A BRIEF REVIEW ON THE INFLUENCE OF FLAG LEAF ON CEREALS PRODUCTION

Denis Marian RĂDOI[1,2], Elena BONCIU[3], Gabriela PĂUNESCU[1], Cătălin Aurelian ROȘCULETE[3], Elena ROȘCULETE[3]

(1) University of Craiova, SCDA Caracal, 106 Vasile Alecsandri Street, Caracal, Romania; radoi_29_1992@yahoo.com; paunescucraiova@yahoo.com
(2) University of Craiova, Doctoral School of Animal and Plant Resources Engineering (IRAV), 19 Libertății street, Craiova, Romania; radoi_29_1992@yahoo.com
(3) University of Craiova, Faculty of Agronomy, 19 Libertății street, Craiova, Romania, elena.agro@gmail.com; catalin_rosculete@yahoo.com

Corresponding author email: elena.agro@gmail.com

Abstract

Production in cereal crops is due to some complex physiological and biochemical processes, but is essentially associated with the process of carbohydrate accumulation in the grain filling phase which in turn is attributed to leaf functionalities.
A critical stage in the development of wheat plants is the emergence of the final leaf called the flag leaf. At this point the emphasis of management needs to shift to its protection as the flag leaf is critical for attaining high grain yields. Unlike other leaves in the reproductive phase, flag leaves are the main organ for photosynthesis, providing the main assimilated source for plant growth and spike development and also for sensing environmental conditions conducive to adaptation.
This short review aims to analyse some of the most important results from the specialized literature regarding the influence of the flag leaf on cereal production. The main documentation platforms were Google Scholar and Web of Science.
The importance of the flag leaf in generating yield in grains is without dispute. Protecting the flag leaf is critical to attaining high yields. The vigil starts as soon as growers are able to recognize when the flag begins to emerge.
***Key words**: grains, flag leaf, yield, critical stage*

INTRODUCTION

Along with climate impact a range of regional and global political and economic factors intensify food insecurity and long term vulnerability in certain regions (Bonciu et al, 2021a).
Cereals are a term used to encompass the main grain-producing species in the world.
Plant morphology and architecture and the transcriptional networks controlling plant development have been targeted in yield improvement studies. All over the world, multi-annual studies have been carried out on the adaptability and stability of cereals (Roșculete et al., 2021)
Identifying varieties and species of plants or grains by morphological means is still the main method used in cereal breeding and varietal identification and provides the basis for the definitive description of a variety (Borrelli et al., 2009).
By understanding the morphology of each species, it is possible to use it to identify the varieties (cultivars) that exist in each classification. Recognition of the importance attached to identifying varieties is highlighted by the existence of UPOV

(The International Union for the Protection of New Plant Varieties). The test guidelines provide useful information of the major characters used in establishing the morphological identification of the different varieties of cereal species. In table 1 are specified the main morphological terms for cereals.

Table 1. Cereals morphological terms

Anther	The male (pollen-producing) part of the flower.
Awn	The bristles on the wheat head (spike).
Coleoptile	Protective sheath covering the emerging shoot.
Flag leaf	The last leaf to emerge before the head (spike).
Floret	Each individual flower (containing anthers and stigma). Several florets form a single spikelet.
Spike	Also known as the wheat head.
Spikelet	The basic unit of a wheat flower. Each spikelet consists of at least three florets.
Stigma	The female (pollen-receptor) part of the flower.
Tiller	A shoot originating from the main stem from the coleoptilar node.

Source: Lindsey et al. (2017)

As farming and agricultural studies have progressed, so have the number of studied stressors (Cotuna et al., 2021; Cotuna et al., 2022a, 2022b; Paraschivu et al., 2020). Food is key to health but some undesirable situations can disrupt the food system (Paraschivu et Cotuna, 2021). Sustainable agricultural practices assure all dimensions of sustainability: environmental, social and economic (Cotuna et al., 2015; Partal and Paraschivu, 2020).

Grain yield of cereals is a particularly complex trait, reflecting the culmination of all the processes of vegetative and reproductive growth and development, and their interactions with the edaphic and aerial environments; yet, the yield is usually the trait of most importance to plant breeders (Bonciu et al, 2021b; Quarrie et al., 2006).

A critical stage in the development of wheat plants is the emergence of the final leaf called the *flag leaf*. The flag leaf is the last leaf to emerge in a cereal plant during its growth; the flag leaf provides majority of the leaf area of the plant and is used as one indicator of its growth stage.

Traditionally, the flag leaf has been considered as the main contributor to grain nitrogen due to its large protein content (Millard and Grelet, 2010). During the last decade, most of the studies dealing with N accumulation in grains have only focused on leaf lamina nitrogen (Bahrani and Joo, 2010; Sanchez-Bragado et al., 2017).

Apart from the flag leaf blade, the contribution of the ear as well as the lower parts of the plant may be relevant. Ear photosynthesis is considered as an important source of assimilates for grain filling in wheat and other cereals (Sanchez-Bragado et al., 2014; Tambussi et al., 2007) especially under drought conditions.

Targeted genome editing includes the creation of plants with improved value and characteristics that provide resistance to various biotic and abiotic stressors (De Souza and Bonciu, 2022). To provide a genome-wide view of gene expression in flag leaves associated with grain yield, it can be compared the flag leaves from different varieties with different yield potentials.

MATERIALS AND METHODS

In this short review, the main objective was the presentation of some recent results from the specialized literature regarding the influence of the flag leaf on the production and productivity elements to cereals.

The used methods included searching of the various databases with the latest publications in the field and identification of some relevant results. The main databases were Web of Science and Google Scholar but also some short online communications.

RESULTS AND DISCUSSIONS

Yield in grains crops is due to complex physiological and biochemical processes, but it is essentially associated with the process of carbohydrate accumulation in the grain filling phase which in turn is attributed to leaf functionalities (Biswal and Kohli, 2013; Ișlicaru et al., 2021).

Leaves are primarily involved in photosynthesis and are material producers and exporters. The number and size of leaves determine a plant's photosynthetic potential and play important roles in determining plant yield, stress responses and disease resistance (Asrar et al., 2016; Khaliq et al., 2008).

Due to its position, very close to the ear and on the surface of the field, the flag leaf can intercept a considerable amount of light energy that it transforms into carbohydrates that will be translocate to grains (Dobre and Lazăr, 2014).

Unlike other leaves in the reproductive phase, flag leaves are the main organ for photosynthesis, providing the main assimilated source for plant growth and spike development and also for sensing environmental conditions conducive to adaptation (Biswal and Kohli, 2013; Tian et al., 2015).

In this context, rates of net photosynthesis of the flag leaves of 15 genotypes of wheat and related species were measured by Austin et al. (1982) throughout their life, using intact leaves on plants grown in the field. The authors reported that the stage when rates were maximal, they were in general highest for the diploid species, intermediate for the tetraploid species and lowest for *Triticum aestivum*.

The flag leaf has been traditionally considered as the main contributor to grain nitrogen. According to Sanchez-Bragado et al. (2017), during the reproductive stage, other organs besides the flag leaf may supply nitrogen to developing grains. Therefore, the contribution of the ear and other organs to the nitrogen supplied to the growing grains remains unclear. It is important to develop phenotypic tools to assess the relative contribution of different plant parts to the N accumulated in the grains of wheat which may help to develop genotypes that use N more efficiently.

A critical stage in the development of wheat plants is the emergence of the final leaf called the flag leaf. At this point the emphasis of management needs to shift to its protection as the flag leaf is critical for attaining high grain yields (Nagelkirk, 2011).

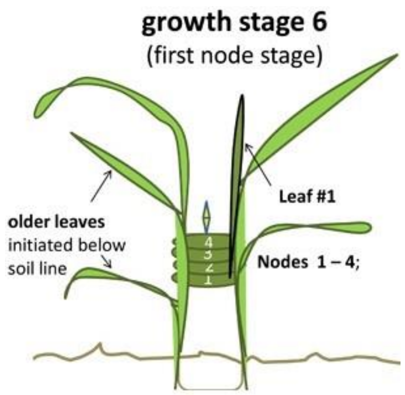

Figure 1. The diagrams of growth stages 6.0 to wheat. The first joint can be seen above ground. Node #1 will generate leaf #1 (Nagelkirk, 2011)

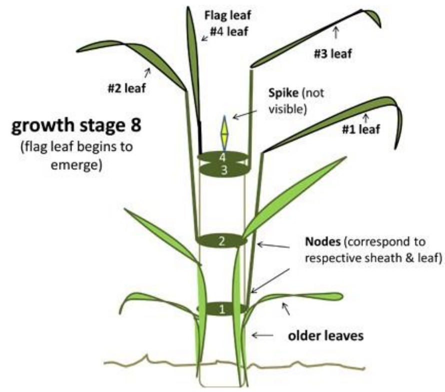

Figure 2. The diagrams of growth stages 8.0 to wheat. The flag leaf begins to emerge. It is the fourth leaf, where the first leaf originates from the first above ground node (Nagelkirk, 2011)

The diagrams of growth stages 6.0 and 8.0 attempt (Figure 1 and Figure 2) to illustrate the relationship between nodes and leaves, and how this can be used to help identify the flag leaf (Nagelkirk, 2011).

When the tip of the flag leaf begins to emerge, the shoot is said to be at Feekes growth stage 8.0. These stages are particularly significant because the flag leaf makes up approximately 75% of the effective leaf area that contributes to grain fill. To determine if an emerging leaf is in fact the flag leaf, one should first identify the leaf and sheath that is attached to the first node near the base of the shoot.

To protect the crop’s flag leaves within a field, growers should monitor their fields to watch for the development of various leaf diseases.

It is therefore important to protect and maintain this leaf healthy (free of disease and insect damage) before and during grain development (Lindsey et al., 2017). When the flag leaf emerges, three nodes are visible above the soil surface. To confirm that the leaf emerging is the flag leaf, it must split the leaf sheath above the highest node. If the head and no additional leaves are found inside, Stage 8.0 is confirmed and the grower should decide whether or not to use foliar fungicides to manage early-season and overwintering foliar fungal diseases. According to Lindsey et al. (2017), this decision should be based upon the following considerations: Is a fungal disease present in the field? Is the variety susceptible or are weather conditions favourable (wet and humid) for rapid spread and development of the disease(s) found in the field? Does the crop yield potential warrant the cost of application of the fungicide in question to protect it? Is the crop under stress?

If a positive answer applies to the first three questions and a negative response to the last, plans should be made to protect the crop from further damage. In most situations, the greatest return to applied foliar fungicides comes from application at Feekes Stages 8.0 through 10.0. Nitrogen applications at or after Feekes 8.0 may enhance grain protein levels but are questionable with respect to added yield. Moreover, additional N may increase the severity of some foliar diseases, particularly the rusts (Lindsey et al., 2017).

At maturity, timely harvest is important. Risks of delayed harvest include disease, lodging and seed sprouting which ultimately reduce grain yield and test weight.

Growers also need to be careful to avoid damaging the flag leaf once it emerges. For example, late applications of fertilizer nitrogen or oil based pesticides can potentially burn the leaf tissue compromising its ability to support grain fill.

The flag leaf is the main component of the canopy in the middle and late growth stages of winter wheat, and is an important organ that determines the grain-filling rate and the final yield (Vicentea et al., 2018). Approximately 30–50% of the dry matter in grains is derived from the assimilation of photosynthetic carbon substrates by flag leaves (Liu, X.J. et al., 2021). The flag leaf of wheat is sensitive to water supply, and drought stress is an important factor causing flag leaf senescence (Sawhney and Singh, 2002).

Under drought conditions, oxidative degradation products occur at the cellular level, leading to oxidative stress. Numerous experiments on the study of wheat drought resistance showed cell-based induction of enzyme oxidative stress protection systems (Păunescu et al., 2021).

The plant cuticle is at the surface of aerial plant organs and thus represents the plants' outermost point of interaction with their environment. Glaucousness refers to the bluish-silverish-gray appearance of organs, such as the flag leaf (Figure 3), stem or spikes and is caused by the scattering of light due to deposition of wax crystals on the plant's surfaces (Würschum et al., 2020).

Glaucousness has been associated with several traits and physiological processes, mainly related to an increased drought and heat tolerance and thus higher yield under dry conditions (Bi et al. 2017; Würschum et al., 2020).

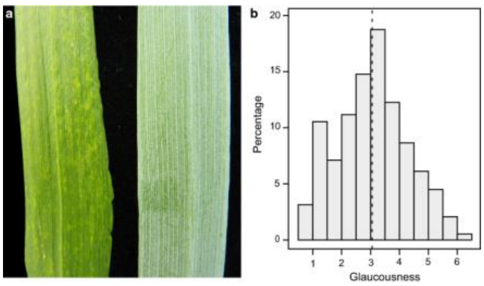

Figure 3. Flag leaf glaucousness in wheat: examples of a glossy and a glaucous flag leaf (a); histogram of flag leaf glaucousness in the panel of some winter wheat cultivars (b) (Würschum et al., 2020)

During the grain-filling stage, drought stress accelerated the accumulation of reactive oxygen species and the decomposition of chloroplasts, and reduced the accumulation of assimilates in wheat flag leaves (Ruberti et al., 2014). Moderate water control could significantly increase catalase and superoxide dismutase activities and the photosynthetic rate of flag leaves, and further improve drought resistance, yield and water use efficiency (Su et al., 2020; Wang et al., 2013).

On the other hand, a multifactorial analysis showed better adaptation of ears to water deficit than flag leaves, underlining the importance of this finding for breeding programs to improve grain yield under future climate change (Bendou et al., 2022). Also, the authors suggested that the lower content of ascorbate had a dual impact on the biomass and antioxidant status of the flag leaves of long water deficit regime-treated plants.

Ding et al. (2018) stated that the net photosynthetic rate and chlorophyll content were differently affected by water deficit in two winter wheat cultivars and the variation content were more stable in spikes compared to flag leaves.

CONCLUSIONS

The leaf surface of cereals is an indicator of productivity, and the flag leaf, being the most important leaf of the plant, can play a significant role in this regard.

Unlike other leaves in the reproductive phase, flag leaves are the main organ for photosynthesis, providing the main source assimilates for plant growth and spike development. Due to its position, very close to the ear and on the surface of the field, the flag leaf can intercept a considerable amount of light energy that it transforms into carbohydrates that will be translocate to grains.

In conditions of drought and lack of water, in cereal crops the leaf surfaces significantly decrease and the basal angle of the flag leaf is adjusted to avoid excessive water loss through transpiration.

The flag leaf makes up approximately 75% of the effective leaf area that contributes to grain fill. It is therefore important to protect and maintain this leaf healthy (free of disease and insect damage) before and during grain development.

Correct growth stage identification and knowledge of factors that affect grain yield can enhance management decisions, avoiding damage to the crop and unwarranted or ineffective applications. It is useful to break down the cereal life cycle into various growth stages.

By understanding the main crop development stages, it becomes easier to measure crop performance and informs husbandry choices.

REFERENCES

Asrar, M., Usama, K., Abdul, R., Ghazanfar, H., Zulqarnain, H. (2016). Heritability of yield and yield components in hexaploid wheat. *Academia Journal of Agricultural Research*, 4(5), 277-280.

Austin, R.B., Morgan, C.L., Ford, M.A., Bhagwat, S.G. (1982). Flag Leaf Photosynthesis of *Triticum aestivum* and Related Diploid and Tetraploid Species. *Annals of Botany*, 49(2), 177-189.

Bahrani, A., Joo, M.H. (2010). Flag leaf role in N accumulation and remobilization as affected by nitrogen in a bread and durum wheat cultivars. *Am. J. Agric. Environ. Sci*., 8, 728-735.

Bendou, O., Gutiérrez-Fernández, I., Marcos-Barbero, E.L., Bueno-Ramos, N., Miranda-Apodaca, J., González-Hernández, A.I., Morcuende, R., Arellano, J.B. (2022). Physiological and Antioxidant Response to Different Water Deficit Regimes of Flag Leaves and Ears of Wheat Grown under Combined Elevated CO2 and High Temperature. *Plants*, 11(18), 2384.

Bi, H., Kovulchuk, N., Langridge, P., Tricker, P.J., Lopato, S., Borisjuk, N. (2017). The impact of drought on wheat leaf cuticle properties. BMC Plant. Biol., 17, 85.

Biswal, A.K., Kohli, A. (2013). Cereal flag leaf adaptations for grain yield under drought: knowledge status and gaps. *Mol. Breeding*, 31(4), 749-66.

Bonciu, E., Păunescu, R.A., Roșculete, E., Păunescu, G. (2021a). Waste management in agriculture. *Scientific Papers: Management, Economic Engineering in Agriculture & Rural Development*, 21(3), 219-227.

Bonciu, E., Păunescu, R.A., Roșculete, E., Florea, D. (2021b). The variability of some characters and their correlations with the yield of an extensive assortment of autumn wheat varieties, tested on the chernozem from ARDS Caracal. *Annals of the University of Craiova - Agriculture, Montanology, Cadastre Series*, 51(1), 244-260.

Borrelli, G.M. et al. (2009). Integrated Views in Plant Breeding. *Crop Physiology*, https://www.sciencedirect.com

Cotuna, O., Paraschivu, M., Sărăţeanu, V., Horablaga, M.N., Durău, C.C. (2022a). Research regarding the contamination with *Fusarium spp*. of the wheat grains from the variety *Triticum aestivum ssp. spelta* before and after the treatment with bio-fungicide - case study. *Scientific Papers. Series A. Agronomy*, LXV(1), 266-273.

Cotuna, O., Paraschivu, M., Sărățeanu, V. (2022b). Charcoal rot of the sunflower roots and stems (*Macrophomina phaseolina* (Tassi) Goid.) - an overview. *Scientific Papers Series Management, Economic Engineering in Agriculture and Rural Development*, 22(1), 107-116.

Cotuna, O., Paraschivu, M., Bulai, A., Toma, I., Sărăţeanu, V., Horablaga, N.M., Buzna, C. (2021). Behaviour of some oat lines to the attack of the fungus *Blumeria graminis* (D. C.) f. sp. *avenae* EM. Marchal. *Scientific Papers Series Management, Economic Engineering in Agriculture and Rural Development*, 21(4), 161-170.

Cotuna, O., Paraschivu, M., Paraschivu, A.M., Sarateanu, V. (2015). The influence of tillage, crop rotation and residue management on Tan Spot (*Drechslera tritici repentis* Died. Shoemaker) in winter wheat. *Research Journal of Agricultural Science*, 47(2), 13-21.

Ding, H., Liu, D., Liu, X. et al. (2018). Photosynthetic and stomatal traits of spike and flag leaf of winter wheat (*Triticum aestivum* L.) under water deficit. *Photosynthetica*, 56, 687-697.

De Souza, C.P., Bonciu, E. (2022a). Progress in genomics and biotechnology, the key to ensuring food security. *Scientific Papers Series Management, Economic Engineering in Agriculture and Rural Development*, 22(1), 149-157.

De Souza, C.P., Bonciu, E. (2022b). Use of molecular markers in plant bioengineering. *Scientific Papers Series Management, Economic Engineering in Agriculture and Rural Development*, 22(1): 159-166.

Dobre, S.P., Lazăr, C. (2014). Surface determinations of flag leaf for a set of mutant DH wheat lines. *An. INCDA Fundulea*, LXXXII, 7-16.

Ișlicaru, I., Roșculete, E., Bonciu, E., Petrescu, E. (2021). Research on the identification of high productivity winter wheat varieties and lines, tested on luvisol from Șimnic in the period 2004-2018, 2021. *Scientific Papers. Series A. Agronomy*, Vol. LXIV(1), 388-396.

Khaliq, I., Irshad, A., Ahsan, M. (2008). Awns and flag leaf contribution towards grain yield in spring wheat (*Triticum aestivum* L.). *Cereal. Res. Commun*., 36 (1), 65-76.

Lindsey, L.E., Paul, P., Lentz, E. (2017). Wheat growth stages and associated Management. Ohio State University, FactSheet AGF-126. Available at: https://ohioline.osu.edu/factsheet/agf-126

Liu, X.J. et al. (2021). Physiological response of flag leaf and yield formation of winter wheat under different spring restrictive irrigation regimes in the Haihe Plain, China. *Journal of Integrative Agriculture*, 20(9), 2343-2359.

Millard, P., Grelet, G.A. (2010). Nitrogen storage and remobilization by trees: ecophysiological relevance in a changing world. *Tree Physiol*. 30, 1083-1095.

Nagelkirk, M. (2011). Flag leaf emergence in winter wheat. Michigan State University Extension, https://www.can.edu/flagleaf

Paraschivu, M., Cotuna, O. (2021). Considerations on COVID 19 impact on Agriculture and Food Security and forward-looking statements. *Scientific Papers Series Management, Economic Engineering in Agriculture and Rural Development*, 21(1), 573-581.

Paraschivu, M., Ciobanu, A., Cotuna, O., Paraschivu, M. (2020). Assessment of the bacterium *Erwinia amylovora* attack on several pear varieties (*Pyrus communis* L.) and the influence on fruits sugar content. *Agricultural Sciences & Veterinary Medicine University, Bucharest. Scientific Papers. Series B. Horticulture*, LXIV(1), 163-168.

Partal, E., Paraschivu M. (2020). Results regarding the effect of crop rotation and fertilization on the yield and qualities at wheat and maize in South of Romania. *Agricultural Sciences & Veterinary Medicine University, Bucharest. Scientific Papers. Series A. Agronomy*, LXIII(2), 184-189.

Paunescu, R.A., Bonciu, E. Rosculete, E., Paunescu, G., Rosculete, C.A., Babeanu, C. (2021). The Variability for the Biochemical Indicators at the Winter Wheat Assortment and Identifying the Sources with a High Antioxidant Activity. *Plants*, 10(11), 2443.

Quarrie, S.A., Pekic Quarrie, Radosevic, S.R., Rancic, Kaminska, D.A., Barnes, J.D. et al. (2006). Dissecting a wheat QTL for yield present in a range of environments: From the QTL to candidate genes. *Journal of Experimental Botany*, 57(11), 2627-2637.

Roșculete, E., Păunescu, R.A., Bonciu, E., Roșculete, C.A., Voicea, I. (2021). Where are the foreign wheat cultivars in competition with the romanian cultivars? - Experiments on the chernozem from Caracal in the period 2019-2021. *Annals of the University of Craiova - Agriculture, Montanology, Cadastre Series*, 51(1), 144-158.

Ruberti, C., Barizza, E., Bodner, M., La-Rocca, N., De-Michele, R., Carimi, F., Lo-Schiavo, F., Zottini, M. (2014). Mitochondria change dynamics and morphology during grapevine leaf senescence. *PLoS ONE*, 9, e102012.

Sanchez-Bragado, R., Dolors Serret, M., José L. Araus, J.L. (2017). The Nitrogen Contribution of Different Plant Parts to Wheat Grains: Exploring Genotype, Water, and Nitrogen Effects. *Front. Plant Sci*., 7, 1986.

Sanchez-Bragado, R., Molero, G., Reynolds, M.P., Araus, J.L. (2014). Relative contribution of shoot and ear photosynthesis to grain filling in wheat under good agronomical conditions assessed by differential organ. *C.J. Exp. Bot*., 65, 5401-5413.

Sawhney, V., Singh, D.P. (2002). Effect of chemical desiccation at the post-anthesis stage on some physiological and biochemical changes in the flag leaves of contrasting wheat genotypes. *Field Crops Research*, 77, 1-6.

Su, R., Chen, L., Wang, Z., Hu, Y. (2020). Differential response of cuticular wax and photosynthetic capacity by glaucous and non-glaucous wheat cultivars under mild and severe droughts. *Field Crops Research*, 147, 303-312.

Tambussi, E.A., Bort, J., Guiamet, J.J., Nogués, S., Araus, J.L. (2007). The photosynthetic role of ears in C 3 cereals: metabolism, water use efficiency and contribution to grain yield. *Crit. Rev. Plant Sci*., 26, 1-16.

Tian, Y, Zhang, H, Xu, P, Chen, X, Liao, Y, Han, B. et al. (2015). Genetic mapping of a QTL controlling leaf width and grain number in rice. *Euphytica*, 202(1), 1-11.

Vicentea, R., Vergara-Díaz, O., Medina, S., Chairi, F., Kefauver, S.C., Bort, J., Serret, M.D., Aparicio, N., Araus, J.L. (2018). *Durum* wheat ears perform better than the flag leaves under water stress: Gene expression and physiological evidence. *Environmental and Experimental Botany*, 153, 271-285.

Wang, D., Yu, Z., White, P.J. (2013). The effect of supplemental irrigation after jointing on leaf senescence and grain filling in wheat. *Field Crops Research*, 151, 35-44.

Würschum, T., Langer, S.M., Longin, C.F.H. et al. (2020). Refining the genetic architecture of flag leaf glaucousness in wheat. *Theor. Appl. Genet.,* 133, 981-991.

Yonezawa, K. (1997). Yield components. In: Matsuo, T., Futsuhara, Y., Kikuchi, F., Yamaguchi, H., editors. *Science of the rice plant vol. III Genetics*. Tokyo: Food and Agriculture Policy Research Center; 1997, 400-412.