UNIVERSITI PUTRA MALAYSIA

RESPONSES OF SOURCE-SINK MANIPULATIONS ON YIELD PRODUCTION AND SUCROSE SYNTHASE ACTIVITY IN GRAINS OF SELECTED RICE (Oryza sativa L.) VARIETIES

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By

SHAFEEQA BINTI SHAHRUDDIN

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The unbalanced allocation pattern of assimilate within panicle has contributed to a significant reduction in grain yield. Thus, the present research was undertaken to assess the physiological factors influencing assimilate partitioning pattern of Malaysian rice varieties. The first study was conducted for determining the genotypic variations on yield and yield components among different rice varieties, so as to identify few components limiting the rice yield. Ten Malaysian rice varieties (Sri Malaysia, Kadaria, Seberang, Pulut Siding, MR84, MR219, MR211, MR167, MR103, MR263) were grown in polybag culture under glasshouse condition. The significant correlation between grain yield and harvest index ($r = 0.38^{*}$) indicated that the remobilization of assimilate from the vegetative parts of plant is critical to improve the grain yield. However, the negative correlation between grain size and the filled grain in the basal spikelet ($r = -0.43^{***}$), suggested that there was an unbalanced assimilate partitioning pattern among all ten rice varieties. Similarly, less than 100% of the filled grain resulted for all ten rice varieties.

In studying the grain filling process, the second study was conducted for evaluating and elucidating the response of source-sink manipulations on; (a) the grain yield and yield components, and (b) the trend of sucrose synthase (*SuS*) activity in the grains among different rice varieties, respectively. Five Malaysian rice varieties (MR263, MR219, MR167, MR84, Pulut Siding) from the first study were subjected to four treatments; i.e. 50% flag leaf cutting, 25 and 50% spikelet removal, and control. Manipulations on grain number have decreased the grain yield in all five rice varieties. The 25 and 50% spikelet removal have increased the grain size of varieties MR167 and Pulut Siding, as well as the filled grain in the basal spikelet of variety MR84, thus lowering their grain yield reduction (less than 25 and 50%). The filled grain was greater in the apical spikelets, suggested that there might be an inadequate supply of assimilate to the basal spikelets. The flag leaf cutting has reduced about 9 - 14% of grain yield, as well as the filled grains (4 – 11%) in all five rice varieties.

Reducing the source strength (flag leaf cutting) did not significantly affect the sucrose content in the apical and basal grains because of the compensation from other vegetative parts of the plant. The 25 and 50% spikelet removal created a situation of lower sink demand which contributed to the higher *SuS* activity in the apical (2 - 9%) and basal grains (3 – 21%) thereby reduced the sucrose accumulation in grains. The positive correlation between the *SuS* activity and sucrose content revealed that the sink strength influenced the sucrose accumulation in grains. However, the *SuS* activity, especially in the basal grains of varieties MR263, MR219, MR167, and Pulut Siding, was more sensitive under the adverse condition of the source-sink manipulations.

Through the study, the grain yield can be increased through increased in biomass production or assimilate partitioning to the sink, which would require to study the grain filling process further. Less than 80% of filled grain for varieties MR263, MR219, MR167, and MR84 suggested that their grain yield was limited by the source strength. The significant increment of grain size and more than 80% of filled grain for variety Pulut Siding suggested that the grain yield was limited by both the source strength and sink capacity. With a limited assimilate from the source parts, the assimilate partitioning trend would be depended on the sink strength (eg. *SuS* activity). The lower *SuS* activity could be one of the reasons causing the lower starch content and higher sucrose accumulation in the basal grains.

Abstrak tesis yang dikemukakan kepada senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

RESPON MANIPULASI *SOURCE* DAN *SINK* KE ATAS HASIL BIJIRIN DAN AKTIVITI ENZIM *SUCROSE SYNTHASE* DALAM BIJIRIN PADA VARIETI PADI (*Oryza sativa* L.) TERPILIH

Oleh

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Corak pengagihan yang tidak seimbang daripada hasil fotosintesis dalam tangkai padi telah menyumbang kepada pengurangan yang ketara kepada hasil bijirin. Oleh itu, kajian kali ini dijalankan bagi menilai faktor-faktor fisiologi mempengaruhi corak pembahagian hasil fotosintesis bagi varieti padi Malaysia. Kajian pertama dijalankan untuk menentukan variasi genotip pada hasil dan hasil komponen antara varieti padi yang berbeza, bagi mengenalpasti beberapa komponen yang menghadkan hasil padi. Sepuluh varieti padi Malaysia (Sri Malaysia, Kadaria, Seberang, Pulut Siding, MR84, MR219, MR211, MR167, MR103, MR263) telah ditanam dalam polibeg di dalam rumah kaca. Hubungan yang signifikan antara hasil bijirin dan indeks penuaian ($r = 0.38^{*}$) menunjukkan bahawa pergerakan semula hasil fotosintesis daripada bahagian vegetatif tumbuhan adalah penting bagi meningkatkan hasil bijirin. Akan tetapi, korelasi negatif antara saiz bijirin dan peratus bijirin penuh dalam spikelet basal ($r = -0.43^{***}$), mencadangkan bahawa terdapat corak pembahagian hasil fotosintesis adalah tidak seimbang di kalangan semua sepuluh variety padi. Begitu juga, kurang daripada 100% daripada peratusan bijirin penuh untuk kesemua sepuluh varieti padi.

Dalam mengkaji proses pengisian bijirin, kajian kedua telah dijalankan untuk menilai dan menjelaskan respon manipulasi *source* (di mana fotosintesis dijalankan) dan *sink* (hasil fotosintesis ditempatkan) ke atas; (a) hasil bijirin dan komponen hasil, dan (b) trend aktiviti *sucrose synthase* (*SuS*) dalam bijirin dalam varieti padi yang berbeza. Lima varieti padi Malaysia (MR263, MR219, MR167, MR84, Pulut Siding) daripada kajian pertama tertakluk kepada empat rawatan; iaitu 50% pemotongan daun pengasuh, 25 dan 50% penyingkiran spikelet, dan kawalan. Manipulasi pada jumlah bijirin telah mengurangkan hasil bijirin dalam kesemua lima varieti padi. Penyingkiran 25 dan 50% spikelet telah meningkatkan saiz bijirin varieti MR167 dan Pulut Siding, serta peratusan bijirin penuh dalam spikelet basal variety MR84, seterusnya mengurangkan peratusan pengurangan hasil bijirin variety-varieti tersebut (kurang daripada 25 dan 50%).

Peratusan bijirin penuh adalah lebih besar dalam spikelet apikal, mencadangkan bahawa kemungkinan hasil fotosintesis tidak mencukupi untuk spikelet basal. Pemotongan daun pengasuh telah mengurangkan kira-kira 9-14% daripada hasil bijirin, serta peratusan bijirin penuh (4 - 11%) dalam semua lima varieti padi.

Mengurangkan kekuatan sumber (memotong daun pengasuh) tidak memberi kesan ketara ke atas kandungan sukrosa dalam apikal dan basal bijirin kerana pampasan dari bahagian-bahagian vegetatif yang lain. Penyingkiran 25 dan 50% spikelet mewujudkan keadaan permintaan yang lebih rendah daripada *sink* yang menyumbang kepada aktiviti *SuS* yang lebih tinggi dalam bijirin apikal (2-9%) dan basal (3-21%), dengan itu mengurangkan pengumpulan sukrosa dalam bijirin. Korelasi positif antara aktiviti *SuS* dan kandungan sukrosa mendedahkan bahawa kekuatan *sink* mempengaruhi pengumpulan sukrosa dalam bijirin. Walau bagaimanapun, aktiviti *SuS*, terutamanya dalam bijirin basal varieti MR263, MR219, MR167, dan Pulut Siding, adalah lebih sensitif di bawah keadaan manipulasi *source-sink*.

Oleh itu, hasil bijirin boleh ditingkatkan melalui peningkatan dalam pengeluaran biomas atau mengasimilasikan pembahagian hasil fotosintesis yang lebih baik kepada *sink*, yang seterusnya memerlukan kajian terhadap proses pengisian bijirin. Kurang 80% bijirin penuh bagi varieti MR263, MR219, MR167, dan MR84 mencadangkan bahawa hasil bijirin mereka dihadkan oleh aktiviti *source*. Peningkatan signifikan saiz bijirin dan lebih 80% bijirin penuh bagi varieti Pulut Siding mencadangkan bahawa hasil bijirin dihadkan oleh kedua-dua aktiviti *source* dan kapasiti *sink*. Dengan hasil fotosintesis yang terhad dari bahagian *source*, trend pembahagian hasil fotosintesis akan bergantung kepada kekuatan *sink* (contohnya; aktiviti *SuS*). Aktiviti *SuS* yang lebih rendah boleh menjadi salah satu sebab yang menyebabkan kandungan kanji yang lebih rendah dan pengumpulan sukrosa yang lebih tinggi dalam bijirin basal.

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I certify that a Thesis Examination Committee has met on 17 October 2014 to conduct the final examination of Shafeeqa binti Shahruddin on her thesis entitled "Responses of Source-Sink Manipulations on Yield Production and Sucrose Synthase Activity in Grains of selected Rice (*Oryza sativa* L.) Varieties" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Master of Science.

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CHAPTER 1

GENERAL INTRODUCTION

In Malaysia, the demand for rice is projected to increase by 40% in year 2015, which requires a sustainable approach to rice production. Malaysia is currently only 73% self-sufficient in rice, together with no change in land area for rice (since the 1980s) (FAOSTAT, 2013). The yield potential of available varieties is approximately 8 – 10 tan/ha. However, actual yield achieved is only 4 tan/ha (FAOSTAT, 2013). Rice increased in Malaysia is only 0.3 – 0.5 tan/ha for the past 10 years, indicating that the available varieties are unable to increase grain yield further and achieve the yield potential. Therefore, further improvement in rice productivity on varieties is needed in order to meet the increasing demand each year.

Other than improving the crop management of rice cultivation, the expansion of rice productivity depends also on their inbuilt genetic variability (Ukaoma *et al*., 2013). Genetic improvement of yield may be accomplished through the selection of a number of morphological traits such as a number of filled grains per panicles, number of panicles per plant, percentage of filled grain per panicle, 1000-grain weight, plant height and panicle length on grain yield (Ashura, 1997; Moncada *et al*., 2001), that has been found to correlate positively with the grain yield in breeding programs for cereals (Ojo and Dashiella, 2002; Ukaoma *et al*., 2013). Study carried out by Moncada *et al.* (2001) observed that there was a negative correlation between yield and percentage sterility of rice genotype. The correlation between grain yield and the morphological traits indicates that these traits could be improved through breeding. Reducing the spikelet sterility or increase spikelet fertility would be the choice to increase rice yield. However, there is little information regarding the physiological constraints causing low number of filled grains of rice varieties cultivated in Malaysia.

Grain yield in rice is defined as the product of filling efficiency (Kato and Takeda, 1996). Grain filling development is the most critical stage in rice plant to determine the success percentage of the plant in producing higher crop yield. Selection of varieties with large sink size (higher number of grains per panicle) would be best in producing high grain yield (Ashraf *et al*., 1994; Kato *et al*., 2007). A large sink size, as well as an efficient transport of assimilate from leaves and stems to developing spikelet is required in producing higher yield (Ashraf *et al*., 1994). Moreover, the capacity to transport assimilate from source to sink (e.g. the number of large vascular bundle) could also be the base assimilate limitation of grain filling. Varieties with compact panicle types, characterized by short panicle with high grain density within panicle, had become available and reported to have a yield potential of 8 to 20% more than other conventional rice varieties (Cheng *et al.*, 2007; Zhang, 2007). However, more previous studies revealed that the compact panicle varieties produced relatively lower in filled grain percentage and grain weight (Zhu *et al*., 2004). Previous studies also showed that the spikelets formed on the individual panicle close to the culm were termed as basal spikelets and produced a partially filled poor quality grain in contrast to the apical spikelets (spikelets located further from the culm) (Patel and Mohapatra, 1996;

Mohapatra *et al.,* 2009). The grain weight and filling rate of basal spikelets can be as low as 21% compared to the apical spikelets (Kobata *et al*., 2006; Zhang, 2007).

From the past studies, most of the researches suspected that the poor grain filling is the consequence of carbon limitation (Sikder and Gupta, 1976; Murty and Murty, 1982; Zhu *et al*., 1988). There are other several physiological mechanisms underlying on the carbohydrate supply factor such as; poor translocation and partitioning of assimilates among the grains within the same panicle (Yang *et al*., 2002), water potential gradient (Barlow *et al*., 1980), sucrose level in the leaf (Chao and Bush, 1998), and several enzymes during the active grain filling period (Yang *et al*., 2001) which have been implicated to influence the grain production/assimilate partitioning, and consequently the seed yields.

During grain filling period, sucrose is the main form of carbohydrate (assimilate) transported through the phloem from photosynthetic leaves (sources) to non-photosynthetic organs (sinks) (Lemoine *et al*., 2013). The differential sucrose concentrations causing a steep gradient of turgor between sources and sinks, and has sustained sucrose transport (Elizabeth and Daniel, 2011). It has been reported that there were various types of enzymes involved in the metabolism of carbohydrate in developing rice endosperm (Nakamura *et al*., 1989). Previous studies reported that only five enzymes namely, sucrose synthase (*SuS*), invertase (*b*-fructofuranosidase), adenosine diphosphate-glucose pyrophosphorylase (*AGPase*), starch synthase (*StSase*), and starch branching enzyme (*SBE*) are reported to play as the major enzymes involved in the metabolism of the carbohydrate (Yang and Zhang, 2010). Among these enzymes, sucrose synthase (*SuS*) is first in the line of conversion of sucrose to starch (Sung *et al*., 1989, Counce and Gravois, 2006). During grain filling, sucrose (assimilate) is broken down by *SuS* enzyme in the cytoplasm of endosperm cell (sinks) to form uridine diphosphoglucose (UDPG) and fructose, prior to its entry into the amyloplast for starch synthesis (Counce and Gravois, 2006). This indicates that *SuS* activity may be valuable in assessing the ability of a sink to import carbohydrate (sink strength) among rice varieties (Counce and Gravois, 2006). Previous study observed that endosperm of apical spikelets of rice panicle possesses higher concentration of starch compared to the basal spikelets (Matsue *et al*., 1995). Low *SuS* enzyme activity may lead to a poor development and quality of basal spikelets (Umemoto *et al*., 1994). This indicates that the efficiency of grain filling is strongly dependent on spatial location of spikelet of the panicle (apical or basal spikelets) (Mohapatra *et al*., 1993).

Among the mechanisms that have been implicated to influence the grain production and the seed yields; poor translocation or partitioning of assimilates among the grains within the same panicle is one of the important components, manipulation of which is a needs for optimizing yield. Therefore, the present research was undertaken to assess the physiological factors influencing the assimilate partitioning pattern of selected Malaysian rice varieties through the responses of source-sink manipulations on yield and sucrose synthase enzyme activity involved during active phloem loading in the sink (grain filling). Specific objectives were; (a) to determine the genotypic variations on yield and yield components among different rice varieties, so as to identify few components limiting the rice yield; (b) to evaluate the grain yield and yield components among different rice varieties in response to source and sink manipulations; and (c) to elucidate the trend of sucrose synthae (*SuS)* enzyme activity in the grains among different rice varieties in response to source and sink manipulations.

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