		
		26	100.0		
		27	12.5		
Mean ± SD	38.5 ± 42.4	Mean ± SD	30.2 ± 37.5	0.49	ND

3. 莎草類雜草出現頻度

將台灣中南部一期作及二期作水田中的莎草類雜草出現頻度進行比較，一期作莎草類雜草佔總覆蓋率之比例為 27.0%，而二期作莎草類雜草佔比為 14.5% (Table 8)，兩期作之莎草類雜草佔總覆蓋率之比例經 Fisher's protected LSD檢定後並未達顯著差異，表示兩期作間水田出現莎草類雜草的情形較一致。

Table 8. Relative coverage percentage of sedges weeds as compared with total weeds at paddy field in central and southern Taiwan during two crop seasons (Investigation period: 2021.03-04 & 2020.08-09).

Location	Crop I Sedges (% of total coverage)	Location	Crop II Sedges (% of total coverage)	P-value	$LSD_{0.05}$
1	0.0	1	0.0		
2	0.0	2	0.0		
3	100.0	3	10.0		
4	80.0	4	0.0		
5	6.2	5	0.0		
6	0.0	6	20.0		
7	0.0	7	59.8		
8	0.0	8	0.0		
9	97.5	9	83.3		
10	96.0	10	0.0		
11	100.0	11	0.0		
12	0.0	12	0.0		
13	0.0	13	20.0		
14	0.0	14	0.0		
15	0.0	15	66.7		
16	0.0	16	0.0		
17	7.1	17	12.50		
18	0.0	18	12.5		
		19	20.0		
		20	0.0		
		21	0.0		
		22	0.0		
		23	0.0		
		24	0.0		
		25	0.0		
		26	0.0		
		27	87.5		
Mean ± SD	27.0 ± 43.4	Mean ± SD	14.5 ± 26.7	0.24	ND

4. 闊葉草類草出現頻度

比較台灣中南部一期作及二期作水田中的闊葉草類雜草出現頻度，一期作闊葉草類雜草佔總覆蓋率之比例為 28.9%，而二期作闊葉草類雜草佔比為 47.8% (Table 9)，兩期作之闊葉草類雜草佔總覆蓋率之比例經 Fisher's protected LSD檢定後並未達顯著差異，表示兩期作間水田出現闊葉類雜草的情形較一致。

根據以上兩期作之田間雜草平均覆蓋率及三大類草相出現頻度可知，一、二期作各調查點的水田雜草發生情形相似，在現行化學除草劑控制下雜草平均覆蓋率分別為 10.4%及 15.3%，並未達到顯著差異。而禾草類、莎草類及闊葉草三大類草相佔總雜草覆蓋率亦相近，經檢定後皆未達到顯著差異，表示兩期作之間三大類草相出現頻度亦相似。

田間雜草覆蓋率及三大類草相為田間實際觀測所得之數據，僅能粗略辨識各調查點的雜草管理及雜草草相變動之情形，並提供後續抗性判斷試驗結果解讀的參考依據。惟田間雜草發生及草相變化涉及諸多因素，研究者指出水田灌溉方式會影響雜草密度及決定優勢草種(Luo et al., 2016)，耕作系統如除草劑的施用會影響草相的變化(Marshall et al., 2003)或是耕耘(tillage)方式及不同施肥處理皆會影響雜草豐富度(weed abundance)及多樣性(diversity) (Travlos et al., 2018)，而土壤種子庫亦會潛在地影響草相種類(Andreasen and Stryhn, 2008)。因此，本研究所調

查之田間雜草覆蓋率及三大類草相頻度與產生除草劑抗性生物型雜草的關聯性較弱，仍有待後續試驗進行分析及判斷。

Table 9. Relative coverage percentage of broad-leaf weeds as compared with total weeds at paddy field in central and southern Taiwan during two crop seasons (Investigation period: 2021.03-04 & 2020.08-09).

Crop I		Crop II			
Location	Broad-leaf weeds (% of total coverage)	Location	Broad-leaf weeds (% of total coverage)	P-value	$LSD_{0.05}$
1	0.0	1	85.7		
2	0.0	2	0.0		
3	0.0	3	80.0		
4	0.0	4	100.0		
5	0.0	5	40.6		
6	0.0	6	67.5		
7	100.0	7	40.2		
8	100.0	8	17.9		
9	0.0	9	16.7		
10	4.0	10	0.0		
11	0.0	11	100.0		
12	5.0	12	0.0		
13	0.0	13	0.0		
14	86.0	14	100.0		
15	35.8	15	33.3		
16	40.0	16	100.0		
17	78.6	17	68.8		
18	70.0	18	0.0		
		19	30.0		
		20	48.7		
		21	77.5		
		22	100.0		
		23	100.0		
		24	85.0		
		25	0.0		
		26	0.0		
		27	0.0		
Mean ± SD	28.9 ± 39.4	Mean ± SD	47.8 ± 40.5	0.13	ND

二、 台灣中南部水田五種主要雜草之發芽率與幼苗出土率測試

本試驗以台灣中南部 27 個水田調查點採集之五種主要雜草種子進行發芽率及幼苗出土率測試，分別為千金子(red sprangle-top, *Leptochloa chinensis*)、稗草(barnyard grass, *Echinochloa crus-galli*)、鴨舌草(sheathed monochoria, *Monochoria vaginalis*)、尖瓣花(ceylon sphenoclea, *Sphenoclea zeylanica*)、及芒稷(jungle rice, *Echinochloa colona*)，測試其直接播種於發芽皿濾紙上並置於生長箱中，以及播種在穴植盤栽培介質上並置於溫室中，以二種栽培環境條件測試雜草種子之發芽效果及幼苗出土能力。

(一)發芽皿濾紙發芽率與穴植盤栽培介質的幼苗出土率差異比較

1. 千金子

(1)發芽皿濾紙測試

本試驗將分別取自第 11、25 個調查點及施行有機栽培之興大農資院農業試驗場(agricultural experiment station, AES)的千金子收集系 RS(II)-11、RS(II)-25 及 RS(II)-AES 種子播種於濾紙並放置於控溫 25~30℃生長箱中，測量其在發芽皿內浸潤 14 天的發芽率，結果發現 RS(II)-11、RS(II)-25 及 RS(II)-AES 在浸潤後第 2 天開始發芽，但 RS(II)-25 及 RS(II)-AES 的發芽率比 RS(II)-11 略高 (Figure 1)。三個千金子收集系的發芽率在浸潤第 11 天後出現顯著差異，RS(II)-11、RS(II)-25 及

RS(II)-AES 在第 14 天的發芽率分別為 9.2%、19.4%及 24.2% (Figure 6)。經 ANOVA 分析後，發現 P-value < 0.05，顯示千金子收集系 RS(II)-AES 及 RS(II)-25 之種子發芽率顯著高於 RS(II)-11。

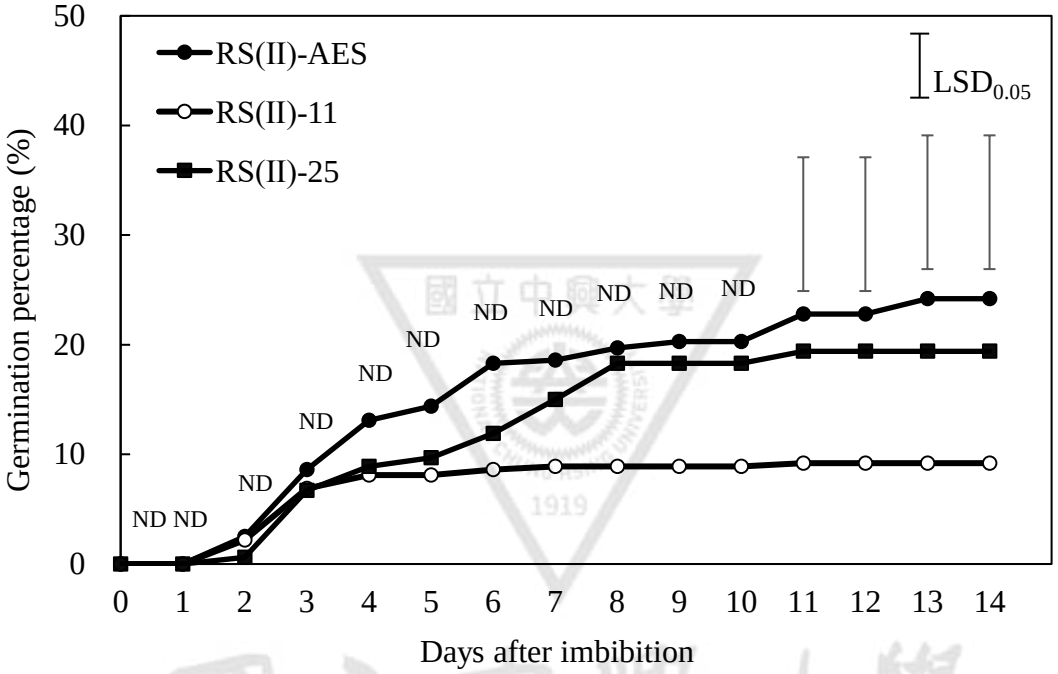


Figure 6. Germination percentage of red sprangle-top (*Leptochloa chinensis*), collected at three locations, were determined within 14 days after imbibition (DAI). Seeds were placed on filter paper in Petri dish and grown in growth chamber. Germination percentages of accessions RS(II)-11, RS(II)-25, and RS(II)-AES were 9.2%, 19.4%, and 24.2%, respectively, at 14 DAI. ND = no difference at the 5% significant level.

根據前人研究成熟的千金子種子其發芽能力極強，於溫度 30℃發芽率最高可達 95% (Benvenuti et al., 2004)，幾乎不具有休眠性，且需高光強度以促進發芽(Chauhan and Johnson, 2008)，但本研究中，生長箱之溫度僅 25.0℃，而光強度為 43 μmol·m^{-2}·s^{-1}，可能為千金子三個收集系種子發芽率偏低之原因，而各收集系間的種子成熟度不同也可能是發芽率出現差異之原因。

(2)栽培介質測試

栽培介質測試中，種子播種後可能沒入介質中較不容易觀察到種子發芽變化，因此以種子發芽後幼苗突破介質表面之數量進行計算，可反映出種子之發芽能力及幼苗之生長情形，故栽培介質測試將以幼苗出土率(emergence rate)進行計量較合適。

試驗將千金子三個收集系 RS(II)-11、RS(II)-25、及 RS(II)-AES 種子同時播種於栽培介質並放置於溫室環境中，結果發現 RS(II)-11 及 RS(II)-25 經浸潤 5 天後幼苗開始出土，而 RS(II)-AES 則在第 7 天幼苗才開始出土(Figure 7)。RS(II)-11、RS(II)-25、及 RS(II)-AES 在第 14 天的幼苗出土率分別為 16.3%、18.8%及 22.9% (Figure 7)，經 ANOVA 分析後尚未達顯著差異，顯示千金子三個收集系之幼苗出土率較相近。本研究中，溫室之平均溫度為 21.4℃，而光強度僅 62 $\mu mol \cdot m^{-2} \cdot s^{-1}$，可能為千金子三個收集系種子發芽率偏低之原因。

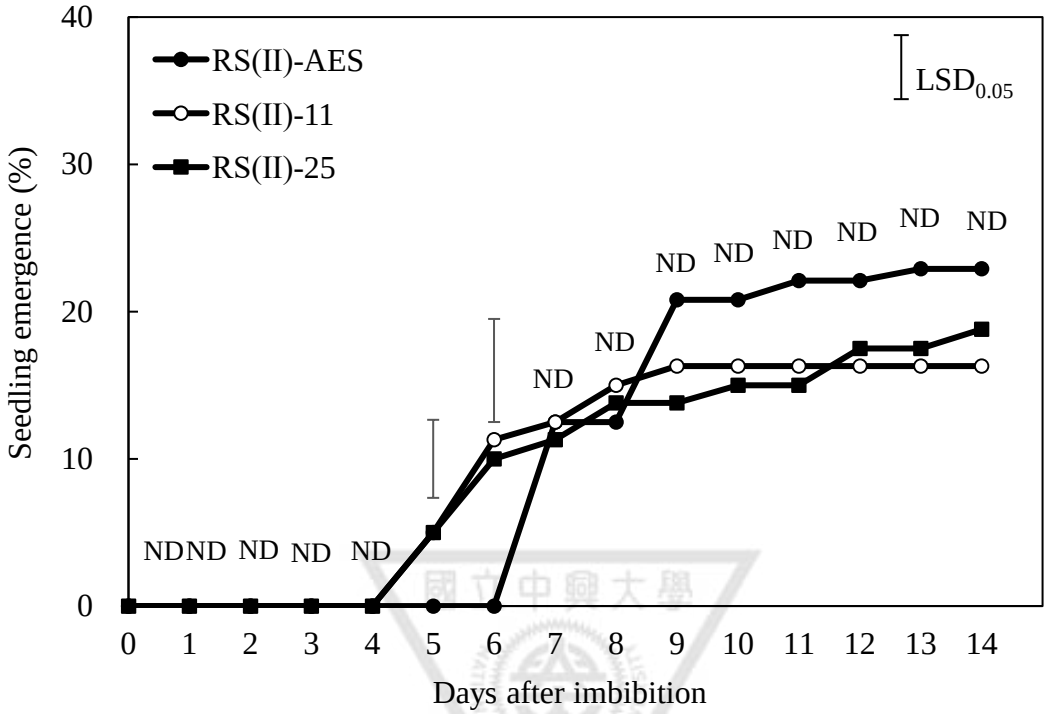


Figure 7. Seedling emergence percentage of red sprangle-top (*Leptochloa chinensis*), collected at three locations, were determined within 14 days after imbibition (DAI). Seeds were placed on cultural medium directly and grown in greenhouse environment. Seedling emergence percentage of accessions RS(II)-11, RS(II)-25, and RS(II)-AES were 16.3%, 18.8%, and 22.9%, respectively, at 14 DAI. ND = no difference at the 5% significant level.

(3)濾紙與栽培介質之發芽及幼苗出土能力比較

綜合比較千金子 RS(II)-11、RS(II)-25、及 RS(II)-AES 種子播種於濾紙中及栽培介質的平均發芽率與幼苗出土率可知，千金子種子播種於濾紙發芽皿並置於生長箱中的發芽速度較快，於 2 DAI 即開始發芽。綜合千金子三個收集系種子於濾紙中浸潤 14 天的平均發芽率為 17.6%；千金子種子播種於栽培介質並置於溫室環境中的幼苗出土速度較慢，直至 5 DAI 才開始逐漸出土，主因種子發芽初期之生長反應可能在介質中進行。千金子三個收集系種子於栽培介質中浸潤 14 天的平均幼苗

出土率為 19.3%，此亦反映出在介質中種子的發芽能力。兩者於 14 DAI 之發芽率並無顯著差異(Figure 8)，表示千金子種子在兩種環境條件下的發芽能力較一致。而由試驗結果可知千金子播種於濾紙中置於生長箱或栽培介質內並置於溫室 14 天後，其發芽能力並無顯著差異，但考慮濾紙發芽之後移植幼苗時可能會傷及根部，故後續試驗將使用栽培介質進行播種與幼苗栽培。

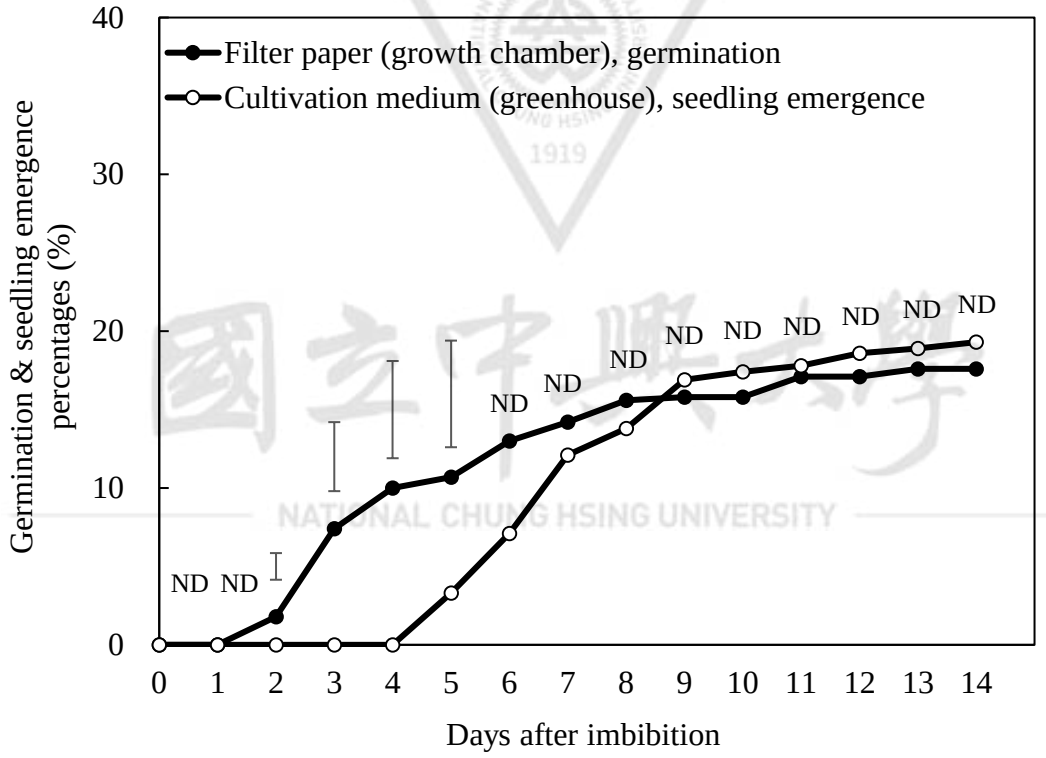


Figure 8. Germination and seedling emergence percentages of red sprangle-top (*Leptochloa chinensis*), that seeds were placed in filter paper (growth chamber) and cultivation medium (greenhouse), respectively. ND = no difference at the 5% significant level.

在前人研究中，千金子種子皆放置於生長箱(growth chamber)中，溫度為 30℃光強度為 100 μmol·m^{-2}·s^{-1}，而本研究 RS(II)-11、RS(II)-25 與 RS(II)-AES 之發芽率皆低於 25%，推測可能與生長箱及溫室之溫度(25.0/21.4℃, growth chamber/greenhouse)、光強度(43/62 μmol·m^{-2}·s^{-1}, growth chamber/greenhouse)太低及種子成熟度有關。

2. 稗草

(1)發芽皿濾紙測試

本試驗將取自第 8、13、17 個水田調查點及 AES 的稗草收集系 BG(II)-8、BG(II)-13、BG(II)-17、及 BG(II)-AES 種子播種於濾紙並置於生長箱中，測量其在發芽皿內浸潤 14 天的發芽率。結果發現 BG(II)-8 於浸潤 3 天後開始發芽，而 BG(II)-17 及 BG(II)-AES 則在第 6 天開始發芽，BG(II)-8、BG(II)-13、BG(II)-17 及 BG(II)-AES 在第 14 天的發芽率分別為 21.4%、0%、1.9%及 1.1% (Figure 9)。經 ANOVA 分析後，發現收集系之間具有極顯著差異(P-value < 0.01)，以 BG(II)-8 發芽率 20%遠高於其他 3 個收集系，表示稗草四個收集系之種子發芽能力並不一致。

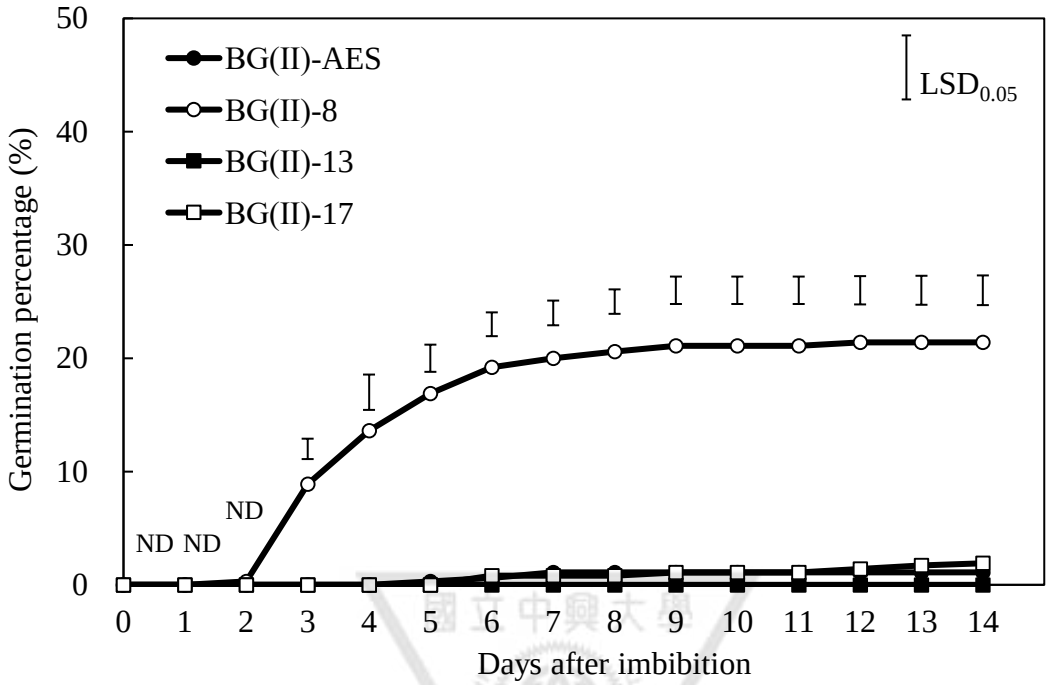


Figure 9. Germination percentage of barnyard grass (*Echinochloa crus-galli*), collected at four locations, were determined within 14 days after imbibition (DAI). Seeds were placed on filter paper in Petri dish and grown in growth chamber. Germination percentages of accessions BG(II)-8, BG(II)-13, BG(II)-17, and BG(II)-AES were 21.4%, 0%, 1.9%, and 1.1%, respectively, at 14 DAI. ND = no difference at the 5% significant level.

根據前人研究，指出成熟的稗草種子具有休眠性，而休眠性來自種子外面包覆的穎(glumes)而非種皮(pericarp)，需經過後熟作用才可發芽(Sung et al., 1987)，但本試驗並無對種子進行物理性破壞去除穎殼，亦無進行後熟作用，在種子採收後即進行發芽試驗。另外，根據 Honek et al. (1996)研究指出稗草的發芽率可能受到微地理變異(microgeographic variation)影響，其研究之 25 種稗草收集系之發芽率介在 0.0%-83.6%，變異極大；且氏等認為稗草需經過幾個月的儲藏，使其種子經過後熟作用(after-ripening)，才能降低休眠性並提升其發芽率。而本試驗採集之

稗草遍及台灣中南部各處水稻田中。此外，研究者亦指出在不同月份所採集之稗草種子，其種子需要後熟的時間亦不相同，研究者推測可能是稗草在發育時期受光照長度變化而影響了種子後熟作用的時間，且稗草種子於後熟期間內的水分含量若低於 18%則可大幅提升種子的發芽率(Sung et al., 1987)。綜合以上推測可能因地區差異導致各個稗草收集系之間發芽率具有顯著差異。

Martinkova et al. (2006)指出稗草種子可藉由後熟作用及層積處理(stratification)以去除種子的休眠性，並且種子儲藏的時間越久，種子能夠發芽的溫度範圍越廣，發芽率也會提升。此外，溫度亦是影響種子發芽能力的關鍵，Honek et al. (1999)表示在低溫環境下，稗草種子能終止其休眠性，提高發芽率。但在不同溫度下，稗草種子的發芽能力也會受到限制，稗草種子於溫度 5-40℃之間皆可發芽，最適合的發芽溫度則在 38℃ (Sadeghloo et al., 2013)。

Leather et al. (1992)研究指出，稗草穎殼中的離層酸(abscisic acid)可能是導致稗草種子產生休眠性的原因，但會在種子進行後熟作用後消失，亦可藉由種子割傷(puncture)處理促使其進行呼吸作用並降低休眠性。研究指出，可使用硫酸(18 M)對稗草種子進行預處理(Sung et al., 1987；Sadeghloo et al., 2013)、或經過室溫儲藏四個月以上進行後熟作用(Honek et al., 1996)、或除掉種子內外穎(dehulled)、以及種子乾燥後

置於低溫(0℃ or 5±2℃)儲藏環境中(Honek et al., 1999；Sadeghloo et al., 2013)，直至試驗開始才取出使用以提高種子發芽率。然而，考量試驗時間有限，本研究發芽率試驗在種子收穫後即進行播種，未經過低溫儲藏及除去種子的內外穎，且栽培介質之 pH 值為 6.9，亦可能因為稗草各收集系之種子休眠性不一，導致各稗草收集系之種子發芽率具有顯著差異，且平均發芽率皆較低。

(2)栽培介質測試

試驗將稗草四個收集系 BG(II)-8、BG(II)-13、BG(II)-17、及 BG(II)-AES 種子同時播種於栽培介質並置放於溫室環境中，結果發現 BG(II)-17 於浸潤 3 天後發現幼苗開始出土，BG(II)-8 於浸潤 4 天後幼苗才逐漸出土，各稗草收集系之種子發芽率於第 4 天開始出現顯著差異。BG(II)-8、BG(II)-13、BG(II)-17、及 BG(II)-AES 在第 14 天的幼苗出土率分別為 17.5%、8.3%、56.7%及 0.0% (Figure 10)，經 Fisher's protected LSD 檢定後，發現具有顯著差異，以 BG(II)-17 發芽率 56.7%遠高於其他 3 個收集系。

稗草收集系 BG(II)-13 及 BG(II)-17 播種於栽培介質後，發芽率皆比播種於濾紙中(Figures 9, 10)較高，可能是溫室之栽培環境及光強度影響，促使其發芽率明顯提升。

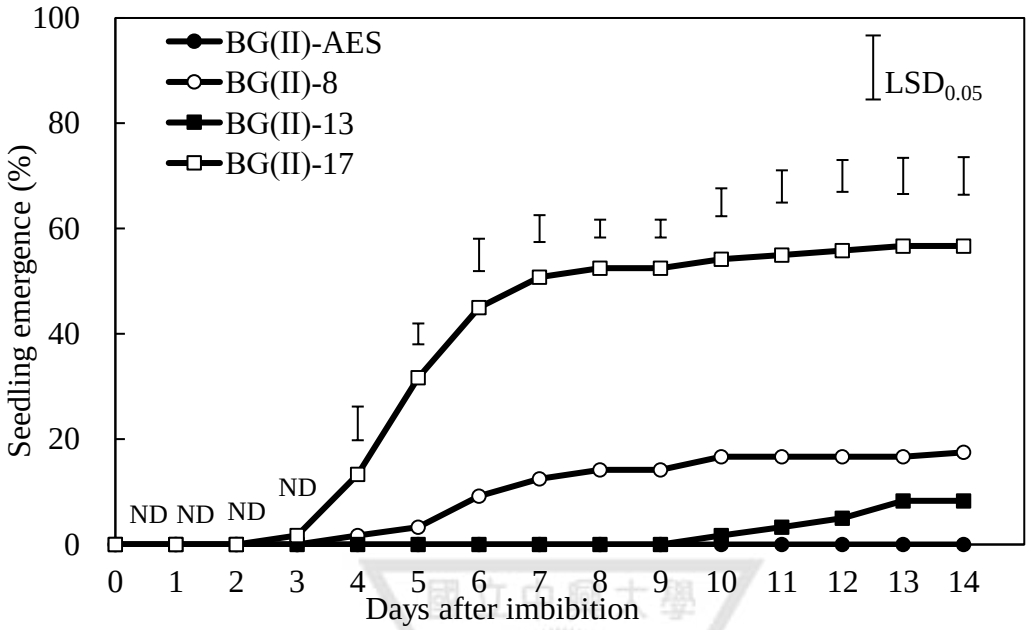


Figure 10. Seedling emergence percentage of barnyard grass (*Echinochloa crus-galli*), collected at four locations, were determined within 14 days after imbibition (DAI). Seeds were placed on cultural medium directly and grown in greenhouse environment. Seedling emergence percentage of accessions BG(II)-8, BG(II)-13, BG(II)-17, and BG(II)-AES were 17.5%, 8.3%, 56.7% and 0.0% respectively, at 14 DAI. ND = no difference at the 5% significant level.

(3)濾紙與栽培介質之發芽率測試比較

綜合各調查點之稗草收集系種子分別播種於濾紙並置放於生長箱中及播種於栽培介質並置放於溫室內的平均發芽率及幼苗出土率，發現濾紙中及介質內之稗草種子經浸潤後第 3 天逐漸發芽及幼苗出土，但第 4 天以後播種於介質中之稗草幼苗出土率較濾紙中的發芽率高。於 14 DAI 播種於濾紙中及栽培介質內的平均發芽率及幼苗出土率分別為 6.1%及 20.6% (Figure 11)，經 Fisher's protected LSD 檢定後，發現兩者具有顯著差異，顯示稗草四個收集系的種子，其播種在栽培介質內的平均幼苗出土率高於濾紙中之平均發芽率。

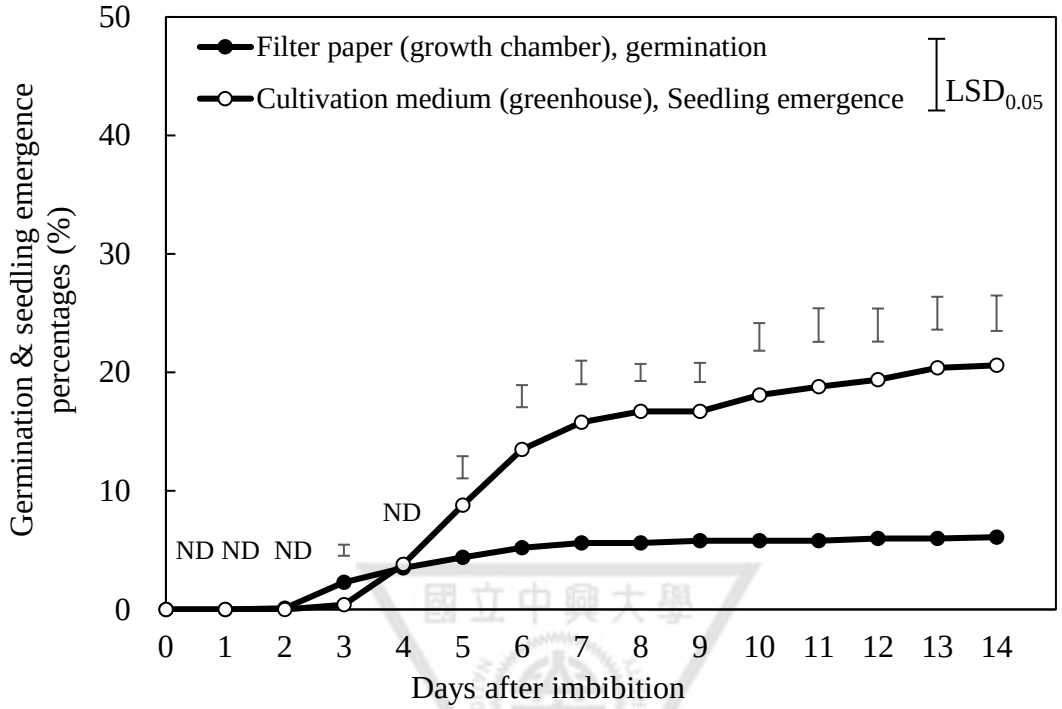


Figure 11. Germination and seedling emergence percentages of barnyard grass (*Echinochloa crus-galli*), that seeds were placed in filter paper (growth chamber) and cultivation medium (greenhouse), respectively. ND = no difference at the 5% significant level.

根據稗草發芽力測試可知，稗草四個收集系種子播種於栽培介質內及濾紙中之平均幼苗出土率及平均發芽率差異相當大，顯示在不同的環境條件下可能影響種子發芽能力。而稗草種子播種於發芽皿濾紙中，種子表面較易吸收水分，因此能快速吸水發芽；而播種於介質表面較無法快速吸附水分且可能覆蓋在介質之下，導致幼苗出土速度較慢，且生長箱及溫室之平均溫度分別為 25.0℃及 21.4℃，可能導致發芽皿濾紙中的種子發芽率較高。但栽培介質置於溫室中的光強度(62 $\mu mol \cdot m^{-2} \cdot s^{-1}$)比生長箱內之光強度(43 $\mu mol \cdot m^{-2} \cdot s^{-1}$)較高，可能是造成稗草平均幼苗出土率與平均發芽率產生差異的原因。

本研究以千金子及稗草為材料，比較種子於發芽皿濾紙上及栽培介質上之發芽效果，雖然千金子之發芽率在二種環境條件下並無顯著差異，但稗草於栽培介質上之幼苗出土率顯然高於濾紙，因此爾後試驗在現有栽培環境條件下均以雜草種子直接播種於栽培介質之方式進行。

(二)比較五種雜草的幼苗出土率差異

由上述試驗可知，將雜草種子播種於栽培介質並置放於溫室環境下，可增加稗草種子的發芽能力，提升幼苗出土率；此外，種子在濾紙上發芽之後，為配合幼苗期試驗需移植幼苗，此過程較容易傷及幼苗根部，故後續試驗將使用栽培介質直接播種以栽培幼苗。本試驗綜合比較五種雜草收集系種子播種於栽培介質中的幼苗出土率，發現其在介質中浸潤 14 天後，千金子[RS(II)-11]、稗草[BG(II) -13]、芒稷[JR(II)-22]、鴨舌草[SM(II)-4]及尖瓣花[CS(II)-6]的幼苗出土率分別為 35.0%、25.0%、0.0%、6.7%、及 0.0% (Figure 12)，經過 Fisher's protected LSD 檢定，結果發現千金子與稗草之種子幼苗出土率並無顯著差異，且兩者均顯著高於芒稷、鴨舌草及尖瓣花之幼苗出土率。

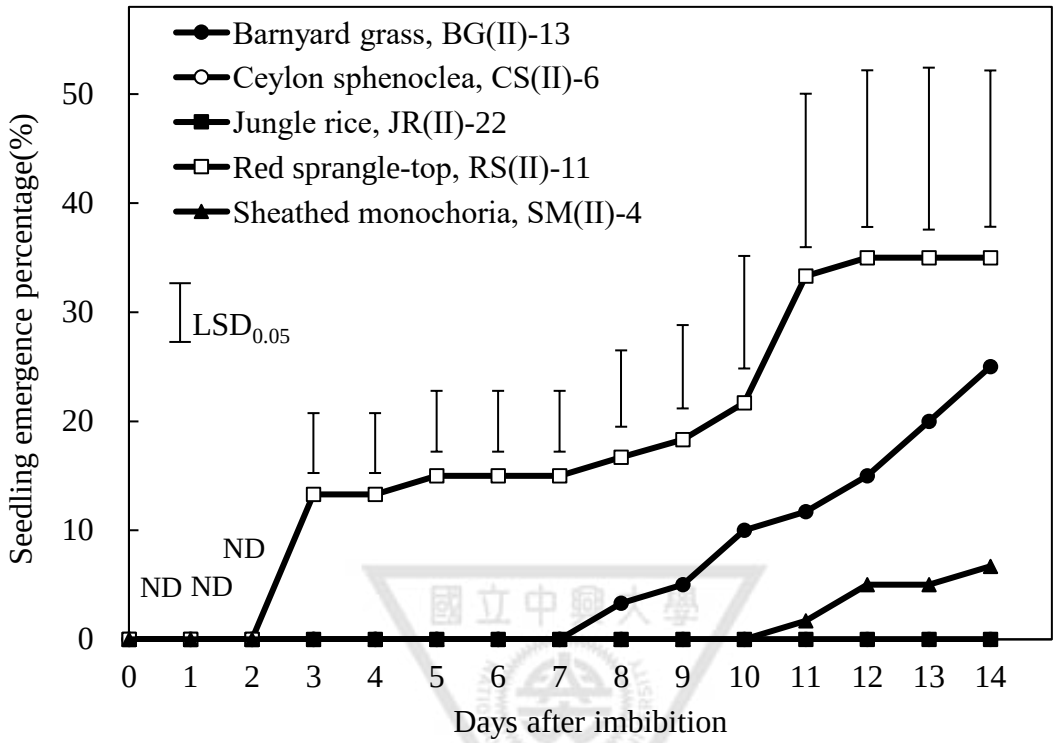


Figure 12. Seedling emergence percentage of five weeds, including red sprangle-top (*Leptochloa chinensis*), barnyard grass (*Echinochloa crus-galli*), jungle rice (*Echinochloa colona*), sheathed monochoria (*Monochoria vaginalis*), and ceylon sphenoclea (*Sphenoclea zeylanica*) that seeds were placed in the cultivation medium (greenhouse). Seedling emergence percentage determined at 14 days after imbibition were 35.0%, 25.0%, 0.0%, 6.7%, and 0.0%, respectively.

由以上試驗結果顯示，五種雜草種子播種於栽培介質並置於溫室環境條件 14 天後，發現千金子及稗草兩種雜草，其幼苗出土能力顯著高於芒稷、鴨舌草及尖瓣花，因此考量爾後進行各種抗性測試之劑量反應分析時所需幼苗數量龐大，研究目標雜草乃採用千金子及稗草二物種。

(三)千金子及稗草收集系之間的幼苗出土率變化

為進一步了解及確定千金子與稗草二物種在本研究採用之栽培介質及環境下之幼苗出土所需時間，乃將幼苗出土率測試延長至 28 天，以確定其是否已呈現穩定狀態。

1. 千金子

試驗將第 11、25 個調查點及 AES 的千金子種子同時播種於栽培介質並置放於溫室中，持續浸潤 28 天，發現千金子三個收集系 RS(II)-11、RS(II)-25 及 RS(II)-AES 在第 7 天的幼苗出土率分別為 12.5%、11.3%及 12.5%，在第 14 天的幼苗出土率分別為 16.3%、18.8%及 22.9%，在第 21 天的幼苗出土率分別為 16.3%、28.8%、及 26.7%，而在第 28 天的幼苗出土率分別為 17.5%、28.8%及 28.3% (Figure 13)。分別將四個時間點的千金子三個收集系之種子幼苗出土率進行 ANOVA 分析，發現皆無顯著差異($P > 0.05$)，表示經浸潤 14 天以後，雖然有二個收集系之幼苗出土率從 20%左右增加至 28%，但於 28 DAI 千金子三個收集系幼苗出土率並無顯著差異。

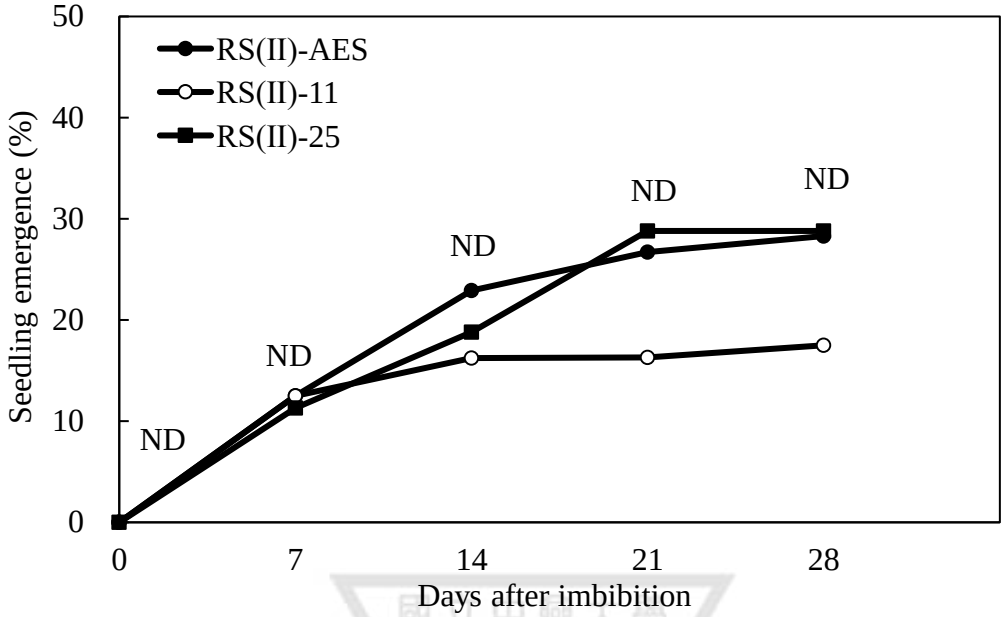


Figure 13. Seedling emergence percentage of red sprangle-top (*Leptochloa chinensis*), collected at three locations, were determined within 28 days after imbibition (DAI). Seeds were placed on cultural medium directly and grown in greenhouse environment. Seedling emergence percentages of red sprangle-top that collected from 11, 25, and AES were 17.5%, 28.8%, and 28.3%, respectively, at 28 DAI. ND means no significant difference among three accessions of red sprangle-top at the 5% level.

2. 稗草

本試驗將第 8、13、17 個水田調查點及 AES 的稗草種子同時播種於栽培介質並置放於溫室中，持續浸潤 28 天，觀測到稗草四個收集系 BG(II)-8、BG(II)-13、BG(II)-17、及 BG(II)-AES 在第 7 天之幼苗出土率分別為 12.5%、0.0%、50.8%、及 0.0%，在第 14 天的幼苗出土率分別為 17.5%、8.3%、56.7%、及 0.0%，在第 21 天的幼苗出土率分別為 22.5%、25.0%、62.5%、及 0.0%，而在第 28 天的幼苗出土率分別為 25.0%、35.0%、65.0%、及 0.0% (Figure 14)。經過 Fisher's protected LSD 檢定後，結果發現浸潤後不同時間各個稗草收集系之幼苗出土率具有

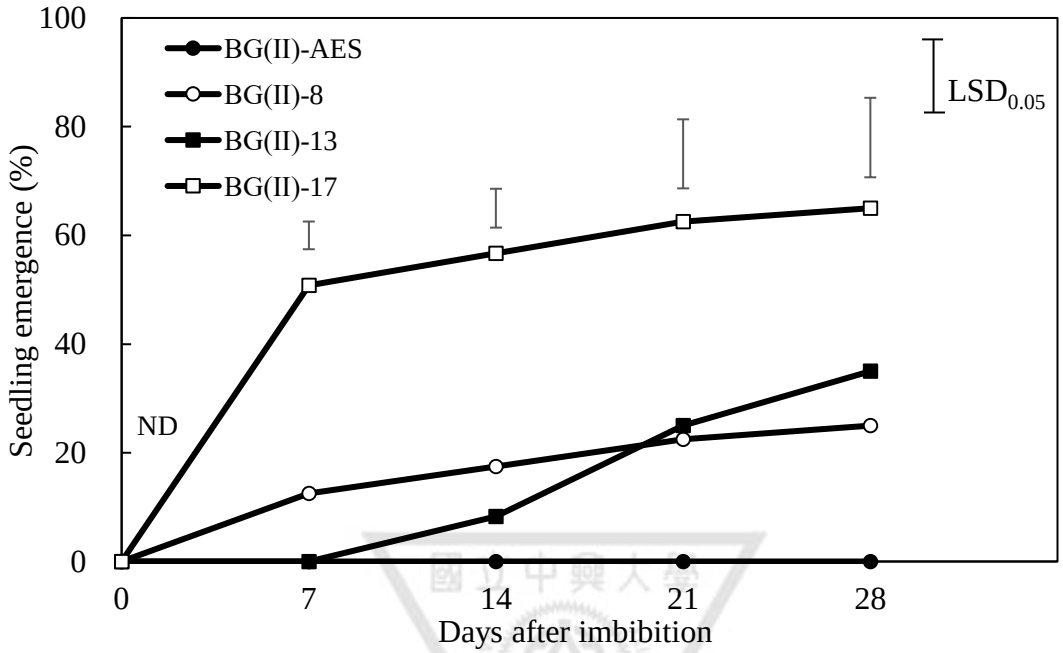


Figure 14. Seedling emergence percentage of barnyard grass (*Echinochloa crus-galli*), collected at four locations, were determined within 28 days after imbibition (DAI). Seeds were placed on cultural medium directly and grown in greenhouse environment. Seedling emergence percentages of barnyard grass that collected from location 8, 13, 17, and AES were 25.0%, 35.0%, 65.0%, and 0.0% at 28 DAI, respectively. ND means no significant difference among three accessions of barnyard grass at the 5% level.

顯著差異($P < 0.05$)，顯示稗草各收集系之幼苗出土能力並不一致，而以 BG(II)-17 之幼苗出土率為最高。此外，以幼苗出土率最大之收集系而言，14 DAI 以後其幼苗出土率由 56.7%增加至 65.0%，僅有小幅度增加。

由試驗結果可知，各個千金子及稗草收集系於 21 DAI 之幼苗出土率已呈現穩定狀態，於 28 DAI 之幼苗出土率僅小幅提升(Figures 8, 9)。因此，可在種子經浸潤 21 天以後進行移植，以取得較多幼苗試驗材料。

三、千金子及稗草對 Apiro Forte 抗性之普篩試驗

(一) 千金子之抗性普篩

本研究以稗草三個收集系及千金子六個收集系進行普篩試驗，於千金子 1~2 葉齡施用 Apiro Forte，之後每週觀察調查傷害指數及存活率，試驗持續進行 28 天。千金子六個收集系在施用 10 倍推薦用量之 Apiro Forte 後，於處理 14 天後(Days after treatment, DAT)出現較明顯之藥效，其傷害指數隨著時間增加而提高(Figure 15)。在藥劑處理下，千金子收集系以 RS(II)-11 之傷害指數 4.1 為最低。經 Fisher's protected LSD 檢定，於 7、14、21 及 28 DAT，千金子六個收集系之間皆未達顯著差異。在無任何藥劑處理下，千金子六個收集系皆無出現任何藥害，傷害指數皆為 0 (data not shown)。

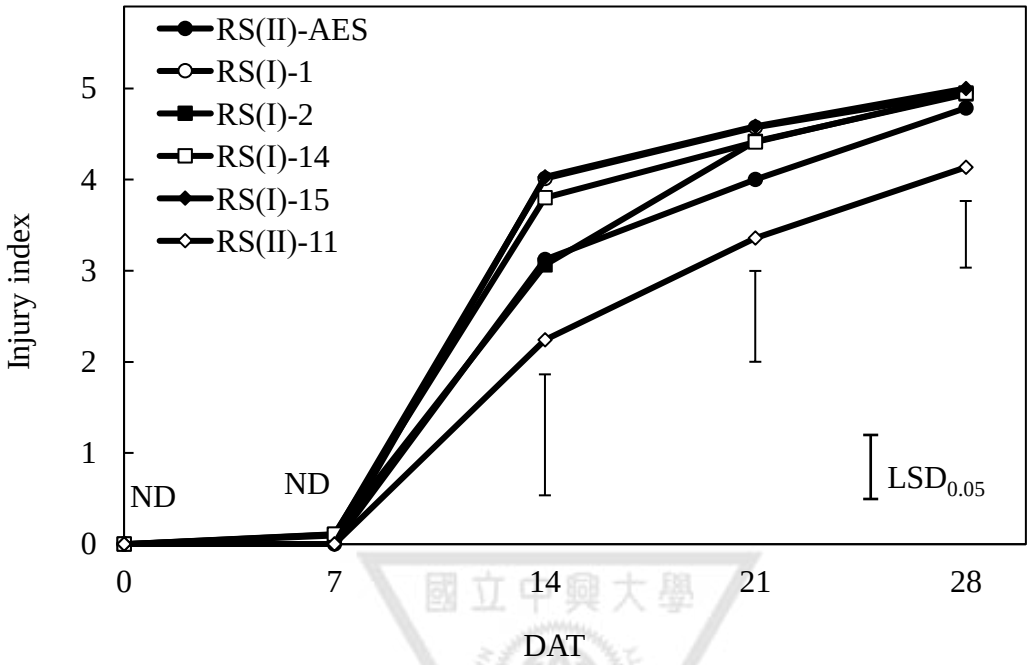


Figure 15. Injury indices of 1-2 leaf red sprangle-top (*Leptochloa chinensis*) accession seedlings after treatment of Apiro Forte with 10-fold recommended dosage. The injury index ranges from 0 to 5, 0 indicates plant alive without herbicidal injury, and 5 indicates plant died due to herbicidal effect. Recommended dosage was 0.550 ppm (w/v). ND = no difference at the 5% level as determined by the Fisher's protected LSD test.

本研究針對千金子六個收集系於 28 DAT 的傷害指數進行比較(Table 10)，在施用藥劑後，六個收集系之傷害指數介於 4.1～5.0 之間，彼此間並未達顯著差異。其中 RS(II)-11 之傷害指數僅 4.1，略低於其他千金子收集系，疑似表現出對 Apiro Forte 之抗性。

Table 10. Injury index of 1-2 leaf red sprangle-top (*Leptochloa chinensis*) accession seedlings observed at 28 days after treatment of herbicide Apiro Forte with 10-fold recommended dosage. The injury index ranges from 0 to 5, 0 indicates all plants survived without herbicide injury, and 5 indicates all plants were killed due to herbicidal effect.

Red sprangle-top accessions	Injury index
RS(II)-AES	4.8
RS(I)-1	5.0
RS(I)-2	4.9
RS(I)-14	5.0
RS(I)-15	5.0
RS(II)-11	4.1
P-value	0.18
$LSD_{0.05}$	ND*

* ND = no difference at the 5% level as determined by the Fisher's protected LSD test.

比較千金子六個收集系於 28 DAT 的存活率(Table 11)，發現在施用藥劑後，六個收集系之存活率介於 0.0 ~ 29.0%之間，彼此間並未達顯著差異。其中 RS(II)-11 之存活率達 29.0%，較高於其他收集系，疑似表現出對 Apiro Forte 之輕微抗性。但亦發現取自有機農場之收集系 RS(II)-AES 亦表現相當程度之抗性。

Table 11. Survival rates of 1-2 leaf red sprangle-top (*Leptochloa chinensis*) accession seedlings observed at 28 days after treatment of herbicide Apiro Forte with 10-fold recommended dosage. The survival rate ranges from 0 to 100%, 0% indicates all plants were killed due to herbicidal effect, and 100% indicates all plants survived without herbicide injury.

Red sprangle-top accessions	Survival rate (%)
RS(II)-AES	13.2
RS(I)-1	0.0
RS(I)-2	6.7
RS(I)-14	0.0
RS(I)-15	0.0
RS(II)-11	29.0
P-value	0.07
$LSD_{0.05}$	ND*

* ND = no difference at the 5% level as determined by the Fisher's protected LSD test.

根據試驗結果推測，千金子收集系 RS(II)-11 其傷害指數相對於其他收集系較低及存活率相對較高，表示其 1-2 葉齡幼苗可能對 Apiro Forte 敏感度較低。根據千金子六個收集系所採集之調查點的用藥經歷，發現 RS(II)-11 為採集自雲林斗南水稻田中之收集系，於整地時曾施用 Apiro Forte 以防除雜草，是否可能使田間殘留存活之 RS(II)-11 相對地具有抗性。本試驗使用 10 倍推薦用量之 Apiro Forte 對於 1-2 葉齡幼苗而言可能濃度偏高，各千金子收集系皆於 14 DAT 之後傷害指數超過一半。後續須進行九種濃度之劑量反應分析確認各收集系間的敏感度差異。

(二)稗草之抗性普篩

本研究以稗草三個收集系於施用 10 倍推薦用量之 Apiro Forte 後，在 7 DAT 開始出現輕微傷害，於 14 DAT 出現較明顯之藥效，其傷害指數隨著時間增加而提高(Figure 16)。經 Fisher's protected LSD 檢定，於 14、21、28 DAT，三個收集系間的傷害指數未達顯著差異。

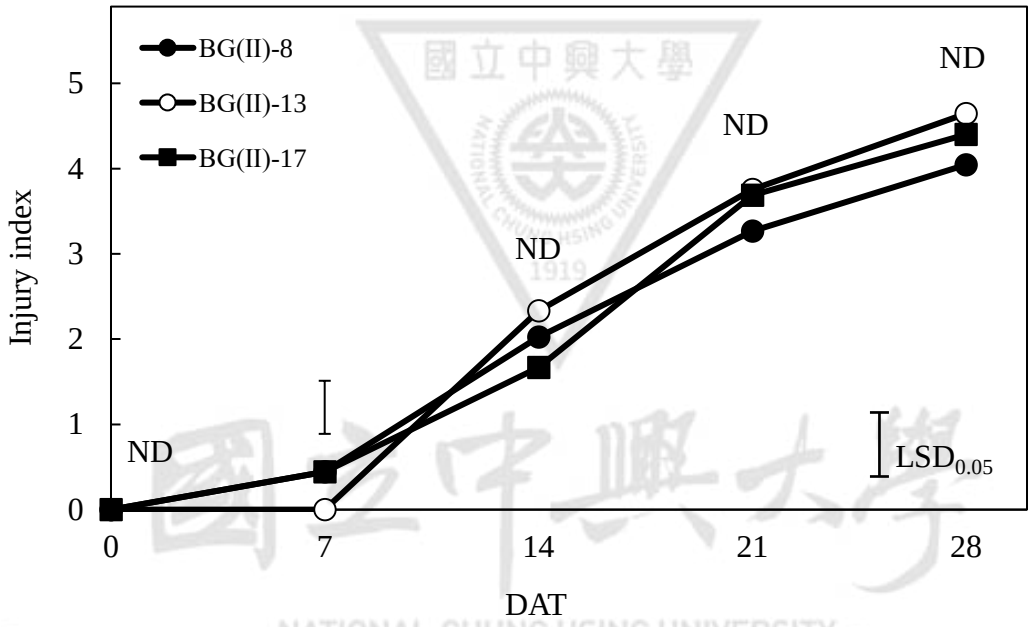


Figure 16. Injury indeices of 1-2 leaf barnyard grass (*Echinochloa crus-galli*) accession seedlings after treatment of herbicide Apiro Forte with 10-fold recommended dosage. The injury index ranges from 0 to 5, 0 indicates plant alive without herbicidal injury, and 5 indicates plant died due to herbicidal effect. Recommended dosage was 0.550 ppm (w/v). ND = no difference at the 5% level as determined by the Fisher's protected LSD test.

比較稗草三個收集系於 28 DAT 的傷害指數(Table 12)，發現三個收集系之傷害指數介於 4.0 ~ 4.6 之間。BG(II)-8 之傷害指數為 4.0，略低於其他稗草收集系。經 Fisher's protected LSD 檢定，稗草三個收集系之傷害指數彼此未達顯著差異，表示其對 Apiro Forte 之敏感度較相近。

Table 12. Injury index of 1-2 leaf barnyard grass (*Echinochloa crus-galli*) accession seedlings at 28 days after treatment of herbicide Apiro Forte with 10-fold recommended dosage. The injury index ranges from 0 to 5, 0 indicates all plants survived without herbicide injury, and 5 indicates all plants were killed due to herbicidal effect.

Barnyard grass accession	Injury index
BG(II)-8	4.0
BG(II)-13	4.6
BG(II)-17	4.4
P-value	0.53
$LSD_{0.05}$	ND*

* ND = no difference at the 5% level as determined by the Fisher's protected LSD test.

比較三個稗草收集系於 28 DAT 的存活率 (Table 13)，發現三個收集系之存活率介於 22.2 ~ 42.2%之間，其中 BG(II)-8 之存活率達 42.2%。經 Fisher's protected LSD 檢定，稗草三個收集系之存活率彼此未達顯著差異，表示其對 Apiro Forte 之敏感度較相近。

Table 13. Survival rates of 1-2 leaf barnyard grass (*Echinochloa crus-galli*) accession seedlings at 28 days after treatment of herbicide Apiro Forte with 10-fold recommended dosage. The survival rate ranges from 0 to 100%, 0% indicates all plants were killed due to herbicidal effect, and 100% indicates all plants survived without herbicide injury.

Barnyard grass accession	Survival rate (%)
BG(II)-8	42.2
BG(II)-13	22.2
BG(II)-17	31.1
P-value	0.85
$LSD_{0.05}$	ND

* ND = no difference at the 5% level as determined by the Fisher's protected LSD test.

根據試驗結果可知，於 10 倍推薦用量之 Apiro Forte 施用後 28 天，稗草三個收集系其傷害指數及存活率皆相近，表示其 1-2 葉齡幼苗可能對 Apiro Forte 具有相同之敏感度。本試驗使用 10 倍推薦用量之 Apiro Forte 對於 1-2 葉齡幼苗而言可能濃度偏高，各稗草收集系於 21 DAT 之後傷害指數皆超過一半。後續仍須進行九種濃度之劑量反應分析確認各收集系間的敏感度差異。

Apiro Forte 普篩試驗之結果發現千金子收集系 RS(II)-11 於施用 10 倍推薦用量 Apiro Forte 下，其存活率較高於其他千金子收集系，而稗草收集系 BG(II)-8 之存活率亦達 42.2%，表示有部分千金子及稗草收集系可能其對 Apiro Forte 具有一定程度的抗性，但本次普篩試驗僅使用單一劑量進行，因此後續仍需對各個千金子及稗草收集系進行九種濃度之劑量反應分析，以較精確地確認各收集系間的敏感度差異。

四、單一抗性

(一)千金子及稗草對 Apiro Forte 之劑量反應分析試驗

由普篩試驗中可知，千金子及稗草各收集系對於Apiro Forte之敏感度較一致，但僅使用單一劑量(濃度)對雜草進行抗性判斷可能較不精確，為進一步辨別各收集系之抗性程度及不同生育時期對藥劑之反應，因此分別對千金子及稗草進行劑量反應分析試驗。

A. 不同生育時期對 Apiro Forte 之劑量反應分析

a. 千金子

本研究將採集自台灣中南部水田一、二期作之千金子六個收集系，於千金子幼苗 1-2 及 3-4 葉齡時分別進行九種劑量的Apiro Forte劑量反應分析，分別在施用藥劑後 28 天及 35 天記錄傷害指數、存活率、鮮重及乾重等性狀，將資料帶入非線性對數邏輯回歸模型(nonlinear log-logistic regression model)，得出劑量反應分析曲線及ED_{50}值，最後比較千金子六個收集系彼此間對Apiro Forte的敏感度以及不同生育時期下千金子各收集系對Apiro Forte的敏感度。

1. 1-2 葉齡

將 1-2 葉齡千金子幼苗對Apiro Forte進行劑量反應分析試驗，於施用藥劑後 28 天後，觀察其生長情形，並記錄傷害指數、存活率、鮮重及乾重等性狀(Figure 17)，將資料以非線性對數邏輯回歸模型，得出千金子各收集系對Apiro Forte之ED_{50}值。

Figure 17. Herbicidal injury of 1-2 leaf red sprangle-top (*Leptochloa chinensis*) accession at 0 (A) and 28 (B) days after treatment of the herbicide Apiro Forte. Plants were observed from side and overlook view. Recommended dosage was 0.550 ppm (w/v).

由 1-2 葉齡千金子六個收集系對Apiro Forte之ED_{50}值表可知，其傷害指數之ED_{50}值介於 0.17-0.59、存活率之ED_{50}值介於 0.37-2.95、存活率經arcsine轉換後之ED_{50}值介於 0.38-1.98、鮮重之ED_{50}值介於 0.19-0.53、鮮重經arcsine轉換後之ED_{50}值介於 0.19-0.46、乾重之ED_{50}值介於 0.17-0.47、乾重經arcsine轉換後之ED_{50}值介於 0.08-0.28 (Table 14)，千金子六個收集系彼此間於四個性狀的ED_{50}值經Fisher's protected LSD檢定後未達顯著差異，表示千金子各收集系對Apiro Forte之敏感度較一致。

根據試驗結果可知，四種性狀之ED_{50}值有些許差異，係因為植株幼苗於施藥後測量指標不同所致，其中應以植株直接表現藥效之傷害指數及存活率作為判斷之主要依據，而鮮重及乾重等性狀在後續分析之表現較不穩定，故建議僅作為藥效判斷之輔助依據。

Table 14. ED_{50} values of herbicide Apiro Forte[*1] for the 1-2 leaf red sprangle-top (RS, *Leptochloa chinensis*) accessions. Data were collected at 28 days after treatment from three independent experiments.

Accession	ED_{50} (ppm, w/v)						
	Injury index	Survival rate		Fresh weight		Dry weight	
		Original data	Arcsine transformation	Original data	Arcsine transformation	Original data	Arcsine transformation
RS(II)-AES	0.38	2.95	0.51	0.39	0.45	0.18	0.12
RS(I)-1	0.42	1.89	0.93	0.34	0.46	0.18	0.19
RS(I)-2	0.17	0.37	0.38	0.25	0.25	0.17	0.28
RS(I)-14	0.33	1.68	1.54	0.19	0.19	0.20	0.18
RS(I)-15	0.59	2.48	1.98	0.53	0.44	0.47	0.27
RS(II)-11	0.46	0.87	0.83	0.30	0.22	0.26	0.21
P-value	0.46	0.57	0.47	0.62	0.53	0.58	0.95
$LSD_{0.05}$	ND	ND	ND	ND	ND	ND	ND

[*1] Theoretical concentration of Apiro Forte in paddy water based on the application rate recommended by Syngenta CO. was 0.550 ppm (w/v).

[*2] ND indicates no significant difference among four accessions according to Fisher's protected LSD test ($\alpha = 0.05$).

2. 3-4 葉齡

將 3-4 葉齡千金子幼苗對Apiro Forte進行劑量反應分析試驗，於施用藥劑後 35 天後，觀察其生長情形，並記錄傷害指數、存活率、鮮重及乾重等性狀，將資料帶入非線性對數邏輯回歸模型，得出千金子各收集系對Apiro Forte之ED_{50}值。

由 3-4 葉齡千金子六個收集系針對Apiro Forte之ED_{50}值表可知，其傷害指數之ED_{50}值介於 0.45-1.09、存活率之ED_{50}值介於 1.07-7.19、存活率經arcsine轉換後之ED_{50}值介於 1.19-7.34、鮮重之ED_{50}值介於 1.05-4.50、鮮重經arcsine轉換後之ED_{50}值介於 0.99-5.66、乾重之ED_{50}值介於 0.65-6.87、乾重經arcsine轉換後之ED_{50}值介於 0.58-6.23 (Table 15)，千金子六個收集系彼此間於四個性狀的ED_{50}值經Fisher's protected LSD檢定後未達顯著差異，表示千金子各收集系對Apiro Forte之敏感度較一致。但可以發現 3-4 葉齡之千金子各收集系之ED_{50}值較 1-2 葉齡高，且高於田間推間用量 0.550 ppm。

Table 15. ED_{50} values of herbicide Apiro Forte[*1] for the 3-4 leaf red sprangle-top (RS, *Leptochloa chinensis*) accessions. Data were collected at 28 days after treatment from three independent experiments.

Accession	ED_{50} (ppm, w/v)						
	Injury index	Survival rate		Fresh weight		Dry weight	
		Original data	Arcsine transformation	Original data	Arcsine transformation	Original data	Arcsine transformation
RS(II)-AES	1.09	2.83	2.85	3.22	3.18	4.52	3.72
RS(I)-1	0.45	1.07	1.19	3.57	5.66	1.27	0.74
RS(I)-2	0.45	2.29	2.10	3.63	3.43	4.65	2.22
RS(I)-14	0.89	2.62	2.56	1.05	0.99	0.65	0.63
RS(I)-15	1.07	7.19	7.34	4.50	4.21	6.87	6.23
RS(II)-11	0.66	2.01	2.35	3.79	4.10	1.15	0.58
P-value	0.67	0.32	0.31	0.99	0.96	0.44	0.43
$LSD_{0.05}$	ND[*2]	ND	ND	ND	ND	ND	ND

[*1] Theoretical concentration of Apiro Forte in paddy water based on the application rate recommended by Syngenta CO. was 0.550 ppm (w/v).

[*2] ND indicates no significant difference among four accessions according to Fisher's protected LSD test ($\alpha = 0.05$).

3. 不同生育時期之劑量反應比較

本試驗進一步比較兩個生育時期之千金子六個收集系對Apiro Forte之傷害指數的ED_{50}值，可知千金子各收集系於不同生育時期ED_{50}值經Fisher's protected LSD 檢定後並未達到顯著差異(Table 16)，表示 1-2 葉齡及 3-4 葉齡的千金子幼苗對藥劑的敏感度相似。

Table 16. Sensitivity comparison of red sprangle-top (RS, *Leptochloa chinensis*) accessions between 1-2 and 3-4 leaf stages to the herbicide Apiro Forte based on injury index. Data of two growth stages from three independent experiments were collected at 28 and 35 days, respectively, after treatment.

Accession	ED_{50} (injury index) (ppm)		P-value	$LSD_{0.05}$
	1-2 leaf	3-4 leaf		
RS(II)-AES	0.38	1.09	0.19	ND*
RS(I)-1	0.42	0.45	0.90	ND
RS(I)-2	0.17	0.45	0.56	ND
RS(I)-14	0.33	0.89	0.30	ND
RS(I)-15	0.59	1.07	0.46	ND
RS(II)-11	0.46	0.66	0.51	ND

* ND indicates no significant difference according to Fisher's protected LSD test (α = 0.05).

比較兩個生育時期之千金子六個收集系對Apiro Forte之存活率的ED_{50}值，可知千金子各收集系於不同生育時期ED_{50}值經Fisher's protected LSD檢定後並未達到顯著差異(Table 17)，表示 1-2 葉齡及 3-4 葉齡的千金子幼苗對藥劑的敏感度相似。

Table 17. Sensitivity comparison of red sprangle-top (RS, *Leptochloa chinensis*) accessions between 1-2 and 3-4 leaf stages to the herbicide Apiro Forte based on survival rate (original data). Data of two growth stages from three independent experiments were collected at 28 and 35 days, respectively, after treatment.

Accession	ED_{50} (Survival rate) (ppm)		P-value	$LSD_{0.05}$
	1-2 leaf	3-4 leaf		
RS(II)-AES	0.49	2.83	0.96	ND*
RS(I)-1	0.91	1.07	0.48	ND
RS(I)-2	0.37	2.29	0.34	ND
RS(I)-14	1.68	2.62	0.63	ND
RS(I)-15	2.48	7.19	0.45	ND
RS(II)-11	0.87	2.01	0.29	ND

* ND indicates no significant difference according to Fisher's protected LSD test (α = 0.05).

比較兩個生育時期的千金子六個收集系對Apiro Forte之存活率經arcsine轉換後的ED_{50} 值，可知千金子各收集系於不同生育時期ED_{50} 值經Fisher's protected LSD檢定後並未達到顯著差異(Table 18)，表示 1-2 葉齡及 3-4 葉齡的千金子幼苗對藥劑的敏感度相似。

Table 18. Sensitivity comparison of red sprangle-top (RS, *Leptochloa chinensis*) accessions between 1-2 and 3-4 leaf stages to the herbicide Apiro Forte based on survival rate (arcsine transformation). Data of two growth stages from three independent experiments were collected at 28 and 35 days, respectively, after treatment.

Accession	ED_{50} (Survival rate) (ppm)		P-value	$LSD_{0.05}$
	1-2 leaf	3-4 leaf		
RS(II)-AES	0.51	2.85	0.23	ND*
RS(I)-1	0.93	1.19	0.63	ND
RS(I)-2	0.38	2.10	0.39	ND
RS(I)-14	1.54	2.56	0.59	ND
RS(I)-15	1.98	7.34	0.40	ND
RS(II)-11	0.83	2.35	0.27	ND

* ND indicates no significant difference according to Fisher's protected LSD test (α = 0.05).

比較兩個生育時期的千金子六個收集系對Apiro Forte之鮮重ED_{50}值，可知千金子各收集系於不同生育時期ED_{50}值經Fisher's protected LSD檢定後，僅RS(II)-AES及RS(I)-14具有顯著差異，但其他收集系則未達顯著差異(Table 19)，表示千金子收集系RS(II)-AES及RS(I)-14可能在3-4葉齡較1-2葉齡對藥劑較具有抗性，抗性指數分別為8.26及5.53。

Table 19. Sensitivity comparison of red sprangle-top (RS, *Leptochloa chinensis*) accessions between 1-2 and 3-4 leaf stages to the herbicide Apiro Forte based on fresh weight (FW, original data). Data of two growth stages from three independent experiments were collected at 28 and 35 days, respectively, after treatment.

Accession	ED_{50} (FW) (ppm)		P-value	$LSD_{0.05}$
	1-2 leaf	3-4 leaf		
RS(II)-AES	0.39	3.22	<0.05	0.74
RS(I)-1	0.34	3.57	0.27	ND
RS(I)-2	0.25	3.63	0.52	ND
RS(I)-14	0.19	1.05	<0.05	0.62
RS(I)-15	0.53	4.50	0.47	ND
RS(II)-11	0.30	3.79	0.35	ND

* ND indicates no significant difference according to Fisher's protected LSD test (α = 0.05).

比較兩個生育時期的千金子六個收集系對Apiro Forte之鮮重經arcsine轉換後的ED_{50}值，可知，千金子各收集系於不同生育時期ED_{50}值經Fisher's protected LSD檢定後，僅RS(II)-AES及RS(I)-14 具有顯著差異，但其他收集系則未達顯著差異(Table 20)，此結果與鮮重之反應相似(Table 19)。

Table 20. Sensitivity comparison of red sprangle-top (RS, *Leptochloa chinensis*) accessions between 1-2 and 3-4 leaf stages to the herbicide Apiro Forte based on fresh weight (FW, arcsine transformation). Data of two growth stages from three independent experiments were collected at 28 and 35 days, respectively, after treatment.

Accession	ED_{50} (FW) (ppm)		P-value	$LSD_{0.05}$
	1-2 leaf	3-4 leaf		
RS(II)-AES	0.45	3.18	<0.05	1.04
RS(I)-1	0.46	5.66	0.28	ND*
RS(I)-2	0.25	3.43	0.52	ND
RS(I)-14	0.19	0.99	<0.05	0.59
RS(I)-15	0.44	4.21	0.47	ND
RS(II)-11	0.22	4.10	0.35	ND

* ND indicates no significant difference according to Fisher's protected LSD test (α = 0.05).

比較兩個生育時期之千金子六個收集系對Apiro Forte之乾重的ED_{50}值，可知千金子各收集系於不同生育時期ED_{50}值經Fisher's protected LSD 檢定後並未達到顯著差異(Table 21)，表示 1-2 葉齡及 3-4 葉齡的千金子幼苗對藥劑的敏感度相似。

Table 21. Sensitivity comparison of red sprangle-top (RS, *Leptochloa chinensis*) accessions between 1-2 and 3-4 leaf stages to the herbicide Apiro Forte based on dry weight (DW, original data). Data of two growth stages from three independent experiments were collected at 28 and 35 days, respectively, after treatment.

Accession	ED_{50} (DW) (ppm)		P-value	$LSD_{0.05}$
	1-2 leaf	3-4 leaf		
RS(II)-AES	0.18	4.52	0.11	ND
RS(I)-1	0.18	1.27	0.35	ND
RS(I)-2	0.17	4.65	0.29	ND
RS(I)-14	0.20	0.65	0.12	ND
RS(I)-15	0.47	6.87	0.16	ND
RS(II)-11	0.26	1.15	0.06	ND

* ND indicates no significant difference according to Fisher's protected LSD test (α = 0.05).

比較兩個生育時期之千金子六個收集系對Apiro Forte之乾重的ED_{50}值，可知千金子各收集系於不同生育時期ED_{50} 值經Fisher's protected LSD 檢定後並未達到顯著差異(Table 22)，表示 1-2 葉齡及 3-4 葉齡的千金子幼苗對藥劑的敏感度相似。

Table 22. Sensitivity comparison of red sprangle-top (RS, *Leptochloa chinensis*) accessions between 1-2 and 3-4 leaf stages to the herbicide Apiro Forte based on dry weight (DW, arcsine transformation). Data of two growth stages from three independent experiments were collected at 28 and 35 days, respectively, after treatment.

Accession	ED_{50} (DW) (ppm)		P-value	$LSD_{0.05}$
	1-2 leaf	3-4 leaf		
RS(II)-AES	0.12	3.72	0.14	ND
RS(I)-1	0.19	0.74	0.05	ND
RS(I)-2	0.28	2.22	0.33	ND
RS(I)-14	0.18	0.63	0.28	ND
RS(I)-15	0.08	6.23	0.12	ND
RS(II)-11	0.21	0.58	0.45	ND

* ND indicates no significant difference according to Fisher's protected LSD test (α = 0.05).

根據以上試驗結果可知，1-2 葉齡千金子六個收集系對Apiro Forte的ED_{50}值幾乎低於田間推薦用量 0.550 ppm，且收集系彼此間之ED_{50}值未達顯著差異，表示千金子六個收集系對Apiro Forte的敏感度相近似。而 3-4 葉齡千金子收集系彼此間對Apiro Forte之ED_{50}值亦未達顯著差異，且ED_{50} 值略高於田間推薦用量，目前尚未有研究發現千金子對ALS抑制型除草劑產生抗性之收集系，可能是千金子對ALS抑制劑較敏感，抑或是水田栽培管理方式變化較大使其較不容易產生抗性。

進一步比較兩個生育時期之千金子各收集系之四個性狀的ED_{50}值，結果發現千金子各收集系於 1-2 葉齡及 3-4 葉齡之傷害指數、存活率及乾重的ED_{50}值皆未達顯著差異，僅RS(II)-AES及RS(I)-14 於 3-4 葉齡其鮮重之ED_{50}值顯著高於 1-2 葉齡，表示RS(II)-AES及RS(I)-14 此二收集系之 3-4 葉齡較成熟植株可能對藥劑之敏感度降低。研究者指出千金子植株越成熟，藥劑對其控制能力就越低，推測可能是千金子在不同生育階段對除草劑之降解速率(degradation rate)及代謝(metabolism)能力增加有關(Chauhan and Abugho et al., 2011)。

b. 稗草

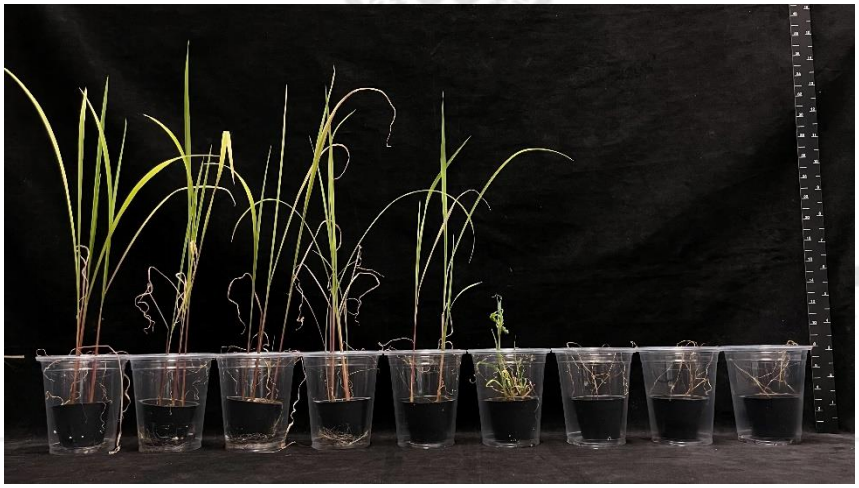
本研究將採集自台灣中南部水田一、二期作之稗草四個收集系，於稗草幼苗生長至 1-2 及 3-4 葉齡時分別進行九種劑量的Apiro Forte劑量反應分析，分別在施用藥劑後 28 天及 35 天記錄傷害指數、存活率、鮮重及乾重等性狀，將資料帶入非線性對數邏輯回歸模型，得出劑量反應分析曲線及ED_{50}值，最後比較稗草四個收集系彼此間對Apiro Forte的敏感度以及不同生育時期下稗草各收集系對Apiro Forte的敏感度。

1. 1-2 葉齡

將 1-2 葉齡稗草幼苗對 Apiro Forte 進行劑量反應分析試驗，於施用藥劑後 28 天後，觀察其生長情形，並記錄傷害指數、存活率、鮮重及乾重等性狀(Figure 18)，將資料以非線性對數邏輯回歸模型，得出稗草各收集系對 Apiro Forte 之及 ED_{50} 值。

A.

B.



. Figure 18 Herbicidal injury of 1-2 leaf barnyard grass (*Echinochloa crus-galli*) at 0 (A) and 28 (B) days after treatment of the herbicide Apiro Forte. Plants were observed from side view. Recommended dosage was 0.550 ppm (w/v).

由 1-2 葉齡稗草四個收集系對Apiro Forte之ED_{50}值表可知，其傷害指數之ED_{50}值介於 0.14-0.65、存活率之ED_{50}值介於 0.29-2.94、存活率經arcsine轉換後之ED_{50}值介於 0.28-3.12、鮮重之ED_{50}值介於 0.06-0.26、鮮重經arcsine轉換後之ED_{50}值介於 0.06-0.26、乾重之ED_{50}值介於 0.05-0.14、乾重經arcsine轉換後之ED_{50}值介於 0.03-0.12 (Table 23)，稗草四個收集系彼此間於傷害指數及存活率的ED_{50}值經Fisher's protected LSD檢定後具有顯著差異，表示稗草各收集系對Apiro Forte之敏感度可能較不一致，其中以稗草收集系BG(II)-8 之ED_{50}值顯著高於BG-WT及BG(II)-13，而後進一步將BG(II)-8 與BG-WT之傷害指數及存活率的ED_{50}值相除可得BG(II)-8 之抗性指數介於 4.64-10.75，表示BG(II)-8 相較於其他稗草收集系可能對Apiro Forte具有一定程度的抗性。

根據試驗結果可知，四種性狀之ED_{50}值有些許差異，係因為植株幼苗於施藥後測量指標不同所致，其中應以植株直接表現藥效之傷害指數及存活率作為判斷之主要依據，而鮮重及乾重等性狀在後續分析之表現較不穩定，故建議僅作為藥效判斷之輔助依據。

Table 23. ED_{50} values of herbicide Apiro Forte[*1] for the 1-2 leaf barnyard grass (BG, *Echinochloa crus-galli*) accessions. Data were collected at 28 days after treatment from three independent experiments.

Accession	ED_{50} (ppm, w/v)						
	Injury index	Survival rate		Fresh weight		Dry weight	
		Original data	Arcsine transformation	Original data	Arcsine transformation	Original data	Arcsine transformation
BG-WT	0.14	0.29	0.29	0.06	0.06	0.05	0.03
BG(II)-8	0.65	2.94	3.12	0.07	0.08	0.14	0.10
BG(II)-13	0.16	0.29	0.28	0.11	0.14	0.11	0.12
BG(II)-17	0.36	0.57	0.56	0.26	0.26	0.08	0.07
P-value	< 0.05	< 0.05	< 0.05	0.23	0.34	0.62	0.64
$LSD_{0.05}$	0.37	1.98	2.11	ND[*2]	ND	ND	ND

[*1] Theoretical concentration of Apiro Forte in paddy water based on the application rate recommended by Syngenta CO. was 0.550 ppm (w/v).

[*2] ND indicates no significant difference among four accessions according to Fisher's protected LSD test ($\alpha = 0.05$).

2. 3-4 葉齡

將 3-4 葉齡稗草幼苗對Apiro Forte進行劑量反應分析試驗，於施用藥劑後 35 天後，記錄傷害指數、存活率、鮮重及乾重等性狀，將資料以非線性對數邏輯回歸模型，得出稗草各收集系對Apiro Forte之ED_{50}值。

由 3-4 葉齡稗草四個收集系針對Apiro Forte之ED_{50}值表可知，其傷害指數之ED_{50}值介於 0.33-1.19、存活率之ED_{50}值介於 0.60-5.41、存活率經arcsine轉換後之ED_{50}值介於 0.61-5.30、鮮重之ED_{50}值介於 0.35-2.51、鮮重經arcsine轉換後之ED_{50}值介於 0.32-2.58、乾重之ED_{50}值介於 0.40-2.38、乾重經arcsine轉換後之ED_{50}值介於 0.28-1.48 (Table 24)，稗草四個收集系彼此間於存活率及乾重的ED_{50}值經Fisher's protected LSD檢定後具有顯著差異，表示稗草各收集系可能對Apiro Forte之敏感度較不一致。其中以稗草收集系BG(II)-8 之ED_{50}值顯著高於BG-WT、BG(II)-13 及BG(II)-17，而後進一步將BG(II)-8 與BG-WT之傷害指數及存活率的ED_{50}值相除可得BG(II)-8 之抗性指數介於 3.09-5.80，表示BG(II)-8 相較於其他稗草收集系可能對Apiro Forte具有一定程度的抗性。試驗結果亦發現 3-4 葉齡之稗草各收集系之ED_{50}值較 1-2 葉齡高，且高於田間推間用量 0.550 ppm。

Table 24. ED_{50} values of herbicide Apiro Forte[*1] for the 3-4 leaf barnyard grass (BG, *Echinochloa crus-galli*) accessions. Data were collected at 35 days after treatment from three independent experiments.

Accession	ED_{50} (ppm, w/v)						
	Injury index	Survival rate		Fresh weight		Dry weight	
		Original data	Arcsine transformation	Original data	Arcsine transformation	Original data	Arcsine transformation
BG-WT	0.59	1.50	1.46	0.43	0.32	0.41	0.28
BG(II)-8	1.19	5.41	5.30	2.51	2.58	2.38	1.48
BG(II)-13	0.33	0.60	0.61	0.35	0.33	0.40	0.50
BG(II)-17	0.69	1.45	1.45	0.76	0.64	0.71	0.60
P-value	0.07	< 0.05	< 0.05	0.13	< 0.05	< 0.05	< 0.05
$LSD_{0.05}$	ND[*2]	2.05	1.97	ND	1.68	1.31	0.71

[*1] Theoretical concentration of Apiro Forte in paddy water based on the application rate recommended by Syngenta CO. was 0.550 ppm (w/v).

[*2] ND indicates no significant difference among four accessions according to Fisher's protected LSD test ($\alpha = 0.05$).

3. 不同生育時期之劑量反應比較

本試驗進一步比較兩個生育時期之稗草四個收集系對Apiro Forte之傷害指數的ED_{50} 值，可知稗草各收集系於不同生育時期ED_{50} 值經Fisher's protected LSD檢定後並未達到顯著差異(Table 25)，表示 1-2 葉齡及 3-4 葉齡稗草幼苗對藥劑的敏感度相近。

Table 25. Sensitivity comparison of barnyard grass (BG, *Echinochloa crus-galli*) accessions between 1-2 and 3-4 leaf stages to the herbicide Apiro Forte based on injury index. Data of two growth stages from three independent experiments were collected at 28 and 35 days, respectively, after treatment.

Accession	ED_{50} (injury index) (ppm)		P-value	$LSD_{0.05}$
	1-2 leaf	3-4 leaf		
BG-WT	0.14	0.59	0.15	ND*
BG(II)-8	0.65	1.19	0.12	ND
BG(II)-13	0.16	0.33	0.27	ND
BG(II)-17	0.36	0.69	0.18	ND

* No significant difference according to Fisher's protected LSD test ($\alpha = 0.05$).

比較兩個生育時期之稗草四個收集系對Apiro Forte之存活率的ED_{50}值，可知稗草各收集系於不同生育時期ED_{50} 值經Fisher's protected LSD檢定後並未達到顯著差異(Table 26)，表示 1-2 葉齡及 3-4 葉齡稗草幼苗對藥劑的敏感度相似。

Table 26. Sensitivity comparison of barnyard grass (BG, *Echinochloa crus-galli*) accessions between 1-2 and 3-4 leaf stages to the herbicide Apiro Forte based on survival rate (original data). Data of two growth stages from three independent experiments were collected at 28 and 35 days, respectively, after treatment.

Accession	ED_{50} (Survival rate) (ppm)		P-value	$LSD_{0.05}$
	1-2 leaf	3-4 leaf		
BG-WT	0.29	1.50	0.34	ND*
BG(II)-8	2.94	5.41	0.12	ND
BG(II)-13	0.29	0.60	0.08	ND
BG(II)-17	0.57	1.45	0.12	ND

* No significant difference according to Fisher's protected LSD test ($\alpha = 0.05$).

比較兩個生育時期的稗草四個收集系對Apiro Forte之存活率經arcsine轉換後的ED_{50} 值，可知稗草各收集系於不同生育時期ED_{50} 值經Fisher's protected LSD檢定後並未達到顯著差異(Table 27)，表示 1-2 葉齡及 3-4 葉齡稗草幼苗對藥劑的敏感度相似。

Table 27. Sensitivity comparison of barnyard grass (BG, *Echinochloa crus-galli*) accessions between 1-2 and 3-4 leaf stages to the herbicide Apiro Forte based on survival rate (arcsine transformation). Data of two growth stages from three independent experiments were collected at 28 and 35 days, respectively, after treatment.

Accession	ED_{50} (Survival rate) (ppm)		P-value	$LSD_{0.05}$
	1-2 leaf	3-4 leaf		
BG-WT	0.29	1.46	0.34	ND*
BG(II)-8	3.12	5.30	0.18	ND
BG(II)-13	0.28	0.61	0.08	ND
BG(II)-17	0.56	1.45	0.11	ND

* No significant difference according to Fisher's protected LSD test ($\alpha = 0.05$).

比較兩個生育時期的稗草四個收集系對Apiro Forte之鮮重ED_{50}值，可知稗草各收集系於不同生育時期ED_{50}值經Fisher's protected LSD檢定後並未達到顯著差異(Table 28)，表示 1-2 葉齡及 3-4 葉齡稗草幼苗對藥劑的敏感度相似。

Table 28. Sensitivity comparison of barnyard grass (BG, *Echinochloa crus-galli*) accessions between 1-2 and 3-4 leaf stages to the herbicide Apiro Forte based on fresh weight (FW, original data). Data of two growth stages from three independent experiments were collected at 28 and 35 days, respectively, after treatment.

Accession	ED_{50} (FW) (ppm)		P-value	$LSD_{0.05}$
	1-2 leaf	3-4 leaf		
BG-WT	0.06	0.43	0.15	ND*
BG(II)-8	0.07	2.51	0.07	ND
BG(II)-13	0.11	0.35	0.15	ND
BG(II)-17	0.26	0.76	0.16	ND

* No significant difference according to Fisher's protected LSD test ($\alpha = 0.05$).

比較兩個生育時期的稗草四個收集系對Apiro Forte之鮮重經arcsine轉換後的ED_{50}值，可知稗草各收集系於不同生育時期ED_{50}值經Fisher's protected LSD 檢定後僅BG(II)-8 出現顯著差異，而其他稗草收集系並未達顯著差異(Table 29)，表示稗草收集系BG(II)-8 可能在 3-4 葉齡較 1-2 葉齡對藥劑較具有抗性，抗性指數為 32.25。

Table 29. Sensitivity comparison of barnyard grass (BG, *Echinochloa crus-galli*) accessions between 1-2 and 3-4 leaf stages to the herbicide Apiro Forte based on fresh weight (FW, arcsine transformation). Data of two growth stages from three independent experiments were collected at 28 and 35 days, respectively, after treatment.

Accession	ED_{50} (FW) (ppm)		P-value	$LSD_{0.05}$
	1-2 leaf	3-4 leaf		
BG-WT	0.06	0.32	0.19	ND*
BG(II)-8	0.08	2.58	< 0.05	2.26
BG(II)-13	0.14	0.33	0.30	ND
BG(II)-17	0.26	0.64	0.24	ND

* No significant difference according to Fisher's protected LSD test ($\alpha = 0.05$).

比較兩個生育時期之稗草四個收集系對Apiro Forte之乾重的ED_{50}值，可知稗草各收集系於不同生育時期ED_{50}值經Fisher's protected LSD檢定後，發現BG(II)-8 及BG(II)-17 具有顯著差異，而其他稗草收集系並未達顯著差異(Table 30)，表示稗草收集系BG(II)-8 及BG(II)-17 可能在 3-4 葉齡較 1-2 葉齡對藥劑較具有抗性，抗性指數分別為 17.00 及 8.88。

Table 30. Sensitivity comparison of barnyard grass (BG, *Echinochloa crus-galli*) accessions between 1-2 and 3-4 leaf stages to the herbicide Apiro Forte based on dry weight (DW, original data). Data of two growth stages from three independent experiments were collected at 28 and 35 days, respectively, after treatment.

Accession	ED_{50} (DW) (ppm)		P-value	$LSD_{0.05}$
	1-2 leaf	3-4 leaf		
BG-WT	0.05	0.41	0.15	ND*
BG(II)-8	0.14	2.38	< 0.05	1.70
BG(II)-13	0.11	0.40	0.12	ND
BG(II)-17	0.08	0.71	< 0.05	0.26

* No significant difference according to Fisher's protected LSD test ($\alpha = 0.05$).

比較兩個生育時期之稗草四個收集系對Apiro Forte之乾重經arcsine轉換後的ED_{50}值，可知稗草各收集系於不同生育時期ED_{50}值經Fisher's protected LSD檢定後，發現BG(II)-8 及BG(II)-17 具有顯著差異，而其他稗草收集系並未達顯著差異(Table 31)，此結果與乾重之反應相似(Table 32)。

Table 31. Sensitivity comparison of barnyard grass (BG, *Echinochloa crus-galli*) accessions between 1-2 and 3-4 leaf stages to the herbicide Apiro Forte based on dry weight (DW, arcsine transformation). Data of two growth stages from three independent experiments were collected at 28 and 35 days, respectively, after treatment.

Accession	ED_{50} (DW) (ppm)		P-value	$LSD_{0.05}$
	1-2 leaf	3-4 leaf		
BG-WT	0.03	0.28	0.20	ND*
BG(II)-8	0.10	1.48	< 0.05	0.57
BG(II)-13	0.12	0.50	0.21	ND
BG(II)-17	0.07	0.60	< 0.05	0.23

* No significant difference according to Fisher's protected LSD test ($\alpha = 0.05$).

根據以上試驗結果可知，1-2 葉齡稗草收集系BG-WT、BG(II)-13 及BG(II)-17 對Apiro Forte的ED_{50}值幾乎低於田間推薦用量 0.550 ppm，而BG(II)-8 對Apiro Forte的傷害指數及存活率之ED_{50}值則皆大於田間推薦用量，且顯著高於其他稗草收集系，表示稗草各收集系對Apiro Forte的敏感度並不一致，之後進一步得出BG(II)-8 的抗性指數為 4.64-10.75。而 3-4 葉齡稗草彼此收集系間對Apiro Forte之ED_{50}值亦具有顯著差異，且BG(II)-8 其四個性狀之ED_{50}值皆高於田間推薦用量，並顯著高於其

他稗草收集系，之後得出BG(II)-8 的抗性指數為 3.09-5.80。另外，本次試驗中千金子及稗草在兩個不同生育時期對Apiro Forte之劑量反應分析圖內，發現兩雜草各收集系對此藥劑的標準誤差較大，表示植株間對同一劑量下的藥劑反應較不一致，但仍符合對數邏輯模型之分布及趨勢，因此本研究依照模型所得各收集系之ED_{50}值進行比較。

綜合試驗結果可知，不同生育時期之稗草收集系BG(II)-8 皆對Apiro Forte表現出一定程度的抗性，而前人研究亦指出在美國阿肯色州(Arkansas)的稗草於連年施用ALS抑制劑後，導致其對多種ALS抑制劑產生抗性(Riar et al., 2013)；在中國安徽亦發現稗草於連年施用ALS抑制劑平速爛(penoxsulam)後，導致稗草對平速爛產生抗性(Fang et al., 2019)；而在西班牙(Spain)埃斯特雷馬杜拉(Extremadura)也發現稗草對ALS抑制劑產生抗性(Amaro-Blanco et al., 2021)。本研究發現稗草收集系BG(II)-8 對Apiro Forte出現一定程度的抗性，但根據田野調查其用藥經歷包括氟氯比、快伏草及本達隆等(Supplementary 2)，並無使用ALS抑制劑的經歷，因此對於BG(II)-8 相關之抗性機制仍須進一步研究。

本研究比較稗草各收集系在兩個生育時期時於四個性狀表現的ED_{50}值。結果發現稗草各收集系於 1-2 葉齡及 3-4 葉齡之傷害指數、存活率及鮮重的ED_{50}值皆未達顯著差異，僅BG(II)-8 及BG(II)-17 於 3-4

葉齡乾重之ED_{50}值顯著高於 1-2 葉齡，表示BG(II)-8 及BG(II)-17 可能在 3-4 葉齡較 1-2 葉齡對藥劑之敏感度顯著降低。Chauhan and Abugho et al. (2011)指出在稗草生長至四葉齡之後，ALS抑制劑bispyribac-sodium對其控制能力大幅降低，且地上部生物量則逐漸增加，推測可能是稗草在不同生育階段對除草劑之降解速率及代謝能力增加有關。Kieloch et al. (2011)亦指出當雜草之生育時期愈成熟，其對藥劑敏感度則愈低，因而較不容易受藥劑控制，且雜草管理常受到雜草種類、生育時期、除草劑種類及劑量等因素影響。

本研究發現不同生育時期之千金子對藥劑之反應較一致，並未表現出生長時期之間的差異性。而稗草在不同生育時期對藥劑之反應則產生顯著差異，推測稗草其對Apiro Forte之劑量反應較易受到生育時期影響。

(二)千金子及稗草對免速隆之劑量反應分析試驗

本試驗進一步使用千金子及稗草各收集系對Apiro Forte混劑中的免速隆單劑進行劑量反應分析試驗，以判斷兩雜草物種各收集系彼此間對於免速隆之抗性以及在不同生育時期下對藥劑的反應。

A. 不同生育時期對免速隆之劑量反應分析

a. 千金子

本研究採集自台灣中南部水田一、二期作之千金子六個收集系，於千金子幼苗 1-2 及 3-4 葉齡時分別進行九種劑量的免速隆劑量反應分析，分別在施用藥劑後 28 天及 35 天記錄傷害指數、存活率、鮮重及乾重等性狀，將資料帶入非線性對數邏輯回歸模式，得出劑量反應分析曲線及ED_{50} 值，最後比較千金子六個收集系彼此間對免速隆的抗性以及不同生育時期下千金子各收集系對免速隆的抗性。

1. 1-2 葉齡

將千金子 1-2 葉齡幼苗對免速隆進行劑量反應分析試驗，於施用藥劑後 28 天後，觀察其生長情形，並記錄傷害指數、存活率、鮮重及乾重等性狀(Figure 19)，將資料以非線性對數邏輯回歸模式分析，得出千金子各收集系對免速隆之劑量反應。

A.

B.

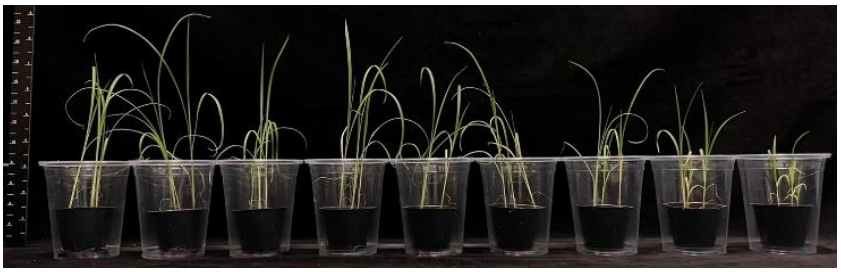


Figure 19. Herbicidal injury of 1-2 leaf red sprangle-top (*Leptochloa chinensis*) accession at 0 (A) and 28 (B) days after treatment of the herbicide bensulfuron-methyl. Plants were observed from side view. Recommended dosage was 0.185 ppm (w/v).

由於大部分千金子收集系其傷害指數及存活率於免速隆各劑量下均未達到 50%之抑制反應，故無法直接獲得 1-2 葉齡千金子各收集系之ED_{50}值，因此後續以四種指標之數值比較千金子各收集系及 1~1,000 倍推薦用量範圍內的反應差異程度。

比較千金子各收集系在施用 1-1,000 倍推薦用量範圍內之免速隆的傷害指數，發現在 1-1,000 倍推薦用量下千金子六個收集系之傷害指數未達顯著差異(Table 32)，表示大部分收集系在 1-2 葉齡對不同劑量的免速隆抗性較一致，且即使在 1,000 倍推薦用量下傷害指數未超過 2.5 (50%)。

Table 32. Sensitivities of 1-2 leaf red sprangle-top (RS, *Leptochloa chinensis*) accessions to the herbicide bensulfuron-methyl based on injury index. Data were collected at 28 days after treatment with three independent experiments.

	Injury index (0-5)			
Accession	1X[*1]	10X	100X	1,000X
RS(II)-AES	0.72	0.99	1.77	2.37
RS(I)-1	0.96	1.59	1.85	2.44
RS(I)-2	1.10	1.43	2.23	3.17
RS(I)-14	0.69	0.85	1.22	2.31
RS(I)-15	0.87	1.33	1.59	1.93
RS(II)-11	0.68	0.99	1.61	2.09
P-value	0.93	0.78	0.72	0.67
$LSD_{0.05}$	ND[*2]	ND	ND	ND

[*1] X represents the theoretical concentration based on the recommended dosage of bensulfuron-methyl applied in paddy water (0.185 ppm).

[*2] No significant difference according to Fisher's protected LSD test ($\alpha = 0.05$).

比較千金子各收集系在施用 1-1,000 倍推薦用量範圍內之免速隆的存活率，發現在 1-1,000 倍推薦用量下千金子六個收集系之存活率未達顯著差異(Table 33)，表示各收集系在 1-2 葉齡對不同劑量的免速隆抗性較一致，且即使在 1,000 倍推薦用量下存活率未低於 50%。

Table 33. Sensitivities of 1-2 leaf red sprangle-top (RS, *Leptochloa chinensis*) accessions to the herbicide bensulfuron-methyl based on survival rate. Data were collected at 28 days after treatment with three independent experiments.

	Survival rate (%)			
Accession	1X[*1]	10X	100X	1,000X
RS(II)-AES	100.00	96.33	78.00	66.67
RS(I)-1	100.00	100.00	100.00	89.00
RS(I)-2	97.56	85.26	70.56	53.07
RS(I)-14	100.00	92.67	88.89	70.33
RS(I)-15	100.00	100.00	89.00	85.33
RS(II)-11	100.00	100.00	100.00	85.33
P-value	0.46	0.20	0.11	0.20
$LSD_{0.05}$	ND[*2]	ND	ND	ND

[*1] X represents the theoretical concentration based on the recommended dosage of bensulfuron-methyl applied in paddy water (0.185 ppm).

[*2] No significant difference according to Fisher's protected LSD test ($\alpha = 0.05$).

比較千金子各收集系在施用 1-1,000 倍推薦用量範圍內之免速隆的鮮重，發現在 10、100 及 1,000 倍推薦用量下千金子六個收集系之鮮重出現顯著差異(Table 34)，表示各收集系對不同劑量的免速隆抗性不一致，其中RS(I)-15 之鮮重顯著高於其他收集系，在鮮重性狀表現上此收集系可能對免速隆之抗性較大。

Table 34. Sensitivities of 1-2 leaf red sprangle-top (RS, *Leptochloa chinensis*) accessions to the herbicide bensulfuron-methyl based on fresh weight. Data were collected at 28 days after treatment with three independent experiments.

	Fresh weight (% of control)			
Accession	1X[*1]	10X	100X	1,000X
RS(II)-AES	55.50	24.95	18.13	14.12
RS(I)-1	44.78	37.42	29.34	23.68
RS(I)-2	54.34	51.62	23.46	12.34
RS(I)-14	83.47	79.39	71.90	35.36
RS(I)-15	86.00	81.89	76.63	47.79
RS(II)-11	60.95	42.29	38.37	23.46
P-value	0.28	< 0.05	< 0.05	< 0.05
$LSD_{0.05}$	ND[*2]	40.93	36.22	21.78

[*1] X represents the theoretical concentration based on the recommended dosage of bensulfuron-methyl applied in paddy water (0.185 ppm).

[*2] No significant difference according to Fisher's protected LSD test ($\alpha = 0.05$).

比較千金子各收集系在施用 1-1,000 倍推薦用量範圍內之免速隆的乾重，發現在 100 倍推薦用量下千金子六個收集系之乾重出現顯著差異(Table 35)，表示各收集系對此劑量的免速隆抗性不一致，其中RS(I)-15 之乾重顯著高於其他收集系，在乾重性狀表現上此收集系可能對免速隆之抗性較大。

Table 35. Sensitivities of 1-2 leaf red sprangle-top (RS, *Leptochloa chinensis*) accessions to the herbicide bensulfuron-methyl based on dry weight. Data were collected at 28 days after treatment with three independent experiments.

	Dry weight (% of control)			
Accession	1X[*1]	10X	100X	1,000X
RS(II)-AES	57.08	51.85	20.85	12.02
RS(I)-1	57.94	42.97	32.56	29.14
RS(I)-2	51.52	27.92	19.36	9.84
RS(I)-14	86.17	74.98	65.95	32.15
RS(I)-15	87.18	84.83	64.78	40.30
RS(II)-11	61.41	38.22	36.57	19.02
P-value	0.46	0.11	< 0.05	0.05
$LSD_{0.05}$	ND[*2]	ND	37.31	ND

[*1] X represents the theoretical concentration based on the recommended dosage of bensulfuron-methyl applied in paddy water (0.185 ppm).

[*2] No significant difference according to Fisher's protected LSD test ($\alpha = 0.05$).

綜合以上試驗結果可知，在不同劑量之免速隆處理下千金子各收集系傷害指數與存活率對於藥劑之反應較一致，RS(II)-AES、RS(I)-2、RS(I)-14、RS(I)-15 及RS(II)-11 皆未能在田間推薦用量(0.185 ppm)下抑制 50%生長反應，且在最高劑量(185 ppm)下其傷害指數及存活率皆未達到 50%，表示 1-2 葉齡千金子此五個收集系其對免速隆具有一定程度的抗性。而千金子收集系RS(I)-15 僅在 10、100 及 1,000 倍劑量處理下，其鮮重性狀反應顯著高於部分收集系，表示此收集系對免速隆之抗性可能較其他收集系大。

2. 3-4 葉齡

將千金子 3-4 葉齡幼苗對免速隆進行劑量反應分析試驗，於施用藥劑後 35 天後，觀察其生長情形，並記錄傷害指數、存活率、鮮重及乾重等性狀，將資料帶入非線性對數邏輯回歸模型，得出千金子各收集系對免速隆之劑量反應。

由於大部分千金子收集系其傷害指數及存活率於免速隆各劑量下均未達到 50%之抑制反應，與 1-2 葉齡之反應相似，因此後續以四種指標之數值比較千金子各收集系及 1~1,000 倍推薦用量範圍內的反應差異程度。

比較千金子各收集系在施用 1-1,000 倍推薦用量範圍內之免速隆的傷害指數，發現在 1-1,000 倍推薦用量下千金子六個收集系之傷害指數未達顯著差異(Table 36)，表示各收集系在 3-4 葉齡對不同劑量的免速隆抗性較一致，且即使在 1,000 倍推薦用量下傷害指數未超過 2.5 (50%)。

Table 36. Sensitivities of 3-4 leaf red sprangle-top (RS, *Leptochloa chinensis*) accessions to the herbicide bensulfuron-methyl based on injury index. Data were collected at 28 days after treatment with three independent experiments.

	Injury index (0-5)			
Accession	1X[*1]	10X	100X	1,000X
RS(II)-AES	0.50	0.72	1.10	1.44
RS(I)-1	0.59	1.04	1.31	1.93
RS(I)-2	0.61	1.17	1.61	2.06
RS(I)-14	0.28	0.43	0.87	1.19
RS(I)-15	0.93	1.37	1.85	2.43
RS(II)-11	0.63	0.78	1.44	1.89
P-value	0.89	0.79	0.88	0.81
$LSD_{0.05}$	ND[*2]	ND	ND	ND

[*1] X represents the theoretical concentration based on the recommended dosage of bensulfuron-methyl applied in paddy water (0.185 ppm).

[*2] No significant difference according to Fisher's protected LSD test ($\alpha = 0.05$).

比較千金子各收集系在施用 1-1,000 倍推薦用量範圍內之免速隆的存活率，發現在 1-1,000 倍推薦用量下六個千金子收集系之存活率未達顯著差異(Table 37)，表示各收集系在 3-4 葉齡對不同劑量的免速隆抗性較一致，且即使在 1,000 倍推薦用量下存活率未低於 50%。

Table 37. Sensitivities of 3-4 leaf red sprangle-top (RS, *Leptochloa chinensis*) accessions to the herbicide bensulfuron-methyl based on survival rate. Data were collected at 28 days after treatment with three independent experiments.

	Survival rate (%)			
Accession	1X[*1]	10X	100X	1,000X
RS(II)-AES	100.00	100.00	100.00	100.00
RS(I)-1	100.00	100.00	92.67	70.33
RS(I)-2	100.00	96.33	96.33	88.89
RS(I)-14	100.00	100.00	100.00	96.33
RS(I)-15	100.00	96.33	85.22	72.22
RS(II)-11	100.00	100.00	96.33	96.33
P-value	--	0.57	0.69	0.26
$LSD_{0.05}$	ND[*2]	ND	ND	ND

[*1] X represents the theoretical concentration based on the recommended dosage of bensulfuron-methyl applied in paddy water (0.185 ppm).

[*2] No significant difference according to Fisher's protected LSD test ($\alpha = 0.05$).

比較千金子各收集系在施用 1-1,000 倍推薦用量範圍內之免速隆的鮮重，發現在 1-1,000 倍推薦用量下六個千金子收集系之鮮重未達顯著差異(Table 38)，表示各收集系在 3-4 葉齡對不同劑量的免速隆抗性較一致。

Table 38. Sensitivities of 3-4 leaf red sprangle-top (RS, *Leptochloa chinensis*) accessions to the herbicide bensulfuron-methyl based on fresh weight. Data were collected at 28 days after treatment with three independent experiments.

	Fresh weight (% of control)			
Accession	1X[*1]	10X	100X	1,000X
RS(II)-AES	72.45	66.24	57.02	39.58
RS(I)-1	83.13	73.52	56.41	39.29
RS(I)-2	63.81	61.40	52.40	41.81
RS(I)-14	93.64	85.75	84.95	67.04
RS(I)-15	71.25	61.87	56.27	52.25
RS(II)-11	82.17	72.85	55.48	47.70
P-value	0.62	0.87	0.75	0.86
$LSD_{0.05}$	ND[*2]	ND	ND	ND

[*1] X represents the theoretical concentration based on the recommended dosage of bensulfuron-methyl applied in paddy water (0.185 ppm).

[*2] No significant difference according to Fisher's protected LSD test ($\alpha = 0.05$).

比較千金子各收集系在施用 1-1,000 倍推薦用量範圍內之免速隆的乾重，發現在 1-1,000 倍推薦用量範圍下千金子六個收集系之乾重未達顯著差異(Table 39)，表示各收集系在 3-4 葉齡對不同劑量的免速隆抗性較一致。

Table 39. Sensitivities of 3-4 leaf red sprangle-top (RS, *Leptochloa chinensis*) accessions to the herbicide bensulfuron-methyl based on dry weight. Data were collected at 28 days after treatment with three independent experiments.

	Dry weight (% of control)			
Accession	1X[*1]	10X	100X	1,000X
RS(II)-AES	75.43	70.93	59.43	35.86
RS(I)-1	91.26	88.52	67.89	38.05
RS(I)-2	61.41	58.32	48.83	36.44
RS(I)-14	94.00	83.11	78.85	60.52
RS(I)-15	66.45	56.28	55.63	47.73
RS(II)-11	79.23	66.21	60.77	50.37
P-value	0.52	0.71	0.88	0.89
$LSD_{0.05}$	ND[*2]	ND	ND	ND

[*1] X represents the theoretical concentration based on the recommended dosage of bensulfuron-methyl applied in paddy water (0.185 ppm).

[*2] No significant difference according to Fisher's protected LSD test ($\alpha = 0.05$).

綜合以上試驗結果可知，在不同劑量之免速隆處理下 3-4 葉齡千金子各收集系之反應較一致，所有千金子收集系皆未能在田間推薦用量(0.185 ppm)下獲得抑制 50%生長之反應，且部分收集系在最高劑量(185 ppm)下尚能存活，表示 3-4 葉齡千金子六個收集系其對免速隆具有一定程度的抗性。

3. 不同生育時期之劑量反應比較

本試驗進一步比較兩個生育時期之千金子六個收集系對免速隆之傷害指數及存活率，可知 1-2 及 3-4 葉齡大部分收集系之抑制反應未能超過 50% (Table 32, 33, 36, 37)，且發現 3-4 葉齡千金子六個收集系之傷害指數在各劑量處理下皆較 1-2 期低(Table 32, 36)，而存活率亦有所提升(Table 33, 37)，根據以上試驗結果可推測千金子各收集系在 3-4 葉齡對免速隆之抗性較 1-2 葉齡高。

b. 稗草

本研究採集台灣中南部水田一、二期作之稗草四個收集系，於稗草幼苗生長至 1-2 及 3-4 葉齡時分別進行九種劑量的免速隆劑量反應分析，分別在施用藥劑後 28 天及 35 天記錄傷害指數、存活率、鮮重及乾重等性狀，將資料帶入非線性對數邏輯回歸模型，得出劑量反應分析曲線及ED_{50} 值，最後比較稗草四個收集系彼此間對免速隆的抗性以及不同生育時期下稗草各收集系對免速隆的抗性。

1. 1-2 葉齡

將稗草 1-2 葉齡幼苗對免速隆進行劑量反應分析試驗，於施用藥劑後 28 天後，觀察其生長情形，並記錄傷害指數、存活率、鮮重及乾重

等性狀(Figure 20)，將資料以非線性對數邏輯回歸模型，得出稗草各收集系對免速隆之劑量反應分析曲線及ED_{50}值。

A.

B.

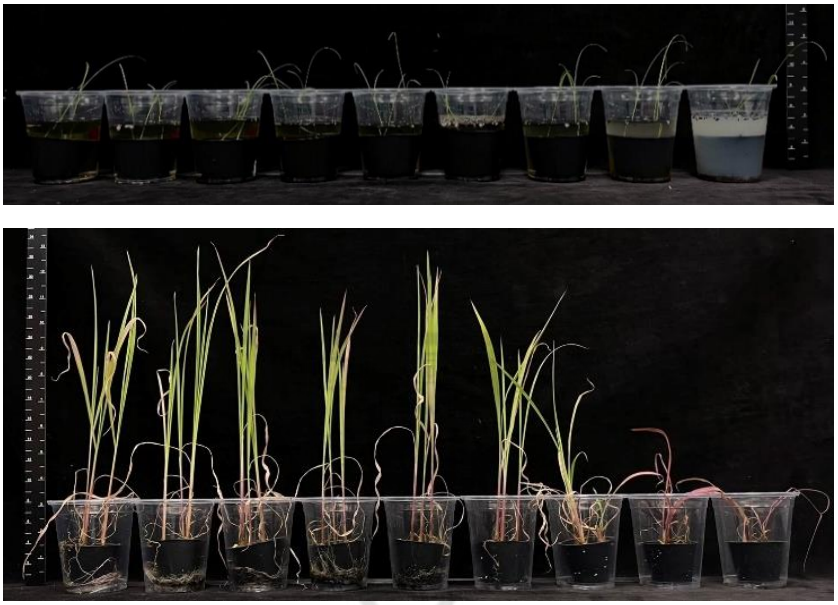


Figure 20. Herbicidal injury of 1-2 leaf barnyard grass (*Echinochloa crus-galli*) accession at 0 (A) and 28 (B) days after treatment of the herbicide bensulfuron-methyl. Plants were observed from side view. Recommended dosage was 0.185 ppm (w/v).

根據傷害指數及存活率之劑量反應分析曲線可知，1-2 葉齡稗草各收集系之於施用 1 倍推薦用量後出現較明顯之反應，且隨著劑量增加抑制反應有逐漸上升的趨勢，但因為部分稗草收集系其存活率於免速隆各劑量下均未達到 50%之抑制反應，故無法直接獲得 1-2 葉齡稗草各收集系之ED_{50}值，因此後續以四種指標之數值比較稗草各收集系在 1~1,000 倍推薦用量範圍內的反應差異程度。

比較稗草各收集系在施用 1-1,000 倍推薦用量範圍內之免速隆的傷害指數，發現在 1、100 及 1,000 倍推薦用量下稗草四個收集系之傷害指數出現顯著差異(Table 40)，表示各收集系對不同劑量的免速隆抗性不一致，其中BG(II)-8 及BG(II)-17 之傷害指數顯著低於其他收集系，在傷害指數性狀表現上二收集系可能對免速隆之抗性較大

Table 40. Sensitivities of 1-2 leaf barnyard grass (BG, *Echinochloa crus-galli*) accessions to the herbicide bensulfuron-methyl based on injury index. Data were collected at 28 days after treatment with three independent experiments.

	Injury index (0-5)			
Accession	1X[*1]	10X	100X	1,000X
BG-WT	2.44	3.37	4.41	4.67
BG(II)-8	1.19	2.38	3.26	3.89
BG(II)-13	1.48	3.37	4.33	4.81
BG(II)-17	0.59	2.43	3.52	4.11
P-value	< 0.05	0.08	< 0.05	< 0.05
$LSD_{0.05}$	0.84	ND[*2]	0.78	0.44

[*1] X represents the theoretical concentration based on the recommended dosage of bensulfuron-methyl applied in paddy water (0.185 ppm).

[*2] No significant difference according to Fisher's protected LSD test ($\alpha = 0.05$).

比較稗草各收集系在施用 1-1,000 倍推薦用量範圍內之免速隆的存活率，發現在 1-1,000 倍推薦用量下稗草四個收集系之存活率未達顯著差異(Table 41)，表示各收集系在 1-2 葉齡對不同劑量的免速隆抗性較一致，而BG(II)-8 及BG(II)-17 即使在 1,000 倍推薦用量下存活率未低於 50%，可能對免速隆之抗性較大。

Table 41. Sensitivities of 1-2 leaf barnyard grass (BG, *Echinochloa crus-galli*) accessions to the herbicide bensulfuron-methyl based on survival rate. Data were collected at 28 days after treatment with three independent experiments.

	Survival rate (%)			
Accession	1X[*1]	10X	100X	1,000X
BG-WT	100.00	85.33	26.00	22.33
BG(II)-8	100.00	96.33	96.33	74.33
BG(II)-13	100.00	85.22	40.67	11.11
BG(II)-17	100.00	100.00	88.89	55.67
P-value	--	0.31	0.08	0.05
$LSD_{0.05}$	ND[*2]	ND	ND	ND

[*1] X represents the theoretical concentration based on the recommended dosage of bensulfuron-methyl applied in paddy water (0.185 ppm).

[*2] No significant difference according to Fisher's protected LSD test ($\alpha = 0.05$).

比較稗草各收集系在施用 1-1,000 倍推薦用量範圍內之免速隆的鮮重，發現在 1 倍推薦用量下稗草四個收集系之鮮重出現顯著差異(Table 42)，其中BG(II)-17 之鮮重顯著高於其他收集系，在鮮重性狀表現上此收集系可能對免速隆之抗性較大。

Table 42. Sensitivities of 1-2 leaf barnyard grass (BG, *Echinochloa crus-galli*) accessions to the herbicide bensulfuron-methyl based on fresh weight. Data were collected at 28 days after treatment with three independent experiments.

	Fresh weight (% of control)			
Accession	1X[*1]	10X	100X	1,000X
BG-WT	18.32	13.39	4.66	2.00
BG(II)-8	52.92	29.63	9.97	5.49
BG(II)-13	48.99	19.89	15.96	5.35
BG(II)-17	82.78	37.53	11.99	4.91
P-value	< 0.05	0.27	0.71	0.41
$LSD_{0.05}$	40.05	ND[*2]	ND	ND

[*1] X represents the theoretical concentration based on the recommended dosage of bensulfuron-methyl applied in paddy water (0.185 ppm).

[*2] No significant difference according to Fisher's protected LSD test ($\alpha = 0.05$).

比較稗草各收集系在施用 1-1,000 倍推薦用量範圍內之免速隆的乾重，發現在 1-1,000 倍推薦用量下稗草四個收集系之乾重未達顯著差異(Table 43)，表示各收集系在 1-2 葉齡對不同劑量的免速隆抗性較一致。

Table 43. Sensitivities of 1-2 leaf barnyard grass (BG, *Echinochloa crus-galli*) accessions to the herbicide bensulfuron-methyl based on dry weight. Data were collected at 28 days after treatment with three independent experiments.

	Dry weight (% of control)			
Accession	1X[*1]	10X	100X	1,000X
BG-WT	15.46	14.88	7.54	4.75
BG(II)-8	56.65	48.04	41.51	39.05
BG(II)-13	47.39	24.71	25.48	14.38
BG(II)-17	69.79	30.40	16.93	10.24
P-value	0.12	0.44	0.54	0.38
$LSD_{0.05}$	ND[*2]	ND	ND	ND

[*1] X represents the theoretical concentration based on the recommended dosage of bensulfuron-methyl applied in paddy water (0.185 ppm).

[*2] No significant difference according to Fisher's protected LSD test ($\alpha = 0.05$).

綜合以上試驗結果可知，在不同劑量之免速隆處理下稗草各收集系之反應較一致，但稗草收集系 BG(II)-8 及 BG(II)-17 皆未能在田間推薦用量(0.185 ppm)下獲得抑制 50%生長之反應，且在最高劑量(185 ppm)下存活率皆未低於 50%，表示此二個稗草收集系在 1-2 葉齡對免速隆之抗性可能較其他收集系大，具有一定程度的抗性。

2. 3-4 葉齡

將稗草 3-4 葉齡幼苗對免速隆進行劑量反應分析試驗，於施用藥劑後 35 天後，記錄傷害指數、存活率、鮮重及乾重等性狀，將資料以非線性對數邏輯回歸模型，得出稗草各收集系對免速隆之劑量反應分析曲線。

根據傷害指數及存活率之劑量反應可知，3-4 葉齡稗草各收集系之於施用 100 倍推薦用量後才出現較明顯之反應，且隨著劑量增加抑制反應有逐漸上升的趨勢(Table 44, 45)，而在鮮重及乾重兩指標下稗草各收集的反應則較為敏感，於 10 倍推薦用量下各收集系之鮮重與乾重均減少達 50%以上(Table 46, 47)。後續將進一步比較 3-4 葉齡稗草各收集系彼此間對免速隆之反應，確認各收集系對藥劑之抗性差異。

比較稗草各收集系在施用 1-1,000 倍推薦用量範圍內之免速隆的傷害指數，發現在 1、100 及 1,000 倍推薦用量下稗草四個收集系之傷害指數出現顯著差異(Table 44)，表示各收集系對不同劑量的免速隆抗性不一致，其中BG(II)-8 之傷害指數顯著低於其他收集系，在傷害指數性狀表現上此收集系可能對免速隆之抗性較大。

Table 44. Sensitivities of 3-4 leaf barnyard grass (BG, *Echinochloa crus-galli*) accessions to the herbicide bensulfuron-methyl based on injury index. Data were collected at 35 days after treatment with three independent experiments.

	Injury index (0-5)			
Accession	1X[*1]	10X	100X	1,000X
BG-WT	0.89	1.70	4.56	5.00
BG(II)-8	0.15	1.04	2.56	3.74
BG(II)-13	0.11	1.41	4.15	4.56
BG(II)-17	0.15	1.11	4.02	4.52
P-value	< 0.05	0.17	< 0.05	< 0.05
$LSD_{0.05}$	0.37	ND[*2]	0.81	0.82

[*1] X represents the theoretical concentration based on the recommended dosage of bensulfuron-methyl applied in paddy water (0.185 ppm).

[*2] No significant difference according to Fisher's protected LSD test ($\alpha = 0.05$).

比較稗草各收集系在施用 1-1,000 倍推薦用量範圍內之免速隆的存活率，發現在 100 及 1,000 倍推薦用量下稗草四個收集系之存活率出現顯著差異(Table 45)，表示各收集系對不同劑量的免速隆抗性不一致，其中BG(II)-8 之存活率顯著高於其他收集系，在存活性狀表現上此收集系可能對免速隆之抗性較大。

Table 45. Sensitivities of 3-4 leaf barnyard grass (BG, *Echinochloa crus-galli*) accessions to the herbicide bensulfuron-methyl based on survival rate. Data were collected at 35 days after treatment with three independent experiments.

	Survival rate (%)			
Accession	1X[*1]	10X	100X	1,000X
BG-WT	100.00	92.67	33.11	0.00
BG(II)-8	100.00	100.00	100.00	66.78
BG(II)-13	100.00	100.00	51.67	29.44
BG(II)-17	100.00	100.00	63.00	37.00
P-value	--	0.05	< 0.05	< 0.05
$LSD_{0.05}$	ND[*2]	ND	34.62	42.66

[*1] X represents the theoretical concentration based on the recommended dosage of bensulfuron-methyl applied in paddy water (0.185 ppm).

[*2] No significant difference according to Fisher's protected LSD test ($\alpha = 0.05$).

比較稗草各收集系在施用 1-1,000 倍推薦用量範圍內之免速隆的鮮重，發現在 1-1,000 倍推薦用量下稗草四個收集系之鮮重未達顯著差異(Table 46)，表示各收集系在 1-2 葉齡對不同劑量的免速隆抗性較一致。

Table 46. Sensitivities of 3-4 leaf barnyard grass (BG, *Echinochloa crus-galli*) accessions to the herbicide bensulfuron-methyl based on fresh weight. Data were collected at 35 days after treatment with three independent experiments.

	Fresh weight (% of control)			
Accession	1X[*1]	10X	100X	1,000X
BG-WT	81.79	71.19	16.39	4.13
BG(II)-8	97.60	67.35	61.90	25.93
BG(II)-13	67.94	75.17	31.97	23.07
BG(II)-17	81.70	86.15	30.89	16.51
P-value	0.17	0.66	0.11	0.20
$LSD_{0.05}$	ND[*2]	ND	ND	ND

[*1] X represents the theoretical concentration based on the recommended dosage of bensulfuron-methyl applied in paddy water (0.185 ppm).

[*2] No significant difference according to Fisher's protected LSD test ($\alpha = 0.05$).

比較稗草各收集系在施用 1-1,000 倍推薦用量範圍內之免速隆的乾重，發現在 10 及 1,000 倍推薦用量下稗草四個收集系之乾重出現顯著差異(Table 47)，表示各收集系對不同劑量的免速隆抗性不一致，其中 BG(II)-13 及BG(II)-17 之乾重顯著高於其他收集系，在乾重性狀表現上此收集系可能對免速隆之抗性較大。

Table 47. Sensitivities of 3-4 leaf barnyard grass (BG, *Echinochloa crus-galli*) accessions to the herbicide bensulfuron-methyl based on dry weight. Data were collected at 35 days after treatment with three independent experiments.

	Dry weight (% of control)			
Accession	1X[*1]	10X	100X	1,000X
BG-WT	69.28	63.52	25.78	9.72
BG(II)-8	81.88	42.82	33.59	19.11
BG(II)-13	82.92	79.42	41.34	38.08
BG(II)-17	80.46	79.82	35.71	24.39
P-value	0.71	< 0.05	0.54	< 0.05
$LSD_{0.05}$	ND[*2]	33.26	ND	13.79

[*1] X represents the theoretical concentration based on the recommended dosage of bensulfuron-methylapplied in paddy water (0.185 ppm).

[*2] No significant difference according to Fisher's protected LSD test (α = 0.05).

綜合以上試驗結果可知，在不同劑量之免速隆處理下 3-4 葉齡稗草各收集系之反應較一致，所有稗草收集系皆未能在田間推薦用量(0.185 ppm)下抑制 50%生長反應，且BG(II)-8 在最高劑量(185 ppm)下存活率超過 50%，表示此稗草收集系在 3-4 葉齡對免速隆具有一定程度的抗性。

3. 不同生育時期之劑量反應比較

本試驗進一步比較兩個生育時期之稗草四個收集系對免速隆之反應，而 1-2 及 3-4 葉齡大部分收集系之抑制反應在 10、100 及 1,000 倍推薦用量下超過 50%，但部分收集系其在最高劑量下仍未達到 50%之反應，其中以 3-4 葉齡稗草四個收集系之傷害指數在各劑量處理下皆較 1-2 期低(Table 43, 44)，而存活率亦有所提升(Table 41, 45)，鮮重及乾重降低程度亦較小(Table 42, 43, 46, 47)，因此根據以上試驗結果可知稗草各收集系在 3-4 葉齡對免速隆之抗性較 1-2 葉齡大。

(三)千金子及稗草對派伏利之劑量反應分析試驗

本試驗進一步使用千金子及稗草各收集系對Apiro Forte混劑中的派伏利單劑進行劑量反應分析試驗，以判斷兩雜草物種各收集系彼此間對於派伏利之抗性以及在不同生育時期下對藥劑的反應。

A. 不同生育時期對派伏利之劑量反應分析

a. 千金子

本研究採集自台灣中南部水田一、二期作之千金子六個收集系，於千金子幼苗 1-2 及 3-4 葉齡時分別進行九種劑量的派伏利劑量反應分析，分別在施用藥劑後 28 天及 35 天記錄傷害指數、存活率、鮮重及

乾重等性狀，將資料帶入非線性對數邏輯回歸模式，得出ED_{50} 值，最後比較千金子六個收集系彼此間對派伏利的抗性以及不同生育時期下千金子各收集系對派伏利的抗性。

1. 1-2 葉齡

將千金子 1-2 葉齡幼苗對派伏利進行劑量反應分析試驗，於施用藥劑後 28 天後，觀察其生長情形，並記錄傷害指數(Figure 21)、存活率、鮮重及乾重等性狀，將資料以非線性對數邏輯回歸模式分析，得出千金子各收集系對派伏利之劑量反應分析曲線。

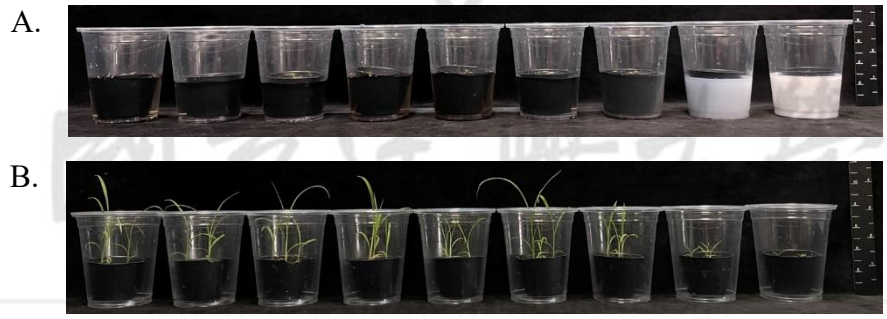


Figure 21. Herbicidal injury of 1-2 leaf red sprangle-top (*Leptochloa chinensis*) accession at 0 (A) and 28 (B) days after treatment of pyriftalid. Plants were observed from side view. Recommended dosage was 0.365 ppm (w/v).

由於部分千金子收集系於派伏利各劑量下未達到 50%之抑制反應，故無法直接獲得 1-2 葉齡千金子各收集系之ED_{50} 值，因此後續以四種指標之數值比較千金子各收集系及 1~1,000 倍推薦用量範圍內的反應差異程度。

比較千金子各收集系在施用 1-1,000 倍推薦用量範圍內之派伏利的傷害指數，發現在 1-1,000 倍推薦用量下千金子六個收集系之傷害指數未達顯著差異(Table 48)，表示大部分收集系在 1-2 葉齡對不同劑量的pyriftalid抗性較一致。

Table 48. Sensitivities of 1-2 leaf red sprangle-top (RS, *Leptochloa chinensis*) accessions to the herbicide pyriftalid based on injury index. Data were collected at 28 days after treatment with three independent experiments.

	Injury index (0-5)			
Accession	1X[*1]	10X	100X	1,000X
RS(II)-AES	0.56	1.04	3.67	4.70
RS(I)-1	1.50	2.56	2.50	4.17
RS(I)-2	1.07	1.78	3.07	4.46
RS(I)-14	0.33	1.56	2.22	3.22
RS(I)-15	0.70	1.11	3.26	4.59
RS(II)-11	0.67	1.61	3.57	4.54
P-value	0.66	0.76	0.61	0.22
$LSD_{0.05}$	ND[*2]	ND	ND	ND

[*1] X represents the theoretical concentration based on the recommended dosage of pyriftalidapplied in paddy water (0.365 ppm).

[*2] No significant difference according to Fisher's protected LSD test ($\alpha = 0.05$).

比較千金子各收集系在施用 1-1,000 倍推薦用量範圍內之派伏利的存活率，發現在 1-1,000 倍推薦用量下千金子六個收集系之存活率未達顯著差異(Table 49)，表示各收集系在 1-2 葉齡對不同劑量的派伏利抗性較一致。

Table 49. Sensitivities of 1-2 leaf red sprangle-top (RS, *Leptochloa chinensis*) accessions to the herbicide pyriftalid based on survival rate. Data were collected at 28 days after treatment with three independent experiments.

	Survival rate (%)			
Accession	1X[*1]	10X	100X	1,000X
RS(II)-AES	100.00	96.33	51.78	14.78
RS(I)-1	83.33	72.17	61.00	38.83
RS(I)-2	92.67	89.00	46.33	14.78
RS(I)-14	100.00	89.00	77.67	66.67
RS(I)-15	96.33	92.67	55.67	22.22
RS(II)-11	100.00	100.00	68.44	25.83
P-value	0.60	0.49	0.73	0.14
$LSD_{0.05}$	ND[*2]	ND	ND	ND

[*1] X represents the theoretical concentration based on the recommended dosage of pyriftalid applied in paddy water (0.365 ppm).

[*2] No significant difference according to Fisher's protected LSD test ($\alpha = 0.05$).

比較千金子各收集系在施用 1-1,000 倍推薦用量範圍內之派伏利的鮮重，發現在 100 及 1,000 倍推薦用量下千金子六個收集系之鮮重出現顯著差異(Table 50)，表示各收集系在二種劑量下的派伏利抗性不一致，其中RS(I)-14 之鮮重顯著高於其他收集系，在鮮重性狀表現上此收集系可能對派伏利之抗性較大。

Table 50. Sensitivities of 1-2 leaf red sprangle-top (RS, *Leptochloa chinensis*) accessions to the herbicide pyriftalid based on fresh weight. Data were collected at 28 days after treatment with three independent experiments.

	Fresh weight (% of control)			
Accession	1X[*1]	10X	100X	1,000X
RS(II)-AES	40.49	31.24	17.96	8.61
RS(I)-1	30.66	21.10	12.27	4.50
RS(I)-2	54.52	47.46	11.46	1.99
RS(I)-14	74.72	37.51	46.21	16.04
RS(I)-15	80.06	40.22	11.41	4.90
RS(II)-11	48.08	40.45	11.43	3.43
P-value	0.18	0.81	< 0.05	< 0.05
$LSD_{0.05}$	ND[*2]	ND	24.65	10.53

[*1] X represents the theoretical concentration based on the recommended dosage of pyriftalid applied in paddy water (0.365 ppm).

[*2] No significant difference according to Fisher's protected LSD test ($\alpha = 0.05$).

比較千金子各收集系在施用 1-1,000 倍推薦用量範圍內之派伏利的乾重，發現在 100 倍及 1,000 倍推薦用量下千金子六個收集系之乾重出現顯著差異(Table 51)，表示各收集系在二種劑量下的派伏利抗性不一致，其中RS(I)-14 之乾重顯著高於其他收集系，在乾重性狀表現上此收集系可能對派伏利之抗性較大。

Table 51. Sensitivities of 1-2 leaf red sprangle-top (RS, *Leptochloa chinensis*) accessions to the herbicide pyriftalid based on dry weight. Data were collected at 28 days after treatment with three independent experiments.

	Dry weight (%)			
Accession	1X[*1]	10X	100X	1,000X
RS(II)-AES	37.93	31.69	18.97	4.50
RS(I)-1	27.41	23.32	14.61	6.34
RS(I)-2	50.19	45.54	12.97	4.31
RS(I)-14	66.21	43.52	48.30	18.50
RS(I)-15	79.34	69.99	20.57	6.34
RS(II)-11	45.74	38.59	13.80	5.91
P-value	0.14	0.09	< 0.05	< 0.05
$LSD_{0.05}$	ND[*2]	ND	19.39	3.85

[*1] X represents the theoretical concentration based on the recommended dosage of pyriftalid applied in paddy water (0.365 ppm).

[*2] No significant difference according to Fisher's protected LSD test ($\alpha = 0.05$).

綜合以上試驗結果可知，在不同劑量之派伏利處理下千金子各收集系傷害指數與存活率對於藥劑之反應較一致，RS(I)-2、RS(I)-14 及RS(I)-15 皆未能在田間推薦用量(0.365 ppm)下抑制 50%生長反應，表示 1-2 葉齡千金子此三個收集系其對派伏利具有一定程度的抗性，而千金子收集系RS(I)-14 僅在 100 及 1,000 倍劑量處理下，其鮮重及乾重性狀反應顯著高於部分收集系，表示此收集系對派伏利之抗性可能較其他收集系大。

2. 3-4 葉齡

將千金子 3-4 葉齡幼苗對派伏利進行劑量反應分析試驗，於施用藥劑後 35 天後，觀察其生長情形，並記錄傷害指數、存活率、鮮重及乾重等性狀，將資料帶入非線性對數邏輯回歸模型，得出千金子各收集系對派伏利之劑量反應分析曲線。

由於大部分千金子收集系其傷害指數及存活率於派伏利各劑量下均未達到 50%之抑制反應，與 1-2 葉齡之反應相似，因此後續以四種指標之數值比較千金子各收集系及 1~1,000 倍推薦用量範圍內的反應差異程度。

比較千金子各收集系在施用 1-1,000 倍推薦用量範圍內之派伏利的傷害指數，發現在 1-1,000 倍推薦用量下千金子六個收集系之傷害指數出現顯著差異(Table 52)，表示各收集系對不同劑量的派伏利抗性不一致，其中RS(I)-14 及RS(I)-15 之傷害指數於 1、10 及 100 倍劑量下顯著低於其他收集系，在傷害指數性狀表現上此收集系可能對派伏利之抗性較大。

Table 52. Sensitivities of 3-4 leaf red sprangle-top (RS, *Leptochloa chinensis*) accessions to the herbicide pyriftalid based on injury index. Data were collected at 28 days after treatment with three independent experiments.

	Injury index (0-5)			
Accession	1X[*1]	10X	100X	1,000X
RS(II)-AES	0.22	1.92	4.22	5.00
RS(I)-1	1.14	2.10	3.70	4.95
RS(I)-2	0.44	0.89	1.56	4.00
RS(I)-14	0.00	0.33	0.50	3.22
RS(I)-15	0.15	0.26	1.67	4.11
RS(II)-11	1.11	2.22	3.37	4.19
P-value	< 0.05	< 0.05	< 0.05	< 0.05
$LSD_{0.05}$	0.82	1.80	2.56	1.34

[*1] X represents the theoretical concentration based on the recommended dosage of pyriftalidapplied in paddy water (0.365 ppm).

比較千金子各收集系在施用 1-1,000 倍推薦用量範圍內之派伏利的存活率，發現在 10、100 及 1,000 倍推薦用量下六個千金子收集系之存活率出現顯著差異(Table 53)，表示各收集系在 3-4 葉齡對不同劑量的派伏利抗性不一致，其中RS(I)-2、RS(I)-14 及RS(I)-15 之存活率於 1、10 及 100 倍劑量下顯著高於其他收集系，在存活性狀表現上此三個收集系可能對免速隆之抗性較大。

Table 53. Sensitivities of 3-4 leaf red sprangle-top (RS, *Leptochloa chinensis*) accessions to the herbicide pyriftalid based on survival rate. Data were collected at 35 days after treatment with three independent experiments.

	Survival rate (%)			
Accession	1X[*1]	10X	100X	1,000X
RS(II)-AES	100.00	88.89	48.11	0.00
RS(I)-1	96.69	81.09	45.91	4.89
RS(I)-2	100.00	100.00	88.89	33.00
RS(I)-14	100.00	100.00	100.00	59.33
RS(I)-15	100.00	100.00	88.89	33.22
RS(II)-11	100.00	77.67	51.89	29.67
P-value	0.11	< 0.05	< 0.05	< 0.05
$LSD_{0.05}$	ND[*2]	20.93	47.49	44.44

[*1] X represents the theoretical concentration based on the recommended dosage of pyriftalid applied in paddy water (0.365 ppm).

[*2] No significant difference according to Fisher's protected LSD test ($\alpha = 0.05$).

比較千金子各收集系在施用 1-1,000 倍推薦用量範圍內之派伏利的鮮重，發現在 1-1,000 倍推薦用量下六個千金子收集系之鮮重未達顯著差異(Table 54)，表示各收集系在 3-4 葉齡對不同劑量的派伏利抗性較一致。

Table 54. Sensitivities of 3-4 leaf red sprangle-top (RS, *Leptochloa chinensis*) accessions to the herbicide pyriftalid based on fresh weight. Data were collected at 28 days after treatment with three independent experiments.

	Fresh weight (% of control)			
Accession	1X[*1]	10X	100X	1,000X
RS(II)-AES	55.36	48.66	27.59	11.17
RS(I)-1	48.73	41.82	13.84	1.77
RS(I)-2	65.47	55.70	47.62	19.98
RS(I)-14	66.67	43.76	32.50	9.53
RS(I)-15	60.58	38.35	21.19	2.71
RS(II)-11	60.78	31.25	21.39	15.87
P-value	0.95	0.88	0.68	0.39
$LSD_{0.05}$	ND[*2]	ND	ND	ND

[*1] X represents the theoretical concentration based on the recommended dosage of pyriftalid which applied in paddy water (0.365 ppm).

[*2] No significant difference according to Fisher's protected LSD test ($\alpha = 0.05$).

比較千金子各收集系在施用 1-1,000 倍推薦用量範圍內之派伏利的乾重，發現在 1-1,000 倍推薦用量範圍下千金子六個收集系之乾重未達顯著差異(Table 55)，表示各收集系在 3-4 葉齡對不同劑量的派伏利抗性較一致。

Table 55. Sensitivities of 3-4 leaf red sprangle-top (RS, *Leptochloa chinensis*) accessions to the herbicide pyriftalid based on dry weight. Data were collected at 28 days after treatment with three independent experiments.

	Dry weight (% of control)			
Accession	1X[*1]	10X	100X	1,000X
RS(II)-AES	56.90	51.45	31.11	12.44
RS(I)-1	51.59	42.22	11.54	2.99
RS(I)-2	69.70	62.89	54.85	21.09
RS(I)-14	57.36	42.33	31.11	8.80
RS(I)-15	70.46	64.11	42.08	9.97
RS(II)-11	46.26	19.17	11.67	8.07
P-value	0.76	0.32	0.28	0.13
$LSD_{0.05}$	ND[*2]	ND	ND	ND

[*1] X represents the theoretical concentration based on the recommended dosage of pyriftalid applied in paddy water (0.365 ppm).

[*2] No significant difference according to Fisher's protected LSD test ($\alpha = 0.05$).

綜合以上試驗結果可知，在 1、10 及 100 倍劑量之派伏利處理下 3-4 葉齡千金子收集系RS(I)-2、RS(I)-14 及RS(I)-15 傷害指數與存活率對藥劑之反應皆未能在田間推薦用量(0.365 ppm)下獲得抑制 50%生長之反應，且RS(I)-2 在最高劑量(365 ppm)下存活率未低於 50%，表示 3-4 葉齡千金子此三個收集系對派伏利具有一定程度的抗性。而千金子收集系RS(I)-2 在 1、10 及 100 倍劑量處理下，其傷害指數及存活率反應皆分別顯著低於或高於部分收集系，顯示其對派伏利之抗性可能較其他收集系大。

3. 不同生育時期之劑量反應比較

本試驗進一步比較兩個生育時期之千金子六個收集系對派伏利之反應，而 1-2 及 3-4 葉齡大部分收集系之抑制反應在 100 及 1,000 倍推薦用量下超過 50%，但部分收集系其在最高劑量下仍未達到 50%之反應，因此僅以傷害指數、存活率、鮮重及乾重之劑量反應曲線進行比較，發現 3-4 葉齡千金子六個收集系之傷害指數在各劑量處理下皆較 1-2 期低(Table 48, 52)，而存活率亦有所提升(Table 49, 53)，鮮重及乾重降低程度較小(Table 50, 51, 54, 55)，根據以上試驗結果可知千金子各收集系在 3-4 葉齡對派伏利之抗性較 1-2 葉齡大。

b. 稗草

本研究採集台灣中南部水田一、二期作之稗草四個收集系，於稗草幼苗生長至 1-2 及 3-4 葉齡時分別進行九種劑量的派伏利劑量反應分析，分別在施用藥劑後 28 天及 35 天記錄傷害指數、存活率、鮮重及乾重等性狀，將資料帶入非線性對數邏輯回歸模型，得出劑量反應分析曲線及ED_{50} 值，最後比較稗草四個收集系彼此間對派伏利的抗性以及不同生育時期下稗草各收集系對派伏利的抗性。

1. 1-2 葉齡

將稗草 1-2 葉齡幼苗對派伏利進行劑量反應分析試驗，於施用藥劑後 28 天後，觀察其生長情形，並記錄傷害指數、存活率、鮮重及乾重等性狀(Figure 22)，將資料以非線性對數邏輯回歸模型，得出稗草各收集系對派伏利之ED_{50}值。

A.

B.

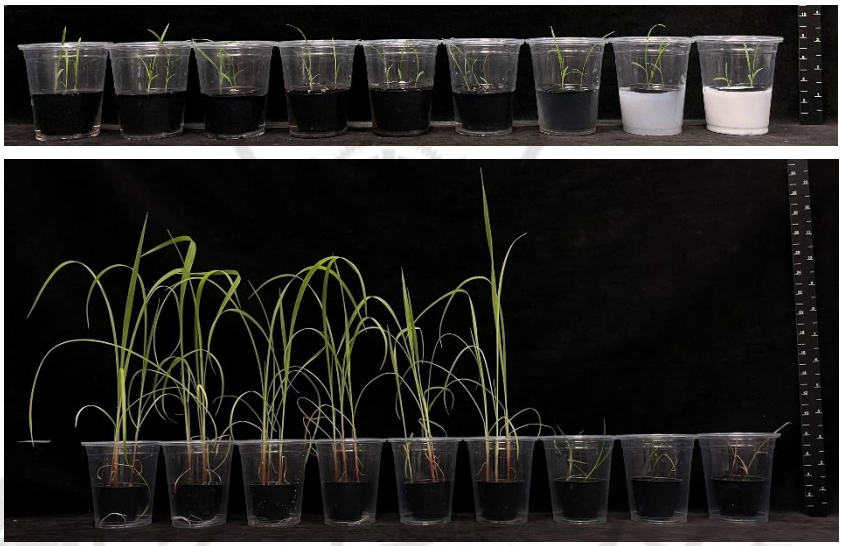


Figure 22. Herbicidal injury of 1-2 leaf barnyard grass (*Echinochloa crus-galli*) accession at 0 (A) and 28 (B) days after treatment of pyriftalid. Plants were observed from side view. Recommended dosage was 0.365 ppm (w/v).

由於部分稗草收集系其傷害指數及存活率於派伏利各劑量下均未達到 50%之抑制反應，故無法直接獲得 1-2 葉齡稗草各收集系之ED_{50}-值，因此後續以四種指標之數值比較稗草各收集系及 1~1,000 倍推薦用量範圍內的反應差異程度。

比較稗草各收集系在施用 1-1,000 倍推薦用量範圍內之派伏利的傷害指數，發現僅在 10 倍推薦用量下稗草四個收集系之傷害指數出現顯著差異(Table 56)，表示各收集系對 10 倍推薦劑量的派伏利抗性不一致，其中BG(II)-8 及BG(II)-17 之傷害指數顯著低於部分收集系，在傷害指數性狀表現上二收集系可能對派伏利之抗性較大，但隨著劑量增減此種差異不復存在。

Table 56. Sensitivities of 1-2 leaf barnyard grass (BG, *Echinochloa crus-galli*) accessions to the herbicide pyriftalid based on injury index. Data were collected at 28 days after treatment with three independent experiments.

	Injury index (0-5)			
Accession	1X[*1]	10X	100X	1,000X
BG-WT	2.11	4.89	5.00	5.00
BG(II)-8	0.59	1.78	2.70	3.81
BG(II)-13	1.33	2.80	3.74	4.37
BG(II)-17	0.96	1.48	2.70	4.00
P-value	0.30	< 0.05	0.17	0.22
$LSD_{0.05}$	ND[*2]	1.87	ND	ND

[*1] X represents the theoretical concentration based on the recommended dosage of pyriftalid applied in paddy water (0.365 ppm).

[*2] No significant difference according to Fisher's protected LSD test ($\alpha = 0.05$).

比較稗草各收集系在施用 1-1,000 倍推薦用量範圍內之派伏利的存活率，發現在 10 及 100 倍推薦用量下稗草四個收集系之存活率出現顯著差異(Table 57)，各收集系對 10 及 100 倍推薦劑量的派伏利抗性不一致，其中BG(II)-8 及BG(II)-17 之存活率顯著高於部分收集系，在存活率性狀表現上二收集系可能對派伏利之抗性較大。

Table 57. Sensitivities of 1-2 leaf barnyard grass (BG, *Echinochloa crus-galli*) accessions to the herbicide pyriftalid based on survival rate. Data were collected at 28 days after treatment with three independent experiments.

	Survival rate (%)			
Accession	1X[*1]	10X	100X	1,000X
BG-WT	100.00	11.00	0.00	0.00
BG(II)-8	100.00	96.33	88.89	59.33
BG(II)-13	100.00	83.33	48.22	29.67
BG(II)-17	100.00	96.33	85.11	51.89
P-value	--	< 0.05	< 0.05	0.20
$LSD_{0.05}$	ND[*2]	40.14	66.88	ND

[*1] X represents the theoretical concentration based on the recommended dosage of pyriftalid applied in paddy water (0.365 ppm).

[*2] No significant difference according to Fisher's protected LSD test ($\alpha = 0.05$).

比較稗草各收集系在施用 1-1,000 倍推薦用量範圍內之派伏利的鮮重，發現僅在 1 倍推薦用量下稗草四個收集系之鮮重出現顯著差異(Table 58)，表示各收集系鮮重對 1 倍推薦劑量派伏利的抗性較不一致，其中BG(II)-8 及BG(II)-17 之鮮重顯著高於部分收集系，在鮮重性狀表現上二收集系可能對派伏利之抗性較大。

Table 58. Sensitivities of 1-2 leaf barnyard grass (BG, *Echinochloa crus-galli*) accessions to the herbicide pyriftalid based on fresh weight. Data were collected at 28 days after treatment with three independent experiments.

	Fresh weight (% of control)			
Accession	1X[*1]	10X	100X	1,000X
BG-WT	38.84	12.26	6.32	4.11
BG(II)-8	81.77	37.44	11.64	8.57
BG(II)-13	57.89	20.31	11.28	4.96
BG(II)-17	72.47	43.42	28.00	5.17
P-value	< 0.05	0.50	0.67	0.75
$LSD_{0.05}$	34.17	ND[*2]	ND	ND

[*1] X represents the theoretical concentration based on the recommended dosage of pyriftalidapplied in paddy water (0.365 ppm).

[*2] No significant difference according to Fisher's protected LSD test ($\alpha = 0.05$).

比較稗草各收集系在施用 1-1,000 倍推薦用量範圍內之派伏利的乾重，發現僅在 1 及 1,000 倍推薦用量下稗草四個收集系之乾重出現顯著差異(Table 59)，在 1 倍推薦用量下各收集系對派伏利抗性不一致，以 BG(II)-8、BG(II)-13 及BG(II)-17 表現較大抗性，尤其是BG(II)-8 之乾重顯著高於BG-WT，在乾重性狀表現上此收集系可能對派伏利之抗性較大，但在 10 倍及 100 倍推薦用量下則未表現差異，至於 1,000 倍推薦用量下，雖然四收集系之乾重彼此呈現顯著差異，但其數值均已降至對照組之 3.97-12.59%，較不具意義。

Table 59. Sensitivities of 1-2 leaf barnyard grass (BG, *Echinochloa crus-galli*) accessions to the herbicide pyriftalid based on dry weight. Data were collected at 28 days after treatment with three independent experiments.

	Dry weight (% of control)			
Accession	1X[*1]	10X	100X	1,000X
BG-WT	29.60	14.40	5.92	3.97
BG(II)-8	77.80	39.81	15.87	12.59
BG(II)-13	62.89	28.31	20.66	12.47
BG(II)-17	64.29	43.45	25.30	7.02
P-value	<0.05	0.48	0.45	< 0.05
$LSD_{0.05}$	39.40	ND[*2]	ND	7.20

[*1] X represents the theoretical concentration based on the recommended dosage of pyriftalid applied in paddy water (0.365 ppm).

[*2] No significant difference according to Fisher's protected LSD test ($\alpha = 0.05$).

綜合以上試驗結果可知，在不同劑量之派伏利處理下稗草各收集系傷害指數與存活率對藥劑之反應不一致，在 10 倍推薦用量下稗草收集系BG(II)-8 及BG(II)-17 相對表現較具抗性，而在田間推薦用量(0.365 ppm)下均未抑制 50%生長反應，且在最高劑量(365 ppm)下BG(II)-8 及BG(II)-17 其存活率皆未低於 50%，表示此二個稗草收集系在 1-2 葉齡對派伏利之抗性可能較其他收集系大。

2. 3-4 葉齡

將稗草 3-4 葉齡幼苗對派伏利進行劑量反應分析試驗，於施用藥劑後 35 天後，記錄傷害指數、存活率、鮮重及乾重等性狀，將資料以非線性對數邏輯回歸模型，得出稗草各收集系對派伏利之ED_{50}值。

由於部分稗草收集系其傷害指數及存活率於派伏利各劑量下均未達到 50%之抑制反應，故無法直接獲得 1-2 葉齡稗草各收集系之ED_{50}-值，因此後續以四種指標之數值比較稗草各收集系及 1~1,000 倍推薦用量範圍內的反應差異程度。

比較稗草各收集系在施用 1-1,000 倍推薦用量範圍內之派伏利的傷害指數，發現在 1、10 及 100 倍推薦用量下稗草四個收集系之傷害指數出現顯著差異(Table 60)，表示各收集系對不同劑量的派伏利抗性不一致，其中BG(II)-8、BG(II)-13 及BG(II)-17 之傷害指數顯著低於BG-WT，在傷害指數性狀表現上此三個收集系可能對派伏利之抗性較大。

Table 60. Sensitivities of 3-4 leaf barnyard grass (BG, *Echinochloa crus-galli*) accessions to the herbicide pyriftalid based on injury index. Data were collected at 35 days after treatment with three independent experiments.

	Injury index (0-5)			
Accession	1X[*1]	10X	100X	1,000X
BG-WT	2.33	5.00	5.00	5.00
BG(II)-8	0.07	1.15	3.26	4.19
BG(II)-13	0.14	1.64	3.44	4.64
BG(II)-17	0.30	1.15	3.37	4.67
P-value	< 0.05	< 0.05	< 0.05	0.48
$LSD_{0.05}$	0.68	1.16	1.16	ND[*2]

[*1] X represents the theoretical concentration based on the recommended dosage of pyriftalid applied in paddy water (0.365 ppm).

[*2] No significant difference according to Fisher's protected LSD test ($\alpha = 0.05$).

比較稗草各收集系在施用 1-1,000 倍推薦用量範圍內之派伏利的存活率，發現在 10 及 100 倍推薦用量下稗草四個收集系之存活率出現顯著差異(Table 61)，示各收集系對 10 及 100 倍劑量的派伏利抗性不一致，其中BG(II)-8、BG(II)-13 及BG(II)-17 之存活率顯著高於BG-WT，在存活率性狀表現上此三個收集系可能對派伏利之抗性較大。

Table 61. Sensitivities of 3-4 leaf barnyard grass (BG, *Echinochloa crus-galli*) accessions to the herbicide pyriftalid based on survival rate. Data were collected at 35 days after treatment with three independent experiments.

	Survival rate (%)			
Accession	1X[*1]	10X	100X	1,000X
BG-WT	100.00	0.00	0.00	0.00
BG(II)-8	100.00	100.00	81.44	44.44
BG(II)-13	100.00	100.00	86.25	30.50
BG(II)-17	100.00	100.00	92.67	25.78
P-value	--	< 0.05	< 0.05	0.40
$LSD_{0.05}$	ND[*2]	0.65	20.60	ND

[*1] X represents the theoretical concentration based on the recommended dosage of pyriftalid applied in paddy water (0.365 ppm).

[*2] No significant difference according to Fisher's protected LSD test ($\alpha = 0.05$).

比較稗草各收集系在施用 1-1,000 倍推薦用量範圍內之派伏利的鮮重，發現在 1 及 10 倍推薦用量下稗草四個收集系之鮮重出現顯著差異(Table 62)，示各收集系對 1 及 10 倍劑量的派伏利抗性不一致，其中 BG(II)-8、BG(II)-13 及BG(II)-17 之鮮重顯著高於BG-WT，在鮮重性狀表現上此三個收集系可能對派伏利之抗性較大。

Table 62. Sensitivities of 3-4 leaf barnyard grass (BG, *Echinochloa crus-galli*) accessions to the herbicide pyriftalid based on fresh weight. Data were collected at 35 days after treatment with three independent experiments.

	Fresh weight (% of control)			
Accession	1X[*1]	10X	100X	1,000X
BG-WT	34.15	5.71	3.30	2.04
BG(II)-8	76.16	70.22	27.31	15.69
BG(II)-13	69.83	64.38	36.99	14.54
BG(II)-17	84.18	68.91	37.77	11.89
P-value	< 0.05	< 0.05	0.12	0.30
$LSD_{0.05}$	30.20	36.66	ND[*2]	ND

[*1] X represents the theoretical concentration based on the recommended dosage of pyriftalid applied in paddy water (0.365 ppm).

[*2] No significant difference according to Fisher's protected LSD test ($\alpha = 0.05$).

比較稗草各收集系在施用 1-1,000 倍推薦用量範圍內之派伏利的乾重，發現在 1 及 10 倍推薦用量下稗草四個收集系之乾重出現顯著差異(Table 63)，示各收集系對 1 及 10 倍劑量的派伏利抗性不一致，其中 BG(II)-8、BG(II)-13 及BG(II)-17 之乾重顯著高於BG-WT，在乾重性狀表現上此三個收集系可能對派伏利之抗性較大。

Table 63. Sensitivities of 3-4 leaf barnyard grass (BG, *Echinochloa crus-galli*) accessions to the herbicide pyriftalid based on dry weight. Data were collected at 35 days after treatment with three independent experiments.

	Dry weight (% of control)			
Accession	1X[*1]	10X	100X	1,000X
BG-WT	31.09	6.77	4.31	2.29
BG(II)-8	74.48	77.51	28.43	19.38
BG(II)-13	59.68	49.06	36.31	16.55
BG(II)-17	81.46	61.31	33.62	13.13
P-value	< 0.05	< 0.05	0.11	0.18
$LSD_{0.05}$	23.80	15.36	ND[*2]	ND

[*1] X represents the theoretical concentration based on the recommended dosage of pyriftalid applied in paddy water (0.365 ppm).

[*2] No significant difference according to Fisher's protected LSD test ($\alpha = 0.05$).

綜合以上試驗結果可知，在不同劑量之派伏利處理下 3-4 葉齡稗草各收集系之反應並不一致，BG(II)-8、BG(II)-13 及BG(II)-17 皆未能在田間推薦用量(0.365 ppm)下抑制 50%生長反應，表示此三個稗草收集系在 3-4 葉齡對派伏利具有一定程度的抗性。而BG(II)-8、BG(II)-13 及 BG(II)-17 在 1 及 10 倍劑量處理下，其傷害指數、存活率、鮮重及乾重性狀反應皆顯著高於BG-WT。

3. 不同生育時期之劑量反應比較

本試驗進一步比較稗草四個收集系在兩個生育時期之對派伏利之反應差異，根據 1-2 及 3-4 葉齡BG-WT之抑制反應在 10、100 及 1,000 倍推薦用量下均超過 50%，但其他收集系在最高劑量下仍未達到 50% 之反應，因此分別以傷害指數、存活率、鮮重及乾重之劑量反應曲線進行比較。根據傷害指數及存活率之劑量反應分析可知，稗草四個收集系在兩個生育時期之ED_{50}值差異不大(Table 56, 57, 60, 61)，但 3-4 葉齡稗草四個收集系在鮮重及乾重性狀下之ED_{50}值則略高於 1-2 葉齡(Table 58, 59, 62, 63)，因此根據以上試驗結果可知稗草各收集系在 3-4 葉齡對派伏利之抗性較 1-2 葉齡大。另外，3-4 葉齡BG(II)-8、BG(II)-13 及 BG(II)-17 於四個性狀表現較一致，對藥劑之抗性均大於BG-WT。

(四)千金子及稗草對平速爛之劑量反應分析試驗

本試驗進一步使用千金子及稗草各收集系對ALS抑制型除草劑中的平速爛(penoxsulam)進行劑量反應分析試驗，以判斷兩雜草物種各收集系彼此間對於平速爛之抗性差異以及在不同生育時期下對藥劑的反應差異。

A. 不同生育時期對平速爛之劑量反應分析

a. 千金子

本研究採集自台灣中南部水田一、二期作之千金子六個收集系，於千金子幼苗 1-2 及 3-4 葉齡時分別進行九種劑量的平速爛劑量反應分析，分別在施用藥劑後 28 天及 35 天記錄傷害指數、存活率、鮮重及乾重等性狀，將資料帶入非線性對數邏輯回歸模式，得出劑量反應分析曲線及ED_{50} 值，最後比較千金子六個收集系彼此間對平速爛的抗性以及不同生育時期下千金子各收集系對平速爛的抗性差異。

1. 1-2 葉齡

將千金子 1-2 葉齡幼苗對平速爛進行劑量反應分析試驗，於施用藥劑後 28 天後，觀察其生長情形，並記錄傷害指數(Figure 23)、存活率、鮮重及乾重等性狀，將資料以非線性對數邏輯回歸模式分析。

A.

B.

Figure 23. Herbicidal injury of 1-2 leaf red sprangle-top (*Leptochloa chinensis*) accession at 0 (A) and 28 (B) days after treatment of penoxsulam. Plants were observed from side view. Theoretical concentration of penoxsulam in paddy water based on the application rate recommended by Dow AgroSciences Taiwan Ltd. was 0.068 ppm (w/v).

比較千金子各收集系在施用 1-1,000 倍推薦用量範圍內之平速爛的傷害指數，發現在 1、10、100 及 1,000 倍推薦用量下千金子六個收集系之間傷害指數出現顯著差異(Table 64)，其中在 1、10 及 100 倍推薦用量下RS(I)-2、RS(I)-14、RS(I)-15 及RS(II)-11 之傷害指數均顯著低於RS(II)-AES，且在四種劑量下，RS(I)-14 及RS(II)-11 均顯著低於RS(II)-AES，在傷害指數性狀表現上此二收集系可能對平速爛之抗性較大，唯當劑量超過 100 倍時，則千金子各收集系之傷害指數均超過 2.5。

Table 64. Sensitivities of 1-2 leaf red sprangle-top (RS, *Leptochloa chinensis*) accessions to the herbicide penoxsulam based on injury index. Data were collected at 28 days after treatment with three independent experiments.

	Injury index (0-5)			
Accession	1X[*1]	10X	100X	1,000X
RS(II)-AES	3.00	3.67	4.67	5.00
RS(I)-1	1.50	2.50	3.00	4.83
RS(I)-2	1.33	2.00	2.67	4.83
RS(I)-14	0.44	1.17	2.67	4.11
RS(I)-15	0.56	0.89	2.78	5.00
RS(II)-11	0.33	1.44	2.56	3.22
P-value	< 0.05	< 0.05	< 0.05	< 0.05
$LSD_{0.05}$	0.79	1.13	1.15	0.69

[*1] X represents the theoretical concentration based on the recommended dosage of penoxsulam applied in paddy water (0.068 ppm).

比較千金子各收集系在施用 1-1,000 倍推薦用量範圍內之平速爛的存活率，發現在 100 及 1,000 倍推薦用量下千金子六個收集系之存活率出現顯著差異(Table 65)，其中RS(I)-14 及RS(II)-11 之存活率顯著高於RS(II)-AES，在存活率性狀表現上此二收集系可能對平速爛之抗性較大，尤其RS(II)-11 在 1,000 倍劑量下存活率尚有 77.67%。

Table 65. Sensitivities of 1-2 leaf red sprangle-top (RS, *Leptochloa chinensis*) accessions to the herbicide penoxsulam based on survival rate. Data were collected at 28 days after treatment with three independent experiments.

	Survival rate (%)			
Accession	1X[*1]	10X	100X	1,000X
RS(II)-AES	100.00	83.50	33.50	0.00
RS(I)-1	100.00	100.00	83.50	33.50
RS(I)-2	100.00	100.00	83.50	16.50
RS(I)-14	100.00	100.00	100.00	38.83
RS(I)-15	100.00	100.00	100.00	0.00
RS(II)-11	100.00	100.00	100.00	77.67
P-value	--	0.06	< 0.05	< 0.05
$LSD_{0.05}$	ND[*2]	ND	34.84	48.76

[*1] X represents the theoretical concentration based on the recommended dosage of penoxsulam applied in paddy water (0.068 ppm).

[*2] No significant difference according to Fisher's protected LSD test ($\alpha = 0.05$).

比較千金子各收集系在施用 1-1,000 倍推薦用量範圍內之平速爛的鮮重，發現雖然在 1,000 倍推薦用量下千金子六個收集系之鮮重出現顯著差異(Table 66)，但鮮重均已降至對照組 4.17~16.67%，比較其抗性差異已無太大意義。而從 1、10 及 100 倍劑量反應結果，似乎在鮮重性狀表現上，六個收集系之間並無顯著差異。

Table 66. Sensitivities of 1-2 leaf red sprangle-top (RS, *Leptochloa chinensis*) accessions to the herbicide penoxsulam based on fresh weight. Data were collected at 28 days after treatment with three independent experiments.

	Fresh weight (% of control)			
Accession	1X[*1]	10X	100X	1,000X
RS(II)-AES	33.45	16.59	6.51	4.17
RS(I)-1	36.11	30.33	24.10	15.92
RS(I)-2	35.10	27.51	19.25	8.43
RS(I)-14	55.15	45.99	24.04	14.79
RS(I)-15	63.47	53.67	26.55	12.44
RS(II)-11	42.76	30.94	20.00	16.67
P-value	0.39	0.07	0.06	< 0.05
$LSD_{0.05}$	ND[*2]	ND	ND	9.94

[*1] X represents the theoretical concentration based on the recommended dosage of penoxsulam applied in paddy water (0.068 ppm).

[*2] No significant difference according to Fisher's protected LSD test ($\alpha = 0.05$).

比較千金子各收集系在施用 1-1,000 倍推薦用量範圍內之平速爛的乾重，發現僅在 100 倍推薦用量下千金子六個收集系之乾重彼此間出現顯著差異(Table 67)，但在其他劑量下則未達顯著差異，表示各收集系可能在乾重性狀表現上對平速爛抗性未出現差異。

Table 67. Sensitivities of 1-2 leaf red sprangle-top (RS, *Leptochloa chinensis*) accessions to the herbicide penoxsulam based on dry weight. Data were collected at 28 days after treatment with three independent experiments.

	Dry weight (%)			
Accession	1X[*1]	10X	100X	1,000X
RS(II)-AES	31.26	15.49	6.82	3.98
RS(I)-1	41.90	31.67	27.05	21.16
RS(I)-2	49.23	32.44	25.03	16.29
RS(I)-14	58.74	48.23	25.77	17.52
RS(I)-15	66.08	55.98	27.54	15.90
RS(II)-11	38.09	27.77	19.08	16.38
P-value	0.51	0.15	< 0.05	0.28
$LSD_{0.05}$	ND[*2]	ND	14.84	ND

[*1] X represents the theoretical concentration based on the recommended dosage of penoxsulam applied in paddy water (0.068 ppm).

[*2] No significant difference according to Fisher's protected LSD test ($\alpha = 0.05$).

綜合以上試驗結果可知，在 1、10 及 100 倍劑量之平速爛處理下，1-2 葉齡千金子收集系RS(I)-2、RS(I)-14、RS(I)-15 及RS(II)-11 之傷害指數均低於RS(II)-AES，表示 1-2 葉齡千金子此四個收集系其對平速爛的抗性高於RS(II)-AES，而RS(I)-14 及RS(II)-11 在 100 及 1,000 倍劑量處理下，其傷害指數性狀反應顯著優於其他收集系，尤其RS(II)-11 在 1,000 倍劑量處理下存活率仍維持 77.67%，表示此收集系對平速爛之抗性可能較其他收集系大。

2. 3-4 葉齡

比較 3-4 葉齡千金子各收集系在施用 1-1,000 倍推薦用量範圍內之平速爛的傷害指數，發現千金子六個收集系彼此間之傷害指數未達顯著差異(Table 68)，於 100 倍推薦用量下，其傷害指數均未超過 2.5，表示千金子各收集系在 3-4 葉齡對藥劑具有相同抗性，且根據 100 倍劑量下之傷害反應(Table 64, 68)，其抗性程度大於 1-2 葉齡。

Table 68. Sensitivities of 3-4 leaf red sprangle-top (RS, *Leptochloa chinensis*) accessions to the herbicide penoxsulam based on injury index. Data were collected at 35 days after treatment with three independent experiments.

	Injury index (0-5)			
Accession	1X[*1]	10X	100X	1,000X
RS(II)-AES	0.44	0.44	0.44	2.44
RS(I)-1	0.42	0.72	0.86	2.97
RS(I)-2	0.39	1.00	1.28	3.50
RS(I)-14	0.00	0.22	0.78	3.00
RS(I)-15	0.00	0.00	1.00	3.56
RS(II)-11	0.00	0.44	1.56	3.33
P-value	0.15	0.34	0.48	0.68
$LSD_{0.05}$	ND[*2]	ND	ND	ND

[*1] X represents the theoretical concentration based on the recommended dosage of penoxsulam applied in paddy water (0.068 ppm).

[*2] No significant difference according to Fisher's protected LSD test ($\alpha = 0.05$).

比較千金子各收集系在施用 1-1,000 倍推薦用量範圍內之平速爛的存活率，發現六個收集系之存活率彼此差異未達顯著水準(Table 69)，且在 100 倍推薦用量下，其存活率仍維持 100%。

Table 69. Sensitivities of 3-4 leaf red sprangle-top (RS, *Leptochloa chinensis*) accessions to the herbicide penoxsulam based on survival rate. Data were collected at 35 days after treatment with three independent experiments.

	Survival rate (%)			
Accession	1X[*1]	10X	100X	1,000X
RS(II)-AES	100.00	100.00	100.00	100.00
RS(I)-1	100.00	100.00	100.00	75.00
RS(I)-2	100.00	100.00	100.00	50.00
RS(I)-14	100.00	100.00	100.00	100.00
RS(I)-15	100.00	100.00	100.00	50.00
RS(II)-11	100.00	100.00	100.00	77.67
P-value	--	--	--	0.18
$LSD_{0.05}$	ND[*2]	ND	ND	ND

[*1] X represents the theoretical concentration based on the recommended dosage of penoxsulam applied in paddy water (0.068 ppm).

[*2] No significant difference according to Fisher's protected LSD test ($\alpha = 0.05$).

在施用 1-1,000 倍推薦用量之平速爛下之後比較千金子各收集系的鮮重，發現在 1、10、100 及 1,000 倍推薦用量下六個收集系之鮮重出現顯著差異(Table 70)，於 10 倍推薦用量下，有 5 個收集系之鮮重均已減少至 50%以下，其中僅RS(I)-14 之鮮重顯著高於RS(II)-AES及RS(II)-11。此外，可見在各種劑量處理下RS(I)-14 均維持相對較高的鮮重。

Table 70. Sensitivities of 3-4 leaf red sprangle-top (RS, *Leptochloa chinensis*) accessions to the herbicide penoxsulam based on fresh weight. Data were collected at 35 days after treatment with three independent experiments.

	Fresh weight (% of control)			
Accession	1X[*1]	10X	100X	1,000X
RS(II)-AES	18.67	10.52	8.95	0.36
RS(I)-1	50.31	39.27	31.05	0.32
RS(I)-2	55.53	48.98	48.09	1.34
RS(I)-14	65.35	53.15	34.21	13.77
RS(I)-15	63.78	49.95	22.17	0.15
RS(II)-11	47.66	20.32	11.63	4.63
P-value	< 0.05	< 0.05	< 0.05	< 0.05
$LSD_{0.05}$	28.67	23.24	17.78	6.64

[*1] X represents the theoretical concentration based on the recommended dosage of penoxsulam applied in paddy water (0.068 ppm).

在施用 1-1,000 倍推薦用量範圍內之平速爛下比較千金子各收集系的乾重，發現在 1、10、100 及 1,000 倍推薦用量下千金子六個收集系之乾重出現顯著差異(Table 71)，於 10 倍推薦用量施用下，有 5 個收集系之乾重均降至對照組 50%以下，其中僅RS(I)-14 之乾重維持較大值，且在 100 及 1,000 倍劑量下亦有相似表現。

Table 71. Sensitivities of 3-4 leaf red sprangle-top (RS, *Leptochloa chinensis*) accessions to the herbicide penoxsulam based on dry weight. Data were collected at 35 days after treatment with three independent experiments.

	Dry weight (% of control)			
Accession	1X[*1]	10X	100X	1,000X
RS(II)-AES	21.62	12.92	12.10	0.40
RS(I)-1	35.95	26.63	23.46	0.22
RS(I)-2	46.40	37.48	36.81	1.25
RS(I)-14	62.78	53.01	35.43	10.64
RS(I)-15	57.52	44.14	18.60	0.36
RS(II)-11	39.15	17.59	10.94	3.22
P-value	< 0.05	< 0.05	< 0.05	< 0.05
$LSD_{0.05}$	25.68	19.35	17.76	3.88

[*1] X represents the theoretical concentration based on the recommended dosage of penoxsulam applied in paddy water (0.068 ppm).

綜合以上試驗結果，根據傷害指數及存活率兩性狀可知 1-2 葉齡千金子收集系RS(I)-14 及RS(II)-11 對平速爛之抗性相對較RS(II)-AES大，而在 3-4 葉齡千金子彼此收集系對平速爛的抗性較一致，且抗性程度大於 1-2 葉齡，表示 3-4 葉齡千金子此收集系對平速爛可能具有一定程度的抗性。而千金子收集系RS(I)-14 僅在 1-1,000 倍劑量處理下，其鮮重及乾重性狀反應皆顯著高於部分收集系，其對平速爛之抗性可能相對較其他收集系大。

3. 不同生育時期之平速爛抗性比較

本試驗進一步比較兩個生育時期之千金子六個收集系對平速爛之反應差異，根據傷害指數、存活率、鮮重及乾重之劑量反應進行比較，發現 3-4 葉齡千金子六個收集系之傷害指數達 2.5 之所需劑量較 1-2 期高且差異較小(Table 64, 68)，僅在 1,000 倍劑量下才超過 2.5，而存活率亦大幅提升(Table 65, 69)，至於鮮重及乾重降低程度之反應則較相近(Table 66, 67, 70, 71)，根據以上試驗結果可知千金子各收集系在 3-4 葉齡對平速爛之抗性相對較 1-2 葉齡大，且各收集系之間的抗性表現亦較為接近。

b. 稗草

本研究採集台灣中南部水田一、二期作之稗草四個收集系，於稗草幼苗生長至 1-2 及 3-4 葉齡時分別進行九種劑量的平速爛劑量反應分析，分別在施用藥劑後 28 天及 35 天記錄傷害指數、存活率、鮮重及乾重等性狀，將資料帶入非線性對數邏輯回歸模式，得出劑量反應分析曲線及ED_{50} 值，最後比較稗草四個收集系彼此間對平速爛的抗性以及不同生育時期下稗草各收集系對平速爛的抗性。

1. 1-2 葉齡

稗草 1-2 葉齡幼苗於施用平速爛後 28 天內，觀察其生長情形(Figure 24)，並記錄傷害指數、存活率、鮮重及乾重等性狀，將資料以非線性對數邏輯回歸模式分析。

A.

B.

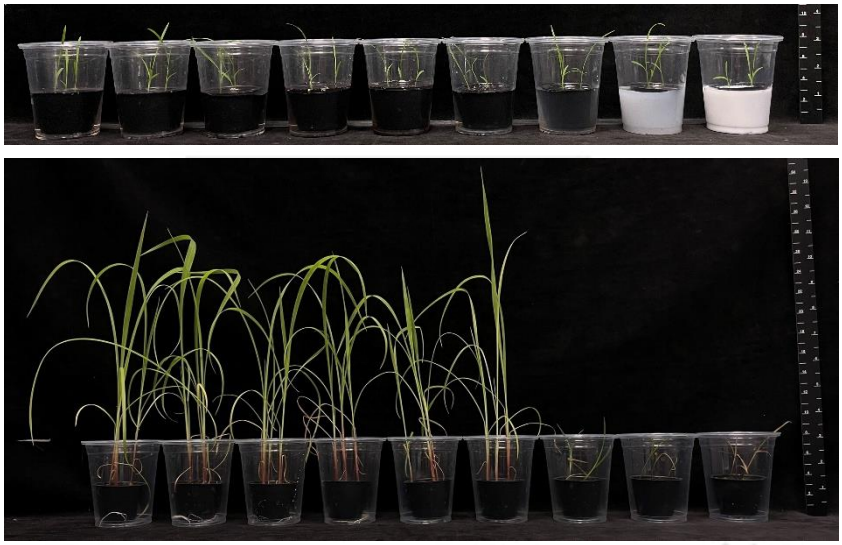


Figure 24. Herbicidal injury of 1-2 leaf barnyard grass (*Echinochloa crus-galli*) accession at 0 (A) and 28 (B) days after treatment of penoxsulam. Plants were observed from side view. Theoretical concentration of penoxsulam in paddy water based on the application rate recommended by Dow AgroSciences Taiwan Ltd. was 0.068 ppm (w/v).

由 1-2 葉齡稗草四個收集系對平速爛之 ED_{50} 值可知，其傷害指數之 ED_{50} 值介於 0.01-0.48 ppm、存活率之 ED_{50} 值介於 0.03-1.65 ppm、存活率經 arcsine 轉換後之 ED_{50} 值介於 0.03-1.67 ppm、鮮重之 ED_{50} 值介於 0.01-0.18 ppm、鮮重經 arcsine 轉換後之 ED_{50} 值介於 0.01-0.15 ppm、乾重之 ED_{50} 值介於 0.01-0.10 ppm、乾重經 arcsine 轉換後之 ED_{50} 值介於

0.01-0.06 (Table 72)，稗草四個收集系彼此間於傷害指數、存活率、鮮重及乾重的 ED_{50} 值經 Fisher's protected LSD 檢定後未達顯著差異，表示稗草各收集系對平速爛之抗性可能較接近，因 BG(II)-8、BG(II)-13 及 BG(Ⅱ)-17 之 ED_{50} 值皆高於平速爛田間推薦用量 0.068 ppm，此表示在推薦用量下三個稗草收集系對藥劑均具有抗性。

Table 72. ED_{50} values of herbicide penoxsulam[*1] for the 1-2 leaf barnyard grass (BG, *Echinochloa crus-galli*) accessions. Data were collected at 28 days after treatment from three independent experiments.

Accession	ED_{50} (ppm, w/v)						
	Injury index	Survival rate		Fresh weight		Dry weight	
		Original data	Arcsine transformation	Original data	Arcsine transformation	Original data	Arcsine transformation
BG-WT	0.01	0.03	0.03	0.01	0.01	0.01	0.01
BG(II)-8	0.47	1.65	1.67	0.15	0.06	0.04	0.01
BG(II)-13	0.48	1.00	1.02	0.07	0.09	0.05	0.03
BG(II)-17	0.19	0.38	0.38	0.18	0.15	0.10	0.06
P-value	0.51	0.07	0.07	0.24	0.30	0.27	0.19
$LSD_{0.05}$	ND[*2]	ND	ND	ND	ND	ND	ND

[*1] Theoretical concentration of penoxsulam applied in paddy water based on the application rate recommended by Dow AgroSciences Taiwan Ltd. was 0.068 ppm (w/v).

[*2] ND indicates no significant difference among four accessions according to Fisher's protected LSD test ($\alpha = 0.05$).

2. 3-4 葉齡

由 3-4 葉齡稗草四個收集系針對平速爛之ED_{50}值可知，其傷害指數之ED_{50}值介於 0.015-1.626 ppm、存活率之ED_{50}值介於 0.051-11.431 ppm、存活率經arcsine轉換後之ED_{50}值介於 0.050-9.869 ppm、鮮重之ED_{50}值介於 0.006-0.506 ppm、鮮重經arcsine轉換後之ED_{50}值介於 0.004-0.697 ppm、乾重之ED_{50}值介於 0.004-0.658 ppm、乾重經arcsine轉換後之ED_{50}值介於 0.001-0.369 ppm (Table 73)，稗草四個收集系彼此間於存活率、鮮重及乾重的ED_{50}值經Fisher's protected LSD檢定後具有顯著差異，表示稗草各收集系可能對平速爛之抗性較不一致。其中以稗草收集系BG(II)-8 之ED_{50}值顯著高於BG-WT、BG(II)-13 及BG(II)-17，而後進一步將BG(II)-8 與BG-WT之傷害指數、存活率、鮮重及乾重的ED_{50}值相除可得BG(II)-8 之抗性指數介於 84.3-369.0，表示BG(II)-8 相較於其他稗草收集系可能對平速爛具有相當高度的抗性。試驗結果亦發現 3-4 葉齡之稗草各收集系之ED_{50}值似乎較 1-2 葉齡高，且高於田間推薦用量 0.068 ppm，因此進一步比較稗草收集系在不同生育時期對平速爛之ED_{50}值。

Table 73. ED_{50} values of herbicide penoxsulam[*1] for the 3-4 leaf barnyard grass (BG, *Echinochloa crus-galli*) accessions. Data were collected at 35 days after treatment from three independent experiments.

Accession	ED_{50} (ppm, w/v)						
	Injury index	Survival rate		Fresh weight		Dry weight	
		Original data	Arcsine transformation	Original data	Arcsine transformation	Original data	Arcsine transformation
BG-WT	0.015	0.051	0.050	0.006	0.004	0.004	0.001
BG(II)-8	1.626	11.431	9.869	0.506	0.697	0.658	0.369
BG(II)-13	0.516	5.502	3.265	0.056	0.036	0.025	0.015
BG(II)-17	0.215	3.278	3.202	0.123	0.083	0.046	0.034
P-value	0.27	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
$LSD_{0.05}$	ND[*2]	7.68	5.98	0.20	0.24	0.15	0.24

[*1] Theoretical concentration of penoxsulam applied in paddy water based on the application rate recommended by Dow AgroSciences Taiwan Ltd. was 0.068 ppm (w/v).

[*2] ND indicates no significant difference among four accessions according to Fisher's protected LSD test ($\alpha = 0.05$).

3. 不同生育時期之劑量反應比較

比較兩個生育時期之稗草四個收集系對平速爛之傷害指數、存活率、鮮重及乾重的ED_{50}值，並以Fisher's protected LSD檢定後判定不同生育時期之稗草幼苗對藥劑之抗性差異程度。結果可知稗草各收集系於兩個生育時期的ED_{50}值經Fisher's protected LSD test檢定後並未達到顯著差異(Table 74)，表示 1-2 葉齡及 3-4 葉齡稗草幼苗對藥劑的抗性相近。

Table 74. Comparison of ED_{50} values of herbicide penoxsulam for barnyard grass (BG, *Echinochloa crus-galli*) accessions between 1-2 and 3-4 leaf stages based on injury index. Data from three independent experiments were collected at 28 and 35 days, respectively, after treatment.

Accession	ED_{50} (injury index) (ppm)		P-value	$LSD_{0.05}$
	1-2 leaf	3-4 leaf		
BG-WT	0.009	0.015	0.06	ND*
BG(II)-8	0.469	1.626	0.38	ND
BG(II)-13	0.476	0.516	0.93	ND
BG(II)-17	0.187	0.215	0.73	ND

* ND indicates no significant difference according to Fisher's protected LSD test (α = 0.05).

比較兩個生育時期之稗草四個收集系對平速爛之存活率的ED_{50}值，可知稗草各收集系於不同生育時期的ED_{50}值經Fisher's protected LSD檢定後僅BG(II)-13 出現顯著差異，而其他稗草收集系並未達顯著差異(Table 75)。

Table 75. Comparison of ED_{50} values of herbicide penoxsulam for barnyard grass (BG, *Echinochloa crus-galli*) accessions between 1-2 and 3-4 leaf stages based on survival rate (original data). Data from three independent experiments were collected at 28 and 35 days, respectively, after treatment.

Accession	ED_{50} (survival rate) (ppm)		P-value	$LSD_{0.05}$
	1-2 leaf	3-4 leaf		
BG-WT	0.033	0.051	0.51	ND*
BG(II)-8	1.646	11.431	0.08	ND
BG(II)-13	1.003	5.502	< 0.05	4.287
BG(II)-17	0.377	3.278	0.13	ND

* ND indicates no significant difference according to Fisher's protected LSD test (α = 0.05).

比較兩個生育時期的稗草四個收集系對平速爛之存活率經arcsine轉換後的ED_{50}值，經Fisher's protected LSD檢定後僅BG(II)-8 出現顯著差異，而其他稗草收集系並未達顯著差異(Table 76)。

Table 76. Comparison of ED_{50} values of herbicide penoxsulam for barnyard grass (BG, *Echinochloa crus-galli*) accessions between 1-2 and 3-4 leaf stages based on survival rate (arcsine transformation). Data from three independent experiments were collected at 28 and 35 days, respectively, after treatment.

Accession	ED_{50} (survival rate) (ppm)		P-value	$LSD_{0.05}$
	1-2 leaf	3-4 leaf		
BG-WT	0.033	0.050	0.54	ND*
BG(II)-8	1.673	9.869	< 0.05	7.950
BG(II)-13	1.017	3.265	0.27	ND
BG(II)-17	0.376	3.202	0.16	ND

* ND indicates no significant difference according to Fisher's protected LSD test (α = 0.05).

比較兩個生育時期的稗草四個收集系對平速爛之鮮重ED_{50}值，經Fisher's protected LSD檢定後並未達到顯著差異(Table 77)，表示 1-2 葉齡及 3-4 葉齡稗草幼苗對藥劑的抗性相似。

Table 77. Comparison of ED_{50} values of herbicide penoxsulam for barnyard grass (BG, *Echinochloa crus-galli*) accessions between 1-2 and 3-4 leaf stages based on fresh weight (FW, original data). Data from three independent experiments were collected at 28 and 35 days, respectively, after treatment.

Accession	ED_{50} (FW) (ppm)		P-value	$LSD_{0.05}$
	1-2 leaf	3-4 leaf		
BG-WT	0.007	0.006	0.84	ND*
BG(II)-8	0.145	0.506	0.09	ND
BG(II)-13	0.066	0.056	0.83	ND
BG(II)-17	0.181	0.123	0.17	ND

* ND indicates no significant difference according to Fisher's protected LSD test (α = 0.05).

比較兩個生育時期的稗草四個收集系對平速爛之鮮重經arcsine轉換後的ED_{50}值，經Fisher's protected LSD檢定後僅BG(II)-8 出現顯著差異，而其他稗草收集系並未達顯著差異(Table 78)。

Table 78. Comparison of ED_{50} values of herbicide penoxsulam for barnyard grass (BG, *Echinochloa crus-galli*) accessions between 1-2 and 3-4 leaf stages based on fresh weight (FW, arcsine transformation). Data from three independent experiments were collected at 28 and 35 days, respectively, after treatment.

Accession	ED_{50} (FW) (ppm)		P-value	$LSD_{0.05}$
	1-2 leaf	3-4 leaf		
BG-WT	0.007	0.004	0.41	ND*
BG(II)-8	0.064	0.697	< 0.05	0.424
BG(II)-13	0.087	0.036	0.48	ND
BG(II)-17	0.147	0.083	0.38	ND

* ND indicates no significant difference according to Fisher's protected LSD test (α = 0.05).

比較兩個生育時期之稗草四個收集系對平速爛之乾重的ED_{50}值，經Fisher's protected LSD檢定後僅BG(II)-8 出現顯著差異，而其他稗草收集系並未達顯著差異(Table 79)。

Table 79. Comparison of ED_{50} values of herbicide penoxsulam for barnyard grass (BG, *Echinochloa crus-galli*) accessions between 1-2 and 3-4 leaf stages based on dry weight (DW, original data). Data from three independent experiments were collected at 28 and 35 days, respectively, after treatment.

Accession	ED_{50} (DW) (ppm)		P-value	$LSD_{0.05}$
	1-2 leaf	3-4 leaf		
BG-WT	0.009	0.004	0.35	ND*
BG(II)-8	0.035	0.658	< 0.05	0.245
BG(II)-13	0.047	0.025	0.24	ND
BG(II)-17	0.103	0.046	0.31	ND

* ND indicates no significant difference according to Fisher's protected LSD test (α = 0.05).

比較兩個生育時期之稗草四個收集系對平速爛之乾重經 arcsine 轉換後的 ED_{50} 值，經 Fisher's protected LSD 檢定後並未達到顯著差異(Table 80)，表示 1-2 葉齡及 3-4 葉齡稗草幼苗對藥劑的抗性相似。

Table 80. Comparison of ED_{50} values of herbicide penoxsulam for barnyard grass (BG, *Echinochloa crus-galli*) accessions between 1-2 and 3-4 leaf stages based on dry weight (DW, arcsine transformation). Data from three independent experiments were collected at 28 and 35 days, respectively, after treatment.

Accession	ED_{50} (DW) (ppm)		P-value	$LSD_{0.05}$
	1-2 leaf	3-4 leaf		
BG-WT	0.007	0.001	0.14	ND*
BG(II)-8	0.014	0.369	0.07	ND
BG(II)-13	0.027	0.015	0.68	ND
BG(II)-17	0.055	0.034	0.86	ND

* ND indicates no significant difference according to Fisher's protected LSD test (α = 0.05).

根據以上試驗結果可知，1-2 葉齡稗草四個收集系對平速爛之 ED_{50} 值經 Fisher's protected LSD 檢定後並未達顯著差異，表示收集系彼此間對藥劑之抗性較相似，而 BG(II)-8、BG(II)-13 及 BG(II)-17 對平速爛

的傷害指數、存活率及鮮重之 ED_{50} 值則皆大於田間推薦用量，可能對藥劑有一定程度的抗性。至於 3-4 葉齡稗草收集系彼此間對平速爛之 ED_{50} 值出現顯著差異，其中以稗草收集系 BG(II)-8 的傷害指數、存活率及鮮重之 ED_{50} 值顯著高於稗草收集系 BG-WT，並得出 BG(II)-8 的抗性指數為 84.3-369.0，顯示 BG(II)-8 在 3-4 葉齡對平速爛之抗性較大。

綜合試驗結果可知，3-4 葉齡稗草收集系 BG(II)-8 對平速爛表現出一定程度的抗性，而前人研究亦指出在美國阿肯色州(Arkansas)的稗草於連年施用 ALS 抑制劑後，導致其對平速爛產生抗性，根據乾重性狀其抗性指數高達 33.9 (Norsworthy et al., 2014)；在中國亦發現稗草於連年施用 ALS 抑制劑平速爛後，導致稗草對平速爛產生高度或極高度抗性(Chen et al., 2019)。本研究發現稗草收集系 BG(II)-8 對平速爛出現一定程度的抗性，但根據取樣地點之田野調查其用藥經歷包括氟氯比(fluroxypyr)、快伏草(quizalofop-ethyl)及本達隆(bentazon)等(Supplementary 2)，並無使用 ALS 抑制劑的經歷，因此對於 BG(II)-8 相關之抗性機制及抗性行為，包括單一(single)、交叉(cross)及多重(multiple)抗性等，仍須後續進一步研究。

本研究比較稗草各收集系在兩個生育時期四個性狀表現的 ED_{50} 值，結果發現，雖有少數收集系之特定性狀表現出兩個生育時期之抗性差異，但整體而言未出現顯著差異。

綜合比較千金子及稗草在不同生育時期對平速爛之反應，根據傷害指數及存活率之劑量反應分析可知，千金子收集系 RS(I)-14 及 RS(II)-11 在 1-2 葉齡對藥劑之抗性均顯著高於其他收集系，而在 3-4 葉齡對藥劑之抗性則較一致。比較千金子在不同生育時期對藥劑的反應，可知千金子在 3-4 葉齡對平速爛之抗性似乎較 1-2 葉齡大，少數收集系在最高劑量下存活率達 100%。稗草四個收集系在 1-2 葉齡對藥劑之反應較一致，但 BG(II)-8 在 3-4 葉齡對藥劑之抗性顯著高於其他收集系，顯示 BG(II)-8 在 3-4 葉齡對平速爛之抗性較大。

(五)千金子及稗草對丁基拉草之劑量反應分析試驗

本試驗進一步使用千金子及稗草各收集系對極長鏈脂肪酸合成抑制型除草劑中的丁基拉草(butachlor)進行劑量反應分析試驗，以判斷兩雜草物種各收集系彼此間對於丁基拉草之抗性差異以及在兩個生育時期下對藥劑的反應差異。

A. 兩個生育時期對丁基拉草之劑量反應分析

a. 千金子

本研究採集自台灣中南部水田一、二期作之千金子六個收集系，於千金子幼苗 1-2 及 3-4 葉齡時分別進行九種劑量的丁基拉草劑量反應分析，分別在施用藥劑後 28 天及 35 天記錄傷害指數、存活率、鮮重

及乾重等性狀，將資料帶入非線性對數邏輯回歸模式，得出劑量反應分析曲線及ED_{50} 值，最後比較千金子六個收集系彼此間對丁基拉草的抗性差異，以及兩個生育時期下千金子各收集系對丁基拉草的抗性差異。

1. 1-2 葉齡

將千金子 1-2 葉齡幼苗對丁基拉草進行劑量反應分析試驗，於施用藥劑 28 天後，觀察其生長情形(Figure 25)，並記錄傷害指數、存活率、鮮重及乾重等性狀，將資料以非線性對數邏輯回歸模式分析。

A.

B.

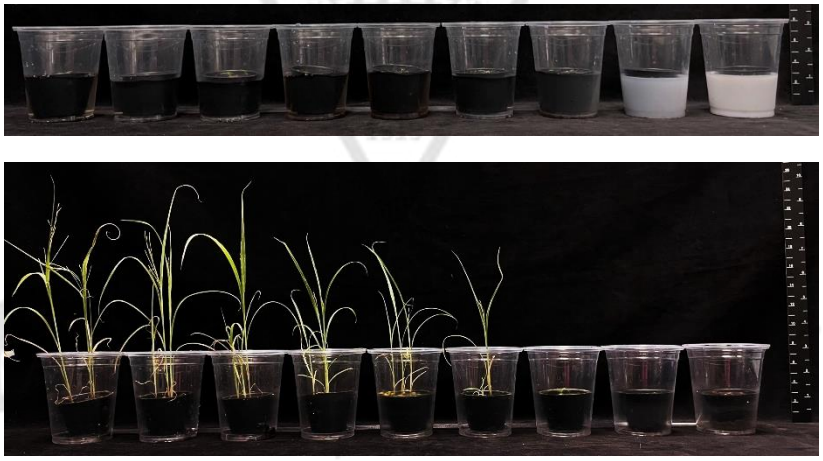


Figure 25. Herbicidal injury of 1-2 leaf red sprangle-top (*Leptochloa chinensis*) accession at 0 (A) and 28 (B) days after treatment of butachlor. Plants were observed from side view. Theoretical concentration of butachlor applied in paddy water based on the application rate recommended by Sinon Co. was 4.840 ppm (w/v).

由 1-2 葉齡千金子六個收集系對丁基拉草反應之ED_{50}值可知，其傷害指數之ED_{50}值介於 0.11-15.61 ppm、存活率之ED_{50}值介於 8.78-78.24 ppm、存活率經arcsine轉換後之ED_{50}值介於 8.97-80.28 ppm、鮮重之ED_{50}值介於 0.18-1.75 ppm、鮮重經arcsine轉換後之ED_{50}值介於 0.27-1.28 ppm、乾重之ED_{50}值介於 0.14-0.30 ppm、乾重經arcsine轉換後之ED_{50}值介於 0.07-0.59 (Table 81)，千金子六個收集系彼此間於傷害指數、存活率、鮮重及乾重的ED_{50}值經Fisher's protected LSD檢定後未達顯著差異，表示千金子各收集系對丁基拉草之抗性可能較接近。

Table 81. ED_{50} values of herbicide butachlor [*1] for the 1-2 leaf red sprangle-top (RS, *Leptochloa chinensis*) accessions. Data were collected at 28 days after treatment from three independent experiments.

Accession	ED_{50} (ppm, w/v)						
	Injury index	Survival rate		Fresh weight		Dry weight	
		Original data	Arcsine transformation	Original data	Arcsine transformation	Original data	Arcsine transformation
RS(II)-AES	15.61	73.22	73.44	0.96	1.20	0.30	0.34
RS(I)-1	3.69	78.24	80.28	0.18	0.27	0.14	0.45
RS(I)-2	0.11	35.65	35.45	1.16	0.92	0.18	0.43
RS(I)-14	4.17	25.93	26.21	1.19	0.89	0.21	0.59
RS(I)-15	9.33	63.15	65.56	1.75	1.28	0.18	0.13
RS(II)-11	1.26	8.78	8.97	0.66	0.53	0.14	0.07
P-value	0.12	0.53	0.50	0.69	0.81	0.93	0.75
$LSD_{0.05}$	ND[*2]	ND	ND	ND	ND	ND	ND

[*1] Theoretical concentration of butachlor in paddy water based on the application rate recommended by Sinon Co. was 4.840 ppm (w/v).

[*2] ND indicates no significant difference among six accessions according to Fisher's protected LSD test ($\alpha = 0.05$).

2. 3-4 葉齡

由 3-4 葉齡千金子六個收集系對丁基拉草之ED_{50}值可知，其傷害指數之ED_{50}值介於 5.20-38.71 ppm、存活率之ED_{50}值介於 28.75-512.29 ppm、存活率經arcsine轉換後之ED_{50}值介於 28.77-504.50 ppm、鮮重之ED_{50}值介於 0.04-5.30 ppm、鮮重經arcsine轉換後之ED_{50}值介於 0.10-7.51 ppm、乾重之ED_{50}值介於 0.04-8.98 ppm、乾重經arcsine轉換後之ED_{50}值介於 0.07-6.50 (Table 82)，千金子六個收集系彼此間於傷害指數、鮮重及乾重的ED_{50}值經Fisher's protected LSD檢定後未達顯著差異，僅存活率之ED_{50}值出現顯著差異，其中RS(I)-14 及RS(I)-15 的ED_{50}值顯著高於其他千金子收集系，表示此二個千金子收集系對藥劑的抗性相對其他收集系較大。試驗結果亦發現 3-4 葉齡千金子各收集系之ED_{50}值似乎較 1-2 葉齡高，且高於丁基拉草田間推薦用量 4.840 ppm，因此進一步釐清千金子收集系在兩個生育時期對丁基拉草之抗性差異。

Table 82. ED_{50} values of herbicide butachlor [*1] for the 3-4 leaf red sprangle-top (RS, *Leptochloa chinensis*) accessions. Data were collected at 35 days after treatment from three independent experiments.

Accession	ED_{50} (ppm, w/v)						
	Injury index	Survival rate		Fresh weight		Dry weight	
		Original data	Arcsine transformation	Original data	Arcsine transformation	Original data	Arcsine transformation
RS(II)-AES	5.20	51.23	50.45	0.04	0.10	0.17	0.17
RS(I)-1	37.25	256.78	250.88	0.90	1.69	2.54	2.51
RS(I)-2	7.55	102.35	102.07	4.22	3.57	8.98	6.50
RS(I)-14	25.12	489.49	489.35	2.02	3.81	0.60	0.54
RS(I)-15	27.52	512.29	504.50	5.30	7.51	1.68	1.32
RS(II)-11	6.42	28.75	28.77	2.39	0.45	0.04	0.07
P-value	0.37	< 0.05	< 0.05	0.31	0.32	0.26	0.20
$LSD_{0.05}$	ND[*2]	224.67	218.81	ND	ND	ND	ND

[*1] Theoretical concentration of butachlor in paddy water based on the application rate recommended by Sinon Co. was 4.840 ppm (w/v).

[*2] ND indicates no significant difference among six accessions according to Fisher's protected LSD test ($\alpha = 0.05$).

3. 不同生育時期之劑量反應比較

比較兩個生育時期之千金子六個收集系對丁基拉草之傷害指數的ED_{50} 值，可知千金子各收集系於兩個生育時期的ED_{50} 值，經Fisher's protected LSD 檢定後僅RS(II)-11 出現顯著差異，其他收集系則未達到顯著差異(Table 83)。

Table 83. Comparison of ED_{50} values of herbicide butachlor for red sprangle-top (RS, *Leptochloa chinensis*) accessions between 1-2 and 3-4 leaf stages based on injury index. Data from three independent experiments were collected at 28 and 35 days, respectively, after treatment.

Accession	ED_{50} (injury index) (ppm)		P-value	$LSD_{0.05}$
	1-2 leaf	3-4 leaf		
RS(II)-AES	15.61	5.20	0.26	ND*
RS(I)-1	3.69	37.25	0.23	ND
RS(I)-2	0.11	7.55	0.28	ND
RS(I)-14	4.17	17.79	0.15	ND
RS(I)-15	9.33	27.52	0.23	ND
RS(II)-11	1.26	6.42	< 0.05	2.61

* ND indicates no significant difference according to Fisher's protected LSD test (α = 0.05).

比較兩個生育時期之千金子六個收集系對丁基拉草存活率的ED_{50}值，可知千金子各收集系於兩個生育時期的ED_{50}值，經Fisher's protected LSD檢定後僅RS(I)-14、RS(I)-15 出現顯著差異，其他收集系則未達到顯著差異(Table 84)。

Table 84. Comparison of ED_{50} values of herbicide butachlor for red sprangle-top (RS, *Leptochloa chinensis*) accessions between 1-2 and 3-4 leaf stages based on survival rate (original data). Data from three independent experiments were collected at 28 and 35 days, respectively, after treatment.

Accession	ED_{50} (survival rate) (ppm)		P-value	$LSD_{0.05}$
	1-2 leaf	3-4 leaf		
RS(II)-AES	73.22	51.23	0.62	ND*
RS(I)-1	78.24	256.78	0.28	ND
RS(I)-2	35.65	102.35	0.22	ND
RS(I)-14	25.93	489.49	< 0.05	59.15
RS(I)-15	63.15	512.29	< 0.05	127.57
RS(II)-11	8.78	28.75	0.11	ND

* ND indicates no significant difference according to Fisher's protected LSD test (α = 0.05).

比較兩個生育時期之千金子六個收集系對丁基拉草存活率經arcsine轉換後的ED_{50}值，可知千金子各收集系於兩個生育時期的ED_{50}值，經Fisher's protected LSD檢定後僅RS(I)-14、RS(I)-15出現顯著差異，其他收集系則未達到顯著差異(Table 85)。

Table 85. Comparison of ED_{50} values of herbicide butachlor for red sprangle-top (RS, *Leptochloa chinensis*) accessions between 1-2 and 3-4 leaf stages based on survival rate (arcsine transformation). Data from three independent experiments were collected at 28 and 35 days, respectively, after treatment.

Accession	ED_{50} (Survival rate) (ppm)		P-value	$LSD_{0.05}$
	1-2 leaf	3-4 leaf		
RS(II)-AES	73.44	50.45	0.61	ND*
RS(I)-1	80.28	250.88	0.29	ND
RS(I)-2	35.45	102.07	0.22	ND
RS(I)-14	26.21	489.35	< 0.05	46.86
RS(I)-15	65.56	504.50	< 0.05	125.86
RS(II)-11	8.97	28.77	0.12	ND

* ND indicates no significant difference according to Fisher's protected LSD test (α = 0.05).

比較兩個生育時期之千金子六個收集系對丁基拉草鮮重的ED_{50}值，可知千金子各收集系於兩個生育時期的ED_{50}值，經Fisher's protected LSD檢定後皆未達到顯著差異(Table 86)。

Table 86. Comparison of ED_{50} values of herbicide butachlor for red sprangle-top (RS, *Leptochloa chinensis*) accessions between 1-2 and 3-4 leaf stages based on survival rate (FW, original data). Data from three independent experiments were collected at 28 and 35 days, respectively, after treatment.

Accession	ED_{50} (FW) (ppm)		P-value	$LSD_{0.05}$
	1-2 leaf	3-4 leaf		
RS(II)-AES	0.96	0.04	0.34	ND*
RS(I)-1	0.18	0.90	0.12	ND
RS(I)-2	1.16	4.22	0.21	ND
RS(I)-14	1.19	2.02	0.70	ND
RS(I)-15	1.75	5.30	0.22	ND
RS(II)-11	0.66	2.39	0.50	ND

* ND indicates no significant difference according to Fisher's protected LSD test (α = 0.05).

比較兩個生育時期之千金子六個收集系對丁基拉草之鮮重經arcsine轉換後的ED_{50}值，可知千金子各收集系於兩個生育時期的ED_{50}值，經Fisher's protected LSD檢定後皆未達到顯著差異(Table 87)。

Table 87. Comparison of ED_{50} values of herbicide butachlor for red sprangle-top (RS, *Leptochloa chinensis*) accessions between 1-2 and 3-4 leaf stages based on survival rate (FW, arcsine transformation). Data from three independent experiments were collected at 28 and 35 days, respectively, after treatment.

Accession	ED_{50} (FW) (ppm)		P-value	$LSD_{0.05}$
	1-2 leaf	3-4 leaf		
RS(II)-AES	1.20	0.10	0.37	ND*
RS(I)-1	0.27	1.69	0.27	ND
RS(I)-2	0.92	3.57	0.15	ND
RS(I)-14	0.89	3.81	0.46	ND
RS(I)-15	1.28	7.51	0.23	ND
RS(II)-11	0.53	0.45	0.79	ND

* ND indicates no significant difference according to Fisher's protected LSD test (α = 0.05).

比較兩個生育時期之千金子六個收集系對丁基拉草之乾重的ED_{50}值，可知千金子各收集系於兩個生育時期的ED_{50}值，經Fisher's protected LSD 檢定後僅RS(I)-15 出現顯著差異，其他收集系則未達到顯著差異(Table 88)。

Table 88. Comparison of ED_{50} values of herbicide butachlor for red sprangle-top (RS, *Leptochloa chinensis*) accessions between 1-2 and 3-4 leaf stages based on survival rate (DW, original data). Data from three independent experiments were collected at 28 and 35 days, respectively, after treatment.

Accession	ED_{50} (DW) (ppm)		P-value	$LSD_{0.05}$
	1-2 leaf	3-4 leaf		
RS(II)-AES	0.30	0.17	0.62	ND*
RS(I)-1	0.14	2.54	0.12	ND
RS(I)-2	0.18	8.98	0.26	ND
RS(I)-14	0.21	0.60	0.52	ND
RS(I)-15	0.18	1.68	< 0.05	0.99
RS(II)-11	0.14	0.04	0.29	ND

* ND indicates no significant difference according to Fisher's protected LSD test ($\alpha = 0.05$).

比較兩個生育時期之千金子六個收集系對丁基拉草之乾重經arcsine轉換後的ED_{50}值，可知千金子各收集系於兩個生育時期的ED_{50}值，經Fisher's protected LSD檢定後僅RS(I)-15出現顯著差異，其他收集系則未達到顯著差異(Table 89)。

Table 89. Comparison of ED_{50} values of herbicide butachlor for red sprangle-top (RS, *Leptochloa chinensis*) accessions between 1-2 and 3-4 leaf stages based on survival rate (DW, arcsine transformation). Data from three independent experiments were collected at 28 and 35 days, respectively, after treatment.

Accession	ED_{50} (DW) (ppm)		P-value	$LSD_{0.05}$
	1-2 leaf	3-4 leaf		
RS(II)-AES	0.34	0.17	0.54	ND*
RS(I)-1	0.45	2.51	0.16	ND
RS(I)-2	0.43	6.50	0.24	ND
RS(I)-14	0.59	0.54	0.95	ND
RS(I)-15	0.13	1.32	< 0.05	0.50
RS(II)-11	0.07	0.07	0.99	ND

* ND indicates no significant difference according to Fisher's protected LSD test ($\alpha = 0.05$).

根據以上試驗結果可知，千金子六個收集系在 1-2 葉齡對丁基拉草傷害指數、存活率、鮮重及乾重之ED_{50}值經Fisher's protected LSD檢定後皆未達顯著差異，表示收集系彼此間對藥劑之抗性較相似；而在 3-4 葉齡對丁基拉草之傷害指數、鮮重及乾重之ED_{50}值亦未達顯著差異，整體而言千金子各收集系彼此間在兩個生育時期對藥劑之抗性較一致。至於 3-4 葉齡千金子收集系於RS(I)-14 及RS(I)-15 存活率之ED_{50}值顯著高於RS(II)-AES及RS(I)-2，表示RS(I)-14 及RS(I)-15 可能在此性狀表現上其抗性相對RS(II)-AES及RS(I)-2 較大。

比較兩個生育時期之千金子各收集系對藥劑之反應，整體而言千金子六個收集系在四個性狀指標下的反應經檢定後未達顯著差異，表示千金子在兩個生育時期下對藥劑之抗性較一致，但其中 3-4 葉齡RS(I)-15 在存活率及乾重指標下ED_{50}值顯著高於 1-2 葉齡，顯示生育時期可能影響RS(I)-15 之抗性表現。

綜合試驗結果可知，3-4 葉齡千金子收集系RS(I)-14 及RS(I)-15 在存活率性狀下對丁基拉草表現出一定程度的抗性，可能對丁基拉草具有單一抗性。根據此二收集系取樣地點之田野調查，其用藥經歷分別為丁拉依速隆及丁基拉草等(Supplementary 1)，推測此二收集系可能在除草劑選汰壓力下對丁基拉草產生抗性。

b. 稗草

本研究採集台灣中南部水田一、二期作之稗草四個收集系，於稗草幼苗生長至 1-2 及 3-4 葉齡時分別進行九種劑量的丁基拉草劑量反應分析，分別在施用藥劑後 28 天及 35 天記錄傷害指數、存活率、鮮重及乾重等性狀，將資料帶入非線性對數邏輯回歸模式，得出劑量反應分析曲線及ED_{50} 值，最後比較稗草四個收集系彼此間對丁基拉草的抗性差異以及兩個生育時期之稗草各收集系對丁基拉草的抗性差異。

1. 1-2 葉齡

稗草 1-2 葉齡幼苗於施用藥劑後 28 天，觀察其生長情形(Figure 26)，並記錄傷害指數、存活率、鮮重及乾重等性狀，將資料以非線性對數邏輯回歸模式分析。

A.

B.

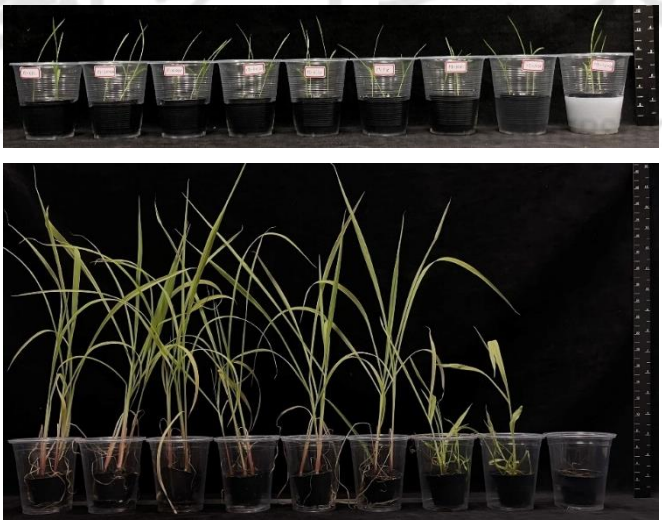


Figure 26. Herbicidal injury of 1-2 leaf barnyard grass (*Echinochloa crus-galli*) accession at 0 (A) and 28 (B) days after treatment of butachlor. Plants were observed from side view. Theoretical concentration of butachlor applied in paddy water based on the application rate recommended by Sinon Co. was 4.840 ppm (w/v).

由 1-2 葉齡稗草四個收集系對丁基拉草反應之ED_{50}值可知，其傷害指數之ED_{50}值介於 0.1-94.9 ppm、存活率之ED_{50}值介於 39.3-778.8 ppm、存活率經arcsine轉換後之ED_{50}值介於 37.4-793.6 ppm、鮮重之ED_{50}值介 0.4-91.2 ppm、鮮重經arcsine轉換後之ED_{50}值介於 1.4-101.4 ppm、乾重之ED_{50}值介於 0.6-94.1 ppm、乾重經arcsine轉換後之ED_{50}值介於 4.9-146.7 (Table 90)，稗草四個收集系彼此間於傷害指數及鮮重的ED_{50}值經 Fisher's protected LSD檢定後出現顯著差異，其中以BG(II)-8 及BG(II)-17 之ED_{50}值顯著高於BG-WT，表示此二個稗草收集系對藥劑的抗性相對較BG-WT大。雖然部分收集系之ED_{50}值經檢定後無顯著差異，但數值相差較大，如BG(II)-8 及BG(II)-17 之存活率ED_{50}值分別為 207.2 及 778.8 ppm均遠大於BG-WT及BG(II)-13，表示BG(II)-8 及BG(II)-17 可能對丁基拉草之抗性相對較BG-WT及BG(II)-13 大。

Table 90. ED_{50} values of herbicide butachlor[*1] for the 1-2 leaf barnyard grass (BG, *Echinochloa crus-galli*) accessions. Data were collected at 28 days after treatment from three independent experiments.

Accession	ED_{50} (ppm, w/v)						
	Injury index	Survival rate		Fresh weight		Dry weight	
		Original data	Arcsine transformation	Original data	Arcsine transformation	Original data	Arcsine transformation
BG-WT	0.1	39.3	37.4	0.4	1.4	0.6	4.9
BG(II)-8	68.4	207.2	218.2	6.7	17.7	94.1	146.7
BG(II)-13	5.1	76.4	75.6	36.1	29.9	20.5	49.0
BG(II)-17	94.9	778.8	793.6	91.2	101.4	24.8	78.7
P-value	< 0.05	0.09	0.08	< 0.05	0.24	< 0.05	0.31
$LSD_{0.05}$	37.0	ND[*2]	ND	73.2	ND	77.9	ND

[*1] Theoretical concentration of butachlor in paddy water based on the application rate recommended by Sinon Co. was 4.840 ppm (w/v).

[*2] ND indicates no significant difference among four accessions according to Fisher's protected LSD test ($\alpha = 0.05$).

2. 3-4 葉齡

由 3-4 葉齡稗草四個收集系針對丁基拉草之ED_{50}值可知，其傷害指數之ED_{50}值介於 42.9-270.7 ppm、存活率之ED_{50}值介於 84.9-1,393.4 ppm、存活率經arcsine轉換後之ED_{50}值介於 84.8-1,341.3 ppm、鮮重之ED_{50}值介於 71.0-1,067.9 ppm、鮮重經arcsine轉換後之ED_{50}值介於 370.7-4,091.0 ppm、乾重之ED_{50}值介於 21.1-300.1 ppm、乾重經arcsine轉換後之ED_{50}值介於 137.9-1,547.2 ppm (Table 91)，稗草四個收集系雖然傷害指數之ED_{50}值彼此間差異未達顯著水準，但於存活率ED_{50}值經Fisher's protected LSD檢定後具有顯著差異，表示稗草各收集系可能對丁基拉草之抗性差異較不一致。其中以稗草收集系BG(II)-17 之ED_{50}值顯著高於BG-WT，而後進一步將BG(II)-17 與BG-WT之存活率的ED_{50}值相除可得BG(II)-17 之抗性指數介於 15.8-16.4，表示稗草收集系BG(II)-17 相較於BG-WT可能對丁基拉草具有一定程度的抗性。試驗結果亦發現 3-4 葉齡之稗草各收集系之ED_{50}值似乎較 1-2 葉齡高，且高於田間推薦用量 4.840 ppm，因此進一步比較稗草收集系在兩個生育時期對丁基拉草之ED_{50}值差異。

Table 91. ED_{50} values of herbicide butachlor[*1] for the 3-4 leaf barnyard grass (BG, *Echinochloa crus-galli*) accessions. Data were collected at 35 days after treatment from three independent experiments.

Accession	ED_{50} (ppm, w/v)						
	Injury index	Survival rate		Fresh weight		Dry weight	
		Original data	Arcsine transformation	Original data	Arcsine transformation	Original data	Arcsine transformation
BG-WT	42.9	84.9	84.8	71.0	370.7	21.1	137.9
BG(II)-8	145.9	405.4	396.5	107.5	1,129.7	24.7	193.9
BG(II)-13	200.6	1,179.7	1,181.1	1,147.2	990.3	142.4	555.2
BG(II)-17	270.7	1,393.4	1,341.3	1,067.9	4,091.0	300.1	1,547.2
P-value	0.08	< 0.05	< 0.05	0.54	0.46	0.13	0.15
$LSD_{0.05}$	ND[*2]	1,180.1	1,126.3	ND	ND	ND	ND

[*1] Theoretical concentration of butachlor in paddy water based on the application rate recommended by Sinon Co. was 4.840 ppm (w/v).

[*2] ND indicates no significant difference among four accessions according to Fisher's protected LSD test ($\alpha = 0.05$).

3. 不同生育時期之劑量反應比較

比較兩個生育時期之稗草四個收集系對丁基拉草之傷害指數的 ED_{50} 值，可知稗草各收集系於兩個生育時期的 ED_{50} 值經 Fisher's protected LSD 檢定後僅 BG(II)-17 出現顯著差異，其他收集系並未達到顯著差異(Table 92)。

Table 92. Comparison of ED_{50} values of herbicide butachlor for barnyard grass (BG, *Echinochloa crus-galli*) accessions between 1-2 and 3-4 leaf stages based on injury index. Data from three independent experiments were collected at 28 and 35 days, respectively, after treatment.

Accession	ED_{50} (injury index) (ppm)		P-value	$LSD_{0.05}$
	1-2 leaf	3-4 leaf		
BG-WT	0.1	42.9	0.13	ND*
BG(II)-8	68.4	145.9	0.06	ND
BG(II)-13	5.2	200.6	0.11	ND
BG(II)-17	94.9	270.7	< 0.05	121.2

* ND indicates no significant difference according to Fisher's protected LSD test (α = 0.05).

比較兩個生育時期之稗草四個收集系對丁基拉草之存活率的 ED_{50} 值，可知稗草各收集系於兩個生育時期的 ED_{50} 值經 Fisher's protected LSD檢定後僅BG(II)-13 出現顯著差異，而其他稗草收集系並未達顯著差異(Table 93)。

Table 93. Comparison of ED_{50} values of herbicide butachlor for barnyard grass (BG, *Echinochloa crus-galli*) accessions between 1-2 and 3-4 leaf stages based on survival rate (original data). Data from three independent experiments were collected at 28 and 35 days, respectively, after treatment.

Accession	ED_{50} (survival rate) (ppm)		P-value	$LSD_{0.05}$
	1-2 leaf	3-4 leaf		
BG-WT	39.3	84.9	0.31	ND*
BG(II)-8	207.2	405.4	0.18	ND
BG(II)-13	76.4	1,179.7	< 0.05	1,004.1
BG(II)-17	778.8	1,393.4	0.37	ND

* ND indicates no significant difference according to Fisher's protected LSD test (α = 0.05).

比較兩個生育時期的稗草四個收集系對丁基拉草之存活率經arcsine轉換後的ED_{50} 值，可知稗草各收集系於兩個生育時期的ED_{50} 值經Fisher's protected LSD檢定後僅BG(II)-13 出現顯著差異，而其他稗草收集系並未達顯著差異(Table 94)。

Table 94. Comparison of ED_{50} values of herbicide butachlor for barnyard grass (BG, *Echinochloa crus-galli*) accessions between 1-2 and 3-4 leaf stages based on survival rate (arcsine transformation). Data from three independent experiments were collected at 28 and 35 days, respectively, after treatment.

Accession	ED_{50} (survival rate) (ppm)		P-value	$LSD_{0.05}$
	1-2 leaf	3-4 leaf		
BG-WT	37.4	84.8	0.29	ND*
BG(II)-8	218.2	396.5	0.24	ND
BG(II)-13	75.6	1,181.1	< 0.05	1,001.4
BG(II)-17	793.6	1,341.3	0.40	ND

* ND indicates no significant difference according to Fisher's protected LSD test (α = 0.05).

比較兩個生育時期的稗草四個收集系對丁基拉草之鮮重ED_{50}值，可知稗草各收集系於兩個生育時期ED_{50}值經Fisher's protected LSD檢定後並未達到顯著差異(Table 95)，表示 1-2 葉齡及 3-4 葉齡稗草幼苗對藥劑的抗性相似。

Table 95. Comparison of ED_{50} values of herbicide butachlor for barnyard grass (BG, *Echinochloa crus-galli*) accessions between 1-2 and 3-4 leaf stages based on fresh weight (FW, original data). Data from three independent experiments were collected at 28 and 35 days, respectively, after treatment.

Accession	ED_{50} (FW) (ppm)		P-value	$LSD_{0.05}$
	1-2 leaf	3-4 leaf		
BG-WT	0.4	71.0	0.32	ND*
BG(II)-8	6.7	107.5	0.15	ND
BG(II)-13	36.1	1,147.2	0.37	ND
BG(II)-17	91.2	1,067.9	0.26	ND

* ND indicates no significant difference according to Fisher's protected LSD test (α = 0.05).

比較兩個生育時期的稗草四個收集系對丁基拉草之鮮重經arcsine轉換後的ED_{50}值，可知稗草各收集系於兩個生育時期ED_{50}值經Fisher's protected LSD檢定後並未達到顯著差異(Table 96)，表示 1-2 葉齡及 3-4 葉齡稗草幼苗對藥劑的抗性相似。

Table 96. Comparison of ED_{50} values of herbicide butachlor for barnyard grass (BG, *Echinochloa crus-galli*) accessions between 1-2 and 3-4 leaf stages based on fresh weight (FW, arcsine transformation). Data from three independent experiments were collected at 28 and 35 days, respectively, after treatment.

Accession	ED_{50} (FW) (ppm)		P-value	$LSD_{0.05}$
	1-2 leaf	3-4 leaf		
BG-WT	1.4	370.7	0.31	ND*
BG(II)-8	17.7	1,129.7	0.35	ND
BG(II)-13	29.9	990.3	0.12	ND
BG(II)-17	101.4	4,091.0	0.28	ND

* ND indicates no significant difference according to Fisher's protected LSD test (α = 0.05).

比較兩個生育時期之稗草四個收集系對丁基拉草之乾重的 ED_{50} 值，可知稗草各收集系於兩個生育時期 ED_{50} 值經 Fisher's protected LSD 檢定後並未達到顯著差異(Table 97)，表示 1-2 葉齡及 3-4 葉齡稗草幼苗對藥劑的抗性相似。

Table 97. Comparison of ED_{50} values of herbicide butachlor for barnyard grass (BG, *Echinochloa crus-galli*) accessions between 1-2 and 3-4 leaf stages based on dry weight (DW, original data). Data from three independent experiments were collected at 28 and 35 days, respectively, after treatment.

Accession	ED_{50} (DW) (ppm)		P-value	$LSD_{0.05}$
	1-2 leaf	3-4 leaf		
BG-WT	0.6	21.1	0.25	ND*
BG(II)-8	94.1	24.7	0.10	ND
BG(II)-13	20.5	142.4	0.30	ND
BG(II)-17	24.8	300.1	0.10	ND

* ND indicates no significant difference according to Fisher's protected LSD test (α = 0.05).

比較兩個生育時期之稗草四個收集系對丁基拉草之乾重經arcsine轉換後的ED_{50} 值，可知稗草各收集系於兩個生育時期ED_{50} 值經Fisher's protected LSD檢定後並未達到顯著差異(Table 98)，表示 1-2 葉齡及 3-4 葉齡稗草幼苗對藥劑的抗性相似。

Table 98. Comparison of ED_{50} values of herbicide butachlor for barnyard grass (BG, *Echinochloa crus-galli*) accessions between 1-2 and 3-4 leaf stages based on dry weight (DW, arcsine transformation). Data from three independent experiments were collected at 28 and 35 days, respectively, after treatment.

Accession	ED_{50} (DW) (ppm)		P-value	$LSD_{0.05}$
	1-2 leaf	3-4 leaf		
BG-WT	4.9	137.9	0.17	ND*
BG(II)-8	146.7	193.9	0.76	ND
BG(II)-13	49.0	555.2	0.15	ND
BG(II)-17	78.7	1,547.2	0.14	ND

* ND indicates no significant difference according to Fisher's protected LSD test (α = 0.05).

根據以上試驗結果可知，稗草四個收集系在 1-2 葉齡對丁基拉草之傷害指數、鮮重及乾重的ED_{50}值經Fisher's protected LSD檢定後出現顯著差異，其中BG(II)-8 及BG(II)-17 對丁基拉草的傷害指數、鮮重及乾重之ED_{50} 值顯著高於BG-WT，可能對藥劑有一定程度的抗性；而 3-4 葉齡稗草彼此收集系間亦對丁基拉草存活率之ED_{50} 值出現顯著差異，其中以稗草收集系BG(II)-17 的存活率之ED_{50}值顯著高於BG-WT，表示 BG(II)-17 在 3-4 葉齡對丁基拉草具有較大的抗性。

比較兩個生育時期之稗草各收集系對藥劑之反應，整體而言稗草四個收集系在四個性狀下的反應經檢定後大部分未達顯著差異，表示稗草在兩個生育時期下對藥劑之抗性較一致，但其中 3-4 葉齡之BG(II)-13 及BG(II)-17 分別在傷害指數及存活率指標下ED_{50}值顯著高於 1-2 葉齡，顯示生育時期可能對BG(II)-13 及BG(II)-17 之抗性影響較大。

綜合試驗結果可知，稗草收集系BG(II)-17 在 1-2 及 3-4 葉齡皆對丁基拉草相對BG-WT表現出一定程度的抗性，可能對丁基拉草具有單一抗性。根據此收集系取樣地點之田野調查其用藥經歷包括丁基拉草及丁拉免速隆等(Supplementary 2)，可能此收集系在除草劑選汰壓力下對丁基拉草產生抗性。

(六)千金子及稗草對樂滅草之劑量反應分析試驗

本試驗進一步使用千金子及稗草各收集系對原紫質原氧化酶(protoporphyrinogen oxidase)抑制劑中的樂滅草(oxadiazon)進行劑量反應分析試驗，以判斷兩雜草物種各收集系彼此間對於樂滅草之抗性差異以及在兩個生育時期下對藥劑的反應差異。

A. 兩個生育時期對樂滅草之劑量反應分析

a. 千金子

本研究採集自台灣中南部水田一、二期作之千金子六個收集系，於千金子幼苗 1-2 及 3-4 葉齡時分別進行九種劑量的樂滅草劑量反應分析，分別在施用藥劑後 28 天及 35 天記錄傷害指數、存活率、鮮重及乾重等性狀，將資料帶入非線性對數邏輯回歸模式分析，得出劑量反應分析曲線及ED_{50} 值，最後比較千金子六個收集系彼此間對樂滅草的抗性差異，以及兩個生育時期之千金子各收集系對樂滅草的抗性差異。

1. 1-2 葉齡

將千金子 1-2 葉齡幼苗對樂滅草進行劑量反應分析試驗，於施用藥劑後 28 天，觀察其生長情形(Figure 27)，並記錄傷害指數、存活率、鮮重及乾重等性狀，將資料以非線性對數邏輯回歸模式分析，得出千金子各收集系對樂滅草之劑量反應分析曲線。

A.

B.

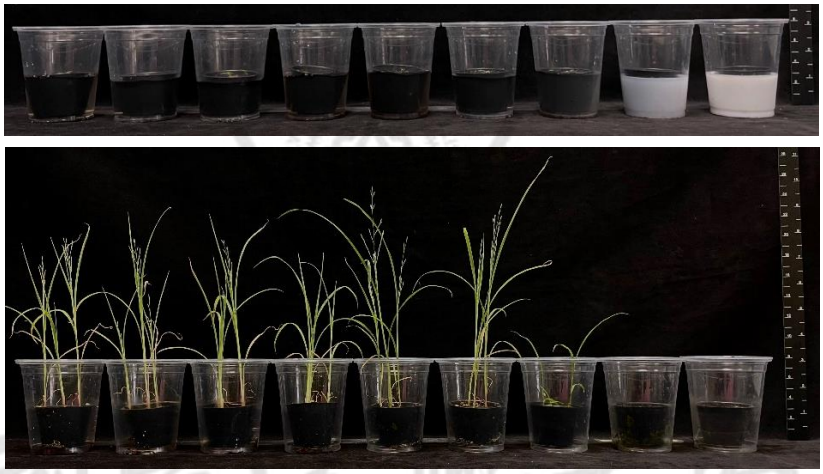


Figure 27. Herbicidal injury of 1-2 leaf red sprangle-top (*Leptochloa chinensis*) accession at 0 (A) and 28 (B) days after treatment of oxadiazon. Plants were observed from side view. Theoretical concentration of butachlor applied in paddy water based on the application rate recommended by Chia Tai enterprise CO. was 2.145 ppm (w/v).

由 1-2 葉齡千金子六個收集系對樂滅草反應之ED_{50}值可知，其傷害指數之ED_{50}值介於 0.07-15.24 ppm、存活率之ED_{50}值介於 17.37-84.91 ppm、存活率經arcsine轉換後之ED_{50}值介於 17.40-82.94 ppm、鮮重之ED_{50}值介於 0.06-15.99 ppm、鮮重經arcsine轉換後之ED_{50}值介於 0.08-10.12 ppm、乾重之ED_{50}值介於 0.02-3.15 ppm、乾重經arcsine轉換後之ED_{50}值介於 0.02-1.86 (Table 99)，千金子六個收集系彼此間傷害指數之ED_{50}值經Fisher's protected LSD檢定後出現顯著差異，其中以RS(I)-14之ED_{50}值顯著高於RS(I)-2，將其ED_{50}值相除，可得RS(I)-14 的抗性指數為 217.7，表示RS(I)-14 對樂滅草之抗性相對RS(I)-2 較大。

Table 99. ED_{50} values of herbicide oxadiazon[*1] for the 1-2 leaf red sprangle-top (RS, *Leptochloa chinensis*) accessions. Data were collected at 28 days after treatment from three independent experiments.

Accession	ED_{50} (ppm, w/v)						
	Injury index	Survival rate		Fresh weight		Dry weight	
		Original data	Arcsine transformation	Original data	Arcsine transformation	Original data	Arcsine transformation
RS(II)-AES	0.88	17.37	17.40	0.73	0.50	0.88	0.54
RS(I)-1	0.98	84.91	82.94	0.06	0.08	0.02	0.02
RS(I)-2	0.07	18.30	17.95	0.57	0.63	0.34	0.38
RS(I)-14	15.24	66.44	66.91	2.24	1.54	3.05	1.86
RS(I)-15	6.96	39.24	39.08	0.27	0.19	0.65	0.48
RS(II)-11	5.26	39.32	39.15	15.99	10.12	3.15	1.84
P-value	< 0.05	0.70	0.69	0.29	0.17	0.37	0.31
$LSD_{0.05}$	9.22	ND[*2]	ND	ND	ND	ND	ND

[*1] Theoretical concentration of butachlor in paddy water based on the application rate recommended by Chia Tai enterprise CO. was 2.145 ppm (w/v).

[*2] ND indicates no significant difference among six accessions according to Fisher's protected LSD test ($\alpha = 0.05$).

2. 3-4 葉齡

由 3-4 葉齡千金子六個收集系對樂滅草之ED_{50}值可知，其傷害指數之ED_{50}值介於 4.92-31.34 ppm、存活率之ED_{50}值介於 36.89-98.93 ppm、存活率經arcsine轉換後之ED_{50}值介於 37.03-99.89 ppm、鮮重之ED_{50}值介於 3.31-39.48 ppm、鮮重經arcsine轉換後之ED_{50}值介於 2.38-21.73 ppm、乾重之ED_{50}值介於 1.81-40.35 ppm、乾重經arcsine轉換後之ED_{50}值介於 2.31-47.42 (Table 100)，千金子六個收集系彼此間於鮮重及乾重的ED_{50}值經Fisher's protected LSD檢定後出現顯著差異，其中RS(I)-14的ED_{50}值顯著高於其他千金子收集系，以RS(I)-1 為對照，兩者之ED_{50}值相除可得RS(I)-14 的抗性指數介於 7.21-9.13，表示此收集系對藥劑的抗性相對較RS(I)-1 大。試驗結果亦發現 3-4 葉齡千金子各收集系之ED_{50}值似乎較 1-2 葉齡高，且高於樂滅草田間推薦用量 2.145 ppm，因此進一步比較千金子收集系在兩個生育時期對樂滅草之ED_{50}值。

Table 100. ED_{50} values of herbicide oxadiazon [*1] for the 3-4 leaf red sprangle-top (RS, *Leptochloa chinensis*) accessions. Data were collected at 35 days after treatment from three independent experiments.

Accession	ED_{50} (ppm, w/v)						
	Injury index	Survival rate		Fresh weight		Dry weight	
		Original data	Arcsine transformation	Original data	Arcsine transformation	Original data	Arcsine transformation
RS(II)-AES	18.24	37.61	37.33	5.01	3.89	1.86	2.31
RS(I)-1	8.37	37.03	37.21	3.31	2.38	5.60	9.77
RS(I)-2	9.04	98.93	99.89	3.69	2.54	1.81	4.14
RS(I)-14	30.17	68.09	68.09	39.48	21.73	40.35	47.42
RS(I)-15	31.34	68.09	68.09	4.19	2.53	7.30	6.90
RS(II)-11	4.92	36.89	37.03	6.06	5.57	2.05	2.07
P-value	0.06	0.46	0.46	< 0.05	< 0.05	< 0.05	0.11
$LSD_{0.05}$	ND[*2]	ND	ND	19.15	10.54	29.76	ND

[*1] Theoretical concentration of oxadiazon in paddy water based on the application rate recommended by Chia Tai enterprise CO. was 2.145 ppm (w/v).

[*2] ND indicates no significant difference among six accessions according to Fisher's protected LSD test ($\alpha = 0.05$).

3. 不同生育時期之劑量反應比較

比較兩個生育時期之千金子六個收集系對樂滅草之傷害指數的ED_{50} 值，可知千金子各收集系於兩個生育時期的ED_{50} 值，經Fisher's protected LSD檢定後僅RS(II)-AES及RS(I)-1 出現顯著差異，其他收集系則未達到顯著差異(Table 101)。

Table 101. Comparison of ED_{50} values of herbicide oxadiazon for red sprangle-top (RS, *Leptochloa chinensis*) accessions between 1-2 and 3-4 leaf stages based on injury index. Data from three independent experiments were collected at 28 and 35 days, respectively, after treatment.

Accession	ED_{50} (injury index) (ppm)		P-value	$LSD_{0.05}$
	1-2 leaf	3-4 leaf		
RS(II)-AES	0.88	18.24	< 0.05	14.22
RS(I)-1	0.98	8.37	< 0.05	4.22
RS(I)-2	0.07	9.04	0.22	ND*
RS(I)-14	15.24	30.17	0.30	ND
RS(I)-15	6.96	31.34	0.06	ND
RS(II)-11	5.26	4.92	0.89	ND

* ND indicates no significant difference according to Fisher's protected LSD test (α = 0.05).

比較兩個生育時期之千金子六個收集系對樂滅草存活率的ED_{50}值，可知千金子各收集系於兩個生育時期的ED_{50}值，經Fisher's protected LSD檢定後皆未達到顯著差異(Table 102)。

Table 102. Comparison of ED_{50} values of herbicide oxadiazon for red sprangle-top (RS, *Leptochloa chinensis*) accessions between 1-2 and 3-4 leaf stages based on survival rate (original data). Data from three independent experiments were collected at 28 and 35 days, respectively, after treatment.

Accession	ED_{50} (survival rate) (ppm)		P-value	$LSD_{0.05}$
	1-2 leaf	3-4 leaf		
RS(II)-AES	17.37	37.61	0.27	ND*
RS(I)-1	84.91	37.03	0.56	ND
RS(I)-2	18.30	98.93	0.22	ND
RS(I)-14	66.44	68.09	0.94	ND
RS(I)-15	39.24	68.09	0.29	ND
RS(II)-11	39.32	36.89	0.94	ND

* ND indicates no significant difference according to Fisher's protected LSD test (α = 0.05).

比較兩個生育時期之千金子六個收集系對樂滅草存活率經arcsine轉換後的ED_{50}值，可知千金子各收集系於兩個生育時期的ED_{50}值，經Fisher's protected LSD檢定後皆未達到顯著差異(Table 103)。

Table 103. Comparison of ED_{50} values of herbicide oxadiazon for red sprangle-top (RS, *Leptochloa chinensis*) accessions between 1-2 and 3-4 leaf stages based on survival rate (arcsine transformation). Data from three independent experiments were collected at 28 and 35 days, respectively, after treatment.

Accession	ED_{50} (Survival rate) (ppm)		P-value	$LSD_{0.05}$
	1-2 leaf	3-4 leaf		
RS(II)-AES	17.40	37.33	0.28	ND*
RS(I)-1	82.94	37.21	0.57	ND
RS(I)-2	17.95	99.89	0.22	ND
RS(I)-14	66.91	68.09	0.96	ND
RS(I)-15	39.08	68.09	0.29	ND
RS(II)-11	39.15	37.03	0.94	ND

* ND indicates no significant difference according to Fisher's protected LSD test (α = 0.05).

比較兩個生育時期之千金子六個收集系對樂滅草鮮重的ED_{50}值，可知千金子各收集系於兩個生育時期的ED_{50}值，經Fisher's protected LSD檢定後僅RS(I)-14 出現顯著差異，其他收集系則未達到顯著差異(Table 104)。

Table 104. Comparison of ED_{50} values of herbicide oxadiazon for red sprangle-top (RS, *Leptochloa chinensis*) accessions between 1-2 and 3-4 leaf stages based on survival rate (FW, original data). Data from three independent experiments were collected at 28 and 35 days, respectively, after treatment.

Accession	ED_{50} (FW) (ppm)		P-value	$LSD_{0.05}$
	1-2 leaf	3-4 leaf		
RS(II)-AES	0.73	5.01	0.19	ND*
RS(I)-1	0.06	3.31	0.32	ND
RS(I)-2	0.57	3.69	0.38	ND
RS(I)-14	2.24	39.48	< 0.05	31.58
RS(I)-15	0.27	4.19	0.28	ND
RS(II)-11	15.99	6.06	0.49	ND

* ND indicates no significant difference according to Fisher's protected LSD test (α = 0.05).

比較兩個生育時期之千金子六個收集系對樂滅草鮮重經 arcsine 轉換後的 ED_{50} 值，可知千金子各收集系於兩個生育時期的 ED_{50} 值，經 Fisher's protected LSD 檢定後僅 RS(I)-14 出現顯著差異，其他收集系則未達到顯著差異(Table 105)。

Table 105. Comparison of ED_{50} values of herbicide oxadiazon for red sprangle-top (RS, *Leptochloa chinensis*) accessions between 1-2 and 3-4 leaf stages based on survival rate (FW, arcsine transformation). Data from three independent experiments were collected at 28 and 35 days, respectively, after treatment.

Accession	ED_{50} (FW) (ppm)		P-value	$LSD_{0.05}$
	1-2 leaf	3-4 leaf		
RS(II)-AES	0.50	3.89	0.10	ND*
RS(I)-1	0.08	2.38	0.24	ND
RS(I)-2	0.63	2.54	0.34	ND
RS(I)-14	1.54	21.73	< 0.05	16.79
RS(I)-15	0.19	2.53	0.13	ND
RS(II)-11	10.12	5.57	0.57	ND

* ND indicates no significant difference according to Fisher's protected LSD test (α = 0.05).

比較兩個生育時期之千金子六個收集系對樂滅草乾重的ED_{50} 值，可知千金子各收集系於兩個生育時期的ED_{50} 值，經Fisher's protected LSD 檢定後皆未達到顯著差異(Table 106)。

Table 106. Comparison of ED_{50} values of herbicide oxadiazon for red sprangle-top (RS, *Leptochloa chinensis*) accessions between 1-2 and 3-4 leaf stages based on survival rate (DW, original data). Data from three independent experiments were collected at 28 and 35 days, respectively, after treatment.

Accession	ED_{50} (DW) (ppm)		P-value	$LSD_{0.05}$
	1-2 leaf	3-4 leaf		
RS(II)-AES	0.88	1.86	0.25	ND*
RS(I)-1	0.02	5.60	0.20	ND
RS(I)-2	0.34	1.81	0.16	ND
RS(I)-14	3.05	40.35	0.13	ND
RS(I)-15	0.65	7.30	0.15	ND
RS(II)-11	3.15	2.05	0.72	ND

* ND indicates no significant difference according to Fisher's protected LSD test (α = 0.05).

比較兩個生育時期之千金子六個收集系對樂滅草乾重經 arcsine 轉換後的 ED_{50} 值，可知千金子各收集系於兩個生育時期的 ED_{50} 值，經 Fisher's protected LSD 檢定後皆未達到顯著差異(Table 107)。

Table 107. Comparison of ED_{50} values of herbicide oxadiazon for red sprangle-top (RS, *Leptochloa chinensis*) accessions between 1-2 and 3-4 leaf stages based on survival rate (DW, arcsine transformation). Data from three independent experiments were collected at 28 and 35 days, respectively, after treatment.

Accession	ED_{50} (DW) (ppm)		P-value	$LSD_{0.05}$
	1-2 leaf	3-4 leaf		
RS(II)-AES	0.54	2.31	0.17	ND*
RS(I)-1	0.02	9.77	0.16	ND
RS(I)-2	0.38	4.14	0.29	ND
RS(I)-14	1.86	47.42	0.17	ND
RS(I)-15	0.48	6.90	0.20	ND
RS(II)-11	1.84	2.07	0.90	ND

* ND indicates no significant difference according to Fisher's protected LSD test (α = 0.05).

根據以上試驗結果可知，1-2 葉齡千金子六個收集系對樂滅草的傷害指數之ED_{50}值經Fisher's protected LSD檢定後出現顯著差異，表示收集系彼此間對藥劑之抗性表現較不一致，其中以RS(I)-14 之ED_{50}值顯著高於其他收集系，表示此收集系可能對藥劑有一定程度的抗性。至於3-4 葉齡千金子收集系彼此間對樂滅草之ED_{50}值亦出現顯著差異，其中RS(I)-14 鮮重及乾重之ED_{50}值顯著高於其他收集系，顯示RS(I)-14 在 1-2 與 3-4 葉齡兩個生育時期皆對樂滅草具有一定程度的抗性。

綜合試驗結果可知，千金子收集系RS(I)-14 在兩個生育時期皆對樂滅草表現出一定程度的抗性。根據此收集系取樣地點之田野調查，其用藥經歷為丁拉依速隆等(Supplementary 1)，並無使用樂滅草之經驗，關於此收集系對樂滅草產生抗性之原因仍需進一步研究。

b. 稗草

本研究採集台灣中南部水田一、二期作之稗草四個收集系，於稗草幼苗生長至 1-2 及 3-4 葉齡時分別進行九種劑量的樂滅草劑量反應分析，分別在施用藥劑後 28 天及 35 天記錄傷害指數、存活率、鮮重及乾重等性狀，將資料帶入非線性對數邏輯回歸模式，得出劑量反應分析曲線及ED_{50} 值，最後比較稗草四個收集系彼此間對樂滅草的抗性差異以及兩個生育時期之稗草各收集系對樂滅草的抗性差異。

1. 1-2 葉齡

稗草 1-2 葉齡幼苗於施用藥劑後 28 天，觀察其生長情形(Figure 28)，並記錄傷害指數、存活率、鮮重及乾重等性狀，將資料以非線性對數邏輯回歸模式分析。

A.

B.

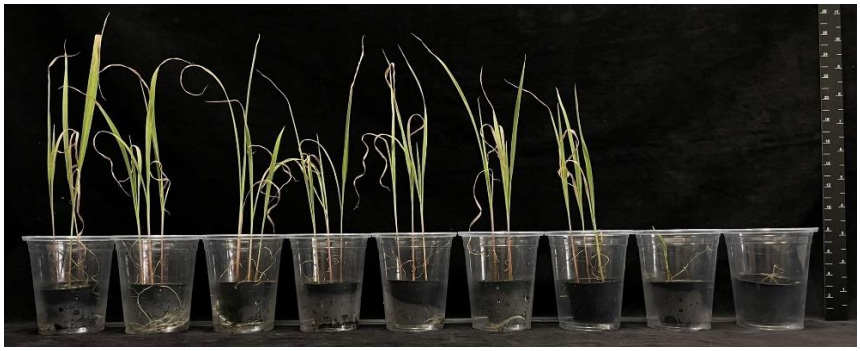


Figure 28. Herbicidal injury of 1-2 leaf barnyard grass (*Echinochloa crus-galli*) accession at 0 (A) and 28 (B) days after treatment of oxadiazon. Plants were observed from side view. Theoretical concentration of oxadiazon applied in paddy water based on the application rate recommended by Chia Tai enterprise CO. was 2.145 ppm (w/v).

由 1-2 葉齡稗草四個收集系對樂滅草反應之ED_{50}值可知，其傷害指數之ED_{50}值介於 7.4-90.6 ppm、存活率之ED_{50}值介於 112.8-166.6 ppm、存活率經arcsine轉換後之ED_{50}值介於 112.8-169.4 ppm、鮮重之ED_{50}值介 2.0-68.6 ppm、鮮重經arcsine轉換後之ED_{50}值介於 5.1-70.8 ppm、乾重之ED_{50}值介於 3.0-64.4 ppm、乾重經arcsine轉換後之ED_{50}值介於 3.0-35.1 (Table 108)，稗草四個收集系彼此間於傷害指數、存活率、鮮重及乾重的ED_{50}值經Fisher's protected LSD檢定後均未達顯著差異，但稗草收集系BG(II)-8、BG(II)-13 及BG(II)-17 之ED_{50}值皆高於田間推薦用量 2.145 ppm，推測這些收集系可能對藥劑具有一定程度的抗性。

Table 108. ED_{50} values of herbicide oxadiazon[*1] for the 1-2 leaf barnyard grass (BG, *Echinochloa crus-galli*) accessions. Data were collected at 28 days after treatment from three independent experiments.

Accession	ED_{50} (ppm, w/v)						
	Injury index	Survival rate		Fresh weight		Dry weight	
		Original data	Arcsine transformation	Original data	Arcsine transformation	Original data	Arcsine transformation
BG-WT	11.3	161.5	166.3	2.0	5.1	3.0	3.0
BG(II)-8	90.6	166.6	169.4	68.6	70.8	55.6	29.1
BG(II)-13	7.4	114.9	112.8	16.8	18.0	17.2	8.7
BG(II)-17	23.9	112.8	115.5	46.9	48.9	64.4	35.1
P-value	0.17	0.77	0.73	0.06	0.10	0.28	0.19
$LSD_{0.05}$	ND[*2]	ND	ND	ND	ND	ND	ND

[*1] Theoretical concentration of oxadiazon applied in paddy water based on the application rate recommended by Chia Tai enterprise CO. was 2.145 ppm (w/v).

[*2] ND indicates no significant difference among four accessions according to Fisher's protected LSD test ($\alpha = 0.05$).

2. 3-4 葉齡

由 3-4 葉齡稗草四個收集系對樂滅草之ED_{50}值可知，其傷害指數之ED_{50}值介於 5.2-154.2 ppm、存活率之ED_{50}值介於 15.5-173.2 ppm、存活率經arcsine轉換後之ED_{50}值介於 15.3-169.8 ppm、鮮重之ED_{50}值介於 0.6-185.9 ppm、鮮重經arcsine轉換後之ED_{50}值介於 4.8-538.8 ppm、乾重之ED_{50}值介於 1.1-141.9 ppm、乾重經arcsine轉換後之ED_{50}值介於 3.2-250.4 ppm (Table 109)，稗草四個收集系彼此間於傷害指數的ED_{50}值經 Fisher's protected LSD檢定後具有顯著差異，表示稗草各收集系可能對樂滅草之抗性表現較不一致。其中以稗草收集系BG(II)-8 之ED_{50}值顯著高於BG-WT，而後進一步以BG-WT為對照組，將BG(II)-8 與BG-WT之傷害指數及存活率的ED_{50}值相除可得BG(II)-8 之抗性指數介於 11.16-29.59，表示BG(II)-8 相較於BG-WT可能對樂滅草具有一定程度的抗性。試驗結果亦發現 3-4 葉齡之稗草各收集系之ED_{50}值似乎較 1-2 葉齡高，且高於田間推薦用量 2.145 ppm，因此進一步比較稗草收集系在兩個生育時期對樂滅草之ED_{50}值。

Table 109. ED_{50} values of herbicide oxadiazon[*1] for the 3-4 leaf barnyard grass (BG, *Echinochloa crus-galli*) accessions. Data were collected at 35 days after treatment from three independent experiments.

Accession	ED_{50} (ppm, w/v)						
	Injury index	Survival rate		Fresh weight		Dry weight	
		Original data	Arcsine transformation	Original data	Arcsine transformation	Original data	Arcsine transformation
BG-WT	5.2	15.5	15.3	0.6	4.8	1.1	3.2
BG(II)-8	154.2	173.2	169.8	185.9	538.8	141.9	250.4
BG(II)-13	20.8	62.5	62.2	13.5	25.4	9.9	16.7
BG(II)-17	36.3	160.2	159.8	52.6	278.3	20.0	32.7
P-value	< 0.05	< 0.05	< 0.05	0.13	0.28	0.16	0.22
$LSD_{0.05}$	104.61	73.46	77.31	ND	ND	ND	ND

[*1] Theoretical concentration of oxadiazon applied in paddy water based on the application rate recommended by Chia Tai enterprise CO. was 2.145 ppm (w/v).

[*2] ND indicates no significant difference among four accessions according to Fisher's protected LSD test ($\alpha = 0.05$).

3. 不同生育時期之劑量反應比較

比較兩個生育時期之稗草四個收集系對樂滅草傷害指數的ED_{50}值，可知稗草各收集系於兩個生育時期的ED_{50}值經Fisher's protected LSD檢定後僅BG(II)-13 出現顯著差異，其他收集系並未達到顯著差異(Table 110)。

Table 110. Comparison of ED_{50} values of herbicide oxadiazon for barnyard grass (BG, *Echinochloa crus-galli*) accessions between 1-2 and 3-4 leaf stages based on injury index. Data from three independent experiments were collected at 28 and 35 days, respectively, after treatment.

Accession	ED_{50} (injury index) (ppm)		P-value	$LSD_{0.05}$
	1-2 leaf	3-4 leaf		
BG-WT	11.3	5.2	0.44	ND*
BG(II)-8	90.6	154.2	0.44	ND
BG(II)-13	7.4	20.8	< 0.05	12.3
BG(II)-17	23.9	36.3	0.28	ND

* ND indicates no significant difference according to Fisher's protected LSD test (α = 0.05).

比較兩個生育時期之稗草四個收集系對樂滅草存活率的ED_{50}值，可知稗草各收集系於兩個生育時期的ED50 值經Fisher's protected LSD檢定後僅BG-WT出現顯著差異，而其他稗草收集系並未達顯著差異(Table 111)。

Table 111. Comparison of ED_{50} values of herbicide oxadiazon for barnyard grass (BG, *Echinochloa crus-galli*) accessions between 1-2 and 3-4 leaf stages based on survival rate (original data). Data from three independent experiments were collected at 28 and 35 days, respectively, after treatment.

Accession	ED_{50} (survival rate) (ppm)		P-value	$LSD_{0.05}$
	1-2 leaf	3-4 leaf		
BG-WT	161.5	15.5	< 0.05	117.5
BG(II)-8	166.6	173.2	0.93	ND*
BG(II)-13	114.9	62.5	0.40	ND
BG(II)-17	112.8	160.2	0.53	ND

* ND indicates no significant difference according to Fisher's protected LSD test (α = 0.05).

比較兩個生育時期的稗草四個收集系對樂滅草存活率經arcsine轉換後的ED_{50} 值，可知稗草各收集系於兩個生育時期的ED_{50} 值經Fisher's protected LSD檢定後僅BG-WT出現顯著差異，而其他稗草收集系並未達顯著差異(Table 112)。

Table 112. Comparison of ED_{50} values of herbicide oxadiazon for barnyard grass (BG, *Echinochloa crus-galli*) accessions between 1-2 and 3-4 leaf stages based on survival rate (arcsine transformation). Data from three independent experiments were collected at 28 and 35 days, respectively, after treatment.

Accession	ED_{50} (survival rate) (ppm)		P-value	$LSD_{0.05}$
	1-2 leaf	3-4 leaf		
BG-WT	166.3	15.3	< 0.05	116.3
BG(II)-8	169.4	169.8	0.99	ND*
BG(II)-13	112.8	62.2	0.42	ND
BG(II)-17	115.5	159.8	0.57	ND

* ND indicates no significant difference according to Fisher's protected LSD test (α = 0.05).

比較兩個生育時期的稗草四個收集系對樂滅草鮮重ED_{50}值，可知稗草各收集系於兩個生育時期ED_{50}值經Fisher's protected LSD檢定後並未達到顯著差異(Table 113)，表示 1-2 葉齡及 3-4 葉齡稗草幼苗對藥劑的抗性相似。

Table 113. Comparison of ED_{50} values of herbicide oxadiazon for barnyard grass (BG, *Echinochloa crus-galli*) accessions between 1-2 and 3-4 leaf stages based on fresh weight (FW, original data). Data from three independent experiments were collected at 28 and 35 days, respectively, after treatment.

Accession	ED_{50} (FW) (ppm)		P-value	$LSD_{0.05}$
	1-2 leaf	3-4 leaf		
BG-WT	2.0	0.6	0.14	ND*
BG(II)-8	68.6	185.9	0.30	ND
BG(II)-13	16.8	13.5	0.80	ND
BG(II)-17	46.9	52.6	0.91	ND

* ND indicates no significant difference according to Fisher's protected LSD test (α = 0.05).

比較兩個生育時期的稗草四個收集系對樂滅草鮮重經arcsine轉換後的ED_{50}值，可知稗草各收集系於兩個生育時期ED_{50}值經Fisher's protected LSD檢定後並未達到顯著差異(Table 114)，表示 1-2 葉齡及 3-4 葉齡稗草幼苗對藥劑的抗性相似。

Table 114. Comparison of ED_{50} values of herbicide oxadiazon for barnyard grass (BG, *Echinochloa crus-galli*) accessions between 1-2 and 3-4 leaf stages based on fresh weight (FW, arcsine transformation). Data from three independent experiments were collected at 28 and 35 days, respectively, after treatment.

Accession	ED_{50} (FW) (ppm)		P-value	$LSD_{0.05}$
	1-2 leaf	3-4 leaf		
BG-WT	5.1	4.8	0.95	ND*
BG(II)-8	70.8	538.8	0.21	ND
BG(II)-13	18.0	25.4	0.65	ND
BG(II)-17	48.9	278.3	0.44	ND

* ND indicates no significant difference according to Fisher's protected LSD test (α = 0.05).

比較兩個生育時期之稗草四個收集系對樂滅草乾重的ED50 值，可知稗草各收集系於兩個生育時期ED50 值經Fisher's protected LSD檢定後並未達到顯著差異(Table 115)，表示 1-2 葉齡及 3-4 葉齡稗草幼苗對藥劑的抗性相似。

Table 115. Comparison of ED_{50} values of herbicide oxadiazon for barnyard grass (BG, *Echinochloa crus-galli*) accessions between 1-2 and 3-4 leaf stages based on dry weight (DW, original data). Data from three independent experiments were collected at 28 and 35 days, respectively, after treatment.

Accession	ED_{50} (DW) (ppm)		P-value	$LSD_{0.05}$
	1-2 leaf	3-4 leaf		
BG-WT	3.0	1.1	0.42	ND*
BG(II)-8	55.6	141.9	0.38	ND
BG(II)-13	17.2	9.9	0.66	ND
BG(II)-17	64.4	20.0	0.38	ND

* ND indicates no significant difference according to Fisher's protected LSD test (α = 0.05).

比較兩個生育時期之稗草四個收集系對樂滅草乾重經arcsine轉換後的ED_{50} 值，可知稗草各收集系於兩個生育時期ED_{50} 值經Fisher's protected LSD檢定後並未達到顯著差異(Table 116)，表示 1-2 葉齡及 3-4 葉齡稗草幼苗對藥劑的抗性相似。

Table 116. Comparison of ED_{50} values of herbicide oxadiazon for barnyard grass (BG, *Echinochloa crus-galli*) accessions between 1-2 and 3-4 leaf stages based on dry weight (DW, arcsine transformation). Data from three independent experiments were collected at 28 and 35 days, respectively, after treatment.

Accession	ED_{50} (DW) (ppm)		P-value	$LSD_{0.05}$
	1-2 leaf	3-4 leaf		
BG-WT	3.0	3.2	0.96	ND*
BG(II)-8	29.1	250.4	0.27	ND
BG(II)-13	8.7	16.7	0.50	ND
BG(II)-17	35.1	32.7	0.93	ND

* ND indicates no significant difference according to Fisher's protected LSD test (α = 0.05).

根據以上試驗結果可知，1-2 葉齡稗草四個收集系對樂滅草之傷害指數、存活率、鮮重及乾重的ED_{50}值經Fisher's protected LSD檢定後皆未達顯著差異，但稗草四個收集系對樂滅草的ED_{50}值皆高於田間用量，可能對藥劑有一定程度的抗性。而 3-4 葉齡稗草彼此收集系間對樂滅草之ED_{50} 值則出現顯著差異，其中以稗草收集系BG(II)-8 的傷害指數之ED_{50} 值顯著高於BG-WT，表示BG(II)-8 在 3-4 葉齡相對其他稗草收集系對樂滅草具有較大的抗性。

綜合試驗結果可知，稗草收集系BG(II)-8 在 3-4 葉齡對樂滅草表現出一定程度的抗性，而針對原紫質原氧化酶(PPO)抑制劑產生目標位置抗性之案例，Giacomini et al. (2017)指出，豚草(*Ambrosia artemisiifolia* L.)在原紫質原氧化酶蛋白上第 128 個胺基酸位置上發生置換(R128L)，使豚草對PPO抑制劑產生抗性。長芒莧(*Amaranthus palmeri*)在相同胺基酸位置上發生置換(R128G及R128M)，亦賦予長芒莧對PPO抑制劑產生抗性(Giacomini et al., 2017)。Bi et al. (2019)則指出牛筋草(*Eleusine indica*)在原紫質原氧化酶蛋白上第 212 個胺基酸位置上發生置換(A212T)，改變PPO之蛋白結構，降低與樂滅草結合之能力，因此賦予牛筋草對樂滅草之抗性。Rangani et al. (2019)指出長芒莧在原紫質原氧化酶蛋白上第 399 個胺基酸位置上發生置換(G399A)，使長芒莧也對PPO抑制劑產生抗性。

根據此收集系之取樣地點之田野調查其用藥經歷包括氟氯比及本達隆等(Supplementary 2)，並未有使用樂滅草之用藥經歷，此收集系對藥劑產生抗性之原因仍需進一步研究。

本研究比較稗草各收集系在兩個生育時期四個性狀表現的ED_{50}值，結果發現，雖有少數收集系之特定性狀表現出兩個生育時期之抗性差異，但整體而言未出現顯著差異。

總結：

根據千金子及稗草對六種藥劑之劑量反應結果，可知二物種各收集系對不同作用機制之藥劑的反應並不相同，其中以 3-4 葉齡千金子及稗草各收集系對六種藥劑之抗性表現大於或等於 1-2 葉齡。因此後續討論以 3-4 葉齡千金子及稗草各收集系對藥劑之劑量反應試驗結果為主，主要以傷害指數及存活率二種性狀判斷各收集系彼此間對藥劑之單一抗性。根據千金子對藥劑之傷害指數及存活率，可知千金子各收集系對Apiro Forte、免速隆、平速爛及樂滅草之抗性未達顯著差異，但對丁基拉草及派伏利之反應則出現顯著差異，其中以RS(I)-14 對藥劑之抗性皆顯著高於RS(I)-1 (Table 117)。根據稗草對藥劑之傷害指數及存活率，可知稗草收集系BG(II)-8 對Apiro Forte、免速隆、樂滅草、平速爛及派伏利之抗性皆顯著大於BG-WT，此收集系可能具有多重抗性；BG(II)-13 對派伏利具有單一抗性；BG(II)-17 則對丁基拉草及派伏利具有抗性(Table 118)。綜合以上試驗結果，BG(II)-8 對多種藥劑皆具有抗性，而BG(II)-17 僅對丁基拉草具有單一抗性，顯示各收集系對不同藥劑之抗性或抗性行為並不一致。

本研究在此僅統整千金子及稗草各收集系對藥劑之單一抗性，後續將進一步以傷害指數及存活率二種性狀判斷千金子及稗草各收集系對除草劑之交叉抗性及多重抗性。

Table 117. Single resistance of 3-4 leaf red sprangle-top (*Leptochloa chinensis*) accession seedlings to six herbicides including Apiro Forte, bensulfuron-methyl, butachlor, oxadiazon, penoxsulam, and pyriftalid.

Accession	Apiro Forte		Bensulfuron-methyl		Butachlor		Oxadiazon		Penoxsulam		Pyriftalid	
	Injury index	Survival rate	Injury index	Survival rate	Injury index	Survival rate	Injury index	Survival rate	Injury index	Survival rate	Injury index	Survival rate
RS(II)-AES	A[*1]	A	A	A	A	S[*2]	A	A	A	A	S	S
RS(I)-1	A	A	A	A	A	S	A	A	A	A	S	S
RS(I)-2	A	A	A	A	A	S	A	A	A	A	S	S
RS(I)-14	A	A	A	A	A	R	A	A	A	A	R	R
RS(I)-15	A	A	A	A	A	R	A	A	A	A	S	S
RS(II)-11	A	A	A	A	A	S	A	A	A	A	S	S

[*1] A means no significant difference among six accessions based on the ED_{50} values after Fisher' protected LSD test.

[*2] S and R mean the accessions sensitive and resistant to indicated herbicide, respectively, based on the ED_{50} values after Fisher' protected LSD test.

Table 118. Single resistance of 3-4 leaf barnyard grass (BG, *Echinochloa crus-galli*) accession seedlings to six herbicides including Apiro Forte, bensulfuron-methyl, butachlor, oxadiazon, penoxsulam, and pyriftalid.

Accession	Apiro Forte		Bensulfuron-methyl		Butachlor		Oxadiazon		Penoxsulam		Pyriftalid	
	Injury index	Survival rate	Injury index	Survival rate	Injury index	Survival rate	Injury index	Survival rate	Injury index	Survival rate	Injury index	Survival rate
BG-WT	A[*1]	S[*2]	S	S	A	S	S	A	A	S	S	S
BG(II)-8	A	R	R	R	A	-	R	A	A	R	R	R
BG(II)-13	A	S	-[*3]	-	A	-	S	A	A	-	R	R
BG(II)-17	A	S	-	-	A	R	S	A	A	S	R	R

[*1] A means no significant difference among four accessions based on the ED_{50} values after Fisher' protected LSD test.

[*2] S and R mean the accessions sensitive and resistant to indicated herbicide, respectively, based on the ED_{50} values after Fisher' protected LSD test.

[*3] Unable to distinguish sensitive and resistant accessions based on the ED_{50} values after Fisher' protected LSD test.

五、千金子及稗草之交叉抗性

由於先前比較千金子及稗草二物種在 1-2 葉齡與 3-4 葉齡對藥劑之反應，發現後者之抗性相對較大，且表現較穩定，故進一步比較千金子及稗草各收集系對免速隆、平速爛與派伏利之交叉抗性反應時均以 3-4 葉齡為對象，主要以傷害指數及存活率二種性狀判斷兩雜草物種各收集系彼此間對於三種ALS抑制劑之交叉抗性差異。另外，本研究亦比較二物種對於先正達公司擬上市之Apiro Forte混劑、及其組成分單劑免速隆及派伏利之反應差異，以判斷雜草對混劑表現抗性是否基於兩種單劑之抗性表現。

A. 千金子及稗草對ALS抑制劑之交叉抗性

本研究比較千金子及稗草在 3-4 葉齡對免速隆、平速爛及派伏利等三種ALS抑制劑之劑量反應分析，分別得出傷害指數及存活率之劑量反應分析結果，並檢定千金子及稗草收集系對三種ALS抑制劑的抗性表現差異。

a. 千金子對ALS抑制劑之交叉抗性

1. 千金子六個收集系之整體表現

比較 3-4 葉齡千金子六個收集系整體在施用免速隆、平速爛及派伏利之傷害指數及存活率劑量反應分析曲線，根據傷害指數可知，3-4 葉齡千金子所有供試收集系在施用免速隆後之反應皆未達 2.5 (Table 36)；在施用派伏利後，千金子收集系RS(II)AES、RS(I)-1 及RS(II)-11 於 100 倍劑量下傷害指數較高，在 1,000 倍劑量下六個收集系之傷害指數皆超過一半(Table 52)；而施用平速爛後，僅在 1,000 倍推薦用量下超過 2.5 (Table 68)。但根據存活率可知，3-4 葉齡千金子收集系在施用免速隆後所有收集系之存活率皆高於 70.0% (Table 37)；在施用派伏利後，千金子收集系RS(I)-2、RS(I)-14 及RS(I)-15 之存活率顯著高於其他收集系 (Table 53)，而在施用平速爛後，僅在最高劑量下獲得抑制反應之一半 (Table 69)。根據傷害指數與存活率之表現，千金子此物種對於免速隆之抗性高於平速爛，而對於派伏利之抗性相對較低。後續將直接比較千金子對三種藥劑之傷害指數及存活率數值，以判斷收集系彼此間對藥劑間的抗性表現差異。

根據傷害指數可知，3-4 葉齡千金子六個收集系在 10-1,000 倍推薦劑量範圍內對免速隆及平速爛之反應較一致，但對派伏利之反應則出現顯著差異，其中RS(I)-14 在 10-1,000 倍劑量範圍內之傷害指數皆顯著低於RS(II)-AES及RS(I)-1 (Table 119)。而存活率之反應與傷害指數相似，RS(I)-14 在 10-1,000 倍劑量範圍內之存活率皆顯著高於RS(II)-AES及RS(I)-1 (Table 120)，顯示其對派伏利之抗性顯著大於RS(II)-AES及RS(I)-1。後續將以對三種藥劑皆較敏感之RS(I)-1 作為對照組，判斷較具抗性之RS(I)-14 是否具有交叉抗性。

雖然 3-4 葉齡千金子六個收集系對免速隆及平速爛之藥劑反應較一致且並未達顯著差異，但皆未獲得藥劑抑制反應之一半，因此將以千金子所有收集系之平均傷害指數及存活率比較三種ALS之整體抗性差異。

Table 119. Comparison of dose-response of 3-4 leaf red sprangle-top (*Leptochloa chinensis*) accession seedlings to three herbicides including bensulfuron-methyl, penoxsulam, and pyriftalid. Data of injury index were collected according to three independent experiments.

Accession	Bensulfuron-methyl			Penoxsulam			Pyriftalid		
	10X[*1]	100X	1,000X	10X	100X	1,000X	10X	100X	1,000X
RS(II)-AES	0.72	1.10	1.44	0.44	0.44	2.44	1.92	4.22	5.00
RS(I)-1	1.04	1.31	1.93	0.72	0.86	2.97	2.10	3.70	4.95
RS(I)-2	1.17	1.61	2.06	1.00	1.28	3.50	0.89	1.56	4.00
RS(I)-14	0.43	0.87	1.19	0.22	0.78	3.00	0.33	0.50	3.22
RS(I)-15	1.37	1.85	2.43	0.00	1.00	3.56	0.26	1.67	4.11
RS(II)-11	0.78	1.44	1.89	0.44	1.56	3.33	2.22	3.37	4.19
P-value	0.79	0.88	0.81	0.34	0.48	0.68	< 0.05	< 0.05	< 0.05
$LSD_{0.05}$	ND[*2]	ND	ND	ND	ND	ND	1.80	2.56	1.34

[*1] X represents the theoretical concentration based on the recommended dosage of bensulfuron-methyl, penoxsulam, and pyriftalid applied in paddy water were 0.185, 0.068, and 0.365 ppm, respectively.

[*2] No significant difference among six accessions according to Fisher's protected LSD test ($\alpha = 0.05$)

Table 120. Comparison of dose-response of 3-4 leaf red sprangle-top (*Leptochloa chinensis*) accession seedlings to three herbicides including bensulfuron-methyl, penoxsulam, and pyriftalid. Data of survival rate were collected according to three independent experiments.

Accession	Bensulfuron-methyl			Penoxsulam			Pyriftalid		
	10X[*1]	100X	1,000X	10X	100X	1,000X	10X	100X	1,000X
RS(II)-AES	100.00	100.00	100.00	100.00	100.00	100.00	88.89	48.11	0.00
RS(I)-1	100.00	92.67	70.33	100.00	100.00	75.00	81.09	45.91	4.89
RS(I)-2	96.33	96.33	88.89	100.00	100.00	50.00	100.00	88.89	33.00
RS(I)-14	100.00	100.00	96.33	100.00	100.00	100.00	100.00	100.00	59.33
RS(I)-15	96.33	85.22	72.22	100.00	100.00	50.00	100.00	88.89	33.22
RS(II)-11	100.00	96.33	96.33	100.00	100.00	77.67	77.67	51.89	29.67
P-value	0.57	0.69	0.26	--	--	0.18	< 0.05	< 0.05	< 0.05
$LSD_{0.05}$	ND[*2]	ND	ND	ND	ND	ND	20.93	47.49	44.44

[*1] X represents the theoretical concentration based on the recommended dosage of bensulfuron-methyl, butachlor, oxadiazon, penoxsulam, and pyriftalid applied in paddy water were 0.185, 0.068, and 0.365 ppm, respectively.

[*2] No significant difference among six accessions according to Fisher's protected LSD test ($\alpha = 0.05$)

根據劑量反應分析試驗結果，以傷害指數 2.5 及存活率 50%為劃分抗性收集系之界線，發現 3-4 葉齡千金子六個收集系對免速隆的平均傷害指數於 10-1,000 倍劑量下皆未達到 2.5 (Figure 29A)，而對免速隆及平速爛之平均存活率皆未降低至 50%以下(Figure 29B)，僅見派伏利在 1,000 倍推薦用量下之存活率降至 20%左右，可知 3-4 葉齡千金子收集系對三種ALS抑制劑具有不同程度之交叉抗性，抗性大小依序為免速隆、平速爛及派伏利。

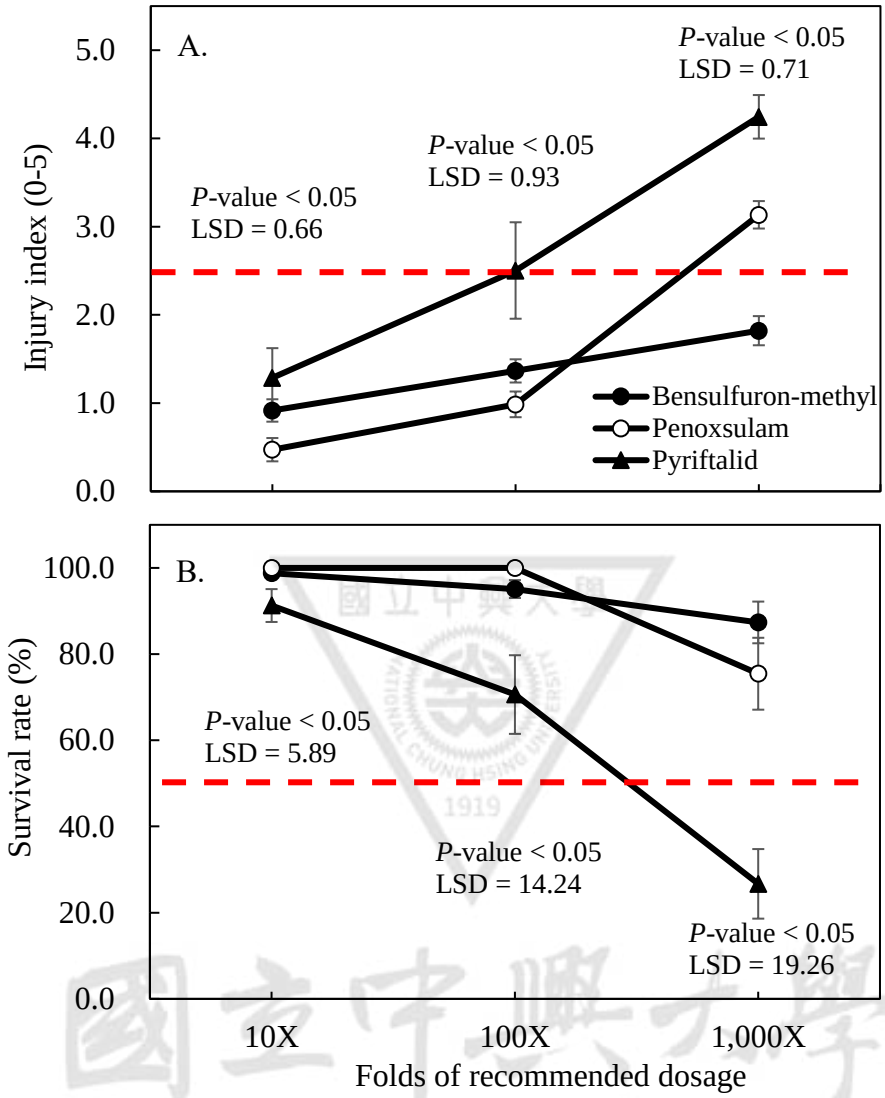


Figure 29. Comparison of dose-response of 3-4 leaf red sprangle-top (*Leptochloa chinensis*) accession seedlings to bensulfuron-methyl, penoxsulam, and pyriftalid under treatment with 10, 100, and 1,000 folds of the recommended dosage. Data of injury index (A) and survival rate (B) were collected according to three independent experiments.

2. 千金子抗性收集系之表現

根據千金子收集系對免速隆、平速爛及派伏利之劑量反應試驗可知，不同收集系對派伏利之反應差異較大，先前研究中得知RS(I)-1 及RS(I)-14 對 10-1,000 倍劑量派伏利之傷害指數及存活率皆出現顯著差異，因此分別以RS(I)-1 及RS(I)-14 此二千金子收集系進行耐感性差異之比較。因二收集系對免速隆及平速爛二種藥劑之存活率反應未達抑制一半以上之反應，故後續僅以 1-1,000 倍劑量下之傷害指數及存活率比較二收集系對三種ALS抑制劑之抗性差異。

比較 RS(I)-1 及 RS(I)-14 在 1-1,000 倍劑量範圍內之免速隆的傷害指數，經 Fisher's protected LSD 檢定後二收集系在各劑量下皆未達顯著差異，表示在傷害指數性狀下，二收集系對藥劑之抗性較一致，但可發現二收集系在最高劑量下傷害指數仍未達 2.5 (Table 121)，顯示二收集系皆對免速隆具有較大的抗性。

Table 121. Comparison of injury index of red sprangle-top (RS, *Leptochloa chinensis*) accessions at 3-4 leaf stage after treatment of bensulfuron-methyl. Data from three independent experiments were collected at 35 days after treatment.

Dosage	Injury index (0-5)		P-value	$LSD_{0.05}$
	RS(I)-1 (S)[*1]	RS(I)-14 (R)		
1X[*2]	0.59	0.28	0.50	ND[*3]
10X	1.04	0.43	0.42	ND
100X	1.31	0.87	0.64	ND
1,000X	1.93	1.19	0.51	ND

[*1] S and R represent accessions sensitive and resistant, respectively, to bensulfuron-methyl.

[*2] X represents the theoretical concentration based on the recommended application rate of bensulfuron-methyl applied in paddy water [0.185 ppm (w/v)].

[*3] No significant difference between two accessions according to Fisher's protected LSD test ($\alpha = 0.05$).

比較RS(I)-1 及RS(I)-14 在 1-1,000 倍劑量範圍內之免速隆的存活率，經Fisher's protected LSD檢定後二收集系在各劑量下皆未達顯著差異，表示在存活率性狀下，二收集系對藥劑之抗性較一致，但可發現二收集系在最高劑量下存活率仍介於 70.33-96.33 (Table 122)，顯示二收集系皆對免速隆具有較大的抗性。

Table 122. Comparison of survival rate of red sprangle-top (RS, *Leptochloa chinensis*) accessions at 3-4 leaf stage after treatment of bensulfuron-methyl. Data from three independent experiments were collected at 35 days after treatment.

Dosage	Survival rate (%)		P-value	$LSD_{0.05}$
	RS(I)-1 (S)[*1]	RS(I)-14 (R)		
1X[*2]	100.00	100.00	--	ND[*3]
10X	100.00	100.00	--	ND
100X	92.67	100.00	0.37	ND
1,000X	70.33	96.33	0.19	ND

[*1] S and R represent accessions sensitive and resistant, respectively, to bensulfuron-methyl.

[*2] X represents the theoretical concentration based on the recommended application rate of bensulfuron-methyl applied in paddy water [0.185 ppm (w/v)].

[*3] No significant difference between two accessions according to Fisher's protected LSD test ($\alpha = 0.05$).

比較RS(I)-1 及RS(I)-14 在 1-1,000 倍劑量範圍內之平速爛的傷害指數，經Fisher's protected LSD檢定後二收集系在各種劑量下皆未達顯著差異(Table 123)，表示二收集系對平速爛之抗性相似。

Table 123. Comparison of injury index of red sprangle-top (RS, *Leptochloa chinensis*) accessions at 3-4 leaf stage after treatment of penoxsulam. Data from three independent experiments were collected at 35 days after treatment.

Dosage	Injury index (0-5)		P-value	$LSD_{0.05}$
	RS(I)-1 (S)[*1]	RS(I)-14 (R)		
1X[*2]	0.41	0.00	0.07	ND[*3]
10X	0.72	0.22	0.23	ND
100X	0.86	0.78	0.87	ND
1,000X	2.97	3.00	0.97	ND

[*1] S and R represent accessions sensitive and resistant, respectively, to penoxsulam.

[*2] X represents the theoretical concentration based on the recommended application rate of penoxsulam applied in paddy water [0.068 ppm (w/v)].

[*3] No significant difference between two accessions according to Fisher's protected LSD test ($\alpha = 0.05$).

比較RS(I)-1 及RS(I)-14 在 1-1,000 倍劑量範圍內之平速爛的存活率，經Fisher's protected LSD檢定後二收集系在各種劑量下皆未達顯著差異(Table 124)，表示二收集系對平速爛之抗性相似。

Table 124. Comparison of survival rate of red sprangle-top (RS, *Leptochloa chinensis*) accessions at 3-4 leaf stage after treatment of penoxsulam. Data from three independent experiments were collected at 35 days after treatment.

Dosage	Survival rate (%)		P-value	$LSD_{0.05}$
	RS(I)-1 (S)[*1]	RS(I)-14 (R)		
1X[*2]	100.00	100.00	--	ND[*3]
10X	100.00	100.00	--	ND
100X	100.00	100.00	--	ND
1,000X	75.00	100.00	0.16	ND

[*1] S and R represent accessions sensitive and resistant, respectively, to penoxsulam.

[*2] X represents the theoretical concentration based on the recommended application rate of penoxsulam applied in paddy water [0.068 ppm (w/v)].

[*3] No significant difference between two accessions according to Fisher's protected LSD test ($\alpha = 0.05$).

比較 RS(I)-1 及 RS(I)-14 在 1-1,000 倍劑量範圍內之派伏利的傷害指數，經 Fisher's protected LSD 檢定後二收集系在 1-1,000 倍劑量下皆出現顯著差異，RS(I)-14 之傷害指數顯著低於 RS(I)-1 (Table 125)，表示 RS(I)-14 相對於 RS(I)-1 對於派伏利具有較大的抗性。

Table 125. Comparison of injury index of red sprangle-top (RS, *Leptochloa chinensis*) accessions at 3-4 leaf stage after treatment of pyriftalid. Data from three independent experiments were collected at 35 days after treatment.

Dosage	Injury index (0-5)		P-value	$LSD_{0.05}$
	RS(I)-1 (S)[*1]	RS(I)-14 (R)		
1X[*2]	1.14	0.00	< 0.05	0.94
10X	2.10	0.33	< 0.05	0.93
100X	3.70	0.50	< 0.05	1.30
1,000X	4.95	4.00	< 0.05	0.54

[*1] S and R represent accessions sensitive and resistant, respectively, to pyriftalid.

[*2] X represents the theoretical concentration based on the recommended dosage of pyriftalid applied in paddy water [0.365 ppm (w/v)].

比較RS(I)-1 及RS(I)-14 在 1-1,000 倍劑量範圍內之派伏利的存活率，其抗性差異與傷害指數相似，在 10-1,000 劑量範圍下具有顯著差異 (Table 126)，表示RS(I)-14 相對於RS(I)-1 對於派伏利具有較大的抗性。

Table 126. Comparison of survival rate of red sprangle-top (RS, *Leptochloa chinensis*) accessions at 3-4 leaf stage after treatment of pyriftalid. Data from three independent experiments were collected at 35 days after treatment.

Dosage	Survival rate (%)		P-value	$LSD_{0.05}$
	RS(I)-1 (S)[*1]	RS(I)-14 (R)		
1X[*2]	96.69	100.00	0.21	ND[*3]
10X	81.09	100.00	< 0.05	5.05
100X	45.91	100.00	< 0.05	11.20
1,000X	4.89	33.00	< 0.05	8.98

[*1] S and R represent accessions sensitive and resistant, respectively, to pyriftalid.

[*2] X represents the theoretical concentration based on the recommended dosage of pyriftalid applied in paddy water [0.365 ppm (w/v)].

[*3] No significant difference between two accessions according to Fisher's protected LSD test ($\alpha = 0.05$).

綜合試驗結果可知，千金子收集系RS(I)-1 及RS(I)-14 在 3-4 葉齡對三種ALS抑制劑之反應並不相同，二收集系對免速隆及平速爛之抗性較一致且在各劑量處理下皆未能獲得一半之抑制反應(Table 121, 122, 123, 124)，二收集系皆對免速隆及平速爛具有高度抗性，但在派伏利各種劑量下，RS(I)-14 之傷害指數及存活率分別顯著低於或高於RS(I)-1，顯示RS(I)-14 對派伏利之抗性相對RS(I)-1 較高。綜合試驗結果，千金子收集系RS(I)-14 及對照組收集系RS(I)-1 對免速隆、平速爛及派伏利均具有交叉抗性，對免速隆之抗性較大，平速爛次之，而對派伏利之抗性最小，其中RS(I)-14 對於派伏利表現出收集系間顯著抗性差異。

b. 稗草對ALS抑制劑之交叉抗性

1. 稗草四個收集系之整體表現

比較 3-4 葉齡稗草四個收集系在施用免速隆、平速爛及派伏利之傷害指數及存活率劑量反應分析曲線，根據傷害指數可知，稗草收集系 BG(II)-8 之傷害指數顯著低於其他收集系，在傷害指數性狀表現上此收集系可能對免速隆之抗性較大(Table 44)；而施用派伏利後，相較於稗草收集系BG(II)-8、BG(II)-13 及BG(II)-17 於 100 倍劑量下傷害指數皆顯著低於BG-WT (Table 60)；稗草各收集系對平速爛之ED_{50} 值範圍介於 0.015-1.626 ppm之間，收集系間未出現顯著差異(Table 73)。根據存活率可知，3-4 葉齡稗草收集系BG(II)-8 之存活率顯著高於其他收集系，在存活性狀表現上此收集系可能對免速隆之抗性較大(Table 45)；而 BG(II)-8、BG(II)-13 及BG(II)-17 對派伏利之存活率顯著高於BG-WT，可知此三個收集系可能對派伏利之抗性較BG-WT大(Table 61)，平速爛之ED_{50} 值範圍介於 0.51-11.431 ppm之間，並出現顯著差異，表示稗草各收集系可能對平速爛之抗性較不一致(Table 73)，似乎針對免速隆、派伏利及平速爛等三種藥劑，稗草四個收集系有呈現抗性或感性二群現象。後續將直接比較稗草對三種藥劑之傷害指數及存活率數值，以判斷收集系彼此間對藥劑的抗性表現差異。

根據傷害指數分析結果可知，3-4 葉齡稗草四個收集系在免速隆 100 及 1,000 倍劑量下出現顯著差異，在派伏利 10 及 100 倍劑量下亦出現顯著差異，但在平速爛各劑量下四個收集系反應則較一致。在免速隆 100 及 1,000 倍劑量下，BG(II)-8 呈現之傷害指數顯著低於其他收集系，而在派伏利 10 及 100 倍劑量下，BG(II)-8、BG(II)-13 及BG(II)-17 呈現之傷害指數顯著低於BG-WT (Table 127)。類似之表現，亦出現在存活率反應上(Table 128)。根據以上試驗結果顯示BG(II)-8 對免速隆及派伏利之抗性皆相對較BG-WT大。後續將以對三種藥劑皆較敏感之BG-WT及較具抗性之BG(II)-8 進行交叉抗性之判斷。

Table 127. Comparison of dose-response of 3-4 leaf barnyard grass (*Echinochloa crus-galli*) accession seedlings to three herbicides including bensulfuron-methyl, penoxsulam, and pyriftalid. Data of injury index were collected according to three independent experiments.

Accession	Bensulfuron-methyl			Penoxsulam			Pyriftalid		
	10X[*1]	100X	1,000X	10X	100X	1,000X	10X	100X	1,000X
BG-WT	1.70	4.56	5.00	5.00	5.00	5.00	5.00	5.00	5.00
BG(II)-8	1.04	2.56	3.74	2.56	5.00	5.00	1.15	3.26	4.19
BG(II)-13	1.41	4.15	4.56	3.67	5.00	5.00	1.64	3.44	4.64
BG(II)-17	1.11	4.02	4.52	4.67	5.00	5.00	1.15	3.37	4.67
P-value	0.17	< 0.05	< 0.05	0.13	--	--	< 0.05	< 0.05	0.48
$LSD_{0.05}$	ND[*2]	0.81	0.82	ND	ND	ND	1.16	1.16	ND

[*1] X represents the theoretical concentration based on the recommended dosage of bensulfuron-methyl, penoxsulam, and pyriftalid applied in paddy water were 0.185, 0.068, and 0.365 ppm (w/v), respectively.

[*2] No significant difference among four accessions according to Fisher's protected LSD test ($\alpha = 0.05$).

Table 128. Comparison of dose-response of 3-4 leaf barnyard grass (*Echinochloa crus-galli*) accession seedlings to three herbicides including bensulfuron-methyl, penoxsulam, and pyriftalid. Data of survival rate were collected according to three independent experiments.

Accession	Bensulfuron-methyl			Penoxsulam			Pyriftalid		
	10X[*1]	100X	1,000X	10X	100X	1,000X	10X	100X	1,000X
BG-WT	92.67	33.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BG(II)-8	100.00	100.00	66.78	89.00	0.00	0.00	100.00	81.44	44.44
BG(II)-13	100.00	51.67	29.44	44.33	0.00	0.00	100.00	86.25	30.50
BG(II)-17	100.00	63.00	37.00	22.33	0.00	0.00	100.00	92.67	25.78
P-value	0.05	< 0.05	< 0.05	0.06	--	--	< 0.05	< 0.05	0.40
$LSD_{0.05}$	ND[*2]	34.62	42.66	ND	ND	ND	0.65	20.60	ND

[*1] X represents the theoretical concentration based on the recommended dosage of bensulfuron-methyl, penoxsulam, and pyriftalid applied in paddy water were 0.185, 0.068, and 0.365 ppm (w/v), respectively.

[*2] No significant difference among four accessions according to Fisher's protected LSD test ($\alpha = 0.05$).

根據稗草收集系整體劑量反應分析試驗結果，若以傷害指數 2.5 及存活率 50%作為區分對於不同藥劑之抗性差異指標，發現 3-4 葉齡稗草四個收集系整體對免速隆及派伏利之平均傷害指數在 10 倍劑量下皆低於 2.5，顯然稗草對於免速隆及派伏利之抗性顯著高於平速爛，而在 10、100 及 1,000 倍劑量下亦表現相似結果(Figure 30A)。類似之結果也表現在存活率(Figure 30B)。根據傷害指數及存活率之反應可知，3-4 葉齡稗草各收集系對免速隆及派伏利此二種ALS抑制劑具有較大的交叉抗性，抗性大小依序為免速隆、派伏利及平速爛。

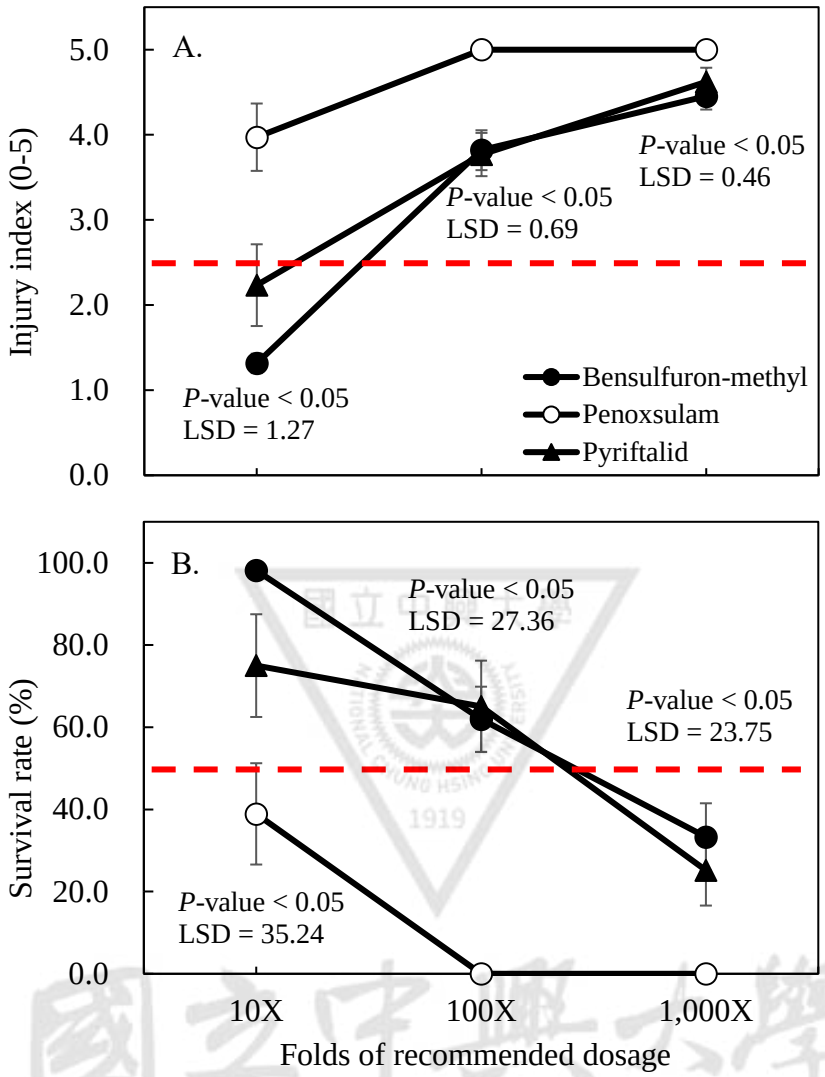


Figure 30. Comparison of dose-response of 3-4 leaf barnyard grass (*Echinochloa crus-galli*) accession seedlings to bensulfuron-methyl, penoxsulam, and pyriftalid under the treatment with 10, 100, and 1,000 folds of the recommended dosage. Data of injury index (A) and survival rate (B) were collected according to three independent experiments.

2. 稗草抗性收集系之表現

根據稗草收集系對免速隆、平速爛及派伏利之劑量反應試驗可知，各收集系對免速隆及派伏利之反應差異較大(Table 127, 128)，其中以BG(II)-8 對此二種ALS抑制劑之抗性皆顯著大於BG-WT，因此本研究將分別以稗草收集系BG-WT及BG(II)-8 作為較敏感及較具抗性之收集系，進行交叉抗性程度之判斷。

根據傷害指數之劑量反應分析可得BG-WT及BG(II)-8 的ED_{50}值，將抗性與感性收集系之ED_{50}值相除可得BG(II)-8 之抗性指數，發現BG(II)-8 對免速隆、平速爛及派伏利之抗性指數分別為 7.3、50.0 及 142.8 (Table 129)，而存活率之抗性指數則分別為 21.8、49.9 及 470.7 (Table 130)，

Table 129. Comparison of ED_{50} values of herbicides bensulfuron-methyl, penoxsulam, and pyriftalid for barnyard grass (BG, *Echinochloa crus-galli*) accessions between BG-WT and BG(II)-8 at 3-4 leaf stages based on injury index. Data from three independent experiments were collected at 35 days after treatment.

Herbicides	ED_{50} values		P-value	$LSD_{0.05}$	RI[*2]
	BG-WT (S)[*1]	BG(II)-8 (R)			
Bensulfuron-methyl	2.30	16.79	< 0.05	2.98	7.3
Penoxsulam	0.01	0.47	< 0.05	0.16	50.0
Pyriftalid	0.34	49.07	< 0.05	23.72	144.3

[*1] S and R represent accessions sensitive and resistant, respectively, to bensulfuron-methyl, penoxsulam, and pyriftalid simultaneously.

[*2] Resistance index (RI) = ED_{50} (R) / ED_{50} (S).

與傷害指數之反應相似，顯示BG(II)-8 對三種ALS抑制劑皆具有不同程度之交叉抗性，與BG-WT相較之下，BG(II)-8 展現出對於派伏利最大

抗性，其次是平速爛，最小是免速隆。

Table 130. Comparison of ED_{50} values of herbicides bensulfuron-methyl, penoxsulam, and pyriftalid for barnyard grass (BG, *Echinochloa crus-galli*) accessions between BG-WT and BG(II)-8 at 3-4 leaf stages based on survival rate. Data from three independent experiments were collected at 35 days after treatment.

Herbicides	ED_{50} values		P-value	$LSD_{0.05}$	RI[*2]
	BG-WT (S)[*1]	BG(II)-8 (R)			
Bensulfuron-methyl	17.61	384.75	< 0.05	37.43	21.8
Penoxsulam	0.03	1.65	< 0.05	1.31	49.9
Pyriftalid	1.48	120.00	< 0.05	11.74	81.1

[*1] S and R represent accessions sensitive and resistant, respectively, to bensulfuron-methyl, penoxsulam, and pyriftalid simultaneously.

[*2] Resistance index (RI) = ED_{50} (R) / ED_{50} (S).

綜合試驗結果可知，整體而言 3-4 葉齡稗草各收集系對此三種ALS抑制劑具有不同程度之交叉抗性，抗性大小依序為免速隆、派伏利及平速爛。其中比較稗草感性BG-WT及抗性BG(II)-8 收集系在 3-4 葉齡對三種ALS抑制劑之反應。根據傷害指數及存活率之反應表現，發現BG(II)-8 之傷害指數及存活率分別顯著低於或高於BG-WT ，顯示BG(II)-8 對免速隆、平速爛及派伏利之抗性皆顯著大於BG-WT。進一步以BG-WT為對照組，從BG(II)-8 對三種ALS抑制劑表現之RI，可知BG(II)-8 對於派伏利之交叉抗性最大，其次是平速爛，而最小是免速隆。推測稗草感性與抗性收集系對免速隆之抗性差異較小。

根據前人研究，Riar et al. (2013)指出第 122、197 及 205 個胺基酸位置皆位於ALS酵素中的domain A，且處於ALS反應基質(substrate)進入其

催化結構域(catalytic domain)的通道上。而ALS抑制劑主要結合在此通道上，阻止反應基質進入導致酵素無法發生反應。因此，若ALS酵素中第 122、197 及 205 個胺基酸位置發生置換，則可能使ALS抑制劑無法結合在此通道上，無法有效地間接抑制ALS活性。Yu and Powles (2013)則指出不同種類之ALS抑制劑與目標酵素結合的胺基酸位置並不相同。因此，若是在不同胺基酸位置發生置換，可能會影響不同種類的ALS抑制劑對目標位置酵素之結合能力，進而使兩者間無法有效結合，最後使稗草對不同種類的ALS抑制劑產生不同程度的交叉抗性(cross-resistance)。

目前在全球因為在ALS酵素蛋白上不同胺基酸位置發生置換的案例眾多，例如在希臘(Greece)的水稗[*Echinochloa crus-galli* (L.) P. Beauv. var. oryzicola (Vasinger) Ohwi]在ALS酵素蛋白第 574 個胺基酸位置發生置換，色胺酸(tryptophan)置換成白胺酸(leucine)，因而對平速爛、bispyribac sodium及imazamox、foramsulfuron、nicosulfuron及rimsulfuron等ALS抑制劑產生交叉抗性(Kaloumenos et al., 2012)；稗草抗性生物型ALS酵素在第 205 個胺基酸位置發生置換導致ALS抑制劑與目標位置酵素的結合能力下降，進而使稗草抗性生物型對五種類型ALS抑制劑[硫醯尿素類(sulfonylureas)、三唑嘧啶類(triazolopyrimidines)、咪唑啉酮

類(imidazolinones)、硫代苯甲醯胺類(pyrimidinyl-thiobenzoates) 及磺醯胺基羰基三唑啉酮類(sulfonyl-aminocarbonyl triazolinones)]產生目標位置抗性(Fang et al., 2019)；稗草抗性生物型在ALS酵素第 197 個胺基酸位置發生置換，Pro置換成Ser，使稗草抗性生物型對azimsulfuron、byspiribac-sodium、imzamox及pnoxsulam等四種ALS抑制劑產生交叉抗性，且抗性程度皆較高(Amaro-Blanco et al., 2021)；歐洲的稗草[*Echinochloa crus-galli* (L.) Pal. Beauv.]四個收集系分別在ALS酵素蛋白第 122 及 574 個胺基酸位置發生置換，使其對foramsulfuron、rimsulfuron 、 foramsulfuron + thiencarbazone 及 foramsulfuron + thiencarbazone + iodosulfuron等四種ALS抑制劑單劑及混劑產生交叉抗性(Löbmann et al., 2021)。

除了胺基酸置換而造成禾本科雜草對ALS抑制劑產生目標位置抗性，亦可藉由其他代謝解毒酵素導致禾本科雜草產生非目標位置抗性，例如水稗(*Echinochloa phyllopogon*)可藉由細胞色素P450 (cytochrome P450)中的*CYP81A12* 及*CYP81A21* 二個基因過表現，使免速隆去甲基化以降低抑制劑活性，進而使水稗對免速隆產生抗性(Iwakami et al., 2014)；水稗 (*E. phyllopogon*)其細胞色素P450 中CYP81A家族的酵素蛋白可代謝免速隆及派伏利 (Dimaano et al., 2020)；研究者亦指出細胞色

素P450 過表現及穀胱苷肽S-轉移酶活性提升可賦予硬直黑麥草(*L. rigidum*)對ALS抑制劑之交叉抗性(Torra et al., 2021)。本研究發現稗草抗性收集系BG(II)-8 對三種ALS抑制劑具有交叉抗性，其抗性機制為目標位置抗性或非目標位置抗性仍需進一步研究。

B. Apiro Forte混劑對千金子及稗草產生協同藥效之原因

a. 千金子

比較 3-4 葉齡千金子六個收集系整體在施用Apiro Forte、免速隆及派伏利之傷害指數及存活率劑量反應分析曲線，可知千金子所有供試收集系對三種藥劑之反應較不一致。3-4 葉齡千金子六個收集系對Apiro Forte之ED_{50} 值範圍介於 0.45-1.09 ppm (Table 15)，而派伏利在 1,000 倍劑量下才使六個收集系傷害指數超過 2.5 (Table 36)，對免速隆則表現顯著抗性，整體皆未達到抑制一半以上之反應(Table 52)。而千金子六個收集系之存活率之反應與傷害指數相似(Table 15, 37, 53)。Apiro Forte係免速隆及派伏利二種單劑之混合劑，根據傷害指數之ED_{50} 值範圍，於 0.45-1.09 ppm之Apiro Forte可使千金子收集系達到抑制一半之反應，而換算其中所含之派伏利單劑之ED_{50} 值範圍在ppm [0.37/0.55=0.66, 0.66×(0.45-1.09)=0.30-0.72 ppm]，相對派伏利單劑在 1,000 倍劑量下才出現抑制一半之反應，故推測Apiro Forte中派伏利之藥效可能與免速隆

混合時產生協同作用，而增強Apiro Forte之效果。

b. 稗草

比較 3-4 葉齡稗草四個收集系在施用Apiro Forte、免速隆及派伏利之傷害指數及存活率劑量反應分析曲線，可知稗草各收集系對三種藥劑之反應較不一致。稗草收集系對Apiro Forte傷害指數之ED_{50}值範圍分別落在 0.33-1.19 ppm (Table 24)，而在免速隆及派伏利 100 倍劑量下才達到抑制一半以上之反應 (Table 44, 60)，存活率之反應與傷害指數相似(Table 24, 45, 61)。而根據傷害指數之ED_{50}值範圍，於 0.33-1.19 ppm之Apiro Forte可使稗草收集系達到抑制一半之反應，換算其中所含之免速隆及派伏利單劑之ED_{50}值範圍分別落在 0.11-0.40 及 0.22-0.79 ppm，相對免速隆及派伏利單劑在 100 倍劑量下才出現抑制一半之反應，故推測Apiro Forte中派伏利之藥效可能與免速隆混合時產生協同作用，而增強Apiro Forte之效果。

根據千金子及稗草所有供試收集系在施用Apiro Forte混劑、免速隆及派伏利後之傷害指數及存活率劑量反應，可知二雜草物種對Apiro Forte之ED_{50}值範圍皆小於免速隆及派伏利單劑，表示Apiro Forte混劑效果大於單劑之現象均出現在千金子及稗草二種物種中，故推測Apiro Forte中派伏利之藥效可能與免速隆混合時產生協同作用，或是二種

ALS抑制劑在ALS酵素蛋白上，有不同的結合位置，二種抑制劑同時結合其上，使得反應基質進入催化位置之通道被完全阻斷，而增強Apiro Forte之效果。

六、千金子及稗草對除草劑之多重抗性

本研究進一步比較 3-4 葉齡千金子及稗草各收集系對丁基拉草(VLCFAs inhibitor)、樂滅草(PPO inhibitor)、及派伏利 (ALS inhibitor)之反應，主要以傷害指數及存活率二種性狀判斷兩雜草物種各收集系彼此間對於三種不同作用機制除草劑之抗性差異。

A. 千金子及稗草對除草劑之多重抗性

根據千金子及稗草在 3-4 葉齡對丁基拉草、樂滅草及派伏利等三種不同作用機制除草劑之劑量反應分析，分別得出傷害指數及存活率之劑量反應分析曲線，並檢定千金子及稗草收集系對三種除草劑的多重抗性表現差異。

a. 千金子對除草劑之多重抗性

1. 千金子六個收集系之整體表現

根據傷害指數可知，3-4 葉齡千金子六個收集系對丁基拉草之ED_{50}值介於 5.2-37.3 ppm；對樂滅草之ED_{50}值介於 4.9-31.3 ppm；對派伏利之ED_{50}值介於 5.7-153.8 ppm (Table 131)，發現各收集系彼此間對丁基

Table 131. Comparison of ED_{50} values of three herbicides including butachlor, oxadiazon, and pyriftalid for 3-4 leaf red sprangle-top (*Leptochloa chinensis*) accession seedlings. Data of injury index and survival rate were collected according to three independent experiments.

Accession	ED_{50} (ppm)					
	Butachlor[*1]		Oxadiazon		Pyriftalid	
	Injury index	Survival rate	Injury index	Survival rate	Injury index	Survival rate
RS(II)-AES	5.2	51.2	18.2	37.6	6.3	26.7
RS(I)-1	37.3	256.8	8.4	37.0	5.7	23.0
RS(I)-2	7.6	102.4	9.0	98.9	119.3	214.2
RS(I)-14	25.1	489.5	30.2	68.1	153.8	461.2
RS(I)-15	27.5	512.3	31.3	68.1	128.4	179.6
RS(II)-11	6.4	28.8	4.9	36.9	75.9	39.1
P-value	0.37	< 0.05	0.06	0.46	< 0.05	< 0.05
$LSD_{0.05}$	ND	224.7	ND	ND	96.0	124.3

[*1] Theoretical concentrations based on the recommended dosage of butachlor, oxadiazon, and pyriftalid applied in paddy water were 4.840, 2.145 and 0.365 ppm, respectively.

[*2] No significant difference among six accessions according to Fisher's protected LSD test ($\alpha = 0.05$)

拉草及樂滅草二種藥劑之ED_{50} 值皆未達顯著差異，表示各收集系對此二種藥劑之抗性反應較一致，但對派伏利則出現顯著差異。而根據存活率可知，3-4 葉齡千金子六個收集系對丁基拉草之ED_{50} 值介於 28.8-512.3 ppm；對樂滅草之ED_{50} 值介於 36.9-98.9 ppm，對派伏利之ED_{50} 值介於 23.0-461.2 ppm (Table 131)，發現千金子各收集系彼此間對丁基拉草及派伏利之ED_{50} 值出現顯著差異，表示各收集系間對二種藥劑之抗性較不一致，其中根據傷害指數及存活率之表現，發現千金子收集系 RS(I)-14 及RS(I)-15 均對丁基拉草及派伏利之抗性皆顯著大於RS(II)-

AES，後續將以對三種藥劑皆較敏感之RS(II)-AES作為對照組，依據抗性指數表現，判斷較具抗性或抗性之RS(I)-14 是否具有多重抗性。

2. 千金子抗性收集系之表現

根據千金子收集系對丁基拉草、樂滅草及派伏利之劑量反應分析可知，各收集系對丁基拉草及派伏利之反應差異較大(Table 131)，其中以RS(I)-14 對此二種除草劑之抗性皆顯著大於RS(II)-AES，因此本研究將分別以千金子收集系RS(II)-AES作為感性對照組，而以抗性的RS(I)-14 收集系其抗性指數表現，進行多重抗性程度之判斷。

根據傷害指數之劑量反應分析可得RS(II)-AES及RS(I)-14 的ED_{50}值，將抗性與感性收集系之ED_{50}值相除可得RS(I)-14 之抗性指數，發現RS(I)-14 對丁基拉草、樂滅草及派伏利之抗性指數分別為 4.8、1.7 及 27.1 (Table 132)，而存活率之抗性指數則分別為 9.6、1.8 及 7.8 (Table 133)，與傷害指數之反應相似。依據Beckie and Tardif (2012)劃分的四種抗性程度，分別為無抗性(not resistant) (RI < 2)、低度抗性(low resistance) (RI = 2 - 5)、中度抗性(moderate resistance) (RI = 6 - 10)及高度抗性(high resistance) (RI > 10)。

Table 132. Comparison of ED_{50} values of herbicides butachlor, oxadiazon, and pyriftalid for 3-4 leaf red sprangle-top (RS, *Leptochloa chinensis*) accessions between RS(II)-AES and RS(I)-14 based on injury index. Data from three independent experiments were collected at 35 days after treatment.

Herbicides	ED_{50} (ppm)		P-value	$LSD_{0.05}$	RI[*2]
	RS(II)-AES (S)[*1]	RS(I)-14 (R)			
Butachlor	5.2	25.1	< 0.05	11.6	4.8
Oxadiazon	18.2	30.2	0.40	ND	1.7
Pyriftalid	6.3	153.8	< 0.05	58.5	24.5

[*1] S and R represent accessions sensitive and resistant, respectively, to butachlor, oxadiazon, and pyriftalid simultaneously.

[*2] Resistance index (RI) = ED_{50} (R) / ED_{50} (S).

Table 133. Comparison of ED_{50} values of herbicides butachlor, oxadiazon, and pyriftalid for 3-4 leaf red sprangle-top (RS, *Leptochloa chinensis*) accessions between RS(II)-AES and RS(I)-14 based on survival rate. Data from three independent experiments were collected at 35 days after treatment.

Herbicides	ED_{50} (ppm)		P-value	$LSD_{0.05}$	RI[*2]
	RS(II)-AES (S)[*1]	RS(I)-14 (R)			
Butachlor	51.2	489.5	< 0.05	65.0	9.6
Oxadiazon	37.6	68.1	0.12	ND	1.8
Pyriftalid	32.1	461.2	< 0.05	20.9	7.2

[*1] S and R represent accessions sensitive and resistant, respectively, to butachlor, oxadiazon, and pyriftalid simultaneously.

[*2] Resistance index (RI) = ED_{50} (R) / ED_{50} (S).

根據以上結果可知RS(I)-14 對丁基拉草具有低度或中度抗性，而對派伏利具有中度或高度抗性，但對樂滅草則不具抗性，顯示RS(I)-14 對丁基拉草及派伏利具有不同程度之多重抗性。

綜合試驗結果可知，千金子收集系以RS(II)-AES作為對照組，根據RS(I)-14 在 3-4 葉齡對三種作用機制除草劑之抗性指數反應並不相同，抗性收集系RS(I)-14 對樂滅草並無抗性，但對丁基拉草具有低度或中度抗性，而對派伏利具有中度或高度抗性，顯示RS(I)-14 對丁基拉草及派伏利具有不同程度之多重抗性，針對千金子對二種藥劑的抗性機制值得進一步研究。

前人研究中並未見禾本科千金子對於除草劑出現多重抗性，本研究為國內外研究之首例。Guo et al. (2015)發現禾本科看麥娘(*Alopecurus aequalis*)同時在ACCase及ALS酵素蛋白上出現胺基酸置換，因而對ACCase及ALS抑制劑均產生目標位置抗性，使看麥娘具有多重抗性。Iwakami et al. (2015)指出大穗看麥娘可藉由過表現穀胱苷肽S-轉移酶基因產生對ACCase抑制劑芬殺草(fenoxaprop)及光合作用系統II型抑制劑chlortoluron之抗性。Baltazar (2017)指出稗草可藉由提高脂肪酸醯胺水解酶(fatty acid amide hydrolase, FAAH)之活性增強代謝解毒丁基拉草，進而賦予稗草對丁基拉草的抗性。Vázquez-García et al. (2017)發現義大利黑麥草(*L. multiflorum*)及硬直黑麥草(*L. rigidum*)皆因為累積多個目標位置抗性而對ACCase、ALS及EPSPS抑制劑產生多重抗性。其後，Anthimidou et al. (2020)發現硬直黑麥草(*L. rigidum* Gaud.)抗性族群ALS

酵素蛋白第 197 個胺基酸位置，脯胺酸(proline)分別置換成白胺酸(leucine)、穀胺酸(glutamic acid)、絲胺酸(serine)、丙胺酸(alanine)、蘇胺酸(threonine)及穀胺醯胺(glutamine)，同時ACCase酵素蛋白上第 2,041 個位置亦發生置換，異白胺酸(isoleucine)置換成天門冬醯胺(asparagine)及蘇胺酸，因此使硬直黑麥草產生多重抗性。Lan et al. (2022)發現大穗看麥娘(*Alopecurus myosuroides* Huds.)對ACCase及ALS抑制劑均具有多重抗性，其同時具有目標位置抗性及非目標位置抗性。

綜合前人研究，推測本研究之千金子可能在ALS酵素蛋白中發生突變，對ALS抑制劑產生目標位置抗性，亦或是藉由細胞色素P450、脂肪酸醯胺水解酶及穀胱苷肽S-轉移酶等酵素降低除草劑之毒性，使千金子對ALS抑制劑產生非目標位置之抗性。本研究之千金子抗性收集系可能同時具有對丁基拉草及ALS抑制劑二種不同作用機制除草劑之多重抗性，而針對千金子抗性收集系之抗性機制仍待後續進一步研究。

b. 稗草對除草劑之多重抗性

1. 稗草四個收集系之整體表現

根據傷害指數可知，3-4 葉齡稗草四個收集系對丁基拉草之ED_{50}值介於 42.9-270.7 ppm；對樂滅草之ED_{50}值介於 5.2-154.2 ppm；對派伏利之ED_{50}值介於 0.3-49.1 ppm (Table 134)，發現各收集系彼此間對丁基拉

草、樂滅草及派伏利三種藥劑之ED_{50} 值出現顯著差異，顯示各收集系對三種藥劑之抗性不一致。而根據存活率可知，3-4 葉齡稗草四個收集系對丁基拉草之ED_{50} 值介於 84.9-1,393.4 ppm；對樂滅草之ED_{50} 值介於 15.5-160.2 ppm，對派伏利之ED_{50} 值介於 1.5-139.2 ppm (Table 134)，存活率之表現與傷害指數相似。其中根據傷害指數及存活率之表現，發現稗草收集系BG(II)-8 對樂滅草及派伏利之抗性皆顯著大於BG-WT，後續將以對三種藥劑皆較敏感之BG-WT作為對照組，依據抗性指數表現，判斷較具抗性之BG(II)-8 是否具有多重抗性。

Table 134. Comparison of ED_{50} values of three herbicides including butachlor, oxadiazon, and pyriftalid for 3-4 leaf barnyard grass (*Echinochloa crus-galli*) accession seedlings. Data of injury index and survival rate were collected according to three independent experiments.

Accession	ED_{50} (ppm)					
	Butachlor[*1]		Oxadiazon		Pyriftalid	
	Injury index	Survival rate	Injury index	Survival rate	Injury index	Survival rate
BG-WT	42.9	84.9	5.2	15.5	0.3	1.5
BG(II)-8	145.9	405.4	154.2	173.2	49.1	120.0
BG(II)-13	200.6	1,179.7	20.8	62.5	12.5	139.2
BG(II)-17	270.7	1,393.4	36.3	160.2	18.2	135.7
P-value	0.08	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
$LSD_{0.05}$	ND[*2]	1,180.1	104.6	73.5	11.1	68.7

[*1] Theoretical concentrations based on the recommended dosage of butachlor, oxadiazon, and pyriftalid applied in paddy water were 4.840, 2.145 and 0.365 ppm, respectively.

[*2] No significant difference among six accessions according to Fisher's protected LSD test ($\alpha = 0.05$)

2. 稗草抗性收集系之表現

根據稗草收集系對丁基拉草、樂滅草及派伏利之劑量反應分析可知，各收集系對三種除草劑皆有出現顯著差異(Table 134)，其中BG(II)-8 同時對樂滅草及派伏利二種除草劑之抗性皆顯著大於BG-WT，因此本研究將分別以稗草收集系BG-WT作為感性對照組，而以抗性的BG(II)-8 收集系其抗性指數表現，進行多重抗性程度之判斷。

根據傷害指數之劑量反應分析可得BG-WT及BG(II)-8 的ED_{50}值，將抗性與感性收集系之ED_{50}值相除可得BG(II)-8 之抗性指數，發現BG(II)-8 對丁基拉草、樂滅草及派伏利之抗性指數分別為 3.4、29.6 及 142.8 (Table 135)，而存活率之抗性指數則分別為 4.8、11.2 及 81.1 (Table 136)，與傷害指數之反應相似。依據Beckie and Tardif (2012)劃分的四種抗性程度，BG(II)-8 對丁基拉草具有低度抗性；對樂滅草及派伏利均具有高度抗性，顯示BG(II)-8 對丁基拉草、樂滅草及派伏利具有不同程度之多重抗性。

Table 135. Comparison of ED_{50} values of herbicides butachlor, oxadiazon, and pyriftalid for 3-4 leaf barnyard grass (BG, *Echinochloa crus-galli*) accessions between BG-WT and BG(II)-8 based on injury index. Data from three independent experiments were collected at 35 days after treatment.

Herbicides	ED_{50} (ppm)		P-value	$LSD_{0.05}$	RI[*2]
	BG-WT (S)[*1]	BG(II)-8 (R)			
Butachlor	42.9	145.9	< 0.05	99.6	3.4
Oxadiazon	5.2	154.2	< 0.05	146.7	29.6
Pyriftalid	0.3	49.1	< 0.05	4.1	142.8

[*1] S and R represent accessions sensitive and resistant, respectively, to butachlor, oxadiazon, and pyriftalid simultaneously.

[*2] Resistance index (RI) = ED_{50} (R) / ED_{50} (S).

Table 136. Comparison of ED_{50} values of herbicides butachlor, oxadiazon, and pyriftalid for 3-4 leaf barnyard grass (BG, *Echinochloa crus-galli*) accessions between BG-WT and BG(II)-8 based on survival rate. Data from three independent experiments were collected at 35 days after treatment.

Herbicides	ED_{50} (ppm)		P-value	$LSD_{0.05}$	RI[*2]
	BG-WT (S)[*1]	BG(II)-8 (R)			
Butachlor	84.9	405.4	< 0.05	285.6	4.8
Oxadiazon	15.5	173.2	< 0.05	147.2	11.2
Pyriftalid	1.5	120.0	< 0.05	57.9	81.1

[*1] S and R represent accessions sensitive and resistant, respectively, to butachlor, oxadiazon, and pyriftalid simultaneously.

[*2] Resistance index (RI) = ED_{50} (R) / ED_{50} (S).

綜合試驗結果可知，稗草收集系以BG-WT作為對照組，BG(II)-8 在3-4 葉齡對三種不同作用機制除草劑之抗性指數並不相同，抗性收集系BG(II)-8 對丁基拉草具有低度抗性，而對樂滅草及派伏利皆具有高度抗性，顯示BG(II)-8 對丁基拉草、樂滅草及派伏利具有不同程度之多重抗性。在前人研究中亦發現對平速爛具有抗性的稗草族群，同時亦對

bispyribac-sodium (ALS抑制劑)、quinclorac (生長素型除草劑)、metamifop (ACCase抑制劑)、cyhalofop-butyl (ACCase抑制劑)及oxadiazon (PPO抑制劑)皆具有中度抗性(Chen et al., 2016)。後續可針對稗草對藥劑的多重抗性機制進一步研究。

有關雜草產生多重抗性之研究，Baltazar (2017)指出稗草可藉由提高醯胺水解酶(amide hydrolase)之活性增強代謝解毒丁基拉草，進而賦予稗草對丁基拉草及除草寧(propanil)的抗性。Dimaano et al. (2020)則發現水稗 (*Echinochloa phyllopogon*)其細胞色素P450 中CYP81A家族的酵素蛋白可代謝免速隆(ALS抑制劑)、派伏利 (ALS抑制劑)、pyridazinone (phytoene desaturase inhibitor, PDS抑制劑)、benzothiadiazinone (PSII抑制劑)、pyrazole (PPO抑制劑)、triketone (4-hydroxyphenylpyruvate dioxygenase inhibitor, 4-HPPD抑制劑)、clomazone (1-deoxy-d-xylulose-5-phosphate synthase inhibitor, DXPS抑制劑)以及三大類ACCase抑制劑。Liu et al. (2021)指出除草劑抗性植物可藉由提升α-澱粉酶(α-amylase)、水解酶(hydrolase)及蛋白酶(protease)之活性，或累積植物防禦素(phytoalexins)產生對丁基拉草之抗性。Hwang et al. (2022)發現稗草可藉由減少吸收轉運、增加降解速率，使稗草對florpyrauxifen-benzyl (生長素型除草劑)及cyhalofop-butyl (ACCase抑制劑)產生多重抗性。

有關多重抗性之原因，Gaines et al. (2020)指出雜草可同時對除草劑產生目標位置及非目標位置抗性，Wang et al. (2020)指出菵草(*Beckmannia syzigachne* Steud.)在ALS酵素蛋白第 197 個胺基酸位置發生置換，且其穀胱苷肽S-轉移酶(glutathione S-transferase)亦具有高度活性，因而賦予菵草對ACCase及ALS抑制劑具有多重抗性。

綜合前人研究，本研究之稗草對丁基拉草、樂滅草及pyriftlaid之多重抗性機制可能分為目標位置抗性及非目標位置抗性，稗草抗性收集系可能同時在ALS酵素蛋白及PPO蛋白中不同胺基酸位置發生置換，因此對ALS及PPO抑制劑產生目標位置抗性，亦或是藉由提升細胞色素P450、穀胱苷肽S-轉移酶、脂肪酸醯胺水解酶、α-澱粉酶、水解酶及蛋白酶之活性，以增強代謝除草劑，使稗草能降低除草劑毒性，抑或是藉由減少轉運、吸收等方式使除草劑到達目標位置之濃度降低，賦予稗草對除草劑產生非目標位置抗性，推測本研究之稗草抗性收集系可能同時具有以上二種抗性機制，進而使稗草對多種作用機制之除草劑產生多重抗性，而針對稗草抗性收集系之抗性機制仍待後續進一步研究。

第五章、 結語

本研究旨在判斷台灣中南部水田之千金子及稗草是否具有除草劑抗性，依據千金子及稗草幼苗在施用藥劑後之傷害指數、存活率、鮮重及乾重等四項觀察指標，得知千金子及稗草收集系彼此間對藥劑具有抗性程度差異。經檢定後具有顯著差異則判斷為抗性或感性收集系，再以抗性及感性收集系進行單一、交叉及多重抗性分析。根據分析結果，可知 3-4 葉齡千金子收集系RS(I)-14 及對照組收集系RS(I)-1 對免速隆、平速爛及派伏利均具有交叉抗性，對免速隆之抗性較大，平速爛次之，而對派伏利之抗性最小，其中RS(I)-14 對於派伏利表現出顯著抗性差異。而稗草收集系BG(II)-8 對免速隆、平速爛及派伏利具有不同程度的交叉抗性，其中對於派伏利之交叉抗性最大，其次是平速爛，而最小是免速隆。

進一步比較多重抗性，發現 3-4 葉齡千金子收集系RS(I)-14 則對丁基拉草及派伏利具有多重抗性。而稗草收集系BG(II)-8 對丁基拉草具有低度抗性；對樂滅草及派伏利均具有高度抗性，顯示BG(II)-8 對丁基拉草、樂滅草及派伏利亦具有不同程度之多重抗性。本研究僅對中南部水田中的千金子及稗草二物種進行除草劑抗性判斷，並建立完整之除草劑抗性判斷流程，提供後續研究人員可依循此系統判斷抗性雜草，但有關千金子及稗草對除草劑產生抗性之成因仍待後續進一步研究。

第六章、 參考文獻

王慶裕。2021。除草劑抗性生理學。93-166。臺北市：新學林。

林永立、郭寶錚、王慶裕。1997。對數邏輯模式在劑量反應上的應用。1-18。中華民國雜草學會會刊。第 18 卷。第一期。

Ahmed, S., Alam, M. J., Hossain, A., Islam, A. K. M. M., Awan, T. H., Soufan, W., Qahtan, A. A., Okla, M. K., and El Sabagh, A. (2020). Interactive effect of weeding regimes, rice cultivars, and seeding rates influence the rice-weed competition under dry direct-seeded condition. *Sustainability*, *13*(1).

Amaro-Blanco, I., Romano, Y., Palmerin, J. A., Gordo, R., Palma-Bautista, C., De Prado, R., and Osuna, M. D. (2021). Different mutations providing target site resistance to ALS- and ACCase-inhibiting herbicides in *Echinochloa* spp. from rice fields. *Agriculture*, *11*(5), 382-393.

Andreasen, C., and Stryhn, H. (2008) Increasing weed flora in danish arable fields and its importance for biodiversity. *Weed Research*, *48*, 1–9.

Anthimidou, E., Ntoanidou, S., Madesis, P., and Eleftherohorinos, I. (2020). Mechanisms of *Lolium rigidum* multiple resistance to ALS- and ACCase-inhibiting herbicides and their impact on plant fitness. *Pesticide Biochemistry and Physiology*, *164*, 65-72.

Bajwa, A. A., Jabran, K., Shahid, M., Ali, H. H., Chauhan, B. S., and Ehsanullah. (2015). Eco-biology and management of *Echinochloa crus-galli*. *Crop Protection*, *75*, 151-162.

Baltazar, A. M. (2017). Herbicide-resistant weeds in the Philippines: Status and resistance mechanisms. *Weed Biology and Management*, *17*(2), 57-67.

Baltazar, A. M. (2017). Herbicide-resistant weeds in the Philippines: Status and resistance mechanisms. *Weed Biology and Management*, *17*(2), 57-67.

Beckie, H. J., and Tardif, F. J. (2012). Herbicide cross resistance in weeds. *Crop Protection*, *35*, 15-28.

Benvenuti, S., Dinelli, G., and Bonetti, A. (2004) Germination ecology of *Leptochloa chinensis*: a new weed in the Italian rice agro-environment. *Weed Research*, *44*, 87-96.

Bi, B., Wang, Q., Coleman, J. J., Porri, A., Peppers, J. M., Patel, J. D., Betz, M., Lerchl, J., and McElroy, J. S. (2020). A novel mutation A212T in chloroplast protoporphyrinogen oxidase (PPO1) confers resistance to PPO inhibitor oxadiazon in *Eleusine indica*. *Pest Management Scienc*e, *76*(5), 1786-1794.

Chauhan, B. S., and Abugho, S. B. (2012). Effect of growth stage on the efficacy of postemergence herbicides on four weed species of direct-seeded rice. *The Scientific World Journal*, *2012*, 123071.

Chauhan, B. S., and Johnson, D. E. (2008). Germination ecology of chinese sprangletop (*Leptochloa chinensis*) in the Philippines. *Weed Science*, *56*(6), 820-825.

Chen, G., Wang, Q., Yao, Z., Zhu, L., and Dong, L. (2016). Penoxsulam-resistant barnyardgrass (*Echinochloa crus-galli*) in rice fields in China. *Weed Biology and Management*, *16*(1), 16-23.

Clay, S. A. (2021). Near-term challenges for global agriculture herbicide-resistant weeds. *Agronomy Journal*, *113*, 4463-4472.

Delye, C., Jasieniuk, M., and Le Corre, V. (2013). Deciphering the evolution of herbicide resistance in weeds. *Trends Genet*, *29*(11), 649-658.

Dimaano, N. G., Yamaguchi, T., Fukunishi, K., Tominaga, T., and Iwakami, S. (2020). Functional characterization of cytochrome P450 CYP81A subfamily to disclose the pattern of cross-resistance in *Echinochloa phyllopogon*. *Plant Molecular Biology*, *102*(4-5), 403-416.

Duhoux, A., Carrere, S., Gouzy, J., Bonin, L., and Delye, C. (2015). RNA-Seq analysis of rye-grass transcriptomic response to an herbicide inhibiting acetolactate-synthase identifies transcripts linked to non-target-site-based resistance. *Plant Molecular Biology*, *87*(4-5), 473-487.

Duke, S. O., Lydon, J., Becerril, J. M., Sherman, T. D., Lehnen, L. P., and Matsumoto, H. (2017). Protoporphyrinogen oxidase-inhibiting herbicides. *Weed Science*, *39*(3), 465-473.

Duke, S. O., Stidham, M. A., and Dayan, F. E. (2019). A novel genomic approach to herbicide and herbicide mode of action discovery. *Pest Management Science*, *75*(2), 314-317.

Endo, M., Shimizu, T., Fujimori, T., Yanagisawa, S., and Toki, S. (2013). Herbicide-resistant mutations in acetolactate synthase can reduce feedback inhibition and lead to accumulation of branched-chain amino acids. *Food and Nutrition Sciences*, *4*(5), 522-528.

Fang, J., Liu, T., Zhang, Y., Li, J., and Dong, L. (2019). Target site–based penoxsulam resistance in barnyardgrass (*Echinochloa crus-galli*) from

China. *Weed Science*, *67*(3), 281-287.

Fang, J., Liu, T., Zhang, Y., Li, J., and Dong, L. (2019). Target site–based penoxsulam resistance in barnyardgrass (*Echinochloa crus-galli*) from China. *Weed Science*, *67*(3), 281-287.

Gaines, T. A., Duke, S. O., Morran, S., Rigon, C. A. G., Tranel, P. J., Kupper, A., and Dayan, F. E. (2020). Mechanisms of evolved herbicide resistance. *Journal of Biological Chemistry*, *295*(30), 10307-10330.

Giacomini, D. A., Umphres, A. M., Nie, H., Mueller, T. C., Steckel, L. E., Young, B. G., Scott, R. C., and Tranel, P. J. (2017). Two new PPX2 mutations associated with resistance to PPO-inhibiting herbicides in *Amaranthus palmeri*. *Pest Management Science*, *73*(8), 1559-1563.

Guo, W., Yuan, G., Liu, W., Bi, Y., Du, L., Zhang, C., Li, Q., and Wang, J. (2015). Multiple resistance to ACCase and AHAS-inhibiting herbicides in shortawn foxtail (*Alopecurus aequalis* Sobol.) from China. *Pesticide Biochemistry and Physiology*, *124*, 66-72.

Heap, I. (2014). Global perspective of herbicide-resistant weeds. *Pest Management Science*, *70*(9), 1306-1315.

Heap, I. (2014). Herbicide Resistant Weeds. *Integrated Pest Management* Springer, Dordrecht, 281-301.

Heap, I. M., and Knight, R. (1990) Variation in herbicide cross-resistance among populations of annual ryegrass (*Lolium rigidum*) resistant to diclofop-methyl. *Australian Journal of Agricultural Research*, *41*, 121-128.

Honèk, A., and Martinková, Z. (1995) Geographic variation in seed dormancy among populations of *Echinochloa crus-galli*. *Oecologia*,

108, 419-423.

Honek, A., Martinkova, Z., and Jarosik, V. (1999). Annual cycles of germinability and differences between primary and secondary dormancy in buried seeds of *Echinochloa crus-galli*. *Weed Research*, *39*, 69-79.

Hwang, J. I., Norsworthy, J. K., Gonzalez-Torralva, F., Piveta, L. B., Priess, G. L., Barber, L. T., and Butts, T. R. (2022). Absorption, translocation, and metabolism of florpyrauxifen-benzyl and cyhalofop-butyl in cyhalofop-butyl-resistant barnyardgrass [*Echinochloa crus-galli* (L.) P. Beauv.]. *Pesticide Biochemistry and Physiology*, *180*, 104999.

Iwakami, S., Endo, M., Saika, H., Okuno, J., Nakamura, N., Yokoyama, M., Watanabe, H., Toki, S., Uchino, A., and Inamura, T. (2014). Cytochrome P450 CYP81A12 and CYP81A21 are associated with resistance to two acetolactate synthase inhibitors in *Echinochloa phyllopogon*. *Plant Physiology*, *165*(2), 618-629.

Iwakami, S., Endo, M., Saika, H., Okuno, J., Nakamura, N., Yokoyama, M., Watanabe, H., Toki, S., Uchino, A., and Inamura, T. (2014). Cytochrome P450 CYP81A12 and CYP81A21 are associated with resistance to two acetolactate synthase inhibitors in *Echinochloa phyllopogon*. *Plant Physiology*, *165*(2), 618-629.

Iwakami, S., Hashimoto, M., Matsushima, K., Watanabe, H., Hamamura, K., and Uchino, A. (2015). Multiple-herbicide resistance in *Echinochloa crus-galli* var. *formosensis*, an allohexaploid weed species, in dry-seeded rice. *Pesticide Biochemistry and Physiology*, *119*, 1-8.

Jugulam, M., and Shyam, C. (2019). non-target-site resistance to herbicides:

recent developments. *Plants*, *8*(10).

Juliano, L. M., Casimero, M. C., and Llewellyn, R. (2010). Multiple herbicide resistance in barnyardgrass (*Echinochloa crus-galli*) in direct-seeded rice in the Philippines. *International Journal of Pest Management*, *56*(4), 299-307.

Kaloumenos, N. S., Chatzilazaridou, S. L., Mylona, P. V., Polidoros, A. N., and Eleftherohorinos, I. G. (2013). Target-site mutation associated with cross-resistance to ALS-inhibiting herbicides in late watergrass *(Echinochloa oryzicola* Vasing.). *Pest Management Science*, *69*(7), 865-873.

Kieloch, R., and Domaradzki, K. (2011). The role of the growth stage of weeds in their response to reduced herbicide doses. *Acta Agrobotanica*, *64*, 259-266.

Lan, Y., Li, W., Wei, S., Huang, H., Liu, Z., and Huang, Z. (2022). Multiple resistance to ACCase- and ALS-inhibiting herbicides in black-grass (*Alopecurus myosuroides* Huds.) in China. *Pesticide Biochemistry and Physiology*, *184*, 105127.

Leather, G. R., Sung, S. J., and Hale, M. G. (1992). The wounding response of dormant barnyardgrass (*Echinochloa crus-galli*) seeds. *Weed Science*, 40, 200-203.

Lillie, K. J., Giacomini, D. A., Green, J. D., and Tranel, P. J. (2019). Coevolution of resistance to PPO inhibitors in waterhemp (*Amaranthus tuberculatus*) and Palmer amaranth (*Amaranthus palmeri*). *Weed Science*, *67*(5), 521-526.

Lin, W. T., Chiang, Y. J., Wang, C. S., Wang, C. Y., (2017). Non-target site

mechanisms of resistance to fluazifopbutyl of goosegrass (*Eleusine indica* (L.) Gaertn.) in Taiwan: uptake, translocation and metabolism. *Journal of Agriculture and Forestry*, *65*(1), 1-14.

Liu, W., Bai, S., Zhao, N., Jia, S., Li, W., Zhang, L., and Wang, J. (2018). Non-target site-based resistance to tribenuron-methyl and essential involved genes in *Myosoton aquaticum* (L.). *BMC Plant Biology*, *18*(1), 225.

Liu, X., Merchant, A., Xiang, S., Zong, T., Zhou, X., and Bai, L. (2020). Managing herbicide resistance in China. *Weed Science*, *69*(1), 4-17.

Llewellyn, R. S., and Powles, S. B. (2001). High levels of herbicide resistance in rigid ryegrass (*Lolium rigidum*) in the wheat belt of western Australia. *Weed Technology*, *15*, 242-248.

Löbmann, A., Schulte, M., Runge, F., Christen, O., and Petersen, J. (2021). Occurrence, resistance factors and cross-resistance patterns to herbicides inhibiting acetolactate synthase (ALS) of *Echinochloa crus-galli* (L.) Pal. Beauv. in Central Europe. *Journal of Plant Diseases and Protection*, *128*(3), 843-852.

Luo, Y., Fu, H., Xiong, Y., Xiang, Z., Wang, F., Bugingo, Y. C., Khan, S., and Cui, Y. (2016). Effects of water-saving irrigation on weed infestation and diversity in paddy fields in East China. *Paddy and Water Environment*, *15*(3), 593-604.

Marshall, E. J. P., Brown, V. K., Boatman, N. D., Lutman, P. J. W., Squire, G. R., and Ward, L. K. (2003). The role of weeds in supporting biological diversity within crop fields. *Weed Research*, *43*, 77-89.

Martinkova, Z. (2006). Seed age and storage conditions influence

germination of barnyardgrass (*Echinochloa crus-galli*). *Weed Science*, *54*, 298-304

Matringe, M., Camadro, J. M., Labbe, P., and Scalla, R. (1989) Protoporphyrinogen oxidase inhibition by three peroxidizing herbicides: oxadiazon, LS 82-556 and MandB 39279. *FEBS Letters*, *245*(1), 35-38.

McCourt, J. A., Pang, S. S., King-Scott, J., Guddat, L. W., and Duggleby, R. G. (2006). Herbicide-binding sites revealed in the structure of plant acetohydroxyacid synthase. *Proceedings of the National Academy of Sciences*, *103*(3), 569-573

Mercado, B. L., de Datta, S. K., Migo T. R., and Baltazar, A. M. (1990). Growth behaviour and leaf morphology of Philippine strains of *Sphenoclea zeylanica* showing differential response to 2,4-D. *Weed Research*, *30*, 245-250

Nakka, S., Thompson, C. R., Peterson, D. E., and Jugulam, M. (2017). Target site–based and non–target site based resistance to ALS inhibitors in palmer amaranth (*Amaranthus palmeri*). *Weed Science*, *65*(6), 681-689.

Norsworthy, J. K., Wilson, M. J., Scott, R. C., and Gbur, E. E. (2014). Herbicidal activity on acetolactate synthase-resistant barnyardgrass (*Echinochloa crus-galli*) in Arkansas, USA. *Weed Biology and Management*, *14*(1), 50-58.

Obenland, O. A., Ma, R., O'Brien, S. R., Lygin, A. V., and Riechers, D. E. (2019). Carfentrazone-ethyl resistance in an *Amaranthus tuberculatus* population is not mediated by amino acid alterations in the PPO2 protein. *PLOS ONE*, *14*(4), e0215431.

Oerke, E. C. (2005). Crop losses to pests. *The Journal of Agricultural Science*, *144*(1), 31-43.

Owen, M. J., Goggin, D. E., and Powles, S. B. (2012). Non-target-site-based resistance to ALS-inhibiting herbicides in six *Bromus rigidus* populations from Western Australian cropping fields. *Pest Management Scienc*e, *68*(7), 1077-1082.

Peerzada, A. M., Bajwa, A. A., Ali, H. H., and Chauhan, B. S. (2016). Biology, impact, and management of *Echinochloa colona* (L.) Link. *Crop Protection*, *83*, 56-66.

Pimentel, D., Lach, L., Zuniga, R., and Morrison, D. (2000). Environmental and economic costs of nonindigenous species in the United States. *BioScience*, *50*(1), 53-65 .

Rangani, G., Salas-Perez, R. A., Aponte, R. A., Knapp, M., Craig, I. R., Mietzner, T., Langaro, A. C., Noguera, M. M., Porri, A., and Roma-Burgos, N. (2019). A novel single-site mutation in the catalytic domain of protoporphyrinogen oxidase IX (PPO) confers resistance to PPO-inhibiting herbicides. *Frontiers in Plant Science*, *10*, 568-579.

Riar, D. S., Norsworthy, J. K., Bond, J. A., Bararpour, M. T., Wilson, M. J., and Scott, R. C. (2012). Resistance of *Echinochloa crus-galli* populations to acetolactate synthase-inhibiting herbicides. *International Journal of Agronomy*, *2012*, 1-8.

Riar, D. S., Norsworthy, J. K., Srivastava, V., Nandula, V., Bond, J. A., and Scott, R. C. (2013). Physiological and molecular basis of acetolactate synthase-inhibiting herbicide resistance in barnyardgrass (*Echinochloa crus-galli*). *Journal of Agricultural and Food Chemistry*, *61*(2), 278-

289.

Ryan, G. F. (2017). Resistance of common groundsel to simazine and atrazine. *Weed Science*, *18*(5), 614-616.

Sadeghloo, A., Asghari, J., and Ghaderi-Far, F. (2013). Seed germination and seedling emergence of velvetleaf and barnyardgrass (*Echinochloa crus-galli*). *planta daninha*, *31*, 259-266.

Salas, R. A., Burgos, N. R., Tranel, P. J., Singh, S., Glasgow, L., Scott, R. C., and Nichols, R. L. (2016). Resistance to PPO-inhibiting herbicide in Palmer amaranth from Arkansas. *Pest Management Science*, *72*(5), 864-869.

Seefeldt, S. S., Jensen, J. E., and Fuerst, E. P. (2017). Log-logistic analysis of herbicide dose-response relationships. *Weed Technology*, *9*(2), 218-227.

Shergill, L. S., Bish, M. D., Jugulam, M., and Bradley, K. W. (2018). Molecular and physiological characterization of six-way resistance in an *Amaranthus tuberculatus* var. rudis biotype from Missouri. *Pest Management Science*, *74*(12), 2688-2698.

Shoup, D. E., Al-Khatib, K., and Peterson, D. E. (2003). Common waterhemp (*Amaranthus rudis*) resistance to protoporphyrinogen oxidase-inhibiting herbicides. *Weed Science*, *51*(2), 145-150.

Singh, S., Singh, V., Salas-Perez, R. A., Bagavathiannan, M. V., Lawton-Rauh, A., and Roma-Burgos, N. (2019). Target-site mutation accumulation among ALS inhibitor-resistant Palmer amaranth. *Pest Management Science*, *75*(4), 1131-1139.

Sung, S.-J. S., Leather, G. R., and Hale, M. G. (2017). Development and

germination of barnyardgrass (*Echinochloa crus-galli*) seeds. *Weed Science*, *35*(2), 211-215.

Talbert, R. E., and Burgos, N. R. (2007). History and management of herbicide-resistant barnyardgrass (*Echinochloa crus-galli*) in arkansas rice. *Weed Technology*, *21*(2), 324-331.

Torra, J., Montull, J. M., Taberner, A., Onkokesung, N., Boonham, N., and Edwards, R. (2021). Target-site and non-target-site resistance mechanisms confer multiple and cross- resistance to ALS and ACCase inhibiting herbicides in *Lolium rigidum* from Spain. *Frontiers Plant Science*, 12, 625138.

Travlos, I. S., Cheimona, N., Roussis, I., and Bilalis, D. J. (2018). Weed-species abundance and diversity indices in relation to tillage systems and fertilization. *Frontiers in Environmental Science*, *6*, 11-20.

Trenkamp, S., Martin, W., and Tietjen, K., (2004). Specific and differential inhibition of very-long-chain fatty acid elongases from *Arabidopsis thaliana* by different herbicides. *Proceedings of the National Academy of Sciences*, *101*(32), 11903-11908.

Varanasi, V. K., Brabham, C., and Norsworthy, J. K. (2018). Confirmation and characterization of non–target site resistance to fomesafen in palmer amaranth (*Amaranthus palmeri*). *Weed Science*, *66*(6), 702-709.

Varanasi, V. K., Brabham, C., Korres, N. E., and Norsworthy, J. K. (2019). Nontarget site resistance in Palmer amaranth [*Amaranthus palmeri* (S.) Wats.] confers cross-resistance to protoporphyrinogen oxidase-inhibiting herbicides. *Weed Technology*, *33*(2), 349-354.

Vazquez-Garcia, J. G., Alcantara-de la Cruz, R., Palma-Bautista, C., Rojano-

Delgado, A. M., Cruz-Hipolito, H. E., Torra, J., Barro, F., and De Prado, R. (2020). Accumulation of target gene mutations confers multiple resistance to ALS, ACCase, and EPSPS inhibitors in *Lolium* species in chile. *Frontiers Plant Science*, *11*, 553948.

Vijayarajan, V. B. A., Forristal, P. D., Cook, S. K., Schilder, D., Staples, J., Hennessy, M., and Barth, S. (2021). First detection and characterization of cross- and multiple resistance to acetyl-coa carboxylase (ACCase)- and acetolactate synthase (ALS)-inhibiting herbicides in black-grass (*Alopecurus myosuroides*) and italian ryegrass (*Lolium multiflorum*) populations from Ireland. *Agriculture*, *11*(12), 1272-1286.

Wang, C. S., Lin, W. T., Chiang, Y. J., and Wang, C. Y. (2017). Metabolism of fluazifop-p-butyl in resistant goosegrass (*Eleusine indica*) in Taiwan. *Weed Science*, *65*(2), 228-238.

Wang, D. W., Li, Q., Wen, K., Ismail, I., Liu, D. D., Niu, C. W., Wen, X., Yang, G. F., and Xi, Z. (2017). Synthesis and herbicidal activity of pyrido[2,3-d]pyrimidine-2,4-dione-benzoxazinone hybrids as protoporphyrinogen oxidase inhibitors. *Journal of Agricultural and Food Chemistry*, *65*(26), 5278-5286.

Wang, J., Chen, J., Li, X., Li, D., Li, Z., and Cui, H. (2020). Pro-197-Ser Mutation in ALS and High-Level GST Activities: Multiple Resistance to ALS and ACCase Inhibitors in *Beckmannia syzigachne*. *Frontiers Plant Science*, *11*, 572610.

Wang, S., Li, H., and Lin, C. (2013). Physiological, biochemical and growth responses of Italian ryegrass to butachlor exposure. *Pesticide Biochemistry and Physiology*, *106*(1-2), 21-27.

Whitcomb, C. E. (1999). An introduction to ALS-inhibiting herbicides. *Toxicology and Industrial Health*, *15*, 232-240.

Whitehead, C. W., and Switzer, C. M., (1963) The differential response of strains of wild carrot to 2,4-D and related herbicides. *Canadian Journal of Plant Science*, *43*(3), 255-262.

Widianto, R., Kurniadie, D., Widayat, D., Umiyati, U., Nasahi, C., Sari, S., Juraimi, A. S., and Kato-Noguchi, H. (2022). Acetolactate synthase-inhibitor resistance in *Monochoria vaginalis* (Burm. f.) C. Presl from Indonesia. *Plants*, *11*(3), 400.

Yang, Q., Deng, W., Li, X., Yu, Q., Bai, L., and Zheng, M. (2016). Target-site and non-target-site based resistance to the herbicide tribenuron-methyl in flixweed (*Descurainia sophia* L.). *BMC Genomics*, *17*, 551-563.

Yu, J., Gao, H., Pan, L., Yao, Z., and Dong, L. (2017). Mechanism of resistance to cyhalofop-butyl in Chinese sprangletop (*Leptochloa chinensis* (L.) Nees). *Pesticide Biochemistry and Physiology*, *143*, 306-311.

Yuan, C. I., Chaing, M. Y., and Chen, Y. M. (2002). Triple mechanisms of glyphosate-resistance in a naturally occurring glyphosate-resistant plant *Dicliptera chinensis*. *Plant Science*, *163*, 543-554.

Zhao, L.-X., Jiang, M.-J., Hu, J.-J., Zou, Y.-L., Gao, S., Fu, Y., and Ye, F. (2020). Herbicidal activity and molecular docking study of novel PPO inhibitors. *Weed Science*, *68*(6), 565-574.

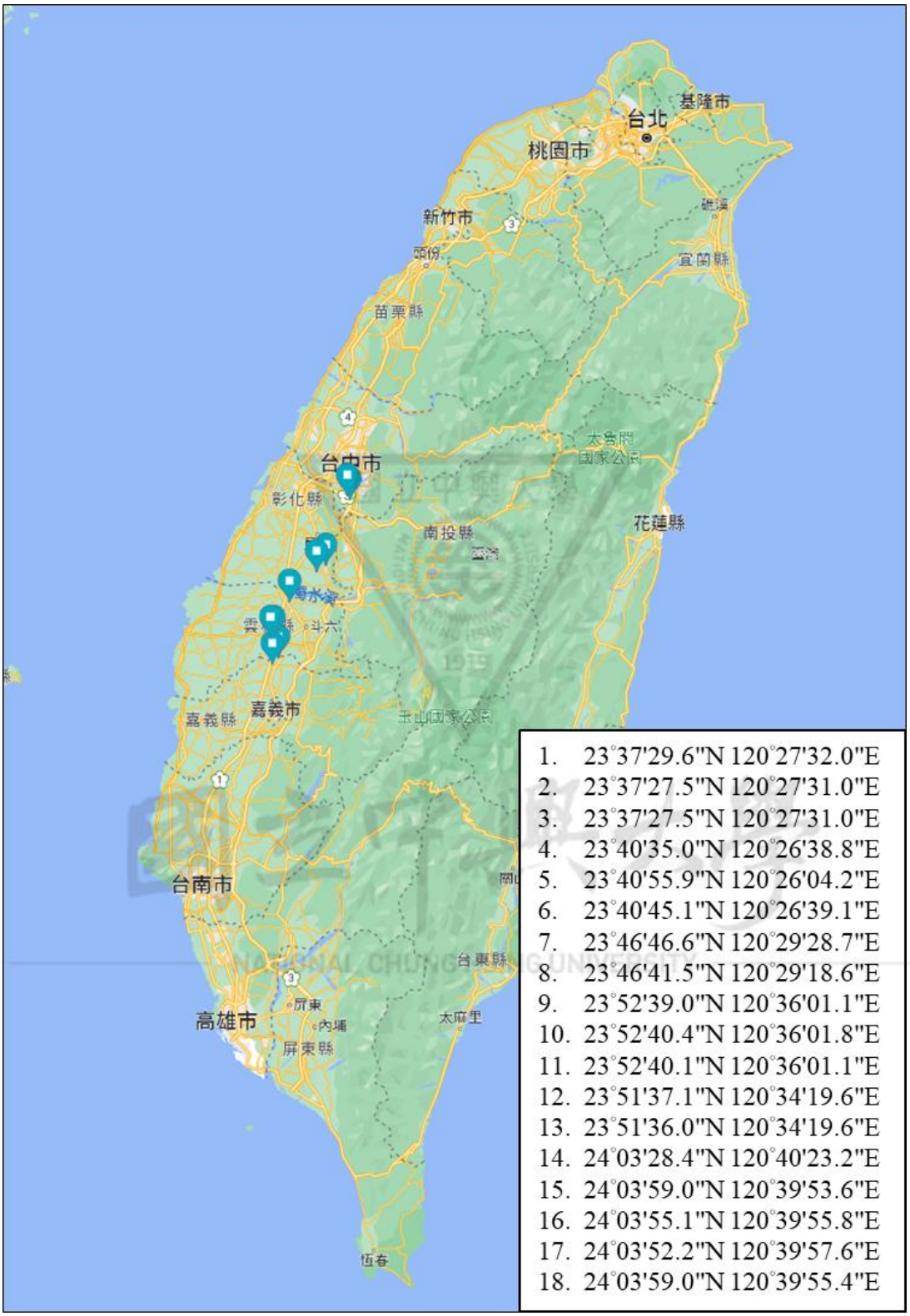
Zhao, N., Li, W., Bai, S., Guo, W., Yuan, G., Wang, F., Liu, W., and Wang, J. (2017). Transcriptome profiling to identify genes involved in

mesosulfuron-methyl resistance in *Alopecurus aequalis*. *Frontiers in Plant Science*, *8*, 1391-1406.

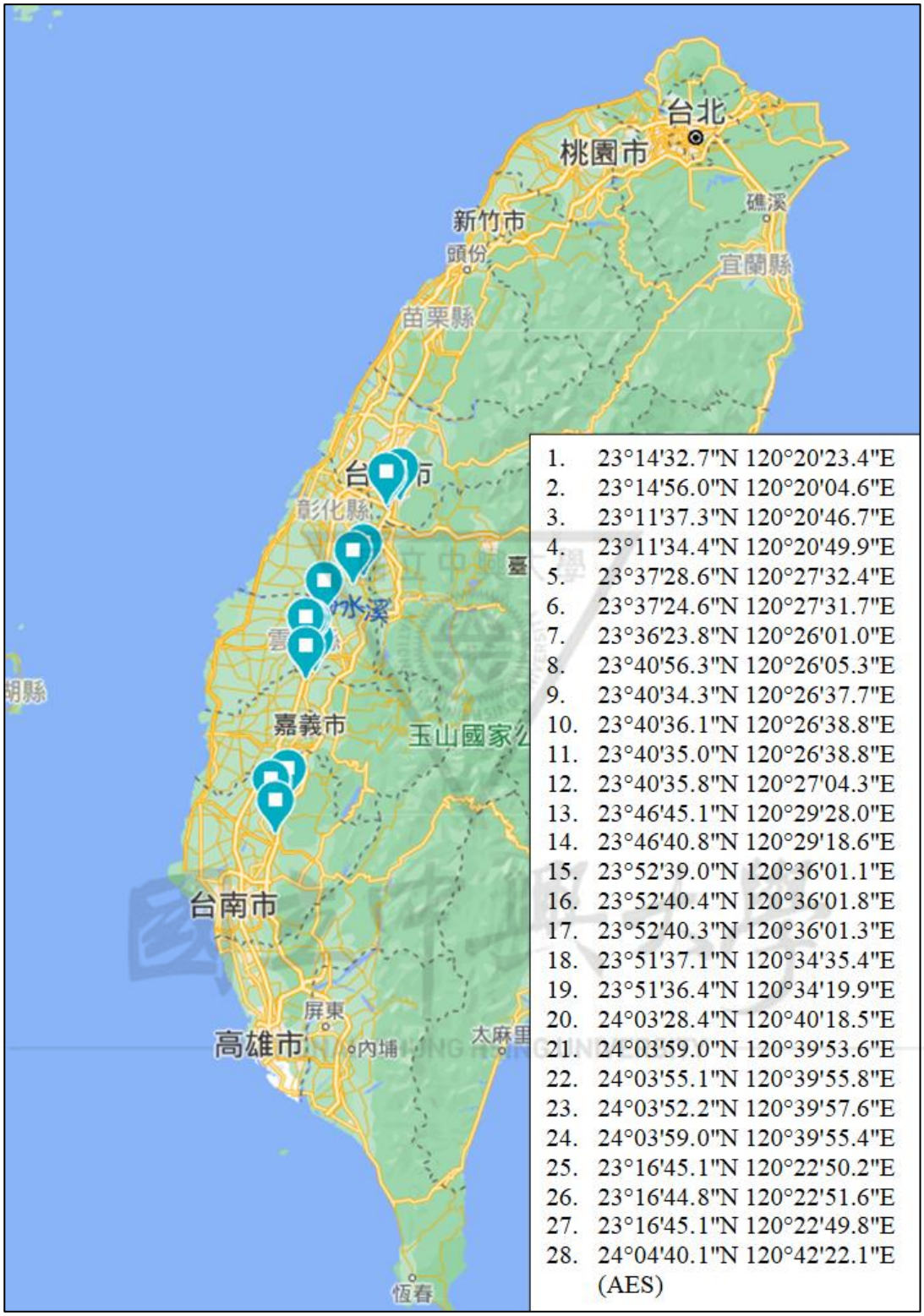
Zhao, N., Yan, Y., Ge, L., Zhu, B., Liu, W., and Wang, J. (2019). Target site mutations and cytochrome P450s confer resistance to fenoxaprop-P-ethyl and mesosulfuron-methyl in Alopecurus aequalis. *Pest Management Science*, 75(1), 204-214.

Zhou, Q., Liu, W., Zhang, Y., and Liu, K. K. (2007). Action mechanisms of acetolactate synthase-inhibiting herbicides. *Pesticide Biochemistry and Physiology,* 89(2), 89-96.

附錄



Supplementary 1A. The location of paddy field appeared suspected herbicide-resistant weeds in central and southern Taiwan during crop season I (Investigation period: 2021.03-04).



Supplementary 1B. The location of paddy field appeared suspected herbicide-resistant weeds in central and southern Taiwan during crop season II (Investigation period: 2020.08-12)

Supplementary 2. Basic information of suspected herbicide-resistant weeds in central and southern Taiwan during crop I (Investigation period: 2021.03-04)						
調查點編號		1	2	3	4	5
調查日期		2021.03.16	2021.03.16	2021.03.16	2021.03.16	2021.03.16
農戶姓名		劉○ (嘉義大林)	劉○ (嘉義大林)	張○承 (嘉義大林)	沈○城 (雲林斗南)	沈○城 (雲林斗南)
GPS 定位 (緯度.經度)		23.6249 120.4589	23.6243 120.4586	23.6101 120.4392	23.6764 120.4441	23.6822 120.4345
插秧日期		2021.03.06	2021.03.06	2021.01.26	2021.01.25	2021.01.25
水稻品種		台農 16 號	台農 16 號	無	無	無
整地時(後)	除草劑	丁基拉草 (滅田草)+ 樂滅草 (草勞滅)	丁基拉草 (滅田草)+ 樂滅草 (草勞滅)	丁基拉草 (馬上除-EC)+ 樂滅草 (草勞滅)	丁基拉草 (草必除)	丁基拉草 (草必除)+ 丁基拉草 (介好治)
	用量	1.2 L/分地 (12 L/ha) + 0.6 L/分地 (6 L/ha)	1.2 L/分地 (12 L/ha) + 0.6 L/分地 (6 L/ha)	0.75 L/分地 (7.5 L/ha) + 0.5 L/分地 (5 L/ha)	0.5 L/分地 (5 L/ha)	0.5 L/分地 (5 L/ha) + 0.25 L/分地 (2.5 L/ha)
插秧後	除草劑	丁拉百速隆 (省草繁-丁)+ 滅芬免速隆 (全期除)	丁拉百速隆 (省草繁-丁)+ 滅芬免速隆 (全期除)	殺丹免速隆 (大野狼)+ 丁基拉草 (馬上除-GR)	滅芬免速隆 (全期除)	丁拉百速隆 (省草繁-丁)
	用量	1.5 kg/分地 (15 kg/ha) + 1.25 kg/分地 (12.5 kg/ha)	1.5 kg/分地 (15 kg/ha) + 1.25 kg/分地 (12.5 kg/ha)	4.5 kg/分地 (45 kg/ha) + 4.5 kg/分地 (45 kg/ha)	無	4.5 kg/分地 (45 kg/ha)
秧後中期	除草劑			丁基拉草 (馬上除-GR)		
	用量			4.5 kg/分地 (45 kg/ha)		
備註		現場水稻生長期為分蘗始期。整地時於耕耘機上滴施丁基拉草及樂滅草。 在 20 DAT 施用丁拉百速隆及滅芬免速隆。	現場水稻生長期為分蘗始期。整地時於耕耘機上滴施丁基拉草及樂滅草。在 20 DAT 施用丁拉百速隆及滅芬免速隆。	現場水稻生長期為分蘗中期。插秧前二天使用丁基拉草及樂滅草，而在 15 DAT 使用殺丹免速隆及丁基拉草，在 30 DAT 使用丁基拉草。	插秧前整地三次，插秧前三天最後一次整地，整地時施用丁基拉草，再於 20 DAT 施用丁拉百速隆。	現場水稻生長期為分蘗中期。插秧前整地三次，插秧前三天最後一次整地，整地時施用兩種丁基拉草，再於 15 DAT 施用丁拉百速隆。

DAT: Day after transplanting (秧後日數)

調查點編號		6	7	8	9	10
調查日期		2021.03.16	2021.03.16	2021.03.16	2021.03.23	2021.03.23
農戶姓名		沈○聰 (雲林斗南)	蔡○周 (雲林莿桐)	蔡○周 (雲林莿桐)	周○彥 (彰化田中)	周○彥 (彰化田中)
GPS 定位		23.6792 120.4442	23.7796 120.4913	23.7782 120.4885	23.8775 120.6003	23.8779 120.6005
插秧日期		2021.01.25	2021.02.04	2021.02.04	2021.02.17	2021.02.17
水稻品種		無	無	無	無	無
整地時 (後)	除草劑		丁基拉草 (馬上除)	丁基拉草 (馬上除)		
	用量		無	無		
插秧後	除草劑	滅芬免速隆 (全期除)	丁拉免速隆 (龍無草-丁)	丁拉免速隆 (龍無草-丁)	丁拉免速隆 (龍無草-丁)	丁拉免速隆 (龍無草-丁)
	用量	無	無	無	3 kg/分地 (30 kg/ha)	3 kg/分地 (30 kg/ha)
備註			現場水稻生長期為分蘗中期。於插秧前施用丁基拉草，於 15 DAT 施用丁拉免速隆。依然無法有效防治稗草。	現場水稻生長期為分蘗中期。於插秧前施用丁基拉草，於 15 DAT 施用丁拉免速隆。	現場水稻生長期為分蘗始期。插秧後 7 天施用丁拉免速隆 田間以莎草科為主。	現場水稻生長期為分蘗始期。插秧後 7 天施用丁拉免速隆 田間以莎草科為主。

調查點編號		11	12	13	14	15
調查日期		2021.03.23	2021.03.23	2021.03.23	2021.04.13	2021.04.13
農戶姓名		周○彥 (彰化田中)	李○庭 (彰化田中)	李○庭 (彰化田中)	林○桂 (台中烏日)	廖○興 (台中霧峰)
GPS 定位		23.8778 120.6003	23.8603 120.5721	23.8600 120.5721	24.0579 120.6731	24.0664 120.6649
插秧日期		2021.02.17	2021.02.14	2021.02.14	2021.02.28	2021.02.28
水稻品種		無	無	無	無	無
整地時 (後)	除草劑		丁基拉草 32%EC (介好治)	丁基拉草 32%EC (介好治)		丁基拉草 60%EC (馬上除)
	用量	無	無	無	無	無
插秧後	除草劑	丁拉免速隆 (龍無草-丁)	丁基拉草 5%GR (馬上除)	丁基拉草 5%GR (馬上除)	丁拉依速隆 2.7%粒劑 (真省工-丁)	
	用量	3 kg/分地 (30 kg/ha)	無	無	3 kg/分地 (30 kg/ha)	無
備註		現場水稻生長期為分蘗始期。插秧後 7 天施用丁拉免速隆。田間以莎草科為主。	現場水稻生長期為分蘗始期。插秧前 3 天施用丁基拉草 32%乳劑，插秧後 7 天施用丁基拉草 5%粒劑。未有效控制田間雜草，雜草叢生。	現場水稻生長期為分蘗始期。插秧前 3 天施用丁基拉草 32%乳劑，插秧後 7 天施用丁基拉草 5%粒劑。未有效控制田間雜草，雜草叢生。	現場水稻生長期為分蘗始期。插秧後使用真省工-丁。	現場水稻生長期為分蘗始期。插秧前兩天用 60%丁基拉草。

調查點編號		16	17	18
調查日期		2021.04.13	2021.04.13	2021.04.13
農戶姓名		廖○興 (台中霧峰)	廖○興 (台中霧峰)	廖○興 (台中霧峰)
GPS 定位		24.0653 120.6655	24.0645 120.6660	24.0664 120.6654
插秧日期		2021.02.28	2021.02.28	2021.02.28
水稻品種		無	無	無
整地時 (後)	除草劑	丁基拉草 60%EC (馬上除)	丁基拉草 60%EC (馬上除)	丁基拉草 60%EC (馬上除)
	用量	無	無	無
備註		現場水稻生長期為分蘗始期。插秧前兩天用 60%丁基拉草。	現場水稻生長期為分蘗始期。插秧前兩天用 60%丁基拉草。	現場水稻生長期為分蘗始期。插秧前兩天用 60%丁基拉草。

Supplementary 3. Basic information of suspected herbicide-resistant weeds in central and southern Taiwan during crop II (Investigation period: 2020.08-9)						
調查點編號		1	2	3	4	5
調查日期		2020.08.13	2020.08.13	2020.08.13	2020.08.13	2020.08.13
農戶姓名		陳○裕 (台南柳營)	陳○裕 (台南柳營)	胡○銘 (台南官田)	胡○銘 (台南官田)	劉○ (嘉義大林)
GPS 定位 (緯度.經度)		23.2424 120.3398	23.2489 120.3346	23.1937 120.3462	23.1929 120.3472	23.6246 120.4590
插秧日期		2020.07.26	2020.07.26	2020.08.06	2020.08.06	無
水稻品種		日本皇后	無	無	無	無
整地時 (後)	除草劑	固殺草+ 嘉磷塞	丁基拉草+ 滅芬免速隆			丁基拉草+ 樂滅草
	用量	0.3 L/分地 (3 L/ha) + 0.3 L/分地 (3 L/ha)	0.5 L/分地 (5 L/ha) + 4.5 kg/分地 (45 kg/ha)			0.45 L/分地 (4.5 L/ha)+ 0.3 L/分地 (3 L/ha)
插秧後	除草劑	丁拉殺丹		丁基拉草+ 殺丹免速隆	丁拉免速隆	
	用量	4.5 kg/分地 (45 kg/ha)		0.5 L/分地 (5 L/ha) + 3.6 kg/分地 (36 kg/ha)	無	
備註		現場水稻生長期為分蘗中期。近 3 年使用過百速隆、丁拉百速隆，施用量為 1.5 包/分地。田埂的牛筋草施用固殺草:嘉磷塞 300:300。	現場水稻生長期為分蘗中期。	現場水稻生長期為分蘗始期。近 3 年使用過丁基拉草 32%、丁拉免速隆施用量為 1 瓶/分地、1 包/分地。藥劑使用三次以上。	現場水稻生長期為分蘗始期。插秧時，鴨舌草已存在。於 8/9 施藥(3 DAT)。	現場水稻生長期為分蘗始期。
DAT: Day after transplanting (秧後日數)						

調查點編號		6	7	8	9	10
調查日期		2020.08.13	2020.08.13	2020.09.02	2020.09.02	2020.09.02
農戶姓名		劉○ (嘉義大林)	張○承 (嘉義大林)	沈○城 (雲林斗南)	沈○聰 (雲林斗南)	沈○聰 (雲林斗南)
GPS 定位		23.6235 120.4588	23.6066 120.4336	23.6823 120.4348	23.6762 120.4438	23.6767 120.4441
插秧日期		2020.07.28	2020.07.28	2020.08.08	2020.08.08	2020.08.08
水稻品種						
整地時(後)	除草劑	丁基拉草+ 樂滅草	丁基拉草+ 樂滅草	氟氯比		左旋莫多草+ 丁基拉草
	用量	0.45 L/分地 (4.5 L/ha)+ 0.3 L/分地 (3 L/ha)	0.5 L/分地 (5 L/ha)+ 0.25 L/分地 (2.5 L/ha)	1.5 L/ha		0.02 L/分地 (0.2 L/ha)+ 0.25 L/分地 (2.5 L/ha)
插秧後	除草劑		滅芬免速隆	本達隆	Apiro Forte	滅芬免速隆
	用量		2.5 kg/分地 (25 kg/ha)	0.17 L/分地 (1.7 L/ha)	0.33 L/ha	2.5 kg/分地 (25 kg/ha)
備註		現場水稻生長期為分蘗始期。	秧前施用丁基拉草 500 mL/分地，及 2.5%樂滅草 250 mL/分地。	現場水稻生長期為分蘗中期。	現場水稻生長期為分蘗始期及中期。 現場 2.9 分地。	現場水稻生長期為分蘗始期及中期。 現場 1.6 分地。

調查點編號		11	12	13	14	15
調查日期		2020.09.02	2020.09.02	2020.09.02	2020.09.02	2020.09.10
農戶姓名		沈○聰 (雲林斗南)	沈○武 (雲林斗南)	蔡○周 (雲林莿桐)	蔡○周 (雲林莿桐)	周○彥 (彰化田中)
GPS 定位		23.6764 120.4441	23.6766 120.4512	23.7792 120.4911	23.7780 120.4885	23.8775 120.6003
整地日期		無	無	2020.07.19	2020.07.28	無
插秧日期		2020.08.08	2020.08.08	2020.07.24	2020.07.30	2020.07.29
水稻品種		桃園 3 號	無	台南 11 號	桃園 3 號	台南 11 號
整地時 (後)	除草劑	Apiro Forte	丁基拉草	丁基拉草 (馬上除)		
	用量	0.4 L/ha	0.25 L/ha	0.25 L/ha		
插秧後	除草劑		丁拉百速隆 (省草繁-丁)	丁拉免速隆 (龍無草)	丁基拉草 (馬上除)+ 丁拉免速隆 (龍無草-丁)	Apiro Forte
	用量		30 kg/ha	30 kg/ha	0.25 L/ha + 30 kg/ha	0.33 L/ha
秧後中期	除草劑					Apiro Forte
	用量					0.33 L/ha
備註		現場水稻生長期為分蘗始期及中期。	現場水稻生長期為分蘗始期及中期。使用耕耘機整地三次。	現場水稻生長期為分蘗中期部分分蘗結束。	現場水稻生長期為分蘗中期部分分蘗結束。	現場水稻生長期為分蘗結束但尚未孕穗。

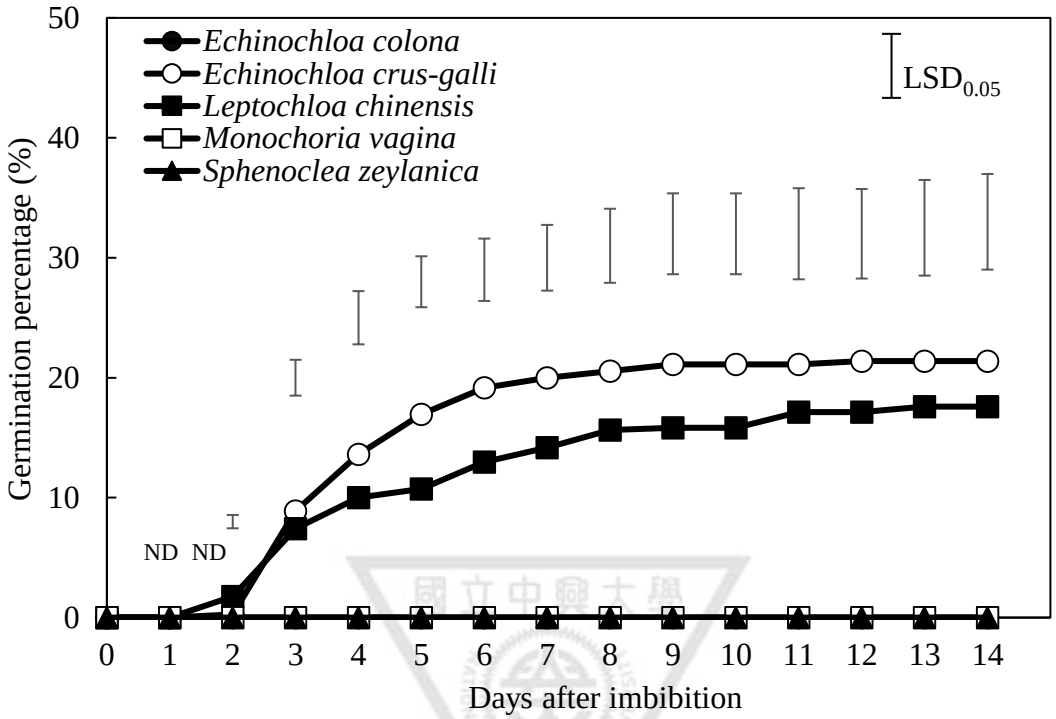
調查點編號		16	17	18	19	20
調查日期		2020.09.10	2020.09.10	2020.09.10	2020.09.10	2020.09.10
農戶姓名		周○彥 (彰化田中)	周○彥 (彰化田中)	李○庭 (彰化田中)	李○庭 (彰化田中)	林○桂 (台中烏日)
GPS 定位		23.8779 120.6005	23.8778 120.6003	23.8603 120.5765	23.8601 120.5722	24.0579 120.6718
插秧日期		2020.07.29	2020.07.29	2020.07.23	2020.07.23	2020.07.29
水稻品種		無	無	無	台南 11 號	台農 71 號 (益全香米)
整地時 (後)	除草劑		丁基拉草	丁基拉草	丁基拉草	丁基拉草+依速隆
	用量		無	無	無	無
插秧後	除草劑		丁拉免速隆 (龍無草-丁)	丁基拉草 (馬上除)	丁基拉草 (馬上除)	丁拉免速隆 (龍無草-丁)
	用量		0.45 kg/ha	30 kg/ha	30 kg/ha	無
秧後中期	除草劑	Apiro Forte		丁基塞伏草 (克稗)+ 平速爛	丁基塞伏草 (克稗)+ 平速爛	
	用量	0.33 L/ha		無	無	
備註			於 40 DAT 進行田野調查	田區保水不良。牛筋草較多。	施用丁基塞伏草+平速爛。現場水稻生長期為分蘗結束。	現場水稻生長期為分蘗結束。施用丁基塞伏草防治千金子等禾本科雜草

調查點編號		21	22	23	24	25
調查日期		2020.09.10	2020.09.10	2020.09.10	2020.09.10	2020.09.15
農戶姓名		廖○興 (台中霧峰)	廖○興 (台中霧峰)	廖○興 (台中霧峰)	廖○興 (台中霧峰)	吳○章 (台南柳營)
GPS 定位		24.0664 120.6649	24.0653 120.6655	24.0645 120.6660	24.0664 120.6654	23.2791 120.3810
整地日期		無	無	無	無	2020.08.06
插秧日期		2020.08.01	2020.08.01	2020.08.01	2020.08.01	2020.08.11
水稻品種		台農 71 號 (益全香米)	無	無	無	無
整地時 (後)	除草劑			Apiro Forte	免速隆+ 普拉草 (踪除龍)	丁基拉草
	用量			無	3 kg/分地 (30 kg/ha)	30 kg/ha
插秧後	除草劑	免速隆+ 普拉草 (踪除龍)	Apiro Forte			
	用量	無	無			
秧後中期	除草劑	本達隆+ 百速隆				殺丹免速隆 +丁拉免速隆
	用量					1.5 kg/分地 (15 kg/ha)
備註					現場水稻生長期為分蘗結束。	田間出現雙穗雀稗

調查點編號		26	27
調查日期		2020.09.15	2020.09.15
農戶姓名		吳○章 (台南柳營)	吳○章 (台南柳營)
GPS 定位		23.2792 120.3806	23.2792 120.3805
插秧日期		2020.08.11	2020.08.11
水稻品種		無	無
整地時(後)	除草劑		
	用量		
插秧後	除草劑	Apiro Forte	Apiro Forte
	用量	0.33 L/分地 (3.3 L/ha)	0.4 L/分地 (4 L/ha)
備註		無	無

Supplementary 4. Five paddy weeds which collected in central and southern Taiwan during crop I & II (Investigation period: 2020.08-12 & 2021.03-04)

Weed species	Scientific name	Accession code
Barnyard grass (BG；稗草)	*Echinochloa crus-galli*	BG-WT, BG(II)-AES, BG(II)-8, BG(II)-13, BG(II)-17
Ceylon sphenoclea (CS；尖瓣花)	*Sphenoclea zeylanica*	CS(II)-AES, CS(II)-3, CS(II)-4, CS(II)-6, CS(II)-20, CS(II)-22, CS(II)-23, CS(II)-24
Jungle rice (JR；芒稷)	*Echinochloa colona*	JR(II)-9, JR(II)-22
Red sprangle-top (RS；千金子)	*Leptochloa chinensis*	RS(II)-AES, RS(I)-1, RS(I)-2, RS(I)-14, RS(I)-15, RS(II)-11, RS(II)-25
Sheathed monochorea (SM；鴨舌草)	*Monochoria vaginalis*	SM(II)-AES, SM(II)-4, SM(II)-7, SM(II)-16, SM(II)-17



Supplementary 5. Germination percentage of *Echinochloa colona*, *Echinochloa crus-galli*, *Leptochloa chinensis*, *Monochoria vagina*, and *Sphenoclea zeylanica* were determined within 14 days after imbibition (DAI). Seeds were placed on filter paper in Petri dish and grown in growth chamber. Germination percentages were 0.0, 21.4, 17.6, 0.0 and 0.0%, respectively, at 14 DAI. ND = no difference at the 5% significant level.

Supplementary 6. Growth stage of red sprangle-top and barnyard grass seedlings.

Supplementary 7. Herbicides applied in the herbicide-resistant weed valuation prograss.

普通名	商品名 (公司)	英文名	劑型 [a]	有效成分含量比例 (%)	藥劑溶液密度 (g/cm^3)	推薦用量 (L/ha)	瓶(包)裝藥劑有效成分			換算每公頃水深 4 cm 之水體中的有效成分 [b]		作用機制	有效期限
							濃度 (kg/L)	分子量	體積莫耳數 (M)	濃度 (mg/L)	體積莫耳數 (μM)		
無	無 (先正達；Syngenta)	Apiro Forte	SC	55.1	1.2	0.333	0.661	無	無	0.550	無	抑制 ALS	2020.9-2023.9
							bensulfuron-methyl:0.185	410.4	0.450	0.185	0.450	抑制 ALS	
							pyriftalid: 0.366	318.3	1.150	0.365	1.147	抑制 ALS	
免速隆	無 (Syngenta)	bensulfuron-methyl	SC	56.0	1.2	0.110[c]	0.672	410.4	1.365	0.185	0.450	抑制 ALS	2021.04-2023.04
丁基拉草	草全除 (興農；Sinon)	butachlor	EC	32.0	1.1	5.500	0.352	311.9	1.129	4.840	15.518	抑制長鏈脂肪酸	2021.02-2023.02
樂滅草	滴滅草 (嘉泰；Chia Tai)	oxadiazon	EC	25.0	1.3	2.640	0.325	345.2	0.941	2.145	6.214	抑制原紫質氧化酶	2020.04-2023.04
平速爛	稻田喜 (道禮；DOW)	penoxsulam	OD	2.7	1.0	1.000	0.027	483.4	0.056	0.068	0.140	抑制 ALS	2020.05-2023.05
派伏利	無 (Syngenta)	pyriftalid	SC	40.0	1.1	0.332	0.440	318.3	1.382	0.365	1.147	抑制 ALS	2021.02-2023.02

[a] SC:suspension concentrate (水懸劑), OD:oil dispersion (水分散性油懸劑), EC:emulsifiable concentrate (乳劑), SL:soluble concentrate (溶液)

[b] 每公頃保持水深 4 公分的水體體積約為 4×10^5 公升，計算藥劑在推薦用量下施用於田間後，理想狀態下在田水中藥劑的濃度及體積莫耳數。

[c] 免速隆 (bensulfuron-methyl)及 pyriftalid 單劑之推薦用量為參考 Apiro Forte 混合劑中之兩種單劑的濃度後，並進行換算所得。