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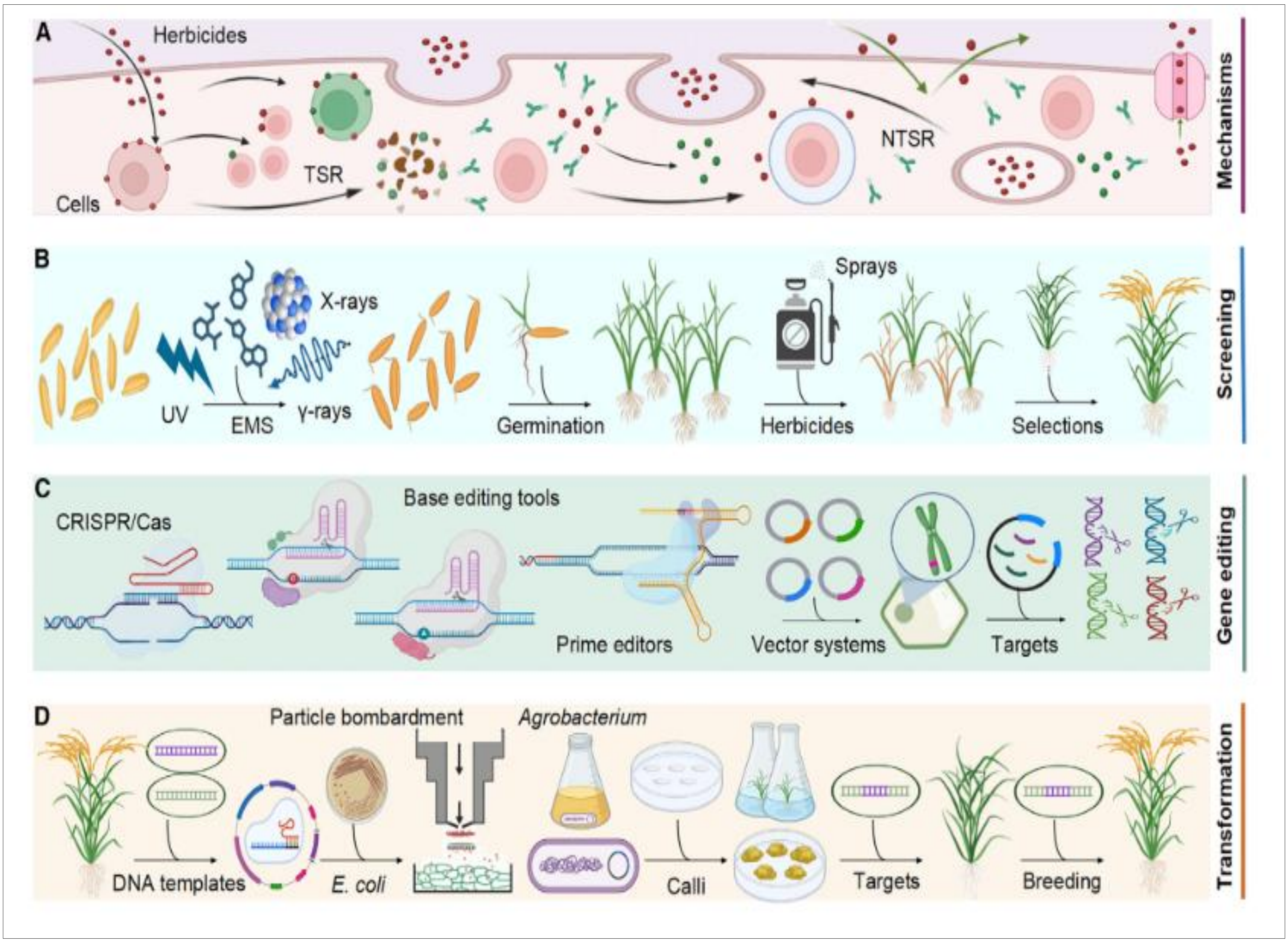

WEEDS

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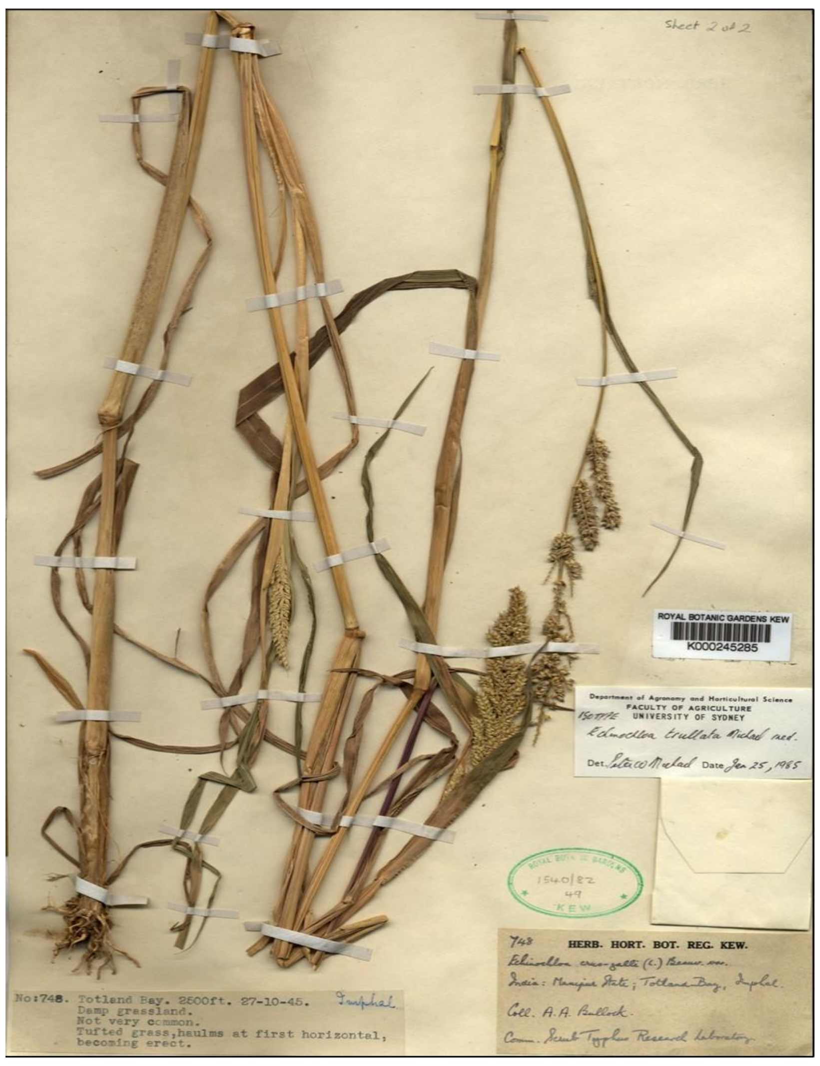

EDITORIAL

One Longs For A Weed

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Abstract

Let us have no doubt - the adverse effects of weeds have been so significant in agriculture that they led to a whole field of science - *Weed Science* - our discipline. Founded in the 1950s, it has since become a formidable discipline that makes an enormous contribution to agriculture, land management, and the conservation of the Planet's land and water resources. Yet, many weed scientists and agriculturists still have a relatively poor grasp of this special group of plants.

Suffice it to say, *Not All Weeds Are Bad All the Time*. *If weeds could speak, they would explain this better to humans*. *Weedy species are universally nothing but colonising taxa*. A weed also does not know that it is a 'weed'. The term is a human epithet, a human construct. The 'weed', on the other hand, is simply a highly successful living organism possessing attributes that we also possess and value.

Humans present the greatest threat to biodiversity, of which people and weedy species are constituent parts. However unpalatable this message might be to some farmers, conservationists and others, it needs to be given much more publicity to achieve a better balance between human greed, the development aspirations of nations, and global biological diversity. A change in attitude and a shift in focus are required to address the issue.

Weedy taxa have long been used as a scapegoat to hide human follies (related to disturbances caused by land-clearing, deforestation, inappropriate forms of agriculture, and excessive population growth). Our discipline, which is now more than 80 years old, recognises that '*consensus helps but is not always necessary for cooperation in successfully conducting investigative research*,' which sheds more light on colonising taxa. Divergent views on weeds appear to be influenced by the experiences of individuals and groups (i.e. negative perceptions about weeds in monoculture agriculture).

In science or any other field of human endeavour, for that matter, repetition is not a crime. It is a fundamental principle in scientific inquiry. It helps to verify hypotheses, ensure consistent results, and build a strong foundation of knowledge. Therefore, I plead again that weed science should broaden the mandate it has and stop ignoring the virtuous side of weedy species. Not to do so would be a human folly and would add to the mistakes that we have made in the last century or so, which have placed the Planet on the brink of collapse.

Keywords: War With Weeds, Colonising species, utilization of weeds, Weed Science, weed research

If A weed Could Speak

"…One longs for a weed, here and there, for variety; though a weed is no more than a flower in disguise, which is seen through at once if love gives a man eyes..." Lowell (1876)

"…It is time for us to eliminate weeds from our cultivated lands. But we should also understand why we do it and what we're doing. Nature has a reason for allowing weeds to grow where we do not want them.

If this reason becomes clear to us, we will have learned from Nature how to deprive weeds of their 'weedy' character; that is, how to eradicate them…, or rather, how to improve our methods of cultivation so that weeds are no longer a problem…" Pfeiffer (ca. 1950)

The first quote, from James Russel Lowell - a famous American poet, pleads people to open their eyes and appreciate *Nature*, of which weeds are an essential part. The poetic freedom of expression allowed Lowell to promote a sympathetic view of weeds rather than viewing them negatively.

The second quote, from Dr. Ehrenfried Pfeiffer, a soil scientist, states that weeds become a nuisance when they interfere with crops or human activities. Pfierffer, the pioneer of *Biodynamic Farming*, suggested that problematic 'weeds' need to be eliminated from arable lands, but people should do so only with a good understanding of why they are there in the first place. Both viewpoints are essential in broadening our thinking about weeds.

Let us have no doubt - the negative impacts of weeds have been so significant in agriculture that they led to a whole field of science - *Weed Science* - our discipline. Founded in the 1950s, weed science has since become a formidable discipline. Over the past seven decades, the discipline, despite its primary focus on herbicides, has significantly enhanced the methods and tools available for effective weed control in farming.

Nevertheless, in tracing the history of *Weed Science* in the USA, Timmons (1970), Holm (1971) and Appleby (2005) concluded that few agriculturists considered weeds a problem before 1500 AD and that weed control was *incidental* to land preparation for growing crops.

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Where *Weed Science* fits within the space of biological sciences, ecology, agriculture, or environmental sciences does not really matter, as weeds affect many areas of human interest. Away from agriculture, the discipline has expanded rapidly in the last few decades to address the problems that native vegetation and landscapes can pose to colonising taxa. *Weed Science* now encompasses studies on the ecological restoration of damaged environments, utilising weedy species to remediate land and water resources or using such species to generate biofuel energy through biomass.

Our founders, many of whom were leading ecologists of the 1950s and 1960s, stated that understanding why weeds are present in the first place is crucial before attempting to control them (Baker, 1965, 1974; Bunting, 1960; Harper, 1960, 1967, 1977). If we also do not forget why weeds are so successful, perhaps we can learn how to mitigate their negative impacts more effectively and *save ourselves some effort and money along the way, too*.

Some people hate weeds without much reason. Others do so because weeds can be a back-breaking nuisance. Weeds despoil their tidy and homely worlds, bothering them in various situations. Even some environmentalists loathe weeds due to their concern that some aggressive taxa will colonise forests, native bushlands, and grasslands, displacing native species. Many people dislike aquatic weeds because their excessive growth makes water bodies unusable for various purposes. Large stands of aquatic weeds can choke rivers, interfering with livelihoods, water supplies, recreational uses, navigation and drainage.

Ecologists and Agriculturists know that weedy species are notorious for occupying places we do not want them to be. They are also sturdy, recalcitrant to control and persistent. They will also cost you time, effort, and money. Weed control labour and herbicides are not cheap. However, the dislike of weeds among people is not universal. I know many people who wonder whether weeds have any redeeming value (Chandrasena, 2023).

Are humans making another mistake by the relentless search-and-destroy missions against weeds, backed by the excessive use of chemical weapons? The devastating damage caused to plants and humans by the US Military spraying the notorious herbicide *Agent Orange* over Vietnam cannot be forgotten. It resulted in the destruction of vast acreages of vegetation and dire health consequences for thousands of Vietnamese, as well as American soldiers, livestock and wildlife (Martini, 2012). Dioxins, byproducts of large-scale chemical manufacturing, were the main culprit.

The military use of herbicides, a rare event, cannot be equated with the everyday use of herbicides to manage weeds. However, poorly executed herbicide-based weed control practices can cause unintended consequences. Similarly, grubbing and other forms of mechanical weed control using heavy machinery cause unnecessary soil disturbances while also reducing the cover of existing vegetation. Intact forests and grasslands are often affected by such interventions. Additionally, depending on the scale, disproportionate weed control can exacerbate soil erosion and disrupt habitats. It also creates conditions under which other colonizers arrive and displace indigenous plants.

* * *

The standard but subjective definition, '*a weed is a plant growing where it is not wanted,*' runs the risk of branding some of the most valuable plants in the world as undesirable. Giving too much credit to human judgments is fraught! This definition is still cited in a large number of *Weed Science* articles without qualification. My suggestion is that it should be urgently replaced with a meaningful (ecological) one. I prefer the one: '*A weed is a pioneering or colonising species, which grows abundantly in a disturbed habitat, often associated with human-caused disturbances*'.

We have known for over 60 years that specific plant taxa possess unique biological attributes that enable them to colonise previously vacant habitats (Bunting, 1960; Baker, 1965; Chandrasena, 2023). Such plants display attributes that collectively appear as a '*weediness syndrome*'. Confusingly, this term also describes the '*weedy condition*' of a cropping field or flower bed. In the latter case, '*weediness*' refers to the abundance of weeds at a given site rather than to the collective traits of the biological entity itself.

Evolutionary evidence suggests that colonising taxa occupied the Earth long before humans. Some taxa evolved with traits and attributes that allowed them to quickly inhabit vacant spaces created by various disturbances. The colonization of the Planet's surface by pioneering plants occurred during the Pleistocene Epoch (approximately 2.6 million to about 11,000 years ago) of the Quaternary Era (2.6 million years ago to the present).

The *Quaternary Era* is called the *'Age of Humans'* because our species (genus *Homo*) evolved in its latter part. However, colonising taxa, most of which are flowering plants (Angiosperms), evolved approximately 140 million years ago, well before our ancestors. Our primate ancestors separated from other mammals around 35-55 million years ago (*Eocene Epoch*). Our closest kin, the great apes (*Hominidae*), evolved less than 20 million years ago. The evolution of humans can be traced back to a few million years (the last 2-4 million years) only [1].

We now live in a period that has been termed the *Anthropocene*. It refers to the geologic epoch dating from the start of a significant human impact on the Planet's ecosystems, including the present era, where humans have expedited climate change (Nature, 2024). As the era of human-induced change, the term will remain an invaluable descriptor in human-environment interactions, of which the relations with weeds are also significant.

Various start dates for the *Anthropocene* have been proposed. These range from the beginning of the *Neolithic Agricultural Revolution* (approximately 12,000 years ago) to the advent of extensive settled Agriculture (approximately 5,000 years ago), the Industrial Revolution (dated to the 18th century), and as recently as the 1960s.

* * *

The concept of 'weediness' is a valuable tool to better understand weeds. It describes the possession of a set of heritable traits, as well as life-cycle strategies, in members belonging to a group of plants. More than 60 years ago, one of our founders - Herbert George Baker - explained this:

> *"A plant is a weed if, in any specified…area, its populations grow entirely or predominantly in situations disturbed by man (without, of course, being a deliberately cultivated plant). Thus, weeds include plants that are called agrestals (they enter agricultural land) and ruderals (which occur in waste places and along roadsides). In many cases, the same species occupy both kinds of habitat."*
>
> *"Ruderals and agrestals face many similar ecological factors…Such disturbed habitat is mostly, but not exclusively, associated with man's activities and is at least partially created by man".* Baker (1965)

Plants of all kinds dominate our world. Although fungi, bacteria, and animals are vital for sustaining natural processes, plants, including both more primitive and evolutionarily advanced plants, are the most abundant life forms on Earth. Importantly, plants not only harness the sun's energy into sugars (which serve as food for animals), but they also oxygenate the air. These effects, directly and indirectly, sustain all life on Earth. In the plant kingdom, *where there are no weeds*, the fast-growing weedy taxa play a crucial role in provisioning these services.

As Baker explained, a weed is a *colonising species*, a *pioneer* taxon, whose populations [2] grow

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[1] *Hominid* refers to the 'great apes', including Asian great apes (orangutans), African great apes (chimpanzees, bonobos, and gorillas) and humans.

[2] A *population* comprises individuals of the _same_ species. A *community*, on the other hand, is an

mainly in situations disturbed by man. Some of the world's major crops are closely related to weedy pioneering taxa. As Jack Harlan (1965) explained, they share a large proportion of their genes with '*wild*' relatives, which is one reason why we can grow crop plants well and produce food for everyone.

Many fast-growing trees, such as willows (*Salix* L. spp.) and poplars (*Populus* L. spp.), and woody shrubs, such as wattles (*Acacia* Mill. spp.), mesquite (*Prosopsis* L. spp.) and lantana (*Lantana camara* L.), are extraordinary colonizers. Ecologically speaking, these species are *pioneers of secondary succession*. Many soft herbs that grow abundantly around our homes also belong to this category. These taxa rapidly colonise and thrive in human-disturbed environments. They have adaptations to succeed not just in human-modified habitats but also in other situations disturbed by natural forces, such as floods, cyclones, landslides, and bushfires.

In agriculture, where the colonising taxa earned their dubious reputation, their interactions with crops are complex and multifaceted. *Not all weeds compete with crops equally or even efficiently*. But those that do can cause significant yield losses (Zimdahl, 1980). Crops also differ significantly in their sensitivity to the abundance of weeds and the duration of weed competition.

The contest in the agricultural field between weeds and crops for resources is most intense at the early stages of a crop's life. This period is called the "*critical period of crop-weed competition*" or the "*critical weed-free period*". It refers to the maximum period that weeds can be tolerated without affecting final crop yields or the point at which weed growth no longer affects the yield. Generally, weeds that emerge earlier, typically during the first third of the crop's life cycle, are more damaging to yields than those that appear much later (Zimdahl, 1980).

Most weed scientists are well aware that a guiding principle of '*weed management*', compared with herbicide-based '*weed control*', is to delay weed emergence relative to the crop. The critical '*weed-free*' period for any crop varies considerably among sites and years due to climate and soil conditions. These conditions influence the emergence of both crops and weeds, as well as their growth rates, weed species composition, and abundance (i.e., densities) (see Zimdahl, 2024).

Man is the 'Weediest' Species

Jack Harlan (University of Illinois), whose primary expertise was in crop evolution, was an early advocate for a better understanding of weeds [3]. To achieve this, he drew analogies with other successful organisms that also thrived under human influence, such as the fruit fly, field mouse, pigeons, and the English sparrow. He also called humans the *weediest* of all species on Earth:

> *"The word 'weed' means a species or a race adapted to conditions of human disturbance. By this definition, weeds are not confined to plants. Animals, such as the English sparrow, the starling, the pigeon, the house mouse, Drosophila melanogaster, and others, are specially fitted to environments created by human disturbances".*
>
> *"Indeed, perhaps no species thrives under human disturbance more than Homo sapiens himself. In an ecological sense, man is primarily a weed".*
>
> *"Weeds have been constant and intimate companions of man throughout his history and could tell us a lot more about man, where he has been and what he has done if only we knew more about them".*
>
> *"Weeds are adapted to habitats disturbed by man. They may be useful in some respects and harmful to others. They may be useful to some people and despised by others,"* Harlan (1965).

Harlan receives no mention in *Weed Science* textbooks written over the past 70 years. This is most likely because the discipline's early focus was on the practices and tools of weed control, especially herbicides. But he was the first to argue that humans are not just the *weediest* of all species but also the *first weed*.

> *"There can be no doubt that the more humans disturb their environment, the more they thrive on those disturbed landscapes". If 'weeds' are species adapted to human disturbances, man*

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assemblage of different species populations sharing the same habitat.

[3] For an appreciation of Jack Harlan's enormous contribution to understanding crops and weeds, see Qualset (1998) and Hymowitz (2003). Harlan's book - *The Living Fields: Our Agricultural Heritage* (1968) also provides deep insights into how agriculture and human influence shaped crops and weedy species.

> *is the first and 'primary weed' under whose influence all other weeds evolved"* (Harlan,1965)

Most early *Weed Science* textbooks failed to emphasise such viewpoints and the role of humans as culpable in spreading weeds or causing perturbations that allow weeds to thrive. In that setting, Harlan and De Wet (1965) and De Wet and Harlan (1975) provided a robust contextual background for our discipline. In 1975, they wrote:

> *"Weeds evolve and are still evolving, within the man-made habitat in three principal ways:*
>
> *(1) from wild colonizers through selection towards adaptation to continuous habitat disturbances; (2) as derivatives of hybridization between wild and cultivated races of domestic species; and (3) from abandoned domesticates through selection towards a less intimate association with man.*
>
> *"Domesticates [wheat and maize] differ from weeds primarily in the degree of dependency on man for survival. They evolved from wild food plants, which were brought into cultivation. The process of domestication was initiated when man started to propagate plants by means of seed or vegetative propagules".*
>
> *"Artificial selection by man during the domestication process is primarily responsible for subspecific variation in domestic species".* (Harlan and De Wet, 1975)

Weeds Are Pioneers of Ecological Succession

The vast repository of *Weed Science* and related ecological literature also reveals that the '*period of ecological enlightenment*' was between 1955 and 1975, during which some defining ideas evolved. These include Baker's views on the '*Ideal Weed*' (Baker, 1965). Contributions of several other ecologists, such as Charles Elton (1958), Herbert Baker (1965; 1974), Ledyard Stebbins (Anderson and Stebbins, 1954), Baker and Stebbins, 1965), Richard Lewontin (1965), Hugh Bunting (1965), Ernst Mayr (1965) and John Harper (1958; 1960; 1977), illuminated this period.

The contributions from plant ecology and population biology have shaped and informed the study of weeds and their management (Sagar and Harper, 1961; Harper, 1967, 1983). These ecological insights essentially drove forward the early development of Weed Science into the formidable scientific discipline it has become today. We should thank our founding ecologists for illuminating the pathway forward.

Summarising the famous 1964 symposium on '*Genetics of Colonizing Species*' (Baker and Stebbins, 1965), Ernst Mayr, the renowned vertebrate zoologist from Harvard, said:

> *"Except for a few endemics, every species is a colonizer because it would not have the range it has if it had not spread, thereby range expansion, or 'colonization', from its place of origin".*

Based on ecological knowledge, we now recognise that colonising taxa thrive in habitats disturbed by human activities (such as cropping fields) or natural phenomena. In any habitat, they can be *pioneers* where there is no organic soil to begin with. They can establish themselves on barren land and rocky areas devoid of soil where other species will struggle. After establishment, they guide the changes that follow, including building substrates for others to live on. This is called *primary succession*.

The *pioneers* then take charge and drive changes in plant communities where well-developed soil exists and has been disturbed in some way. Such vegetation changes are referred to as *secondary succession*. Weedy taxa are, therefore, best described as *pioneers of secondary succession*.

Terms such as pioneers, disturbances, succession, and colonization are indeed the ecological keys to understanding why, when, and how weeds emerge and grow. Weedy plants are the first to grow in areas disturbed by humans or other animals (such as grazing livestock) or in areas affected by natural forces, including floods, bushfires, hurricanes, or similar events.

Weeds colonise and grow exceptionally well in garden beds, crop fields, cemeteries, golf courses, urban bushlands, and other areas that are continually modified by humans. As Alfred Crosby (1986) explained, weedy species are a kind of '*Ecological Red Cross*': they are the first to rush into disturbed places, occupy those places, and initiate the transformative ecological processes, such as nutrient cycling and soil microbial interactions.

Taken individually by species or genera, weeds are top-notch survivors. They can thrive in harsh conditions that would be detrimental to other plants, especially the slow-growing but long-lived perennials. Weeds are often present in the earliest stages of ecological succession. For example, in abandoned croplands, they grow in abundance because there is usually a large weed seed bank in the soil that is still rich in nutrients. In pristine forests also, if natural forces cause a perturbation that opens up an area, it would be the fast-growing 'weedy' taxa that would first occupy the forest floor before giving way to their co-existing colleagues.

All pioneering plants are, however, not 'weedy'. Consider the various liverworts (Bryophytes) and mosses (Pteridophytes) that inhabit damp places, forming mats on moist surfaces, such as on bricks or the gaps between backyard pavers. All liverworts, such as *Marchantia* L. species, and mosses, such as *Pogonatum* P. Beauv. Species, are typically innocuous, pioneering plants. Such *pioneers of primary succession* can also occasionally expand to nuisance levels that bother humans.

Weeds Are Good Teachers

It can be said that all species and the entire group we call 'weeds' are exclusively colonising pioneers, which can move into vacant and disturbed spaces unoccupied by others (in both space and time). From an ecological viewpoint, it would be correct to say they move into '*ecological niches*' (see below) unoccupied by other species at a particular time and space in a disturbed environment. *Weeds can certainly teach us how to be frugal, use available resources more effectively and adapt to survive*.

One must wonder why some people are so hard-wired to malign other successful organisms. *Is this an innate jealousy against others who are equally or more successful*? As humans face significant uncertainty in an unstable future climate, the survival strategies of weeds teach us great lessons. *Weeds live frugally*; they do not ask for much, which is a lesson in itself. Yes, they may take some of the Earth's resources for their growth; they may also make humans toil a bit, but they give back a lot more than we realise.

In a fast-changing world with limited resources and a rapidly growing human population, weeds teach us how to share resources effectively. This survival and behavioural attribute of weeds, and indeed, of many other highly successful organisms, is the opposite of the indulgent way most humans live, relentlessly pursuing material wealth and, in so doing, damaging our environment.

Populations of different weeds are also adept at differentiating the *ecological niche* available to them (Hutchinson, 1957). Conceptualised initially by George Hutchinson, the "*Hutchinsonian Niche*" is a "*n-dimensional hypervolume*". The dimensions are environmental conditions that define the requirements of an individual or a species to practice "*its way of life*" and for its population to persist. Such 'requirements' include sunlight, water, nutrients, space to live and trophic interactions.

In Nature, the different species occupying a shared space assume various but overlapping functional ecological roles. Each species plays its part without necessarily being hierarchical. By so doing, they reduce conflicts with their neighbours. '*Co-existing*' with neighbouring plants is a crucial lifestyle strategy for colonising taxa, especially in the early stages of colonization (Harper, 1977).

In the natural world, no one is in charge or has a singular power to dominate, least of all humans. Ecology has taught us that the balance and stability of Nature depend on inter-relationships and biological interactions between species as well as their physical (abiotic) environment. Often, humans forget these crucial facts of life on Earth.

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The effects that colonising taxa have on their neighbours are usually subtle rather than violent conflicts and total displacement (Harper, 1958; 1967; Sagar and Harper, 1961). Over time, they will dominate the vegetation community due to the faster growth of individuals and more significant biomass production, or, simply, sheer abundance in numbers.

As John Harper explained (1965), in plant populations, the capacity to germinate quickly and establish a seedling population rapidly were among the most critical factors in the Darwinian sense of 'survival of the fittest'. These characteristics allowed the successful spread of species and their resistance to native flora (Harper, 1967, 1983). As George Baker identified, the same traits are among the dominant attributes of the more 'weedier' species (Baker, 1965 – '*The Ideal Weed*'). In my view, all the learning that is to be had in Nature can be found in the plant world.

Nevertheless, there may be short periods of precarious existence for weedy individuals, as in any plant population. However, once initially established, the grip of habitat capture by colonising taxa in any environment will tighten as they become firmly rooted. Once entrenched, they are almost impossible to remove entirely.

A '*co-existence'* strategy will also reveal that humans often fall short. Sharing resources for the common good or living within one's means are other aspects in which humans fail miserably. My view is that if we learn a few key lessons from colonising taxa, we can then apply those learnings to all other living beings. We may also achieve some peace with Nature rather than bludgeoning our natural ecosystems to the point of collapse.

Prejudice against Other Successful Species

Paradoxically, weeds present a dilemma for most people. As weeds invade our *'humanised spaces'*, the whole group is vilified as *evil* plants! Negative attitudes towards weeds are hard-wired in many European-born Australians. These feelings evolved in Britain and Europe during the 17th and 18th Centuries as part of agricultural enterprises.

The broad generalisations about the harmful effects of weeds and constant disparagement of particular species are unfair. Persistent negative messages about weeds are prevalent in the media, particularly in developed countries. Regrettably, judging by those discourses, it appears that most people do not care much about human history, geography, and other cultures. As a result, weeds cop a terrible name.

Living in Australia, one is constantly exposed to shallow discourses that vilify weedy species. In my view, the narrative of ostracising weeds has gone on for too long. It is misleading, as it hides the role humans play in creating the conditions that cause the spread of weeds and then perpetuating those perturbations and disturbances. The subtext of this story suits those who want to blame everything else but themselves.

It helps to conceal the human folly of destroying Australia's environment through the overexploitation of the continent's natural resources, large-scale deforestation and land clearing, unsustainable farming practices, excessive livestock farming, and relentless urban expansion. The lack of balanced attention given to weeds as potentially valuable resources is a blight on human intelligence.

Ironically, parts of Australian society also have a xenophobic attitude towards new immigrants. They seem to forget that most of them were also unwittingly 'colonizers' themselves. The new colonists then killed or displaced the Indigenous population [4] from much of the areas on the continent.

In Australia, an *inconvenient truth* is that the early Australian settlers were convicts who were, at one time, unwillingly transported to a distant continent and then forced to take possession of someone else's land. This was done under the pretence that no one lived on the continent ('*terra nullius'*) [5]. In 1788, London wanted the convicts to move '*as far away as possible*' from Britain.

Colonization in Australia led to land grabs, mass killing and the destruction of Indigenous people and their culture. Aboriginal Australians immediately lost their right to self-determination (the right to determine their social, cultural, and economic development) (Horton, 2000).

As a relic of colonialism, Australia's mistaken notion is that Indigenous Australians are static, lethargic, unchanging cultural, political, and spiritual people, less civilised than Europeans. Such an attitude, palpably prevalent even today, has done enormous damage to Australia's image as a nation.

When dealing with plants, the same feelings of dislike are readily extended towards weeds, which are denigrated as unwelcome intruders. *Why this nastiness*? Perhaps it is the hard-wired fear that *new immigrants, weeds, or newly arriving people might take up the available and limited resources, which the established colonists may lose*. Arguably, modern-day asylum-seekers fall into this category.

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The inability of most Anglo-European Australians to recognise *virtues in weeds* is partly due to deeply entrenched prejudices of a pioneering society. No doubt, in the late 18th century, from 1788

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[4] The term 'indigenous' arose in the 17th Century from the Latin word: '*indigena*', meaning "*sprung from the land; native*" or '*existing naturally in a region or country'*. The United Nations took into account the modern European colonist era (15th to 20th Century), which displaced native people from their traditional lands and defined '*Indigenous*' as: "*peoples of long settlement and connection to specific lands, adversely affected by colonization and incursions by industrial economies, displacement and settlement of their traditional territories by others*".

[5] *Terra nullius*, in Latin, meaning "nobody's land", is a principle used in to justify claims that territory may be acquired by a state's occupation of it.

onwards to be precise, the new colonists had a pretty hard time as they battled to colonise the harsh Australian landscapes. In so doing, they also overran the original inhabitants of the continent who had prevailed on those unforgiving lands for more than 70,000 years (Horton, 2000).

The conquest of Australia is similar to those of other continents invaded by Europeans. Colonization is characterized by violence - war, death, murder, rape, and similar atrocities. As Donald Horne (1964) said, *'Colonization of continents never occurred through amicable settlements, although this truth is usually well hidden in official government narratives'*.

In Australia, the denial of the past atrocities was then combined with other distasteful policies to create the *Commonwealth of Australia* in 1901. It included preferential immigration for white people - the '*White Australia Policy*', or the *Immigration Restriction Act* (1901), which created a racially-insulated society in Australia.

The Act remained in effect until superseded by the *Racial Discrimination Ac*t of 1975 (Horne, 1964). These are possibly why many Australians subconsciously dislike anything 'non-white', deemed 'foreign'. It is then extended to weeds and other highly successful organisms. Resentment towards newcomers is a prevalent negative attitude in Australia and most other wealthy countries.

The common factor is that these societies are still clinging to *Eurocentric values*. It is, therefore, not surprising to find intolerant and nasty attitudes in societies built around the forced colonization of already inhabited continents. The constant maligning of weeds reflects this intolerance.

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Most Australians also forget that many of the continent's problematic weeds were introduced by the colonists after 1788 during the colonization process [6]. Weeds are harshly blamed for despoiling everything, from home gardens to urban parks and bushlands. It is a flawed and mistaken attitude built on the mythology that humans can and do dominate every other species on Earth.

The same negative attitudes are extended to other introduced but highly successful organisms. Species, such as camels (*Camelus* L. spp.), cane toads (*Rhinella marina* L.), European rabbits (*Oryctolagus cuniculus* Lilljeborg), European foxes (*Vulpus vulpes* L.) and Indian mynah (*Acridotheres tristis* L.) did not come to Australia on their own. All of these highly successful animal species were accidentally introduced or deliberately imported for perceived benefits during the past 240 years of the continent's colonial history.

Such species are among the best survivors under highly adverse conditions, as encountered in Australia's harsh outback. Their adverse effects on ecosystems are often overstated. A good example is the aforementioned Indian myna. It is disliked for displacing Australian native birds, including the Indigenous 'noisy miner' (*Manoria melanocephala* Latham), from tree hollows. Research, however, has shown that the overall impact of the noisy indigenous miner on natural ecosystems is far more profound than that of the Indian myna [7].

However, such stories are not sensational enough to receive publicity in an era of intense intolerance compounded by a 24-hour news cycle. While the Indian mynah can be an irritating and noisy inhabitant, it is not as problematic as it is made out to be. The species thrives on scavenging food in our backyards, shopping complexes and other humanised spaces. It is hardly found elsewhere.

The noisy miner, on the other hand, is regarded as a dangerous pest in public spaces due to its aggressive behaviour, especially during the breeding season. This species is also an urban dweller, occupying a range of habitats that extend out towards the per-urban fringes of cities and townships. In my view, there is room in the natural world for both species to play their roles and co-exist successfully. *Neither is any more villainous than we humans are*.

The media thrives on sensationalising issues to attract audiences. However, the media alone cannot be blamed because they reflect our society. Driving a balanced discourse on contentious matters of

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[6] The manifest of Captain Arthur Phillips' First Fleet (1788) shows that plants and seeds of cocoa, cotton, coffee, guava, oranges, and tamarind were brought, along with prickly pear (*Opuntia* spp.) (**http://home.vicnet.net.au/~firstff/story.htm**).

[7] Under Section 183 of Australia's *Environment Protection & Biodiversity Conservation Act* (EPBC Act), 'Aggressive exclusion of birds from potential woodland and forest habitat by over-abundant noisy miners (*Manoria melanocephala*)' is a *Key Threatening Process*.

social and scientific interest (such as climate change) is a collective responsibility of all of us.

* * *

In sharp contrast to Australia, plant resources are highly revered in many parts of the world. Many species are deemed sacred and revered. In Southeast Asian countries like Japan, South Korea, and China, there is a respectful attitude towards all plants in general, with some mild intolerance of weeds. A pragmatic view is prevalent in Africa, as well as in most parts of Central and South America and the Mediterranean region, recognising that even weeds have utility values (mainly in the form of medicines and food), serving the needs of societies (Chandrasena and Rao, 2017).

A respectful attitude towards plants is prevalent in the Indian subcontinent (comprising India, Nepal, Bhutan, Tibet, Pakistan, Bangladesh, and Sri Lanka), rooted in religious beliefs that have evolved over millennia. Hinduism, Buddhism, and Islam, in that order, influenced the sub-continent. Through Buddhism, reverence for all plants exists in Thailand, Myanmar, Vietnam, Laos, and Cambodia.

People of ancient cultures, including those in China, Korea, and Japan, instinctively knew that all plants are critical elements in Nature. Other, more trade-based cultures in the Asian-Pacific region (Thailand, Malaysia, Indonesia and the Philippines) also value plant resources as they are consumptive and tradeable. The ancient indigenous societies (Papua New Guinea) and the Pacific Islands also value all plants primarily because of their practical and marketable values.

Not denigrating any plant is a cultural attitude and has nothing to do with the wealth of individual farmers or landowners. Pre-industrial societies certainly valued plants and animals for practical purposes. Such attitudes are prevalent across all societies and cultures on every continent (Chandrasena and Rao, 2017).

In my view, one must consider different cultures to gain a thorough understanding of human ecology, human history, and how people interact with weeds. Over many decades, as a weed scientist, ecologist and an educator, I have observed that many weed researchers lack a solid foundation in botany, plant physiology, ecology, evolution, and plant taxonomy. Such subjects are never taught adequately in the agricultural degrees of most countries. I would also add biogeography and human history to this list.

There is far too much emphasis in agriculture degrees on the '*agri-cultural'* aspects of cropping, i.e., agronomy, soil, pests and diseases, etc. Many agriculture colleagues lament not being exposed to more profound learnings of botany and ecology.

As a result, most *Weed Science* courses in agricultural faculties fail to provide the foundational ecological basis for understanding weeds, their strengths and weaknesses, as well as their beneficial and utilitarian values and roles in Nature. To reiterate, although humans accuse weeds of being evil vagabonds, in Nature, there are no weeds.

Virtuous Weeds

As the title of this article says, *I long for a weed* because of the multifaceted beneficial roles these colonising species play in Nature. In doing so, they offer a vast array of benefits to society (see Chandrasena, 2023, 2024).

I am not alone in promoting such views, which date back to the latter half of the 19th century. For example, Ralph Waldo Emerson, one of the most prominent orators of that period, had an enlightened view of weeds. His words, spoken in a famous speech, '*Fortune of the Republic*', in December 1863, were: "*What is a weed? A weed is a plant whose virtues have not yet been discovered*. These words are often quoted in *Weed Science* books.

As a humanist, Emerson was keen to highlight to his audience and followers that *Weeds have admirable virtues, and one would see them if one looked hard*. Undoubtedly, his comments would have raised the eyebrows of the more agriculture-focused farmers. Yet, naturalists and conservationists across the Americas would have welcomed Emerson's rational views.

However, one also needs both *humility* and a positive attitude to recognise virtues in others. These are qualities that Emerson had in abundance. For a long time, such thoughts have inspired me to look at weeds *with new eyes*. However, I fully understand that *through the eyes of long-suffering farmers, weeds may appear as nothing but trouble!*

Humans and weeds are highly successful exploiters of opportunities, using different tactics to colonise habitats and spread across the globe. Both humans and weeds can thrive in association with disturbances to natural habitats. More often than not, humans cause those large-scale disturbances to which weeds respond. They trek the world with men.

Weeds are, therefore, '*shadows of men'*, just like flies, mice, mosquitoes and cockroaches. Weeds, as well as some of these pest species, follow in the footsteps of humans, leaving behind an imprint. *The history of weeds, spanning past millennia, is an integral part of human history.* Weeds certainly spotlight man's relentless, adverse impacts on Nature. Not only did they 'evolve' with man, but by stealing resources, they earned our wrath.

Many people malign weeds, but this dislike is not universal. Ancient cultures universally accepted weeds as part of Nature and valued them for the benefits they provided (Chandrasena, 2023; Chandrasena and Rao, 2017). These sharply divergent attitudes towards weeds are part of the paradox we have. Conceived in arrogance, some people believe that humans are 'masters of the universe' when, in fact, we are not. *People need to understand that Nature does not exist for the convenience of man*.

Apart from Lowell and Pfieffer's appreciation of weeds, others have shared a similar sentiment. A memoir written in 1950 by Joseph Cocannouer is laudable. Introducing Cocannouer's book - *Weeds – Guardians of the Soil*, the publisher said:

> *"This is perhaps the first book to be written in praise of weeds. While Professor Cocannouer does not believe that weeds should be allowed to go rampant and take over our farms and gardens, the book demonstrates how the controlled use of weeds can be sound ecology, good conservation and a boon to farmers".*

According to Cocannouer (1950), weeds perform valuable services: (1) When used in crop rotation, they produce roots to feed deeply; (2) They fertilize and improve the condition of soil, making soil productive; (3) They are also indicators of soil condition; (4) Weeds are deep divers and feeders; they enable crops to withstand drought better; (5) As companion crops, they enable crops to get unavailable food; (6) Weeds store up minerals and nutrients and keep them readily available; and (7) Weeds also make good eating. Indeed, they do.

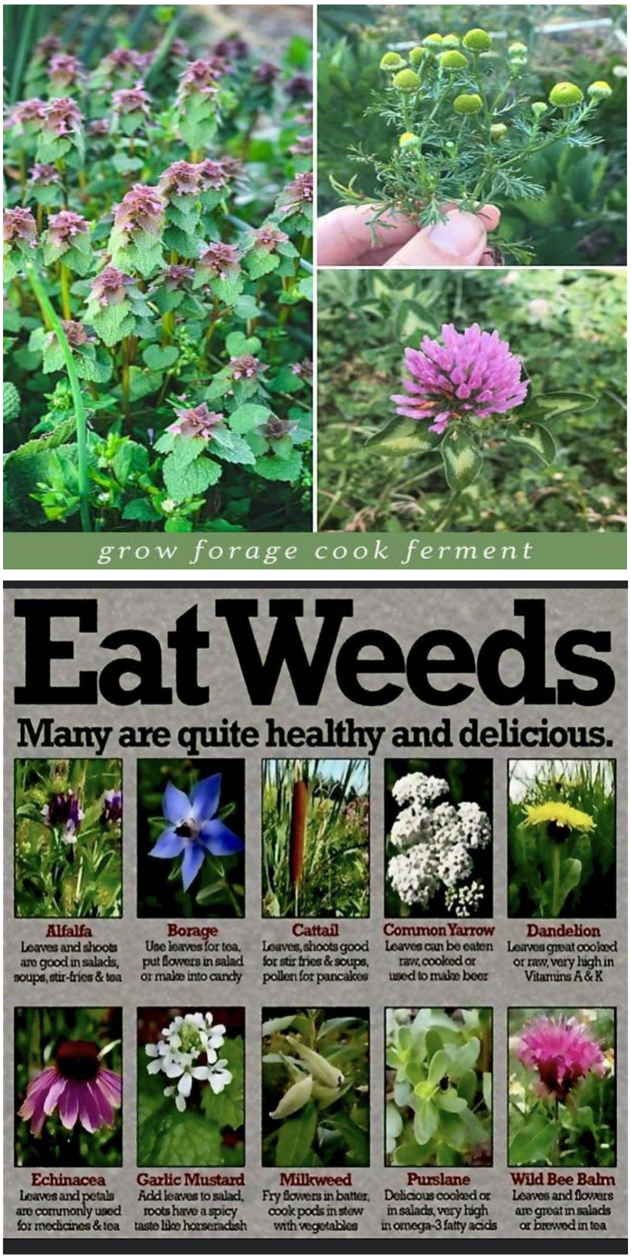
Just like me, Cocannouer (1950) resented deriding weeds as homeless '*vagabonds*'. In fact, quite the opposite is true. At a time when agriculture in the USA was in trouble due to soil degradation, overuse of pesticides, groundwater contamination, pollution and other unsustainable, ecological perturbations, he saw the positive roles weeds play in such battered landscapes.

For him, weeds were simple but often functional, practical and friendly immigrants to areas where space and opportunities existed for occupation. These were significant ideas at a time (1950s) when ecological and biological studies on weeds were beginning to take place in Britain and the USA (see Harper, 1967; Baker and Stebbins, 1965).

* * *

Two notable quotes that I have come across, both from Britain, suggest that, for some people, weeds are virtuous. Audrey Wynne Hatfield's (1969) and Joy Griffith-Jones's (1978) views on the virtues of weeds resonate with me:

> *"We have corrupted the word 'weeds' and its meaning; it was wèods, the Anglo-Saxon name for all herbs or small plants; some they call wyrt, our wort. To past generations of men, all plants were regarded with respect, some with affection, and some feared. Many of them were either food or medicine, or they possessed religious or magical influences".*
>
> *"Plants we scorn today as weeds were ready with their health-giving qualities to serve man and beast long before grasses had fat ears, root crops had thick tubers or fruit trees produced large and juicy fruits…We should never belittle the constant value of such herbs".* (Hatfield, 1969).
>
> *"Generations of tidy gardeners have conditioned us to tear them up, banish them forever from our clean gardens. But these humble citizens of the soil have many virtues. In the garden, they can signal a need and then deal with it".*
>
> *"Daisies…not only indicate a lack of lime but, through death and decay, provide the remedy. Wild garlic drives moles from the ground. Lady's Smock attracts the Orange Tip butterfly. In the kitchen, nettles can be cooked like spinach, while coltsfoot brews a good wine. Chicory, chickweed, and red clover can also be used to grace a salad. In the sickroom, cleavers can treat skin cancer, cinquefoil makes an efficacious gargle, and a decoction of lesser celandine does wonders with piles".*
>
> *"Henbane is a must for witches, whom red clover will detect and cinquefoil keep at bay, while buttercup chains were used to garland the cows and bless the milk; virgins used powder from this plant for bridal beds…"* (Griffith-Jones, 1978).



Alfalfa: Leaves and shoots are good in salads, soups, stir-fries & tea
Borage: Use leaves for tea, put flowers in salad or make into candy
Cattail: Leaves, shoots good for stir fries & soups, pollen for pancakes
Common Yarrow: Leaves can be eaten raw, cooked or used to make beer
Dandelion: Leaves great cooked or raw, very high in Vitamins A & K
Echinacea: Leaves and petals are commonly used for medicines & tea
Garlic Mustard: Add leaves to salad, roots have a spicy taste like horseradish
Milkweed: Fry flowers in batter, cook pods in stew with vegetables
Purslane: Delicious cooked or in salads, very high in omega-3 fatty acids
Wild Bee Balm: Leaves and flowers are great in salads or brewed in tea

Figure 1. As Joy Griffith-Williams and Audrey Wynn Hatfield suggested, many weeds in our backyards are now promoted for use as edible weeds or medicinal weeds (Chandrasena, 2024)

Another popular American website promoting edible weeds is *Mother Earth Living*, which highlights the palatability of many weeds, including dandelion, nettle, purslane, and chickweed, among others, with advice on preparing these species as food.

Much like the Permaculture Movement, *Mother Earth Living* promotes the principles of sustainable living, in resonance with Nature, fostering an attitude of tolerating and utilizing edible and medicinal weeds where possible [8].

It is also important to remember that the ready availability of weeds as nutritious food makes them '*the ultimate convenience food*'. As Grub and Raser-Rowland (2012) noted, *gathering requires only a walk in the park before dinner*. Their popular Australian book highlights the virtues of weeds as both food and medicine: "*Weeds ask of you no money, no search for a parking space at the supermarket, no planting, no watering or any other maintenance whatsoever*". Can anyone argue against these enlightened comments?

* * *

Introducing Griffith-Jones' book (1978), Ernst Schumacher (1911-1977), the economist famous for "*Small Is Beautiful*" (1975), emphasised that *the more we learn about Nature, the more we must doubt our theories* [9]. Schumacher said,

> *"While evolution by natural selection allows the fittest to survive, it obscures the marvels of Nature, which is an artistic wonder, infinitely playful, subtle and inventive, whose wisdom we should be humbly eager to understand".*

Praising weeds, Schumacher wrote:

> *"Is there no virtue in weeds? Are they really unmanageable? Thoughtful, gentle, loving management instead of 'killing the enemy' (weeds), and study, as our ancestors have done, with science and sensitivity, and learning from Nature…We can start where we may expect the least, but can find enough for a lifetime, in our own backyard, with The Virtuous Weed"* (Griffith-Jones, 1978).

The Virtuous Weed is powerful terminology in conveying the message I want to give. *Weeds are indeed virtuous*. Revisiting the topic allows me to

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[8] *Mother Earth Living* (https://www.motherearthnews.com/natural-health/herbal-remedies-zmaz10onzraw/).

[9] Wes Jackson (1981), delivering the *Schumacher Memorial Lecture* said: "It is significant that Schumacher, economist that he was, was very much interested in ecology. He was president of the Soil Society of England. He was a strong advocate of planting and caring for trees, which he saw as more than bearers of fruit, for he thought of them as symbols of what he called "permanence," for him a synonym for sustainability. He was a man who grew a garden, which by definition consists of patches. A man whose primary message was *transcendence* of the economic world saw perennial trees as *redeemers* of the landscape".

share my own experiences with weeds and make an effort to reevaluate their place in our lives.

My plea is also for weed scientists, agriculturists and conservationists not to despise the humble weed. '*Living with weeds'* fits the narrative of '*living in harmony with Nature*'. The Earth does not belong to us; we belong to the Earth, sharing the Planet's environment with trillions of other organisms.

In rethinking this conundrum of how to deal with weeds, we should not deny that some of these taxa are recalcitrant to control efforts, will fight back and pose challenges to human endeavours, including how to produce enough food. Nevertheless, the prevailing narrative of blaming weeds for our inability to improve agricultural production or better manage our environment is essentially flawed.

A vast repository of knowledge about the harmful effects of weeds and how to manage them exists within the field of *Weed Science*. Those tools must be deployed intelligently in situations where and when the colonising taxa have to be appropriately managed. Nevertheless, the much-neglected dimension in weed discourses is the virtuous side of weeds, although the topic has not been entirely forgotten.

In the new millennium, as the discipline looked to the future, the Weed Science Society of America (WSSA) agreed that weeds can be used beneficially. The review cautiously highlighted two areas – that weedy taxa are likely to be future sources of pharmaceuticals and that there are possibilities of using some species for phyto-remediation of degraded landscapes (Hall et al., 2000).

Interestingly, and quite regrettably, the WSSA review was hesitant to venture into other, more contentious areas, such as the promising biofuel options provided by many colonising taxa. Also noteworthy was the lack of promotion of edible weeds and their wild relatives, which, in my view, are crucial for meeting the nutritional needs of societies and cultures worldwide. Already in the USA, a wealth of information is available on edible weeds (Duke, 1992), and these ideas have been well promoted among suburban populations (see XXXX).

As the review was USA-focused, it paid no attention to recognising that weedy taxa provide critical raw materials for the broadest spectrum of rural employment in many developing countries.

More than two decades after the WSSA review, the reluctance to bring the beneficial uses and potential utilisation of colonising taxa to a more central position has continued. This is because, from the outset, the discipline's anchoring pillars have been the development and dissemination of knowledge on how to manage weeds. The viewpoint that *weeds perform an ecologically beneficial role or have multiple uses for society* runs counter to this.

There is palpable resistance to change. However, this trend is not limited to developed countries; it also continues in India, Malaysia, Sri Lanka, Pakistan, and other similar countries.

As Zimdahl (2012) has often expressed,

> *"Ecological considerations have never been a central theme within Weed Science, dominated by research and solutions based on herbicides".*
>
> *"Weed scientists are also not historians, nor are most scientists". However, "it will be helpful if we study our history, not assume it, and evaluate it as a guide to the future".*

This *Weeds* Journal, from its inception in 2019, has endeavoured to highlight the virtues of these constant companions of ours. On a personal level, I urge people to consider that the next time you dig weeds out of your lawn or garden beds, it may be a needless action. Unless you are careful, that disturbance will attract more weeds. As I have argued (Chandrasena, 2023), one will also need to consider ways to suppress those weeds in the long term, utilising the many well-developed tools and techniques available.

I urge weed researchers to appreciate that the conflicts weedy species have with humans begin when the taxa start *behaving as they should*. The conflict escalates when their verdant growth interferes with the economic, social, and environmental interests of humans (in that order). Paradoxically, as explored in this book, the same impressive attributes also make these taxa invaluable as bio-resources.

My final words in this plea resonate with those of the Nature-lover, as Joy Griffith-Jones: "*Useful, practical, full of goodness- do not despise the humble weed*". However, to recognise virtues in others, such as weedy taxa, I am well aware that one needs both *humility* and a *positive attitude*.

As Emerson expounded, *Weeds have admirable virtues, and one would see them if one looked hard*. Therefore, I make no excuses for *Longing for A Weed*, especially to see weeds in our human-impacted environments with a burgeoning and hungry population, crying out to save the Planet.

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PERSPECTIVE

Observations on a Changing World

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This is not a report of scientific research. This is an opinion piece that explores the Earth, our science, the environment, education, values, and some of my thoughts on what we ought to do and our responsibilities in a changing world.

I have previously expressed my opinions on a wide range of topics relevant to science, agriculture, the environment, education and ethics [1]. We have not achieved a sustainable society, and certainly not a sustainable agriculture. Students and others involved in agriculture do not question the sustainability of our food systems or our way of life. They ought to.

In this piece, I pose several questions regarding the moral justifications and ethics of agriculture, as concerns about the widespread human impacts and environmental harm associated with agriculture are increasingly being felt, along with public fears about technology and food quality standards.

Agriculture is an essential human activity, and it is also the largest human interaction with the environment. There is an agricultural moral code: *do unto others*. That code, we often assume, was based on the Bible, but it probably had its origins in the mutual help ethics of early agriculture long before Christianity emerged. Much of modern morality originated from the imperatives of early farming life among our ancestors.

Modern industrial agriculture is highly dependent on external inputs (e.g. pesticides, fertiliser, petroleum energy). This modern, capital and energy-intensive agriculture produces an abundance of food, but it is not sustainable. Many are concerned about how those things affect them, their children, grandchildren, other creatures, and the environment.

Those who study and try to understand agriculture are as concerned as you and your friends may be about agriculture's use of water for irrigation (70% of global freshwater), growth-promoting antibiotics for animals (+- 70% of U.S. antibiotic use), confined animal feeding operations (CAFOs), inhumane treatment of animals and migrant labour, the role of agribusiness, the nutrition provided by food. We are often overwhelmed because the problems are big and remote. We want to do something, but have only a few ideas about what to do and how to do it. We are not alone.

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Agriculture’s problems have been developing for a long time, and solving them will take a considerable amount of time. Agriculture, a vital human activity, is the most widespread form of human interaction with the environment. Human activity has dramatically changed the Earth (e.g. global warming, CO_2 emissions and environmental destruction). Humans have negatively affected and often destroyed habitats on which the natural world and we depend.

We are the only creatures who do not have to adapt to the Earth’s environment. We modify it to meet our wants and needs. There is too little discussion about whether or not we will and, if so, how we can change our ways to restore and protect the Earth - the only planet we have. It is up to us.

A major contribution to the success of developed country agriculture is the unchallenged ability to externalise the costs of harmful environmental actions. We live in a post-industrial, information-age society. We are also highly dependent on the seemingly endless supply of food produced by agriculture in developed countries.

No one will ever live in a post-agricultural society. However, there is an appalling lack of knowledge globally about how our food is grown, where it is grown, and who grows it. Concerns grow, and problems persist, although the grocery store is always stocked with all that stuff.

Myth

Prometheus, a Titan, stole fire from the gods and gave its power to man. The gift of fire gave man the power to become toolmaker, explorer, and food grower. It enabled what Jared Diamond (1999) called “The worst mistake in the history of the human race” - the adoption of settled agriculture.

Prometheus’ brother, Epimetheus, married the beautiful Pandora, who accepted a box as a gift from the gods. Pandora’s curiosity and disobedience led her to open the box. Once opened, all the evils and miseries of the world escaped and tormented humankind forever. Only *hope* remained in the box.

Hope is what drives us to find solutions for our agricultural, economic, social, and political problems. It is interesting that Prometheus, forward-looking, life-giving, creative, courageous, and Pandora, beautiful, enticing, and persuasive, yet whose curiosity loosed a thousand plagues, are part of the same myth that affects our societies and agriculture.

The Promethean/Pandora myth originated in a pre-literate society. It should be regarded as a public dream (Campbell, 1973, p 12). Dreams are often dismissed as false - after all, they are not literally true. They are just myths derived from the richest strata of the human spirit.

They are not simply imagined or false cultural stories of historical events. They express timeless truths of people’s daily existence and appeal to and express enduring ideas about deep, commonly held emotions (love, future, friends, children).

The myth helps us think about agriculture’s ethical dilemmas and values. It encourages thought about who we are, where we have come from, and what we have or have not done. It stimulates forward-looking, creative, courageous thought. For most of modern history, the Western world has enjoyed the Promethean power of energy (fire) and science. It has enabled human evolution from makers of simple tools to developers of sophisticated instruments and machines, and from explorers to conquerors.

The power of science enabled us to abandon hunting and gathering for food and transformed the developed world’s agriculture from subsistence to abundance and surplus for some. We learned new ways to grow food differently and more efficiently. We enjoyed and benefited from our power, but often ignored the harm it caused. Pandora’s and our unchecked curiosity has led to wonderful and potentially dangerous consequences.

In many ways, agricultural scientists have met the challenge of addressing important questions and framing them in a way that leads to manageable tasks and technology that improve food production. For all its wonders and undeniable benefits, agricultural science and its associated technology have a disquieting aura of fallibility. The gift of fire allowed us to dominate, but in spite of our immense power, we have not achieved dominion or control over the natural world (Kirschenmann, 2010).

The Earth is finite. A child born this decade can expect to become an adult when almost half of the world’s forests will be gone, and 1/5 of the world’s present plant, animal and bird species will be extinct. Since 1970, approximately 60% of animals, including birds and fish, have disappeared. We do not even know what some of them were or how many are disappearing each year.

The UN Food and Agriculture Organisation (FAO, 2022) estimates that as much as 40% of world crop production is lost to pests every year (valued at U.S. $220 billion). In early 2025, the Earth had 8.2 billion people, growing at a rate of 0.85% per year. The human population is projected to peak at 10.3 billion in the mid-2080s and then slowly decline.

Global warming will soon pass a tipping point, after which nearly all outcomes will be detrimental to humans. Those who demand absolute proof of human-caused environmental and, therefore, agricultural problems simply don't or refuse to understand the scientific evidence of environmental degradation's effects on agriculture. The environment suffers, while legislators seem to be much more concerned about getting re-elected than solving the obvious problems. *We have not achieved a sustainable society or a sustainable agriculture*.

World agriculture produces 17% more calories per person today than it did 30 years ago, despite a 70% increase in population. There is enough food produced to feed all. Still, approximately 835 million people are hungry every day due to unsustainable agricultural practices, unequal food distribution, government inaction, inadequate infrastructure for shipment and receipt, insufficient funding, food waste during storage, and food discarded by consumers (World Food Programme, 2025). We have dramatically changed the world, probably past its carrying capacity.

Do we value the environment and farms enough to protect and save them? Can we acknowledge the need for and create a regenerative system of agricultural food production, recognise the interdependence of everyone in the world, and the importance of the natural environment (Baggini, 2025, p. 55). It demands questioning our assumptions and developing a sustainable agricultural system where crop yields are increased without adverse environmental effects and without more land (Baggini, p. 65).

Farmers are bound to the land. Good farmers are true husbandmen who strive to obtain the most favourable conditions for their crops. Many food growers and others have lost their connection to the land and the values it creates. Good farmers and ranchers strive to produce the highest, most profitable levels of crops and animals they can, in full recognition that they do not have dominion over the land. Nature knows best. Good farmers protect and cherish the land.

The specifics of sustainable and regenerative agriculture need not be a system all farmers must adopt - Montana is different from Texas, New Jersey is different from Virginia, and Australia is different from Africa. The different systems involve value judgments. However, I am aware that many people do not spend much time thinking about their values. Therefore, it isn't easy to have a conversation about values if one cannot define what is valued and why some things are and others are not.

We have lost what some call our moral fibre. I am not sure our educational system includes a discussion of whether there should be self-imposed or collectively imposed limits on abusing the Earth. Similarly, we lack a desirable tolerance of other cultures and a love of learning, which are essential to a good life. We lack the wisdom to know what to do and, more importantly, to know why we ought to do some agricultural things and not harm the environment on which agriculture depends.

* * *

The purpose of this short essay is to ask all involved in agriculture and other disciplines to consider how we can change our ways so we can begin to restore the Earth and save the only planet we have for our grandchildren and all others. To begin, we must reconsider our assumptions and their ethical basis.

Most professions, indeed, most people, do not want their assumptions about life and their profession questioned or examined. They want to use their basic assumptions. Review and inevitable questioning make us uncomfortable or angry.

For example, the cost of one U.S. ballistic missile-capable nuclear submarine is at least $9 billion. It may be as high as $15 billion. It's easy to say, 'It's not my problem!' If it is not, who will decide what is important and how your tax money will be spent? It is some of your tax money that will pay. Is a nuclear submarine really the best way to ensure our collective future? If not, what is the best way?

A farmer might struggle with buying new equipment that eliminates the need to plough. Another farmer might struggle with whether or not to buy a nearby farm and expand his or her sustainable farming system. These are complex personal, economic, and future-oriented questions. They are ethical and value-based questions that help us discuss and negotiate problems.

The agricultural system that contributed to these problems accepts credit but resists accepting blame for its negative effects, and this is part of the tragedy. It is an example of the agricultural mindset and justifies Mayer and Mayer's (1974) conclusion that the system is unsustainable. Their second claim is that the integration and isolation of agriculture within the university and society have led to what they call *'The Island Empire*.' Agriculture is a vast, wealthy, powerful intellectual and institutional island.

The Land-Grant system created Colleges of agriculture and allowed agriculture to remain isolated within the university and from mainstream American life. Mayer and Mayer accuse agricultural colleges of being separated from the university, from the mainstream of scientific thought, and from national discussions about social policy. Agriculture does not ask for and only reluctantly receives outside criticism. Those who practice agriculture must move off their island.

There are ethical principles (see Rachels, 2007) that are not universally or absolutely applicable to guide discussions on what is the right thing to do. *Questions are inevitable*. Most people don't spend time thinking about their values and find it difficult to discuss their own values and those of others. Many farm people have values and live by them. In urban areas, the transmission of values appears to have shifted from the family to the omnipresent social networks. It is not working well.

James Rachels, in *The Elements of Moral Philosophy* (2007), acknowledges that while ethical principles can provide a helpful framework, they are not universally or absolutely applicable to guide all moral discussions. Moral judgments and practices vary across cultures, suggesting that there is no single set of ethical principles that holds true for all people, at all times, and in all places.

There is also no single book or social media network that will tell you what you ought to do. We must think about and struggle with such decisions. The educational system appears to prepare young people for jobs and careers in an economy that is designed to expand without limits. Boulding (1966) said, "*Anyone who believes exponential growth can go on forever in a finite world is either a madman or an economist*".

Students are prepared for their role in extending human dominion over the natural world, which, in my view, is precisely what we *should not do*. A related assumption is that the dominant values in many societies are not found in religious institutions (see Stewart, 2025, for an alternative view), educational institutions, or social institutions; however, economic institutions do dominate.

Having been involved in education throughout my career, I've come to believe that good education should comfort the afflicted and afflict the comfortable. This article asks hard questions. It may encourage thoughts about what one ought to do.

Final Comments

The question and challenge for educational institutions is not only how to plan for the future, which, of course, is unknown; it is also how to adapt to the unknown. It is about preparing students for life, with all its vicissitudes and mutability.

Our assumptions need to be discussed and questioned. It's okay if one ends with the same opinions and assumptions after they have been examined. If they were never examined, never debated, and never questioned, education would be incomplete. Education should foster wonder, gratitude, and ecological competence.

Those engaged in agriculture and environmental studies possess a definite, yet unexamined, moral confidence or certainty about the correctness of their actions. The origin of that confidence needs to be questioned about its validity. The basis of moral confidence is not obvious to those who possess it nor to the public. In fact, the moral confidence that pervades agriculture is potentially harmful because it is unexamined.

It is necessary for those engaged in science to analyse what aspects of their science and society inhibit or limit their progress. All should strive to nourish and strengthen the beneficial aspects and change those that are not. To achieve this, we must be confident in studying ourselves and our institutions and also be dedicated to the task of revising the goals of both.

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“Genome Edited” Rice in India and the Potential for Genome Editing for Rice Weed Management

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Abstract

Innovative crop and weed management technologies are necessary to meet the food and nutrition demands of an increasingly global population while addressing other challenges. The challenges that people face worldwide include a changing climate, limited cultivable land, erratic weather patterns and the emergence of new pests, diseases and weeds with greater adaptability to a changing climate.

This paper aims to synthesise information on the recent practical applications and successes of gene editing technology in developing two multiple stress-tolerant, high-yielding rice varieties in India. We commend this new development and discuss the possibility of utilising gene editing technology to improve various components of integrated weed management in rice.

Recently, two rice varieties, viz. DRR Dhan 100 (Kamala) and Pusa DSR Rice were developed by the *Indian Council of Agricultural Research* (ICAR), India, using the CRISPR-Cas9 genome-editing technology. India is the first country in the world to develop and approve genome-edited rice varieties using gene editing technology that does not involve genetically modified organisms.

These varieties, developed under the project “Enhancing climate resilience and ensuring food security with genome editing tools,” are early maturing by 20 days and have significantly improved drought and salinity tolerance, as well as nitrogen-use efficiency in rice. Simultaneously, the varieties provide higher yields while reducing methane emissions.

Other areas where gene editing technology may be utilised to enhance components of Integrated Weed Management (IWM) in rice include the development of herbicide-tolerant (HT) rice varieties through targeted genome editing and modifying the genes involved. Recent advances in gene editing, particularly ‘gene drives’, also offer promising tools and novel approaches that can modify weed populations, making them more susceptible to weed management tactics.

Gene technology may also help produce rice varieties that are less susceptible to competition from weeds. This would require identifying novel quantitative trait loci (QTLs) and genes/alleles related to competitive abilities in major rice weeds, as well as allelopathy traits in rice. Gene editing may then lead to the production of weed-competitive and strongly allelopathic rice varieties that can be bred more successfully. Recent research has also shown that gene editing could be used to make weedy species more visible to machine-learned robots.

This paper presents several examples of the potential applications of gene editing, highlighting the capabilities of these new genetic technologies in enhancing the components of integrated weed management. It is possible to predict that IWM in rice is changing rapidly with the novel technologies offering hope for improved management of rice weeds, leading to associated yield improvements.

Keywords: CRISPR-Cas9, Genome editing, India, Herbicide-tolerant rice, Weed management

Introduction

The current world population is expected to reach 9.8 billion in 2050 and 11.2 billion in 2100 (UN, 2017). This increase, which appears inevitable, would result in an ever-increasing demand for nutritious food. It necessitates the need for innovative technologies to combat challenges such as climate change, limited arable land, unpredictable weather patterns, and the emergence of new pests, diseases and weeds, with greater adaptability to a changing climate. Humans have used genetic modification, in varying forms, for centuries to create crop plants with desired traits.

Selective breeding and mutagenesis or mutation breeding have long been used for crop improvement (Hernández-Soto et al., 2021). However, the experience of the past six decades of plant breeding suggests that traditional breeding strategies are insufficient for the rapid development of new plant traits that improve rice productivity and production to meet the increasing demands of global food and nutrition security (ISAAA, 2019; Bacha et al., 2025).

With the advent of genetic engineering technologies, transgenic technologies, and *Clustered Regularly Interspaced Short Palindromic Repeats* (**CRISPR**) genome editing, these tools are becoming the most preferred options for rice improvement (see **Figure 1** for a schematic).

CRISPR is a technology that enables scientists to edit the genome of living organisms, including animals, plants, and even human cells. The CRISPR system relies on an enzyme called Cas9, which acts as molecular scissors and a guide RNA molecule that directs the Cas9 to a specific DNA sequence. CRISPR was initially discovered in bacteria as a defence mechanism against viruses. Bacteria utilise CRISPR arrays to store the DNA sequences of viruses. When the virus attacks again, the bacteria produce RNA that guides the Cas9 enzyme to cut the viral DNA into pieces, thereby disabling it (Westra et al., 2016; Wada et al., 2020; Li et al., 2023; Qi, 2024).

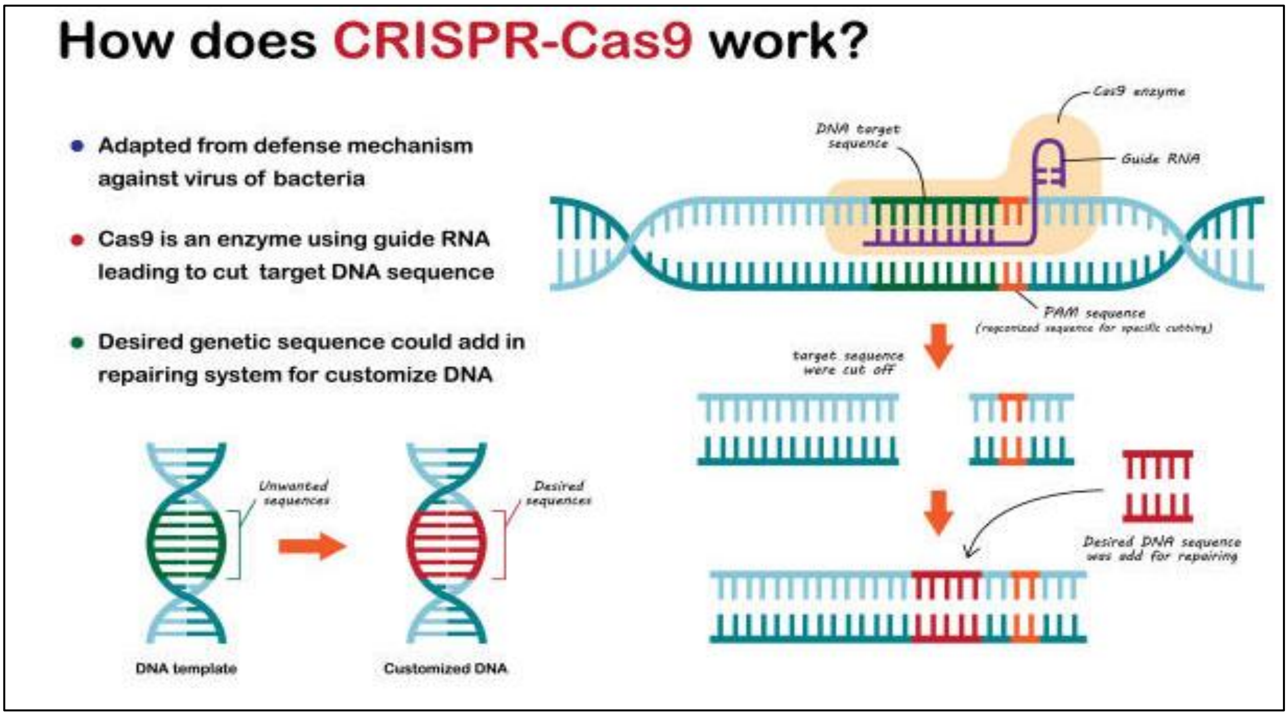


Figure 1. A schematic diagram of CRISPR technology

CRISPR/Cas9 is now the most widely used and efficient site-directed nuclease system in modern biotechnology. It consists of two main parts: (a) Guide RNA, which acts like a GPS, leading the system to the exact spot in the DNA where editing is needed. (b) The Cas9 protein, which acts like molecular scissors, cuts the DNA at that specific location.

Once the DNA is cut, the cell tries to repair the break. During this repair, scientists can either allow the gene to get disrupted or make specific changes to the gene sequence. This makes CRISPR/Cas9 an extremely valuable research tool in agriculture, medicine and the applications mentioned above.

The CRISPR/Cas9 technology is pivotal to producing the next generation of crops that are better adapted to changing climates, achieving higher yields and improved product quality. In crop improvement, the tool is now extensively employed for genetic enhancement due to its advantages, including cost-effectiveness, ease of use, and the ability to effectively and precisely edit multiple genes (IGA, 2022; Luo and Liu, 2025).

The technology has also enabled the enhancement of various traits, allowing crops to become more tolerant and better suited to withstand the challenges posed by both biotic and abiotic stresses (**Figure 2**).

As discussed by Somado, et al. (2008), Westra, et al. (2016), Char et al. (2019), Usman, et al. (2020), Liu, et al. (2020), Zhu, et al. (2020), Wada, et al. (2020), Kobayashi, et al. (2023), Li, et al. (2023), Qi (2024), Pacesa, et al. (2024) and Luo and Liu (2025) from various perspectives, these new genetic technologies also offer options for addressing global food and nutrition security challenges.

This article aims to synthesise the information on the recent practical utility successes of gene editing technology for developing multiple stress-tolerant and high-yielding rice varieties in India and to discuss the possibility of utilising gene editing technology in improving different components of Integrated Weed Management (IWM) in rice.

New Tools for Genetic Modifications

Research over the past 25 or so years has proven that CRISPR has a wide range of potential applications (Li et al., 2023; Qi, 2024), including:

- **Treating genetic diseases:** By correcting disease-causing mutations, CRISPR offers the potential to cure or prevent genetic disorders.
- **Developing new therapies**: CRISPR is being explored for the treatment of cancer, infectious diseases, and other conditions.
- **Improving crops**: CRISPR can be used to develop crops that are more resistant to pests, diseases, and harsh environmental conditions.
- **Creating disease models:** Scientists can utilise CRISPR to develop animal models of human diseases, enabling the study of the disease and testing potential treatments.

In highlighting the importance of CRISPR genome editing, coupled with advances in computing and imaging capabilities, Wang and Doudna (2023) said that it has initiated a new era in which genetic diseases and individual disease susceptibilities are both predictable and actionable. Similarly, genes responsible for specific plant traits can be identified and altered rapidly, thereby transforming the pace of agricultural research and plant breeding (**Figure 2**).

The power of CRISPR technologies is in their ability to make specific changes to individual plant genes, generating new plant genomes with targeted traits rather than relying on random DNA changes (Char et al., 2019; Usman et al., 2020; Liu et al., 2020; Zhu et al., 2020; Wada et al., 2020; Lin et al., 2020; Kobayashi et al., 2023; Pacesa et al., 2024; Luo and Liu, 2025).

Breeding precisely altered plants can quickly yield varieties that can reliably exhibit the desired trait. While CRISPR technologies offer significant promise, they also raise ethical and moral concerns, particularly regarding the editing of germline cells, such as eggs, sperm, or embryos.

Advances in genome editing technologies, particularly CRISPR/CRISPR-associated protein 9 (Cas9) (CRISPR/Cas9), have the potential to revolutionise rice varietal improvement through targeted genome modifications. There is ample and convincing evidence available to show that novel genetic technologies, such as CRISPR/Cas9, enable researchers to precisely edit genes in rice, modifying favourable traits, including biotic and abiotic stress tolerance and herbicide tolerance.

Three major types of site-directed nucleases (outlined below) have revolutionised gene-editing technologies, allowing researchers to precisely target and modify DNA sequences within living cells.

CRISPR-Cas Systems

These systems use a guide RNA (gRNA) to direct a Cas protein (such as Cas9) to a specific DNA sequence, where it can then make a targeted cut. The CRISPR-Cas system, derived from bacterial immune systems, has become a widely used tool for gene editing due to its simplicity and versatility (Westra et al., 2016; Wada et al., 2020).

Zinc Finger Nucleases (ZFNs)

ZFNs consist of a zinc finger DNA-binding domain fused to a *Fok*I nuclease domain. The zinc fingers can be engineered to recognise and bind to a specific DNA sequence, while the *Fok*I domain creates a double-strand break (Miller et al., 2007).

*Fok*I is an unusual restriction endonuclease enzyme that recognises a specific DNA sequence and cleaves DNA at a non-specific site a short distance away from its recognition sequence. The *Fok*I protein has two distinct domains: a DNA recognition domain and a DNA cleavage domain. The recognition domain binds to the DNA sequence 5'-GGATG-3’, while the cleavage domain cuts the DNA on both strands, nine base pairs away on one strand and 13 base pairs away on the other (Wah et al., 1998).

Transcription activator-like effector nucleases (TALENs)

TALENs are similar to ZFNs in that they use a DNA-binding domain (TALE) fused to a *Fok*I nuclease domain. The TALE domain can be engineered to recognise a specific DNA sequence, and the *Fok*I domain then creates a double-strand break (Christian et al., 2010).

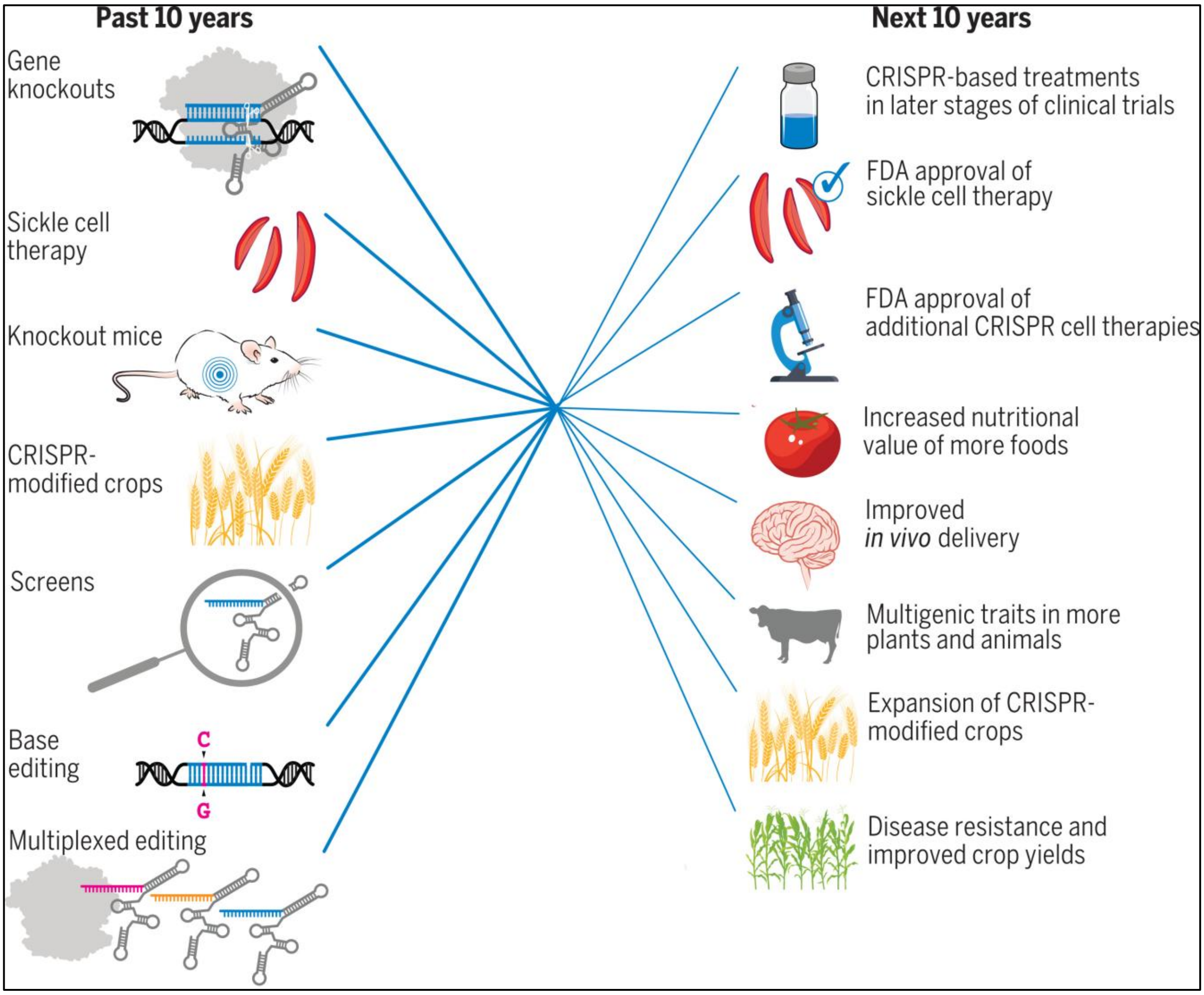


Figure 2. Source: Wang and Doudna (2023). CRISPR: past, present, and future

The past decade of CRISPR technology has focused on building platforms for generating gene knockouts, creating ‘knockout mice’ and other animal models, conducting genetic screening, and multiplexed editing.

CRISPR’s applications in medicine and agriculture are already underway and will continue to serve as the focus for the next decade, as society’s demands drive further innovation in CRISPR technology. These include improved crop varieties, resistance to pests and diseases, and herbicide resistance.

Development of New Rice Varieties using CRISPR genome editing

India needs to produce 520 million tons of food grains by 2047, which is 1.6 times the current production. Concurrently, water and nutrient use efficiency must be increased by more than 1.7-fold to address dwindling freshwater resources, deteriorating soil health, and the impacts of climate change. Thus, a quantum leap in quality yield is necessary to ensure India's food and nutritional security. Simultaneously, such a yield improvement must be achieved in line with the *Sustainable Development Goals* (SDGs) in India.

Based on our experience, it is clear that this yield increase in rice must primarily result from improved genetic gains in rice breeding and variety improvement programs, as well as technological advances in rice crop management that can combat biotic stresses, such as pests, diseases, and weeds.

Recognising the potential of genome editing to cost-effectively develop improved varieties with enhanced yield, nutritional quality, and climate resilience while reducing agrochemical inputs, the *Indian Council of Agricultural Research* (ICAR) initiated a project titled "Enhancing Climate Resilience and Ensuring Food Security with Genome Editing Tools".

In this project, ICAR successfully utilised gene editing to develop high-yielding, drought- and salt-tolerant mutants in the rice CV. **MTU1010**, which is a high-yielding mutant of *Samba Mahsuri*. The work was carried out at ICAR-Indian Agricultural Research Institute (IARI), New Delhi, and ICAR-Indian Institute of Rice Research (ICAR-IIRR), Hyderabad, respectively.

Following the development of the mutant varieties, ICAR obtained IBSC and RCGM exemption for these mutants under Rules 7-11 of the 1989 Rules. As a consequence, for the first time in the country, genome-edited mutants have been nominated for AICRIP trials in kharif 2023 (**http://genetools.iari.res.in/about.html**). The two rice varieties developed by ICAR are described below:

i. DRR Dhan 100 (Kamala)

The genome-edited rice variety 'Kamala' was developed by the ICAR-IIRR from the popular *Samba Mahsuri* variety. Through precise editing of the CKX2 gene, researchers achieved a 19% yield increase, early maturity by 20 days, improved drought tolerance, enhanced nitrogen-use efficiency and reduced methane emissions.

ICAR-IIRR researchers utilised a novel OsCKX2-deficient mutant allele, modified through SDN-1 genome editing, to increase cytokinin levels in rice panicle tissue. The loss of OsCKX2, a gene in rice that encodes a cytokinin oxidase enzyme involved in the degradation of cytokinin, thus boosts the growth-promoting cytokinin hormone in rice panicle tissue, resulting in higher grain yield and better productivity (Mayee and Choudhary, 2025).

The genome-edited rice variety 'Kamala' is now promoted for cultivation across all of the most critical rice-growing states of India, including Andhra Pradesh, Telangana, Karnataka, Tamil Nadu, Puducherry, Kerala, Chhattisgarh, Maharashtra, Madhya Pradesh, Odisha, Jharkhand, Bihar, Uttar Pradesh, and West Bengal (**Figure 3**).

ii. Pusa DSR Rice 1

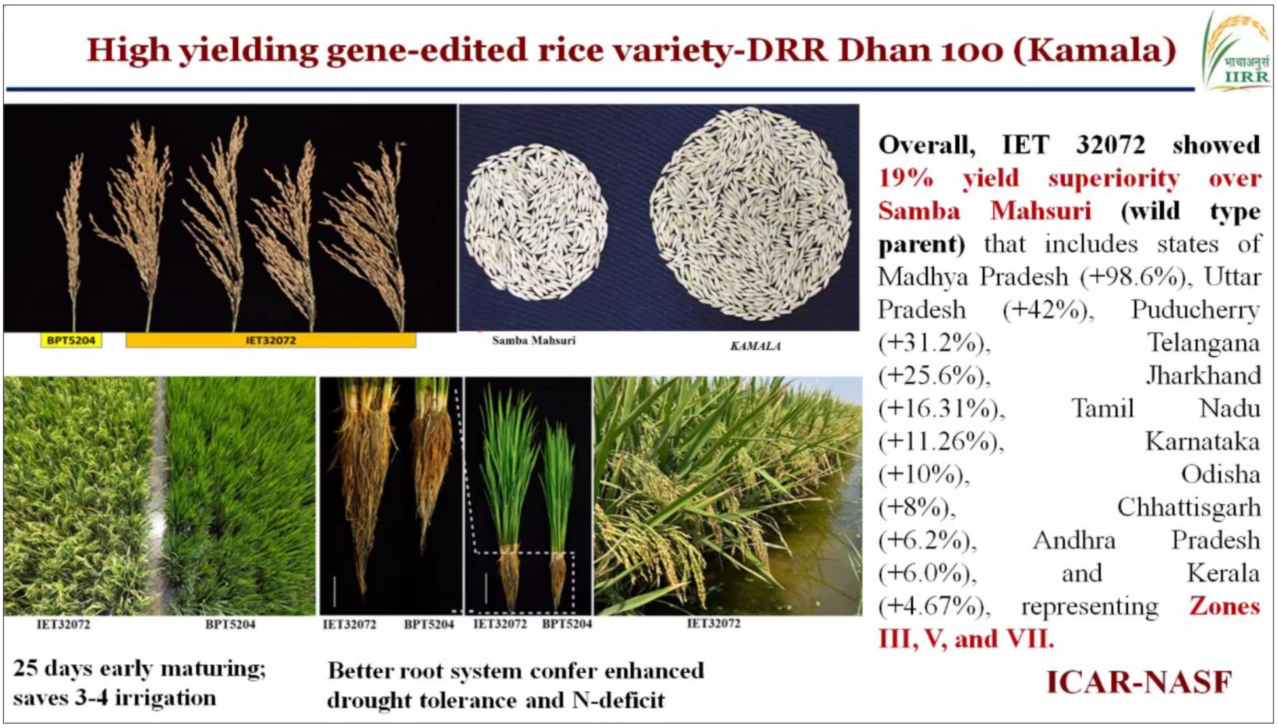
Pusa DSR Rice 1 was developed by ICAR-IARI in the popular MTU1010 rice background by editing the DST gene using the SDN-1 technique of CRISPR-Cas9. By removing a gene responsible for suppressing stress resistance using SDN-1 technology again, scientists achieved plants with reduced stomatal density and water use, along with improved tillering, grain yield, and salt tolerance (Mayee and Choudhary 2025).

The new variety is drought- and salinity-tolerant, with yield improvements ranging from 9.66% to 30.4% in challenging soil conditions. It is also suitable for direct seeding (DSR), which helps conserve water, reduce fuel consumption, and lower greenhouse gas emissions.

The '**Pusa DST Rice 1**' is now recommended for cultivation in most of the states in which Kamala is also promoted. Cultivating these two improved varieties over five million hectares, particularly in eastern and southern India, could yield 4.5 million tonnes of additional rice. ICAR estimated that the two varieties could also save approximately 7,500 million cubic meters of irrigation water while reducing greenhouse gas emissions by 20% (**Figure 3**).

* * *

It is important to note that these varieties were developed using CRISPR/Cas9 technology, which does not introduce any foreign DNA, unlike other genetically modified (GM) crops. This distinction placed them under the *Site-Directed Nuclease 1* (SDN-1) and *Site-Directed Nuclease 2* (SDN-2) categories of genome modifications. Both SDN-1 and SDN-2 category modifications to DNA are regulated more flexibly in India compared with other GM crops. These rice varieties, therefore, represent India's first significant success in applying CRISPR-based genome editing under the framework of New Breeding Technologies (NBTs).



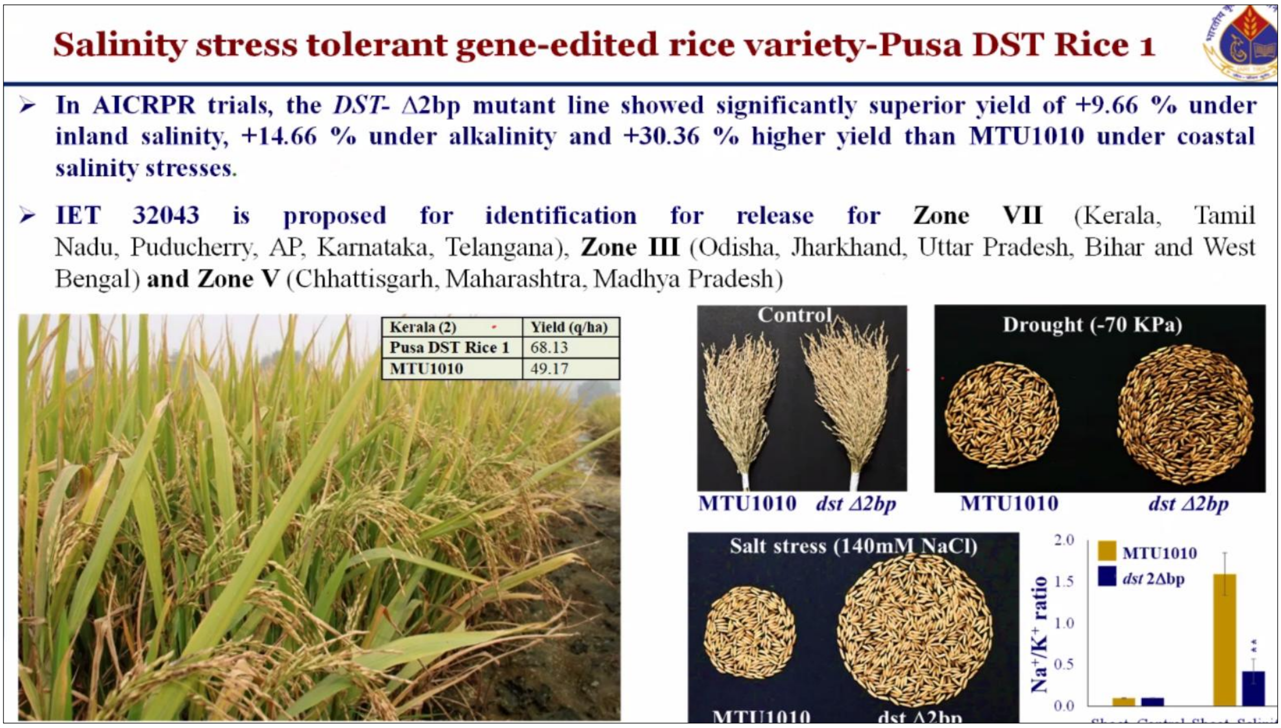
High yielding gene-edited rice variety-DRR Dhan 100 (Kamala)

Overall, IET 32072 showed 19% yield superiority over Samba Mahsuri (wild type parent) that includes states of Madhya Pradesh (+98.6%), Uttar Pradesh (+42%), Puducherry (+31.2%), Telangana (+25.6%), Jharkhand (+16.31%), Tamil Nadu (+11.26%), Karnataka (+10%), Odisha (+8%), Chhattisgarh (+6.2%), Andhra Pradesh (+6.0%), and Kerala (+4.67%), representing **Zones III, V, and VII.**

25 days early maturing; saves 3-4 irrigation

Better root system confer enhanced drought tolerance and N-deficit

ICAR-NASF



Salinity stress tolerant gene-edited rice variety-Pusa DST Rice 1

- **In AICRPR trials, the *DST*- Δ2bp mutant line showed significantly superior yield of +9.66 % under inland salinity, +14.66 % under alkalinity and +30.36 % higher yield than MTU1010 under coastal salinity stresses.**
- **IET 32043 is proposed for identification for release for Zone VII** (Kerala, Tamil Nadu, Puducherry, AP, Karnataka, Telangana), **Zone III** (Odisha, Jharkhand, Uttar Pradesh, Bihar and West Bengal) **and Zone V** (Chhattisgarh, Maharashtra, Madhya Pradesh)

Kerala (2)	Yield (q/ha)
Pusa DST Rice 1	68.13
MTU1010	49.17

Figure 3. Genome revolution: India's trailblazing path to first edited rice varieties (Chinnusamy, 2025)

Site-directed nucleases are unique molecular tools that create targeted breaks in DNA at specific locations. To develop these two rice varieties, the SDN-1 and SDN-2 techniques were used to precisely edit specific genes without introducing any foreign DNA. In this approach, the DNA is cut at a specific site using the CRISPR/Cas9 system.

The cell then repairs the break using its natural repair system, known as the non-homologous end joining (NHEJ) process. This process may introduce minor errors such as insertions or deletions. It is known that these small changes can also disrupt a gene, preventing it from functioning correctly. No foreign DNA is added in this method. It is often used to turn off unwanted genes.

In the SDN-2 method, the DNA is also cut at a precise location. But this time, a small piece of repair DNA is also given to the cell. This repair of DNA has a few specific changes that the scientist wants to introduce. The cell employs a process called homology-directed repair (HDR) to repair the break and incorporate the small changes from the repaired DNA into its own genome. Just like SDN-1, no foreign gene is inserted. Only a few base pairs are altered with great precision.

These tools are designed to recognise and cut DNA at a specific site. Once the DNA is cut, the cell uses its natural repair mechanisms to fix the break. During this repair process, scientists can either disable a gene or introduce precise changes. This allows for highly accurate editing of the genome without affecting other parts of the DNA. This makes the process non-transgenic and different from traditional genetically modified crops.

The gene editing process in developing two varieties is precise and yields a natural outcome. These genome-edited novel crop genomes, which contain no foreign genes, have been approved by the international scientific community. With these breakthroughs, India became the first country in the world to develop and approve genome-edited rice varieties using gene editing technology that does not involve genetically modified organisms.

Although the success of the two gene-edited new varieties has been widely lauded, concerns have also been raised about safety issues and future environmental effects (Menon, 2025). Nevertheless, the ICAR proponents highlighted that SDN-1 and SDN-2 genome edits are as safe as natural mutations. In our view, after the successes of technology, the success of the developed gene-edited rice depends on creating effective awareness, educating farmers, adopting stewardship guidelines, ensuring access to seeds, and building farmer confidence through targeted campaigns.

iii. Other Gene-edited Rice Mutants

In India, there are a few varieties that are most popular and most widely cultivated. These are called ‘mega varieties’ and include ‘SWARNA’, IR 64 and MTU 1010 varieties. These varieties are known to have higher adaptability to different environments, along with desirable morphological features, favourable grain quality and high rice grain recovery. Such characteristics make them popular not only among farmers but also among consumers and exporters (Sah et al., 2024; Kar et al., 2024).

All of these varieties are presently targeted for gene editing and varietal improvement. For example, in addition to the above-mentioned gene-edited rice varieties, other gene-edited rice mutants for the genes DEB1, CKX2, and TB1 have also been developed in the rice cultivar CV MTU1010 using CRISPR technology. These genes are involved in various aspects of plant development, including grain yield, cytokinin regulation, and plant architecture. For instance, the DEB1 (OsSPL16) gene is involved in regulating the rice grain yield.

Mutations in DEB1 increase the grain yield in rice, potentially through alterations in protein expression related to pyruvate metabolism and cell division (Usman et al., 2020).

In addition, targeting the ‘Ideal Plant Architecture’ gene (IPA-1), gene-edited mutant lines of ‘SWARNA’ have been developed by the ICAR-National Rice Research Institute (NRRI) in Cuttack. The rice variety “Swarna” is highly popular in India, as it yields reasonable profits to farmers even under low-input management.

Gene editing of the SWARNA cultivar has successfully produced mutants that show favourable differences in plant architecture. These include increased plant height, the number of panicle branches, panicle length, and the number of spikelets per panicle relative to the original, traditional cultivar (Bandita et al., 2024; Sah et al., 2024). These mutants are currently under analysis to identify the presence of any exogenous DNA. Those that are free of foreign DNA are expected to enter field trials in India soon.

Gene Editing Applications for IWM in Rice

Weeds are among the most significant biotic limitations on agricultural output, posing substantial yield losses to crops alongside other pests and diseases (Zimdahl, 1980; 2007; Hernández-Soto et al., 2021; Rao, 2022a, b). Weeds compete with rice for essential resources, including space, sunlight, water, and nutrients, contributing to reduced crop productivity (Rao et al., 2017).

Furthermore, weeds can serve as hosts for various insects, bacteria and viruses that can harm crop plants, exacerbating damage in the field. Beyond agricultural impacts, weeds also adversely affect native habitats, threatening local flora and fauna and disrupting ecosystems. Addressing these challenges is critical for ensuring food security and maintaining biodiversity.

Over the decades, many weed control tactics, tools and management strategies have been developed and deployed. Combined packages of these come under the banner of *Integrated Weed Management* (IWM). Despite various successes in rice weed management, as reviewed elsewhere (Rao et al., 2007; Ramesh et al., 2017; Rao et al., 2017), a continuing need remains for the development of more sustainable and affordable methods for weed management.

Modern tools, such as gene editing, appear to offer robust options that can be incorporated as a component of future IWM in rice. Several crucial areas where gene editing technologies might be applicable to enhance IWM are discussed below.

Developing Herbicide-Tolerant (HT) rice varieties

Herbicides are widely used to manage undesirable weeds. However, one of the most significant problems associated with the continuous use of herbicides is that weeds develop resistance to these chemicals. Cultivating herbicide-tolerant (HT) crops provides farmers with alternative options for effective weed management of herbicide-resistant weeds, thereby realising increased rice productivity (Yaduraju, 2021; Dong et al., 2021; Kar et al., 2024; Luo and Liu, 2025).

Herbicide-tolerant (HT) rice refers to rice varieties that have been genetically modified or bred to withstand the application of specific herbicides. This trait allows farmers to control weeds more effectively by using herbicides that would otherwise damage or kill the rice plants. The most common method for developing HT rice is through mutagenesis of the acetolactate synthase (ALS) gene, which is a target for several herbicides (Luo and Liu, 2025).

Introducing HT crops via genetic engineering is one of the most effective strategies for controlling a broad spectrum of herbicide-resistant weeds. In recent decades, traditional breeding, combined with transgenic methods and mutagenesis, has played a pivotal role in driving the progress of herbicide-tolerant (HT) rice (Rao et al., 2007).

The genetic approaches to creating HT rice have been comprehensively reviewed recently by Luo and Liu (2025). The two central herbicide-tolerance mechanisms in rice are (a) target-site resistance (TSR; conferred by mutations or overexpression of target proteins) and (b) non-target-site resistance (NTSR, involving the sequestration, translocation, detoxification via metabolic degradation, or reduced penetration of herbicides).

The primary techniques used to create HT rice using one or the other tolerance mechanism include (a) Mutagenesis, (b) Transgenic methods, and (c) CRISPR/Cas9 gene editing.

Mutagenesis - This non-transgenic approach involves selecting naturally occurring mutations or inducing random mutations by irradiation (such as UV light, X-rays, gamma rays, or ion beams) or chemical mutagens (such as ethyl methane sulfonate). These aim to alter the responsible gene in a way that reduces its sensitivity to specific herbicides without introducing foreign genes from other organisms into the rice genome. Herbicide-resistant mutant rice genes, derived from mutagenesis breeding, are then usually transferred into other rice varieties by backcrossing.

Commercialised HT rice, developed through non-transgenic approaches, includes the *Clearfield*®, *Provisia*®, and *Jietian*® varieties. Among these, *Clearfield* is the most widely used HT variety (Chen et al., 2021; Jin et al., 2022). **Provisia** rice is resistant to ACCase inhibitors (Ile to Leu mutant) in the ACCase protein, and **Jietian** rice varieties, named from Chinese (meaning rice fields free of weeds), are resistant to ALS inhibitors carrying a mutation (Trp to Met) in the ALS gene (Jin et al., 2022). *Clearfield* rice was produced by mutagenesis of cultivated rice, via modification of a single codon (Ser to Asn) in the AHAS gene (Tan et al., 2005).

After 15 years of use, *Clearfield* rice continues to produce high yields in Brazil owing to its superior weed-control effects. Nevertheless, *Clearfield* rice is now facing challenges from herbicide-resistant barnyard grass [Echinochloa crus-galli (L.) Beauv.] and weedy rice (*Oryza sativa*) (Ulguim et al., 2021).

Transgenic Methods – Transgenesis is the process of introducing foreign genes (transgenes) into an organism's germline, allowing the transgene to be inherited by all offspring. Several examples discussed below demonstrate that this approach has been effective in creating HT rice.

The introduction of specific transgenes reduces the crop plant's sensitivity to herbicides through target-site resistance (TSR) or non-target-site resistance (NTSR) mechanisms. HT genes for this purpose can be isolated from bacteria, mutants produced by mutagenesis breeding, or herbicide-resistant weed biotypes. For example, the CP4-EPSPS gene from *Agrobacterium* sp. strain CP4 is widely used for the breeding of glyphosate-resistant 'Roundup Ready' crops that have been accepted and grown in many countries (Cuhra, 2015) [1].

However, Ouyang et al. (2021; 2024) found that mutations in the *5-enolpyruvylshikimate-3-phosphate synthase* (EPSPS) gene (i.e. TIPS-EiEPSPS) obtained from a herbicide-resistant biotype of goosegrass [*Eleusine indica* (L.) Gaertn.], which contains two mutated sites (T102I and P106S), conferred better resistance to glyphosate than CP4-EPSPS in transgenic rice (Zhonghua11).

Emerging research continues to focus on enhancing the resistance of rice to herbicides that can kill weeds by transferring well-established resistance genes from other organisms to the crop. Herbicide resistance-imparting genes have been derived from both soil bacteria and recalcitrant weeds (see recent reviews by Kobayashi et al. [2023] and Luo and Liu [2025]).

In one significant example, transgenic rice (*Nipponbare*) [2] expressing the rigid ryegrass (*Lolium rigidum* Gaud.) metabolic P450 gene CYP81A10v7 exhibited resistance to seven herbicides: diclofop-methyl (6000 g ha^{-1}), tralkoxydim (200 g ha^{-1}), chlorsulfuron (400 g ha^{-1}), Mesotrione (200 g ha^{-1}), atrazine (2000 g ha^{-1}), chlortoluron (2000 g ha^{-1}), and trifluralin (240 g ha^{-1}) (Han et al., 2021).

In a recent study, the potential effects of transgene stacking in glyphosate-tolerant rice and its wild-type parent, Zhonghua 11, were examined as a safety assessment strategy (Wang et al., 2023b). Another study analysed the genetic stability of insect- and herbicide-resistant genes in transgenic rice lines. The findings suggested that growing Bar-transgenic rice and using Basta (up to 300 mg/l) could be an effective strategy for overcoming weed damage in rice (Sun et al., 2023).

Transgenic methods offer several advantages, including the ability to utilise genes from diverse organisms, ranging from wild crop relatives to domesticated crops. They also enable gene stacking ('pyramiding') to obtain improved phenotypes or alter multiple traits simultaneously.

However, transgenic technologies have several disadvantages, including biosafety concerns and the potential for causing off-target mutations. Also, consumers and regulatory agencies have expressed concerns about the introduction of foreign DNA into food crops and the potential for adverse effects on biodiversity. Indeed, biosafety concerns about the breeding of genetically modified (GM) rice have halted their commercial cultivation in some rice-growing countries.

CRISPR/Cas9 Approach - The current, most suitable alternative to conventional genetic engineering approaches for developing HT rice is the creation of transgenic varieties through targeted genome editing using CRISPR-Cas9 (Dong et al., 2021; Akhtar et al., 2024; Luo and Liu, 2025).

Various gene editing tools are now available that could be used to develop HT rice. These tools include: target-based editing (ABEs and CBEs), CRISPR ribonucleo-protein complexes/Cas9, prime-editing-library-mediated saturation mutagenesis (PLSM), Prime editing (PE), single-nucleotide

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[1] The CP4-EPSPS gene has been widely used commercially to create glyphosate-resistant crops, including soybeans, corn, cotton, and canola. These crops, often referred to as "Roundup Ready" crops, allow farmers to use glyphosate to control weeds without harming their crop.

[2] *Nipponbare* is a widely used temperate *O. sativa* var. *japonica* cultivar of rice. Its well-annotated and fully sequenced genome makes it valuable as a model organism and a research tool for genetic studies and the development of transgenic lines. Transgenic *Nipponbare* rice has been engineered for various traits, including improved tolerance to environmental stresses, such as salinity, enhanced nutritional value, and resistance to herbicides (Matsumoto et al., 2016). However, the genetically modified HT Nipponbare is yet to be commercialised.

polymorphisms (SNPs), Non-homologous end joining (NHEJ), base-editing-mediated gene evolution (BEMGE), and Homology-directed repair (HDR), along with 2 DNA targeting systems (protein-based): namely, TALENs, ZFNs—that are utilised for site-directed genome mutagenesis (Char et al., 2019; Asadullah and Shah, 2025).

As recently reviewed by Luo and Liu (2025), impressive and rapid advances have been made utilising genetic tools to develop varieties with broad-spectrum tolerance to rice herbicides (see **Figure 4**).

The precise gene editing approach provides a reliable method for developing HT rice through successive rounds of gene editing. The outputs offer efficient alternatives to traditional gene modification techniques. Research has shown that by targeting specific genes and inducing precise mutations, CRISPR/Cas9 has facilitated the development of rice that can withstand specific herbicide applications, as discussed below.

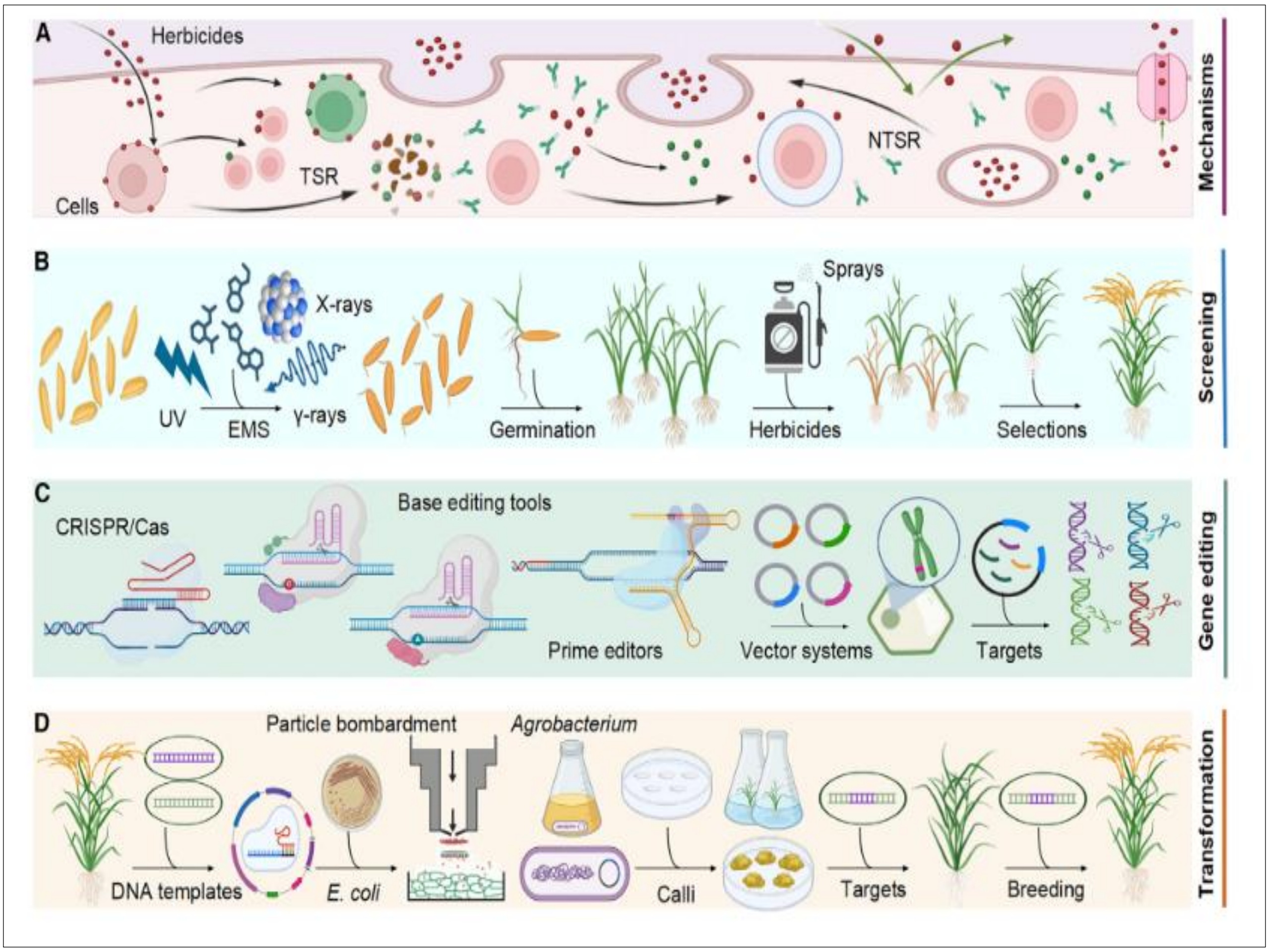

Figure 4. Source: Luo and Liu (2025). Graphical representation of the strategies used to breed herbicide-resistant rice.

(A) There are two central herbicide-resistance mechanisms in rice cells: target-site resistance (TSR; conferred by mutations or overexpression of target proteins) and non-target-site resistance (NTSR; involving the sequestration, translocation, detoxification via metabolic degradation, or reduced penetration of herbicides).

(B) Steps involved in the screening of herbicide-resistant rice mutants generated by chemical treatment or irradiation, with subsequent herbicide treatment used to impose selection pressure.

(C) The use of gene-editing tools, including gene knockout, base editing, and prime editing, in the breeding of HT rice.

(D) The two principal systems for delivery of transgenes during the breeding of herbicide-resistant rice are particle bombardment and Agrobacterium-mediated methods.

The new varieties are said to provide higher crop yields and highly sustainable rice production [see reviews by Faizal et al. (2024) and Luo and Liu (2025)]. For instance, Sun et al. (2016) had earlier described how two specific amino acid residues in the Acetolactate Synthase (ALS) gene were precisely edited and replaced to develop HT rice plants with homozygous resistance.

Following a similar approach, Wang et al. (2021) employed the base editing technique mediated by CRISPR/Cas9 to modify the OsALS gene, thereby conferring ALS herbicide resistance to rice in response to imazethapyr. Butt et al. (2020), using *Nipponbare*, also described how similar CRISPR modifications to the ALS gene provided HT rice resistant to the rice ALS-inhibiting herbicide bispyribac-sodium.

In another study, Li et al. (2016) developed gene replacement and insertion strategies targeting the non-homologous end-joining (NHEJ) pathway using CRISPR/Cas9. This strategy was successfully employed to induce local lesions in genomes and to introduce amino acid substitutions in the rice 5-enol pyruvylshikimate-3-phosphate synthase (EPSPS) gene, conferring resistance to glyphosate in rice.

Building on these studies, Sony et al. (2023) recently described the development of glyphosate-resistant rice lines through site-specific amino acid substitutions (G172A, T173I, and P177S: GATIPS-m*OsEPSPS*) and modification of the phosphoenol pyruvate-binding site in the *OsEPSPS* gene. They employed the CRISPR/Cas9 system to use the fragment knockout technique.

Interestingly, the GATIPS mutations in the *OsEPSPS* gene created not only new rice lines with high glyphosate resistance (foliar spray of 6 mL L-1) but also those with enhanced aromatic amino acids (Phenylalanine, two-fold; tryptophan, 2.5-fold; and Tyrosine, two-fold), and improved rice grain yields. The authors suggested that this gene modification would be a new strategy for higher rice productivity (Sony et al., 2023)

Herbicides that inhibit 4-hydroxyphenylpyruvate dioxygenase (HPPD), including Mesotrione (MST), block electron transport in photosynthetic systems, resulting in bleaching and plant death. Wu et al. (2023) edited the gene involved, *OsHPPD* 3′ UTR, using CRISPR-Cas9 and CRISPR-Cas12a and created new rice lines with HPPD resistance to Mesotrione (120–480 g ai ha^{-1}). Their results demonstrated that CRISPR-Cas9-mediated editing in the 3′ UTRs of elite rice genes may facilitate improvement of important plant agronomic traits.

Acetyl-CoA carboxylase (ACCase) catalyses the first step of fatty acid biosynthesis in plants. Loss-of-function mutations in ACCase are lethal to plants. As a consequence, the ACCase enzyme is the target of a large number of herbicides (e.g., 'Fops' and 'Dims'). Using the CRISPR-Cas9 gene editing tool, Liu et al. (2020) modified the ACCase gene, *OsACC* (LOC_Os05g22940) of an elite *japonica* rice variety, cv. Feigeng2020. The CRISPR-mediated new rice mutants demonstrated stability in their modified genomes and showed no fitness losses, indicating that the approach could be used to confer ACCase herbicide resistance in rice (Wu et al., 2020).

The successes demonstrated by such examples reveal that CRISPR/Cas9 is an efficient method for both identifying and modifying target genes, making rice tolerant to herbicides that can suppress its major weeds. The literature on the uses of these technologies is growing rapidly, as reviewed by Luo and Liu (2025).

Their view is that key genes in HT signalling pathways could be edited to manipulate the underlying biological processes. Studying structural features of receptor proteins that bind to herbicides with different modes of action in HT mutants should accelerate the development of methods to modify genes that encode for HT target enzymes. Other potential areas for future research include the stacking of mutations in HT genes using gene editing to confer multiple herbicide resistance in rice.

The premise of this intensified research is that creating a greater number of HT rice varieties can simultaneously achieve both improved rice yields and management of herbicide resistance in weeds by modifying specific genes.

'Gene Drive' Systems to Modify Weed Populations

Over the last eight decades, the constant use of herbicides has led to the widespread evolution of herbicide resistance in numerous weed species (Duke, 2005; Heap, 2025). The CRISPR/Cas9 'gene drive' has come as a novel genetic control strategy in managing herbicide resistance in weeds (Kumam et al., 2023).

The CRISPR tool could be used to 'edit' weed genomes and modulate their fitness and 'weediness' in the field. The introduction and proliferation of some mutations could make target weed populations more prone to subsequent weed management strategies, including herbicides (Neve, 2018).

'Gene drives' are genetic elements that increase the likelihood of a specific gene being inherited by offspring, causing it to spread rapidly through a population over generations. This is different from normal Mendelian inheritance, where a gene has a 50% chance of being passed on.

It is a process that promotes a mechanism of biased inheritance of specific genes from one generation to the next. The process can be harnessed to ‘drive’ a desired allele throughout a population (Alphey et al., 2020). Thus, it can serve as a tool to effect specific changes in a biological population. Gene drives can be found in nature, but scientists are also developing ‘synthetic gene drives’ using CRISPR technology, which can be used to modify organisms and potentially control populations or combat diseases.

‘Gene drives’ could be designed to modify populations of weed species. One promising application is to ‘knock out’ a reproduction-specific gene, which could lead to the sterility of a species. Such a change could lead to a population-level decline in a highly problematic weed species.

Another application might be to modify weed populations and make them more susceptible to herbicide applications, as has been suggested (Barrett et al., 2019). Neve (2018) also suggested that gene drive technology may enable the reversal of herbicide-resistant weeds to their natural forms, making them susceptible to herbicides once again.

It appears that gene drive systems can be safely used as an approach to suppress the aggressive growth and reproductive behaviour of weeds and the targeted elimination of some problematic species. However, as these are novel approaches, their efficacy is yet to be thoroughly tested (Kumam et al., 2023). Such approaches are not currently used for the management of any species and need to be more cautiously explored.

Nevertheless, gene drives do seem to have the potential to become an effective and efficient tool for weed management. As an alternative to the excessive and unsustainable use of herbicides, gene drive poses no safety concerns regarding exposure to hazardous chemicals. The added advantages of using gene drive include fewer disturbances to the soil or environment (Myers et al., 2016), reduced long-term costs for managing weed populations, and minimal ongoing human intervention (Croghan et al., 2023).

Based on concerns about unintended consequences, we recommend applying the precautionary principle in modifying weed populations. A cautious approach is necessary when utilising novel gene drive technology to prevent unexpected gene flow and related undesirable effects that could further complicate weed management. Moreover, significant regulatory and ethical challenges exist with genetic manipulations of plant genomes. As discussed by Yaduraju (2021) and Menon (2025), these are obstacles that need to be addressed in countries like India.

Strengthening the Competitive Ability of Rice against Weeds

In most rice-growing regions of the world, considerable research effort has been made to produce high-yielding rice varieties. While high-yielding varieties are globally available, they are often less competitive against major rice weeds. As a result, if agronomic conditions and weed management strategies are not appropriately implemented, significant yield losses could occur.

For example, the New Rice for Africa (NERICA) reported that newly developed African rice (*Oryza glaberrima* Steud.) varieties can thrive in the challenging African environment. In addition to favourable growth, they also demonstrated some degree of the high-yielding potential of *O. sativa* (Somado et al., 2008). However, the new varieties lack resistance mechanisms to certain local constraints, including weeds, compared to the traditional *O. glaberrima* varieties (Mmbando, 2020).

Oryza glaberrima is recognised as a source of genes that confer resistance to various biotic stresses, including those from weedy species (Johnson et al., 1998; Dingkuhn et al., 1999; Fofana and Rauber, 2000). A cross-species hybridisation between *O. glaberrima* and *O. sativa* combined the greater competitive ability of the former and the higher yield qualities of the latter (Dingkuhn et al., 1997). The hybridisation resulted in rice lines with increased competitiveness and improved yields.

Given that *O. glaberrima* has been a potential source for improving weed competitive traits in Rice, it has been subjected to genetic analysis, especially to identify the quantitative trait loci (QTLs) associated with weed competitive traits. Nine QTL hotspots for weed competitive traits (qWCA2a, qWCA2b, qWCA2c, qWCA3, qWCA5, qWCA7, qWCA8, qWCA9, and qWCA10) were identified in BC1F2:3 population derived from weed competitive accession of *O. glaberrima* (IRGC105187) and *O. sativa* cultivar IR64, wherein several QTLs were co-localised (Bharamappanavara et al., 2020).

As demonstrated by this research, advanced molecular technologies offer significant opportunities to identify QTLs as well as specific genes and alleles associated with weed-competitive traits in rice.

A few of the rice plant characteristics associated with weed competitiveness are plant height, early canopy cover, high tiller density, vertical leaf orientation, high biomass accumulation at the early crop stage, high leaf area index and high specific leaf area during vegetative growth, early vigour, and greater root biomass and volume (Saito et al., 2010; Ramesh et al., 2017). The gene editing tools hold great promise for identifying the specific genes involved in such plant attributes and for boosting rice's ability to compete with weeds by strengthening its competitive characteristics.

Seedling vigour, especially early seedling vigour (ESV) of seedlings less than 28 days old, is imperative for crop stand establishment and weed competitiveness (Richards, 1996; Zhao et al., 2007). The ESV is highly correlated with the ability of rice seedlings to compete with weeds, especially under aerobic conditions (Mahender et al., 2015).

Four QTL regions, qSV1a, qSV3e, qSV4c, and qSV7c, have now been identified, which delimit and harbour quantitative trait nucleotides responsible for ESV-related traits. Chen et al. (2019) recently reported favourable haplotype mining for the candidate genes within these four regions, as well as the ESV gene OsGA20ox1. These are considered highly promising developments.

The development of competitive rice cultivars requires interdisciplinary approaches. It involves screening rice germplasm to identify potential donors, as well as utilising races and other wild species that have been proven to harbour genetic heterogeneity and offer competitive advantages.

The availability of novel gene editing techniques could accelerate the development of competitive rice cultivars that can then be integrated into innovative weed management packages (Bharamappanavara et al., 2020). However, as Zhao et al. (2007) discussed, a more thorough understanding is also required of genotype-environment interactions and environmental variance concerning the development of a competitive rice phenotype using gene editing.

Developing Allelopathic Rice Cultivars Using Gene Editing Tools

Allelopathy is the ability of plants to inhibit or stimulate the growth of other plants in the neighbouring environment through the activity of exuded bioactive secondary metabolites, referred to as allelochemicals. However, as discussed by Bhowmik and Inderjit (2003) and Olofsdotter et al. (1999, 2002a, b), there are numerous challenges to utilising allelopathy for natural weed management.

Despite claims of incorporating allelopathy as a weed management tool, in our view, actual progress has been limited. This is mainly due to the complex challenge of accurately assessing allelopathic interactions in the field, where natural variability and changing environmental conditions prevail (see review by Chandrasena, 2023, pp. 202-216).

Allelopathic potential exists in many of the major world crops, including rice (Dilday et al., 2001; Olofsdotter et al., 2002a; b; Khanh et al., 2007; 2009; Yang and Kong, 2017). Key allelochemicals in rice include phenolic acids, terpenoids, and flavonoids.

While the allelopathic potential of rice was recognised decades ago, many questions remain unresolved regarding the biosynthesis, exudation, and biological activity of momilactones, phenolic acids and other bioactive chemicals exuded by rice (Kato-Noguchi and Ino, 2003; Kato-Noguchi et al., 2008; Amb and Ahluwalia, 2016; Serra et al., 2021).

Many studies have confirmed that rice roots, shoots, and leaves produce momilactones, which are diterpenoids released into the rhizosphere, inhibiting the growth of numerous plant species and exhibiting strong interactions within the rhizosphere zone. Apart from momilactones, an impressive array of other allelochemicals is also produced by rice (Khanh et al., 2007; Amb and Ahluwalia, 2016).

Specific compounds, particularly momilactone A and B, are capable of strongly inhibiting the growth of barnyard grass (Kato-Noguchi and Ino, 2003; Kato-Noguchi et al., 2008).

Their direct use of allelochemicals identified in rice and other crops as pesticides has not been successful for several reasons. These include the stability of most compounds in the natural soil environment, their selectivity and limited activity, as well as potential effects on non-target organisms.

Additionally, developing any novel allelopathic compound that could be used as a commercially viable biopesticide is known to be prohibitively expensive, thereby limiting investment opportunities. Even the isolation of allelochemicals from plants in required amounts is a tedious process. This has been the *Achilles' heel of allelopathy research,* and the reason why there are not many that have been earmarked for commercial production.

Furthermore, the genetics of allelopathic effects in crops and weeds, as well as the genes involved in producing allelochemicals, have been poorly studied. Mapping populations consisting of recombinant inbred lines (RILs) have highlighted that the allelopathic nature of rice is a quantitatively inherited trait (Olofsdotter et al., 2002a; b).

Recently, Yang and Kong (2017) investigated two rice genotypes, *Huagan-3* (an allelopathic variety) and *Liaojing-9* (non-allelopathic), for their effects on several major rice weeds, including dirty Dora (*Cyperus difformis* L.), barnyard grass, false daisy [*Eclipta prostrata* (L.) L.], red sprangletop

[*Leptochloa chinensis* (L.) Nees], and *Oryza sativa* (weedy Rice). The findings indicated that significant allelopathic inhibition occurred more at the root level (total root length, total root area, maximum root breadth, and maximum root depth) of the weedy species than at the shoot level.

Nevertheless, the identification of allelopathic genes or genomic regions (i.e. Quantitative Trait Loci, QTLs) has been a challenge in implementing specific breeding programs (Aci et al., 2022). A new approach to utilising the concept of allelopathy would be the development of transgenic allelopathic rice through gene editing technologies.

More than 20 years ago, Ebana et al. (2001) identified some quantitative trait loci (QTLs) associated with the allelopathic effect of rice exudates using restriction fragment length polymorphism (RFLP) markers. The study, using lettuce (*Lactuca sativa* L.) as the test species, identified seven QTLs on rice chromosomes 1, 3, 5, 6, 7, 11, and 12. One of the QTLs on chromosome 6 had the most significant effect on the allelopathic inhibition of lettuce, explaining 16.1% of the test plant’s response. The other six QTLs explained the variation in the range from 9.4% to 15.1%.

Since then, the last 20 years have seen numerous studies on genes that produce allelochemicals and may be implicated in rice allelopathy (see reviews by Amb and Ahluwalia, 2016; Rahaman et al., 2022). Chung et al. (2020) more recently studied the occurrence of QTLs in rice using ‘Sathi’, an indica cultivar with high allelopathic potential, and ‘Nong-an’, a non-allelopathic cultivar.

As the test species, the researchers used a lettuce cultivar ‘Yeolpungjeokchima’, which was highly sensitive to low concentrations of allelochemicals. This study led to the identification of a QTL region on chromosome 8, a 194-kbp segment containing 31 genes, as being responsible for inhibiting the shoot length and total length of lettuce. The research showed that qISL-8 was directly implicated in the highest inhibition (20.83%) of the test species, suggesting that this region is a possible candidate for further study to clone genes for allelopathy traits (Chung et al., 2020).

A review of the literature on rice research, particularly the genetic studies conducted over the past 20 years, reveals no decline in interest in using allelopathic rice varieties for weed suppression in the field. However, in our view, the real challenge is to retain the highly favourable yield, plant architecture, and grain quality of rice varieties while conserving the crop’s weed-competitive capabilities through genetic manipulations of allelopathic and non-allelopathic traits. Developing novel varieties through the rapid advancement of genetic tools may help achieve this highly desired outcome.

Gene editing for visual recognition of Rice Weeds by machine-learned robots

Weeds in rice, such as weedy rice and barnyard grasses, are strong competitors with rice. Often, most rice cultivars are unable to outcompete such aggressors (Johnson et al., 1998; Saito et al., 2010). The removal of such grasses by manual or mechanical means is difficult, as they closely resemble rice. Rice weed managers have been attempting to solve this problem for many decades (Rao et al., 2017; Rao, 2021, 2022a, b).

Hence, in rice weed management, it is also worth testing the proposal made by Pedro et al. (2024) to use gene editing techniques to introduce traits into crops, enabling visual recognition of the crops by weeding robots trained through machine learning.

Given the rapid advancements in machine learning, artificial intelligence (AI), robots and drones that can identify weeds, this possibility offers an opportunity for further development for future applications. In India, an AI-driven robotic system incorporating advanced image recognition capabilities has already demonstrated remarkable precision and speed, outperforming manual labour in weed removal (Mohanty et al., 2025).

Whether these systems can be further enhanced by slight modifications to the visual image of the crops remains to be seen.

Genome editing to manage parasitic weeds

Infestations of purple witchweed [*Striga hermonthica* (Delile) Benth.] and related parasitic plants result in substantial yield losses in many crops, including Rice. These are significant problems for agriculture in sub-Saharan Africa, Southern Europe, the Middle East and Asia, including India (Parker, 2009).

Nevertheless, recent research has been very promising in this regard. Genome editing and gene silencing-based technologies offer new opportunities to enhance crop resistance to parasitic weeds (Yildirim et al., 2024). The strategies of silencing host or parasite genes may serve as an effective strategy to obtain more sustainable and durable crop resistance to parasitic weeds. For example, CRISPR/Cas9 has been used to knock out the CCD7 gene in Rice, thereby reducing strigolactone content in the roots (Butt et al., 2018).

The reduced levels of CCD7 may help fine-tune the levels of strigolactones, leading to altered plant architecture (especially tillering to improve crop yields) and thereby lowering the risk of *Striga* infection and adverse effects. Based on these findings (see Butt et al., 2018; 2020), it is possible to predict that knowledge of whole-genome sequences and transcriptomes of parasitic plants can be utilised to enhance resistance in rice to parasitic weeds by employing molecular breeding and advanced genome editing strategies.

Conclusions

We agree with the assessments of Kobayashi et al. (2023) and Luo and Liu (20025) that genetic tools are robust options that can be deployed to safeguard food security and nutrition, which is crucial for countries to overcome hunger and malnutrition problems in many regions, including India and the broader Asian-Pacific region.

The application of new genome-editing breeding technologies has significantly expanded the possibilities for improving rice crops. In recent years, various genome-editing techniques, including CRISPR-directed evolution, CRISPR-Cas9, and base editors, have emerged as powerful tools for efficient and precise genome modifications in rice.

The suitability of rice as a model system for functional studies, its small genome size, and its close relationships with other cereal crops have further accelerated the development of novel genome-editing technologies in rice. The advances in genetic studies and their applications in rice research over the last decade are revolutionary.

As shown by the examples we highlighted, advances in biotechnology are now driving a new wave of potential increases in food production (ISAAA, 2019; Hernández-Soto et al., 2021; Bacha et al., 2025). Biotechnology is revolutionary in that it now offers novel opportunities that were previously unavailable, thereby increasing productivity and contributing to global food, feed, and fibre security.

New crops and food production approaches via biotechnology will support self-sufficiency on any nation’s arable land while conserving biodiversity, reducing deforestation, and protecting the environment. They also mitigate the challenges associated with climate change and improve economic, health, and social benefits.

Public acceptance and enabling policies in the government are crucial for the agricultural, socio-economic, and environmental benefits of biotechnology crops to reach those experiencing poverty and hunger. While there are challenges to overcome – both technological and regulatory – the new generation of crops produced by genetic technologies must be viewed as crucial to meeting the food and nutrition demands of an increasingly global population.

The use of gene editing technologies in rice presents various opportunities for more strategic and enhanced integrated weed management in rice cultivation. Among the many options is the capacity to introduce modifications to the genomes of weedy species that make them less successful in rice fields and more susceptible to rice herbicides (Asadullah and Shah, 2025). Other options include identifying and utilising novel herbicide target sites of action, novel genes for improving crop competitive traits, allelopathic weed-suppressive traits, and innovative means of weed management.

In a recent review. Akhtar et al. (2024) discussed how allelopathic research may once again focus on improving weed management. We agree with them that by combining molecular, genetic, biochemical, and bioinformatic tools, research can unravel the complexities of allelopathic interactions and their potential for sustainable crop production.

The new genetic technologies, such as gene drive, transgene technologies, gene silencing, marker-assisted selection (MAS), and CRISPR-Cas9, are promising in this regard. By strengthening the competitive characteristics of rice, these tools hold great promise for boosting crops’ ability to compete with weeds.

The rapid integration of AI across disciplines is now driving another transformative phase in genome editing, including the optimisation of editing systems, the prediction of editing site efficiency, and the design of editing strategies, as well as the streamlining of workflows and the enhancement of precision (Jiang et al., 2025).

While integrating classical and advanced genetic technologies and utilising novel tools for weed management, we must also necessitate a critical evaluation of the ecology and physiology of weeds using genomic technologies.

Looking forward, we can expect to see CRISPR-edited crops, including rice varieties, continue to emerge in the literature, laboratories, and even our markets over the next decade. Generally, the new crop varieties will possess favourable traits related to climate adaptation, improved consumer quality, and yield enhancement. The rapidly changing gene editing technology will go way beyond the simple “knocking out” of particular genes in favour of precise gene insertions, base-pair edits, and/or multiple types of edits carried out simultaneously. These will represent the growing use of more technically complex gene editing techniques (Dong et al., 2021; Kobayashi et al., 2023; Luo and Liu, 2025).

The technological power of CRISPR is undeniable. However, the ultimate global impact across various fields of endeavour, including its use as a tool for improved weed management, depends on implementation. The most significant obstacles to implementation include favourable regulation, fast-tracked approval processes of gene-edited products, grower education, and public understanding and acceptance of such technologies.

We believe that it is not just technological innovation but also navigating the complex sociopolitical landscape of sustainable food systems that is crucial to determining the extent to which gene editing should be used to improve our food systems and food security.

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ORIGINAL RESEARCH

THE PREVALENCE OF SENNA TORA IN PENINSULAR MALAYSIA

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Abstract

Senna tora, an important medicinal plant in Malaysia, is a major introduced pasture weed in the Pacific island nation of Vanuatu. This weed contains toxic compounds, including sennosides, which can be harmful to livestock if ingested in large quantities. The seeds spread easily, leading to infestations in pastures and rangelands. A biological control program to mitigate its impacts in Vanuatu commenced, with funding from the New Zealand government. Early literature searches and climate matching suggested that Southeast Asia was the most promising region to survey for natural enemies. Therefore, surveys were conducted to determine the distribution of *S. tora* in Malaysia, which will help identify the best places to search for potential candidates for biological control. Field studies were conducted within a 30-60 km radius of the first location chosen based on accessible roads and near water resources. The distribution of *S. tora* in Malaysia occurred mostly along the west coast of Peninsular Malaysia. The highest density of *S. tora* was observed in Johor, followed by Negeri Sembilan and Pahang. Perlis had the lowest density, while other states fell in between. This weed is most abundant in abandoned areas, shrubland, and near rivers.

Keywords: abundance, density, distribution, frequency, gelenggang kecil, weed.

Introduction

Weeds pose a significant threat to agriculture and global biodiversity. Depending on the crop and plant type, yield losses resulting from weed infestations could run from 10% to 90% (Flessner et al., 2021). These invasive weeds compete with other crops for nutrients, light and space, ultimately reducing crop yields (Gebrekiros et al., 2018).

However, prolonged use of herbicides could cause deleterious effects on our environment and ecosystem (Buhler, 2002; Baki, 2004). However, weeds can also be managed by non-herbicidal methods, which include the use of biological control agents.

A common practice for controlling weeds is to spray herbicides. This is due to their availability in the market, fast results, and ease of application.

Biological control is more environmentally friendly, as the agents are host-specific and attack only the target weed. Biological control is also cost-effective and sustainable. Numerous examples exist of major weeds being successfully controlled through the use of biological control agents (Winston et al., 2014).

Senna tora (L.) Roxb. (Fabaceae) [syn. *Cassia tora* L.] is a small woody shrub (1-2 metres tall), native to Central America and distributed throughout India, Sri Lanka, West China, Southeast Asia and other tropical regions (CABI, 2022). It is now found in 41 countries or islands, including the United States (GBIF, 2024). Its ability to invade and dominate pastures and disturbed areas underscores the necessity for effective management strategies to mitigate its spread and impact.

In its native range, *S. tora* is often grown for its visual significance as an ornamental plant blossom in parks or gardens. The leaves are edible and have therapeutic applications. The seeds can also be utilised to relieve dizziness, inflammation, and headaches. In Indonesia, the Philippines and Malaysia, the plants are utilised to remove intestinal worms, and the seeds and leaves are used to treat skin diseases and as a laxative (Bhandirge et al., 2016; Akbar, 2020).

The whole plant, roots, leaves, and seeds have been widely used in traditional Indian and South Asian medicine. Young leaves can be cooked as a vegetable, and roasted seeds are used as a substitute for coffee. *Senna tora* is used as a natural pesticide in organic farms. Mixed with guar gum, it is used in mining and other industrial applications (Pawar and Lalitha, 2014). In Malaysia, *S. tora* is locally called '*gelenggang kecil*'.

However, *S. tora* is considered a major weed in numerous countries in the Pacific. In these countries, it is mainly a weed of pastures, outcompeting preferred species. In some areas, *S. tora* has completely taken over paddocks, rendering them unproductive, resulting in significant losses in production and income.

Senna tora is also toxic to cattle if ingested (Macfarlane and Shelton, 1986; CABI, 2022). For many farmers in the Pacific region, conventional control using herbicides is not feasible due to the size of the infestations and the cost of chemicals. Therefore, biological control is the only long-term sustainable means to manage this weed.

Senna obtusifolia (L.) H.S. Irwin & Barneby (Fabaceae) has been a target weed for biological control, particularly in the USA and Australia. *Alternaria cassiae* Juriar & Khan (Pleosporaceae) was formulated as a mycoherbicide and has provided greater than 96% control of *S. obtusifolia*, resulting in increased yields of soybeans (Parsons and Cuthbertson, 1992). Therefore, there might be some specific biological control agents for *S. tora* as well.

In an attempt to manage the weed in Vanuatu, a biological control programme funded by the New Zealand government undertook native range field surveys to search for potential natural enemies of *S. tora*. This paper documents the distribution of *S. tora* in Peninsular Malaysia to determine the most suitable regions for surveying potential biological agents.

Materials and Methods

Field surveys

Initially, the field surveys were conducted in five Peninsular Malaysia states: Selangor, Negeri Sembilan, Melaka, Johor and Perak. These surveys were conducted from January to December 2021. Another six states were surveyed from January to September 2022.

Three of the states, Penang, Kedah and Perlis, are located in the northern part of Peninsular Malaysia, while the other three states, Kelantan, Terengganu and Pahang, are located in the eastern part of Peninsular Malaysia.

Observations were made along the main roads and riverbanks, with an interval of 30-60 km. Farmlands, wastelands, residential lands, and agricultural lands around the survey spots were considered in the survey. The geographical coordinates were recorded using the apps MAPS and Google Earth and plotted using Google Maps.

Sample identification

Plant samples of *S. tora* were gathered as part of the survey activities. The healthiest plants, free from insect and disease damage, were chosen as samples. These selected plants were allowed to dry, then wrapped in damp tissue and placed in sample bags before being transported to the laboratory.

In the laboratory, the samples were dried at a temperature of 40°C to 50°C before being mounted on herbarium paper. The samples were then morphologically characterised as herbarium specimens.

Sampling description

In order to describe the sampling that occurred, frequency refers to the proportion of sampling units (such as plots or quadrats) in which a particular weed species occurs (Nkoa *et al*., 2015). This indicates the extent to which a weed is prevalent within a given area or population. Abundance describes the total number or biomass of weeds present in a specific area. It provides information about the overall population size of a weed species.

Abundance can be measured by counting individual plants or estimating their total biomass. It is essential for assessing the impact of weeds on ecosystems or agricultural systems. Density represents the number of individuals of a weed species per unit area. It quantifies how closely spaced the weeds are within a given plot or field.

The weed density was measured in a quadrat of 0.5 m x 0.5 m, randomly placed on the survey spots. Density was calculated as applied by Tauseef et al. (2012).

For the abundance calculation, a formula was used based on the one employed by Kilewa and Rashid (2014).

Density = total number of *S. tora* plants/total area of a quadrat (1m^2)

Frequency (%) = number of quadrats with *S. tora* x 100/total number of quadrats used at each site

Abundance = total number of *S. tora* plants in all quadrats/total number of quadrats in which *S. tora* occurred.

Statistical Tests

The difference in the mean number of *S. tora* between the locations was analysed by analysis of variance using a single factor in SAS version 9.4.

Results and Discussion

Morphological characterisation of *S. tora*

Senna tora can grow 30–150 centimetres tall. The leaves are pinnate, with leaflets mostly arranged in three opposite pairs. They are obovate in shape with a rounded tip 3.0–6.0 cm long and 1.0- 4.0 cm wide. Pale yellow flowers occur in pairs in the axils of leaves, with five petals.

The pods are somewhat flattened or four-angled, 10–25 cm long, and sickle-shaped, hence the common name “sicklepod.” Each pod contains 30–50 seeds.

Moreover, similar species to *S. tora* (Figure 1) were also found during the collection, specifically *S. obtusifolia.* Both species showed identical morphological characteristics and were difficult to distinguish; both also gave off a strong, unpleasant smell. However, they can be distinguished by the presence of two glands in *S. tora* leaves (Figure 2) and only one gland in *S. obtusifolia* (Figure 3).

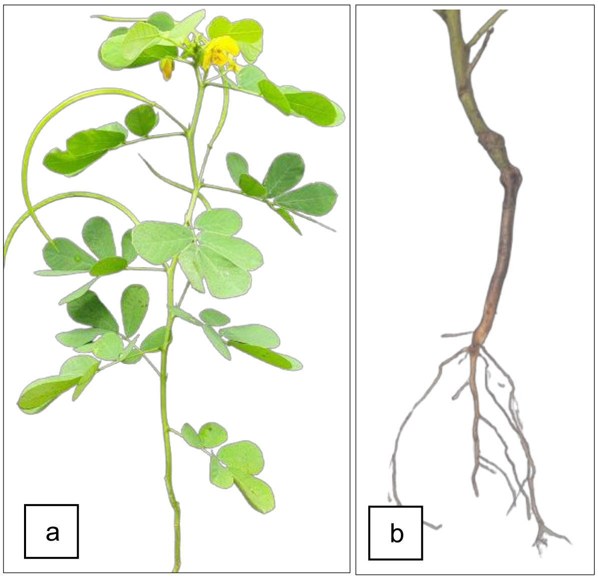

Figure 1. Morphology of *S. tora* (a) shoot system (b) root system

Figure 2. *S. tora* with two glands

Figure 3. *S. obtusifolia* with one gland

According to Takano et al. (2002), *S. tora* have flowers near the branches' terminal, while the inflorescence position in *S. obtusifolia* was at the main axils. However, there are still many disputes between these two species. Generally, any plant with similar characteristics was considered *S. tora* in this survey. Several sample collections were kept as herbarium voucher specimens for future reference (Figure 4).

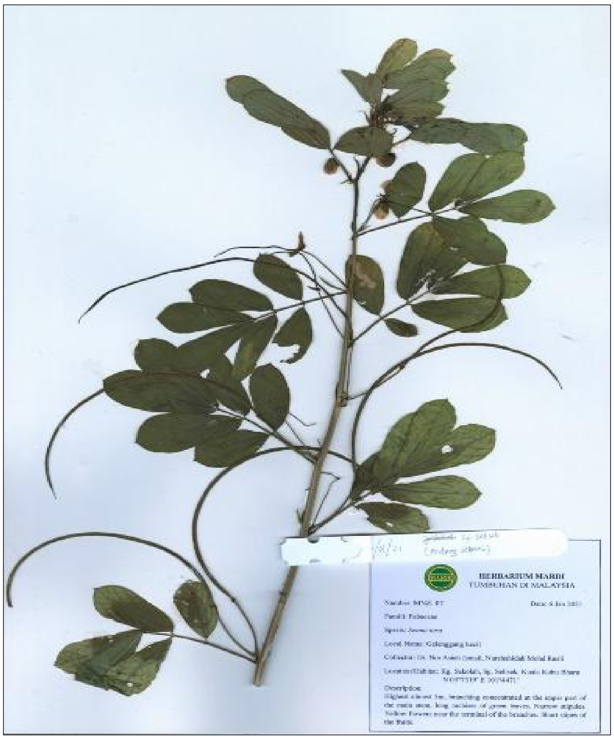

Figure 4. *S. tora* sample kept in herbarium collection at MARDI

Location and distribution of *S. tora* infestations

Senna tora was commonly found in abandoned areas, along roadsides, in agricultural areas, in residential areas, and near rivers and streams (Figure 5). *Senna tora* was often found in open, dry fields such as lemongrass cultivation plots. These environments, which lack irrigation systems, dry soil, and hot temperatures, are particularly susceptible to infestations (see Figures 5-7).

Senna tora is an annual plant and completes its life cycle within one growing season. Poppenwimer et al. (2023) suggested that annuals are favoured in hot and dry regions. Meanwhile, in paddy fields, infestations typically occur at the edges due to the presence of water in the field. If not managed, *S. tora* can aggressively take over these spaces, displacing the main crops and preferred plants.

The survey results in 11 states of Peninsular Malaysia indicated that *S. tora* was most common along the west coast areas of Peninsular Malaysia. It was found less frequently and did not grow so vigorously on the east coast of Peninsular Malaysia (see Figures 8-12).

Figure 5. *S. tora* infestations in Peninsular Malaysia: (a) near a residential area; (b) adjacent to a paddy field

Figure 6 *S. tora* infestations in Peninsular Malaysia: (c) near a lemon grass cultivation plot; (d) roadsides

Figure 7 *S. tora* infestations in Peninsular Malaysia: (a) near a stream; (b) grazing lands

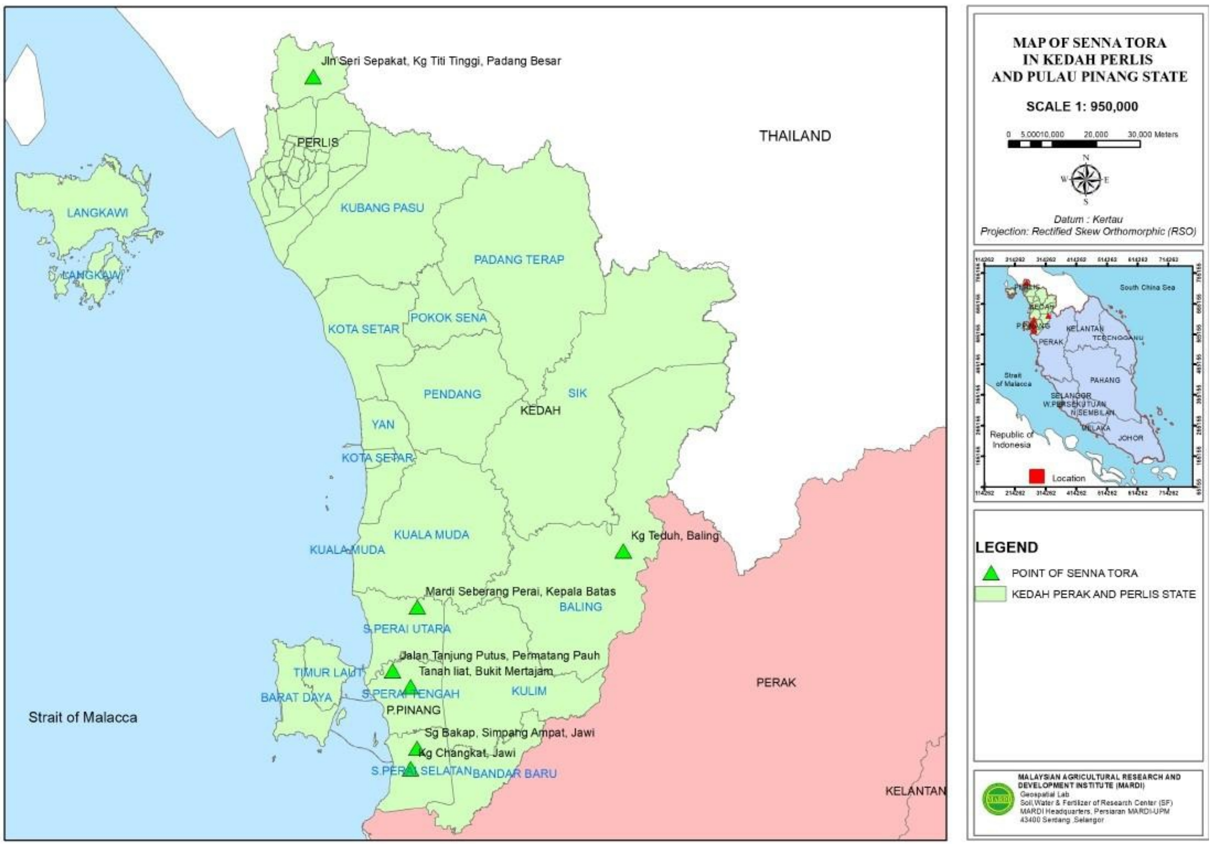

Figure 8 Distribution of *S. tora* in Peninsular Malaysia – States of Perlis, Kedah, P. Pinang

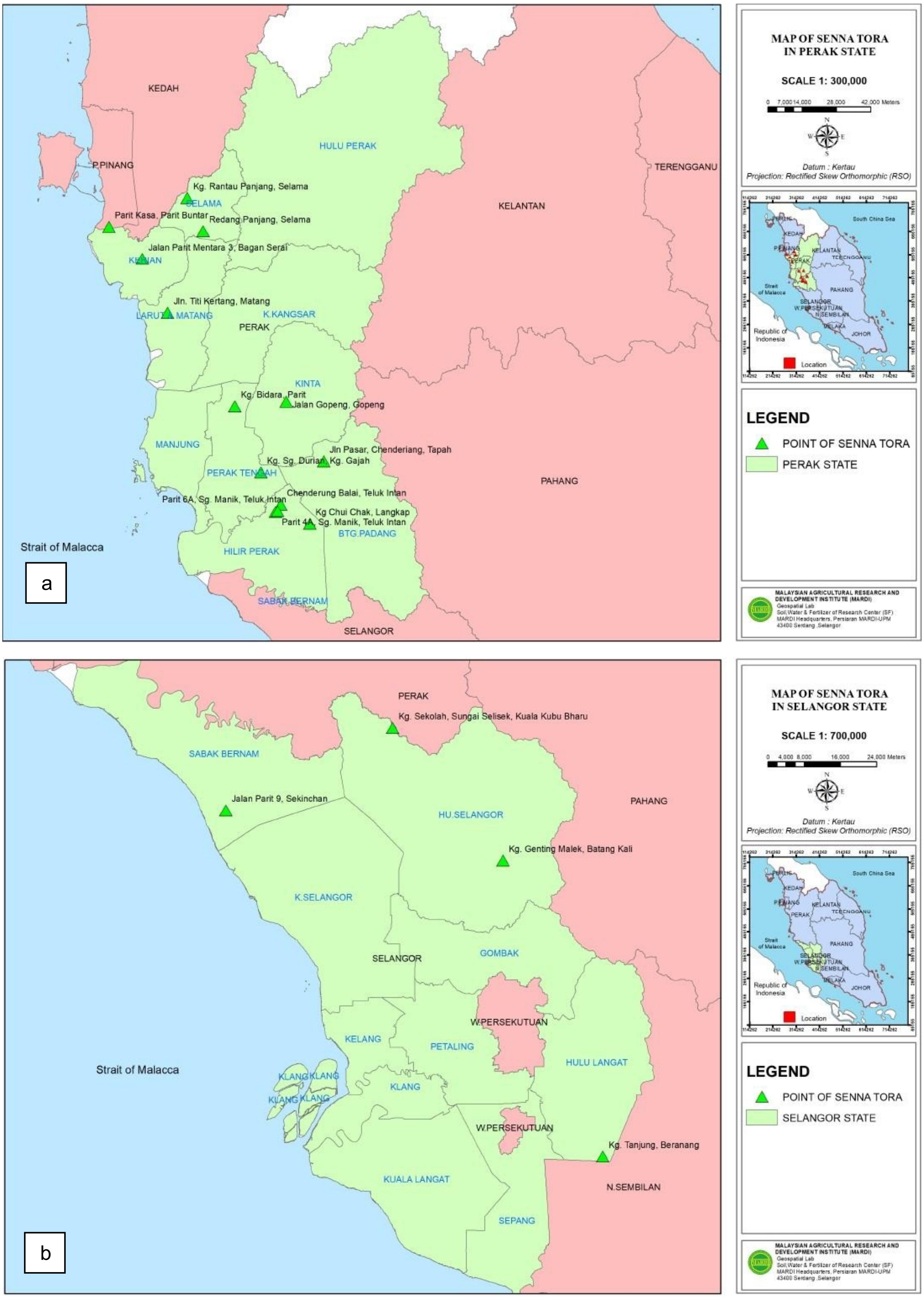

Figure 9 Distribution of *S. tora* in Peninsular Malaysia States of (a) Perak (b) Selangor

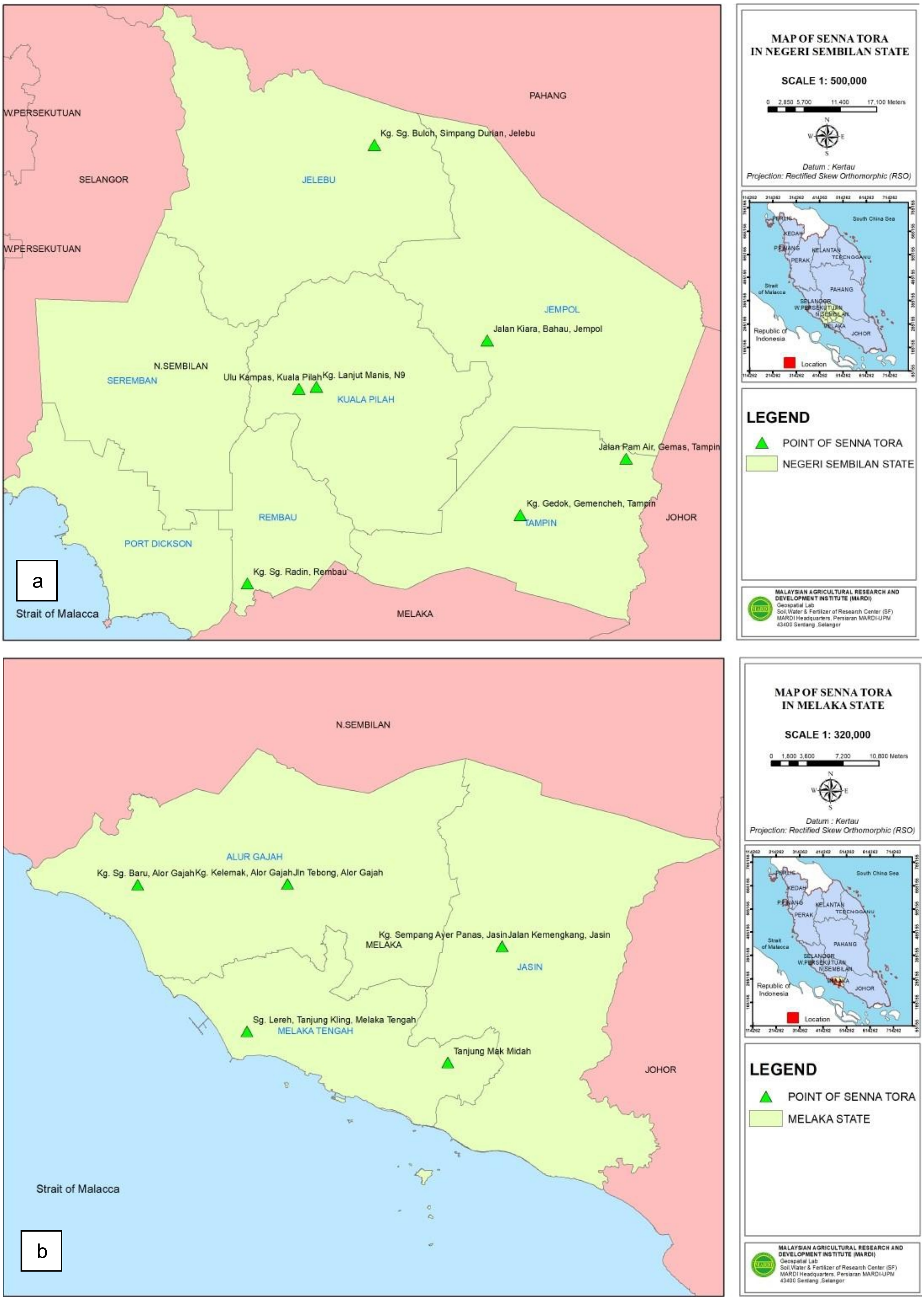

Figure 10 Distribution of *S. tora* in Peninsular Malaysia, (a) Negeri Sembilan (b) Melaka

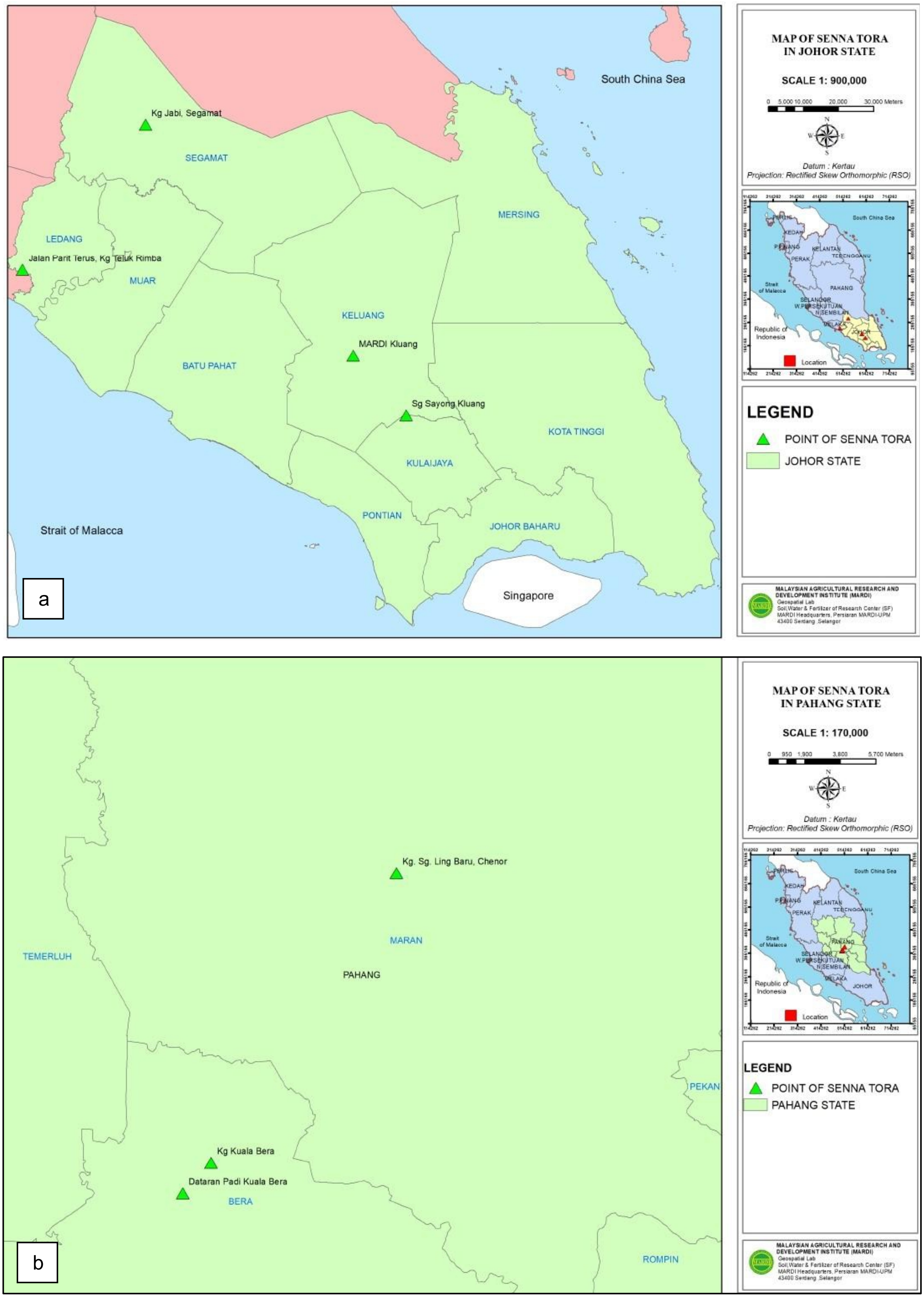

Figure 11 Distribution of *S. tora* in Peninsular Malaysia (a) Johor (b) Pahang

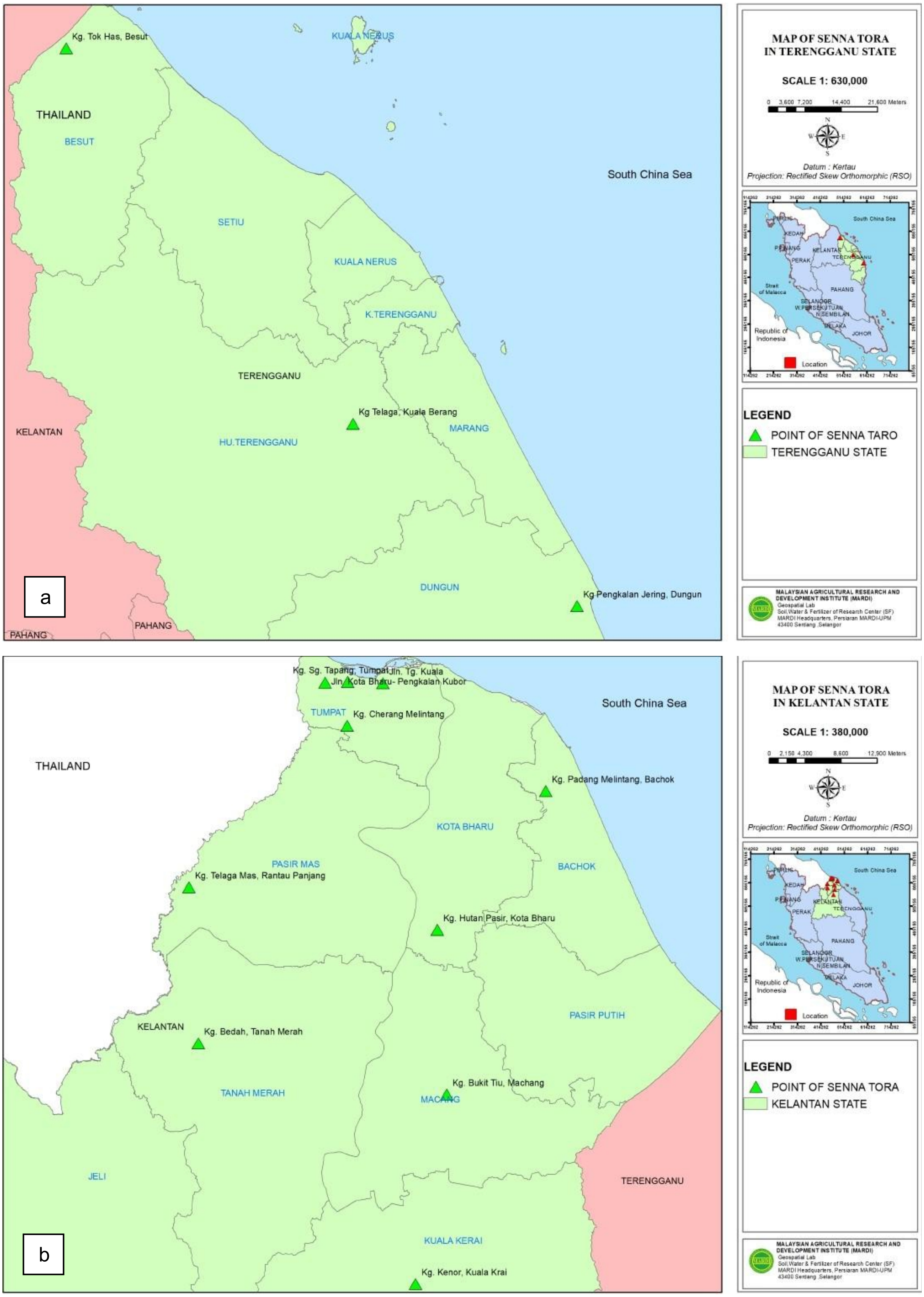

Figure 12 Distribution of *S. tora* in Peninsular Malaysia States of (a) Terengganu (b) Kelantan

Density, frequency and abundance of Senna tora at different sites

Table 1 shows the distribution of *S. tora* across nine states in Peninsular Malaysia. The states with the highest density of *S. tora* were Johor (34.0 plants/m²), Negeri Sembilan (24.7 plants/m²), Kelantan (19.6 plants/m²), Perak (18.7 plants/m²) and Pahang (13.4 plants/m²).

The highest weed frequency of *S. tora* was detected in Negeri Sembilan (73% of quadrats), followed by Johor (54%), Kedah (50%), Kelantan (50%), Melaka (42%) and Perak (42%). Johor (81.9 plants/m²) and Negeri Sembilan (61.1 plants/m^2) had the highest abundance of *S. tora.*

The variation in density suggests that certain states provide more favourable conditions for *S. tora* growth. Johor, with the highest density and second-highest frequency, likely has more suitable habitats and a large soil seed bank. Schwartz-Lazaro and Copes (2019) state the seed bank will decrease if consistent control measures are implemented. However, this weed has been observed to grow uncontrollably in the absence of intensive management. Negeri Sembilan and Pahang also offer conducive environments, supporting vigorous populations of *S. tora*. In addition, these states have different agricultural systems, with non-granary areas where active control is practised less often. In contrast, states such as Kedah, Perak, and Selangor, which have granary areas, use herbicides more frequently than other states.

Malaysia is the top user of herbicides among Southeast Asian countries (Casimero et al., 2022). However, active control is not applied in all states, which gives the opportunities for weeds to grow better in non-granary areas than in granary areas. Perlis, which is the smallest state in Peninsular Malaysia, exhibits the lowest abundance of *S. tora*.

This is possibly due to factors such as competition, herbivory, or limited resources due to the small state. Tessel et al. (2016) state that weed species may be more prevalent in larger states that offer a greater likelihood of suitable habitat, resources, and ecological variability, all of which contribute to a higher level of species diversity.

The possibility of new species colonisation is also increased by seed dispersal and species migration and is usually more widespread across larger areas. The frequency provides insights into how often *S. tora* occurs in each state. Negeri Sembilan stands out due to its frequent occurrences, suggesting widespread distribution and adaptability. Perlis lacks *S. tora* occurrences, emphasising its rarity or absence in that region.

Besides tabulating *S. tora* distribution by states of Peninsular Malaysia, Table 2 documents the distribution of *S. tora* in different regions of Peninsular Malaysia, such as the north, south, middle and east.

The highest density of *S. tora* was encountered in the east region (34.7 plants/m^2), followed by the middle region (11.7 plants/m^2) and the north region (6.7 plants/m^2).

Table 1. Average density, abundance and frequency of *S. tora* in every state in Peninsular Malaysia

State	Density (plant/m²)	Frequency (%)	Abundance (plant/m²)
Johor	34.00	54	81.90
Kedah	6.45	50	15.40
Kelantan	19.60	50	27.70
Melaka	14.50	42	21.90
N. Sembilan	24.70	73	61.10
P. Pinang	6.96	36	23.80
Pahang	13.40	39	32.40
Perak	18.70	42	20.90
Perlis	0.80	20	4.00
Selangor	5.20	30	16.00
Terengganu	2.70	30	8.50

The south region has the lowest density (5.4 plants/m^2). The eastern region had the highest abundance (42.5 plants/m^2), followed by the middle region (24.2 plants/m^2). The northern region has an abundance of 19.7 plants/m^2, and the south region has the lowest abundance (12.9 plants/m^2).

The frequencies for the north region were 40 occurrences, the east region was 70 occurrences, the south region was 37.5 occurrences, and the middle region was 47.5 occurrences. The frequencies of occurrence of *S. tora* were not significantly different among the regions. The statistical analysis only indicated that there were significant differences in density and abundance among the regions (Table 2).

Table 2. The average of *Senna tora* distribution representative state of the region in Peninsular Malaysia

Region	Density (plant/m^2)	Frequency (%)	Abundance (plant/m^2)
Northern	6.70 b	40 a	19.73 b
Eastern	34.7 a	70 a	42.53 a
Southern	5.4b	37.5 a	12.9 b
Middle	11.7 b	47.5 a	24.18 ab

Means with the same letter are not significantly different at $P \geq 0.05$ with the LSD test.

The distribution of *S. tora* can be influenced by several factors. First are the ecological preferences such as specific habitats, i.e. well-drained soils, open areas, or disturbed sites. Soil pH, moisture levels, and light availability might also play a role in its distribution.

Efficient seed dispersal allows *S. tora* to colonise new areas. Wind, water, and animals aid in spreading seeds. The pods can throw seeds up to 5 m as they open. Seeds can be carried by streams, overland flow and in mud attached to the feet and fur of animals. They also move in contaminated mulch and mud on machinery, vehicles and footwear. Although the species is generally unpalatable, livestock nibble on the pods and seeds will pass through the animals and disperse when the animals are moved about (Mohler et al., 2021).

Conclusions

The findings of this study show that the states in Peninsular Malaysia with the highest densities of *S. tora* are Johor, Negeri Sembilan, and Pahang. *Senna tora* is primarily found in abandoned fields, roadsides, agricultural lands, and near water sources, usually thriving in disturbed environments.

Therefore, surveys to find potential biological control agents for Vanuatu and other countries in the Pacific region should first be conducted in these states. Indeed, preliminary surveys have found numerous lepidopterous larvae, leaf-feeding beetles and a pathogen. These are yet to be formally identified.

The high density and frequency of *S. tora* in some regions of Peninsula Malaysia emphasise the potential threat the weed poses to agricultural productivity, biodiversity, and pasturelands in this country, too. Given the rapid spread and adaptability of *S. tora*, further investigations into understanding the socio-economic impact of *S. tora* on local farming communities are warranted so that sustainable management strategies for the weed can be developed.

The presence of natural enemies, such as pathogens and herbivorous insects, suggests potential for biological control efforts. Further efforts should focus on identifying effective biological control agents, assessing their feasibility, and integrating them into weed management programs.

The knowledge gained from this study serves as a foundation for future research and policy recommendations. Effective control measures, including monitoring and integrated weed management approaches, are crucial to mitigate the spread of *S. tora* and minimise its impact on agriculture and the environment in Malaysia and other countries where *S. tora* is considered a significant problem.

Acknowledgements

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Taxonomy of *Echinochloa* (L.) P. Beauv (barnyard grass) in the Asian-Pacific Region: An Update

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Editor's Note:

The article on barnyard grasses (*Echinochloa* P. Beauv. spp.) republished below was one of the first to be received and published by the APWSS Journal **WEEDS** (2019, Volume 1, Issue 1, pp. 30-42).

It is republished in honour of Peter Michael, for the benefit of new APWSS members and other weed scientists for their appreciation. I have added a few additional notes and photographs of *Echinochloa* specimens that Peter Michael named that were sent to me by the Kew Herbarium.

Our weed science community would be interested to learn that Peter Michael's interest in *Echinochloa* spp. began with the first APWSS Conference in 1967 as he has stated in the article..

Peter Michael's findings on *Echinochloa* species across the world have been well captured by the updated *Kew Plant List – Plants Of The World Online database* (**https://powo.science.kew.org/taxon/urn:lsid:ipni.org:names:17976-1**) and also by *The Atlas of Living Australia Online database* (**https://bie.ala.org.au/search?q=Echinochloa&fq=&dir=&sortField=&rows=&offset=20&max=10**).

The rhizomatous perennial, native to Papua New Guinea and North and North-East Australia, *Echinochloa praestans*, which P. W. Michael had described in *Telopea* 2:31 (1980) had earlier been relegated as a synonym of *E. polystachya*. However, *E. praestans* has now been accepted as a different species and the naming authority credited to Peter Michael (**https://powo.science.kew.org/taxon/urn:lsid:ipni.org:names:399726-1**).

Abstract

This paper provides a revised key to the identification of taxa of *Echinochloa* in the Asian-Pacific region, the result of many years' study of this important weedy genus, with an emphasis on the importance of association with the Asian-Pacific Weed Science Society. Descriptions of two new Indian species are included.

Key words: *Echinochloa*, barnyard grass, Asian-Pacific grasses, *E. mentiens, E. trullata*

Introduction

The inauguration of the Asian-Pacific Weed Science Society (APWSS) at the Asian-Pacific Weed Control Interchange in 1967 coincided with the beginning of my serious interest in the taxonomy of *Echinochloa*. After a year in Japan in 1965 on a technical scholarship at the National Institute of Agricultural Sciences in Tokyo, where I learnt much about one form of *Echinochloa* now known as *E. oryzicola* (*tainubie* in Japan), I was keen to find out whether it occurred in Australia. This led me into a field of surprises.

Contrary to the belief held by grass botanists in Australia that all of our barnyard grasses were exotic, Australia did have a number of native species, as Dr Joyce Vickery—distinguished grass taxonomist of the National Herbarium of New South Wales (NSW)—and I found in our detailed studies of

Australian and exotic collections. Only one of these had been noted as a weed in rice.

In my annual report for 1966, in dealing with my studies on *Echinochloa*, I drew attention to the confused state of the taxonomy of the genus, noting that I was "…*in the process of trying to elucidate (with the help of plants grown from seed) some of the problems involved*…," which I expected would "…*take some time in view of a number of difficulties, not the least being the relative inaccessibility of the relevant literature*…"

In those days I was working in the Ecology Section of the Division of Plant Industry at the Commonwealth and Scientific Research Organisation (CSIRO) in Canberra, ACT, where I was encouraged in my work by the staff of the Herbarium, now included in the Australian National Herbarium (CANB). On my moving to the Faculty of Agriculture at the University of Sydney in 1969, I was able to continue my work in closer association with Dr. Vickery.

My first association with the APWSS was at the Fourth Conference held in 1973 at Rotorua, New Zealand, where I presented a paper, my first on *Echinochloa* in the Asian-Pacific region, and again met Japanese delegates, who I had first been introduced to in 1965 in Japan. Since then I have received help and suggestions from various members of the Society and from others in the countries it represents. Attending APWSS conferences has enabled me to collect *Echinochloa* in New Zealand, Japan, the Philippines, and India.

Visits to herbaria in these countries as well as in St Petersburg (Leningrad), Europe and the United States have been of great benefit. Special collecting trips in the Philippines, Indonesia and Burma (Myanmar) have given me a good appreciation of the distribution and variation of the species. I must acknowledge, too, the great support I have had in Australia, especially in relation to travelling costs.

The main purpose of this paper is to describe two new annual species of *Echinochloa*, collected originally from India, and to also present a revised key to *Echinochloa* in the Asian-Pacific region.

My first key (Michael, 1983) was the first attempt to put the world members of the genus in proper focus; the second key (Michael, 1994) included only *Echinochloa* in China; and the third key (Michael, 2001), here revised, include species and varieties in the Asian-Pacific region. It is important for readers to absorb the contents of the notes in these three attempts as background to my new key. In this paper I have provided additional comments on only a few taxa. My recent publications on *Echinochloa* have included an account of the genus in North America north of Mexico (Michael, 2003) and in Australia (Simon et al. 2009).

A great inspiration has been the revised edition of studies on the natural history of *Echinochloa* (Yabuno and Yamaguchi, 2001). It would be good to have an English translation of this thoroughly satisfying book. Additional useful contributions to the taxonomy of *Echinochloa* are to be found in K-U Kim and Labrada (2003).

Two new annual species of *Echinochloa* from India

In the following two descriptions, I have used codes for the various herbaria mentioned. They are:

BM	The Natural History Museum, London, UK
K	Royal Botanic Gardens, Kew, UK
MO	Missouri Botanic Gardens, St. Louis, Missouri, USA
NSW	Royal Botanic Gardens & Domain Trust, Sydney, New South Wales, Australia
P	Museum National d'Histoire Naturelle, Paris, France
US	Smithsonian Institution, District of Columbia, Washington, USA

I am most grateful for the opportunities to visit these and other herbaria throughout the world. Without their help, my work on *Echinochloa* would have been impossible. The acronym KFP in the first description means the Karnataka Flora Project.

1. *Echinochloa mentiens* P.W. Michael

Description:

Annual grass of rice-fields, mimicking rice. Culms close, erect to 1.3 m tall with lower portions up to 10 mm thick. Leaf blades erect, strongly scabrid. Ligules sparingly, finely pubescent. Panicles narrow, linear with branches (racemes) appressed to the primary axis, up to 2.5 mm long and 7 mm wide with the internodes scarcely longer. The nodes of the primary axis of the panicles and the whole length of the branch rhachises bear numerous bristles (setae).

Spikelets are in pairs, congested from the base of the branches, often appearing to be in regular rows, ovate, rigidly cuspidate, around 3.5 mm long. Lower glume reaches to be about half the length of the spikelet. Mature caryopses brownish, 2.0-2.3 mm long. An image of the holotype, from the Kew herbarium catalogue, is reproduced in **Figure 1**.

Diagnosis:

Similar to *E. colona* (L.) Link but with more robust habit, racemes of the panicles broader and with abundant bristles, spikelets bigger and the mature caryopses brownish, not whitish. The quite common form of *E. colona* in wetland rice (Michael, 2001) with spikelets around 2.5 mm long and whitish caryopses is much less robust than *E. mentiens*. *Echinochloa frumentacea* Link differs from *E. mentiens* in its panicles with spreading, curved racemes, often nodding at maturity. Spikelets are more swollen, and caryopses are whitish. **Figure 2** provides images that can be compared.

Holotype:

(see Figure 1). India, Karnataka, Hassan District, Maranahalli, 15 km from Sakleshpur, on main road from Hassan to Mangalore. In rice-field, standing above the level of mature paddy. C. J. Saldanha, P. W. Michael and S. R. Ramesh. KFP 14236, 30 Nov 1981 (K); Image ID – K000245284.

Isotypes:

St. Joseph's College Herbarium, Bangalore, India; NSW, Australia.

The specific epithet '*mentiens*' implies both imitation and deception and is considered appropriate to describe a plant that *mimics* rice so closely. Other rice mimics in the genus *Echinochloa* include *E. crus-galli* (L.) Beauv. var. *formosensis* Ohwi (syn. *E. glabrescens* Munro ex Hook f.) and the two, often misunderstood, taxa, *E. crus-galli* (L.) Beauv. var. *oryzoides* (Ard.) Lindm. [(syn. *E. oryzoides* (Ard.) Fritsch and *E. phyllopogon* (Stapf) Koss)] and *E. oryzicola* (Vasing.) Vasing.

Distribution and other Specimens:

Known only from India. North-West India ex Herb. Ind. Or. Hook.fil. & Thomson, originally labelled *Oplismenus frumentaceus*, collected by T. Thomson, without precise location or date (P) but quite likely to have been collected in 1842-1847 (Hooker and Thomson, 1855).

Central India, Madhya Pradesh, Gwalior, ex BM, C. Maries, 1 Oct. 1890 (NSW)

South India, Karnataka, near Mangalore. Plants were collected by J. F. Metz (1819-1886) in 1853, named as *Oplismenus colonus* Kunth var. *pseudocolonus* ejusd. by C. F. F. Hochstetter (1787-1860) and distributed by R. F. Hohenacker (1819-1886). The publication of this new name has been long delayed because of doubts about the name *Panicum pseudocolonus* Roth, which had been applied by Hochstetter under the derived name *Oplismenus colonus* Kunth var. *pseudocolonus* ejusd [1].

The type of Roth's species was based on a collection of Benjamin Heyne (1770-1819), now believed to be lost (unpublished note by J. F. Veldkamp, 2003). Roth's brief diagnosis is insufficient to separate it from the somewhat bristly forms of *E. colona* commonly occurring in the tropics. Nor did Roth (1821) refer to the large spikelets, thus pointing along with other distinguishing features to the new species, *E. mentiens*, described here.

Specimens have been seen in P (Herb. Steudel, Herb. E. Drake del Castillo and Herb. Mus. P.). These specimens prompted me to ask Fr. C. J. Saldanha of St. Joseph's College, Bangalore, for help in a search for the plants fitting those old specimens. It was due to his great kindness that we were able to rediscover the plants in 1981.

Hohenacker's distributed specimens have also been seen in K and BM, along with specimens of *E. colona* collected in the same region. Additional specimens from the location of the holotype – KFP 14237 - are to be found in St. Joseph's College Herbarium and NSW.

Echinochloa mentiens may have been introduced to Louisiana, USA. with rice. A photograph that appears to be of this plant, referred to as a variety of *E. crus-galli* and given the common name 'Baronet grass' was presented by Robert E. Williams in 1956, in '*The Rice Journal*' (see **Figure 3**). Unfortunately, I have not been able to locate the authentic specimens of the original plants discovered on the farm of Mr. Jules Baronet, in about 1920.

It is highly probable that *E. mentiens* has been derived at least in part from the very variable *E. colona* (L.) Link as a response to the hand-weeding of rice throughout its long period of cultivation in India. A form of *E. colona*, showing appressed panicle branches, with unusually setose rhachises, has been collected from Karnataka (Herbarium of St. Joseph's College, Bangalore, Hassan District, Arsikere – C. J. Saldanha 13746, 10 June 1969; Mysore District, Virajpet – S. R. Ramesh and P. Prakash, KFP 3119, 9 Oct 1978).

This form has also been collected as a rice-weed from Louisiana (south of Crowley, C. E. Chambliss July 1930 (US); Plants of Louisiana, St. Mary Parish, D. S & H. B. Corell 9432, 3 July 1938 (MO); Crowley

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[1] **<u>Editor's Note</u>**: *Ejusdem generis* is a Latin phrase used also in scientific names of plants and animals to mean "**of the same kind**."

Research Station, B. Cox, 23 Aug 1984 (NSW) – see **Figure 3**).

These plants are called 'Baronet grass' (*pers. comm*. J. B. Baker, 1989), suggesting that both *E. mentiens* and its supposed progenitors may have been introduced together to rice fields in Louisiana. Further investigations are needed to find the current distribution of *E. mentiens* in India and, perhaps, to locate specimens, old or new, from Louisiana.

2. *Echinochloa trullata* P.W. Michael

Description:

Robust, tufted, annual to 150 mm tall, geniculate or horizontal at the base and rooting from lower nodes, becoming erect. Leaf sheaths glabrous, ligular area smooth, occasionally with tubercle-based bristles at the margins of blade or sheath. Leaf blades up to 45 cm long and 1.0 cm wide.

Panicles stiffly erect at length, exserted, 8.5 to 17 cm long, rarely longer, no greater in width than one quarter to one fifth of their length and narrower than the length of the longest raceme; the greatest width is at the tips of the lower one to four racemes, gradually narrowing upwards becoming ovate-triangular in outline (trullate or trowel-shaped).

Racemes densely crowded with elliptical-ovate to ovate spikelets 2.5 to 3.5 mm long and 1.5 to 2.0 mm wide, often borne at right angles to racemes when mature. Glumes evenly rounded or truncate above the 1 to 2 mm long stipe-like base. Lower glume acute, one third to one half the length of the spikelet. Spikelets awnless (or rarely short-awned), falling very readily at maturity.

Caryopses ovate to broadly ovate, 1.5 to 2.0 mm long and 1.2 to 1.5 mm wide, pale golden brown. Embryo two thirds the length of the caryopses. An image of the holotype, from the Kew herbarium catalogue, is reproduced in **Figure 4**.

Diagnosis:

Similar to *E. crus-galli* (L.) Beauv. var. *crus-galli*, but the panicle, rarely exceeding 17 cm, always stiffly erect, ovate-triangular, no greater in width than one quarter or one fifth of its length and narrower than the length of the longest raceme, with greatest width at the tips of the lower one to four racemes. Spikelets mostly awnless, 2.5 to 3.5 mm long, falling very readily at maturity. Lower glume one third to one half length of the spikelet.

Holotype:

India, Manipur State, Tetland Bay, Imphal. A. A. Bullock 748, 27 Oct. 1945. Scrub Typhus Research Herbarium, Sheet 1 of 2 (K); Damp grassland. Not very common. Tufted grass, culm at first horizontal, becoming erect. An image is available at K of the isotype (sheet 2 of 2) (ID K – 000245285).

Distribution and other Specimens:

India, Assam, ex Herb. Hort. Bot. Calcuttensis W. Griffiths (1810-1845), no precise locality or date (P).

India, Manipur State, Dehra Dun, N. L. Bor 17188, 2 Nov 1942. A grass in the political agent's (PA's) garden, alt. 610 m (K).

India, Manipur State, Kanglatongbi, A. A. Bullock 657, 7 Oct 1945, alt. 910 m. Common in oak scrub (K).

Pakistan, Rawalpindi, A. Rahman 24852, May 1950. By stream alt. 510 m.

Fiji, Koronivia Research Station, Naitasiri D. Kooriveibau L18247, 8 June 1971. In rice field, common in wet land (NSW).

Australia, New South Wales, Camden glasshouse, grown from seed from Fiji, P. W. Michael, 6 Feb 1973 (NSW).

Indonesia, Sumatra, Lampung Utara, Sumberjaya, P. W. Michael 6681, 5 April 1981. Coffee plantation in water (NSW).

Myanmar, Maymyo, P. W. Michael 25, 28 Oct 1982. Annual in upland rice field, alt. 1050 m (NSW).

This species is poorly known and requires further investigation. It is clear, however, that its home is the Indian sub-continent and it would be surprising if it were not found to be widespread. The occurrences in Sumatra and Fiji are most likely explained by the migration of Indian peoples.

Dr. Joyce Vickery and I recognized this plant as an unusual *Echinochloa* among specimens from Kew, which we called the "Assam form". During the APWSS Conference at Hyderabad in 2015, Dr. Iswar Barua, from the Assam Agricultural University, India, showed me specimens that reminded me of the "Assam form".

Dr. Hirohiko Morita (*pers. comm*., Morita, 2018), from Japan, has recently recognized it as a distinct form. These, in turn, have encourage me to describe it as a new species.

Figure 1 An image of the holotype *Echinochloa mentiens* P. W. Michael from the Herbarium catalogue at Kew (url: http://apps.kew.org/herbcat/getImage.do?imageBarcode=K000245284)

A fragment of *Echinochloa mentiens* P. W. Michael from the type collection

Oplismenus frumentaceus (Roxb.) Link *

Echinochloa frumentacea Link **

Figure 2 The new species - *Echinochloa mentiens* compared with old herbarium specimens of *E. frumentacea*

* Image from Muséum National d'Histoire Naturelle, Paris (France) (url: https://science.mnhn.fr/institution/mnhn/collection/p/item/p02722638)

** Image from the Herbarium catalogue at Kew (url: http://www.kew.org/herbcatimg/632497.jpg)


Figure 3 (Left) a scanned image of Baronet grass from Williams (1956); (Right) an image of a fragment of *E. colona* (L.) Link, called Baronet grass, collected by B. Cox at Crowley Research Station, Louisiana, 23 Aug 1984 (NSW)

List of Echinochloa taxa in the Asian-Pacific region

Given below is an updated list of the *Echinochloa* taxa in the Asian-Pacific region, based on my studies and reviews. A revised key to the species is also provided overleaf.

World Tropics

E. colona (L.) Link

Eurasia

E. crus-galli (L.) Beauv. var. *crus-galli*

Asia (South-East Asia, Indonesia, New Guinea and adjacent islands)

E. caudata Roshev.

E. crus-galli (L.) Beauv. var. *praticola* Ohwi.

E. crus-galli (L.) Beauv. var. *hispidula* (Retz.) Honda

E. crus-galli (L.) Beauv. var. *austro-japonensis* Ohwi

E .crus-galli (L.) Beauv. var. *formosensis* Ohwi

E. crus-galli (L.) Beauv. var. *persistens* Diao

E. crus-galli (L.) Beauv. var. *oryzoides* (Ard.) Lindm.

E. esculenta (A.Br.) Scholz

E. frumentacea Link

E. mentiens P.W. Michael [2]

E. oryzicola (Vasing.) Vasing

E. picta (Koen.) P.W. Michael

E. stagnina (Retz.) Beauv.

E. trullata P.W. Michael

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[2] **Editor's Note:** The taxonomic position of the two new species Peter Michael named in this article: *E. mentiens* and *E. trullata* are yet to be examined and resolved by *The Kew Plant List*. I have now registered these two species for consideration by the *International Plant Names Index* (IPNI: https://ipni.org/registration/). The species names will now appear in all other databases and resolved at a future date.

Figure 4 An image of the holotype *Echinochloa trullata* P. W. Michael specimen from the Herbarium catalogue at Kew (url: http://apps.kew.org/herbcat/getImage.do?imageBarcode=K000245285)

Australia

- *E. dietrichiana* P.W. Michael
- *E. elliptica* P.W. Michael et Vickery
- *E. inundata* P.W. Michael et Vickery
- *E. macrandra* P.W. Michael et Vickery
- *E. kimberleyensis* P.W. Michael et Vickery
- *E. lacunaria* (F. Muell.) P.W. Michael et Vickery
- *E. telmatophila* P.W. Michael et Vickery
- *E. turneriana* (Domin.) J.M. Black

Africa

- *E. pyramidalis* (Lam.) Hitchc. et Chase

North America

- *E. muricata* (Beauv.) Fernald var. *microstachya* Wiegand

South America

- *E. crus-pavonis* (Kunth) Schult.
- *E. polystachya* (Kunth) Hitchc.

Revised key to *Echinochloa* in the Asian-Pacific region

NB. Spikelet length measurements do not include awns

A. Annuals

1.	Spikelets 3-5 mm long.	2.
1.	Spikelets less than 3 mm or greater than 5 mm long.	18.
2.	Ligule a line of bristles or fine short cilia.	3.
2.	Ligule absent, or the ligular regions bearing a few cilia or fine pubescence.	4.
3.	Numerous long bristles at nodes of inflorescence. Panicle spindle-shaped, up to 15 cm long. Spikelets narrowly elliptical. Awns of lower lemma up to 30 mm long, of second glume up to 10 mm long.	*E. elliptica*
3.	No long bristles along main axis or branches of panicle. Panicle narrow, linear. Spikelets broadly ovate or ovate-elliptical.	*E. turneriana*
4.	Spikelets broadly ovate, crowded along the often incurved branches of the inflorescence. Fertile florets and caryopses markedly humped, so that the second glume often appears to be shorter than the spikelet. Mature fertile florets not easily deciduous.	5.
4.	Fertile floret and caryopses not markedly humped.	6.
5.	Spikelets brownish at maturity. Commonly awnless, sometimes awned. Caryopses brownish.	*E. esculenta*
5.	Spikelets pale green at maturity, awnless. Caryopses whitish.	*E. frumentacea*
6.	Essentially obligate weeds of rice or crop plants in rice fields. Close tufted erect habit. Greatly resemble rice before flowering.	7.
6.	Not obligate weeds of rice, but all growing in wet places and often occurring in rice. Plants more or less spreading at base.	11.
7.	Panicle narrowly linear with alternate branches up to 25 mm long pressed closely to the primary axis. Spikelets around 3.5 mm long, caryopses 2–2.3 mm long, brownish.	*E. mentiens*
7.	Panicles erect or nodding, branches not pressed closely to the primary axis.	8.
8.	Spikelets 3–4 mm long.	9.
8.	Spikelets 3.5–5 mm long.	10.
9.	Spikelets 3–3.5 mm long. Lower lemma convex, hard and shiny. Awnless or less often awned, occasionally found on banks and fallow land.	*E. crus-galli* var. *formosensis*
9.	Spikelets 3–4 mm long, persistent, lower glume 0.22 length of spikelet. Leaf sheaths glabrous.	*E. crus-galli* var. *persistens*

10.	Spikelets broadly ovate to ovate. Inflorescence hanging almost horizontal at maturity. Spikelets nearly always awned. Awns sometimes as long as 50 mm. Lower glume 0.33–0.5 the length of spikelet. Collar region of leaves rarely with tufts of hairs. Caryopses ovate, embryo 0.7–0.8 the length of the caryopsis.	*E. crus-galli* var. *oryzoides*
10.	Spikelets ovate-elliptical. Inflorescence more or less erect at maturity. Spikelets awned or awnless. Lower glume 0.5–0.66 length of spikelet. Lower lemma often convex, hard, and shiny. Collar of leaves often with tufts of hairs. Caryopses oblong, embryo often 0.9 or more the length of the caryopses.	*E. oryzicola*
11.	Lemma and palea of fertile floret acute or acuminate with stiff tip. Panicle spreading, erect. Caryopses yellowish. Spikelets 3–3.5 mm.	*E. muricata* var. *microstachya*
11.	Lemma of fertile floret with withering tip sharply differentiated from the body of the lemma.	12.
12.	Panicle erect, ovate-triangular. Spikelets 2.5–3.5 mm long, crowded, mostly awnless, falling very readily at maturity.	*E. trullata*
12.	Panicle erect or nodding. Spikelets short- or long-awned, sometimes apparently awnless but, if so, there are always a few awned at the ends of the racemes.	13.
13.	Inflorescence strongly drooping at maturity, sometimes bending over as much as 180 degrees. Spikelets crowded with short, curved awns, mostly 3–10 mm long, but can be up to 15 mm long.	*E. crus-pavonis*
13.	Inflorescence often nodding but not strongly drooping at maturity.	14.
14.	Spikelets narrowly elliptical, up to 4.2 mm long. Awns of lower lemma up to 40 mm long. Awn on the second glume up to 7 mm long or longer. Bristles on spikelets not spreading. Leaf sheaths glabrous.	*E. telmatophila*
14.	Spikelets broadly ovate to elliptical, never narrowly elliptical, almost awnless, short- or long-awned.	15.
15.	Spikelets ovate or ovate-elliptical up to 5 mm long. Panicle linear, anthers 1 mm or more long.	16.
15.	Spikelets broadly ovate, ovate, or ovate-elliptical, 3–4 mm long. Long bristles abundant along main axis and branches of panicle. Panicles various, often pyramidal. Anthers generally less than 1 mm long.	17.
16.	Spikelets ovate, uniformly 3 mm with strongly spreading bristles up to 1 mm long. Long bristles prominent at point of attachment of racemes and along main axis. Panicles not becoming purplish.	*E. dietrichiana*
16.	Spikelets 3.5–5 mm long, with few or no bristles on main axis and/or branches of panicle.	*E. inundata*
17.	Spikelets broadly ovate or ovate. Awnless except at the ends of branches, short-awned or long-awned. Lower lemma flat, occasionally convex and shiny. Caryopses ovate. Panicles of variable length, more or less erect, often pyramidal, sometimes nodding, branches never obviously whorled. Long panicles, often with secondary branches on lower primary ones.	*E. crus-galli* var. *crus-galli*
17.	Spikelets ovate-elliptical, short or long awns. Caryopses more or less oblong. Panicles rarely pyramidal, erect or nodding, branches often whorled, more or less erect except for the lowermost ones.	*E. crus-galli* var. *hispidula*
18.	Spikelets 5 mm long or longer.	19.
18.	Spikelets 3 mm long or shorter.	22.
19.	Spikelets with awns up to 90 mm long. Anthers more than 1.5 mm long. Ligule a line of bristles or cilia.	20.
19.	Spikelets awnless or awned. Ligule absent, rarely a line of short cilia.	21.
20.	Anthers 1.5–2 mm long. Palea of lower floret about half the length of the lemma, sometimes absent. Lower floret neuter.	*E. kimberleyensis*
20.	Anthers 2–2.8 mm long. Palea of lower floret about length of lemma. Lower floret staminate.	*E. macrandra*

21.	Spikelets awnless, ovate, very finely pubescent. Main axis and short branches of inflorescence without bristles.	*E. lacunaria*
21.	Spikelets awned, ovate. Panicles hanging more or less horizontally at maturity. Awns up to 50 mm long. Obligate weed of rice.	*E. crus-galli* var. *oryzoides*
22.	Palea of lower floret absent of poorly developed. Spikelets dense, 1 mm broad, with awns up to 45 mm long. Panicles up to 20 cm long.	*E. caudata*
22.	Palea of lower floret fully developed.	23.
23.	Spikelets broadly ovate to ovate, awnless with panicle not more than about 15 cm long.	24.
23.	Spikelets ovate-elliptical to elliptical, usually with short awns. Inflorescence close, short with more or less erect branches.	*E. crus-galli* var. *austro-japonensis*
24.	Spikelets regularly arranged in rows. First glume regularly half the length of the spikelet. Caryopses whitish. Long bristles mostly absent from main axis and branches of inflorescence, occasionally a few scattered along the branches and clustered at the nodes.	*E. colona*
24.	Spikelets irregularly arranged. First glume about 0.33 length of spikelet. Caryopses brownish. Long bristles along main axis and branches of inflorescence present or absent.	*E. crus-galli* var. *praticola*

B. Perennials

All species have spikelets 3 mm or more long. Ligular bristles are always present and obvious, especially in the lower leaves. The lower floret is often staminate. Plants may have long creeping rhizomes and/or stolons and spongy floating stems. Sometimes the rhizomes are much shortened and thickened.

1.	Spikelets awnless or with short awns or long cusps. Spikelets crowded, very finely pubescent or for the most part glabrous, with short bristles and short awns or long cusps. Inflorescence often more than 40 cm long. Secondary branches often closely appressed to primary branches of inflorescence. Plant often up to 4 m tall with stout culms.	*E. pyramidalis*
1.	Spikelets awned, awns often long.	2.
2.	Spikelets elliptical or lanceolate, up to 5 mm long with bristles up to 1 mm long and with long, narrow lower glumes. Floating, often with long culms.	*E. stagnina*
2.	Spikelets awned, 3–4 mm long.	3.
3.	Spikelets lanceolate, 3.5–4 mm long, finely pubescent. Awns up to 15 mm long. Racemes up to 90 mm long. Culms stout, up to 3.6 m tall. Leaves up to 20 mm or more broad. Nodes and leaf sheaths glabrous. Ligular bristles obvious on all leaves.	*E. polystachya*
3.	Spikelets broadly ovate, 3–4 mm long with bristles 0.5 mm long. Awns up to 18 mm long, whitish. Panicles sometimes one-sided. Racemes 20–50 mm long. Culms generally less than 1 m. Leave often with transverse purplish bands. Ligular bristles often not on upper leaves.	*E. picta*

Notes on selected taxa

E. crus-galli var. *formosensis*

Echinochloa crus-galli var. *formosensis* is often referred to as *E. glabrescens* Munro ex Hook. f.

E. crus-galli var. *hispidula*

I believe that this is the appropriate name to use for *E. crus-galli* with non-pyramidal panicles, ovate-elliptical spikelets, usually prominently awned, common in sub-tropical areas and extending to Japan and southern China. There has been disagreement about the nature of *Panicum hispidulum* Retz., on which the name *E. crus-galli* var. *hispidula* is based. Ohwi (1962), who showed a picture of the Retzius specimen collected in India, believed it did not fit features of *tainubie* (now known as *E. oryzicola*).

The density of its spikelets, short inflorescence branches and the long fine awns can be fitted easily to occasional specimens from wet places in Japan.

E. crus-galli var. *persistens*

This was originally described by Diao (1988) as *E. persistentia* and later as *E. crus-galli* var. *persistentia* Diao (1990). Its very short lower glume is unusual in *Echinochloa*.

E. picta

Yamaguchi (2007), in his treatment of a hidden variety of barnyard grass (*E. crus-galli* var. *riukiuensis* Ohwi), provided a photograph (see below, **Figure 5**) showing plants with distant racemes, whitish awns and one-sided panicles, which made me think immediately of *E. picta.* It would not surprise me to find *E. picta* in the far southern Ryukyu Islands. I have collected it in the far north of Luzon in the Philippines.

E. polystachya

My *E. praestans* has been relegated to a synonym of *E. polystachya* (Simon et al., 2009). I had previously followed South American treatments, which considered *E. polystachya* and *E. spectabilis* Nees both as varieties of *E. polystachya*. I now believe they are separate species. The much more open panicles of *E. polystachya* with its long racemes distinguishes it from the more crowded inflorescence of *E. spectabilis* with its shorter racemes.

Figure 5 ***E. crus-galli*** **var.** ***riukiuensis, r*****eproduced from Plate 2 of Yamaguchi (2007). Regenerating young shoots (left) and panicles (centre and right)**

Conclusions

It is to be hoped that readers will have the opportunity to test this key and to report any deficiencies. My hope is that some day more use will be made of the collections of *Echinochloa* in the National Herbarium of New South Wales, which now includes all of the species originally housed in the Faculty of Agriculture at the University of Sydney.

It would be good if this paper were followed by up-to-date treatments of *Echinochloa* in the Americas (New World) and in Africa, including especially Madagascar. It might then be possible, with the help of pertinent molecular studies, to prepare a world key to replace my first attempt in Michael (1983).

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URLs for important, old references now available online, is also appreciated.

I am thankful to the custodians and curators of the specimens and images from the Kew Botanic Gardens, London (UK) and Muséum National d'Histoire Naturelle, Paris (France) for retaining the digitised images for use by researchers. No permission was required to reproduce the photographs, which add value to the *Echinochloa* species discussed. I also thank an anonymous reviewer for some helpful comments, which improved the manuscript.

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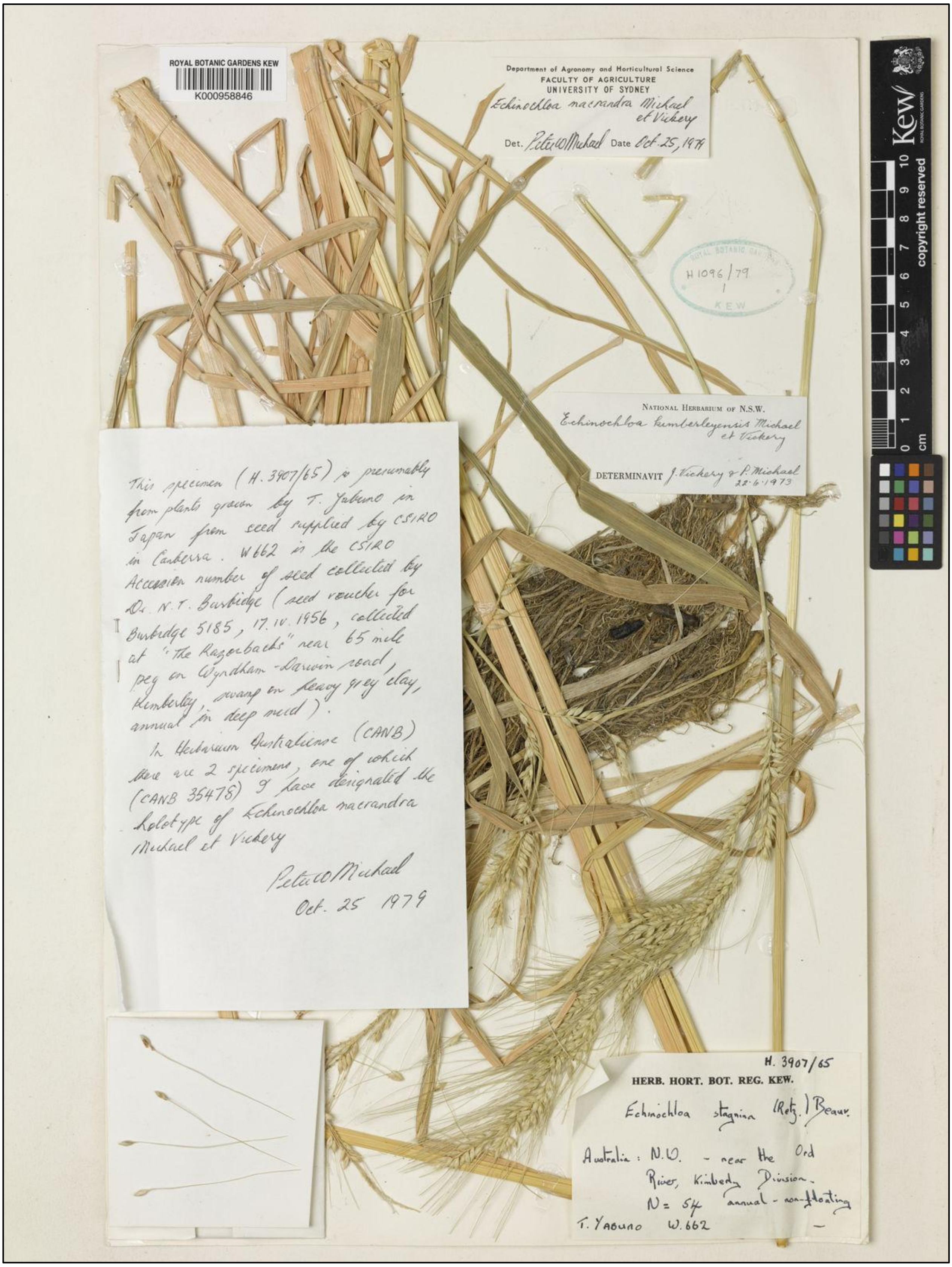
Editor's note:

The four figures overleaf were provided by the Royal Botanic Gardens (RGB), Kew Herbarium. These images have been created and licensed under CC-BY-4.0. They are being reproduced in this publication for educational purposes only.

The Journal is thankful to Rachael McCarthy, Digital Collections Support Officer, Science Collections Digitisation Project, digital revolution, Royal Botanic Gardens, Kew, Richmond, TW9 3AE for kindly supplying the images, in honour of Peter Michael.



Department of Agronomy and Horticultural Science
FACULTY OF AGRICULTURE
UNIVERSITY OF SYDNEY
Echinochloa macrandra Michael et Vickery
Det. Peter W Michael Date Oct. 25, 1979

NATIONAL HERBARIUM OF N.S.W.
Echinochloa kimberleyensis Michael et Vickery
DETERMINAVIT J. Vickery & P. Michael 22·6·1973

This specimen (H. 3907/65) is presumably from plants grown by T. Yabuno in Japan from seed supplied by CSIRO in Canberra. W662 is the CSIRO Accession number of seed collected by Dr. N. T. Burbidge (seed voucher for Burbidge 5185, 17. iv. 1956, collected at "The Razorbacks" near 65 mile peg on Wyndham-Darwin road, Kimberley, swamp on heavy grey clay, annual in deep mud).

In Herbarium Australiense (CANB) there are 2 specimens, one of which (CANB 35478) I have designated the holotype of Echinochloa macrandra Michael et Vickery

Peter W Michael
Oct. 25 1979

H. 3907/65
HERB. HORT. BOT. REG. KEW.
Echinochloa stagnina (Retz.) Beauv.
Australia: N.W. - near the Ord River, Kimberley Division.
N = 54 annual - non-floating
T. YABUNO W. 662

Figure 5 An image of the holotype *Echinochloa kimberleyensis* P. W. Michael et Vickery specimen from the Herbarium catalogue at Kew (Specimen Barcode: K000958846). Note the comments from Peter Michael as the determinant

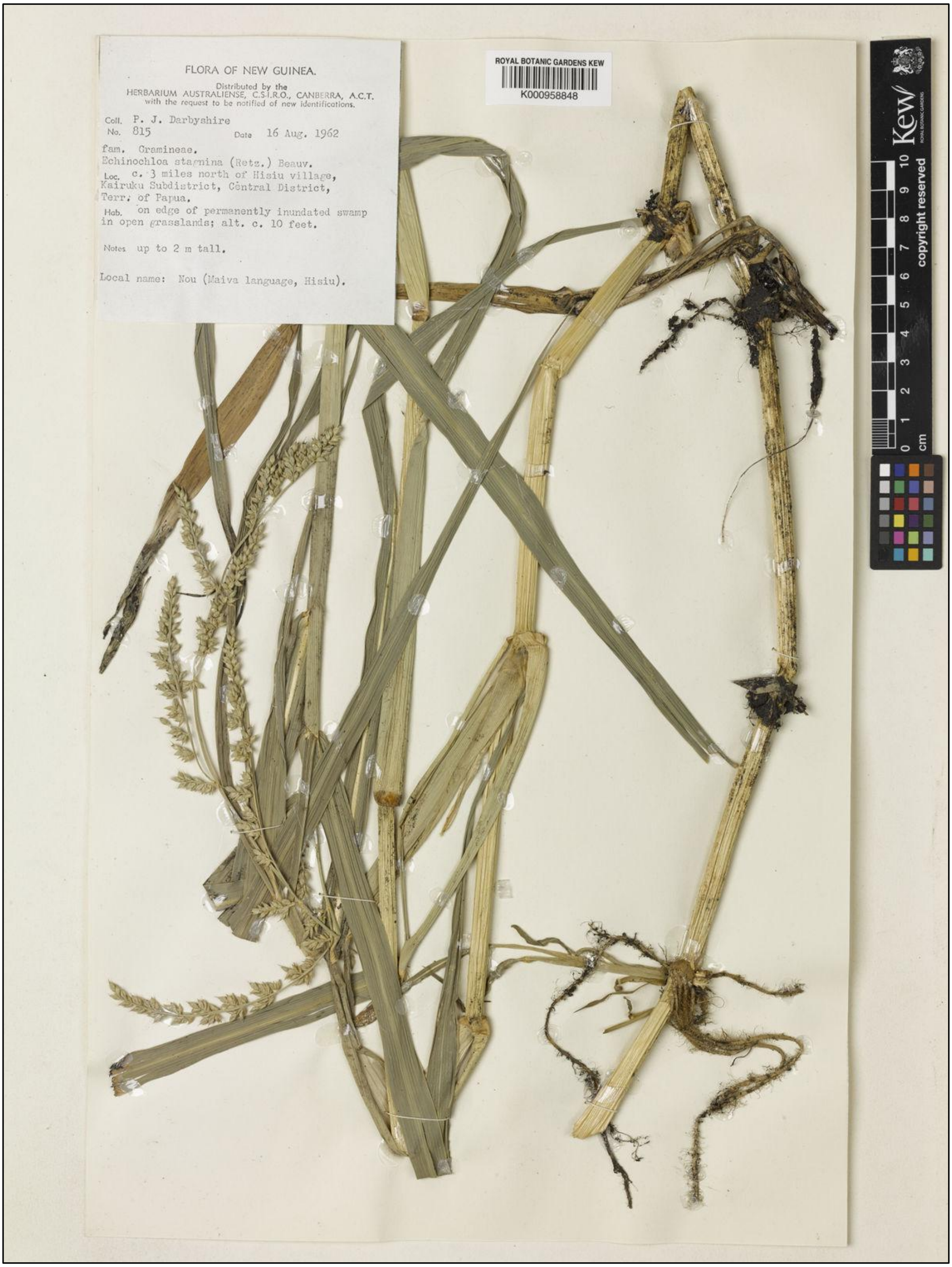
NATIONAL HERBARIUM OF N.S.W.
Echinochloa elliptica Michael et Vickery
Type Number
DETERMINAVIT J. Vickery & P. Michael 22·6·1973

EX HERBARIO AUSTRALIENSI
C.S.I.R.O., CANBERRA
Collected and distributed by Division of Land Research and Regional Survey, C.S.I.R.O., Canberra

Name Echinochloa stagnina (Retz.) Beauv.
Det. S. T. Blake Date 18.iii.1963
Coll. M. Lazarides 6805 Date 13.iii.1963
Loc. Coastal Plains Research Station, 30 miles S.E. of Darwin, N.T.
Hab. Common on heavy soil banks of rice bays.
Notes Tufted, erect perennial 3-4 ft high.

This specimen is presented on the condition that new identifications will be communicated to C.S.I.R.O., Canberra.
6754/60.

Figure 6 An image of the holotype *Echinochloa elliptica* P. W. Michael et Vickery specimen from the Herbarium catalogue at Kew (Specimen Barcode: K000958847).



FLORA OF NEW GUINEA.

Distributed by the
HERBARIUM AUSTRALIENSE, C.S.I.R.O., CANBERRA, A.C.T.
with the request to be notified of new identifications.

Coll. P. J. Darbyshire
No. 815 Date 16 Aug. 1962

fam. Gramineae.
Echinochloa stagnina (Retz.) Beauv.
Loc. c. 3 miles north of Hisiu village,
Kairuku Subdistrict, Central District,
Terr. of Papua.
Hab. on edge of permanently inundated swamp
in open grasslands; alt. c. 10 feet.

Notes up to 2 m tall.

Local name: Nou (Maiva language, Hisiu).

Figure 7 An image of the holotype *Echinochloa praestans* P. W. Michael from the Herbarium catalogue at Kew (Specimen Barcode: K000958848)

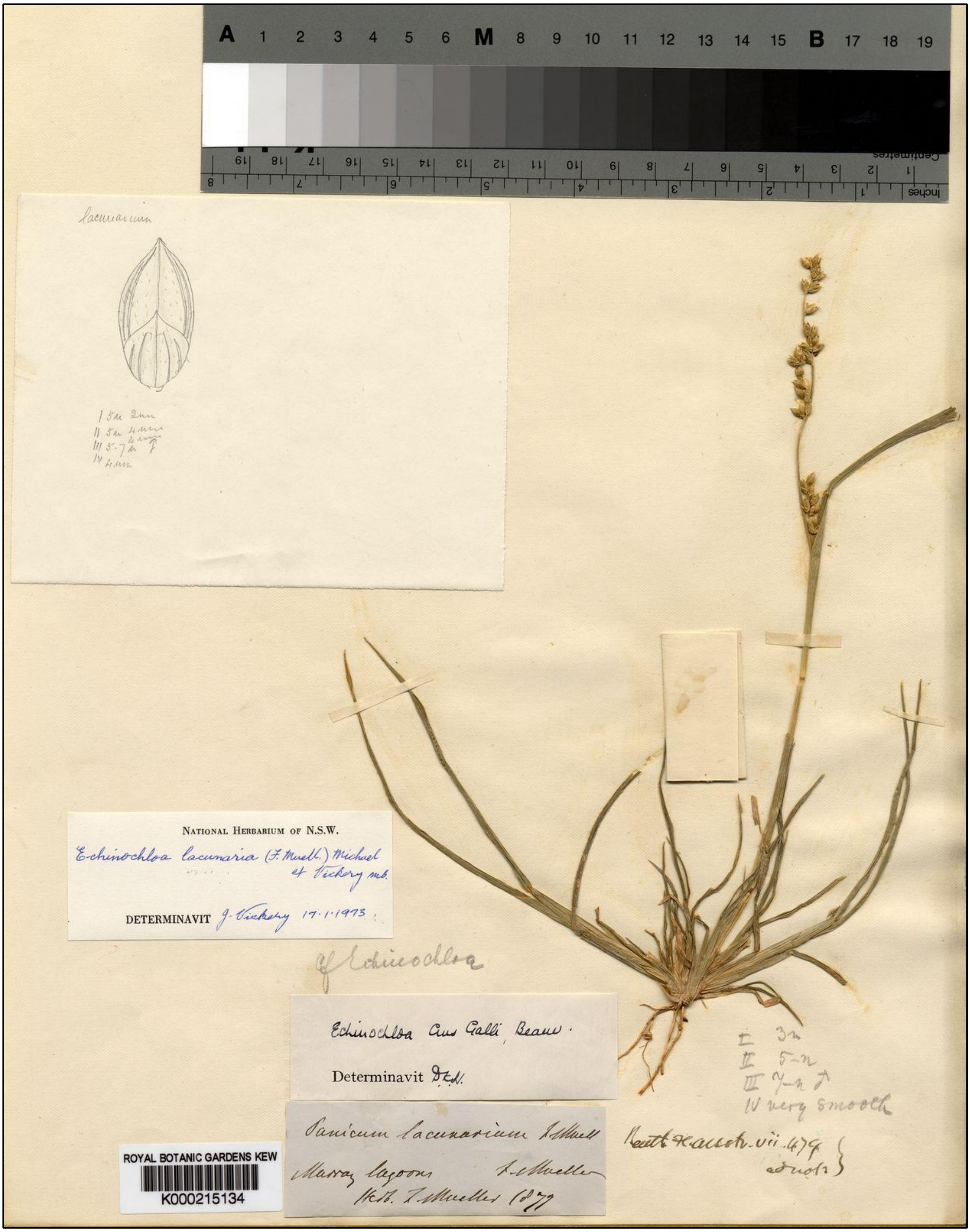


Figure 8 An image of the holotype *Echinochloa lacunaria* (F. Muell) Michael et Vickery from the Herbarium catalogue at Kew (Specimen Barcode: 000215134).

Dr. Peter W. Michael – An Appreciation – From the Asian-Pacific Weed Science Society (APWSS)

By Dr. Nimal Chandrasena, Editor-In-Chief, APWSS

Dr. Peter Michael, an eminent Australian botanist and taxonomist, passed away recently at the age of 97 peacefully. Those of us in the *Asian-Pacific Weed Science Society* (APWSS) who knew him closely are deeply saddened by this news.

The family informed me on 6 June 2025 that Peter died peacefully on 5 June in a palliative care hospital in Sydney, with his wife Janet and his children by his side. He was 97.

"*He did not suffer long and had moments of joy even in the last weeks. His mind was lucid till the end. We feel lucky he was in our lives for so many years. Warm thanks to you for your part in helping him work late in his life. We would be very grateful if you could inform the Asian-Pacific Weed Science Society and anyone else who knew him*".

I and our society have lost a great friend and personal mentor, who is hard to replace. Australia, too, has lost one of its greatest modern-day plant taxonomists.

In later years, as our society launched its journal, WEEDS, in 2019, Peter served as both a reviewer and contributor of articles. As the journal's Editor-in-Chief, if I had any issue regarding a botanical name or nomenclatural compliance, Peter was my advisor. I recall many instances where I sought his advice on Latin words and English expressions.

Peter was also one of the reviewers of parts of my book, *The Virtuous Weed* (published in 2023). I also often sought his views on taxonomic and nomenclatural matters. We frequently exchanged views and historical information on early botanists of the 18th and 19th Centuries.

Peter was APWSS President from 1977 to 1979 and organised the 7th APWSS Conference in Sydney. The society was formed in 1967 and is currently in its 58th year of existence. More importantly, Peter was one of the world's foremost authorities on barnyard grass (*Echinochloa* species) taxonomy.

The association Peter had with the APWSS was profound and endearing. As Peter himself stated in the article published herein, his interest in weed science began in earnest in 1967 with the first APWSS Conference:

> "*The inauguration of the Asian-Pacific Weed Science Society (APWSS) at the Asian-Pacific Weed Control Interchange in June 1967 coincided with the beginning of my serious interest in the taxonomy of Echinochloa. After a year in Japan in 1965 on a technical scholarship at the National Institute of Agricultural Sciences in Tokyo, where I learnt much about one form of Echinochloa, now known as E. oryzicola (tainubie in Japan), I was keen to find out whether it occurred in Australia. This led me into a field of surprises*".

And it certainly did! Peter Michael spent more than 60 years of his life studying and recording barnyard grasses from around the world. He was a highly sought-after taxonomist and won the respect of a large group of taxonomists worldwide due to his expertise.

As an active member of our Society, Peter attended many APWSS conferences (it has held 28 conferences to date, spanning over 58 years). Peter's preeminent taxonomic contributions to weed science, particularly in barnyard grass taxonomy and numerous other topics related to weed ecology and management, are unparalleled within our membership.

Currently, there are 37 *Echinochloa* species accepted by the world authority, the Kew Plant List, from the Royal Botanic Gardens, Kew, in London. Of these, Peter was the naming authority of **ten species**, including many from Papua New Guinea and North and North-East Australia. Two other barnyard grasses that Peter described as new species in 2019 (i.e., ***Echinochloa mentiens*** and ***Echinochloa trullata***) are currently under investigation by Kew taxonomists for taxonomic resolution.

One species, *Echinochloa praestans*, which Peter rightfully elevated to a species level from its previously relegated position (as a form of *E. polystachya*), has now been accepted as a distinct species.

On a personal level, he was a mentor to me since we first met at an APWSS Conference in 1985. I found him to be cultured, enlightened on all matters in society, and a warm human being. He worried about many things going wrong in modern-day Australia.

After I immigrated to Australia in 1993, I frequently visited him at his home in Epping and maintained a close friendship that lasted for 40 years. Unassuming to a fault, he was the epitome of the 'perfect gentleman'. In many ways, he was a relic of the past!

Peter never retired from research, although he did retire in 1989 from his position as a senior lecturer in weed science in the Department of Agronomy at the University of Sydney. After his retirement, he became an honorary associate at the University, and he also spent time at the Sydney Herbarium as an honorary research associate. In those days, he would assist me with plant identifications and also show me around the impressive plant collections.

When I was leading the *Botany Wetlands Ecological Restoration* project for Sydney Water, it was Peter who clarified for me the two different weedy purpletops (*Verbena* species), the dominant and widespread, common purpletop, *Verbena bonariensis* L. and ***Verbena incompta* P. W. Michael** – the latter with a narrower distribution in Australia.

I was fully aware of his other significant contributions to Australian taxonomy (especially on the Verbenaceae family) and his work at the Sydney and Mount Annan Botanic Gardens and Herbaria. His last article (published in *Telopea* in February 2025) was a clarification of *Eryngium undulatum*, a new name for the New Zealand plant long known as *E. vesiculosum*.

The Journal and our Society will miss an outstanding researcher, a world expert in taxonomy, and a mentor to many weed scientists in Australia, the Asian-Pacific region, and beyond. As we bid farewell, the APWSS extends our deepest and heartfelt condolences to his family.

As his funeral notice said, Peter will "***Forever remembered for his remarkable mind, his acceptance of everyone he met, his love of nature, and his compassion***".

The following tributes are from other APWSS Stalwarts:

Dr. N. T. Yaduraju, Former President, Asian Pacific Weed Science Society; Former Director, ICAR-Directorate of Weed Research, Jabalpur, India

"I had the good fortune of meeting Dr Peter Michael, a noble person, during the 25th APWSS Conference held at Hyderabad, India. His simplicity and generosity touched me deeply. His knowledge of weed science was profound and practical. I want to thank Dr Nimal Chandrasena for accompanying Dr Peter Michael to the Conference and introducing him to the Indian delegates. It was memorable indeed. We cherish this memory. I pray to the Almighty to bless this noble soul with eternal peace. My deep condolences to the family".

Dr. Adusumilli Narayana Rao, Chief Editor, *Indian Journal of Weed Science*; Former Agronomist (Weed Scientist), IRRI and Former General Secretary, APWSS (2012-2023)

Dr. Peter W. Michael is a world-renowned plant taxonomist, a global authority on the Taxonomy of *Echinochloa* spp. I became aware of the quality scientific contributions of Dr. Peter W. Michael and his work after reading his paper [Michael, P.W. (1983). Taxonomy and distribution of *Echinochloa* species with special reference to their occurrence as weeds of Rice. pp. 291-302. In: *Weed Control in Rice*. International Rice Research Institute (IRRI) and International Weed Science Society, Manila, Philippines. At that time, I was a post-doctoral fellow at IRRI, Philippines, in 1985.

As the Chairperson of the Technical Program Committee for the 25th APWSS Conference in Hyderabad, I have corresponded with him regarding his plenary presentation at that Conference. On 14 October 2015, Peter Michael gave a plenary presentation on "*Towards a better understanding of weeds in the Asian-Pacific Region*". During the Conference, I had the privilege of communicating with Dr. Peter, listening to him, and meeting him personally. I found him to be a Plant Taxonomist with immense dedication.

I was well aware of his close friendship with Dr. Nimal Chandrasena of the APWSS and that he had persuaded Dr. Peter to attend the Conference in Hyderabad. It was an honour for the APWSS to have one of its former presidents attending and speaking.

Dr. P. Michael rightly emphasised in his plenary presentation the need for proper weed identification and stated that this task has been made easier by high-quality digital photography. It is desirable to take photographs not only of whole plants but also detailed pictures of important plant parts. He also encouraged the production of a compilation of books and monographs to aid in weed identification (Source: page 14 of Post-Conference Proceedings and Recommendations: 25th Asian-Pacific Weed Science Society Conference, Indian Society of Weed Science, ICAR-Directorate of Weed Research, Jabalpur, India). 77 p.).

Many weedy genera and individual species still require better collections and thorough taxonomic study for a deeper understanding. It is, therefore, crucial to encourage young scientists with an interest in plants to become actively involved in taxonomic studies on weeds. Additionally, there is a need for the continuation of or even expansion of University and College educational courses in taxonomic methods.

His demise is a significant loss to the Plant Taxonomists community, particularly at a time when plant taxonomists of his quality are scarce. Also, taxonomy is often given the least importance by research funding administrators. I pray to God that his soul may rest in peace. I extend my deepest condolences to his family.

Dr. Hirohiko Morita Professor Emeritus, Akita Prefectural University, Japan

I wish to express my heartfelt condolences on the passing of Dr. Peter William Michael on 5 June 2025 at the age of 97. I am deeply grateful for his kind and accurate guidance on weed science, particularly on the taxonomy of grass weeds, including *Echinochloa* species.

My friendship and association with Dr. Michael date back to 1993, when I attended the 14th APWSS Conference held in Brisbane, Australia. At this Conference, he kindly chaired my oral presentation on *Beckmannia* weed in Southern Japan.

I fondly remember Dr. Michael as an excellent plant taxonomist whose advice was invaluable to everyone. When I visited his home in Epping, I enjoyed a one-day trip to Mount Tomah Botanic Gardens in New South Wales with him and Dr. Bruce Auld on 23 September 2011 (Photo below).

On another occasion, during a private visit to Sydney on 14 August 2018, he showed me several *Echinochloa* specimens, including candidates for new species, at the Herbarium of the Sydney Botanical Gardens.

These were *E. mentiens* P. W. Michael and *E. trullata* P. W. Michael, described as *species nova* in the paper ”Taxonomy of *Echinochloa* (L) Beauv. (Barnyard grass) in the Asian-Pacific Region: Un Update, Weeds 1(1):30-42, 2019.

I express my sincere respect and gratitude for his immortal achievements in weed science. I pray that Dr. P. Michael rests in peace.

Professor Eiji Tanesaka

Faculty of Agricultural Science, Kindai University, 631-8505, Nakamachi 3327-204, Nara, Japan.
e-mail: tanesaka@nara.kindai.ac.jp

The photo on the left shows Peter Michael on a field trip to Macquarie Marshes, NSW, in 2008. He was assisting Dr. Eiji Tanesaka, who was on a study tour to Australia on a research grant. The following is an excerpt from the Acknowledgements published in Dr. Tanesaka’s research article (see below):

“We thank Professor Peter William Michael and his daughter Diana for pinpoint guidance on the field work during this survey trip. We are again grateful to Prof Peter Michael for his kind comments, including his new opinions on Echinochloa species on the manuscript.

This research was supported by the Japanese Ministry of Education, Culture, Sports, Science and Technology, Grant-in-Aid for Scientific Research, No. 19405017”.

Citation:

Tanesaka E; Ohno T; Yamaguchi H. (2010). Species diversity of the genus *Echinochloa* (Poaceae), native to eastern Australia: a focus on their habitat and the threat of exotic species. *Journal of Crop Research*, 55: 13-17 (**https://www.jstage.jst.go.jp/article/jcr/55/0/55_KJ00007114895/_article**).

Abstract:

The natural habitat of the *Echinochloa* species growing in eastern Australia was investigated in May 2008. In this survey, four annual native species, *E. dietrichiana*, *E. inundata*, *E. telmatophila*, and *E. turneriana*, and three exotic species, *E. colona*, *E. crus-galli*, and *E. polystachya*, were observed.

The native species clearly have separate habitats: permanent stagnant pools for *E. dietrichiana*, inland floodplains for *E. inundata*, in or beside streams for *E. telmatophila*, and inland watercourses for *E. turneriana*.

While the habitat of the exotic species greatly overlaps that of the natives, especially perennial *E. polystachya*, which forms monospecific stands in stagnant pools and in or beside flood rivers due to its remarkable productivity, and *E. crus-galli*, which has the potential to adapt to several moisture conditions. We predict that the invasive exotic *Echinochloa* species will become more and more threatening, causing serious damage to the native species within the same genus.

Dr. Iswar Chandra Barua

Retired Principal Scientist, AICRP on Weed Management, Assam Agricultural University, Jorhat, Assam, India

Peter Michael & I C Batua, at Hyderabad on 16-10-2015

"The demise of Peter Michael is a great loss to APWSS and the Weed Science community. He provided me with valuable advice, especially on my work with Echinochloa in India.

We spent several valuable and cherished moments at the 2015 APWSS Conference in Hyderabad over a four-day period.

I adore his simplicity and generosity. He will always be alive in our hearts."

Editor's Note:

The photo on the left shows Peter Michael's meeting with Iswar Barua at the 2015 Hyderabad APWSS Conference.

Peter Michael can be seen examining herbarium specimens and discussing *Echinochloa* species with Dr. Barua.

Peter referred to this meeting in his article, describing two new species of Echinochloa from India, published in 'Weeds' in 2019.

Peter had time for everyone, especially those in plant taxonomy. The APWSS was very special to him, as also stated in his article (see pp. 50-66).