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Research Article

Forage Productivity and Quality of Early, Medium, and Late Maturing Italian Ryegrass (*Lolium multiflorum* Lam.) Varieties at Two Distinct Harvest Times in Middle Regions of Korea

Chang-Woo Min[1], Jae Hoon Woo[1], Bo Ram Choi[1], Eun-A Lim[2] and Ki-Won Lee[1,*]

[1]Grassland & Forage Division, National Institute of Animal Science, RDA, Cheonan 31000, Republic of Korea

[2]Relocation Service Team for Department of Animal Resources Development, National Institute of Animal Science, RDA, Cheonan 31000, Republic of Korea

ABSTRACT

Due to climate change and the expansion of cultivation areas through the use of reclaimed land, changes in the selection of Italian ryegrass (*Lolium multiflorum* L.) varieties are anticipated. This study was conducted to compare the growth characteristics before overwintering, productivity, and feed value of eight Italian ryegrass varieties with different maturing stages under the same cultivation conditions. The variety 'Lm4ho', a medium-maturing type, showed superior growth characteristics before overwintering, including plant height, leaf length, and leaf width. The heading date was advanced in all varieties, with a greater degree of advancement observed in varieties with earlier heading dates. When harvested at the heading stage of the early-maturing types, the dry matter yield of the medium-maturing types was not significantly different from that of the early-maturing types. However, when harvested at the heading stage of the medium-maturing types, the dry matter yield was higher than that of the early-maturing types. Specifically, 'Lm4ho' produced 2,518 kg/ha more than 'Kowinearly'. The late-maturing variety IR901 and the medium-maturing varieties 'Lm4ho' and 'Kowinmaster' showed statistically superior dry matter yields. In terms of forage value, including crude protein (CP), total digestible nutrients (TDN), and relative feed value (RFV), the medium- and late-maturing types outperformed the early-maturing types. Notably, 'Lm4ho', 'IR 901', and 'Hwasan 104' were evaluated as suitable varieties for high-quality forage production. These results suggest that medium-maturing varieties may be suitable for double cropping in the central regions due to climate change. We propose that future breeding of Italian ryegrass should expand from focusing on cold tolerance and early-maturing varieties to include medium- and late-maturing varieties that consider both productivity and quality.

(**Key words**: Italian ryegrass, Variety, Different maturity, Growth characteristics)

Ⅰ. INTRODUCTION

According to the Ministry of Agriculture, Food and Rural Affairs, as of 2023, 74% of domestically produced forage crops in South Korea are winter forage crops, among which Italian ryegrass (*Lolium multiflorum* Lam.) is the most widely cultivated, accounting for 86% of winter forage crops. Italian ryegrass is commonly used in temperate regions due to its excellent forage quality, palatability, and high dry matter yield (Wang et al., 2015). It is particularly favored by farmers for its excellent waterlogging tolerance, allowing it to be cultivated on paddy fields after rice cultivation (Ji et al., 2011; Oh et al., 2021). However, Italian ryegrass has a lower cold tolerance compared to other winter forage crops, limiting its cultivation primarily to the southern regions of Korea (Kim and Sung, 2021; Nam et al., 2023). For this reason, there has been ongoing research to develop early-maturing varieties suitable for double cropping with rice, as well as those with enhanced cold tolerance (Choi et al., 2006; Choi et al., 2007; Ji et al., 2018).

According to the Sixth Assessment Report (AR6) published by the Intergovernmental Panel on Climate Change (IPCC), the global average temperature is projected to rise between 1.4℃ and 4.4℃ by the late 21st century (2081-2100) under the SSP scenarios (IPCC, 2021). In South Korea, the average annual temperature is expected to increase by 2.3℃ to 6.3℃ compared

*Corresponding author: Ki-Won Lee, Grassland & Forages Division, National Institute of Animal Science, RDA, Cheonan 31000, Republic of Korea
Tel: +82-41-580-6757, E-mail: kiwon@korea.kr

to the present (2000-2019) (NIMS, 2022), which will shift the country's climate zone from temperate to subtropical and expand the suitable cultivation areas for crops northward (Hur et al., 2024).

For Italian ryegrass, regions like Gangwon-do, which showed less than 45% suitability in the past (1950-2000), are predicted to achieve over 94% suitability by the 2080s (2070-2099) (Kim et al., 2014). Research applying the RCP (Representative concentration pathways) 8.5 scenario predicts that up to 88.9% of South Korea's land area will become suitable for Italian ryegrass cultivation by the end of the 21st century (Jung et al., 2020). Additionally, the rise in average temperatures due to climate change is extending the growing season of plants by approximately 4.2 days per decade (Jung et al., 2015), with spring temperature increases leading to earlier flowering (Lee et al., 2020b).

Early-maturing Italian ryegrass varieties have been preferred due to their rapid maturation, which makes them suitable for double cropping with rice, with the variety 'Kowinearly' being particularly popular (Woo et al., 2024). However, global warming and the resulting phenological changes may alter the preferences for Italian ryegrass varieties. For example, recent reports indicate that the average heading date of medium-maturing varieties is 8 May (Min et al., 2024), similar to the 7 May heading date of the early-maturing Kowinearly when it was first reported (Choi et al., 2011). This suggests that medium-maturing varieties, which previously had limited cultivation due to their later heading despite their higher yield, could now replace early-maturing varieties as climate change advances their heading dates. Furthermore, the warmer winters resulting from global warming have underscored the importance of varieties with enhanced cold tolerance. Rising winter temperatures negatively impact cold acclimation, reducing overwintering rates, and increasing vulnerability to cold wave and late cold snap (Min et al., 2015; Frascaroli, 2018). Late-maturing varieties strengthen cold tolerance by slowing growth to adapt to chronic abiotic stress (Keep et al., 2021) and have been reported to exhibit superior cold tolerance compared to early-maturing varieties (Tyler and Chorlton, 1978; Humphreys and Eagles, 1988).

Policy factors also play a significant role in influencing the preference for Italian ryegrass varieties. To stabilize rice supply, the government aims to utilize reclaimed paddy fields, which were originally developed for rice cultivation, for multiple purposes. Consequently, there is a recommendation to cultivate forage crops on these reclaimed lands, as they have higher environmental resistance compared to upland crops (Sohn et al., 2009; Back et al., 2011). This shift has led to increased demand for medium- and late-maturing Italian ryegrass varieties with superior productivity.

Farmers aim to select varieties suited to their cultivation environments while considering input costs, making comparative data on the productivity and forage value of each variety a critical indicator. However, studies on Italian ryegrass varieties in South Korea have been conducted under varying conditions, making direct comparisons between varieties challenging. Even studies conducted under uniform conditions have been limited to comparisons among varieties with similar maturity (Song et al., 2023; Min et al., 2024). Therefore, this study aims to conduct a comparative analysis of growth characteristics, productivity, and feed value among eight Italian ryegrass varieties, including three early-maturing, three medium-maturing, and two late-maturing varieties, cultivated under uniform conditions and harvested on the same date. This analysis is intended to provide empirical data to inform the optimal selection of varieties in response to climate change and policy demands.

Ⅱ. MATERIALS AND METHODS

1. Experimental site and plant materials

This study was conducted to compare the growth characteristics of eight Italian ryegrass varieties, which were classified into three early-maturing varieties ('Kowinearly', 'Oasis', 'Florida 80'), three medium-maturing varieties ('Kowinmaster', 'Lm4ho', 'Typhoon'), and two late-maturing varieties ('IR 901', 'Hwasan 104'). The experiment was carried out from September 2023 to May 2024 at the experimental fields of the Grassland and Forage Division, National Institute of Animal Science, located in Cheonan, Chungcheongnam-do, South Korea (36°55′54.1″N, 127°06′21.9″E). The chemical properties of the soil at the experimental site are presented in Table 1, and the climate conditions during the experimental period are shown in Table 2. All varieties were sown simultaneously on 20 September, 2023. To evaluate the growth characteristics and productivity of each variety at the early-maturing and medium-maturing harvest stages, six plots of 1 m² (1 m × 1 m) were established per variety. Three plots were assessed and harvested on 25 April, and the remaining three plots were assessed and harvested on 14 May.

2. Cultivation conditions

The Italian ryegrass was sown at a rate of 30 kg/ha with a row spacing of 20 cm. Fertilization rates were 200-150-150 kg/ha for N-P_2O_5-K_2O, respectively. For nitrogen, 30% was applied as basal fertilizer before sowing, and 70% was applied as topdressing at the beginning of spring growth. Phosphorus and potassium were each applied at 50% as basal fertilizer before sowing, with the remaining 50% applied as topdressing at the beginning of spring growth. Weed control was conducted through hand weeding throughout the cultivation period.

3. Growth characteristics

The emergence rate was evaluated based on the coverage of the entire plot, with good plants rated as 1 and poor plants rated as 9. Leaf length and leaf width before overwintering were measured on the most recently fully emerged leaf, while the flag leaf measurements at the heading stage were taken from the leaf directly below the inflorescence. Leaf length was measured from the base where it meets the stem to the tip of the leaf, and leaf width was measured vertically at the midpoint of the leaf length. Plant length was measured from the ground to the top of the stem or the tip of the leaf. The day when 40% of plants in an experimental plot were headed was considered the heading date. Cold tolerance, lodging resistance, waterlogging tolerance, and disease resistance among the growth characteristics of Italian ryegrass were assessed visually by observing the plants within the plots. Plants were rated on a scale from 1 to 9, with 1 representing strong or good plants and 9 representing weak or poor plants.

4. Productivity

The productivity of each Italian ryegrass variety was assessed by harvesting the entire plot and measuring the fresh weight, which was then converted to a per hectare basis. For dry matter yield, samples weighing approximately 300-400 g were collected from each plot on the harvest day and dried in a circulating air dryer at 65℃ for at least 72 hours. The weight of the dried samples was measured to calculate the dry matter content. The dry matter yield was determined by multiplying the fresh yield by the dry matter content.

5. Feed value

The acid detergent fiber (ADF) and neutral detergent fiber (NDF) contents of Italian ryegrass were analyzed according to the method of Goering and Van Soest (1970). Crude protein content was analyzed using the AOAC (1990) method. The total digestible nutrient (TDN) was analyzed and calculated using the method of Menke and Huss (1980). Dry matter intake (DMI), digestible dry matter (DDM), and relative feed value (RFV) were calculated using the following formulas provided by Goering and Van Soest (1970).

- TDN = 88.9 - (0.79 × ADF %)
- DDM = 88.9 – (0.779 × ADF %)
- DMI (% of Body Weight) = 120 / (NDF %)
- RFV = (DDM × DMI) / 1.29

6. Statistical analysis

Statistical analysis was performed using the R program (version R-4.4.0, 2024) (Team, 2024). Analysis of variance (ANOVA) was conducted using the *aov* function from the *stats* package, following a randomized complete block design to compare the means between varieties. For factors showing significant differences, multiple comparison method was performed at the 5% significance level using Duncan's multiple range test with the *duncan.test* function from the *agricolae* package (de Mendiburu, 2023).

Ⅲ. RESULTS AND DISCUSSION

1. Soil and climate condition on the experimental site

The chemical properties of the soil at the experimental field are presented in Table 1. The reference range for cultivating Italian ryegrass in the experimental field was based on prescription criteria for fertilizer use by crop (NIAS, 2022). The soil pH was 6.5, which is within the optimal range of 6.0-6.5 for Italian ryegrass cultivation. Organic matter and

Table 1. Chemical properties of soil at experimental site

pH (1:5)	T-N[1] (%)	OM[2] (g/kg)	Av. P_2O_5[3] (mg/kg)	EC[4] (dS/m)	Ex. cations ($cmol_c$/kg)			CEC[4] ($cmol_c$/kg)
					K	Ca	Mg	
6.5	0.17	31.60	1309.25	0.28	0.38	7.97	2.31	13.80

T-N[1], total nitrogen; OM[2], organic matter; Av.[3], available; EC[4], electric conductivity; Ex.[5], exchangable; CEC[6], cation exchange capacity.

Table 2. Mean air temperature (℃) and total precipitation (mm) during experimental periods compared to the previous decade (2014-2023) at the experimental site

Month	Mean air temperature (℃)			Total precipitation (mm)		
	Experimental period '23-'24	Normal year	Anomaly	Experimental period '23-'24	Normal year	Anomaly
Sep.	22.5	20.6	1.9	404	198.5	205.5
Oct.	13.9	13.3	0.6	180.3	149.8	30.5
Nov.	6.5	6.6	-0.1	72.5	147.2	-74.7
Dec.	0.6	-0.8	1.4	348	137.9	210.1
Jan.	-0.9	-2.6	1.7	23	148.9	-125.9
Feb.	3	-0.2	3.2	276.6	81.7	194.9
Mar.	6	6.3	-0.3	135.9	100.2	35.7
Apr.	14.5	11.7	2.8	49.5	183.7	-134.2
May	15.8	17.8	-2	242.1	151.6	90.5

Source : Agricultural Weather Infomation Service (RDA).

available phosphorus contents were 31.60 g/kg and 1,309.25 mg/kg, respectively, both exceeding the upper limits of the recommended ranges of 30 g/kg and 250 mg/kg. For exchangeable cations, potassium (K) was 0.38 $cmol_c$/kg, which is below the minimum recommended range of 0.45 $cmol_c$/kg. In contrast, calcium (Ca) and sodium (Na) levels were 7.97 $cmol_c$/kg and 2.31 $cmol_c$/kg, respectively, both exceeding the upper limits of their respective recommended ranges of 6.0 $cmol_c$/kg and 2.0 $cmol_c$/kg. The cation exchange capacity was 13.80 $cmol_c$/kg, which is within the optimal range of 10-15 $cmol_c$/kg for Italian ryegrass cultivation.

The mean air temperature and precipitation during the experimental period are shown in Table 2. The monthly mean air temperatures were generally 0.6-3.2℃ higher than the normal year. Notably, during the overwintering period from December to February, the mean air temperature was 2.1℃ higher than the normal year, maintaining above-freezing temperatures except in January. Consequently, the overwintering period was shorter because the mean air temperature reached the lower limit of 5℃ earlier than normal, which is the threshold for the accumulation of growing degree days (Kim and Sung, 2021). The total precipitation during the cultivation period was 432.4 mm higher than the normal year total. In February and March, the total precipitation was 276.6 mm and 135.9 mm, respectively, which were 194.9 mm and 35.7 mm more than the normal year totals for those months.

2. Growth characteristics

The growth characteristics before overwintering for the eight Italian ryegrass varieties are shown in Table 3. Emergence rates were highest in the early-maturing varieties 'Kowinearly', 'Oasis', and 'Florida 80', with 'Oasis' showing the best emergence rate. For plant length, the medium-maturing varieties 'Lm4ho' and 'Typhoon' were significantly longer than the other varieties, measuring 39.4 cm and 39.6 cm, respectively. The number of tillers was the most in the Kowinearly variety (10.7), while the Oasis variety had the lowest number of tillers (6.3). the most recently fully emerged leaf length and width before overwintering were also measured, with 'Lm4ho' showing the longest and widest leaves at 29.3 cm and 7.61 mm, respectively. The growth characteristics of Italian ryegrass at their respective heading stages

Table 3. Comparison of growth characteristic, which include emergence rate, plant length, number of tillers, leaf length and width in 8 Italian ryegrass varieties before over wintering

Varieties/ Parameters	Emergence rate (1~9)*	Plant length (cm)	No. tillers per plant	Leaf length (cm)	Leaf wide (mm)
Kowinearly	2.0^{de}	26.5^{e}	10.7^{a}	18.5^{c}	5.58^{c}
Oasis	1.0^{e}	30.3^{cd}	6.3^{d}	20.6^{c}	5.14^{c}
Florida 80	2.3^{cd}	36.2^{b}	8.0^{bc}	26.5^{b}	6.99^{b}
Kowinmaster	3.0^{bcd}	27.5^{de}	8.2^{bc}	20.6^{c}	5.59^{c}
Lm4ho	3.7^{ab}	39.4^{a}	8.0^{bc}	29.3^{a}	7.61^{a}
Typhoon	3.3^{abc}	39.6^{a}	8.4^{bc}	25.9^{b}	7.01^{b}
IR 901	3.3^{abc}	34.9^{b}	7.7^{cd}	27.9^{ab}	6.77^{b}
Hwasan 104	4.3^{a}	33.3^{bc}	9.3^{ab}	26.4^{b}	6.91^{b}
p-value	$6.72 \cdot 10^{-4}$	$8.00 \cdot 10^{-7}$	$6.31 \cdot 10^{-4}$	$7.05 \cdot 10^{-7}$	$5.11 \cdot 10^{-7}$
SEM	0.6	2.97	0.73	2.32	0.255

[a-e] means within a row without a common superscript letter are significantly different ($p<0.05$).
[*] 1 : strong or excellent, 9 : weak or worst.
SEM, standard error of the mean.

Table 4. Comparison of growth characteristic, which include winter survival, lodging tolerance, leafiness, heading date, flag leaf length and width in 8 Italian ryegrass varieties at heading stage

Varieties / Parameters	Winter survival (1~9)*	Logging tolerance (1~9)*	Leafiness (1~9)*	Heading date (month/day)	Flag leaf length (cm)	Flag leaf wide (mm)
Kowinearly	1	3	3	4/22	15.53^{c}	6.61^{bc}
Oasis	1	2	3	4/29	15.53^{c}	6.31^{c}
Florida 80	1	3	4	4/26	16.40^{c}	6.33^{c}
Kowinmaster	1	2	3	4/26	17.58^{c}	6.44^{c}
Lm4ho	1	1	1	5/07	24.69^{a}	9.42^{a}
Typhoon	1	3	3	4/26	17.80^{c}	6.87^{bc}
IR 901	1	1	1	5/11	20.81^{b}	6.85^{bc}
Hwasan 104	1	1	1	5/19	20.91^{b}	7.42^{b}
p-value					$1.42 \cdot 10^{-5}$	$2.77 \cdot 10^{-5}$
SEM					1.242	0.483

[a-c] Means in the column with different superscripts are significantly different ($p<0.05$).
[*] 1 : strong or excellent, 9 : weak or worst.
SEM, standard error of the mean.

are shown in Table 4. All Italian ryegrass varieties exhibited excellent overwintering rates under the climatic conditions of Cheonan, a central region in Korea. When grouped by maturity (early, medium, and late), the flag leaf length was greater than 20 cm in the medium- and late-maturing varieties, and the flag leaf width exceeded 7 mm. Among the medium- and late-maturing varieties, ‘Lm4ho’ had the longest and widest flag leaves at 24.69 cm and 9.42 mm, respectively, followed by ‘Hwasan 104’ and ‘IR 901’, which had flag leaf lengths and widths of over 20.80 cm and 6.85 mm, respectively. ‘Lm4ho’, ‘IR 901’, and ‘Hwasan 104’ demonstrated superior resistance to lodging and leafiness compared to other varieties. The correlation between heading date and leafiness has been reported in Crested wheatgrass, where leafiness was positively correlated with a later heading date (Tandoh et al., 2019). Additionally, in Perennial ryegrass, expression of the Arabidopsis ATH1 gene delayed heading and increased leafiness; this study reported that leafiness generally increased in varieties with delayed heading (van der Valk et al., 2004).

The heading date was earliest in the early-maturing varieties, averaging 25 April, with ‘Kowinearly’ being the earliest at 22 April. In this study, the average heading date of the medium-maturing varieties was 29 April, which is over two weeks earlier than when the ‘Kowinmaster’ was first developed (Choi et al., 2008) and over 10 days earlier than when growth characteristics and productivity of ‘Typhoon’ were evaluated in Korea, 2012 (Shin et al., 2012). The average heading date for the late-maturing varieties was 15 May, with ‘Hwasan 104’ having the latest heading date on 19 May. Compared to the time when these varieties were developed, there was no difference in the heading date for ‘Hwasan 104’ (Choi et al., 2005), whereas ‘Kowinearly’ showed a 15-day advancement from its original heading date of 7 May (Choi et al., 2011). Global warming due to greenhouse gas emissions has been inducing phenological changes, particularly affecting spring (Jung et al., 2015). The warming and drying of spring have shortened the first flowering dates, with more dramatic changes observed in early-maturing species (Lee et al., 2020b). Considering these results, the advancement of heading dates in Italian ryegrass, especially in early-maturing varieties, is likely influenced by climate change.

3. Comparison of growth characteristics and productivity of italian ryegrass varieties at two uniform harvesting times

The growth characteristics and productivity of eight Italian ryegrass varieties harvested on 25 April, corresponding to the harvesting time for the early-maturing varieties, are presented in Table 5. When plant length was measured by maturity stage, the early-maturing varieties had an average height of 101 cm, the medium-maturing varieties averaged 98.5 cm, and the late-maturing varieties averaged 79.9 cm, with the early-maturing varieties being the longest. Notably, the ‘Kowinearly’ variety had the greatest plant height at 108.1 cm. In contrast, there was an inverse relationship between stem diameter and plant height, with early-maturing varieties having an average stem diameter of 2.66 mm, medium-maturing varieties averaging 2.73 mm, and late-maturing varieties averaging 3.02 mm. Among these, the medium-maturing variety ‘Lm4ho’ had the thickest stems at 3.30 mm, followed by the late-maturing varieties ‘IR 901’ and ‘Hwasan 104’ at 3.05 mm and 2.99 mm, respectively. Resistance to lodging in crops increases with stronger stem strength, which is strongly positively correlated with stem diameter (Inoue et al., 2004). When the lodging resistance of the eight Italian ryegrass varieties was assessed at their respective heading dates, these three varieties showed the best resistance, likely due to their thicker stems compared to the other varieties. At harvesting times of the

Table 5. Comparison of agronomic characteristic, which include plant length, stem diameter, fresh and dry matter in 8 Italian ryegrass varieties at heading date of early-maturing varieties

Varieties / Parameters	Early-maturity heading stage (4/25)			
	Plant length (cm)	Stem diameter (mm)	Fresh matter (kg/ha)	Dry matter (kg/ha)
Kowinearly	108.1^{a}	2.78^{bcd}	$46,333^{cd}$	$9,265^{b}$
Oasis	94.2^{c}	2.59^{bcd}	$53,333^{b}$	$9,643^{b}$
Florida 80	100.7^{b}	2.62^{bcd}	$62,667^{a}$	$9,675^{b}$
Kowinmaster	101.4^{b}	2.36^{d}	$54,667^{b}$	$9,388^{b}$
Lm4ho	96.4^{bc}	3.30^{a}	$56,000^{b}$	$8,954^{b}$
Typhoon	97.6^{bc}	2.54^{cd}	$53,667^{b}$	$11,369^{a}$
IR 901	87.9^{d}	3.05^{ab}	$49,333^{bc}$	$7,583^{c}$
Hwasan 104	71.8^{e}	2.99^{abc}	$40,333^{d}$	$6,210^{d}$
p-value	$1.17 \cdot 10^{-8}$	$5.35 \cdot 10^{-3}$	$1.80 \cdot 10^{-4}$	$1.20 \cdot 10^{-5}$
SEM	2.44	0.214	5394.9	792.0

$^{a-e}$ means in the column with different superscripts are significantly different (p<0.05).
SEM, Standard error of the mean.

early-maturing varieties, the dry matter yield of Italian ryegrass averaged 9,903 kg/ha for medium-maturing varieties, which was the highest among the groups, followed by early-maturing varieties at 9,528 kg/ha, and late-maturing varieties at 6,897 kg/ha. The high average dry matter yield of the medium-maturing group was primarily due to the 'Typhoon' variety, which had a significantly higher yield of 11,369 kg/ha when harvested in late April, the harvest time for early-maturing varieties, while 'Kowinmaster' and 'Lm4ho' each produced less than 9,000 kg/ha. Comparing the dry matter yields of individual varieties, there were no significant differences between the early-maturing varieties 'Kowinearly', 'Oasis', and 'Florida 80', and the medium-maturing varieties 'Kowinmaster' and 'Lm4ho', except for 'Typhoon'. The late-maturing variety 'Hwasan 104' had the lowest yield at 6,210 kg/ha. Since the medium-maturing varieties had similar productivity to the early-maturing varieties at the early-maturing harvest time, it is expected that cultivating medium-maturing varieties under current climate conditions in central regions, and harvesting them at the same time as the harvest time for early-maturing varieties for double cropping, would not result in yield reductions. This suggests that the cultivation range for medium-maturing varieties could be extended to central regions.

The productivity and growth characteristics of eight Italian ryegrass varieties harvested on 14 May, corresponding to harvest time for the medium-maturing varieties, are presented in Table 6. When measured by maturity, the plant length of early- and medium-maturing varieties were similar, averaging around 114 cm, with no significant differences among the six varieties in length. Nonetheless, 'Kowinmaster' tended to have a greater plant length at 117.1 cm. The late-maturing varieties had the shortest plant height, averaging 97.9 cm, with 'Hwasan 104' being the shortest at 91.0 cm. The late-maturing varieties had the thickest average stem diameter at 3.25 mm, followed by medium-maturing varieties at 2.93 mm, and early-maturing varieties at 2.68 mm. The two late-maturing varieties and the medium-maturing variety 'Lm4ho', which showed strong lodging resistance, all had stem diameters exceeding 3.00 mm with 'Hwasan 104' having the thickest stems at 3.30 mm. When the dry matter yield of the eight Italian ryegrass varieties was compared by maturity at the harvest time for medium-maturing varieties, medium-maturing varieties had the highest average yield of 14,741 kg/ha, followed by late-maturing varieties at 13,908 kg/ha, and early-maturing varieties at 13,507 kg/ha. Among the varieties, the late-maturing 'IR 901' and the medium-maturing 'Lm4ho' and 'Kowinmaster' were in the highest yield group, with 'IR 901' having the highest yield at 16,702 kg/ha, followed by 'Lm4ho' at 15,828 kg/ha. These results suggest that cultivating medium- and late-maturing varieties, and harvesting at the typical Italian ryegrass harvest time in May, can provide higher dry matter productivity.

Table 6. Comparison of agronomic characteristic, which include plant length, stem diameter, fresh and dry matter in 8 Italian ryegrass varieties at heading date of mid-maturing varieties

Varieties / Parameters	Mid-maturity heading stage (5/14)			
	Plant length (cm)	Stem diameter (mm)	Fresh matter (kg/ha)	Dry matter (kg/ha)
Kowinearly	112.7^{a}	2.68^{cd}	$38,133^{e}$	$13,310^{cd}$
Oasis	114.7^{a}	2.44^{d}	$46,467^{bcd}$	$13,670^{bc}$
Florida 80	116.1^{a}	2.93^{abc}	$41,567^{cde}$	$13,541^{bc}$
Kowinmaster	117.1^{a}	2.87^{abcd}	$47,533^{bc}$	$15,094^{abc}$
Lm4ho	113.7^{a}	3.11^{abc}	$57,100^{a}$	$15,828^{ab}$
Typhoon	111.8^{a}	2.80^{bcd}	$41,200^{de}$	$13,302^{cd}$
IR 901	104.8^{b}	3.19^{ab}	$60,967^{a}$	$16,702^{a}$
Hwasan 104	91.0^{c}	3.30^{a}	$49,200^{b}$	$11,115^{d}$
p-value	$1.66 \cdot 10^{-5}$	$7.46 \cdot 10^{-3}$	$6.15 \cdot 10^{-6}$	$2.71 \cdot 10^{-3}$
SEM	3.44	0.193	4633.5	1687.8

$^{a-e}$ means in the column with different superscripts are significantly different ($p<0.05$).
SEM, Standard error of the mean.

4. Comparison of feed value of Italian ryegrass varieties at two uniform harvesting times

The feed value of eight Italian ryegrass varieties at the early-maturing harvest time is presented in Table 7. The neutral detergent fiber (NDF) content was highest in the early-maturing varieties, averaging 55.95%, followed by medium-maturing varieties at 52.55%, and lowest in late-maturing varieties at 47.62%. When comparing individual varieties, 'Florida 80' had the highest NDF content at 58.34%, while 'IR 901' and 'Hwasan 104' had the lowest values at 46.77% and 48.46%, respectively. Acid detergent fiber (ADF) content followed a similar trend to NDF, with early-maturing varieties averaging 32.42%, medium-maturing varieties at 30.34%, and late-maturing varieties at 26.66%. Among the varieties, 'Florida 80' also had the highest ADF content at 33.64%, whereas the late-maturing varieties 'IR 901' and 'Hwasan 104' had the lowest values at 26.50% and 26.81%, respectively. In terms of crude protein (CP) content, late-maturing varieties had the highest average at 10.75%, followed by early-maturing varieties at 10.71%, and medium-maturing varieties at 9.83%. Among individual varieties, the early-maturing 'Florida 80', the medium-maturing 'Kowinmaster', and the late-maturing 'Hwasan 104' had the highest CP contents at 12.26%, 11.82%, and 11.48%, respectively. In contrast, the medium-maturing variety 'Typhoon' had the lowest CP content at 7.43%. Although there were differences in CP content among varieties, it is generally known that CP content decreases as growth progresses (Erkovan et al., 2009). Therefore, the medium-maturing varieties, which are in a younger growth stage than early-maturing varieties, would typically be expected to have higher CP content. However, the early heading of 'Typhoon' likely influenced the lower average CP content observed.

Relative feed value (RFV), which combines digestibility and intake potential into a single index and is widely used as a forage quality index(Tucak et al., 2021; Stokes and Prostko, 2024), was highest in late-maturing varieties at an average of 133.24, followed by medium-maturing varieties at 115.64, and early-maturing varieties at 106.20. When comparing individual varieties, 'IR 901' and 'Hwasan 104', both late-maturing varieties, had the highest RFV at 135.83 and 130.64, respectively. They were followed by the medium-maturing 'Lm4ho' and 'Typhoon', with RFVs of 119.45 and 116.73, respectively. Total digestible nutrients (TDN), which represent the usable energy content in forage for livestock (Kim et al., 2019), were also highest in the late-maturing varieties at an average of 67.85%, followed by medium-maturing varieties at 64.93%, and early-maturing varieties at 63.29%. Among the individual varieties, 'IR 901' and 'Hwasan 104' had the highest TDN values at 67.97% and 67.72%, respectively, followed by

Table 7. Comparison of feed value, which include ndf, adf, cp, tdn and rfv in 8 italian ryegrass cultivars at heading date of early-maturing varieties

varieties / parameters	early-maturity heading stage (4/25)				
	ndf[1] (%)	adf[2] (%)	cp[3] (%)	tdn[4] (%)	rfv[5] (%)
kowinearly	55.74[b]	32.54[ab]	9.96[c]	63.19[de]	106.60[d]
oasis	53.76[bc]	31.09[bcd]	9.91[c]	64.34[bcd]	112.02[cd]
florida 80	58.34[a]	33.64[a]	12.26[a]	62.33[e]	99.99[e]
kowinmaster	54.16[b]	31.38[bc]	11.82[ab]	64.11[cd]	110.74[cd]
lm4ho	51.45[d]	29.34[d]	10.25[bc]	65.72[b]	119.45[b]
typhoon	52.04[cd]	30.30[cd]	7.43[d]	64.97[bc]	116.73[bc]
ir 901	46.77[e]	26.50[e]	10.01[c]	67.97[a]	135.83[a]
hwasan 104	48.46[e]	26.81[e]	11.48[abc]	67.72[a]	130.64[a]
p-value	$8.25 \cdot 10^{-8}$	$3.76 \cdot 10^{-6}$	$3.29 \cdot 10^{-4}$	$3.74 \cdot 10^{-6}$	$7.23 \cdot 10^{-8}$
sem	1.421	0.995	1.035	0.785	4.442

[a-e] means in the column with different superscripts are significantly different ($p<0.05$).
ndf[1], neutral detergent fiber; adf[2], acid detergent fiber; cp[3], crude protein; tdn[4], total digestible nutrients; rfv[5], relative feed value; sem, standard error of the mean.

the medium-maturing ‘Lm4ho’ and ‘Typhoon’ at 65.72% and 64.97%, respectively.

The feed value of the eight Italian ryegrass varieties at the harvest time for medium-maturing varieties is shown in Table 8. As forage crops mature, the proportion of stems increases, leading to higher ADF and NDF contents and lower CP content (Jimenez-Rosales et al., 2022). Therefore, when harvested at the harvest time for medium-maturing varieties, the NDF content increased by 2.85% and 2.41% in the medium- and late-maturing varieties, respectively, while the ADF content increased by 2.20% and 2.25%, respectively. In contrast, the early-maturing varieties showed a decrease in NDF content by 1.19% and a decrease in ADF content by 0.14% compared to those harvested at the harvesting time for early-maturing varieties. This exception is likely due to the decreases in NDF by 1.99% and 3.53% and ADF by 1.06% and 1.09% observed in ‘Kowinearly’ and ‘Florida 80’ when harvested at the harvesting time for medium-maturing varieties, which may be related to the maturation of grains. Studies using whole crop rice have shown that the accumulation of starch in grains tends to reduce NDF content after heading (Kim et al., 2007). Similarly, in Triticale, NDF content, which increases from pre-heading stage to post-flowering stage, decreases when grain maturation progresses (Lee et al., 2020a). Therefore, the accumulation of starch in grains can influence overall NDF content, particularly in early-maturing varieties such as ‘Kowinearly’ and ‘Florida 80’, which reach the grain maturation stage earlier. CP content decreased in all varieties as maturity progressed, with late-maturing varieties averaging 7.35%, medium-maturing varieties at 6.93%, and early-maturing varieties at 5.62%. Among the late-maturing varieties, only ‘Hwasan 104’ had a CP content above 8%, while the remaining late- and medium-maturing varieties were between 6% and 8%, and all early-maturing varieties were below 5%. When comparing RFV by maturity at the medium-maturing harvest time, late-maturing varieties averaged 123, followed by early-maturing varieties at 109, and medium-maturing varieties at 107, indicating that the decreases in NDF and ADF content reversed the ranking of early- and medium-maturing averages. Among individual varieties, the late-maturing ‘IR 901’ had the highest RFV at 126.29, followed by ‘Hwasan 104’ at 120.21, and the medium-maturing ‘Lm4ho’ at 118.96. Notably, ‘Lm4ho’ showed the smallest decrease in RFV. TDN followed the same trend as RFV, with late-maturing varieties averaging 65.87%, early-maturing varieties at 63.39%, and medium-maturing varieties at 63.19%. Among individual varieties, the late-maturing ‘IR 901’, ‘Hwasan 104’, and medium-maturing ‘Lm4ho’ had the highest TDN at 65.98%, 65.75%, and 64.97%, respectively. Considering RFV, TDN, and CP content, the late-maturing varieties consistently exhibited the highest forage quality at all harvest times, while the medium-maturing varieties were generally superior or comparable to the early-maturing varieties. These results suggest that selecting medium- or late-maturing varieties is appropriate for producing

Table 8. Comparison of feed value, which include NDF, ADF, CP, TDN and RFV in 8 Italian ryegrass cultivars at heading date of mid-maturing varieties

Varieties / Parameters	Mid-maturity Heading stage (5/14)				
	NDF[1]	ADF[2]	CP[3]	TDN[4]	RFV[5]
Kowinearly	53.75[c]	31.48[bc]	5.20[c]	64.03[bc]	111.66[c]
Oasis	55.73[abc]	32.82[ab]	5.92[bc]	62.97[cd]	106.42[cd]
Florida80	54.81[bc]	32.55[ab]	5.74[bc]	63.18[cd]	108.00[cd]
Kowinmaster	57.17[ab]	33.63[a]	7.17[ab]	62.33[d]	102.24[d]
Lm4ho	51.27[d]	30.29[cd]	6.47[bc]	64.97[ab]	118.96[b]
Typhoon	57.76[a]	33.69[a]	7.16[ab]	62.28[d]	101.18[d]
IR901	48.86[e]	29.01[d]	6.61[abc]	65.98[a]	126.29[a]
Hwasan104	51.20[d]	29.30[d]	8.08[a]	65.75[a]	120.21[ab]
p-value	$6.00•10^{-6}$	$2.58•10^{-4}$	$1.09•10^{-2}$	$2.57•10^{-4}$	$8.32•10^{-6}$
SEM	2.590	1.960	0.760	1.548	7.900

[a-e] Means in the column with different superscripts are significantly different ($p<0.05$).
NDF[1], neutral detergent fiber; ADF[2], acid detergent fiber; CP[3], crude protein; TDN[4], total digestible nutrients; RFV[5], relative feed value; SEM, standard error of the mean.

high-quality forage crops.

Ⅳ. CONCLUSIONS

As climate change progresses and cultivation areas extend from paddy fields to reclaimed lands, the selection of Italian ryegrass varieties is also expected to change. To contribute to this adaptation, this study compared the growth characteristics, productivity and feed value of eight Italian ryegrass varieties under the uniform cultivation conditions. In terms of growth characteristics prior to overwintering, the medium-maturing varieties showed superior plant length, while the late-maturing varieties had superior leaf length and width. Among all varieties, the medium-maturing ‘Lm4ho’ was significantly superior in plant length, leaf length, and leaf width. The heading date was advanced in all varieties, with this change being more pronounced in the earlier-maturing varieties. At the harvesting time for early-maturing varieties, the dry matter yield of medium-maturing varieties showed no significant difference from that of the early-maturing varieties. However, at the harvesting time for medium-maturing varieties, the yield of the medium-maturing varieties was significantly greater than that of the early-maturing varieties. Specifically, the medium-maturing variety ‘Lm4ho’ outperformed the early-maturing variety ‘Kowinearly’, producing 2,518 kg/ha more in dry matter yield. Statistically, the varieties with the highest dry matter yield were the late-maturing ‘IR 901’ and the medium-maturing ‘Lm4ho’ and ‘Kowinmaster’. In terms of feed value, considering crude protein (CP), total digestible nutrients (TDN), and relative feed value (RFV), medium- and late-maturing varieties were better than early-maturing varieties. Notably, the medium-maturing ‘Lm4ho’ and the late-maturing ‘IR 901’ and ‘Hwasan 104’ were found to be suitable for producing high-quality forage crops. These results suggest that, as the heading dates of Italian ryegrass are shortened under the current warmer climate conditions, medium-maturing varieties could be suitable for double cropping with rice even in the central regions. Additionally, harvesting medium- and late-maturing varieties at the typical harvest time in May can ensure higher yields and superior forage quality. Therefore, future breeding goals for Italian ryegrass should move beyond focusing solely on cold tolerance and early-maturing varieties adapted to the cropping system. Instead, there should be an expansion towards breeding medium- and late-maturing varieties that consider productivity and quality, as well as the diversity of varieties.

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