Journal of the Korean Society of Grassland and Forage Science 41(3): 217~222, 2021
https://doi.org/10.5333/KGFS.2021.41.3.217

ISSN 2287-5824 (Print)
ISSN 2287-5832 (Online)

Research Article

A Study on Features of Forage Barnyard Millet and Related Research Trends

Eun-A Lim, Ki-Won Lee, Bo Ram Choi, Hyung Soo Park, Jae Hoon Woo, Da In Kim and Sang-Hoon Lee*
Grassland & Forages Division, National Institute of Animal Science, RDA, Cheonan, 31000, Republic of Korea

ABSTRACT

Barnyard millet is a short-lived tropical, short-term C4 plant and has superior vitality in humid conditions owing to its freshwater habitat. It shows strong adaptability to soils with poor drainage and low fertility, and efficiently competes with rice in paddy fields. Barnyard millet grain is used as feed in the Indian region and is a great source of dietary fiber, proteins, fats, vitamins, and some essential amino acids. Considering its high nutritional value and its potential as a food resource and fodder crop, various countries are showing interest in cultivating barnyard millet. However, in Korea, farm households have not yet recognized the benefits of cultivating barnyard millet, and research regarding this is scarce. In this review, the features of forage barnyard millet and its related research trends are discussed, with the aim of improving interest in this crop and promoting its cultivation.

(Key words: Barnyard Millet, Feed, Forage, Grassland)

Ⅰ. Introduction of Barnyard Millet

Barnyard millet (*Echinochloa* spp.) has been cultivated since the early days of agriculture and has been used as food and feed in the Goryeo dynasty (Chang, 1989). Until the Joseon dynasty period, it was one of the five important grains cultivated in the region, with a cultivation area of over 100,000 ha. However, the Center for Tropical Agriculture, Japanese Ministry of Agriculture (1976) reported a reduction in consumption of barnyard millet due to industrialization and the abundant self-supply of rice in Korea. Barnyard millet is a short-lived, tropical short-term C4 plant (Cho et al., 2001c) and possesses superior vitality in humid conditions owing to its freshwater habitat. Its seeding time is between May and June, while flowering occurs in August. It shows strong adaptability to soils with poor drainage and low fertility (Baker et al., 2003; Lee et al., 2009) and competes efficiently with rice in paddy fields; notably, many studies have been conducted on the cultivation of barnyard millet on reclaimed lands to promote its agronomy (Shin et al., 2006, 2007; Hwang et. al., 2017).

Barnyard millet grain, which is a great source of dietary fiber, proteins, fats, vitamins, and some essential amino acids, is used as feed in the Indian region (Singh et al., 2010; Saleh et al., 2013; Chandel et al., 2014). The nutritional composition of 100 g of Barnyard millet grains comprises 281 mg phosphate, 5 mg zinc, 83 mg magnesium, and 10 mg calcium as shown in Fig. 1 (IFCT 2017; Ugare et al., 2014). They are rich in micronutrients that are beneficial to health (Saleh et al., 2013; Ugare et al., 2014).

Barnyard millet is an ancient crop and has been widely cultivated in regions located between 50º N and 40º S latitudes. Notably, the Indian barnyard millet and Japanese barnyard millet are the two most common derivative species. Fig. 2 shows a brief phylogeny of both the derivative species. The scientific name of the Indian barnyard millet is *Echinochloa frumentacea* (Roxb.), and it is known to have originated from *E. colona* (L.), which is a wild species termed “jungle rice.” The scientific name of the Japanese barnyard millet is *E. esculenta* (A. Braun) H. Scholz, which originated from *E. crus-galli* (L.), a wild species, approximately 4,000 years ago (De Wet et al., 1983; Doggett, 1989). *E. crus-galli* is a dominant weed in paddy fields owing to its extensive ecological tolerance and the ability to germinate and grow rapidly and imitate the characteristics of rice (Barrett, 1983). *E. crus-galli* propagates through wind pollination of unknown diplonts of wild species and *E. oryzicola* (tetraploid of wild species) (Aoki and Yamaguchi, 2008). To date, 35 species of barnyard millet have been identified based on their classification and phylogeny as well as by the morphological,

*Corresponding author: Sang Hoon Lee, National Institute of Animal Science, RDA, Cheonan, 31000, Republic of Korea. Tel: +82-41-580-6767, Fax: +82-41-580-6779, E-mail: sanghoon@korea.kr

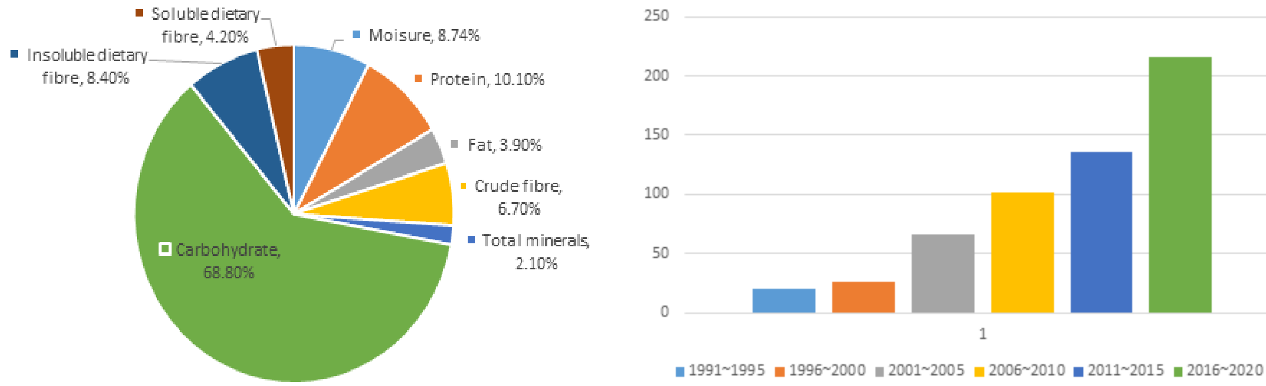

Fig. 1. (A) Nutritional components of barnyard millet grains, and (B) PubMed (https://www.ncbi.nlm. nih.gov/pubmed).

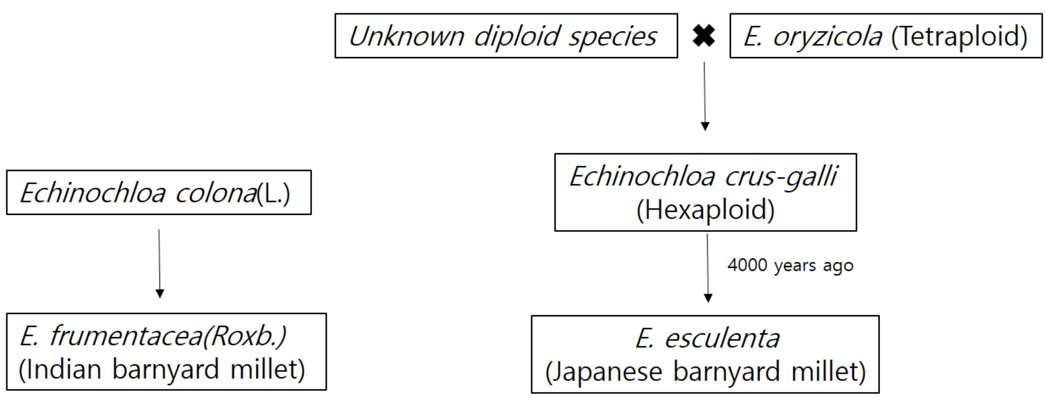

Fig. 2. Phylogeny of the Indian and Japanese barnyard millets (Echinochloa spp.).

cytological, and molecular markers of this plant (Yabuno, 1966, 1987; Yuichiro et al., 1999; Yamaguchi et al., 2005).

Ⅱ. Species description and harvest estimate

The various species of *Echinochloa* spp. have been described below, as represented in Table 1.

1. Echinochloa frumentacea

Echinochloa frumentacea (Roxb.), also called the “Indian barnyard millet” or “sawa” millet or “billion dollar grass,” is commonly known as the “shama” millet. It has evolved from India and Africa and comprises four varieties: stolonifera, intermedia, robusta, and laxa (Doggett, 1989; Upadhyaya et al., 2014). India is the world’s largest producer of the barnyard millet, which is cultivated in the mid-hill areas of the Himalayan region in northern Uttarakhand and the Deccan Plateau in southern Tamil Nadu (Sood et al., 2015). In India, on an average, 1034 kg/ha barnyard millet is produced for use as grains (ICAR-IIMR, 2018), whereas 5 ton/ha is produced for use as coarse fodder (AICSMIP, 2014).

2. Echinochloa esculenta

Echinochloa esculenta (A. Braun) H. Scholz is commonly referred to as the “Japanese barnyard millet,” a synonym of *E. utilis var. esculenta*. It has widely evolved from Korea, Japan, China, and Russia (De Wet et al, 1983), and utilis and intermedia are the two main varieties. In the United States, the Japanese barnyard millet is used as dry grass or haylage and can be harvested up to eight times per year (Kajuna, 2001). In Australia, it is produced and has been recognized as a short-term rotating crop for use in grazing land during spring–early summer (Sood et al., 2015). In Australia, the average dry matter of the Shirohie variety is 16.3 ton/ha, with a digestion rate of 65.9% and nitrogen content of 1.9%, which are higher than the digestion rate (63.3%) and nitrogen content (1.5%) of sorghum sudangrass (Sood et al., 2015). Similarly, a study

Table 1. Features of the barnyard millet species (*Echinochloa* spp.)

	Echinochola colona	*Echinochola cru-gall*	*Echinochola frumentacea*	*Echinochola esculenta*
Common name	Jungle rice	Barnyard grass	Indian barnyard millet	Japanese barnyard millet
Synonyms	Echinochola Colonum Echinochola crus-galli subsp. Colona Panicum colonum	Panicum crus-galli Milium crus-galli	Billion Dollar grass Sawa millet Sama millet	Marsh millet Siberian millet white millet
Origin	China, Japan	China, Japan, Korea	India, Pakistan, Nepal	Eastern Asia, China, Japan, Korea
Distribution	Southeast Asia, Australia, Africa, Europe, America	Southeast Asia, Africa, Europe, America	Central Africa, Asia, Australia, South Africa	Asia, Australia, Pacific
Altitude	-	-	Below 1,900m	Below 2,500m
Plant Shape	Erect to Decumbent	Erect	Erect	Robust
Plant Height	60cm	200cm	242cm	60~122cm
Leaf blade long	3~30cm	0.5~35cm	15~40cm	10~50cm
Leaf bland width	2~8mm	6~20mm	1~2.5mm	7~25mm

*Renganathan V. G. et. al.(2020)

from Bangladesh showed that the average dry matter yield of the Japanese barnyard millet was 15.7 ton/ha after clipping thrice (Kanak et al., 2013).

Ⅲ. Research trends in cultivation of domestic barnyard millet

In Korea, it is strongly perceived that barnyard millet is a weed that grows in paddy fields, and there are abundant data on pest control against the crop. When the Korean government proposed the livestock industry promotion plan in 1970, the native grass was used to supply coarse fodder. Park et al. (1971) used the wild millet distributed in Korea for the first time and studied its digestion rate based on the application of fertilizers. Their study revealed a relatively high digestion rate of this crop up to June (before vigorous growth and development occurs) and that the effectiveness of fertilization is much more evident in the early days of growth and development (Park, 1971). Subsequently, Lee (1980) conducted a study on the effects of seed quantity and nitrogen content on the growth, general components, and dry matter yield of the barnyard millet. Furthermore, Lee (1981) reported the production and management of the summer forage barnyard millet and the agronomic characteristics and harvest yield of three millet species. In this study, the bionomical characteristics and fodder productivity between Chiwapa (as introduced species) and Jinju barnyard millet and Jeju barnyard millet (as domestic species) were compared and the Jinju and Jeju barnyard millets were found to have higher dry matter yield (1700 kg/ha). Moreover, as the climatic conditions favor the growth of barnyard millet over northern grass showing summer depression under higher temperatures in Korea, it is a better alternative for green fodder (Lee, 1981). Cho (2001a) reported that it can be used as summer green fodder, as it can be cultivated within a short time (2–3 months) and in wide areas, including the southern regions such as the Jeju Island. In 2013, Lee studied the growth conditions, productivity, and feed value of forage barnyard millet in central regions based on the sowing period of the barnyard millet; this study comprised an experiment on the Shirohie variety as the precocious species and a variety collected from Jeju as the late-maturing variety. The average dry matter yield of the Shirohie variety was about 10.2 MT/ha, and that from Jeju was 19.5 MT/ha. The average digestion rates were 58.9 % and 59.6 % for the Shirohie variety and the Jeju variety, respectively, which were lower than the digestion rates of the varieties cultivated in Australia. It is considered that both varieties could reach a stable production if sown before June 1.

Since the early 21st century, Korea began to take interest in the cultivation of fodder crops in reclaimed lands. Shin (2004) conducted a study on the selection of optimal crops, with the representative summer fodder crops being corn, sorghum sudangrass, and forage barnyard millet. Dry matter production was found to be high in forage barnyard millet, and it was considered the most suitable summer fodder crop in reclaimed areas (field). However, its feed value was lower than that of other summer forage crops. Additionally, Shin (2006) selected the forage barnyard millet species optimal for reclaimed areas with the domestic and overseas barnyard millet genetic resources and compared their growth conditions, productivity, and feed value; the results revealed that summer green species had the highest productivity. With an increasing interest in the utilization of reclaimed lands for cultivating barnyard millets, Hwang (2017) determined the optimum amount of planted seeds and nitrogen fertilizers for the stable production of forage and revealed that a quantity of 36 kg/ha sown seeds provided the maximum dry matter yield. Compared to non-fertilized soils, the application of 200 kg/ha and 250 kg/ha nitrogenous fertilizers led to the production of 16.6 ton and 169 ton forage, respectively, which indicated an increase in harvest of 43 % and 45 %, respectively.

Ⅳ. Trends in Genomic research of barnyard millet

Genomic research on the small millet is in its early stages and studies on barnyard millet are scarce compared to those on other millets (Renganathan et al., 2020). This scarcity is attributed to the fact that research on barnyard millet has slowed down because of negative awareness that portrays barnyard millet as a minor crop characterized by a complex genome. *E. esculenta* and *E. frumentacea*, the two main species of *Echinochloa* spp., are allohexaploid and allotetrapoid, respectively. Interestingly, wild and cultivated species can generate a specific crossbreed hybrid after a normal reduction division, but between two wild species (*E. esculenta* × *E. frumentacea)* or two cultivated species (*E. crus-galli* × *E. colona)*, interspecific hybrids are difficult to produce because of an irregular reduction division (Yabuno, 1966, 1984). In 2005, Yamaguchi et al. identified three groups using the chloroplast DNA sequence reported by Yabuno (1966). The first group was classified as the *E. oryzicola* complex, the second as *E. crus-galli* complex, and the third as *E. colona-frumentacea* complex. Furthermore, in 2008, Aoki and Yamaguchi reported, through polymerase chain reaction-restriction fragment length polymorphism (PCR-RFLP) analysis, that all three groups had different protoplasm systems and that the first and second groups showed high affinity between nuclear systems. Renganathan (2020) mentioned that they would provide ancestral information by analyzing the reduction division in interspecific crossing through advanced cytogenetic technologies, such as genomic *in situ* hybridization (GISH) and fluorescent *in situ* hybridization (FISH). In 2017, the full genome sequence of *E. crus-galli* was published, and its unique breeding and adaptation phenomena were annotated in the field (Guo et al., 2017). Guo et al. predicted that the full length of the sequence would be 1.27 Gb, which is ~90.7 % of the genome size. Manimekalai et al. (2018) studied the genetic diversity using an expressed sequence tag-derived simple sequence repeat marker, and based on this, they presented an effective breeding program for barnyard millet from the southern Indian regions.

Genomic research has been conducted since the early 2000s, and for the last five years, genetic diversity and crop selection using molecular markers have been studied. Currently, however, small millet genome mapping is in its early stages, and additional research on marker assisted selection (MAS) is required (Renganathan et al., 2020). There are only few molecular biological studies on barnyard millet. Therefore, the information provided in our review can be used for the selection and breeding of superior crop species in future.

Ⅴ. Conclusion

During the last five years (2016–2020), 216 research papers on barnyard millet have been published in the National Center for Biotechnology Information (NCBI) PubMed, which accounts for double the number of papers (102) published over the past 10 years (2006–2020). Recently, various countries have shown an increased interest in barnyard millet, which is considered a promising food resource and a fodder crop. In Korea, however, farm households do not recognize the potential benefits of this crop. Furthermore, research on barnyard millet is lacking. Therefore, our review aims to draw attention toward this crop and promote its cultivation.

Ⅵ. Acknowledgments

This research was supported by the Cooperative Research Program for Agriculture Science & Technology Development (Project No. PJ015925 of the National Institute of Animal Science, RDA, Republic of Korea).

Ⅶ. REFERENCES

AICSMIP. 2014. Annual report 2013-2014. All India Coordinated Small Millet Improvement Project (ICAR), Bangalore, BR122.

Aoki, D. and Yamaguchi, H. 2008. Genetic relationship between Echinochloa crus-galli and Echinochloa oryzicola accessions inferred from internal transcribed spacer and chloroplast DNA sequences. Weed Biology and Management. 8:233-242.

Arnold, G.W. and Dudzinki, M.L. 1967. Studies on the diet of the grazing animal. III. The effect of pasture species and pasture structure on the herbage intake of sheep. Australian Journal of Agricultural Research. 18:657-666.

Baker, R.D. 2003. Millet production-guide A-414. New Mexico State University, College of Agriculture and Home Economics, Las Cruces, NM.

Barrett, S.H. 1983. Crop mimicry in weeds. Society for Economic Botany. 37:255-282.

Chandel, G., Meena, R., Dubey, M. and Kumar, M. 2014. Nutritional properties of minor millets: Neglected cereals with potentials to combat malnutrition. Current Science. 107:1109-1111.

Chang, K.Y. 1989. Old references related to agriculture in Korea Ⅱ. Kinds and varieties of cereal crops (1492-1886). Korean Journal of Breeding. 20:341-355.

Cho, N.K., Boo, C.H., Kang, Y.K. and Cho, Y.I. 2001a. Effects of nitrogen rate on agronomic characteristics, forage yield, and chemical composition of Japanese millet. Journal of Korean Animal Science & Technology. 43:259-266.

Cho, N.K., Kang, Y.K. 2001c. Effect of Seeding Date on Forage Yield and Chemical Composition of Echinochloa crusgalli var. Frumentacea (Roxb) Wight in Jeju Region. Journal of The Korean Society of Grassland and Forage Science.

De Wet, J., Prasada Rao, K., Mengesha, M. and Brink, D. 1983. Domestication of mawa millet (Echinochloa colona). Society for Economic Botany. 37:283-291.

Doggett, H. 1989. Small millets-a selective overview. Small Millets in Global Agriculture. pp. 3-18.

Dumont, B., Carrère, P. and D’hour, P. 2002. Foraging in patchy grasslands: Diet selection by sheep and cattle is affected by the abundance and spatial distribution of preferred species. Animal Research. 51:367-381.

Guo, L., Qiu, J., Ye, C., Jin, G., Mao, L., Zhang, H., Fan, L. 2017. Echinochloa crus-galli genome analysis provides insight into its adaptation and invasiveness as a weed. Nature communications. 8(1):1-10.

Hwang, J.B., Park, T.S., Park, H.K., Kim, H.S., Choi, I.B. and Vae, H.S. 2017. Effect of seeding and nitrogen rates on the growth characters, forage yield, and feed value of barnyard millet in the reclaimed tidal land. Weed&Turfgrass Science. 6(2):124-129.

IFCT(Indian Food Composition Tables), National Institute of Nutrition, Telangana, India. 2017.

JIRCAS. 1976. The Center for Tropical Agriculture, Japanese Ministry of Agriculture Report.

Kajuna, S.T.A.R. 2001. MILLET: Post-harvest operations. Available at: http://www.fao.org/fileadmin/user_upload/inpho/docs/Post_Harvest_Compendium_-_MILLET.pdf (Accessed on July 21, 2014).

Kanak, A.R., Khan, M.J., Debi, M.R., Khandakar, Z.H. and Pi-kar, M.K. 2013. Comparison on biomass production of three fodder germ-plasms. Banglasdesh Journal of Animal Science. 42:35-39.

Lee, D., Hanna, W., Buntin, G.D., Dozier, W., Timper, P. and Wilson, J.P. 2009. Pearl millet for grain. College of Agricultural and Environmental Sciences & Family and Consumer Sciences, University of Georgia and USDA-ARS Cooperating.

Lee, H.W. 1981. Studies on the production and management of Japanese millet (Echinochloa crusgalli) for summer forage I. Agronomic characteristics and yield performance of three Japanese millet cultivars. Korean Journal of Animal Sciences. 23:264-269.

Lee, H.W. and Kim, D.A. 1980. Effect of seeding rates and nitrogen fertilization on the growth, chemical composition and forage yield of Japanese barnyard millet Echinochloa crusgalli var frumentacea (Roxb.) WF Wight. Korean Journal of Animal Sciences. 22:83-92.

Lee, J.J., Kim, J.G., Sung, B.R., Song, T.H. and Park, T.S. 2013. Studies on growth, forage yield, and nutritive value according to different seeding dates of barnyard millet. Journal of the Korean Society of Grassland and Forage Science. 33(4):245-251.

Madhusudhana, R., Padmaja, P.G., Cheruku, D., Rao, K.R. and Tonapi, V.A. 2018. ICAR-IIMR Millets Annual Report 2017-18.

Manimekalai, M., Dhasarathan, M., Karthikeyan, A., Murukarthick, J., Renganathan, V.G., Thangaraj, K., et al. (2018). Genetic diversity in the barnyard millet (Echinochola frumentacea) germplasms revealed by morphological traits and simple sequence repeat markers. Current Plant Biology. 14:71-78.

Park, S.H., Shin., J.N., Kim, S.C., 1971. Effect of Species, Growing Stage and Location on Digestibility of Korean Native Grasses Determined in vitro. Journal of Animal Science. 13(1):72-76.

Ranjhan, S.K. 1980. Animal nutrition in the tropics. Bikas Publication of House, Dist. Ghabidad, India, p. 480.

Renganathan, V.G., Vanniarajan, C., Karthikeyan, A. and Ramalingam, J. 2020. Barnyard millet for food and nutritional security: Current status and future research direction. Frontiers in Genetics. 11:500.

Saleh, A., Zhang, Q., Chen, J. and Shen, Q. 2013. Millet grains: Nutritional quality, processing, and potential health benefits. Comprehensive Reviews in Food Science and Food Safety. 12:281-295.

Shin, J.S., Kim, W.H., Lee, S.H., Yoon, S.H., Chung, E.S. and Lim, Y.C. 2004. Comparison of dry matter and feed value of major summer forage crops in the reclaimed tidal land. Journal of The Korean Society of Grassland and Forage Science, 24(4):335-340.

Shin, J.S., Kim, W.H., Lee, S.H. and Shin, H.Y. 2006. Comparison of forage yield and feed value of millet varieties in the reclaimed tidelands. Journal of the Korean Society of Grassland and Forage Science. 26(4):215-220.

Shin, J.S., Kim, W.H., Yoon, S.H. and Seo, S. 2007. Study on optimum forage cropping system in reclaimed tidal land. Journal of the Korean Society of Grassland and Forage Science. 27(2):117-122.

Singh, K.P., Mishra, H.N. and Saha, S. 2010. Moisture-dependent properties of barnyard millet grain and kernel. Journal of Food Engineering. 96:598-606.

Sood, S., Khulbe, R., Kumar, R.A., Agrawal, P.K. and Upadhyaya, H. 2015. Barnyard millet global core collection evaluation in the sub mountain Himalayan region of India using multivariate analysis. The Crop Journal. 3:517-525.

Ugare, R., Chimmad, B., Naik, R., Bharati, P. and Itagi, S. 2014. Glycemic index and significance of barnyard millet (Echinochloa frumentacae) in type II diabetics. Journal of Food Science and Technology. 51:392-395.

Upadhyaya, H., Dwivedi, S.L., Singh, S.K., Sube, S., Vetriventhan, M. and Sharma, S. 2014. Forming core collections in Barnyard, Kodo, and little millets using morphoagronomic descriptors. Crop Science. 54:2673-2682.

Yabuno, T. 1966. Biosystematic study of the genus Echinochloa. Japanese Journal of Botany. 19:277-323.

Yabuno, T. 1984. A biosystematic study on Echinochloa oryzoides (Ard.) Fritsch. Cytologia. 49:673-678.

Yabuno, T. 1987. Japanese barnyard millet (Echinochloa utilis. Poaceae) in Japan. Society for Economic Botany. 41:484-493.

Yamaguchi, H., Utano, A.Y.A., Yasuda, K., Yano, A. and Soejima, A. 2005. A molecular phylogeny of wild and cultivated Echinochloa in East Asia inferred from non-coding region sequences of trnT-L-F. Weed Biology and Management. 5:210-218.

Yuichiro, M., Shinya, U. and Yamaguchi, H. 1999. Identification of polyploid groups in the genus Echinochloa by isozyme analysis. Journal of Weed Science and Technology. 44:205-217.

(Received : September 7, 2021 | Revised : September 27, 2021 | Accepted : September 27, 2021)