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Integrated Control of *Echinochloa crus-galli* Resistant to ALS and ACCase Inhibitor Herbicides

ALS ve ACCase İnhibitörü Herbisitlere Dayanıklı *Echinochloa crus-galli*'nin Entegre Mücadelesi

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INTEGRATED CONTROL OF *ECHINOCHLOA CRUS-GALLI* RESISTANT TO ALS AND ACCASE INHIBITOR HERBICIDES

ABSTRACT

Rice is an important cereal crop, both due to its high domestic consumption and its significant role in global food security. The challenges of crop rotation and the difficulty of fallow-free cultivation in rice production have led to the emergence of competitive weed species that have a rapid reproductive capacity and are adapted to aquatic environments. The adverse effects of these weeds on rice yield and farm profits have created a demand for cost-effective weed management strategies. Prolonged use of herbicides with the same mode of action has rapidly increased the number and population of herbicide-resistant weed species. So integrated weed control is the only method and an important solution in managing the rice weeds that should be developed according to the countries' production systems. *Echinochloa crus-galli* (barnyardgrass) is one of the earliest resistant weeds adapted to rice production areas. In this study, the aim was to determine the interaction between cultivation methods, water management, and rice varieties (Osmancık, Gönen, Koral) for effective weed management. The experiments were conducted in Turkey's Marmara and Black Sea Regions with four replications. The water level, especially high water levels, not only had a highly suppressive effect on weeds but also contributed to the growth and yield of rice. Deep and moderate water levels increased the tillering number and dry weight of rice. The data obtained indicated that maintaining the water level in rice cultivation areas can lead to better rice growth and higher yields. The development of competitive and local rice varieties is considered a viable approach in an integrated herbicide-resistant weed control program.

Keywords: *Echinochloa crus-galli,* Cultural Control, Rice, Integrated Management.

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ALS VE ACCASE İNHİBİTÖRÜ HERBİSİTLERE DAYANIKLI *ECHİNOCHLOA CRUS-GALLİ*'NİN ENTEGRE MÜCADELESİ

ÖZ

Çeltik, yüksek iç tüketimi ve küresel olarak gıda güvenliği açısından önemli bir tahıl ürünüdür. Üretiminde münavebe ve nadassız ekimin zorluğu nedeniyle, hızlı üreme kapasitesine sahip, suya adapte olmuş rekabetçi yabancı ot türleri sorun haline gelmiştir. Yabancı otların çeltik verimi ve çiftlik kârları üzerindeki olumsuz etkileri, uygun maliyetli yabancı ot yönetim stratejileri için bir talep yaratmıştır. Aynı etki mekanizmasına sahip herbisitlerin uzun süreli kullanımı herbisitlere dayanıklı yabancı ot türlerinin sayısı ve populasyonunu hızla artırmıştır. Dolayısıyla entegre yabancı ot kontrolü, ülkelerin üretim sistemlerine göre geliştirilmesi gereken ve çeltik yabancı otlarıyla mücadelede önemli bir çözümdür. *Echinochloa crus-galli* (darıcan), çeltik üretim alanlarına uyum sağlamış en önemli yabancı otlarından biridir. Bu çalışmada, etkili yabancı ot yönetimi adına yetiştirme yöntemi, su yönetimi ve çeltik çeşitleri (Osmancık, Gönen, Koral) arasındaki etkileşimin belirlenmesi amaçlanmıştır. Denemeler Türkiye'nin Marmara ve Karadeniz Bölgelerinde, dört tekerrürlü olarak yürütülmüştür. Su seviyesi (özellikle yüksek su seviyesi) sadece yabancı ota karşı oldukça baskılayıcı bir etkiye sahip olmakla kalmayıp, aynı zamanda çeltiğin büyümesini ve verimini artırmaya da yardımcı olmuştur. Derin ve orta su seviyeleri, çeltiğin kardeşlenme sayısı ve kuru ağırlığını artırmıştır. Elde edilen veriler, çeltik ekim alanlarında su seviyesinin korunması ile daha iyi çeltik gelişimi ve yüksek verim elde edilebileceğini ortaya koymuştur. Rekabetçi ve yerel çeltik çeşitlerinin geliştirilmesi, herbisite dayanıklı yabancı otlarla entegre mücadele programında geçerli bir yaklaşım olarak görülmektedir.

Anahtar Kelimeler: *Echinochloa crus-galli, Kültürel Mücadele, Çeltik;Entegre Mücadele.*

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1. INTRODUCTION

The rice production system necessitates a completely aquatic environment, which results in a limited but significant number of weed species that are adapted to this system. Among the most problematic weed species in rice cultivation areas across Asia, America, and Europe, the majority belong to the *Echinochloa* genus. These weed species pose substantial challenges in rice-growing regions and are notoriously difficult to control (Holm et al., 1977; Ruiz-Santaella et al., 2006; Talbert and Burgos, 2007; Mennan et al., 2012). Within this genus, Echinochloa crus-galli stands out as the most prominent species that presents challenges for weed management both globally and in our country (Işık and Mennan, 2001; Damalas et al., 2008; Mennan and Kaya-Altop, 2012). The significant negative impact of weeds on rice yield and farm profitability has spurred a demand for cost-effective weed management strategies. It has been reported that weed-related losses in rice yield account for approximately 40% of total production worldwide (Chauhan and Abugho, 2013).

Yield losses resulting from weed competition not only lead to increased labor costs but also contribute to water shortages, prompting producers to explore alternative weed control methods. Selective herbicides have been widely adopted due to their ease of application, high effectiveness, and cost efficiency when compared to alternative approaches. However, the global use of herbicides has raised concerns about the potential development of herbicide-resistant weeds, shifts in weed populations, environmental contamination, and impacts on human health (Johnson and Mortimer, 2005).

Rice weed control primarily relies on chemical-based methods, predominantly employing ALS and ACCase inhibitor herbicides. However, the issue of herbicide resistance is on the rise, particularly among species within the *Echinochloa* genus. A comprehensive analysis of herbicide resistance across various product groups has identified resistance in 267 weed species since the initial reports, with 154 categorized as dicotyledons and 113 as monocotyledons. Taking into account the number of biotypes within the same species, this figure has expanded to 513. When evaluating the mechanisms of action of herbicides in these studies, the highest resistance has been observed against ALS (Acetolactate Synthesis Enzyme) inhibitory herbicides in 167 species, followed by Photosystem II inhibitor herbicides in 103 species and ACCase (Acetyl-CoA Carboxylase Enzyme) inhibitor herbicides in 49 species. Echinochloa crus galli tops the list of the ten most resistant species to herbicides. In the context of herbicide resistance in rice, 89 out of 171 cases are associated with the Echinochloa and Cyperus genera, and 60 of these cases involve ALS and ACCase resistance records (Anonymous, 2022). It has been determined by Mennan et al. (2012) that E. crus-galli exhibits resistance to at least one or both inhibitor groups of ALS and ACCase inhibitor herbicides in approximately 50% of rice cultivation areas in Turkey's Marmara and Black Sea regions, a problem that is growing over time.

The emphasis on integrated control stems from the dual objectives of maintaining yields and reducing unsustainable herbicide applications. Integrated Weed Management (IWM), encompassing various weed control methods, can aid in rice weed control by delaying resistance development and/or enabling the management of herbicide-resistant weeds. Research has shown that farmers are transitioning to the seedling planting method to address weed concerns, leading to significant investments in machinery. Hence, an integrated control system seeks to establish a connection between planting methods, water management, rice varieties, and weed control. Studies have highlighted the importance of planting methods and water management in weed control (Azmi et al., 1994; Chauhan, 2013). It is imperative to determine the effectiveness of weed suppression, especially as rice planting using the seedling method has recently gained traction.

Given these findings, the goal is to contribute to the development of local integrated control techniques and implement them to manage *E. crus-galli* populations resistant to ALS and ACCase inhibitor herbicides.

2. MATERIAL AND METHOD

Trials were conducted in farmers' fields with the aim of developing a culturally integrated control program to manage herbicide resistance, representing both the Marmara and Black Sea Regions. Careful consideration was given to the selection of trial sites, with a focus on fields previously confirmed to have herbicide-resistant weeds. Several trial factors were taken into account, including the sowing method (broadcast sowing and seedling transplantation), water management (5-7 cm, 10-15 cm, and submergence in winter at 15-20 cm), and rice varieties (Osmancık, Koral, and Gönen). The experiments were carried out with four replications, and the plots were subdivided according to the experimental design. Plot dimensions were set at 50 m^2 (10 m x 5 m), leaving a 2 m safety strip. Once the weeds had emerged, *Echinochloa crus-galli* (barnyardgrass) was intentionally left within the experimental setup, while other weed species were treated with herbicides based on their susceptibility. The average weed density was standardized to 25 plants per m^2 across all plots. In the trials representing the Black Sea Region, rice was planted at a rate of 200 kg/ha in the third week of May in both 2015 and 2016, specifically in the Bafra district of Samsun. In the trials representing the Marmara Region in Edirne Center, adjustments were made during seedling transplantation to achieve a density of 140 plants per m^2. Fertilization and maintenance practices followed regional guidelines. After sowing and planting, various observations were made regarding barnyardgrass and rice varieties, and the potential for weed control was assessed, following criteria established by Estorninos et al. (2005). Various parameters were assessed to understand the competitiveness of rice plants and their interaction with weed control methods. These parameters included:

Seedling Growth Rate: Approximately 21 days after sowing and seedling transplantation, rice plants were carefully removed from a 0.25 m^2 area, and their fresh and dry biomass weights were determined in the laboratory. This data was then used to investigate the relationship between seedling growth rate and competitiveness.

Leaf Area: In each plot, 10 rice plants were selected and brought to the laboratory, where their leaf areas were measured using a leaf area meter, following the method outlined by Gibson et al. (2003b). This assessment aimed to determine whether leaf area had any impact on competition between rice and weeds.

Number of Tillering: Tillering, or the production of additional shoots from the base of the rice plant, is known to play a significant role in competition among rice cultivars. To evaluate this, plants in a 1 m2 area were counted 6 weeks after emergence, and the tillering numbers were manually counted during the harvest. A logistic function was applied to determine the number of tillers with T representing tillering number, Tm as the maximum tillering number, T as the number of days after sowing, and Ta and Tb being fixed parameters of the function.

$$T = Tm/1 + \exp (Ta - Tbt)$$

Plant Height: Plant height was measured at 30, 60, and 90 days after emergence, with ten randomly selected rice plants from each plot and rice cultivar. A logistic function was utilized to explore the competitive relationship, with H representing plant height, Hm as the maximum plant height, t as the number of days, and Ha and Hb as fixed parameters of the function.

$$H = Hm/1 + \exp (Ha - Hbt)$$

Root Weight: At intervals of 30, 60, and 90 days after emergence, ten rice plants from each plot and rice variety were randomly harvested. After washing and sorting, the root parts were separated, and their wet weights were recorded. Subsequently, these roots were dried in an oven at 65°C for 72 hours to determine their dry weights, following the procedure described by Ottis et al. (2005).

Yield: Yield values were obtained by harvesting rice varieties from each plot within a 10 m^2 area. The mean values obtained in the experiment were subjected to statistical analysis using Fisher's protected test with LSD (Least Significant Difference). Arcsine transformations were applied to improve homogeneity before conducting variance analysis (ANOVA) on the obtained weed control percentage values.

3. RESULT

3.1 The Effects of Competition of E. Crus-Galli on Seedling Growth with Different Cultivars in Different Rice Growing Systems

In both the Black Sea Region and the Marmara Region, the data from both years, 2015 and 2016, were found to be statistically nonsignificant in the trials. However, a significant difference between the two regions was identified ($P<0.05$). Therefore, the results from both years were combined to provide a comprehensive overview of the trial outcomes.

Table 1 presents the percentage of dry biomass loss caused by herbicide-resistant Echinochloa crus-galli at a density of 25 plants/m^2 across different rice varieties, planting methods, and water levels for the Black Sea Region, averaging data from 2015 and 2016. Statistical analysis of the two-year averages indicated that the year itself was not a significant factor, allowing for the presentation of combined data. It was observed that planting methods and water levels played a crucial role in rice seedling biomass formation. Notably, the competitive ability of *E. crus-galli* was heightened due to its very early emergence, with the seedling method offering a substantial advantage in early-stage competition. Broadcasting at a water level of only 5-7 cm resulted in intense competition, leading to the highest biomass loss. Conversely, it was noted that biomass loss was reduced at other water levels. The Gonen variety exhibited the highest biomass loss among seedlings at all water levels, with an observed decrease in competition as the water level increased.Turning to the results obtained in the Marmara Region, it is evident that competition was more intense, yielding similar outcomes as shown in Table 2.

These findings shed light on the dynamics of competition between rice and herbicide-resistant *E. crus-galli* under various conditions, emphasizing the importance of planting methods and water management in influencing rice seedling biomass and weed competition.

Table 1. Seedling biomass loss caused by herbicide-resistant *E. crus-galli* in different varieties at 25 plants/m^2 density, different planting methods and water levels, the average of 2015 and 2016 for the Black Sea Region (%).

Planting Methods	Variety	Water Level (cm)			LSD P<0.05
		5-7	10-15	UVV (15-20)	
		Seedling Biomass Loss (%)			
Broadcasting	Osmancık	5.1	2.3	0	0.8
	Koral	5.6	3.0	1.2	1.5
	Gönen	10.6	6.1	5.3	1.1
Transplanting	Osmancık	3.7	0	0	NS
	Koral	2.9	0	0	NS
	Gönen	8.1	5.1	0	1.9

NS; LSD P<0.05 not significant

UVV; under water in winter

Table 2. The percentage of dry biomass loss caused by herbicide-resistant *E. crus-galli* in different varieties at 25 plants/m^2 density, different planting methods and water levels, the average of 2015 and 2016 for the Marmara Region (%).

Planting methods	Variety	Water Level (cm)			LSD P<0.05
		5-7	10-15	UVV (15-20)	
		Seedling Biomass Loss (%)			
Broadcasting	Osmancık	7.1	3.4	2.1	1.9
	Koral	5.9	4.2	1.1	0.8
	Gönen	11.6	8.7	5.7	2.1
Transplanting	Osmancık	3.9	2.4	0	NS
	Koral	3.3	2.1	0	NS
	Gönen	8.2	9.4	6.3	1.2

NS; LSD P<0.05 not significant

UVV; under water in winter

3.2. Effects of Competition of E. Crus-Galli on Tillering of Different Cultivars in Different Rice Growing Systems

Upon combining the results of the studies conducted in 2015 and 2016, the log-logistic model for tillering was found to be significant for both broadcasting and transplanting methods, as illustrated in Figure 1 and Figure 2. The analysis revealed that, on average, there were 4 tillers per plant for the Osmancık variety and 5 tillers per plant for the Koral variety. In the case of the Gonen cultivar, an average of 3.85 tillers was observed (Figure 1). Similarly, when examining the tillering numbers in seedlings, they were lower than expected and consistent with the 2015 results (Figure 2).

Modeling proved to be particularly significant for broadcasting when considering the two-year average. Referring to the tillering numbers in the Black Sea Region from Table 3, it becomes evident that the transplanting method and water level played crucial roles in terms of competition. The highest tillering loss occurred at a water level of 5-7 cm, reaching 23% for the Gonen variety. In contrast, this rate was reduced to 12.4% when transplanting was adopted at the same water level and with the same variety.

This analysis underscores the significant advantage of the seedling method in early-stage competition. However, it is important to note that the cumulative effects observed during the yield phase indicate that this approach may not be the most economically efficient in the long run.

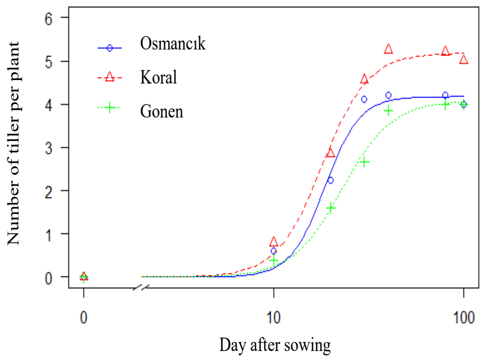

Figure 1. The log-logistic model of tillering numbers obtained in the control plots in the broadcasting system according to the averages of 2015 and 2016 in the Black Sea Region.

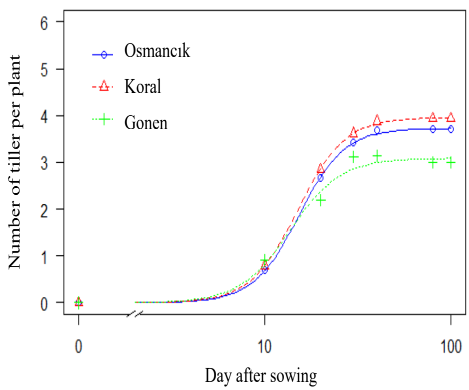

Figure 2. The log-logistic model of tillering numbers obtained in the control plots in the transplanting system according to the averages of 2015 and 2016 in the Black Sea Region.

The tillering rates obtained from the control plots were lower than in the Black Sea Region, as in 2015, and the planting method and water level played an important role in the competition and affected the number of tillers in rice varieties (Table 3). In the results obtained from the Marmara Region, it was seen that the competition of *E. crus-galli* was more intense in both planting methods (Table 4).

Table 3. Tillering number loss by herbicide-resistant *E. crus-galli* in different varieties at 25 plants/m^2 density, different planting methods and water levels, the average of 2015 and 2016 for the Black Sea Region (%).

Planting Methods	Variety	Water Level (cm)			LSD P<0.05
		5-7	10-15	UVV (15-20)	
		Tillering Number Loss (%)			
Broadcasting	Osmancık	10.2	6.3	3.1	2.6
	Koral	14.9	4.4	2.3	3.1
	Gönen	23.1	14.2	9.7	2.7
Transplanting	Osmancık	8.1	4.5	1.1	NS
	Koral	7.7	9.8	1.3	3.1
	Gönen	12.4	8.1	14.1	NS

NS; LSD P<0.05 not significant

UVV; under water in winter

Table 4. The percentage of tillering number loss caused by herbicide-resistant *E. crus-galli* in different varieties at 25 plants/m^2 density, different planting methods and water levels, the average of 2015 and 2016 for the Marmara Region (%).

Planting Methods	Variety	Water Level (cm)			LSD P<0.05
		5-7	10-15	UVV (15-20)	
		Tillering Number Loss (%)			
Broadcasting	Osmancık	12.2	2.4	1.1	1.7
	Koral	11.9	6.8	0.9	2.1
	Gönen	18.7	18.9	15.9	NS
Transplanting	Osmancık	10.1	2.0	0	3.8
	Koral	10.9	3.7	5.4	4.7
	Gönen	21.6	15.5	14.9	NS

NS; LSD P<0.05 not significant

UVV; under water in winter

3.3. The Effects of Competition of E. Crus-Galli on Leaf Area with Different Cultivars in Different Rice Growing Systems

The flag leaf area has revealed that it is not important in competition in different planting methods and in different water levels in 2016, as in 2015. This is thought to be due to the varieties used.

3.4. The Effects of Competition of E. Crus-Galli on Plant Height with Different Cultivars in Different Rice Growing Systems

The results of the log-logistic modeling and variance analysis conducted on the average plant heights from control plots in the Black Sea and Marmara Regions revealed significant differences (P<0.01) between planting methods and rice cultivars, as depicted in Figure 3 and Figure 4.

In plots where the seedling method was employed, plant heights were notably shorter compared to field planting. Notably, variations were observed in the changes in plant height due to competition between the Black Sea Region and the Marmara Region (Tables 5 and 6). Overall, it was observed that competition intensified as water levels decreased. The highest loss in plant height was recorded in the *Echinochloa crus-galli* Gönen variety, amounting to 10.6% at a density of 25 plants/m^2. Moreover, it was evident that the seedling method resulted in greater plant height loss, with the Gönen cultivar experiencing the highest loss at 12.4%. Conversely, an increase in water levels correlated with reduced losses in plant height. These findings underscore the impact of planting methods, water levels, and competition on plant height in rice cultivation, with significant variations observed between regions and varieties.

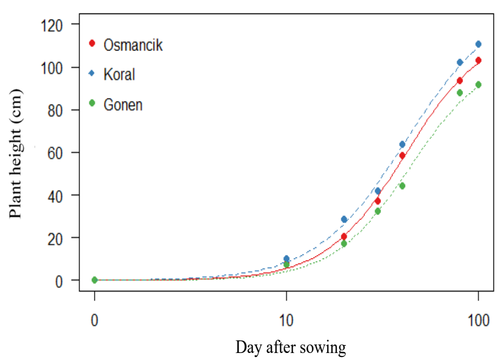

Figure 3. The log-logistic model of plant height was obtained in the control plots in the broadcasting system according to the averages of 2015 and 2016 in the Black Sea Region.

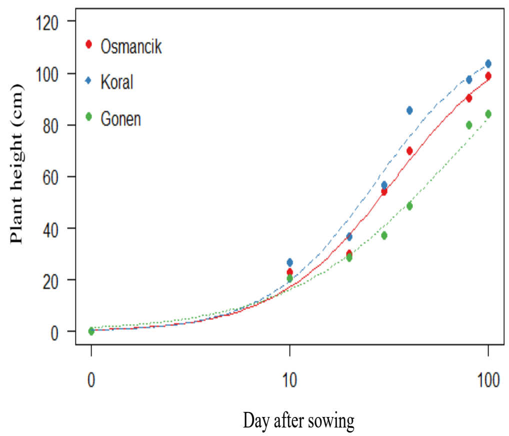

Figure 4. The log-logistic model of plant height was obtained in the control plots in the broadcasting system according to the averages of 2015 and 2016 in the Black Sea Region.

Table 5. Plant height loss caused by herbicide-resistant *E. crus-galli* in different varieties at 25 plants/m^2 density, different planting methods and water levels, the average of 2015 and 2016 for the Black Sea Region (%).

Planting Methods	**Variety**	**Water Level (cm)**			**LSD P<0.05**
		5-7	10-15	UVV (15-20)	
		Plant Height Loss (%)			
Broadcasting	Osmancık	4.3	2.2	1.5	NS
	Koral	6.9	3.8	2.3	1.7
	Gönen	10.6	9.3	10.8	NS
Transplanting	Osmancık	7.3	2.6	0	2.0
	Koral	4.7	3.9	0	1.1
	Gönen	11.9	12.4	9.7	NS

NS; LSD P<0.05 not significant

UVV; under water in winter

Table 6. The percentage of plant height loss caused by herbicide-resistant *E. crus-galli* in different varieties at 25 plants/m^2 density, different planting methods and water levels, the average of 2015 and 2016 for the Marmara Region (%).

Planting Methods	Variety	Water Level (cm)			LSD P<0.05
		5-7	10-15	UVV (15-20)	
		Plant Height Loss (%)			
Broadcasting	Osmancık	6.2	3.9	2.6	NS
	Koral	5.9	7.8	0	1.9
	Gönen	10.1	8.6	5.9	2.2
Transplanting	Osmancık	6.4	5.1	1.2	1.2
	Koral	8.1	2.1	3.9	1.9
	Gönen	14.6	11.4	9.3	NS

NS; LSD P<0.05 not significant

UVV; under water in winter

3.5. The Effects of Competition of E. Crus-Galli on Root Weight with Different Cultivars in Different Rice Growing Systems

Based on the first-year results obtained, there was no observed interaction between root fresh and dry weights, planting methods, and water levels in rice cultivars. These findings suggest that rice varieties may not play a significant role in weed competition in this context. Consequently, specific data related to these parameters are not presented.

3.6. The Effects of Competition of E. Crus-Galli on Yield with Different Cultivars in Different Rice Growing Systems

The average yield values of *Echinochloa crus-galli,* obtained from the trials conducted in the Black Sea Region in 2015 and 2016, focusing on the competition between rice cultivation methods and water levels, are presented in Figure 5 and Figure 6. Among the rice cultivars, the highest grain yield of 903 kg da^{-1} was achieved with the Osmancık variety in the control plots using the pre-germinated and broadcast sowing method. The Koral variety followed closely with a yield of 841 kg da^{-1}. In contrast, the Gonen cultivar exhibited the lowest yield, particularly in the 5-7 cm and 10-15 cm water regimes (Figure 5). Considering the first-year results, there was a significant interaction between Region, Variety, and Water regime (Table 7). Notably, the Gonen variety suffered a product loss of over 20% at the lowest water level, highlighting the sensitivity of this variety to water availability. Regarding seedling yield, it was consistently lower across all cultivars and other factors (Figure 6). The highest yield among seedlings was recorded at 804 kg da^{-1} in the control plots for the Osmancık variety, which employed a sprinkling method.

Following closely, the Koral variety achieved a yield of 799 kg da^{-1}. Importantly, there was no significant difference between these two cultivars in terms of control plots, indicating their similar competitive abilities. Conversely, the lowest seedling yield of 485 kg da^{-1} was observed in the Gonen variety under the 5-7 cm water regime (Figure 6). These findings illustrate the impact of rice cultivar, cultivation method, and water level on grain yield and highlight the importance of water management in achieving optimal crop yields.

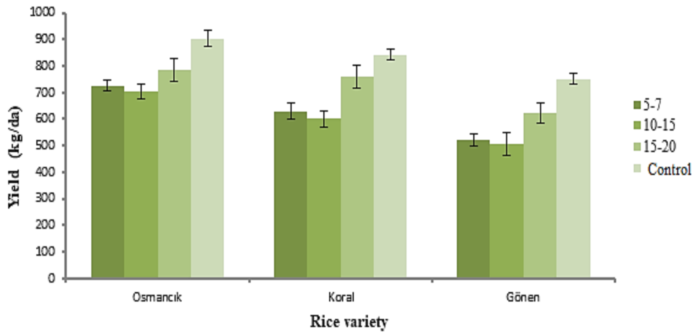

Figure 5. According to the averages of 2015 and 2016 in the Black Sea Region, the broadcasting method of *E. crus-galli* at a density of 25 plants/m^2 and the yield loss in varieties at different water levels.

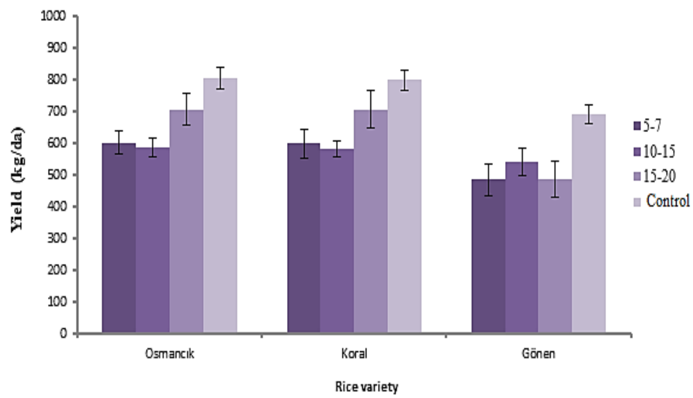

Figure 6. According to the averages of 2015 and 2016 in the Black Sea Region, the transplanting method of *E. crus-galli* at a density of 25 plants/m^2 and the yield loss in varieties at different water levels.

The yields obtained from the Marmara Region, as depicted in Figures 7 and 8, demonstrated outcomes similar to those observed in the Black Sea Region. Significant differences were identified, as in the Black Sea Region, with respect to weed competition involving planting methods, rice cultivars, and water levels. Upon examining the results for the seedling method, although similar trends were observed, it became apparent that *Echinochloa crus-galli* exhibited more pronounced competition with rice varieties. These findings underscore the consistent impact of planting methods, rice cultivars, and water levels on crop yields across different regions, emphasizing the importance of these factors in weed management and optimizing rice production.

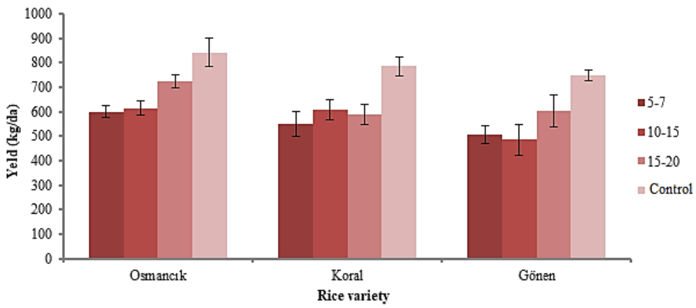

Figure 7. According to the averages of 2015 and 2016 in the Marmara Region, the broadcasting method of *E. crus-galli* at a density of 25 plants/m^2 and the yield loss in varieties at different water levels.

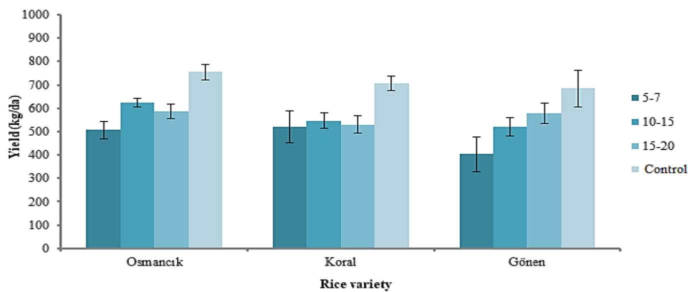

Figure 8. According to the averages of 2015 and 2016 in the Marmara Region, the transplanting method of *E. crus-galli* at a density of 25 plants/m^2 and the yield loss in varieties at different water levels.

Table 7. The importance levels of the competition of *E. crus-galli* with different cultivars according to the ANOVA results in different rice growing systems in Marmara and Black Sea Regions according to the average of 2015 and 2016.

Variation Source	Df	Seedling Fresh Biomass	Seedling Dry Biomass	Tillering Number	Flag Leaf Area	Plant Height	Root Fresh Weight	Root Dry Weight	Yield
Year (Y)	1	NS	*	NS	NS	NS	NS	*	NS
Region (R)	1	NS	*	*	NS	*	NS	NS	**
Variety (V)	2	NS	*	*	NS	**	NS	NS	**
Water regime(W)	2	NS	**	**	NS	**	NS	NS	**
R x Y	1	*	*	NS	NS	NS	NS	NS	NS
R x V	2	NS	NS	***	NS	***	NS	NS	***
Y x V	2	*	NS	**	NS	NS	*	NS	NS
R x W	2	NS	NS	NS	NS	NS	NS	NS	NS
V x W	4	NS	*	**	NS	**	NS	NS	**
Y x V x W	4	*	NS	*	NS	**	NS	NS	*
R x V x W	4	NS	*	NS	NS	*	NS	NS	**
Y x R x V x W	4	*	NS	*	NS	NS	NS	NS	**

NS; not significant
*P<0.05 significant
**P<0.01 significant

4. DISCUSSION AND CONCLUSION

Despite the widespread use of intensive herbicides for weed control in rice cultivation globally, there remains a significant yield loss of 25-35% (Özer, 1993; Radosevich and Holt, 1984; Savary et al., 1997; 2000). If left uncontrolled, this loss can range from 45% to 90% depending on ecological and climatic conditions in different cultivated plants (Ampong-Nyarko and De Data, 1991; Moody, 1996). Developing integrated control systems that rely less on chemical control is crucial in managing weeds resistant to ALS and ACCase inhibitor herbicides (Watanabe et al., 1997; Itah et al., 1999; Fischer et al., 2000). Studies investigating integrated control possibilities for *Echinochloa crus-galli* populations resistant to ALS and ACCase inhibitor herbicides have emphasized the importance of the interaction between water levels, rice cultivars, and planting methods based on cultural practices. Comparing sowing methods, it has been observed that broadcast sowing results in higher yields than seedling planting and demonstrates greater competitive ability against these types of weeds. This advantage is often attributed to the increased tillering of rice and its relationship with competition and yield.

Water levels have also emerged as a critical factor in weed control. Research has consistently shown that maintaining the water level at around 20 cm is essential for effective weed management. Variations in competition among rice varieties have been documented in previous studies. Fischer et al. (1997) found that competition between *Echinochloa* species and different rice varieties can lead to yield differences ranging from 27% to 60%. Other researchers have also noted that certain rice varieties exhibit varying characteristics in terms of yield and weed suppression (Callaway and Forcella, 1992; Rutger et al., 1993; Pester et al., 1999; Gibson et al., 2003b). In regions where weed competition is more pronounced, such as Asia, differences of up to 75% in weed suppression by rice varieties have been observed (Garrity et al., 1992). Additionally, some researchers have found differences within the same rice type and between species (Gealy et al., 2003). Given the challenges posed by cultivation systems and weed control, using rice varieties with high competitiveness is essential (Saito et al., 2010; Chauhan and Johnson, 2011; Mennan et al., 2012).

When examining factors influencing competition between rice varieties and ALS and ACCase inhibitor herbicide-resistant *E. crus-galli*, parameters such as tillering number and rice height were identified as crucial. These parameters yielded similar results in both locations where the experiments were conducted. Overall, factors such as seedling growth rate, flag leaf area, plant height, tillering number, and leaf and root development have been recognized as important in assessing competition between different rice varieties and weeds (Fischer et al., 1997; 2001; Gibson et al., 2003a).

In conclusion, the water level has emerged as a pivotal factor in rice weed competition, and effective weed control hinges on proper water management. Given the potential challenges posed by climate change and water scarcity, it is essential to maintain the water level in rice fields at an optimal level, typically around 20 cm. Furthermore, the development of competitive and locally adapted rice varieties is considered a promising approach in integrated herbicide-resistant weed control programs.

Conflict of Interest

The authors declare that there is no conflict of interest.

Ethics

This study does not require ethics committee approval.

Author Contribution Rates

Design of Study: EKA(%50), HM(%50)

Data Acquisition: EKA(%50), HM(%50)

Data Analysis: EKA(%50), HM(%50)

Writing up: EKA(%100)

Submission and Revision: EKA(%100)

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