Faculty of Resource Science & Technology

The Growth and Development of Sarawak Rice Towards Photoperiod

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DECLARATION

I declare that the work in this thesis was carried out in accordance with the regulations of Universiti Malaysia Sarawak. Except where due acknowledgements have been made, the work is that of the author alone. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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ABSTRACT

A series of controlled environment treatments were conducted on Sarawak traditional rice, notably Bario Sederhana and Biris landraces, aimed to quantify the development and growth performance when sown at five photoperiod regimes (8, 9, 10, 11 and 12 hours). This study revealed that both landraces had a short basic vegetative phase, as crop sensitivity to photoperiod commenced after the appearance of fourth leaf for Bario Sederhana ($P<0.001$) and third leaf ($P<0.001$) for Biris. For Bario Sederhana landrace, phyllochron varied with different photoperiod regimes, except for rice plants that were sown at 11 and 12 hours photoperiod. Under these photoperiods, Bario Sederhana took a longer time to produce each successive main stem leaf at 12 hours photoperiod (215 ^{o}Cd/leaf, 8.5 day/leaf) compared with 11 hours photoperiod (135 ^{o}Cd/leaf, 5.6 day/leaf). Similar trend was seen in Biris landrace where the landrace sown at 12 hours photoperiod took an extended duration (213 ^{o}Cd/leaf, 8.4 day/leaf) to produce a new leaf than Biris sown at 11 hours photoperiod (117 ^{o}Cd/leaf, 4.9 day/leaf). Bario Sederhana produced a maximum number of 9.3 leaves on the mainstem with thermal time requirement between 1513-2903 ^{o}Cd and 64-122 calendar days to reach flag leaf development. In contrast, Biris failed to produce flag leaf under 8, 10, and 11 hours photoperiod and did not develop further. Nevertheless, Biris took 3667-3831 ^{o}Cd (152-160 days) to produce a maximum of 7.9 main stem leaves under both 9 and 12 hours photoperiod. The reproductive development towards photoperiod showed a delayed pattern in time to heading, anthesis and maturity for Bario Sederhana under lengthening photoperiod from 10 to 12 hours. For example, under 10 hours photoperiod the crop required 1680 ^{o}Cd (~71 days) from emergence to heading but took an extended duration of 3147 ^{o}Cd (~133 days) when it was sown at 12 hours photoperiod. Similarly, Biris took a longer time to heading ($P<0.05$) at 12 hours photoperiod (4067 ^{o}Cd, 169 days) compared with 9 hours photoperiod (3800 ^{o}Cd, 158 days). The prolonged time taken for reproductive development modified by photoperiod resulted in higher yield components. This is because the extended time from heading to maturity means longer duration of grain filling. In both landraces, the longest photoperiod of 12 hours gave the highest percentage of filled spikelets, consequently the heaviest grain weight per panicle (1.4 g for Bario Sederhana, 3.5 g for Biris). Hence, under optimum photoperiod and proper farm management practices, the cultivation of the two Sarawak rice landraces will improve the socio-economics of local farmers.

Keywords: Daylength, growing degree days, phenology, plant growth chamber, traditional rice cultivar.

Tajuk: Pertumbuhan dan Perkembangan Padi Sarawak Terhadap Tempoh Pencahayaan

ABSTRAK

Sebuah siri eksperimen persekitaran terkawal telah dijalankan ke atas padi tradisional Sarawak, Bario Sederhana dan Biris, bertujuan bagi menyelidik pertumbuhan dan perkembangan padi tersebut apabila disemai di bawah tempoh pencahayaan yang berbeza (8 jam, 9 jam, 10 jam, 11 jam dan 12 jam). Kajian ini menunjukkan bahawa kedua-dua varieti padi tersebut mempunyai fasa juvana yang pendek. Hal ini demikian kerana tindak balas pokok padi terhadap tempoh pencahayaan bermula selepas kemunculan daun keempat bagi Bario Sederhana ($P<0.001$), dan daun ketiga bagi Biris ($P<0.001$). Bagi padi Bario Sederhana, kadar kemunculan daun adalah berbeza bergantung dengan tempoh pencahayaan, kecuali bagi pokok padi yang ditanam di bawah tempoh pencahayaan 11 dan 12 jam. Di bawah tempoh pencahayaan tersebut, pokok padi mengambil masa yang lebih lama untuk menghasilkan daun baharu pada batang utama pada tempoh pencahayaan 12 jam (215 ^{o}Cd/daun, 8.5 hari/daun) berbanding tempoh pencahayaan 11 jam (135 ^{o}Cd/daun, 5.6 hari/daun). Padi Biris turut menunjukkan trend yang sama apabila padi tersebut mengambil masa yang lebih lama untuk menghasilkan daun baharu pada batang utama di bawah tempoh pencahayaan 12 jam (213 ^{o}Cd/daun, 8.4 hari/daun) berbanding tempoh pencahayaan 11 jam (117 ^{o}Cd/daun, 4.9 hari/daun). Bilangan maksimum daun pada batang utama bagi Bario Sederhana adalah sebanyak 9.3 helai daun, dan keperluan masa terma antara 1513-2903 ^{o}Cd dan 64-122 hari diperlukan untuk menghasilkan daun terakhir. Padi Biris yang disemai di bawah tempoh pencahayaan 8, 10 dan 11 jam gagal menghasilkan daun terakhir serta mengalami perkembangan yang terbantut. Walau bagaimanapun, padi Biris mengambil masa 152-160 hari (3667-3831 ^{o}Cd) untuk menghasilkan sebanyak 7.9 helai daun pada batang utama di bawah tempoh pencahayaan 9 jam dan 12 jam. Tindak balas perkembangan *reproduktif Bario Sederhana seperti tempoh kemunculan tangkai padi, tempoh berbunga dan kematangan padi terhadap tempoh pencahayaan tertunda apabila disemai di bawah tempoh pencahayaan 10 hingga 12 jam. Sebagai contoh, di bawah tempoh pencahayaan 10 jam Bario Sederhana memerlukan 1680 ^{o}Cd (~71 hari) dari perkecambahan benih ke tempoh kemunculan tangkai padi. Namun begitu, Bario Sederhana mengambil tempoh yang lebih lama 3147 ^{o}Cd (~133 hari) apabila padi tersebut ditanam di bawah tempoh pencahayaan 12 jam. Padi Biris turut mengambil masa yang lebih lama untuk mencapai tempoh kemunculan tangkai padi ($P<0.05$) pada tempoh pencahayaan 12 jam (4067 ^{o}Cd, 169 hari) berbanding dengan tempoh pencahayaan 9 jam (3800 ^{o}Cd, 158 hari). Tempoh perkembangan reproduktif padi yang berpanjangan yang telah diubahsuai oleh tempoh pencahayaan telah menghasilkan hasil padi yang lebih tinggi. Hal ini demikian kerana pokok padi mempunyai tempoh pengisian bijian yang lebih lama akibat tempoh perkembangan reproduktif yang berpanjangan tersebut. Bagi Bario Sederhana dan Biris, tempoh pencahayaan 12 jam menghasilkan peratusan bijirin padi yang tertinggi, oleh itu ia turut menghasilkan bijirin yang paling berat bagi setiap tangkai (1.4 g untuk Bario Sederhana, 3.5 g untuk Biris). Oleh itu, di bawah tempoh pencahayaan yang optimum dan amalan pengurusan ladang yang betul, penanaman dua padi tradisional Sarawak tersebut mampu meningkatkan sosio-ekonomi pesawah.*

Kata kunci: *Tempoh pencahayaan, suhu pertumbuhan harian, fenologi, ruang pertumbuhan tumbuhan, padi tradisional.*

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

1.1 Study Background

Rice (*Oryza sativa* L.) is predominantly grown throughout Asia, as well as certain parts of Europe, America and Australia. This is because rice plant is well adapted to a wide range of climatic variation from tropical to temperate. Several environmental factors, in addition to genetic factors, influence rice plant growth and development. Temperature is the main driver of crop growth and development, but it can also be modified by photoperiod (Mapalana, 2017). Photoperiod also known as daylength is calculated as the duration from sunrise to sunset and includes civil twilight. Photoperiod influences crop development rate such as leaf production (Nemoto et al., 1995) and time to flowering (Jackson, 2009). Depending on whether the plant species exhibits a short-day or a long-day photoperiodic response, photoperiod can either shorten or delay crop development. This could have an influence on the yield production. For example, delayed development results in longer duration of phenophases, consequently leads to an increase in biomass accumulation (Debaeke & Aboudrare, 2004). However, the disadvantage is that it could increase the cost of crop management in relation to fertilizer input, pests and weed control.

In general, rice is classified under short-day plant because it initiates panicle primordia in response to short photoperiod (Yoshida, 1981), which means it requires shorter exposure to daylight in order to transition from vegetative to reproductive phases. However, the degree of sensitivity to photoperiod varies widely among rice cultivars. Vergara and Chang (1985) reported that tropical rice cultivars are more sensitive to photoperiod compared to temperate rice cultivars. A study done by Dore (1959) reported that 14 minutes difference between day length in January and September in Melaka at latitude of 2 ^{o}N can result in a significant variation in time to flowering of rice plants. According to the study, rice plants sown in September took just 161 days to flower compared to 329 days for rice plants sown in January. In annual crop species, the modification in time taken to flowering caused by photoperiod variation can affect the growth performance and consequently affecting the final yield production (Sonego, 2000).

Sarawak is renowned for its vast range of traditional rice cultivars. Several examples of Sarawak traditional rice cultivars are Bario, Biris, Bajong, and Mamut. Farmers in Sarawak prefer to grow traditional rice because of its eating quality in terms of its exquisite taste, texture, and fragrant (Teo, 2007b). In addition, Sarawak traditional rice is well adapted to the undulating topography which makes it difficult to cultivate soil and construct an irrigation system in the rice fields. Therefore, the rice cultivation in Sarawak is mostly rainfed. In order to target grain ripening and harvesting activities in March when rainfall has drastically decreased, Sarawak traditional rice is often being planted on October. The rainy season allows the best vegetative development of the rice plants.

1.2 Problem Statement

It has been asserted that Sarawak traditional rice cultivars are photoperiodic sensitive, possessing longer growth duration, therefore can only being planted in one cropping season (Teo, 2007b). For example, the cultivation of Bario rice is a time-consuming process that takes six months of manual labour from sowing to grain harvesting (Naeg, 2012). Likewise, Biris rice matures within five to six months from the time of planting (Morni, 2014). However, there are still outstanding concerns regarding how photoperiod affects the growth and development of Sarawak traditional rice. To date, there is no published study that investigates the developmental responses of Sarawak traditional rice towards photoperiod.

In general, traditional rice cultivars in the tropics are classified as photoperiod-sensitive, however most of the current knowledge regarding the photoperiodic sensitivity of traditional rice and its effect on growth and development are from Cambodia (Tsubo et al., 2009), Thailand (Cha-um & Kirdmanee, 2007; Boling et al., 2011), and Sri Lanka (Mapalana, 2017; Padukkage et al., 2017; Pushpakumari et al., 2017). The geographical locations of these countries are within 7.9 ^{o}N-15.9 ^{o}N latitude, thus experiencing different changes in daylength throughout the year compared to Sarawak which is positioned at 1.5 ^{o}N near the equator.

Therefore, these reports may not be directly applicable to the environmental conditions in Sarawak. Given that the changes in daylength at the equatorial region is significantly small, controlled environment chambers can be used to grow rice plants within a range of photoperiod hours. Observation of leaf appearance, time to flowering, and grain production could be used to establish the physiological characteristics of Sarawak traditional rice in relation to its sensitivity to photoperiod changes. Understanding the effects of photoperiod variation on rice physiology is important to understand the maximum yield potential of Bario Sederhana and Biris, consequently increasing the socio-economic status of local farmers through promoting the cultivation of high-yielding rice varieties. The hypotheses of this study were as followed:

Null hypothesis, H_0 : Photoperiod has no effect on the growth and development of Sarawak traditional rice.

Alternative hypothesis, H_a : Photoperiod affects the growth and development of Sarawak traditional rice.

1.3 Objectives

The aim of this study was to understand how photoperiod variation influences the growth and subsequent development of Sarawak traditional rice specifically Bario Sederhana and Biris landraces. To achieve this aim, a series of controlled environment experiments were conducted with the following objectives:

i. To identify the commencement of photoperiod sensitivity in Bario Sederhana and Biris landraces.

ii. To quantify duration of vegetative developmental stages i.e., leaf appearance rate and time to flag leaf.

iii. To quantify duration of reproductive developmental stages i.e., time to flowering and duration to grain maturity.

iv. To quantify growth in relation to rice yield components.

CHAPTER 2

LITERATURE REVIEW

2.1 Rice Cultivation in Sarawak

Rice plants are mainly being cultivated in the upland and lowland of Sarawak in three different ecologies; (i) rainfed upland; (ii) rainfed lowland; and (iii) irrigated lowland (Kendawang et al., 2005; Sang et al., 2018). The mountainous and hilly topography of Sarawak makes rice cultivation challenging (Hoki, 1977). Sarawak undulating terrain makes constructing an irrigation system and convey mechanisation aid to the upland rice cultivation difficult. Additionally, Sarawak lowland rice cultivation experiences frequent flooding, and proper irrigation is only feasible in limited lowland area due to topographical conditions. Hence, the main supply of water for the majority of the lowland rice fields from October to April is from natural rainfall (Teo, 2007b; Izzah et al., 2021). In 2019, the highest total rainfall recorded in Sarawak was between 3200 and 4600 mm (2019 Malaysian Meteorological Department Annual Report).

A majority of the rice fields in Sarawak practised monoculture farming except for a few irrigation projects (Teo, 2007b). Monoculture rice cultivation in Sarawak is mostly performed by manual labor with minimum mechanisation aid (Hoki, 1977; Hanafi et al., 2009). Land preparation is often done in July and August after the *Gawai* festival in June. Most rice fields are neither ploughed nor harrowed before the transplantation of rice seedlings because farmers planted the crop traditionally without mechanisation aid. Herbicide is applied to remove herbaceous species and other vegetation on the land (Hoki, 1977; Kendawang et al., 2005).

Local farmers practice shifting cultivation that refers to a rotational farming technique in which land is cleared for upland rice cultivation and then left to regenerate after a few years (Kendawang et al., 2005; Echoh et al., 2017). According to Echoh et al. (2017), the high acidic soil of Sarawak makes it unsuitable for agricultural pursuits, hence shifting cultivation is preferred by the local farmers. This is due to the fact that the long fallow period of shifting cultivation could replenish soil fertility while minimising weed infestation (De Rouw, 1995). However, the present shifting cultivation system consists of continuous rice cropping for 2 years or more with a shorter fallow period of about 5 years (Kendawang et al., 2004). Various measures have been implemented to reduce shifting cultivation while encouraging permanent and sustainable agricultural systems (Kendawang et al., 2004; Hansen & Mertz, 2006). Subsidised fertilisers for upland rice are provided in order to prevent soil degradation while preserving the remnant tropical forests.

Although Sarawak traditional rice cultivars have a high commercialisation potential, the commercialisation is hindered by its lower grain yield when compared to modern rice cultivars. A study conducted by Shafiee et al. (2013) on MR 220 a local modern rice cultivar revealed that when SBAJA, a foliar-spray growth and yield enhancer is applied to the rice cultivar, the cultivar yielded 9660 kg ha$^{-1,}$ compared to 7490 kg ha^{-1} in a different planting ecosystem. In contrast, the average yield of Sarawak upland rice is low, ranging from 460 to 1184 kg ha^{-1} with an average value of 738 kg ha^{-1} (Hanafi et al., 2009). Low grain yields of upland rice are attributed to poor field management by farmers during rice cultivation period. In addition, inadequate water and fertiliser supplies could limit productivity and lead to a variety of problems that inevitably result in low yield production (Filzah et al., 2014).

In order to reduce input costs, farmers do not use excessive pesticides and fungicides during the cultivation of rice. Eventhough farmers received amorphous fertilisers (16% N and 48% P_2O_5) from the government as part of a fertiliser subsidy scheme, farmers are still reluctant to apply chemical fertiliser throughout rice cultivation period (Hanafi et al., 2009). Even so, government fertiliser subsidies are insufficient, and most farmers are unwilling to acquire additional fertilisers and pesticides at their own expense due to the increasing cost of these agricultural inputs (Fahmi et al., 2013). According to Hoki (1977), the lack of fertiliser is due to frequent flooding and unresolved field management problems in Sarawak that lead fertiliser to wash away when applied.

2.2 Sarawak Traditional Rice

Traditional rice cultivars, including pigmented and aromatic rice offer excellent eating qualities and health benefits (Nicholas et al., 2014). According to Bhat and Riar (2015), traditional rice cultivars possess low sugar content, higher amount of glutamic acid, fiber, and vitamins such as thiamine, iron, vitamin D, niacin, riboflavin, and calcium. Traditional rice cultivars that are pigmented and aromatic are also known to have high content of bioactive components. Pigmented and aromatic traditional rice cultivars besides having an excellent eating quality also possess an abundant content of anthocyanin such as Cyanidin-3-O-β-glucoside (Ryu et al., 1998). Such compound is associated with diverse functional properties such as anti-neurodegenerative activity (Kim et al., 2008), inhibition of glycogen phosphorylase (Jakobs et al., 2006), and possessing antioxidant (Tuncel & Yılmaz, 2011) and higher scavenging activity compared to modern and hybrid rice cultivars.

2.2.1 Bario Sederhana

Bario rice cultivar is cultivated by Kelabit farmers at the Kelabit Highlands in the northern region of Sarawak (4.2238 ^{o} N, 114.3661 ^{o}E). The cultivar is mainly being cultivated in cool climates at altitudes more than 1200 meters (Kevin et al., 2007). Bario rice offers a wide range of cultivars, such as Bario Sederhana, Bario Chelum, Bario Halus, and Bario Banjal (Wong et al., 2009). The annual cultivation of Bario in July is done manually and traditionally by the farmers while the rice fields are irrigated by the clean mountain streams of the Kelabit Highlands (Kevin et al., 2007; Teo et al., 2008; Henrita et al., 2015). Therefore, it takes 170 to 175 days to mature from sowing for Bario rice to be harvested in January (Henrita et al., 2015). Due to the scarcity and the difficulty of transporting it to the Kelabit Highlands, pesticides and chemical fertilisers are not used in the cultivation of Bario rice.

Bario rice is considered one of the finest rice grains in the world due to its smooth texture, fine and elongated grains (Figure 2.1), and desirable eating qualities (Wong et al., 2009). Nicholas et al. (2014) reported that the ash contents in Bario rice were in the range of 1.07-1.46% making it useful in improving health due to the availability of minerals (Khalili et al., 2006). Besides that Nicholas et al. (2014) also reported that based on the Nutrient Reference Value in 18C Act, Table II Food Regulations of Malaysia, Bario rice is a good source of protein (> 5 g/ 100 g), low in fat content (< 3 g/100 g), contained higher crude fibre content (1.40-2.05%) than modern rice cultivar, MR 219 (0.90%) as well as lower carbohydrate content (73.96-76.76%) than that in MR 219 (78.45%). Hence, these numerous nutritional benefits proved that Bario rice cultivars have a high potential to be promoted as a healthy dietary ingredient. The cultivation of Bario rice may be sufficient for subsistence farming, but while the rice cultivar is in demand, the optimum yield has yet to be achieved.

On average, the yield of uphill rice in Sarawak is 0.46 to 1.1 tonnes per hectare (Sohrabi et al., 2012). Accordingly, if the rice cultivar is to be exported and sold as a specialty product outside of Sarawak, the existing farm management strategy may require improvements.

Figure 2.1: Bario Sederhana landrace grain.

2.2.2 Biris

Biris rice cultivar originated in Simunjan, Kota Samarahan (1.2406 ^{o}N, 110.6923 ^{o}E). Similar to Bario rice, the cultivation of Biris rice is done annually from September to October (Teo, 2007a). Biris rice can be harvested 5 to 6 months following the date of sowing (Morni, 2014). The cultivation required less input from farmers since it is done manually and with less fertiliser applications, while water availability is largely dependent on rainfall. Due to its significant economic potential in comparison to other Sarawak traditional rice cultivars such as Bario and Bajong, Biris was ranked among the top three rice cultivars in Sarawak by the Department of Agriculture Sarawak in the 1980s (Teo, 2007a; Sang et al., 2018).