Chapter 4

Competitive Ability of Rice Cultivars in the Era of Weed Resistance

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Additional information is available at the end of the chapter

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Abstract

Almost all plants are negatively affected by neighboring plants, which impose some degree of competition within the population, depending mainly on the quantity and quality of natural resources available in the environment. In rice cultivation, the occurrence of a high and diverse infestation of weeds results in high competition levels among the species. In addition, the high and growing number of cases about herbicide-resistant weeds, especially the widespread distribution of Imidazolinone-resistant weedy-rice and the high infestation of weeds belonging to the *Echinochloa* genus, has increased the competition levels within rice cultivation due to the lack of control. Therefore, the inclusion of rice cultivars with greater competitive ability represents a promising tool for weed management, since new cases of resistance to herbicides are often reported and alternative control strategies are scarce. The use of rice cultivars with a greater ability to suppress weeds can alleviate the competitive effect of these species, giving priority to the crop for the use of environmental resources due to the faster occupation of the ecological niches. Thus, this chapter aims to explore the competitive ability of rice cultivars against troublesome weed species, accounting for the role of their morphological and physiological traits as a function of environment-friendly crop practices.

Keywords: weed, competition, weed free period, competitiveness traits

1. Introduction

The occurrence of a high and diverse weed infestation in paddy rice is among the various adversities that can be encountered during the crop life cycle, which might hamper crop yields. Weeds compete with the crops for natural resources that enable them to survive and reproduce, such as light, water and nutrients. Thus, the presence of a very diverse weed community within a field, together with the high rate of occurrence, makes the control difficult, and has negative consequences on rice grain quantity and quality increasing as well the production costs [1].

Competition can be defined as an interaction between individuals or populations, which is negative for both and it is rare to find a plant which has not been affected by neighboring plants [2]. Within a plants' community, competition is generally indirect, in which one individual affects negatively another by taking up resources that are limited in the environment, and could otherwise be available for other individuals. Direct competition can occur within a plant community, but these mechanisms are rare or still unknown, such as allelopathy. In general terms, it is very difficult to establish the cause for competition, because in natural systems, multiple resources are often simultaneously limited [3].

The losses in rice yield due to weed competition vary with the system of crop implantation: conventional system, minimum tillage, no-tillage, pre-germinate, pre-germinate mix, and transplant seedlings; with rice cultivars (e.g., cycle and height) with soil fertility; with the weeds present in the crop (e.g., species, density, duration and time of occurrence); and with management practices [4]. In areas where weed control strategies are not applied, the reduction in productivity can reach almost totality. Significant reductions in world rice production are estimated at 35, 24 and 16%, respectively, due to weeds, pests and pathogens [5]. In lowland rice crop, in Brazil, there were decreases in production caused by weeds from 50 to 100%. Therefore, this crop is quite sensitive to weed interference [4].

The most troublesome weed species that occur in Brazilian paddy rice are *Oryza sativa* (weedy-rice), *Echinochloa* sp. (*E. crus-galli*, *E. crus-pavonis* and *E. colona), Eleusine indica*, *Cyperus* spp. (*C. rotundus* and *C. difformis*) and *Sagittaria* spp. (*S. montevidensis*), with cases of herbicide resistant biotypes being reported for all these species. These are mainly associated with the intensive use of ALS-inhibiting herbicides, poor crop rotation schemes and crop varieties with low competitive ability. The current resistance problem demonstrates the urgent need of alternative management strategies to efficiently control these species and reduce the reliance on the chemical control. Thus, herbicide resistance and the lack of control alternatives led to the search for more competitive rice cultivars as a weed management tool in the crop technology [6].

The introduction of weed-competitive rice cultivars represents a low-cost and safe nonchemical addition to an integrated weed management (IWM) program. In addition, the use of more competitive cultivars can minimize yield losses and herbicide dependence, because these cultivars can suppress weed seed production, limit future weed infestations and fit easily into current agronomic practices [7]. However, trade-offs between competitiveness and productivity and inconsistent trait expression under weedy and weed-free conditions could complicate the breeding of competitive rice cultivars.

Crop competitiveness is a complex attribute that involves the ability to sustain yields despite the presence of weeds and the ability to suppress weed growth [8]. Thus, the competitive ability of different rice cultivars can be compared by assessing the competitive effect of plants or the ability to suppress other individuals or by assessing the competitive response of plants or the ability to avoid being suppressed.

More recently, the ecology and physiology of crops and weed species gained increasing importance in the development of methods of weed control [9, 10]. Ecology may be roughly divided in two sub-sections: synecology and autecology [11]. These areas present complementary aims in the study of ecology. Summarizing the concepts, autecology considers the species as an ecological unit while synecology considers the community as an ecological unit [11]. On the present chapter, we will focus on the competitive aspects of the autecology of rice plants, including the morphophysiological traits that confer superior competitive ability to rice, and on the phytosociological aspects of the weed communities into rice fields, e.g., the weed species against whom rice has to withstand and outstand competition.

2. Competition between plant species (interspecific competition)

Among several interpretations, "plant competition" essentially means a reduction in performance of a given plant species of importance, due to the shared use of a limited available resource [9]. Unlike animals, plants have limited mobility and, therefore, the competition between them is different, being apparently more passive and not visible at the beginning of the development [12]. However, it is known that crops, in general, do not show high competitive ability against weed species, which is the result of breeding for cultivars with productive traits and not to endure stress or aggressiveness [13].

It is of common consensus between researchers that competition occurs when neighboring plants use the same resources, and, therefore, the plant with the capacity to capture faster these resources is often more successful [13]. This capacity is normally associated with high relative growth rate, which enables the plant to capture the resources quickly, but these plants should also use the resources very efficiently. Nevertheless, it is also believed that a good competitor has both the ability to extract scarce resources and to tolerate the lack of them [13]. Thus, following this theory, a good competitor should be the species that requires fewer resources to survive, develop and reproduce [10].

In a cropping field, several weeds species can grow together with the crop cultivar in the same area. It is known that crops and the weed community tend to require similar environmental resources to survive, such as water, light, nutrients and CO_2. However, different species need these resources at different levels, but usually they are not enough even for the crop and, thus, the competition occurs. Under this situation, any plant that emerges in the cropping field will fight for these limited resources causing a reduction in crop productivity and probably reducing the quality of the harvested product as well [12].

The environmental factors that determine plant growth are commonly classified as "resources" and "conditions" [10]. Resources are the factors that can be consumed by plants such as water, CO_2, nutrients and light. Plants usually respond to resources following a standard curve, meaning that they tend to be small, if the resources are limited, and reach maximum development at the saturation point. After saturation point plant development can decline, if the resource becomes toxic (e.g., toxicity due to excessive zinc availability in the soil and water flood). On the other hand, conditions are factors not directly consumed, such as pH and soil density, which interfere in the development of plants because they can be associated reduce resources availability or plants capacity to explore them. It is always important to highlight that plant competition only occurs when the demand of a certain resource by a plant community is higher than its availability in the environment [12].

When weeds are established in the cropping fields before the crop, the competition tends to be critical and crop plants are normally inclined to fail under these circumstances [10]. However, if the crop plants are established first in the area and have similar competitive ability to the weeds, they will cover the soil reducing the weeds' access to essential resources for plant establishment such as light [9, 12, 13].

Moreover, competition is not only established between different species (interspecific competition) but can also occur among individuals of the same species (intraspecific competition). Even so, different parts of the same plant, such as leaves and roots, can compete for photo-assimilates. Based on the abovementioned aspects the following premises should be considered for the competition between crops and weeds [13]:

- Early states of crop development; the first 8 weeks for annual crops are critical for competition and this is the period where crop plants should grow free of weeds;
- Weed species that share similar biological and morphological traits with the crop are usually the most competitive when compared to those that differ greatly from crop plants;
- The size of the weeds' community is not the most important factor in terms of competition, a discreet weed infestation can be as harmful as a heavy infestation depending on the crop development stage before completion occurs;
- Direct competition between crops and weeds is established for limited environmental factors (water, light, CO_2, nutrients and physical space). Indirect competition occurs when weeds or crops release allelopathic compounds in the soil and/or air, which are capable of inhibiting the germination and/or growth of other plant species.

3. Rice traits for weed competitiveness

Crop-weed competition studies are often found in the literature and the outcome of these are normally applied when planning integrated management practices that include crop rotation with winter crops that are capable to suppress weeds and can also be used for crop-livestock integration [14, 15]. The main outcome of these studies is to model weed dynamics in the cropping fields based on their biological and morphological traits to optimize management strategies. Germination and emergence patterns, dry mass, dry mass accumulation, plants height, number of tillers or branches, number of inflorescences and other variables are often measured for future estimations [16–18].

Several traits have been associated with irrigated rice competitiveness with weeds in previous studies. Some authors believe that there is a negative correlation between competitiveness and productivity [19, 20], while others have suggested that is possible to enhance rice competitiveness and maintain high yields at the same time [7, 21]. The reasons for these divergences have not been totally elucidated, since most of these studies are based only on analyses of simple correlations and lack a mechanistic analysis of the relationships between plant characteristics that determine competitiveness and those that determine yielding ability [22, 23].

3.1. Morphological traits

Studies report the relationship between competitive morphological characteristics of cultivated plants, which offers a competitive advantage against weeds [22, 24]. Some of these characteristics are germination, growth velocity, height, canopy architecture, high biomass, leaf area and photo-assimilates [23]. For instance, rice traits associated to light capture are plant height, tillering ability, leaf morphology and area, while the development of the root system is important in terms of nutrients capture.

A number of comparative studies have shown that plant size, accounting specially for shoot length, is the main indicator of competitive ability [25]. It is clear that big plants can win over little plants, but it remains unclear whether large size confers enhanced competitive ability by reducing the resources availability to another individual or the bigger plant can tolerate reduced levels of the respective resource [2]. For instance, when light competition is in place between plants, several factors determine the ability to capture or inhibit the availability of this resource to other individuals, such as the position of the leaves. However, it is still not clear whether the leaves that have higher positions in the canopy are tolerant to lower light levels.

Adjustments in root and shoot growth are often associated with plant's phenotypic plasticity in response to changes in the environment. However, it is important to mention that not all adjustments that occur in plants size or growth rate are necessarily adaptive responses to compensate for resource limitations or competition imposed by its neighbors [26]. Some authors believe that shortages of nutrients or water could maximize a plant's probability of capturing those resources, especially if a competitor fails to respond to a comparable extent. Therefore, such responses will be associated ultimately with increased fitness and not necessarily with greater competitive ability [27]. However, the occupation of space below-ground is a fundamental characteristic of competitive success, since the nutrient uptake at the first development stages for certain species reduces the nutrients availability to neighboring plants, which indicates a competitive advantage [28].

Moreover, as plant height increases, more energy is invested for biomass production in the stem to support their own weight, which in turn reduces the fraction of leaf mass in the plant and can reflect in reduced crop yields [29]. In addition, being tall can lead to some disadvantages because these plants may be exposed to stronger winds than the neighbors, which might entail negative effects on plant growth due to excessive transpiration and mechanical stress [30, 31].

3.2. Physiological traits

Nowadays, physiological and highly specialized studies dealing with crop-weed competition still lack perspectives that could be integrated for practical everyday weed management.

Consequently, weed biologists tend to avoid the use of physiological parameters in association to the directly measured variables to support their findings. However, changes have been proposed in this scenario with the introduction of more basic research in applied studies [9, 10] propose changes to this scenario.

When rice is subjected to strong competition with weeds during cultivation, its physiological characteristics of growth and development are usually changed. This results in differences regarding the use of environmental resources, especially water, which directly affects the availability of CO_2 in leaf mesophyll and leaf temperature, therefore, the photosynthetic efficiency [32].

3.2.1. Competition for light

For some authors, competition for light is not as important as competition for water and nutrients mainly because the understanding of plant physiology traits is only starting to be included in weed studies [33]. However, it should be considered that there is an interrelation among these factors [13].

It is known that when crop plants shade completely the soil surface, there is no competition for light. Moreover, as a consequence of genetic improvement of crop cultivars, these plants tend to be more efficient in intercepting light, thus plants of crop species present high Light Use Efficiency (LUE) when evaluated alone [12]. This is probably the reason why light competition is not often included in crop-weed competition experiments. However, some studies can be found such as the one evaluating the LUE between bean and soybean crops with three weed species (*Euphorbia heterophylla*, *Bidens pilosa* and *Desmodium tortuosum).* The results show that crops accumulated more dry mass per unit of intercepted light than any of the studied weeds [34], but even though weeds were less efficient than crops in using light, they present high competitive ability in field conditions due to a more efficient extraction and use of other resources, like water and nutrients.

Light competition is complex because it is a result of several factors, mainly the species in question. For instance, species characteristics such as carbon metabolism of the C3, C4 or CAM types and the natural habitat (native to shaded or sunny environments) are highly important when studying light competition and will regulate the reactions that take place at the dark phase of photosynthesis [9, 12].

It is common to imagine that C4 plants are always more efficient than C3 plants; however, this is true only under certain conditions [13]. C4 plants demand more energy to produce photo-assimilates, due to the presence of two carboxylative systems. Moreover, the relation of CO_2 fixed/ATP/NADPH is 1:3:2 for C3 species and 1:5:2 for C4 species, which also evidences the higher need of energy for photosynthesis in C4 plants. Thus, it is reasonable to conclude that when the access to light is limited, C4 plants have a reduced competitive ability than C3 species because all the energy comes from light.

On the other hand, in C4 species, the enzyme responsible for carboxylation has high affinity for CO_2, which confers a high competitive ability to these species under high temperatures, light availability and also under temporary water deficit. In these situations, C4 species are capable to overcome C3 species, accumulating twice the dry mass per unit of leaf area in the same time interval [13].

3.2.2. Competition for water

There are various factors influencing water competition, such as the volume of soil that is covered by the rooting systems, physiological traits of the plant, stomatal regulation, osmotic adjustment in roots and hydraulic conductivity capacity of the roots [12]. Crop cultivars are normally less tolerant to water deficit than weeds, and it is common to observe crop plants with some degree of wilting, while weed plants are still completely turgid. Moreover, the competition for water is commonly associated with the competition also for light and nutrients [13].

Plant species vary in the amount of water needed per unit of dry mass accumulated; the species that use more efficiently the water are known to have high water use efficiency (WUE = amount of dry mass accumulated as a function of water used at the same period). Thus, it is reasonable to expect that species with higher WUE should be more competitive under water deficit and, therefore, more productive [10]. However, some weed species may present distinct values of WUE throughout the cycle, being more competitive for water in certain stages of their development [13].

It is very important to know the WUE of the different species within an area, although this only one of the mechanism allowing that confers water competition. In this sense, stomatal self-regulation becomes very important to overcome periods of water deficit.

3.2.3. Competition for CO_2

CO_2 competition is not often considered in crop-weed competition studies, because the availability of this gas is normally not considered an issue. However, it is known that plants differ in their carbon cycling mechanisms (C3 and C4 plants), resulting in different dry mass accumulation. Thus, the ability to capture CO_2 from the air is important in terms of competition because this regulates the photosynthesis under competing situation and may affect mainly C3 species [13].

3.2.4. Case study: influence of barnyardgrass on rice physiology

The main form of interference between barnyardgrass and irrigated rice is the competition for light and nutrients, constituting one of the main limiting factors of productivity in irrigated rice [30, 31]. In addition, it is important to note that weed competition can affect crop production and its quality, since it modifies the efficiency of use of environmental resources [35, 36].

In a study focusing on competition of Quinclorac-resistant barnyardgrass with rice plants by the additive experimental model (**Figure 1**), there were practically no differences in the accumulation of dry mass and photosynthesis, and weak differences regarding water use efficiency of rice plants as a function of competition with distinct biotypes, although rice was clearly affected by the increase in competition (**Figure 2**).

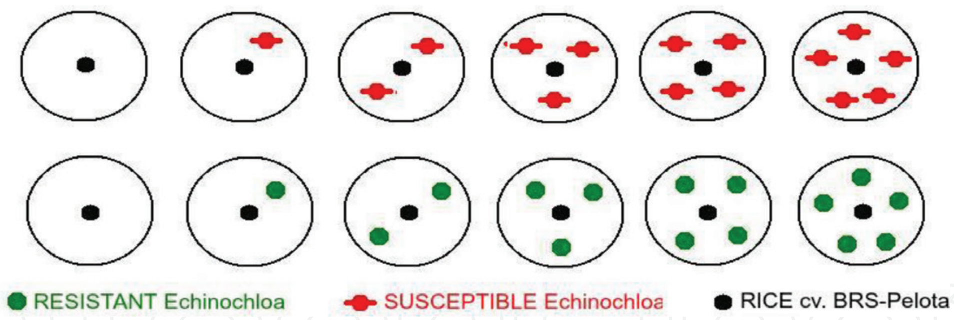

Figure 1. Schematics of the additive-model trial about the influence of barnyardgrass biotypes resistant or susceptible to the Quinclorac herbicide on the rice variety BRS Pelota, under distinct competition levels [37].

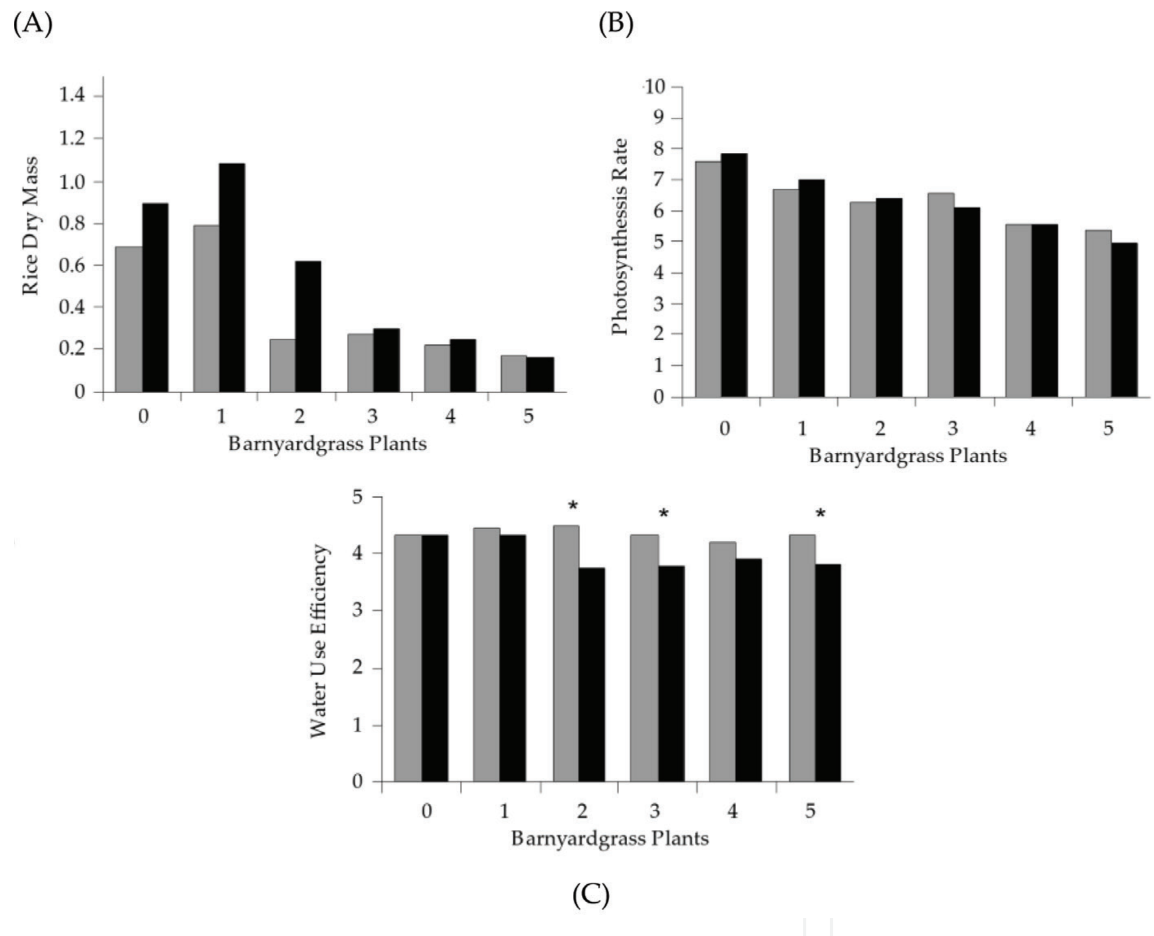

Figure 2. Dry mass (g plant^{-1}) (A), photosynthesis (μmol m^{-2} s^{-1}) (B), and water use efficiency (mol CO_2 mol H_2O^{-1}) (C) of rice plants variety BRS-Pelota as single plant, as function of competition with different numbers of barnyardgrass plants from the resistant (■) or susceptible (■) biotypes to Quinclorac. Source adapted from [37]. * Biotypes differ according to the LSD test at 5% probability.

Rice dry mass under competition with barnyardgrass did not differ from the plant free from competition, when competing with only one barnyardgrass plant. However, under competition with two or more barnyardgrass plants, the rice reduced its accumulation of dry mass per plant (**Figure 2**). Thus, the level of competition between the rice and the surrounding weeds is more important than the probable differences that may occur between biotypes or ecotypes of the same weed species [3].

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In Brazil, Andres et al. were pioneers in collaborating with rice breeding programs in trying to identify those rice lineages from Embrapa Clima Temperado's rice breeding program that coupled superior ability to outstand emergence under unfavorable conditions (**Figure 3**) and superior ability to compete with weeds under field conditions (**Figure 4**) [35].

The superiority of genotype #19 is clearly visible in keeping seed emergence and vigor even after several days under moderately inadequate germination conditions (**Figure 4**). Furthermore, this genotype was also superior in a subsequent competition study by the substitutive method installed under field conditions, whose competitor species was exclusively the barnyardgrass (**Figure 5**).

Most academic studies that find significant differences on the impact of distinct biotypes of the same weed on rice are probably due to the application of inadequate experimental and statistical methods [39]. Most of these studies adopt designs that simply lack enough statistical power to identify any real difference between plant biotypes. Only few significant studies notify real differences on morphophysiological traits among biotypes.

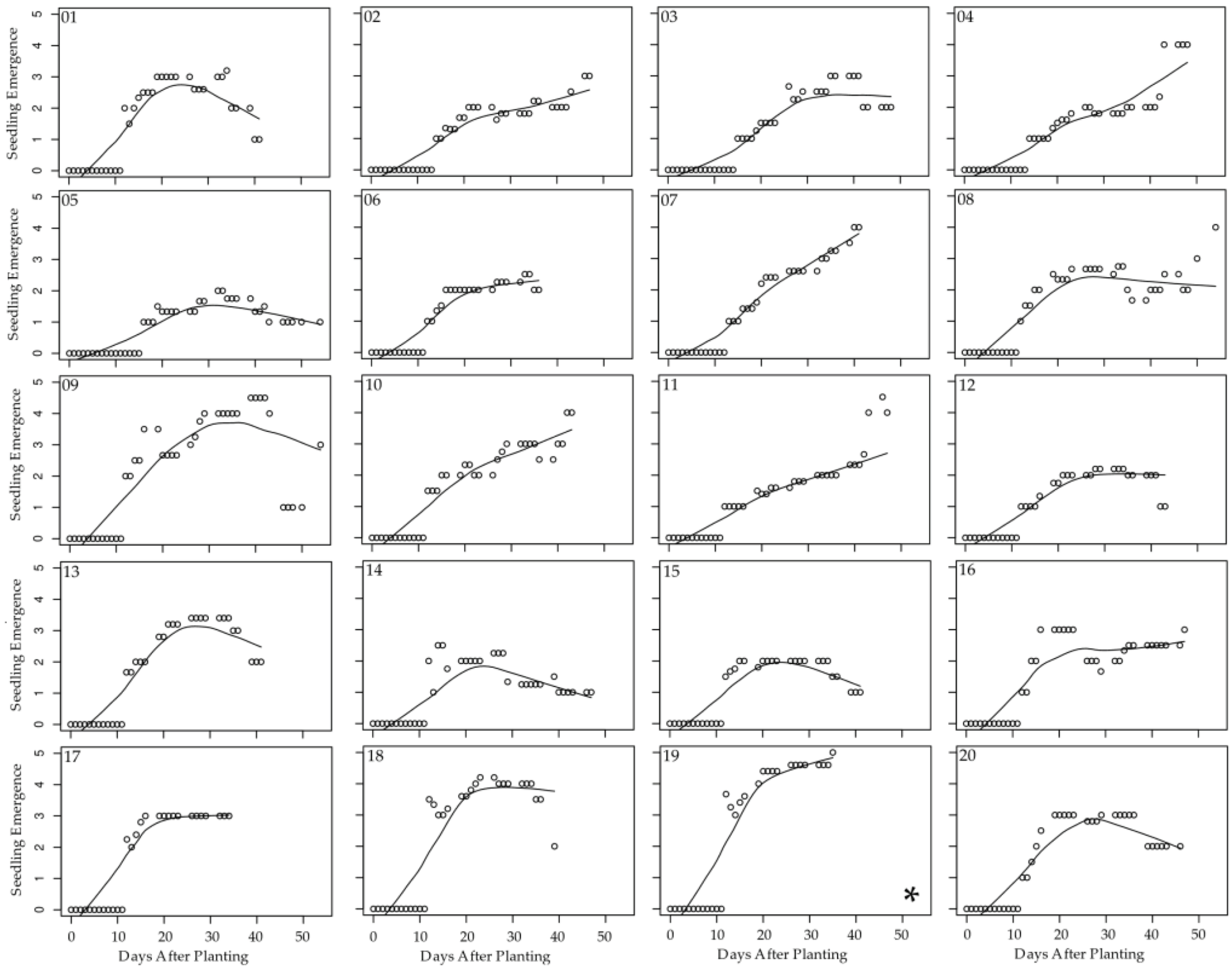
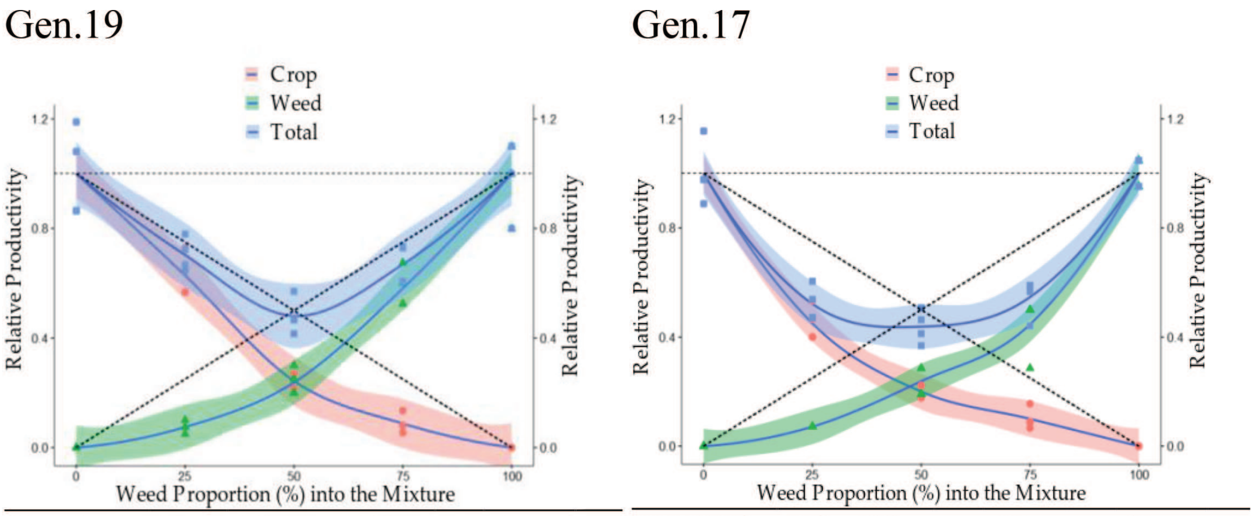


Figure 3. Emergence speed of 20 rice lineages randomly selected from the Embrapa Clima Temperado's irrigated rice breeding program. Source: adapted from [35].



Gen.19

Crop:Weed[1]	NPl[2]	CR[3]		Kc[4]		A[5]	
100:0(F)	9.25						
75:25	7.75	3.041	*	0.598	*	0.269	*
50:50	4.5	1.05	ns	0.323	ns	0.006	ns
25:75	3.25	0.461	*	0.292	ns	-0.212	*
0:100	0						
C.V.	20.4	%					

Gen.17

Crop:Weed[1]	NPl[2]	CR[3]		Kc[4]		A[5]	
100:0(F)	11.25						
75:25	6.75	2.1	*	0.279	ns	0.157	*
50:50	4.5	0.875	ns	0.251	ns	-0.038	ns
25:75	4.5	0.775	ns	0.338	ns	-0.098	ns
0:100	0						
C.V.	20	%					

[1] plant proportion (crop:weed), being (F) the control plot free from competition; [2] crop emergence at the indicated competition level compared to the (F) plot by Dunnett's test; [3] significant when it differed from "1" according to the T-test; [4] difference between K_{crop} and K_{weed} (K_{weed} not shown) at the same competition levels, according to the T-test with Welch criteria; [5] significant when differed from "0" according to the T-test; * = significant difference at 5% level; [ns] = non-significant.

Figure 4. Relative performance of rice emergence under competition with barnyardgrass in field conditions, by the substitutive method of study. Source: adapted from [35].

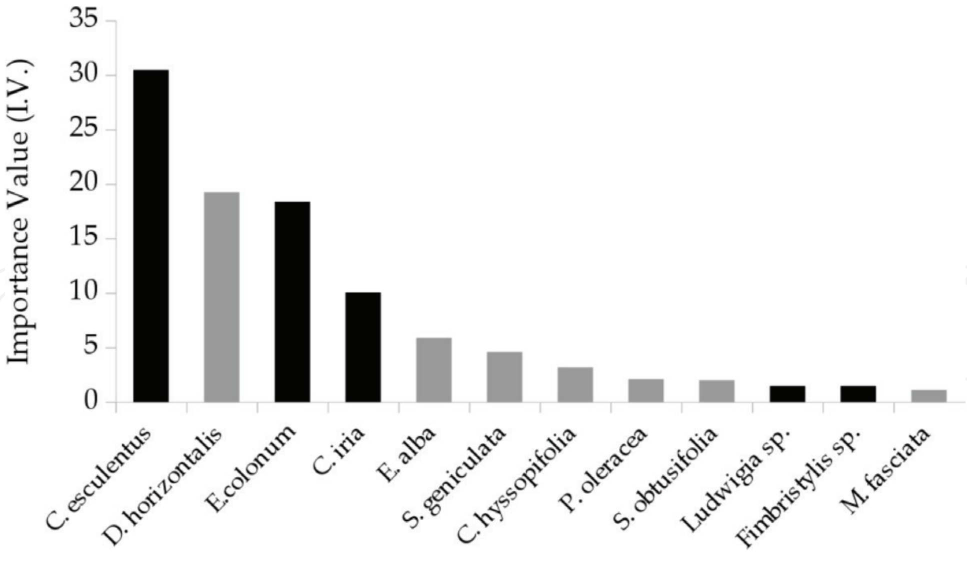


Figure 5. Importance value for weed species in areas with rice-soybean rotation for at least 5 years, in the Center-West region of Brazil. Source: adapted from [38].

Anyway, it seems not very wise to assign big efforts and resources in trying to differentiate weed biotypes in terms of their competitive ability with rice; there is a most urgent need in characterizing the main weed species traits, which confer them superior ability to compete with rice. Furthermore, it is also wise to focus on rice breeding programs that will select not only the most productive rice lineages for becoming commercial varieties, but that also associate to this important trait the presence of the morphophysiological features that are known to confer superior competitive ability to rice against the most important weed species occurring in this crop. This will confer stability to the rice grain yield and may help reducing the demand for herbicides as well [7, 8, 13].

Thus, the study illustrated in **Figure 2** shows that the proper moment for applying weed control techniques in rice is probably the same for any barnyardgrass biotype, and most probably the same tends to occur with biotypes of other weed species. The theory of weed impact on crops based on old ecological concepts like the *Critical Period for Weed Competition* (CPWC) [40], although applicable to the time they were adapted from ecological concepts, need to be at least partially reviewed considering the number of cases of weed biotypes with resistance to herbicides that appear every year [41].

In CPWC, there seems to be a most urgent need to revise the *Period Prior to Interference* (PPI) concept: considering the current case scenario regarding the difficulty to reach proper weed control with herbicides, it seems most prudent to always start the fields clean from any weed species; thus, the PPI would always be equal to zero.

4. Synecology of weeds in rice crops

The principles of the application of synecological methods to the weed science were summarized by Concenço et al. and will not be discussed in the present chapter [40]. We will focus on the application of synecology to rice fields.

Weed density or abundance is expressed by the number of plants within each quadrat. The density information collected in each quadrat is normally extrapolated to bigger areas. On the other hand, frequency is the proportion of total quadrats containing the individuals of the same species. If this species covers the most basal area of the community, it is considered a Dominant species.

According to several parameters (density, frequency, and dominance), the Importance Value (iv) of each species in the community can be easily estimated. Thus, the species that is present in higher density and frequency and is capable of suppressing other species due to a faster growth and mass accumulation (dominant) is the most important species (iv) within a plant community.

Weed composition of rice fields located in the lowlands of Southern Brazil was assessed and the authors reported the list of weed species found highlighting the ones with the highest potential to interfere in rice growth and development, thus impacting rice grain yield. The main results of this study are summarized in **Table 1** [39].

Barnyardgrass (*E. colona*) was responsible for 22.6% of the importance value of infestation into the studied areas. If this weed is completely eliminated from the area, the problems with weeds should be reduced with 22%, until another species takes advantage of physical

Weed species	Control	Clom. + Cyhal.	Clom. + Cyhal.	Penox. + Cyhal.	Penox. + Cyhal.	Imazet. + Imazap. + Cyhal.	Imazet. + Imazap. + Imazet. + Imazap.	Imazapyr + Imazap. + Cyhal.
Aeschynomene denticulata	0	0	0	0	5.73	0	0	0
Alternanthera filoxera	0	0	6.16	0	0	0	0	0
Brachiaria sp.	0	1.58	0	0	1.91	0	4.24	0
Conyza canadensis	0	0	0	5.03	3.9	0	3.67	0
Cynodon dactylon	18.92	10.48	2.68	10.71	11.3	13.27	26.92	21.57
Cyperus distans	0	0	10.79	0	0	0	0	0
Cyperus esculentus	12.83	29.38	18.99	41.5	25.92	30.26	20.52	22.27
Cyperus odoratus	3.47	2.62	0	0	0	0	0	0
Echinochloa crus-galli	22.57	15.76	5.19	4.92	5.35	8.57	0	8.55
Eleocharis elegans	0	0	0	0	0	4.14	0	0
Eleocharis sp.	4.56	1.88	0	7.06	1.68	2.71	0	0
Fimbristylis autumnalis	0	0	0	7.69	0	0	0	0
Fimbristylis sp.	14.64	9.3	20.27	9.44	18.94	31.1	18.46	11.96
Hypochaeris sp.	0	0	0	0	1.63	0	0	0
Kyllinga brevifolia	19.24	7.05	24.09	5.76	15.19	4.23	8.71	19.72
Lolium multiflorum	1.83	3.41	9.44	0	5.33	0	0	3.96
Oryza sativa	0	1.57	2.4	4.34	0	3	0	0

Weed species	Control	Clom. + Cyhal.	Clom. + Cyhal.	Penox. + Cyhal.	Penox. + Cyhal.	Imazet. + Imazap. + Cyhal.	Imazet. + Imazap. + Imazet. + Imazap.	Imazapyr + Imazap. + Cyhal.
Paspalum notatum	0	0	0	0	0	0	0	3.04
Pluchea sagittalis	1.94	0	0	0	1.64	2.73	11.44	5.63
Polygonum hydropiperoides	0	10.67	0	1.61	1.47	0	0	3.29
Porophyllum sp.	0	6.29	0	0	0	0	0	0
Rhynchospora sp.	0	0	0	0	0	0	3.31	0
Spermacoce capitata	0	0	0	0	0	0	0	3.29
Trifolium sp.	0	0	0	1.92	0	0	0	0

Source: adapted from Concenço et al [39].

Table 1. Importance value (iv—%) of weed species in rice fields in Southern Brazil, as a function of herbicide treatments.

Cultivar	Cycle	Clearfield®	Resistance to low temperatures	Resistance to diseases[1]	Resistance to insects[2]	Resistant to lodging	Susceptibility to iron toxicity	Grain quality	Productivity
EPAGRI 106	Early	NO	NI[3]	High	NI	Intermediate	Intermediate	NI	NI
EPAGRI 108	Late	NO	NI	Intermediate	NI	High	Low	High	High
EPAGRI 109	Late	NO	NI	Intermediate	NI	High	Low	High	High
SCS 114 Andosan	Late	NO	NO	Intermediate	NI	High	Intermediate	NI	NI
SCS 115 CL	Intermediate	YES	NI	Intermediate	NI	Low	High	High	NI
SCS 116 Satoru	Late	NO	YES	Intermediate	NI	NI	Intermediate	High	High
SCS117 CL	Late	YES	YES	Intermediate	NI	NI	High	High	High
BR-IRGA 409	Intermediate	NO	NI	NI	NI	NI	NI	High	High
BR-IRGA 410	Intermediate	NO	YES	Low	NI	NI	Low	Intermediate	High
BR-IRGA 414	Early	NO	NI	Low	NI	NI	High	High	High
BRS 6 Chuí	Early	NO	NI	NI	NI	NI	Intermediate	High	High
BRS 7 Taim	Intermediate	NO	NI	Intermediate	NI	NI	NI	High	High
BRS Atalanta	Very early	NO	NI	NI	Intermediate	NI	NI	High	High
BRS Querência	Early	NO	NI	Intermediate	NI	NI	NI	High	High
BRS Sinuelo CL	Intermediate	YES	NI	High	NI	High	NI	High	High
BRS Pampa	Early	NO	NI	High	NI	High	NI	High	High
IRGA 416	Early	NO	NI	High	NI	NI	NI	High	High

Cultivar	Cycle	Clearfield®	Resistance to low temperatures	Resistance to diseases[1]	Resistance to insects[2]	Resistant to lodging	Susceptibility to iron toxicity	Grain quality	Productivity
IRGA 417	Early	NO	YES	High	NI	NI	High	High	High
IRGA 421	Very early	NO	NI	Low	NI	NI	Intermediate	High	High
IRGA 422 CL	Early	YES	NI	NI	NI	NI	NI	High	High
IRGA 423	Early	NO	NI	High	NI	NI	High	High	High
IRGA 424	Intermediate	NO	YES	High	NI	NI	High	Intermediate	High
IRGA 426	Intermediate	NO	NI	High	NI	High	Intermediate	High	High
IRGA 427	Intermediate	NO	NI	Intermediate	NI	High	High	High	High
IRGA 428	Intermediate	YES	NI	Intermediate	NI	NI	High	High	High
PUITÁ INTA-CL	Intermediate	YES	NI	NI	NI	NI	Intermediate	High	High
GURI INTA CL	Intermediate	YES	YES	NI	NI	NI	Intermediate	High	High
Avaxi CL	Early	YES	YES	High	NI	NI	High	High	High
Inov CL	Early	YES	YES	High	NI	NI	High	High	High

[1]Resistance to *Pyricularia grisea*.

[2]Resistance to *Oryzophagus oryzae*.

[3]NI—Information is not available.

Table 2. List of the currently used rice cultivars in Southern Brazil and their key physiological traits [31].

space made available by the control of the previous species. This weed was followed by *C. esculentus*, *C. dactylon*, and *Fimbristylis* sp. (**Table 1**) but the herbicides adopted in such rice fields are efficient against these species as well. It is also possible to observe that all herbicides were efficient in controlling barnyardgrass (treatments 2–8) (**Table 1**). Moreover, any other weed species was capable to take the place of barnyardgrass when the herbicides were applied. However, *C. esculentus* had increased in all treatments from 2 to 8, depending on the applied dose. This species was also dominant at T4, but with low frequency (**Table 1**).

In another study that was conducted in the lowlands of Center-West Brazilian region, Erasmo et al. found a similar composition of important weed species in rice fields installed in rotation with soybean for at least 5 years (**Figure 5**). In such study, *C. esculentus*, *E. colona* and *Fimbristylis* sp. were also among the most important weed species, similarly to what was observed in Southern lowland rice fields [39].

This raises a series of questions: (1) the most commonly herbicides used for weed control in rice may not be as effective on these weed species; (2) these weed species have similar demands for edaphoclimatic and nutritional resources to rice, thus adapting to the same environments; (3) it seems that soybean, when included into a crop rotation scheme with rice, may be not as effective in helping controlling rice weed species as anticipated by some authors on the long-run. These aspects need to be elucidated in future synecological studies.

Synecological studies are the first step for developing successful and competitive rice varieties against weeds since they allow for clearly identifying those species that are most harmful to rice. The further steps would include dedicated autoecological studies on these species and rice, and later breeding programs aiming to select the most significant features of rice varieties, which would make it most competitive against the weeds originally identified.

In Southern Brazil, there are several rice cultivars that have different physiological traits that can be already explored to increase crop competitive ability (**Table 2**). Even though these cultivars were not breed to compete with weeds, some of them have interesting features that allow crop plants to grow more rapidly and healthier, such as resistance to diseases, insects, iron toxicity, increasing their ability to compete with weeds in various environmental conditions. Moreover, the cultivars that perform better when weeds are present in the cropping fields with great biomass production and high yields should be selected for future breeding programs aiming to produce cultivars with high competitive ability against weeds.

5. Final considerations

In addition to the introduction of more competitive rice cultivars against weeds, the crop can also obtain some advantage when other cultural methods are manipulated, such as the adoption of higher sowing density [42, 43]. In a cropping field, the density of the weed community tends to be much higher compared to cultivated species. Thus, it is common to assume that weeds have higher competitive ability than the crop; however, this effect could be caused by the higher weed densities and not the real competitive potential of these species.

It is important to mention that moving forward for the understanding of crop competitive ability it is relevant to include other factors and variables in competition experiments, excluding the ones in which only the degree of competition varies and growth suppression are evaluated. It is also important to learn about individual morphophysiological traits, especially about root competition. Moreover, understanding the link between genetic traits and competitive ability is essential to ensure that a crop cultivar is competitive and productive.

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