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Full Length Research Paper

Growth characteristics and productivity of cold-tolerant "Kowinearly" Italian ryegrass in the northern part of South Korea

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The objective of this research is to evaluate differences in growth characteristics and productivity between Kowinearly and Florida 80 Italian ryegrass varieties in regions with severely cold winters. This research was carried out in Suwon (in central South Korea) and Yonchun (in northern South Korea) during the 2002-2006 growing seasons. Kowinearly is a diploid variety with green leaf colour and a semi-prostrate growth habit in autumn and a semi-erect one in spring. There were differences among the varieties in terms of cold tolerance, heading date, and forage yield in Yonchun. The winter field survival of Kowinearly was 85%, while that of Florida 80 was 43%. The dry matter yield of Kowinearly in Yonchun was 9,662 kg/ha, which was 31% more than that of Florida 80. In Suwon, the heading date of Kowinearly was May 7, which was 2 days later than that of Florida 80. In Yonchun, Kowinearly's heading date was May 12, 1 day earlier than that of Florida 80. These results indicate that Kowinearly has good cold tolerance, and that in spring, it starts growth earlier than Florida 80, because of its higher cold tolerance.

Key words: Italian ryegrass, Kowinearly, cold tolerance, new variety, forage crop.

INTRODUCTION

Italian ryegrass (*Lolium multiflorum* Lam.) is an important crop that is cultivated for the production of high-quality forage in temperate regions around the world. However, its low cold tolerance prevents it from being cultivated in cold climates (Heath et al. 1973, Redfearn et al. 2002, Blount et al. 2005). Therefore, increasing the cold tolerance of Italian rye-grass is crucial for expanding its cultivation region (Waldron et al., 1998a; Park et al., 1991). Since Korean winters are very cold, cultivation of Italian ryegrass is confined to the southern part of the Korean peninsula (Yang 1992).

Thanks to winter cropping on drained rice paddy fields, Italian ryegrass can be cultivated for high-quality forage while maintaining rice production (Chae et al., 1993; Yang 1992). In order to develop an Italian ryegrass species with high cold tolerance, there have been studies on hybrid ryegrass, including hybridization between Italian ryegrass and perennial ryegrass and between different species and genera, to combine the cold tolerance of the fescue genus and the palatability of ryegrass (Park and Kim, 1989; Park et al., 1991; Lee and Park, 1993). The cold tolerance of Italian ryegrass varies according to polyploidy and species (Park et al., 1987) It has been reported that some species have higher cold tolerance than the others (Blount et al., 2005). Therefore, the selection of a ryegrass germplasm with enhanced winter hardiness is necessary to develop species with increased cold tolerance (Blount et al., 2005), and most previous studies have focused on early screening of such germplasms (Cohen and Wood 1986; Waldron et al.,

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Abbreviations: KSVS, Korean seed and variety service; **CP,** crude protein; **TDN,** total digestible nutrients; **IVDMD,** *in vitro* dry matter digestibility; **ADF,** acid detergent fiber; **NDF,** neutral detergent fiber.

1988b, Casler et al., 2002).

Recently, improving the cold tolerance of Italian ryegrass has become an important issue in South Korea, and there have been various efforts to develop cold-tolerant species of Italian ryegrass. Registered cold-tolerant Italian ryegrass species that were developed in Korea include Hwasan 101 (Choi et al., 2000), Hwasan 102 (Choi et al., 2001a), Hwasan 103 (Choi et al., 2001b), and Hwasan 104 (Choi et al., 2005). However, the Italian ryegrass species developed in Korea are medium-late flowering varieties with heading dates around May 20, and winter cropping of these species on drained rice paddy fields does not correspond well with the rice harvesting seasons in the middle and mid-northern regions of South Korea. This study was conducted to evaluate the growth characteristics and productivity of Kowinearly, an Italian ryegrass species with high cold tolerance, an early heading date, quick maturity, and compatibility with winter cropping on drained rice paddy fields in the mid-northern regions of South Korea.

MATERIALS AND METHODS

Plant material

The Italian ryegrasss species used in the experiment were Hwasan 101, Florida 80, and Kowinearly. Hwasan 101 is a medium-late flowering variety that was developed by the National Institute of Animal Science (NIAS) at the rural development administration (RDA) in 1998 and registered at the Korean seed and variety service (KSVS) in 2000. Florida 80 is an early-maturing species that has been widely cultivated on Korean farms as a recommended species since 1992. Kowinearly is an early-maturing variety with high cold tolerance that was developed by the breeding program at the NIAS in 2006 and was registered at the KSVS in 2008.

Characteristics of Kowinearly

The agricultural characteristics of Italian ryegrass varieties were tested from 2002 to 2006 at the NIAS experimental field located in Suwon. Experiments were conducted according to the KSVS's survey guidelines for ryegrass variety characteristics. The items surveyed were ploidy, growth habit in autumn, growth habit in spring, leaf colour, flag leaf width, flag leaf length, plant length, stem thickness, length of the longest stem, spike length, number of spikelets per spike, and heading date.

Field test

Experiments were conducted from 2002 to 2006 in Suwon and Yonchun with Hwasan 101, Florida 80, and Kowinearly. The experimental plots were laid out according to three repetitions of a randomized block design. The size of the experimental plot was 6 m^2 (2 m × 3 m). Each year, from 2002, seeding was performed between September 25 and 30 in Suwon and between September 22 and 25 in Yonchun. Drill seeding of 20 cm was performed at the rate of 30 kg/ha. The fertilizers applied were N, P_2O_5, and K_2O at the respective rates of 140, 150, and 150 kg/ha. In terms of the fertilizing schedule, 40 kg/ha of nitrogen was applied as the basal dressing and 100 kg/ha was applied at the start of the growth period in early spring. Half of the phosphoric acid and potassium were applied as the basal dressing, and the remaining half were applied at the start of the growth period in early spring.

Winter field survival was evaluated by visually inspecting the number of surviving and dead individual plants in early spring and calculating the survival rate of the field. The day when 40% of the plants in an experimental plot were headed was considered the heading date. When 80% of the heading was complete, the entire experimental plot was harvested and the green forage weight was measured. A 500 g sample of green forage was dried at 60°C for 48 h to calculate the dry matter rate, and the green forage weight was converted into dry matter yield using the dry matter rate. In terms of feed value analysis, crude protein (CP) was analyzed with the AOAC method (1990). Total digestible nutrients (TDN) were calculated using the Menke and Huss method (1980), and *in vitro* dry matter digestibility (IVDMD) was examined with the method proposed by Tilley and Terry (1963). Acid detergent fiber (ADF) and neutral detergent fiber (NDF) were analyzed using the Goering and Van Soest (1970) method.

RESULTS AND DISCUSSION

Winter climate conditions

The winter field survival of Italian ryegrass is significantly affected by the lowest temperature and amount of precipitation during the coldest month of January. The average temperature and precipitation in the two areas during the winter months of experiments are shown in Table 1. The average low temperature in January in Yonchun, from 2003 to 2006, was between -10.1 and -15°C, whereas the temperatures in Suwon did not cause much of a problem for Italian ryegrass's winter survival.

Agricultural characteristics of the species

As shown in Table 2, Kowinearly is a diploid variety, semi-prostrate in autumn and semi-erect in spring, which can be disadvantageous to surviving winter. Kowinearly had green leaves, and its flag leaf was wider and longer than that of Florida 80. The length of Kowinearly upon heading was 82 cm, which was about 1 cm shorter than that of Florida 80. As with Florida 80, Kowinearly had a medium stem thickness, and the spike length was 3 cm longer than that of Florida 80. Kowinearly is an early-maturing variety; its heading date is May 7, which is 2 days later than and 16 days earlier than Florida 80 and Hwasan 101, respectively.

Comparison of cold tolerance

The cold tolerance of Italian ryegrass is significantly affected by the climate conditions of the cultivation region. As shown in Table 3, the tolerance of the varieties varied each year in the two regions. In Suwon, Kowinearly and Florida 80 had winter survival rates of 90% or greater, while in Yonchun, Kowinearly displayed greater cold tolerance than Florida 80 or Hwasan 101. In Yonchun, there

Table 1. Minimum average air temperature and amount of precipitation during the winter season at trial regions in Korea.

Year	Month	Minimum average air temp. (℃)		Amount of precipitation (mm)	
		Suwon	Yonchun	Suwon	Yonchun
2002	Dec.	-4.0	-8.3	15.4	16.5
2003	Jan.	-8.2	-13.1	10.4	11.0
2003	Feb.	-3.5	-8.0	46.2	21.0
2003	Dec.	-3.7	-10.0	14.1	2.0
2004	Jan.	-6.4	-15.0	17.8	7.5
2004	Feb.	-2.5	-8.9	58.5	99.5
2004	Dec.	-7.2	-7.6	24.1	20.0
2005	Jan.	-6.6	-14.3	23.7	3.0
2005	Feb.	-6.0	-12.7	25.3	24.0
2005	Dec.	-8.2	-15.1	12.0	4.0
2006	Jan.	-4.3	-10.1	38.6	25.6
2006	Feb.	-4.5	-8.7	19.5	8.3

Table 2. Agronomic characteristics of Italian ryegrass varieties cultivated in Suwon, Korea, from 2003 to 2006.

Characteristic	Hwasan 101	Kowinearly	Florida 80
Ploidy	Tetraploid	Diploid	Diploid
Growth habit in autumn	Semi-prostrate	Semi-prostrate	Semi-erect
Growth habit in spring	Medium	Semi-erect	Erect
Leaf colour	Dark green	Green	Green
Flag leaf width (mm)	9.9	8.3	7.6
Flag leaf length (cm)	30	21	17
Plant length (cm)	91	82	83
Stem thickness	Medium	Medium	Medium
Length of longest stem (cm)	69	66	69
Spike length (cm)	34	24	21
No. of spikelet per Spike	24	20	20
Heading date	May 23	May 7	May 5

was no significant difference in the winter survival rates among the varieties in 2003 and 2004. However, in 2005 and 2006, the survival rates of Kowinearly was 93 and 85%, respectively, whereas those of Florida 80 in same year was 57 and 43%, respectively, showing significant differences between species (Figure 1)

In a comparative experiment of diploid and tetraploid Italian ryegrass varieties, Park et al. (1987) reported that the diploid variety had higher cold tolerance than tetraploid. However, having examined the cold tolerances in Yonchun (Table 3), it is believed that winter field survival is determined by whether the climate of a particular year benefits the diploid or the tetraploid variety, rather than by chromosome polyploidy itself having an effect. As Pfahler et al. (1984) reported, cold tolerance of rye is dependent not upon chromosome polyploidy but upon the genetic properties of the breeding material; it is believed that the differences in winter field survival rates among the three varieties were caused by the combination of genes that determine cold tolerance. Based on the results, it can be inferred that Kowinearly is a cold-tolerant variety that displays a consistent winter survival rate, despite widely

Table 3. Winter field survival of Italian ryegrass varieties in Suwon and Yonchun, Korea, from 2003 to 2006.

Trial region and years	Winter field survival (%)		
	Hwasan 101	Kowinearly	Florida 80
Suwon			
2003	92	96	95
2004	100	100	100
2005	95	95	95
2006	93	96	94
Average	95	97	96
Yonchun			
2003	92	93	85
2004	87	90	90
2005	95	93	57
2006	47	85	43
Average	80	90	69

varying conditions.

Variation in heading dates between varieties and regions

The heading dates of Italian ryegrass are shown in Table 4. The heading date for Kowinearly in Suwon (in the middle region of South Korea) was May 7 which was 1–2 days later than that of Florida 80. In the northern region of Yonchun, the heading date for Kowinearly was May 12, which was a day earlier than that of Florida 80. Since Kowinearly's maturity was similar to that of Florida 80, we were able to conclude that Kowinearly is an early-starting variety with a heading date approximately 15 days earlier than that of Hwasan 101. While the heading dates of Kowinearly was 2 days later than that of Florida 80, in Suwon, the former was a day earlier than the latter in Yonchun. In Yonchun, when the winters were especially cold, the heading dates of Kowinearly were earlier than those of Florida 80 by 1 and 4 days, in 2005 and 2006, respectively. Being exposed to low temperature brings about formational, biochemical, and physiological variations that are closely related to the plant's cold tolerance (Fowler et al. 1999), which is highly associated with the heading date (Yamada et al. 2004). Accordingly, it can be inferred that the heading date of Kowinearly, which was later than that of Florida 80 in warm regions, became expedited in cold regions due to the difference in cold tolerance between the two varieties. In this study, the reversal of heading dates between Kowinearly and Florida 80 in different regions is believed to have been caused by the difference in their cold tolerances.

Dry matter yield

The dry matter yield of the two varieties of Italian ryegrass differed according to cultivation region and year, as shown in Table 5. As reported by Redfearn et al. (2005), there were substantial annual fluctuations in the yields based on the climate conditions of the year. Kowinearly's dry matter yield was similar to that of Florida 80 in Suwon where the climate is somewhat mild in winter. However, the yield of Kowinearly was greater than that of Florida 80 in Yonchun, where winters are cold ($P < 0.05$). The dry matter yield of Kowinearly in 2005 and 2006 was 5,513 and 6,309 kg/ha, respectively, which was 144 and 77% greater than Florida 80's yields of 2,263 and 3,565 kg/ha. We believe that the differences in cold tolerances directly affected the dry matter yields shown in Table 5. Based on the results, it is believed that, in South Korea's middle and northern regions with cold winters, Kowinearly offers better productivity, higher cold tolerance, and earlier maturity than Florida 80.

Feed value

Table 6 displays the factors that indicate the feed quality: CP, IVDMD, ADF, NDF, and TDN. Kowinearly's CP was 13.5%, which was higher than that of Hwasan 101 and Florida 80. Kowinearly's IVDMD was 72.2%, which was 3.8% lower than that of Hwasan 101 and 1.2% higher than that of Florida 80. In terms of ADF and NDF, Kowinearly was on par with Hwasan 101 and Florida 80. These levels indicate that Kowinearly has a feed value similar to that of Florida 80, while offering better cold

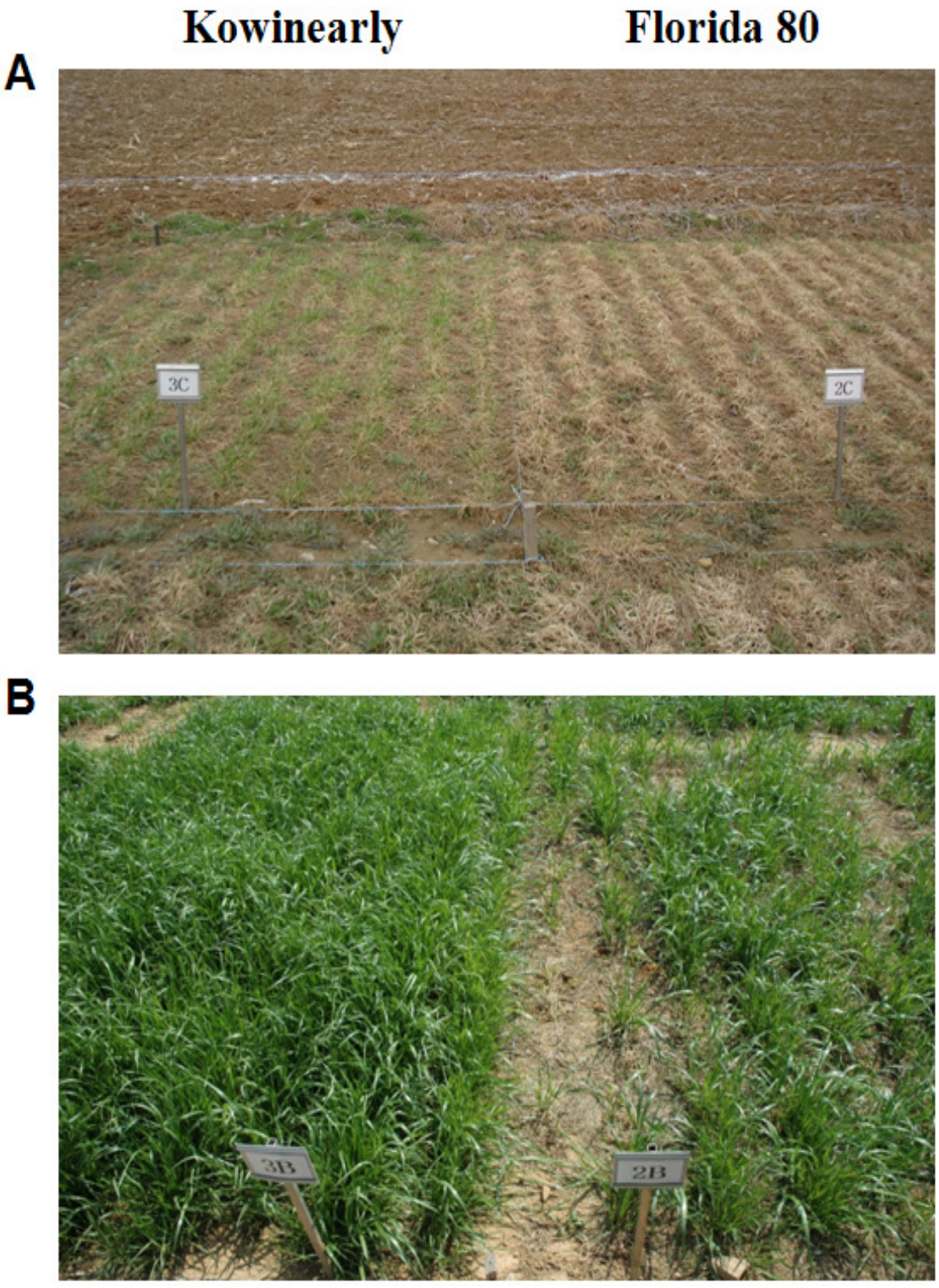

Figure 1. Comparison of cold tolerance of Italian ryegrass at Yonchun in 2005 and 2006.

tolerance.

Developing an Italian ryegrass variety that offers early maturity and high cold tolerance is crucial for preventing harvest reduction in exceptionally cold winters in regions like South Korea. This study was conducted by the Feed Resource Department of NIAS from 2002 to 2006. The objective of this study is to evaluate the regional adaptability of Kowinearly, a cold-tolerant, early-maturing

Table 4. Heading date of Italian ryegrass varieties in Suwon and Yonchun, Korea, from 2003 to 2006.

Trial region and years	Heading date		
	Hwasan 101	Kowinearly	Florida 80
Suwon			
2003	May 26	May 6	May 4
2004	May 17	May 1	May 1
2005	May 25	May 12	May 8
2006	May 20	May 7	May 6
Average	May 22	May 7	May 5
Yonchun			
2003	May 26	May 8	May 5
2004	May 21	May 7	May 7
2005	May 29	May 17	May 18
2006	June 4	May 17	May 21
Average	May 28	May 12	May 13

Table 5. Dry matter yield of Italian ryegrass varieties in Suwon and Yonchun, Korea, from 2003 to 2005.

Trial region, Year	Dry matter yield (kg/ha)		
	Hwasan 101	Kowinearly	Florida 80
Suwon			
2003	8,757[a*]	6,476[b]	6,652[b]
2004	8,527[b]	9,498[a]	10,131[a]
2005	4,761[a]	4,720[a]	4,392[a]
2006	6,911[a]	6,971[a]	7,213[a]
Average	7,239	6,916	7,097
Yonchun			
2003	12,718[a]	13,125[a]	11,950[a]
2004	9,313[c]	13,701[a]	11,676[b]
2005	8,169[a]	5,513[b]	2,263[c]
2006	6,810[a]	6,309[a]	3,565[b]
Average	9,253	9,662	7,364

Same letter in same row is not significantly different.

variety of Italian ryegrass. Kowinearly was cultivated in two regions of South Korea-Suwon, Yonchun from 2003 to 2006, along with Hwasan 101, a late-flowering variety, and Florida 80, an early-flowering variety. Kowinearly displayed stronger cold tolerance than that of Hwasan 101 or Florida 80. The heading dates for Kowinearly is May 7 in Suwon (in the middle region of South Korea), which was 2 days later than the heading dates for Florida 80. In the northern region of Yonchun, the heading date for Kowinearly was May 12, which was a day earlier than that for Florida 80. These results suggest that the heading date of a variety with higher cold tolerance is earlier in regions with cold winters, because it is less likely to suffer from freezing than is a variety with lower cold tolerance. The average dry matter yield from Kowinearly in the four regions was 9,705 kg/ha, 3% more than that from Florida 80. In particular, in Yonchun, Kowinearly yielded 24% more dry matter than did Florida 80,

Table 6. CP, IVDMD, ADF, NDF and TDN of Italian ryegrass varieties cultivated in Suwon from 2003 to 2006.

Variety	CP (%)	IVDMD (%)	ADF (%)	NDF (%)	TDN (%)
Hwasan 101	12.0	76.0	32.6	58.0	63.2
Kowinearly	13.5	72.2	32.8	58.1	63.0
Florida 80	12.3	71.0	32.6	57.0	63.1

indicating that the difference in cold tolerance significantly affects the variety's productivity. In terms of feed value, Kowinearly's CP, IVDMD, ADF, and NDF is 13.5, 72.2, 32.8, and 58.1%, respectively, which is on par with the feed value of Florida 80.

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