



Faculty of Resource Science and Technology

**Phenological Development of Sarawak Traditional Rice Landraces;
Bario Sederhana and Biris**

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Phenological Development of Sarawak Traditional Rice Landraces; Bario
Sederhana and Biris

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A thesis submitted

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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

Phenological development and growth of Sarawak traditional rice landraces, i.e. Bario Sederhana and Biris were quantified from a series of field and incubation experiments. In both landraces, incubation study estimated cardinal temperatures of 10 °C for base, 32 – 33 °C for optimum and 43 °C for maximum seed germination. The thermal time (Tt) requirement for 75% germination in the sub-optimal range for Bario Sederhana was 61 °Cd and 54 °Cd for Biris meanwhile within the supra-optimal range, both landraces required 27 – 29 °Cd. Bario Sederhana had 93% of seed populations germinated at 30 °C while Biris had 100% at 27.5 °C. For phenological pot experiments, both landraces had the highest Tt requirement for third leaf appearance for crops sown in June (358 °Cd for Bario Sederhana and 386 °Cd for Biris) and the lowest for crops sown in December (149 °Cd for Bario Sederhana and 165 °Cd for Biris). The leaf appearance rate (phyllochron) for Bario Sederhana decreased with each successive sowing date from 646 °Cd/leaf for April sown crops to 467 °Cd/leaf for the crops were in late October. In contrast, the phyllochron of Biris was the shortest in late June sowing (495 °Cd/leaf) and the longest (~624 °Cd/leaf) for April and late October sown crops. Irrespective of landraces, thermal time to flag leaf decreased with sowing date from 4051 °Cd in April to 2569 °Cd in late October with a total production of nine leaves on the primary stem across all sowing dates. In both landraces, crops took the longest time to reach flowering for April sowing (4790 °Cd for Bario Sederhana and 4315 °Cd for Biris) and the shortest time for October sown crop (2980 °Cd for Bario Sederhana and 2857 °Cd for Biris). Nevertheless, the duration of grain filling was the longest for October sown crops (784 – 818 °Cd, 30-33 calendar days) which resulted in the highest grain weight (48 g/pot for Bario Sederhana and 22 g/pot for Biris). For field experiment conducted at Pusat Penyelidikan Tumbuhan (PPT), UNIMAS, both landraces took almost similar

calendar days to flower (151 days). Bario Sederhana and Biris rice had almost similar yield components when planted in the field.

Keywords: Development of rice, growing degree days, linear model, *Oryza sativa*, paddy

Pembangunan Fenologi Padi Tradisi di Sarawak; Bario Sederhana dan Biris

ABSTRAK

Satu siri eksperimen lapangan dan inkubasi bertujuan untuk mengukur perkembangan pertumbuhan dan fenologi landraces padi tradisional Sarawak, iaitu Bario Sederhana dan Biris. Suhu kardinal (asas, optimum dan maksimum) telah dikira dan kedua-dua landraces mempunyai T_{base} 10 °C, T_{opt} antara 32 – 33 °C, dan T_{max} 43 °C. Keperluan masa terma (Tt) untuk 75% percambahan dalam julat sub-optimum untuk Bario Sederhana ialah 62 °Cd dan 53 °Cd untuk Biris manakala dalam julat supra-optimum, kedua-dua landraces memerlukan 27-29 °Cd. Bario Sederhana mempunyai 93% populasi benih bercambah pada suhu 30 °C manakala Biris 100% pada suhu 27.5 °C. Untuk fenologi eksperimen dalam bekas, bagi kedua-dua landrace, keperluan Tt untuk penampilan daun ketiga adalah yang tertinggi untuk semaian pada bulan Jun (358 °Cd untuk Bario Sederhana dan 386 °Cd untuk Biris) dan yang paling rendah untuk semaian pada bulan Disember (149 °Cd untuk Bario Sederhana dan 165 °Cd untuk Biris). Kadar penampilan daun (phyllochron) untuk Bario Sederhana menurun dengan setiap tarikh penanaman berturut daripada 646 °Cd/daun untuk semaian pada bulan April kepada 467 °Cd/daun untuk semaian pada akhir bulan Oktober. Sebaliknya, phyllochron Biris adalah yang paling singkat pada akhir bulan Jun (495 °Cd/daun) dan yang paling lama (~624 °Cd/daun) untuk semaian pada bulan April dan akhir Oktober. Tanpa mengira landrace, keperluan masa terma untuk penampilan daun bendera berkurangan dengan tempoh penyemaian daripada 4051 °Cd pada bulan April kepada 2569 °Cd pada akhir bulan Oktober dengan jumlah pengeluaran sebanyak sembilan helai daun pada batang utama merentasi semua tarikh semaian. Kedua-dua landraces memerlukan masa yang tertinggi untuk berbunga bagi semaian pada bulan April (4790 °Cd

untuk Bario Sederhana dan 4315 °Cd untuk Biris) dan yang paling rendah bagi semaian pada bulan Oktober (2980 °Cd untuk Bario Sederhana dan 2857 °Cd untuk Biris). Namun begitu, tempoh pengisian bijirin adalah paling lama untuk semaian pada bulan Oktober (784 – 818 °Cd, 30-33 hari) yang menghasilkan berat bijirin tertinggi (48 g/pasu untuk Bario Sederhana dan 22 g/pasu untuk Biris). Bagi ujikaji lapangan yang dijalankan di Pusat Penyelidikan Tumbuhan (PPT), UNIMAS, kedua-dua landrace mengambil masa hampir sama hari kalendar untuk berbunga (151 hari). Padi Bario Sederhana dan Biris mempunyai komponen hasil yang hampir serupa apabila ditanam di lapangan.

Kata kunci: *Pembangunan padi, hari peningkatan darjah, model linear, Oryza sativa, padi*

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LIST OF ABBREVIATIONS

PPT	Pusat Penyelidikan Tumbuhan
UNIMAS	Universiti Malaysia Sarawak
Tt	Thermal Time

CHAPTER 1

INTRODUCTION

1.1 Study Background

In rural regions of Sarawak, East Malaysia, traditional rice remains a popular choice among rice growers because it is pest resistance, requires a minimum farm input and resilient to unploughed land environments. Thus, cultivation of traditional rice is prevalent in Sarawak with estimation of at least 300 rice varieties identified (Khazanah Research Institute, 2018). Many of these varieties are said to possess exceptional quality in terms of taste (Wong et al., 2009), texture (Huei Ying, 2016), aroma (Libin et al., 2012) and nutritional properties (Ronie et al., 2022). These varieties are sold as specialty rice and they fetch a premium price between MYR 8.00 – 19.50 per kilogram in the retail market (Lai et al., 2017). Coupled with high consumer demand for specialty rice, the emphasis on production of specialty, premium rice products could increase the farmers' profits and improve rural development. In fact, some varieties have a specific locational origin and qualities derived from its origin and were registered as Malaysia Geographical Indication. Such varieties are Bario and Biris rice.

Bario rice originates from the Kelabit Highland in Bario, Sarawak. The varieties of Bario rice are renowned for its finest grain qualities such as aromatic, soft texture, tasty, palatable, and nutritious (Wong et al., 2009; Thomas et al., 2013; Nicholas et al., 2014; Ronie et al., 2022). Its moderate glycemic index suggests that Bario rice has a potential to control blood glucose level and thus can be marketed as health food (Nicholas et al., 2014). Specifically, a commercially grown variety 'Bario Sederhana' is classified as medium grain rice with high protein and low fat content, low gelatinization temperature and high gel

consistency which indicates a soft texture of cooked grain (Huei Ying, 2016). This variety is suitable for health conscious consumers who at the same time prefer food with excellent taste.

Biris rice originates from the rice farms of Simunjan, Kota Samarahan, Sarawak. This variety produced an average grain yield of 2.2 tonnes per hectare with stem height of 0.81 m (Nori et al., 2009). Biris rice is popular for its strong aroma and the grain is classified as very long and slender with low percentage of chalkiness (Huei Ying, 2016). Similar with Bario varieties, the cooked grains of Biris have a soft texture and high in protein content. In addition, extracts from seedlings of Biris rice were reported to contain antioxidant properties that may have a potential to complement anti-cancer drug, i.e., doxorubicin (Yeo et al., 2019).

Typically, traditional rice in Sarawak is grown as rainfed lowland and upland rice due to a lack of infrastructures for irrigation. To achieve the maximum potential of rice, it is pertinent to understand the crop's phenology and growth processes in relation to seasonal changes in environmental factors in a year. In particular, variation in temperature over a year at the location of planting can alter timing of crop phenology and the duration of each phenophase (Oteros et al., 2015) as well as the crop growth performance which determine its grain yield (Tao et al., 2006). Therefore, knowing the timing and variability of phenological events can facilitate farmers in planning, decision making and timely execution of farm management that require advanced information on the dates of specific stages of crop development (Selvaraju, 2012). Given the seasonal variation of temperature and climate change, estimation of crop phenology can be quantified using growing heat units or thermal time.

On account of crop phenology and growth, decision on sowing time at the location of planting plays a significant role in ensuring early crop establishment and subsequent vegetative phase occurs during a period of favourable temperatures and optimum amount of rainfall (Cerioli et al., 2021). For example, Ali et al. (2006) and Shimono et al. (2007) reported a threshold temperature of 12 °C was critical for seed germination and for the following 30 days to ensure optimum number of seedling emergence. Moreover, suitable sowing time ensures crop flowering during optimum temperatures which increases spikelets' fertility rate thus maximises number of filled grains, leading to high grain yield (Cerioli et al., 2021). Several studies reported that different time of sowing resulted in different grain yield due to modification in crop vegetative and reproductive phenophases (Shah et al., 2006; Fazily, 2021). For example, sowing earlier than the optimal date was reported to extend the duration of crop growth and delay grain maturity; resulting in a longer period of pesticide and weed control, increased water consumption, higher straw yield but reduced in grain yield (Slaton, 2001). In contrast, the author reported that delayed sowing produced immature panicles due to shorter growth duration thus leading to reduction in grain yield.

1.2 Problem Statement

Given the seasonal fluctuations in the environment and the impact of climate change, there has been a growing recognition of the changing timing of crop phenology and the duration of their phenophases. The knowledge of crop phenology time is important because it determines crop management decisions such as the best time to apply fertiliser, pesticides, and herbicides for optimum grain production. For example, basal fertiliser is applied to rice plant at the appearance of third leaf and top dressings are given at active tillering, heading and grain filling (Alias et al., 2002). Typically, farmers accomplished these agricultural

activities through visual evaluation. However, the risk lies in the possibility that farmers might miss the chronological events, making the execution of these activities unattainable. The primary approach for predicting plant phenology is typically based on calendar days. However, due to weather fluctuations across different locations and years, calendar-based predictions often prove to be unreliable. As a result, an alternative method of measuring chronological events in crops is by employing thermal time or growing degree days. When plant phenology is evaluated in terms of thermal time, using degree days as the unit of measurement, the required amount of thermal time remains consistent for a plant to reach a specific developmental stage. The thermal time approach offers a standardised measurement of plant phenology that can be universally applied across various climatic conditions. Accordingly, time of sowing which correlates with environmental variation plays a significant role in the crop growth performance and its subsequent yield through the modification of crop phenology.

1.3 Hypotheses

The hypotheses of this study were as below:

H₀: Time of planting did not affect the growth and development of Bario Sederhana and Biris rice landraces.

H_a: Time of planting affected the growth and development of Bario Sederhana and Biris rice landraces.

1.4 Objectives

The aim of this study was to understand the development and growth of Bario Sederhana and Biris rice landraces at different time of planting. To achieve this aim, several experiments were conducted with the following objectives:

- i. To quantify the thermal time requirement and cardinal temperatures for germination in a series of incubation experiments.
- ii. To quantify thermal time requirement and calendar days for vegetative phenophases, heading and grain development.
- iii. To quantify yield and yield components.

CHAPTER 2

LITERATURE REVIEW

2.1 Background of Cultivation System of Rice in Sarawak

Sarawak has diverse types of rice ranging from commercial high-yielding varieties to indigenous traditional cultivars (Lee et al., 2011). About 95% of the rice system relies on rain-fed and upland cultivation, leaving only 5% being irrigated. In addition, the cultivation of rice in Sarawak has remained a monoculture (Teo, 2010a) due to lack of basic infrastructure, drainage, and irrigation systems. Therefore, Sarawak's present rice output can only meet 35% of the state's yearly rice demand, with the rest coming from imports (Teo, 2007). Rice farmers who are mostly villagers practice slash and burn for land clearing to prepare for rice cultivation because the soil has never been plowed (Teo, 2010b) due to limited resources and facilities for farming. They also grow rice for their own consumption and sell the surplus in local markets. Their choice of cultivar is usually traditional rice because of its exquisite taste, texture, and resistance to pests (Nicholas et al., 2014). Besides that, traditional rice requires a minimum farm input and adapted to undulating topography and soil conditions of Sarawak (Teo, 2010b). As a result, traditional rice is in high demand in the market. These varieties are advertised as high-quality rice and command a premium price in the market, ranging from RM 8.00 to RM 19.50 per kilogram (Lai et al., 2017). Bario, Biris, Bajong, Beras Hitam, and Beras Merah are some of the most well-known kinds. Despite the high value and demand for traditional rice varieties, there has been little published research on their physiological characteristics. As a result, farmers lack adequate guidance on how to maintain these varieties to schedule fertiliser and insecticide applications, harvesting as well as to achieve desired plant populations. Such farm

management activities are relevant to the crop development phases and their response toward seasonal changes in the environment. Therefore, understanding the life cycle of traditional rice in relation to planting time is the aim of this study.

2.2 Sarawak Traditional Rice Varieties

2.2.1 Bario Sederhana

Bario rice is a distinct landrace characterized by its tall stature and robust stem. It is among the plants that are resistant to pest and diseases, and thrives at absorbing nutrients from the soil. Bario rice takes around six months to mature and only one cropping cycle can be completed within a year. Its rice grain is classified as medium length with a marble white colour (*Bario Rice*, 2008). Bario rice is well-known for its unique characteristics including a sticky texture cooked grain, fine elongated grains, a mild pleasant aroma (Wong et al., 2009) and contains high nutrients (Nicholas et al., 2014). Based on study conducted by Huei Ying (2016), Bario had the shortest length recorded among the eight rice varieties tested (Bubuk, Bajong, Biris, Mamut, MR219, MR269 and MR253). The shape of Bario rice was in the range of medium shape which differ from the other traditional rice varieties which had long grain size and slender shape. Cooked grain of Bario rice had a high rate of grain elongation. A higher elongation rate of grain contains a higher amylose percentage. According to Thomas et al. (2013), Bario rice fell under the immediate amylose content range. Amylose influences the grain elongation by regulating the water absorption of rice grain during cooking (Nyak Husain, 1984). Bario rice was also found to have a high gel consistency despite having high amylose percentage. High gel consistency rice cooks more tenderly and maintains its softness after cooling (Okon et al., 2012). Bario rice has low crude fat ($3.0 \pm 0.48\%$) (Huei Ying, 2016) and might be favored due to the criteria of low crude

fat because consuming too much dietary fat can lead to body weight gain and subsequently increase cholesterol levels (Oko et al., 2012). Previous study stated that Bario possesses a high content of protein (5.85-7.30g/100g) and is low in fat (0.5 – 1.05 g/100g) (Nicholas et al., 2014). Bario received an International Presidia Award from the Slow Food Foundation of Italy in 2002. This showed the feasibility of Bario rice being sold on a global scale.

2.2.2 Biris

Biris rice variety is also known as Beras Wangi Simunjan and has a strong aroma. The rice plant is tall and does not require a lot of fertiliser. Biris can grow up from 0.8 m - 1.60 m height and possess a thick and sturdy stem (Geffry Ujie et al., 2008; Nori et al., 2009). The panicles are 0.30 to 0.31 meters long, and each panicle may contain about 230 grains. After 165 days of sowing, these varieties are ready to harvest (Teo, 2007). According to the International Grain Classification system, Biris rice is a long slender grain with an approximate grain length of 6.88 mm and width of 2.47 mm, and a length/width ratio of 3.10 mm (*Sarawak Beras Biris*, 2009). Similar finding recorded by Huei Ying (2016) whereby, Biris was categorised as a very long grain and had high length/width ratio (most slender). Nevertheless, Biris had low value in gelatinisation temperature. Gelatinisation temperature, is the temperature at which 90% of starch expands in hot water, determines the amount of time required for cooking (Danbaba et al., 2011). Biris rice was also categorised in the range of high amylose content (> 25%) (Huei Ying, 2016) and it may thus be consumed as starchy food by diabetics considering high amylose concentration is linked with lower blood glucose level (Oko et al., 2012). Moreover, Biris rice had averagely high percentage of protein (8.5%) which can be considered as good quality rice and both rice also have > 70% of carbohydrate content (Huei Ying, 2016).

2.3 Effect of Temperature on Growth and Development of Rice

Temperature is the main factor that influences plant growth and development. In rice cultivation, temperature is necessary because it affects stages of tillering, spikelet formation, and ripening (Chaudhary et al., 2002). Physiological process and development rates increase with temperature. Nonetheless, plant growth is affected by extreme temperatures where extremely high or low temperatures can be detrimental. In rice cultivation, the crucial low and high temperatures, which are typically below 20 °C and over 30 °C, vary according to the growth stage (Table 2.1). However, these crucial temperatures vary according to the variety, duration of critical temperature, diurnal changes, and physiological state of the plant (Yoshida, 1981).

Table 2.1: Critical temperatures for rice stage development (Source: Yoshida, 1981).

Growth stage	Critical temperature (°C)		
	Low	High	Optimum
Germination	10	45	20-35
Seedling emergence and establishment	12-13	35	25-30
Rooting	16	35	25-28
Leaf elongation	7-12	45	31
Tillering	9-16	33	25-31
Initiation of panicle primordia	15	-	-
Panicle differentiation	15-20	38	-
Anthesis	22	35	30-33
Ripening	12-18	30	20-25

Low temperature restricted the period of the growing season in rice and the rate and development of rice meanwhile high temperature can cause thermal stress (Chaudhary et al., 2002). High-temperature stress causes increased sterility during flowering (Moldenhaouer et al., 2013) which can lead to loss of yield. During grain filling, high night-time temperatures can promote higher respiration, causing the plant to consume more carbohydrates. As a result, the photosynthetic process' efficiency during the day is reduced. This will result in less filled spikelets and reduced grain yields. It also causes more chalky kernels, a thicker bran, and a thicker aleurone layer, all of which lead to lower head rice yields (Moldenhaouer et al., 2013).

2.3.1 Crop Phenology

Crop phenology, commonly quantified in calendar day is an essential component of the weather-based dynamic crop growth and yield simulation model and it can be used to

estimate the most suitable date and time of a specific development process (Abhilash et al., 2017). By estimating the crop phenology, better farm management such as the application of fertilisers can be carried out. This helps to improve the rate of yield. Phenological events can be estimated by computing accumulated growing degree days (GDD). Accumulated GDD can provide an estimation of various developmental stages of the crop (Ketring & Wheless, 1989) meanwhile the thermal time approach can be used as a tool for characterising thermal responses (Dwyer & Stewart, 1986). Crop phenology is mainly affected by temperature (Bisnoi et al., 1995). Plants can sense the changes in temperature with a wide array of thermosensors and alter thermal responsiveness in the association of the phenological stage (Bahuguna and Jagadish (2015). The thermal responses of plants during their development phases such as germination and flowering may vary within their growth habit and habitats.

2.3.2 Thermal Time

Thermal time or “growing degree days” (GDD) is defined as a crop heat unit. Thermal time is measured as cumulative heat units over a base temperature on a daily basis. As temperature varies with time and season, a crop's developmental stage may not require the same period of calendar days. As a result, thermal time can be used to measure the phenological development in plants. The thermal time approach gives a consistent assessment of plant development that may be used in a variety of climates (Nori et al., 2014). Thermal time can be used to relate plant growth, development, and maturity to air temperature (Parthasarathi et al., 2013). Thermal time for each day is calculated by using the maximum daily temperature ($T_{\max}$), the minimum daily temperature ($T_{\min}$), and the base temperature (T_b) (Equation 2.1).

$$\text{Daily Thermal Time (Tt)} = \frac{(T_{\max} + T_{\min})}{2} - T_b \quad \text{Equation 2.1}$$

The base temperature is the temperature below which no growth occurs, the optimum temperature is the temperature at which the growth occurs at maximum capacity and the maximum temperature is the highest temperature at which the growth will occur. The base temperatures vary with different crops (Table 2.2). The tropical crops usually have higher base temperatures than the temperate crops (Parthasarathi et al., 2013).

Table 2.2: Threshold Temperature of Agricultural Crops (Parthasarathi et al., 2013).

Crops	Temperature (°C)
Wheat, barley	4.4
Potato, oats, sugar beet	5.0
Sorghum, maize, groundnut	8.0-10.0
Rice	10.0-12.0
Tobacco	13.0-14.0

In a study conducted on Bangladeshi rice, the optimal temperature (T_{opt}) for seed germination was recorded at 31 °C (Ali et al., 2003). However, previous studies have reported a range of T_{opt} for rice seed germination as 20-35 °C (Adair, 1968; Chaudhary & Ghildyal, 1970; Yoshida, 1981), with the most rapid germination occurring at around 30 °C (Krishnasamy & Seshu, 1989). The reported thermal time (T_t) requirement reported for germination of Bangladeshi rice varied between 526-1667 °Cd (Ali et al., 2003). The thermal time (T_t) requirement for crop phenology varies depending on planting dates and cultivars. For instance, the study by Mote et al. (2015) clarified the Jaya cultivar required 123.7 °Cd, while Gurjari required 104.0 °Cd from sowing to emergence when planted on the same date. Additionally, T_t requirements differ across different development stages. In the same research, the Jaya cultivar required 703.7 °Cd from emergence to tillering, 642.4 °Cd from

tillering to panicle initiation, 598.2 °Cd from panicle initiation to anthesis, 92.0 °Cd from anthesis to grain filling, and 549.7 °Cd from grain filling to physical maturity meanwhile Gurjari cultivar required 647 °Cd from emergence to tillering, 859.9 °Cd from tillering to panicle initiation, 658.4 °Cd from panicle initiation to anthesis, 131.9 °Cd from anthesis to grain filling, and 419.5 °Cd from grain filling to physical maturity.

2.3.3 Time of Sowing

The appropriate timing for sowing farm management (Chandra et al., 1997). The sowing date of a rice crop is essential due to three major reasons. Firstly, it ensures that vegetative growth occurs during a period of satisfactory temperatures and high levels of solar radiation. Secondly, the optimum sowing time for each cultivar ensures the cold-sensitive stage occurs when the minimum night temperatures are historically the warmest in temperate region. Thirdly, sowing on-time guarantees that grain filling occurs when milder autumn temperatures are more likely, hence good grain quality is achieved in temperate region (Farell et al., 2003). Delayed sowing usually causes poor emergence and fewer heading panicles per meter square, and fewer spikelets per panicle thus lowering the yield (Hayat & Awan, 2003).

2.4 The Life Cycle of a Rice Plant

Rice plants typically grow from three to six months, depending on the variety and the environment in which they are planted. The vegetative, reproductive, and ripening phases of a rice plant development can be separated into three agronomic stages (Moldenhaus et al., 2013). Germination, seedling, and tillering are the three stages that include in the

vegetative phase. Meanwhile, the rice plant passes through four stages during the reproduction phase: stem elongation, panicle initiation, booting, and flowering. After the flowering stage of the rice plant, the ripening period begins. Yoshida (1981) stated that when planted in the tropics, a 120-day variety spends 60 days in the vegetative phase, 30 days in the reproductive phase and 30 days in ripening phase. The length of time required in the vegetative phase varies among varieties. For example, the vegetative phase for Bario took 100 days meanwhile Biris took 98 days (Abdul Razak, 2014). Following the ripening phase of the rice plant, harvesting is carried out using either traditional or contemporary methods.

2.5 Vegetative Development

The vegetative development is defined as a time from germination to the panicle primordia initiation (Yoshida, 1981). The length of the vegetative development determines the period of growth of the rice cultivars (Moldenhaouer et al., 2013). The vegetative period varies among variety. For example, a shorter maturity cultivars require 60 days to complete vegetative growth (Yoshida, 1981) meanwhile a longer maturity cultivars require about 100 days (Nelson et al., 2014).

2.5.1 Seed Germination and Seedling Emergence

Germination begins once the seed dormancy has been broken, absorbs enough water, and exposed to temperatures ranging 10 ° to 40 °C (Yoshida, 1981). When the seed coat has imbibed water, it will become soft and elastic. The sheath that covers the radicle (coleorhiza) will elongate and emerge through the seed coat thus allowing the radicle to break through the coleorhiza (Moldenhaouer et al., 2013). A combination of sufficient soil moisture and

favourable temperatures is required for successful germination and seedling emergence (Boswell et al., 2003). The cardinal temperatures for germination have been reported for weedy rice with T_b range from 2.0 – 7.3 °C, T_{opt} between 28.1 to 37.5 °C, and T_{max} between 42.2 – 43.4 °C (Puteh et al., 2010). For Bario and Biris landraces, the cardinal temperatures and thermal time (Tt) requirements for germination have been investigated by Abdul Razak (2014). For Bario, the base temperature, T_b was 8.9 °C, optimum temperature, T_{opt} was 36.1 °C, and maximum temperature, T_{max} was 43.7 °C. In contrast, for Biris, T_b was 8.4 °C, T_{opt} was 35.6 °C and T_{max} was 40.5 °C. Abdul Razak (2014) reported that the Tt requirement for germination in the sub-optimal range was 48 °Cd for Bario and 71 °Cd for Biris. Meanwhile, the supra-optimal range was 13 °Cd for both Bario and Biris. However, the range of temperatures used was inadequate to accurately define the cardinal temperatures and Tt requirements for germination.

Seedling emergence is known as the time when the tip of the seedling emerges from the soil or water surface and it includes both germination and post-germination growth (Yoshida, 1981). Seedling emergence occurs when the mesocotyl, the first internode has elongated and pushed the tip of the coleoptile through the surface. Ineffective farm management practices can result in delayed emergence. Initially, after sowing, the seeds are typically flooded with water to ensure sufficient moisture. However, Sato and Maruyama (2002) suggest that providing drainage during seedling establishment yields better seedling emergence compared to continuous flooding. Interestingly, Furuhashi et al. (1998) conducted a pot experiment but did not find any significant differences in seedling emergence between drainage and flooding methods. According to Abdul Razak (2014), the Bario variety took 3 days to fully emerge, while Biris took 1.3 days. The thermal time (Tt) requirement for Bario was 79 °Cd, whereas for Biris it was 27 °Cd. It is important to note that this study only

investigated emergence at a single sowing date, which may limit the ability to draw conclusive findings regarding the time to emergence.

2.5.2 Main Leaf Appearance

According to Moldenhaouer et al. (2013), the first sheathing leaf, known as the prophyll, emerges through the coleoptile. Saichuk (2014) explains that the primary leaf in rice is not a typical leaf blade but rather acts as a protective covering for the developing leaf. As the seedling continues to grow, the next leaf elongates beyond the tip of the primary leaf. Therefore, the second leaf after the primary leaf is considered as the first leaf (Yoshida, 1981) (Figure 2.1). As the leaf further develops, it differentiates into three distinct parts: the sheath, collar, and blade. Once the tip of the next leaf emerges, the leaf is fully developed. The last leaf to emerge is known as the flag leaf. In rice agronomy, the appearance of the third leaf is a significant milestone as it indicates the timing for the first basal fertiliser application (Yoshida, 1981). Abdul Razak (2014) reported that Bario took 11 days to reach the third leaf appearance, while Biris took 12 days. Thus, the thermal time (Tt) requirement for the third leaf appearance was 277 °Cd for Bario and 306 °Cd for Biris. However, this study only considered one sowing date, which limits the ability to draw conclusions about the time taken for the third leaf appearance.

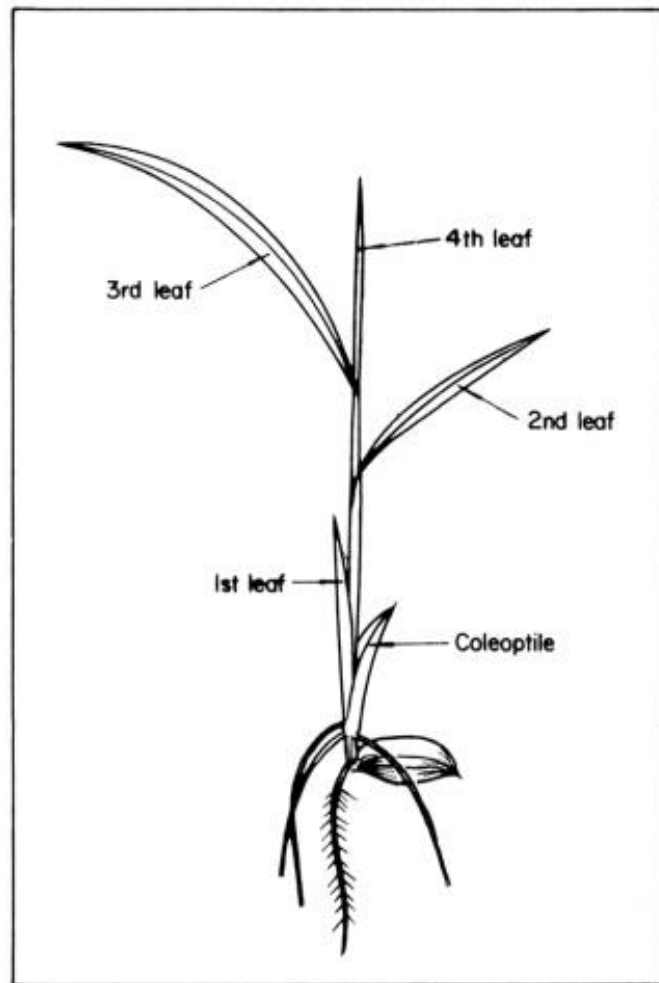


Figure 2.1: Counting leaf number (Source: Yoshida, 1981).

2.5.3 Phyllochron

Phyllochron refers to the time interval between the appearances of two successive leaves (Klepper et al., 1982). According to Nemoto et al. (1995), in the early stages of rice growth, the phyllochron occurs rapidly and then gradually decreases towards the final leaf appearance. The increased duration of the phyllochron is attributed to the preparation for panicle initiation and internode elongation (Yoshida, 1981). The phyllochron is quantified using thermal time (Tt), and Nemoto et al. (1995) noted that its duration is influenced by factors such as temperature, day length, light intensity, humidity, and soil nutrient

availability. For instance, in Los Baños, Laguna, Philippines, the last phyllochron of the rice variety IR 72 took approximately 17 days with a Tt requirement of 257 °Cd (Pablo et al., 2022). However, older seedlings generally have a longer phyllochron compared to younger seedlings (Uphoff, 2000). Phyllochron, the time interval between the appearances of two successive leaves, is primarily influenced by the temperature at the growing point (Peacock, 1975). It has been observed to remain consistent regardless of the planting date (Hotsonyame & Hunt, 1997). In a study by Abdul Razak (2014) it was found that the maximum number of main stem leaves for Bario and Biris was 15 when planted in October.

Thermal time plays a crucial role in predicting the timing of flag leaf appearance, which is significant because heading typically occurs shortly after the flag leaf emerges. This information is valuable for farmers as it enables them to anticipate the appropriate timing for various farm management practices, such as pest management and herbicide application. Controlling weeds before the heading stage is particularly important to prevent competition between the crops and weeds, ensuring optimal growth and yield for the cultivated plants. By utilizing thermal time-based predictions, farmers can effectively plan and implement necessary agricultural interventions to maintain crop health and maximise productivity. The thermal time (Tt) requirement for phyllochron in Bario was 221 °Cd, slightly longer than that of Biris at 219 °Cd (Abdul Razak, 2014).

2.5.4 Tillering and Maximum Tillering

Tillering starts following the appearance of the fifth-leaf stage. Tillers will first appear as the tips of leaf blades emerging from the tops of sheaths of completely developed leaves on the main shoot (Saichuk, 2014). The first tiller is visible and emerges from the axillary bud of the second leaf on the culm (Moldenhaouer et al., 2013). Tillers usually

develop in the same manner as the main shoot but the development is slower than the main shoot. The delay in tiller development will result in the tiller producing fewer leaves, having a less height, and maturing slightly slower than the main shoot (Saichuk, 2014). Maximum tillering is where the tillering increases in a sigmoidal-shaped curve until the maximum tiller number is reached (Moldenhaouer et al., 2013). A rice plant can produce 20-25 tillers under favourable growth conditions (Pawar et al., 2016). At this stage, the main culm will be difficult to differentiate from the tiller. There will be no more effective tillers produced after the crop has reached the maximum tillering stage. The tillers that grow later will eventually die due to competition. The capacity of tillering determines the crop final yield. Therefore, yield components and panicles per unit area will be determined from this study.

2.6 Reproductive Development of Rice

The emergence of the flag leaf marks the transition from the vegetative phase to the reproductive phase. The flag leaf holds significance in rice as it serves as a source of photosynthetic energy during the reproductive phase, as mentioned by Rahman et al. (2014). Their study found a positive and highly significant correlation between the flag leaf and yield. They observed that plants with longer flag leaf length exhibited elongated panicles, which led to an increased number of primary and secondary rachis, ultimately resulting in a higher grain count within the panicle. This, in turn, contributed to the overall improvement in the yield of rice cultivars (Rahman et al., 2014). The reproductive stage in rice is referred from the initiation of panicle primordia to heading (Yoshida, 1981). The reproductive phase is characterised by culm elongation, a decline in tiller number, booting, the emergence of the flag leaf, heading, and flowering (Moldenhaouer et al., 2013). Additionally, it is noted by Taylor and Fageria (2007) that in tropical regions, rice cultivars with a growth cycle of 130

to 140 days generally accomplish the entire reproductive growth stage within a span of 30 days. Under favourable physiological and environmental conditions, the rice plant undergoes the initiation of panicle primordia. These primordia are located at the top of the culm and can be observed under a microscope approximately 30 days prior to heading. The duration from the initiation of panicle primordia to heading remains relatively constant, typically around 30 days (Yoshida, 1981). Panicle initiation is a critical milestone in rice crop management as it signifies the transition from vegetative growth to reproductive development (Vergara & Chang, 1985). Understanding and monitoring this stage is important for implementing appropriate agricultural practices and optimising yield potential.

Panicle initiation refers to the period when the panicle primordia start developing into a panicle at the uppermost node of the rice culm (Moldenhaouer et al., 2013). In tropical regions, panicle initiation typically occurs around 70 to 75 days before the crop reaches maturity (Vergara, 1991). The duration of panicle development can vary depending on the rice variety and prevailing weather conditions, typically ranging from 27 to 46 days (Yoshida, 1981). Additionally, in both temperate and tropical regions, the period from panicle initiation to heading, which is the emergence of the panicle from the flag leaf sheath, typically takes around 23 to 25 days (Yoshida, 1981). Concurrent with panicle initiation, the rice plant enters a phase of internode elongation, also known as the 'jointing stage'. This stage continues until the plant reaches its full height and is followed by the heading process, which is the emergence of the panicle (Moldenhaouer et al., 2013). The jointing stage plays a crucial role in determining the final plant height and the subsequent development of the panicle.

Indeed, the thermal time (T_t) requirement for rice crops can vary among different varieties, locations, and planting seasons. Toriyama et al. (1969) reported that the T_t

requirement for selected Japanese varieties from sowing to heading phase ranges from 1000 to 3000 °Cd. Additionally, the Tt requirement for the ripening phase requires an additional 700 to 800 °Cd (Ishizuka, 1973). Therefore, from sowing to maturity phase, the Tt requirement for a rice crop is estimated to be around 2000 to 4000 °Cd. It is important to note that these values are approximate and can be influenced by various factors such as temperature fluctuations and local growing conditions. In terms of conversion to days, at an average temperature of 25 °C, the Tt requirement of 2000 to 4000 °Cd would correspond to approximately 80 to 160 days (Yoshida, 1981). However, it is essential to consider that these calculations are based on average temperature conditions and actual crop development can be affected by variations in temperature and other environmental factors.

2.6.1 Heading and Booting Stage

During the rice growth and development process, after the emergence of the flag leaf, the internodes continue to elongate. Around 18 days before heading, the panicles start to grow rapidly and climb upward within the flag leaf sheath (Yoshida, 1981). This upward movement of the panicle causes the flag leaf sheath to swell, and this stage is referred to as the booting stage (Moldenhauer et al., 2013). The booting stage typically occurs approximately 6 days before heading (Yoshida, 1981). Subsequently, the panicle fully emerges from the flag leaf sheath, which usually takes around 24 hours (Vergara, 1991). This emergence marks the completion of the booting stage and the transition into the heading stage, where the panicle becomes fully visible and begins the process of flower development. It is important to note that the timing of these developmental stages can vary depending on factors such as rice variety, environmental conditions, and management practices. Therefore, it is advisable to consider local conditions and specific variety characteristics when

monitoring and managing rice crops during these stages. The timing of heading in rice plants can differ among individual plants and even within the same plant due to variations in tiller development. Some tillers within the main stem may head earlier than others, leading to differences in heading times. In a field, it generally takes around 10 to 14 days for all plants to complete the heading process. The heading date is commonly determined as the moment when approximately 50% of the panicles have emerged from the flag leaf sheath. Panicle exertion, which refers to the process of the topmost internode rapidly elongating and pushing the panicle out of the sheath, is synonymous with heading. Yoshida (1981) provides these insights into the concept of panicle exertion and its association with heading. Moldenhaouer et al. (2013) highlight the significance of the heading date in rice cultivation, as it plays a crucial role in determining the crop's yield. Any environmental stress experienced during the booting stage, particularly around the time of heading, can have detrimental effects on grain production. It is important to carefully manage the heading date to avoid coinciding with unfavourable cropping seasons or adverse environmental conditions. For instance, extended periods of low sunlight exposure before and after heading can lead to insufficient panicle exertion, resulting in poor grain filling during the ripening stage. Therefore, proper timing of heading is essential to optimise the grain filling process and ultimately maximise the rice yield.

2.6.2 Anthesis

Anthesis refers to the specific process of the spikelet opening and closing, which typically occurs over a period of 1 to 2.5 hours (Yoshida, 1981). Flowering usually begins upon panicle protrusion and is consequently considered synonymous with a heading (Moldenhaouer et al., 2013). The timing of flowering in rice is closely linked to the

appearance of leaves. To predict the date of flowering based on leaf development, it is crucial to determine and record the final main stem leaf number, as noted by Yin and Kropff (1996) as this information aids in understanding the progression of leaf growth and allows for accurate estimation of the flowering date in rice plants. Anther dehiscence, the process of pollen grain release, typically occurs before or during the opening of the palea and lemma in rice. This mechanism is one of the reasons why rice is considered a self-pollinated plant (Yoshida, 1981). The timing of anthesis is influenced by various factors including temperature, humidity, and photoperiod, as highlighted by Moldenhauser et al. (2013). Anthesis in rice occurs when a portion of the panicle, particularly the spikelets at the tip of the upper panicle branches, has emerged. Therefore, the date of anthesis coincides with the date of heading, as explained by Yoshida (1981). Temperature plays a significant role in influencing the timing of anthesis. High temperatures tend to accelerate the rate of flowering, while low temperatures can delay it, as observed by (Vergara & Chang, 1985). During anthesis, the rice plant is at its most temperature-sensitive stage (Farrell et al., 2003; Satake & Yoshida, 1978). Particularly, pollen viability decreased at anthesis temperatures over 33 °C until there was no viability left at the highest temperature of 40 °C. (Kim et al., 1996). This may result in a high rate of spikelet sterility and empty grain as a result.

According to Yoshida (1981) the spikelets within the same panicle typically take 7-10 days to complete anthesis, while the timeframe extends to 15-20 days within the same field. Environmental conditions also contribute to the variation in anthesis. In tropical regions, anthesis in rice crops typically occurs between 0800 and 1300 hours. Lower temperatures can delay the onset of anthesis, causing it to begin later in the morning and continue into the late afternoon. In addition, pollination in rice crops can still take place during rainy days, even without the opening of the lemma and palea (Yoshida, 1981). The

timing of flowering plays a crucial role in agriculture as it determines the flowering season and the onset of the ripening phase, thereby impacting grain filling and yield formation, which are influenced by climatic conditions after flowering. Rising temperatures generally accelerate the phenological development of the rice crop (Mcmaster & Smika, 1988). However, extremely high temperatures can impede the growth of rice plants throughout the vegetative, reproductive, and ripening phases (Wassmann et al., 2009). It is essential to comprehend the temperature response of rice phenology, particularly concerning the timing of panicle emergence and flowering, in order to ensure stable production. Varying the sowing dates of a crop has an impact on the timing of flowering. Early transition from vegetative to reproductive development allows plants to reproduce before the onset of severe water deficit, which could jeopardise their survival (Sherrard & Maherali, 2006; Franks, 2011). However, early flowering shortens the duration available for carbon assimilation during vegetative growth, potentially leading to a decrease in yield (Schmalenbach et al., 2014).

2.6.3 Ripening and Senescence

Grain growth such as increase in size and weight, and variation in grain colour characterises the ripening period. Initially, the grains are green and gradually transition to a yellow colour as they approach maturity. The ripening period can be classified into further stages such as milky, dough, yellow ripe, and maturity as described by Yoshida (1981). In tropical regions, rice grain typically takes approximately 25 to 30 days to reach maturity (Vergara, 1991). The process of grain filling in rice is primarily influenced by temperature and is considered to be temperature-sensitive (Peng et al., 2004). Higher temperatures generally promote faster grain development and result in a shorter grain filling period

(Yoshida, 1981). In a study by Yoshida (1981), the indica rice variety IR20 took 13 days to reach maximum weight at a temperature of 28 °C, while it took 33 days at a temperature of 16 °C. Temperature also plays a crucial role in the ripening phase of rice. In certain region like Hokkaido, Japan, and New South Wales, Australia, the ripening period ranged from approximately 30 days in tropical regions to 65 days in cooler regions (Tanaka & Vergara, 1967). The duration of grain filling can vary among rice varieties. Yoshida (1981) reported that IR20 took approximately 23 days for grain filling at Los Baños, Philippines, while Tongil took about 33 days at Suweon, Korea. Leaf senescence in paddy begins at the lowers leaves and proceeds upwards as the plant matures. According to Yoshida (1981), the leaf senescence of rice is faster in warm regions than in cool regions. Understanding the timing of grain ripening is crucial for effective agronomic management, including the application of insecticides and fertilisers. By knowing the stage of grain ripening, farmers can appropriately time their interventions to optimise yield and prevent losses due to pests or nutrient deficiencies.

2.7 Yield and Yield Components

Rice yield is usually reported as rough rice (paddy) at 14% moisture content (Yoshida, 1981). Yield performance can be examined by breaking the yield into its components:

$$\begin{aligned} \text{Grain yield (t/ha)} &= \text{panicle number/m}^2 \times \text{spikelet} && \text{Equation 2.2} \\ &\text{number/panicle} \times \% \text{ filled spikelet} \times 1,000 \text{ grain weight (g)} \times 10^{-5} \\ &= \text{spikelet number/m}^2 \times \% \text{ filled spikelet} \times 1,000\text{-grain weight (g)} \\ &\quad \times 10^{-5} \end{aligned}$$

Spikelet number consists of filled, partially filled, and empty spikelets. The filled spikelet is known as grain (Yoshida, 1981). The percentage of filled spikelets is a ratio of the number of grains divided by the total number of spikelets meanwhile the 1,000-grain weight is the average weight in grams of 1,000 grains. Yield components are greatly influenced by weather conditions, nutrient supply, and also cultural management thus it is critical to understand their interrelationship to improve the rice yield (Yoshida, 1981). The formation of spikelets in rice is influenced by various factors, including the growth conditions of the panicle and the development of its components. Additionally, the panicle fertility rate and the availability of photosynthetic products during the maturation phase play a role in spikelet formation (Lack et al., 2012). The variation in the percentage of filled spikelets can be attributed to different environmental temperatures experienced during the reproductive phase, as well as the timing of panicle emergence and maturation period (Lack et al., 2012). Various environmental variations are associated with different sowing times, and even subtle differences can have an impact on the outcomes. Yoshida (1978, 1981) indicated that deviations from the critical temperature limits can affect physiological processes related to spikelet formation. In rice, the rate of leaf growth rose with temperature up to an optimal temperature of 33 °C, but as the crop developed reproductively, temperatures above 25 °C reduced grain formation and yield (Matsushima et al., 1964; Baker et al., 1995). Additionally, temperature fluctuations can lead to decreased fertility during the meiosis division and heading stage. High temperatures specifically during the heading stage have the potential to render flowers infertile. According to Lack et al. (2012), the relative significance of day duration and temperature during panicle emergence affects the percentage of panicle fertility. Furthermore, this attribute is influenced by the properties of the landrace as well as environmental conditions. In study conducted by Yoshida (1981), the

grain yields of 19 crops of an early maturing variety, IR747B2-6, were observed to range from 4.6 to 7.1 t/ha when grown throughout the year at Los Baños, Philippines. The grain yield showed a positive correlation with the spikelet number per square meter. A pre, the IR8 variety grown at Los Baños, Philippines exhibited a linear increase in grain yield as the spikelet number per square meter increased. However, the percentage of filled spikelets and the 1000-grain weight remained constant regardless of the spikelet number (Yoshida et al., 1972).

Yoshida et al., (1972) emphasised that, in different locations and under various environmental conditions, the percentage of filled spikelets becomes a limiting factor for yield compared to the spikelet number per square meter. Yoshida (1981) explains that the number of spikelets per unit land area in rice is influenced by various factors including cultural practices, growth characteristics, and weather conditions. Cultural practices such as plant density and nitrogen application can directly impact the spikelet number. Increasing plant density and providing adequate nitrogen can result in higher spikelet numbers per unit land area. In addition, the interaction between solar radiation, temperature, and plant spacing can also affect the spikelet number during the reproductive development stage. The availability of solar radiation and temperature during this period plays a crucial role in determining the number of spikelets produced. Optimal combinations of plant spacing and nitrogen levels, along with favourable solar radiation and temperature conditions, can contribute to maximising the spikelet number in rice crops.

According to Yoshida (1981), the sterility percentage in rice refers to the combined percentage of unfertilised spikelets and partially filled spikelets. Various factors can influence sterility percentage, including weather conditions, soil characteristics, insect damage, and fertiliser application. Unfavourable weather conditions, such as extreme

temperatures or inadequate sunlight, can contribute to higher sterility percentages. On the other hand, the percentage of filled spikelets is primarily influenced by factors such as temperature, nitrogen levels, solar radiation, soil salinity, lodging, wind, and drought (Yoshida et al., 1972). Optimal temperature conditions, appropriate nitrogen application, and sufficient solar radiation are important for achieving higher filled spikelet percentages. However, adverse conditions like high temperatures, excessive nitrogen levels, or environmental stressors can negatively affect the percentage of filled spikelets. Partially filled spikelets are more likely to occur in shaded crop environments and under extreme environmental conditions (Yoshida, 1981). These conditions limit the availability of sunlight and disrupt normal grain development, leading to a higher proportion of partially filled spikelets. Furthermore, the grain weight of field crops is generally considered a constant varietal characteristic under most conditions (Soga & Nozaki, 1957; Yoshida, 1981). This means that, barring any significant external factors, the grain weight remains relatively consistent and is primarily determined by the inherent characteristics of the rice variety itself.

The size of the hull, which is the outer protective covering of the grain, is known to have an impact on the grain size. Factors such as heavy shading before heading can affect the hull size, resulting in a decrease in the weight of 1000 grains (Matsushima, 1970). Additionally, carbon dioxide (CO₂) enrichment has been found to influence grain weight as well (Yoshida, 1981). Furthermore, inadequate farm management practices can also lead to a reduction in grain weight, as highlighted by Hill (2005) suggests that inadequate farm management practices can lead to a reduction in grain weight. Insufficient moisture in the fields during the latter stages of harvest can limit grain filling, resulting in decreased grain weight and compromised quality. Therefore, it is important to implement proper timing and effective management practices to positively influence the desired yield components,

including grain weight. This includes ensuring adequate moisture levels and appropriate farming techniques throughout the growing season to optimise grain filling and promote higher grain weights and quality.

CHAPTER 3

MATERIALS AND METHODS

3.1 Germination Experiment

3.1.1 Plant Material

The seeds of two traditional varieties of rice, namely Bario Sederhana and Biris were obtained from a farmer's field in Serian District, Sarawak, East Malaysia. This planting location was outside of the historical origin of Bario Sederhana from Bario highland, Sarawak and Biris from Simunjan District, Sarawak. Hence, Bario Sederhana and Biris varieties used in this study are referred to as rice landraces because of their distinct identity, adaption to local environments making them genetically diverse and association with farmers' preferences (Villa et al., 2005).

3.1.2 Germination Study

The germination study experiment took place within the Plant Growth Laboratory, Universiti Malaysia Sarawak (UNIMAS). The experiment was conducted in triplicates with each consisted of 50 seeds of Bario Sederhana and Biris rice landraces. The seeds were placed on moistened filter paper in plastic petri dishes and were germinated in unlit incubators (Conviron G30 Model, Winnipeg, Canada) (Figure 3.1) at twelve constant temperatures of 12.5 °C, 15 °C, 17.5 °C, 20 °C, 22.5 °C, 25 °C, 27.5 °C, 30 °C, 32.5 °C, 35 °C, 37.5 °C, or 40 °C. A mercury thermometer was placed inside the incubators to monitor the targeted temperatures setting. Additional distilled water was added from time to time to ensure adequate moisture for the germination process. No pre-conditioning treatment was

applied to the seeds. During the rapid germination times, germinated seeds were counted and removed twice daily and regularly until the germination process ended (ISTA, 1993). Seeds were deemed as germinated when the radicle length exceeded 2 mm.



Figure 3.1: Germination experiment in unlit incubator (Convion G30 Model, Winnipeg, Canada).

3.1.3 Data Analysis

Cumulative germination percentage at a given period was fitted using a Gompertz function:

$$CG = C \times e^{(-e^{(-B \times (t-M))})}$$
Equation 3.1

Where CG represents the cumulative percentage of seeds germinated over time, t (days), C represents the final germination percentage, and B and M represent constants. The Gompertz equation was then rearranged into Equation 3.2 to determine days to 75% of the final germination percentage (t_{75}), where CG =75:

$$t_{75} = M - \ln \left[-\ln \left(\frac{y}{100} \right) \right] / B \quad \text{Equation 3.2}$$

Germination rate was calculated as the reciprocal of time to 75% germination (1/days) in relation to temperature (T). A ‘broken-stick’ linear model was fitted to germination rate in response to temperatures in the sub-optimal and supra-optimal range for quantification of thermal time and cardinal temperatures. The ‘broken-stick’ model was described as:

$$\text{Germination rate} = a_1 + b_1T \text{ (for sub-optimal temperatures)} \quad \text{Equation 3.3}$$

$$\text{Germination rate} = a_2 + b_2T \text{ (for supra-optimal temperatures)} \quad \text{Equation 3.4}$$

Where a represents the y-axis intercept, b represents the slope of the relationship, and T represents the temperature $\leq T_{\text{opt}}$ (for sub-optimal range) and $\geq T_{\text{opt}}$ (for supra-optimal range). Calculations for T_b , T_{max} , and T_t can be obtained from the regression coefficients as:

$$T_b = -a_1/b_1 \quad \text{Equation 3.5}$$

$$T_{\max} = -a_2/b_2 \quad \text{Equation 3.6}$$

$$T_t = 1/b_1 \text{ (sub-optimal temperatures)} \quad \text{Equation 3.7}$$

$$T_t = -1/b_2 \text{ (supra-optimal temperatures)} \quad \text{Equation 3.8}$$

T_{opt} was calculated from the intersection point of two regression lines in Equation 3.3 and 3.4 as:

$$T_{\text{opt}} = (a_2 - a_1)/(b_1 - b_2) \quad \text{Equation 3.9}$$

Data points were omitted from the regression analysis should germination rate deviated from a linear model at low or high temperatures as these were beyond the species' optimal thermal range (Angus et al., 1981). When 95% confidence intervals included 10 °C, an extra regression analysis was conducted with T_b set to 10 °C to allow direct comparison of T_t for germination among rice landraces (Yoshida, 1981) and previous works (Ali et al., 2003; Tilebeni et al., 2012)

The standard errors (S.E.) for T_b and T_t were determined as follows (Campbell et al., 1974):

$$\text{S.E. } T_b = \frac{\bar{y}}{b} \sqrt{\frac{s^2}{N\bar{y}^2} + \left[\frac{\text{S.E.} \cdot b}{b}\right]^2} \quad \text{Equation 3.10}$$

$$\text{S.E. } T_t = \frac{\text{S.E.} \cdot b}{b^2} \quad \text{Equation 3.11}$$

Where s^2 is the residual mean square of y , i.e., the germination rate, and $\bar{y}$ is the sample mean. Gompertz curves were fitted using SigmaPlot 10.0 (Systat Software Inc. US) and least square regression analyses used Minitab 17.0 statistical software. The maximum standard errors were recorded for each measured variable.

3.2 Pots Experiment

3.2.1 Experiment Location

The pots experiment was conducted on 1st April 2019 in a net house in front of the Plant Growth Laboratory at University Malaysia Sarawak (UNIMAS) (Figure 3.2).



Figure 3.2: Net house to prevent insect infestation and bird attack.

3.2.2 Meteorological Conditions

The month of January (2019-2021) recorded the highest amount of rainfall (578.2 mm) and the lowest air temperature of 26.0 °C (Table 3.1). April and May (2019-2021) were the warmest months with air temperature of 27.5 °C. The driest month was July (2019-2021) with total rainfall of 189.7 mm. Daylength was 12 hours all year round with marginal variations (0.1-0.2 hours).

Table 3.1: Average annual rainfall (mm) from 2019 - 2021, daylight length (hours), average air temperature and average soil temperature (°C) at Kota Samarahan, Sarawak.

	Average rainfall (mm)	Daylight length (hrs)	Air temperature (°C)	Soil temperature (°C)
January	578.2	12.0	26.0	25.9
February	447.0	12.1	26.0	26.3
March	314.7	12.1	27.0	27.4
April	280.5	12.1	27.5	26.6
May	248.1	12.2	27.5	26.0
June	198.0	12.2	27.0	25.1
July	189.7	12.2	26.0	25.2
August	235.4	12.2	26.5	25.8
September	269.0	12.1	26.5	27.1
October	319.3	12.1	27.0	27.3
November	349.8	12.1	26.5	27.6
December	474.0	12.0	26.5	25.7
Average/Total	3903.7 (Total)	12.1	26.7	26.3

Data were obtained from Kuching airport (14 km from Samarahan Division), Sarawak. Air and soil temperature were obtained by data logger (Section 3.2.6.1).

3.2.3 Experimental Design

A split plot design experiment was initiated on six sowing dates as the main plots (Table 3.2) and two rice landraces (Bario Sederhana and Biris) as subplots with four replications.

Table 3.2: Sowing dates (SD) for a series of pots experiments at Universiti Malaysia Sarawak.

SD1	01/04/2019
SD2	27/06/2019
SD3	27/08/2019
SD4	27/10/2020
SD5	28/12/2020
SD6	28/02/2021

3.2.4 Crop Husbandry

Ten liters of plastic pots were filled with an organic potting mix containing top soil, coco peat and sand at 2:1:0.5 (Figure 3.3). The soil was analysed by Sarawak Plantation Services Sdn. Bhd. for exchangeable cations (K, Ca, Mg), cations exchange capacity (CEC) and available Phosphorus (Table 3.3). Any insufficient mineral required by the plants to grow can be made up through fertiliser application based on soil test results in Table 3.3. To avoid poor seeds establishment, 50 rice seeds were sown manually in each pot onto the potting mixed soil at a depth of 10 mm. These seeds were not pre-germinated and no pre-conditioning treatment was applied to the seeds prior to sowing. The pots were established on the ground outside the Plant Growth Laboratory, UNIMAS. A silver shine was placed underneath the pots to control the growth of weeds on the ground. After sowing, the pots were watered gently immediately and were irrigated at 5 cm water level above the soil surface. After the seedlings has reached the third leaf appearance stage (7 to 17 days for

Bario Sederhana and 7 to 18 days for Biris), the plants were thinned to five plants per pot to reduce competition for nutrients, light, and moisture. These five plants were selected for their robust growth and were maintained for detailed measurement.



Figure 3.3: The rice plants during active tillering stage in the pots experiments outside Plant Growth Laboratory, UNIMAS.

Table 3.3: Soil test analysis for pots experiment as reported by Sarawak Plantation Sdn. Bhd.

Analysis	Results
Available Phosphorus (ppm)	72.00
Exchangeable Potassium (mEq %)	1.96
Exchangeable Calcium (mEq %)	36.44
Exchangeable Magnesium (mEq %)	3.70
Cation Exchange Capacity (mEq %)	19.32

3.2.5 Management

Split fertiliser application was applied at the rate of 200kg N/ha, 200 kg P_2O_5 /ha, and 200 kg K_2O /ha. A compound fertiliser, N-P-K 15-15-15 (Cap Jambatan, Hamburg,

Germany) (Figure 3.4) was used in this study. Fertiliser was applied at the third leaf stage, active tillering phase, maximum tillering, and heading to provide nutrients for paddy plants at a total of 7.47 g per pot (Pot surface area = 0.056 m²).



Figure 3.4: Compound fertiliser (Cap Jambatan Hamburg, Germany).

3.2.6 Measurements

3.2.6.1 Soil and Air Temperatures

A temperature sensor was placed at a depth of 10 mm from the soil surface in the pot to measure soil temperature. Both soil and air temperatures were recorded by a data logger (Watchdog 1425, USA) where temperatures were logged every hour to define the daily maximum and minimum temperatures. Daily thermal time was calculated using 8 x 3 hourly temperatures obtained from the maximum and minimum temperatures which were then

incorporated into a sinusoidal model (Jones & Kiniry, 1986). Thermal time calculations also used the ‘broken-stick’ linear model with cardinal temperatures established from the germination study (Figure 4.4).

3.2.6.2 Emergence and Third Leaf Appearance

Following sowing, the number of seedlings that emerged were recorded daily until they ceased. The seedlings were considered emerged when the coleoptile has protruded out from the soil. Cumulative seedling emergence and third leaf appearance against time were fitted using a Gompertz function (Equation 3.1). Time to seedling emergence and third leaf appearance were determined when 50% of the populations have shown such development and calculated using Equation 3.2 where $y = 50$.

3.2.6.3 Leaf Appearance Rate (Phyllochron)

The number of leaves on the main stem was counted and recorded at every four days intervals until the appearance of the flag leaf. A flag leaf is the final leaf produced on the main stem that indicates towards heading and flowering. The leaf appearance rate or also known as phyllochron was calculated from the least square regression of leaf numbers on the main stem against accumulated thermal time and calendar days.

3.2.6.4 Plant Height

The final plant height was recorded when the flag leaf has appeared. Plant height was measured from the soil surface to the tip of the highest leaf of an individual plant. A measuring tape was used to measure the plant height.

3.2.6.5 Basal Internodes

The internode is a part of plant stem between two of the nodes from which leaves emerge. The height of the basal three internodes was measured at maturity, following harvest using a measuring tape.

3.2.6.6 Time to Flowering

Time to flowering (heading) was calculated from seed sowing. The appearance of flag leaf marks the end of vegetative stage of a rice plant. The time to flowering was defined when 50% of the plant populations have produced the first panicle.

3.2.6.7 Grain Development

Following anthesis, seed development can be divided into four stages, i.e., milky, milky dough, hard grain, and ripe grain (Figure 3.5). Time to grain development was quantified from flowering stage in both calendar days and thermal time.

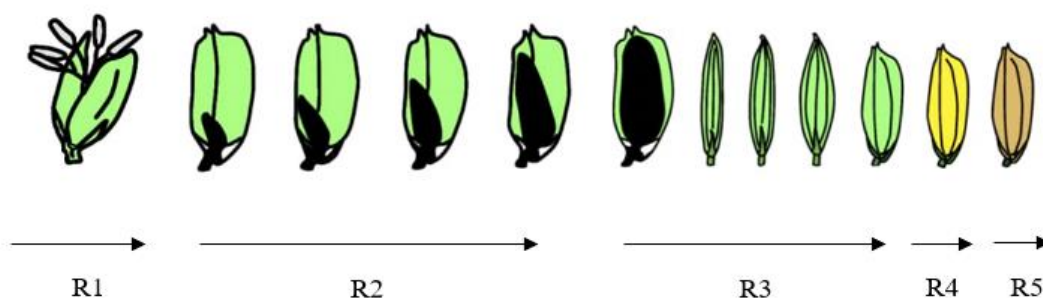


Figure 3.5: Grain development stages. R1: Anthesis. R2: Milky. R3: Milky Dough. R4: Hard Grain. R5: Ripe Grain.

3.2.6.8 Length of Panicle

The length of a rice panicle determines the number of grains it can hold, and consequently rice yield. The length was measured using a ruler starting from the panicle neck to the apex (Huang et al., 2013).

3.2.6.9 Number of Spikelets per Panicle

The number of spikelets per panicle recorded included filled, partially filled, and empty spikelets. Filled spikelets is recognised when the spikelets are fully filled. Partially filled spikelets is when the spikelet is not fully filled due to immaturity at harvest or due to infection of seeds meanwhile empty spikelets do not have any rice kernel inside.

3.2.6.10 Percentage of Filled Spikelets

The percentage of filled spikelets was calculated from the total production of spikelets per panicle:

$$\text{Percentage of Filled Spikelets} = \frac{\text{No.of filled spikelets}}{\text{Total no.of spikelets}} \times 100\% \quad \text{Equation 3.12}$$

3.2.6.11 Grain Weight per Pot

Rice was harvested when more than 50% of the crop populations within the pot area (0.056 m²) had golden brown spikelets. The grain was air dried until it reached around 14% moisture before the final weight was recorded.

3.3 Field Experiment

3.3.1 Experiment Location

This experiment was carried out in the open area of Pusat Penyelidikan Tumbuhan (PPT), Faculty of Resource Science and Technology (FRST), Universiti of Malaysia Sarawak (UNIMAS) (1° 27'N, 110° 26'E, 20 m a.s.l). The arrangement of the rice plants was not consistent due to some of the planted seeds failed to survive (Figure 3.6). The soil samples taken from the field were analysed by Sarawak Plantation Sdn. Bhd. and test results showed low nutrients for crop growth (Table 3.4).



Figure 3.6: The rice plants during flowering stage in the experimental plots for field experiment at Pusat Penyelidikan Tumbuhan (PPT), Universiti Malaysia Sarawak (UNIMAS), Kota Samarahan, Sarawak.

Table 3.4: Soil test analysis for field experiment as reported by Sarawak Plantation Sdn. Bhd.

Analysis	Result
Available Phosphorus, (ppm)	1.00
Exchangeable Potassium (mEq %)	0.11
Exchangeable Calcium (mEq %)	5.46
Exchangeable Magnesium (mEq %)	0.20
Cation Exchange Capacity (mEq %)	4.41

3.3.2 Meteorological Conditions

This experiment location shared similar weather with the pot experiment (Section 3.2.2, Table 3.1) because the distance between these two locations was only 2.3 km.

3.3.3 Experimental Design

A split-plot design experiment was initiated on four sowing dates (15th April 2019, 27th June 2019, 27th August 2019 and 27th October 2020) as main plots, two rice landraces as subplots with four replications. Each main plot size measures 2m x 2m with two subplots measuring 2m x 1m each (Figure 3.7).



Figure 3.7: Experiment plots at Pusat Penyelidikan Tumbuhan (PPT), Universiti Malaysia Sarawak (UNIMAS), Kota Samarahan, Sarawak.

3.3.4 Field Management

Before each consecutive sowing date, the unsown plots were sprayed with herbicide D-Amine 480 (a.i. 2, 4-D dimethylamine at 48.0% concentration) at 1.7 L/ha to eradicate the weeds. The seeds of Bario Sederhana and Biris landrace were sown by direct drill and placement method. Planting holes were drilled by a sowing stick. There were 12 planting holes in each subplot. In each planting hole, 4 to 5 seeds were placed. Unlike in the pots experiment, the crops in the field experiment were not thinned. The experimental plots were not irrigated because the rice cultivation system relied on rainfall for irrigation. Compound

fertiliser (N: P: K 15:15:15, Cap Jambatan, Germany) at the rate of 200 kg/ha was applied accordingly to the crop at different growth stages (third leaf stage, active tillering stage, and flowering stage) based on the experimental plot area (Section 3.2.5). The weeds inside the plot were hand-pulled every week to reduce the competition for nutrients between the weeds and the rice crops. A netting mesh were set up during crop flowering stage to prevent insect infestation (Figure 3.8). One cycle for both Bario Sederhana and Biris landraces took around 5 to 6 months to be completed.



Figure 3.8: Flowering crops covered with insect mesh netting at Pusat Penyelidikan Tumbuhan (PPT), UNIMAS, Kota Samarahan, Sarawak.

3.3.5 Measurements

3.3.5.1 Plant Populations

The plant populations per subplot were counted as soon as all seedlings have emerged.

3.3.5.2 Plant Height

Plant height was measured in same manner as section 3.2.6.3.

3.3.5.3 Basal Internodes

The height of the basal three internodes was measured in the same manner as section 3.2.6.4.

3.3.5.4 Time to Flowering

The time to flowering was measured in the same manner as section 3.2.6.5.

3.3.5.5 Number of Panicles per Subplot

The number of panicles per plant was determined when 100% of the plant populations have reached ripening phase. The number of panicles was counted within each area of subplot (2 m²) for both Bario Sederhana and Biris rice.

3.3.5.6 Yield and Yield Components

The measurements for length of panicle, number of spikelets per panicle, percentage of filled spikelets and grain weight per subplot were measured in the same manner as section 3.2.6.8 until section 3.2.6.11.

3.4 Statistical Analyses

Time to emergence, third leaf appearance, flowering and seed ripening stages were analysed using a One-way analysis of variance (ANOVA). Post-hoc test used Fisher's Least Significant Difference when treatment means varied at $p < 0.05$. These analyses were performed using Minitab 17.0 Statistical Software (Minitab, LCC). All other parameters were analysed using a Two-way ANOVA for comparison between two factors (sowing dates and landraces) and presence of interaction. For these analyses, post-hoc test used Tukey Honestly Significant Difference should the treatments showed significant differences at $P < 0.05$. This was conducted by using Vassarstats Online Statistical Program (<http://vassarstats.net/>). For each treatment, standard error of the mean, confidence interval and coefficient of variance were reported.

CHAPTER 4

RESULTS

4.1 Germination Experiment

4.1.1 Final Germination Percentage

The cumulative germination percentage over time for Bario Sederhana and Biris was explained by the Gompertz functions (Figure 4.1). Typically, there was a distinct linear phase before approaching the final germination. For most temperatures, seeds took less than five days to reach their final germination. At temperature of 15 °C and lower (Figure 4.1), the germination process was delayed. The maximum final germination percentage was above 80% for Bario Sederhana and 90% for Biris landrace.

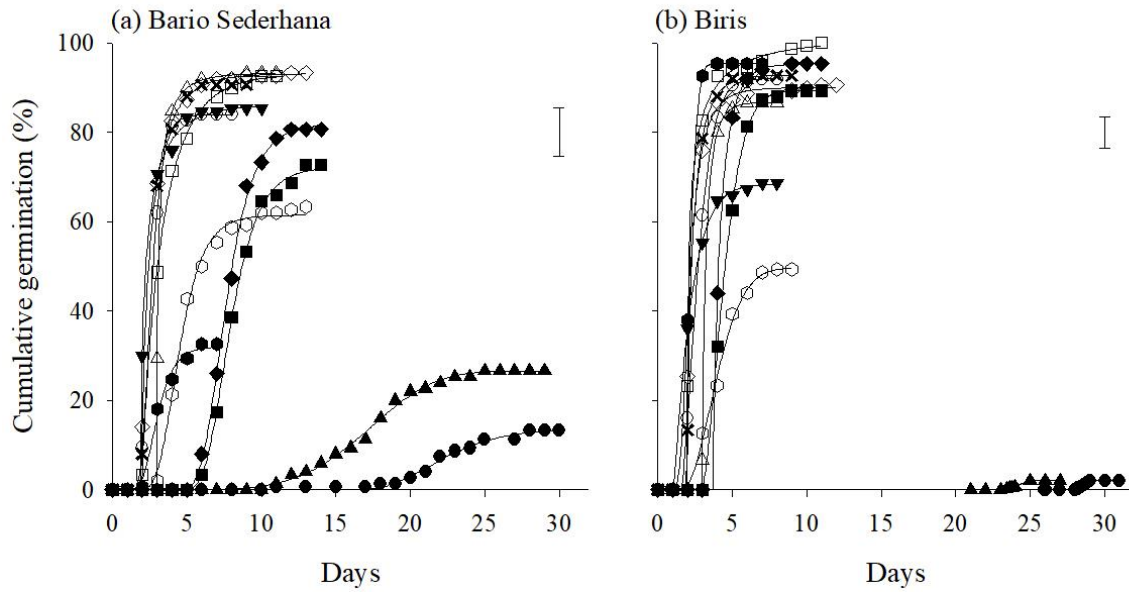


Figure 4.1: Cumulative germination (%) of (a) Bario Sederhana and (b) Biris rice landraces at 12 different constant temperatures. (●) 12.5 °C, (▲) 15 °C, (■) 17.5 °C, (◆) 20 °C, (△) 22.5 °C, (○) 25°C, (□) 27.5 °C, (◇) 30 °C, (▼) 32.5 °C, (×) 35°C, (⊙) 37.5°C, (●) 40 °C. Note: Error bars represent the maximum standard error for the cumulative germination percentage.

However, final germination was lower than these maximum values at near lower and upper end of the temperature range (Figure 4.2). For instance, the maximum germination percentage for Bario Sederhana was 73% - 91% at 17.5-35 °C but then declined to less than 30% at temperatures ≤ 15 °C and 40 °C. In Biris, seeds barely germinated at temperatures ≤ 15 °C.

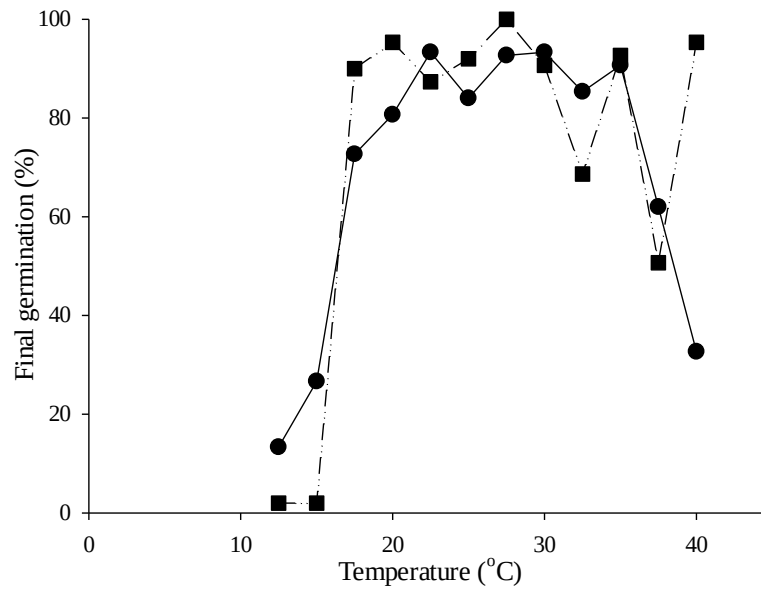


Figure 4.2: Final germination (%) for Bario Sederhana (●) and Biris (■) at different constant temperatures.

4.1.2 Time to 75% Germination and Germination Rate

The time taken to reach 75% of final germination was shortened with every increment of temperature up to 32.5 °C for Bario Sederhana and 27.5 °C for Biris landrace (Figure 4.3). The germination time was then extended until the maximum effective temperature of 37.5 °C was reached. In particular, Biris took a similar time of 2.7 days to germinate at temperatures 27.5 – 35 °C. The cardinal temperatures for each landrace were calculated using the reciprocals of these variables.

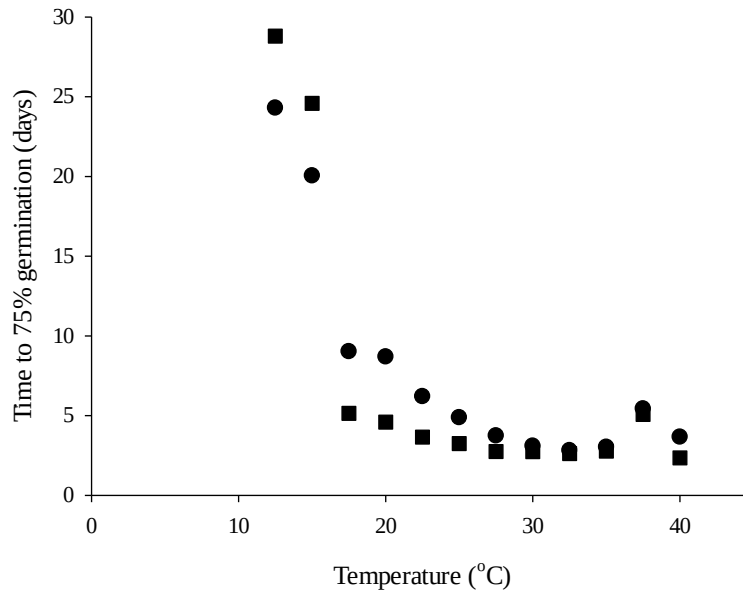


Figure 4.3: Number of days to 75% of final germination for Bario Sederhana (●) and Biris (■) rice at different constant temperatures.

The germination rate increased linearly from the base temperature (T_b) up to the optimum temperature (T_{opt}), and then decreased until germination ceased at the maximum temperature (T_{max}) (Figure 4.4).

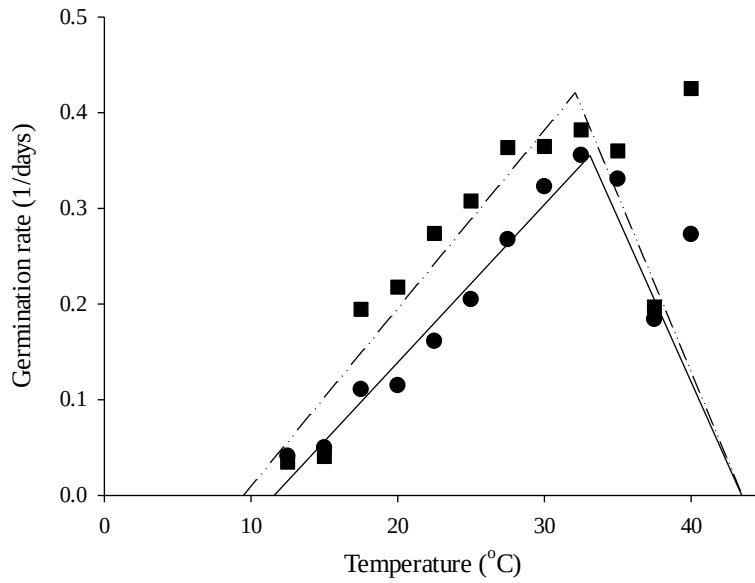


Figure 4.4: Germination of Bario Sederhana (●) and Biris (■) rice at different constant temperatures.

Broken-stick regression analysis enabled the cardinal temperatures to be estimated. The T_b was $11.6 (\pm 0.39) ^\circ\text{C}$ for Bario Sederhana and $9.5 (\pm 0.74) ^\circ\text{C}$ for Biris landrace. For both T_b estimates, the 95% confidence interval included $10 ^\circ\text{C}$ (Table 4.1). The highest germination rate was achieved at T_{opt} of $32.1 - 33.1 ^\circ\text{C}$ in both landraces while germination process began to slow down with further increased in temperature until it stopped at an estimated T_{max} of $43.5 ^\circ\text{C}$. The non-symmetrical broken-stick relationship between germination rate and temperatures, where data showed skewness required a separate thermal time for temperatures within the sub- and supra-optimal range (Figure 4.4, Table 4.1). For sub-optimal temperatures, the T_t requirement for 75% of final germination was $61 (\pm 3.3) ^\circ\text{C d}$ for Bario Sederhana and $54 (\pm 4.7) ^\circ\text{C d}$ for Biris above a T_b of $10 ^\circ\text{C}$. In the supra-optimal range (from T_{opt} to T_{max}), the T_t requirement for Bario Sederhana was $29 (\pm 4.5) ^\circ\text{C d}$ and 27

(± 3.9) °C d for Biris landrace. Temperature of 40 °C was not included in the quantification of Tt because it was outside of the linear range.

Table 4.1: Base (T_b), optimum (T_{opt}), and maximum (T_{max}) temperatures and thermal time (Tt) requirements for 75% germination of Bario Sederhana and Biris rice.

Rice landrace	T_b (°C)	T_{opt} (°C)	T_{max} (°C)	T_{tsub} (°Cd)	T_{tsup} (°Cd)	¹ Tt ($T_b=10^\circ\text{C}$) (°Cd)	² Excluded temperature
Bario Sederhana	11.6	33.1	43.5	61	29	63	40
Biris	9.5	32.1	43.5	54	27	53	40
Maximum S.E.	0.74	1.25	0.30	6.0	4.5	4.7	
95% C.I.	1.8, 15.2	26.6, 39.1	40.0, 49.2				

¹Analysis assumes a base temperature of 10 °C; ²Excluded temperature because germination rate deviated from the linear model; T_{tsub} , from T_b to T_{opt} ; T_{tsup} , from T_{opt} to T_{max} ; S.E., Standard Error; C.I., Confidence Interval.

4.2 Pots Experiment

4.2.1 Seedling Emergence

In both landraces, final emergence count was above 60% for sowing months in June, August, and October with addition of December for Bario Sederhana, irrespective of its year (Figure 4.5). Meanwhile, seedlings populations were below 30% when seeds were sown between December, February and April. Time to emergence quantified in calendar days ranged from 2.5 to 10.1 days ($P=0.002$) for Bario Sederhana and averaged 5.8 days ($P>0.05$) for Biris across six sowing dates (Table 4.2). Thermal time requirement for seedlings emergence varied with sowing dates by landraces ($P<0.05$) but with no particular order of sowing month. Seedlings took between 39 and 228 °Cd to emerge from the ground for Bario meanwhile, 104 and 164 °Cd for Biris.

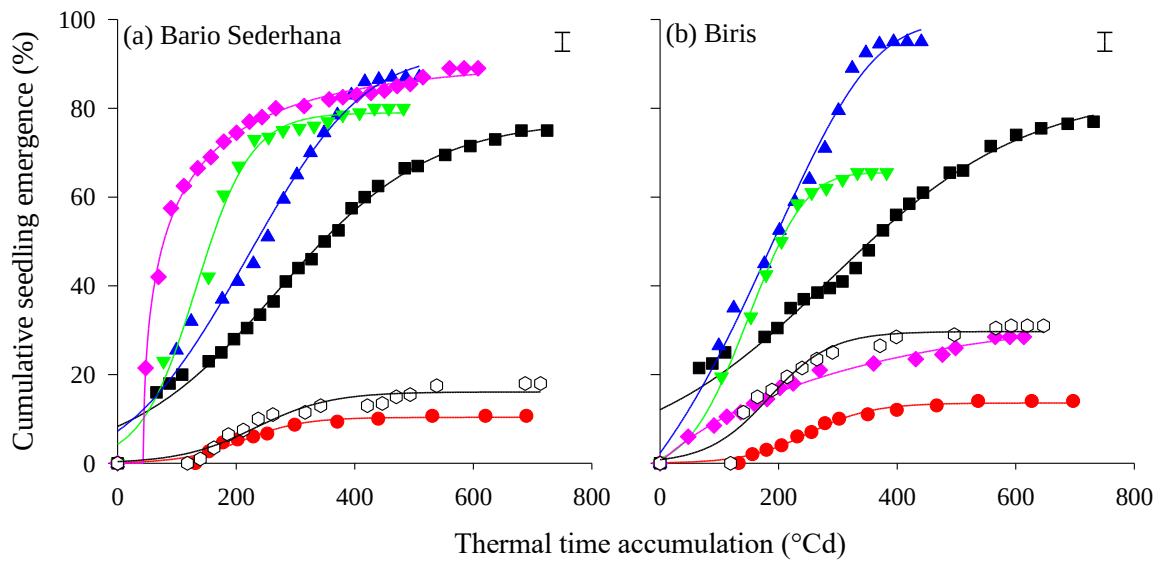


Figure 4.5: Cumulative percentage of seedling emergence against thermal time accumulation for (a) Bario Sederhana and (b) Biris rice sown on six dates at Universiti Malaysia Sarawak. (●) 1 April, (■) 27 June, (▲) 27 August, (▼) 27 October, (◆) 28 December and (○) 28 February. Note: Thermal time calculation used soil temperature ($T_b = 10\text{ }^{\circ}\text{C}$). Error bars represent the maximum standard error for the final number of emerged seedlings.

Table 4.2: Time to seedling emergence in Bario Sederhana and Biris rice sown on six dates in pots at Universiti Malaysia Sarawak.

Landrace	Sowing date	Time to emergence	
		Calendar days	Thermal time (°Cd)
Bario Sederhana	01/04/2019	6.9 ^{ab}	161 ^{ab}
	27/06/2019	9.3 ^a	199 ^a
	27/08/2019	7.6 ^{ab}	184 ^a
	27/10/2020	4.4 ^{bc}	101 ^b
	28/12/2020	2.5 ^c	39 ^c
	28/02/2021	10.1 ^a	228 ^a
	P-value	0.002	0.001
	S.E.M.	0.71	17.0
	CV (%)	50.40	53.7
Biris	01/04/2019	6.9	164 ^a
	27/06/2019	5.4	106 ^b
	27/08/2019	5.8	140 ^{ab}
	27/10/2020	4.8	107 ^b
	28/12/2020	5.0	104 ^b
	28/02/2021	7.0	153 ^a
	P-value	0.07	0.035
	S.E.M.	0.29	7.30
	CV (%)	23.00	26.90

Within each column, means with the same letters (superscript) are not significantly different ($P>0.05$) according to Fisher's Least Significant Difference test. SEM, Standard Error of the Mean; CV, coefficient of variation. Note: Thermal time used soil temperature ($T_b = 10^\circ\text{C}$) and calculated from sowing.

4.2.2 Third Leaf Appearance

Cumulative seedling populations with third leaf appearance followed the same pattern of cumulative seedling emergence (Figure 4.6). Calendar days from sowing to the production of third leaf varied from 7.1 to 18.0 days ($P=0.001$) across sowing dates by landraces (Table 4.3). Generally, the crops took between 149 and 386 °Cd to develop their first three leaves. When thermal time (Tt) to the appearance of third leaf was analysed in relation to sowing month, it exhibited a systematic variation with an increased Tt

requirement from February to June and then declined with subsequent months until the end of December (Figure 4.7).

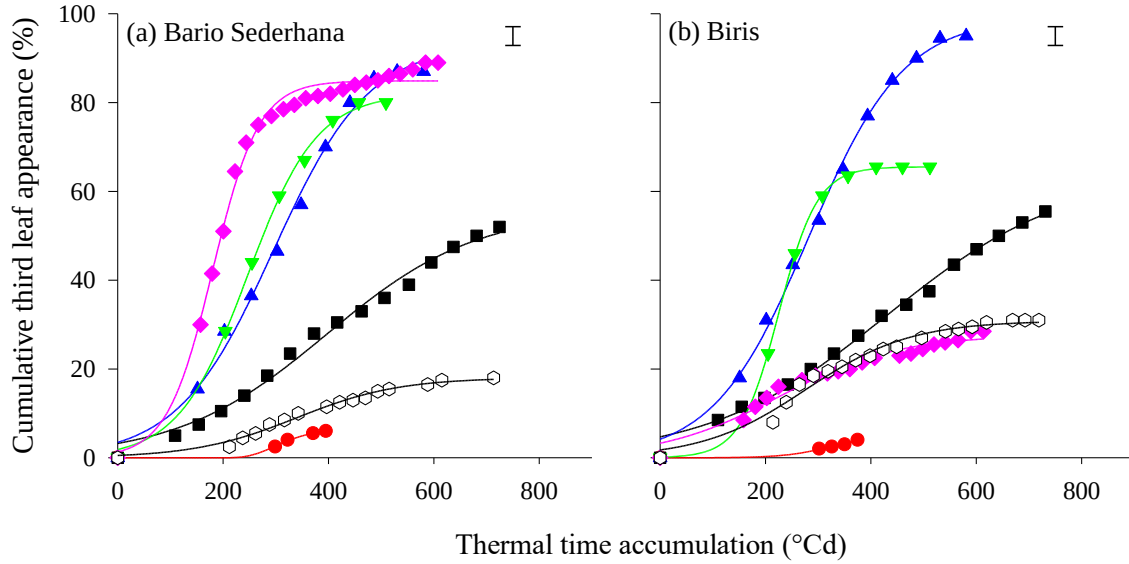


Figure 4.6: Cumulative percentage of third leaf appearance against thermal time accumulation for (a) Bario Sederhana and (b) Biris rice sown on six dates at Universiti Malaysia Sarawak. (●) 1 April, (■) 27 June, (▲) 27 August, (▼) 27 October, (◆) 28 December and (○) 28 February. Note: Thermal time calculation used soil temperature ($T_b = 10\text{ }^{\circ}\text{C}$). Error bars represent the maximum standard error for the final number of plants.

Table 4.3: Time to the third leaf appearance of Bario Sederhana and Biris rice sown on six dates in pots at Universiti Malaysia Sarawak.

Landrace	Sowing date	Time to third leaf appearance	
		Calendar days	Thermal time (°Cd)
Bario Sederhana	01/04/2019	13.7 ^b	327 ^{ab}
	27/06/2019	16.9 ^a	358 ^a
	27/08/2019	11.3 ^b	272 ^b
	27/10/2020	8.4 ^c	209 ^c
	28/12/2020	7.1 ^c	149 ^c
	28/02/2021	13.2 ^c	313 ^{ab}
	P-value	0.001	0.001
	S.E.M.	0.88	17.20
	CV (%)	38.59	30.68
Biris	01/04/2019	12.2 ^b	285 ^b
	27/06/2019	18.0 ^a	386 ^a
	27/08/2019	10.6 ^b	255 ^b
	27/10/2020	7.7 ^c	184 ^{cd}
	28/12/2020	8.0 ^c	165 ^d
	28/02/2021	10.5 ^b	240 ^{bc}
	P-value	0.001	0.001
	S.E.M.	0.84	17.90
	CV (%)	35.36	33.69

Within each column, means with the same letters (superscript) are not significantly different ($P > 0.05$) according to Fisher's Least Significant Difference test. SEM, Standard Error of the Mean; CV, coefficient of variation. Note: Thermal time used soil temperature ($T_b = 10\text{ }^{\circ}\text{C}$) and calculated from sowing.

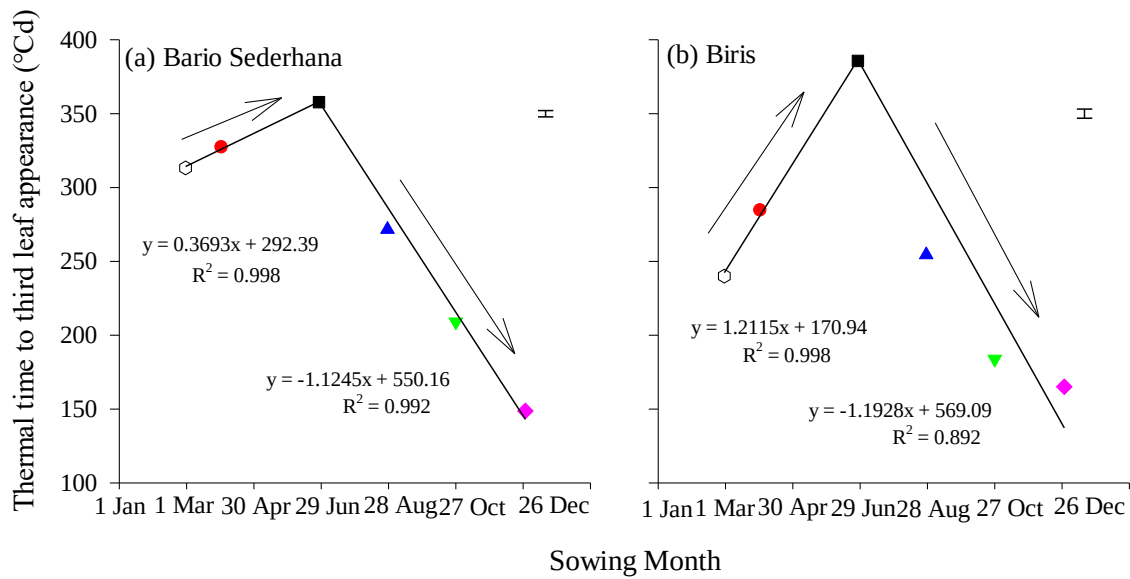


Figure 4.7: Thermal time to third leaf appearance in response to sowing dates for (a) Bario Sederhana and (b) Biris rice sown at Universiti Malaysia Sarawak. (●) 1 April, (■) 27 June, (▲) 27 August, (▼) 27 October, (◆) 28 December and (○) 28 February. Note: Arrows direction indicate increasing and decreasing thermal time to third leaf appearance in relation to sowing time. Error bars are maximum standard error of the mean for thermal time requirement. Thermal time used soil temperature ($T_b = 10\text{ }^{\circ}\text{C}$) and calculated from sowing.

4.2.3 Phyllochron

Initially, Bario Sederhana and Biris rice were sown on six sowing dates (Table 3.2). However, due to Covid-19 restriction movement from March 2020 – October 2021, data collection for sowing dates on 28th December 2020 and 28th February 2021 were limited thus resulting in only four sowing dates being collected. Therefore, only data for April, June, August, and October were available for phyllochron and further data analyses. The production of leaves on the main stem increased with thermal time accumulation (Figure 4.8). The inverse of the slope from the linear relationship determined the rate of leaf production or phyllochron. The phyllochron in calendar days and thermal time were affected by the sowing date and landrace interaction ($P = 0.01$) (Table 4.4 and Table 4.5). For

example, the longest phyllochron was observed for crops sown in April. Specifically, the phyllochron of Bario Sederhana declined quadratically following each successive sowing date with the shortest phyllochron of 467 °Cd when seeds were sown on the month of October (Figure 4.9). Meanwhile, the phyllochron of Biris showed a trend where it started to decline from April towards June before increasing from June towards August until October. The phyllochron of Biris was the shortest (495 °Cd) for crops sown in June.

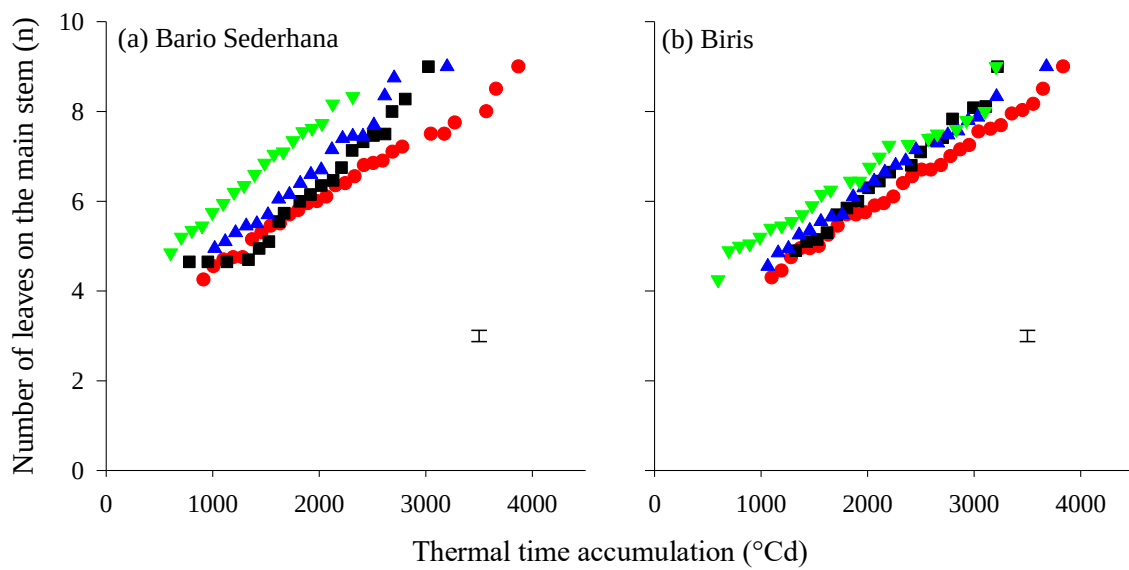


Figure 4.8: Number of leaves on the main stem against thermal time accumulation for (a) Bario Sederhana and (b) Biris rice sown on four dates at Universiti Malaysia Sarawak. (●) 1 April, (■) 27 June, (▲) 27 August, and (▼) 27 October. Note: Thermal time calculation used soil temperature. Error bars represent the maximum standard error for the final number of leaves.

Table 4.4: Phyllochron of Bario Sederhana and Biris rice sown on four dates in pots at Universiti Malaysia Sarawak.

Sowing Date (SD)	Phyllochron (days/leaf)		
	Bario Sederhana	Biris	Mean (SD)
01/04/2019	29.2	28.3	28.7 ^a
27/06/2019	21.6	20.2	20.9 ^b
27/08/2019	19.6	24.1	21.8 ^b
27/10/2020	19.8	26.4	23.1 ^b
Mean (Landrace)	22.5 ^a	24.7 ^b	
	SD	Landrace	SD*Landrace
P-value	<.0001	0.026	0.0104
Tukey HSD (5%)	3.60	1.90	6.10

Within each column and row, means with the same letters (superscript) are not significantly different ($P>0.05$) according to Tukey HSD (5%) test. HSD, Honestly Significant Difference.

Table 4.5: Thermal time requirement for Phyllochron of Bario Sederhana and Biris rice sown on four dates in pots at Universiti Malaysia Sarawak.

Sowing Date (SD)	Phyllochron ($^{\circ}\text{Cd}/\text{leaf}$)		
	Bario Sederhana	Biris	Mean (SD)
01/04/2019	646	631	639 ^a
27/06/2019	524	495	510 ^b
27/08/2019	490	594	542 ^b
27/10/2020	467	617	542 ^b
Mean (Landrace)	532 ^a	584 ^b	
	SD	Landrace	SD*Landrace
P-value	0.0018	0.0222	0.016
Tukey HSD (5%)	84.1	44.4	142.6

Within each column and row, means with the same letters (superscript) are not significantly different ($P>0.05$) according to Tukey HSD (5%) test. HSD, Honestly Significant Difference.

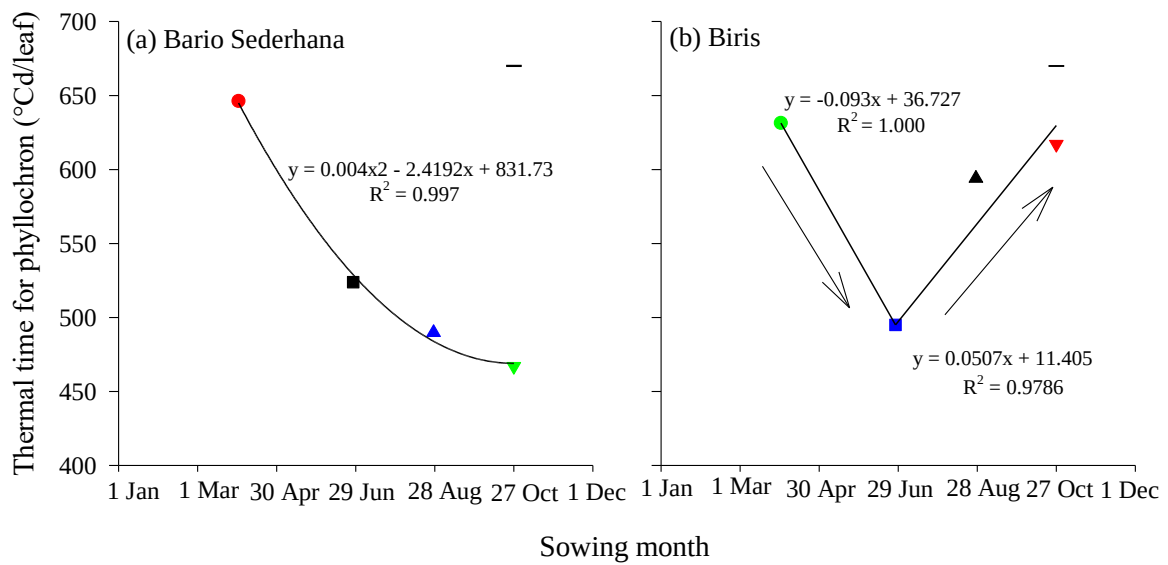


Figure 4.9: Phyllochron of (a) Bario Sederhana and (b) Biris rice sown on four dates at Universiti Malaysia Sarawak. (●) 1 April, (■) 27 June, (▲) 27 August, and (▼) 27 October. Note: Arrows direction indicate increasing and decreasing thermal time for phyllochron in relation to sowing time. Error bars are maximum standard error of the mean for thermal time requirement. Thermal time used soil temperature ($T_b = 10\text{ }^{\circ}\text{C}$) and calculated from sowing.

4.2.4 Total Number of Leaves on the Main Stem

The number of leaves on the main stem was recorded until the plant has produced a flag leaf, which indicates the end of vegetative development. The total number of leaves on the main stem was not affected by sowing dates and landrace ($P > 0.05$) (Table 4.6). Irrespective of the landrace and the sowing date, both Bario Sederhana and Biris rice required the same number of leaves to flower which is about 8.5 leaves.

Table 4.6: Total number of leaves on the main stem of Bario Sederhana and Biris rice sown on four dates in pots at Universiti Malaysia Sarawak.

Sowing Date (SD)	Total number of leaves on the main stem (n)		
	Bario Sederhana	Biris	Mean (SD)
01/04/2019	8.2	9.0	8.6
27/06/2019	8.8	8.4	8.6
27/08/2019	8.7	8.3	8.5
27/10/2020	8.3	8.3	8.3
Mean (Landrace)	8.5	8.5	
	SD	Landrace	SD*Landrace
P-value	0.504	0.919	0.073
Tukey HSD (5%)	0.71	0.38	1.21

HSD, Honestly Significant Difference.

4.2.5 Flag Leaf

Time to flag leaf production quantified using calendar days varied ($P=0.0004$) between landraces (Table 4.7) with longer days taken in Biris (137.5 days) compared with Bario Sederhana (118.8 days). However, when time to flag leaf was quantified using thermal time, there was no significant differences ($P>0.05$) between the landraces (Table 4.8). Thermal time (Tt) requirement for production of flag leaf was affected by sowing dates ($P<0.001$) with the highest Tt for April sown crops but this decreased systematically as sowing months progressed from June towards October (Figure 4.10).

Table 4.7: Time to flag leaf of Bario Sederhana and Biris rice sown on four dates in pots at Universiti Malaysia Sarawak.

Sowing Date (SD)	Time to flag leaf (Days)		
	Bario Sederhana	Biris	Mean (SD)
01/04/2019	143.6	166.0	154.8 ^a
27/06/2019	124.7	136.2	127.6 ^b
27/08/2019	112.4	130.6	124.3 ^b
27/10/2020	94.6	117.3	105.9 ^c
Mean (Landrace)	118.8 ^b	137.5 ^a	
	SD	Landrace	SD*Landrace
P-value	<0.0001	0.0004	0.4703
Tukey HSD (5%)	18.01	9.51	30.56

Within each column and row, means with the same letters (superscript) are not significantly different ($P>0.05$) according to Tukey HSD (5%) test. HSD, Honestly Significant Difference.

Table 4.8: Thermal time to flag leaf of Bario Sederhana and Biris rice sown on four dates in pots at Universiti Malaysia Sarawak.

Sowing Date (SD)	Thermal time to flag leaf (°Cd)		
	Bario Sederhana	Biris	Mean (SD)
01/04/2019	3787	4315	4051 ^a
27/06/2019	3092	3180	3136 ^b
27/08/2019	2539	3034	2786 ^{bc}
27/10/2020	2282	2857	2569 ^c
Mean (Landrace)	2925	3346	
	SD	Landrace	SD*Landrace
P-value	0.0004	0.3317	0.2313
Tukey HSD (5%)	885.3	467.5	1503.5

Within each column, means with the same letters (superscript) are not significantly different ($P>0.05$) according to Tukey HSD (5%) test. HSD, Honestly Significant Difference. Note: Thermal time used air temperature ($T_b = 10\text{ }^{\circ}\text{C}$) and calculated from sowing.

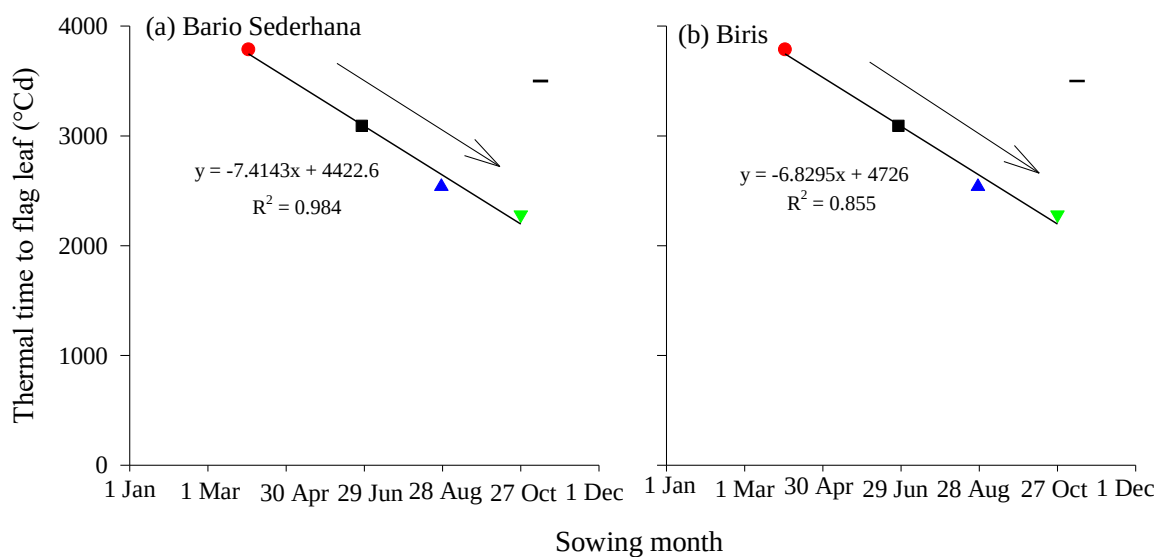


Figure 4.10: Thermal time to flag leaf appearance (°Cd) in response to sowing dates for (a) Bario Sederhana and (b) Biris rice sown at Universiti Malaysia Sarawak. (●) 1 April, (■) 27 June, (▲) 27 August, and (▼) 27 October. Note: Arrows direction indicate decreasing thermal time to flag leaf (°Cd) in relation to sowing time. Error bars are maximum standard error of the mean for thermal time requirement. Thermal time used air temperature ($T_b = 10\text{ }^{\circ}\text{C}$) and calculated from sowing.

4.2.6 Plant Height and Basal Internodes

Plant height was recorded when the crops has produced flag leaf. Plant height varied ($P < 0.005$) among sowing dates (Table 4.9) with the highest plant height recorded in crops sown on October (166.4 cm). However, there was no significant differences ($P > 0.05$) for plant height between the landraces. Both landraces had similar mean plant height which was about ~162 cm.

Table 4.9: The plant height at flag leaf stage of Bario Sederhana and Biris rice sown on four dates in pots at Universiti Malaysia Sarawak.

Sowing Date (SD)	Plant height (cm)		
	Bario Sederhana	Biris	Mean (SD)
01/04/2019	158.0	160.3	159.1 ^c
27/06/2019	159.9	159.9	159.9 ^c
27/08/2019	163.2	162.4	162.8 ^b
27/10/2020	164.8	168.0	166.4 ^a
Mean (Landrace)	161.4	162.6	
	SD	Landrace	SD*Landrace
P-value	<0.0001	0.084	0.128
Tukey HSD (5%)	2.56	1.35	4.34

Within each column and row, means with the same letters (superscript) are not significantly different ($P>0.05$) according to Tukey HSD (5%) test. HSD, Honestly Significant Difference.

Data collection for the length of basal internodes were limited to only two sowing dates due to the Covid-19 restriction movement. Based on Table 4.10, the length of basal internodes was affected by the sowing date and internode interaction ($P<0.01$). All three basal internodes of Bario Sederhana were longer in October compared with April sown crops. In contrast, the 1st and 2nd basal internodes of Biris rice plants grown in October and April had similar length, and only the 3rd internode length was different.

Table 4.10: Basal internode length of Bario Sederhana rice sown on four dates in pots at Universiti Malaysia Sarawak.

Landrace	Sowing Date (SD)	Basal internode length (cm)			Mean (SD)
		1 st	2 nd	3 rd	
Bario Sederhana	01/04/2019	5.3	6.5	8.4	6.7 ^b
	27/10/2020	6.1	10.1	14.5	10.2 ^a
	Mean (Internode)	5.7 ^c	8.3 ^b	11.4 ^a	
		SD	Internode	SD*Internode	
	P-value	<0.0001	<0.0001	0.003	
	Tukey HSD (5%)	1.11	1.65	2.91	
Biris	01/04/2019	4.6	8.4	9.1	7.4
	27/10/2020	4.5	7.4	15.1	9.0
	Mean (Internode)	4.5 ^c	7.9 ^b	12.1 ^a	
		SD	Internode	SD*Internode	
	P-value	0.786	<0.0001	0.0002	
	Tukey HSD (5%)	1.20	1.80	3.16	

Within each column and row, means with the same letters (superscript) are not significantly different ($P>0.05$) according to Tukey HSD (5%) test. HSD, Honestly Significant Difference.

4.2.7 Calendar Days from Time of Sowing to Flowering

Calendar days from sowing to flowering varied ($P<0.001$) from 124.4 days to 211.9 days across sowing dates by landraces (Table 4.11). The crops similarly took between 2980 and 5319 °Cd to reach their flowering stage. When thermal time (Tt) to flowering stage was analysed in relation with sowing month, it exhibited a systematic variation with decreased Tt requirement from April towards October (Figure 4.11). Tt requirement for flowering in Bario Sederhana decreased by 8 °Cd per day whereas Biris decreased by 6 °Cd per day.

Table 4.11: Time to flowering for Bario Sederhana and Biris rice sown on four dates in pots at Universiti Malaysia Sarawak.

Landrace	Sowing date	Time to flowering	
		Calendar days	Thermal time (°Cd)
Bario Sederhana	01/04/2019	183.9 ^a	4790 ^a
	27/06/2019	149.5 ^b	3564 ^b
	27/08/2019	149.6 ^b	3405 ^b
	27/10/2020	124.4 ^c	2980 ^c
	P-value	< 0.0001	< 0.0001
	S.E.M.	5.66	177.0
	CV (%)	14.90	19.3
Biris	01/04/2019	211.9 ^a	5319 ^a
	27/06/2019	155.5 ^{bc}	3649 ^b
	27/08/2019	167.5 ^b	3742 ^b
	27/10/2020	146.6 ^c	3564 ^b
	P-value	< 0.0001	<0.001
	S.E.M.	6.84	193.0
	CV (%)	16.05	18.93

Within each column, means with the same letters (superscript) are not significantly different ($P>0.05$) according to Fisher's Least Significant Difference test. SEM, Standard Error of the Mean; CV, coefficient of variation. Note: Thermal time used air temperature ($T_b = 10\text{ }^{\circ}\text{C}$) and calculated from sowing.

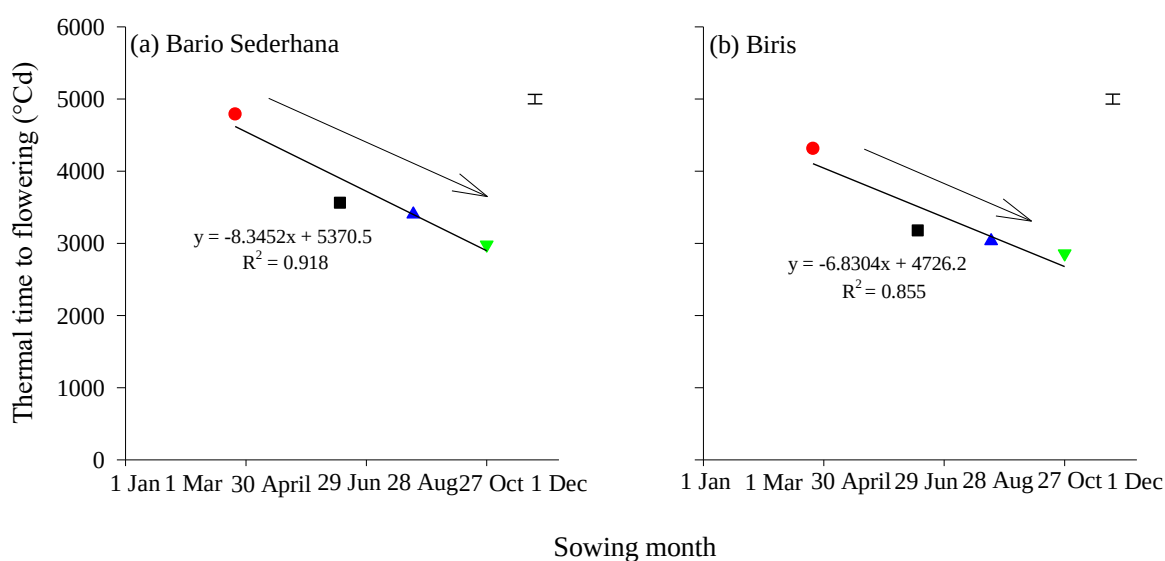


Figure 4.11: Thermal time to flowering (°Cd) in response to sowing dates for (a) Bario Sederhana and (b) Biris rice sown on four dates in pots at Universiti Malaysia Sarawak. (●) 1 April, (■) 27 June, (▲) 27 August, and (▼) 27 October. Note: Arrows direction indicate decreasing thermal time to flowering (°Cd) in relation to sowing time. Error bars are maximum standard error of the mean for thermal time requirement. Thermal time used air temperature ($T_b = 10\text{ °C}$) and calculated from sowing.

4.2.8 Grain Development

Grain development for Bario Sederhana varied with sowing dates ($P < 0.05$) only during hard grain and ripe grain stages (Table 4.12). For this landrace, rice grain took an average of 23.3 days from flowering to become ripened for crops sown between April and August. In contrast, October sown crops required a total of 32.6 days for grain ripening. Similarly, time to grain development for Biris landrace was longer ($P < 0.001$) for crops sown in October (30.2 days), compared with earlier sowing months. When quantified in thermal time, Bario Sederhana crops planted from April to August required an average of 529 °Cd for grains to ripe but the duration was prolonged to 818 °Cd for crops sown on October (Table 4.13). Meanwhile, thermal time for each stage of grain development increased with successive sowing dates in Biris landrace. For example, thermal time for grain ripening in

April sown crops was 472 °Cd but this increased up to 784 °Cd when sowing was delayed into October.

Table 4.12: Calendar days to grain development stages of Bario Sederhana and Biris rice sown on four dates in pots at Universiti Malaysia Sarawak.

Landrace	Sowing date	Grain development stages (Calendar days)			
		Milky	Milky dough	Hard grain	Ripe grain
Bario Sederhana	01/04/2019	8.3 ^{ab}	10.0 ^{ab}	16.2 ^b	23.9 ^b
	27/06/2019	7.7 ^{ab}	9.4 ^{ab}	16.6 ^b	22.8 ^b
	27/08/2019	7.0 ^b	8.2 ^b	15.3 ^b	23.3 ^b
	27/10/2020	11.7 ^a	13.3 ^a	21.2 ^a	32.6 ^a
	P-value	0.127	0.125	0.043	0.001
	S.E.M.	0.78	0.79	0.86	1.20
	CV (%)	35.67	30.76	19.82	18.68
Biris	01/04/2019	8.3 ^b	9.7 ^b	17.4 ^b	25.3 ^b
	27/06/2019	7.0 ^c	9.3 ^{bc}	16.4 ^b	22.7 ^c
	27/08/2019	7.7 ^c	9.0 ^c	16.0 ^b	22.5 ^c
	27/10/2020	9.7 ^a	11.0 ^a	19.9 ^a	30.2 ^a
	P-value	< 0.0001	< 0.0001	0.001	< 0.0001
	S.E.M.	0.23	0.21	0.45	0.84
	CV (%)	10.94	8.74	10.39	13.3

Within each column, means with the same letters (superscript) are not significantly different ($P>0.05$) according to Fisher's Least Significant Difference test. SEM, Standard Error of the Mean; CV, coefficient of variation. Calendar days were calculated from flowering.

Table 4.13: Thermal time to grain development stages of Bario Sederhana and Biris rice sown on four dates in pots at Universiti Malaysia Sarawak.

Landrace	Sowing date	Grain development stages (°Cd)			
		Milky	Milky dough	Hard grain	Ripe grain
Bario Sederhana	01/04/2019	193 ^{ab}	235 ^{ab}	369 ^b	520 ^b
	27/06/2019	163 ^b	197 ^b	375 ^b	521 ^b
	27/08/2019	172 ^b	198 ^b	371 ^b	545 ^b
	27/10/2020	286 ^a	318 ^a	521 ^a	818 ^a
	P-value	0.111	0.1	0.019	< 0.0001
	S.E.M.	20.4	20.2	22.5	35.5
	CV (%)	40.2	34.2	22.0	23.6
Biris	01/04/2019	144 ^c	168 ^c	321 ^c	472 ^c
	27/06/2019	157 ^c	202 ^b	367 ^{bc}	509 ^{bc}
	27/08/2019	182 ^b	207 ^b	380 ^b	526 ^b
	27/10/2020	248 ^a	274 ^a	514 ^a	784 ^a
	P-value	< 0.0001	< 0.0001	< 0.0001	< 0.0001
	S.E.M.	10.8	10.4	19.8	32.3
	CV (%)	23.7	19.7	20.1	22.6

Within each column, means with the same letters (superscript) are not significantly different ($P>0.05$) according to Fisher's Least Significant Difference test. SEM, Standard Error of the Mean; CV, coefficient of variation. Note: Thermal time used air temperature ($T_b = 10\text{ }^{\circ}\text{C}$) and calculated from flowering.

4.2.9 Panicle Length

Irrespective of landraces, the panicle length varied ($P<0.005$) across sowing dates (Table 4.14) with the long mean panicle produced in October (27.2 cm) and April (24.6 cm) crops and the shortest mean panicle length of 20.8 cm was produced by crops planted on August.

Table 4.14: The panicle length of Bario Sederhana and Biris rice sown on four dates in pots at Universiti Malaysia Sarawak.

Sowing Date (SD)	Panicle length (cm)		
	Bario Sederhana	Biris	Mean (SD)
01/04/2019	25.5	23.6	24.6 ^{ab}
27/06/2019	24.4	23.2	23.8 ^b
27/08/2019	22.1	19.5	20.8 ^c
27/10/2020	27.2	27.1	27.2 ^a
Mean (Landrace)	24.8	23.4	
	SD	Landrace	SD*Landrace
P-value	0.001	0.134	0.808
Tukey HSD (5%)	3.69	1.95	6.27

Within each column, means with the same letters (superscript) are not significant ($P>0.05$) according to Tukey HSD (5%) test. HSD, Honestly Significant Difference.

4.2.10 Percentage of Filled Spikelets

The percentage of filled spikelets varied between landraces ($P<0.05$) with highest filled spikelets percentage in Bario Sederhana (64.8%) compared with Biris (52.3%) (Table 4.15). The variation among sowing dates was significant at $P=0.002$ with the lowest percentage filled spikelets observed for crops sown on August (37.1%).

Table 4.15: The percentage of filled spikelets of Bario Sederhana and Biris rice sown on four dates in pots at Universiti Malaysia Sarawak.

Sowing Date (SD)	Filled spikelets (%)		
	Bario Sederhana	Biris	Mean (SD)
01/04/2019	61.3	55.0	58.1 ^a
27/06/2019	69.2	69.7	69.4 ^a
27/08/2019	46.6	27.7	37.1 ^b
27/10/2020	82.2	56.9	69.5 ^a
Mean (Landrace)	64.8 ^a	52.3 ^b	
	SD	Landrace	SD*Landrace
P-value	0.002	0.047	0.425
Tukey HSD (5%)	23.27	12.29	39.50

Within each column and row, means with the same letters (superscript) are not significant ($P>0.05$) according to Tukey HSD (5%) test. HSD, Honestly Significant Difference.

4.2.11 Total Spikelets per Panicle

The total spikelets/panicle varied ($P < 0.05$) across sowing dates with the highest mean number observed in crops sown on October (204.5 spikelets/panicle) in comparison with the other three sowing dates (Table 4.16). However, there were no significant differences ($P > 0.05$) between the landraces.

Table 4.16: The total spikelets/panicle of Bario Sederhana and Biris rice sown on four dates in pots at Universiti Malaysia Sarawak.

Sowing Date (SD)	Total spikelets/panicle (n)		
	Bario Sederhana	Biris	Mean (SD)
01/04/2019	112.0	105.1	108.5 ^b
27/06/2019	124.1	119.9	122.0 ^b
27/08/2019	107.3	90.1	98.7 ^b
27/10/2020	212.5	196.4	204.5 ^a
Mean (Landrace)	139.0	127.9	
	SD	Landrace	SD*Landrace
P-value	< 0.001	0.302	0.962
Tukey HSD (5%)	41.07	21.69	69.7

Within each column, means with the same letters (superscript) are not significant ($P > 0.05$) according to Tukey HSD (5%) test. HSD, Honestly Significant Difference.

4.2.12 Filled Grain Weight per Pot

The mean filled grain weight per pot varied ($P < 0.001$) between landraces (Table 4.17) with higher grain weight for Bario Sederhana (34.2 g/pot) compared with Biris (18.8 g/pot). In addition, differences among sowing dates were significant and ranged from 17.8 g/pot in crops sown on August to 35.0 g/pot for crops sown on October.

Table 4.17: The filled grain weight (g/pot) of Bario Sederhana and Biris rice sown on four dates in pots at Universiti Malaysia Sarawak.

Sowing Date (SD)	Filled grain weight (g/pot)		
	Bario Sederhana	Biris	Mean (SD)
01/04/2019	39.6	18.0	28.8 ^{ac}
27/06/2019	26.5	22.2	24.3 ^{ac}
27/08/2019	22.9	12.6	17.8 ^{bc}
27/10/2020	47.8	22.3	35.0 ^a
Mean (Landrace)	34.2 ^a	18.8 ^b	
	SD	Landrace	SD*Landrace
P-value	0.0095	0.0001	0.1178
Tukey HSD (5%)	13.01	6.87	22.08

Within each column and row, means with the same letters (superscript) are not significantly different ($P>0.05$) according to Tukey HSD (5%) test. HSD, Honestly Significant Difference. Pot surface area = 0.056 m².

4.3 Field Experiment at Pusat Penyelidikan Tumbuhan (PPT), UNIMAS

4.3.1 Plant Populations per Subplot

The plant populations per subplot were not affected by sowing dates and landraces ($P>0.05$) (Table 4.18). Irrespective of the landraces and sowing dates, both Bario Sederhana and Biris rice have the same mean number of plant populations per subplot which is 26 plants on an average basis.

Table 4.18: The plant populations per subplot of Bario Sederhana and Biris rice sown on four dates in field at PPT Universiti Malaysia Sarawak.

Sowing Date (SD)	Plant populations/subplot (n)		
	Bario Sederhana	Biris	Mean (SD)
15/04/2019	21.8	28.5	25.1
27/06/2019	24.8	23.3	24.0
27/08/2019	41.3	33.8	37.5
27/10/2020	21.8	17.3	19.5
Mean (Landrace)	27.4	25.7	
	SD	Landrace	SD*Landrace
P-value	0.062	0.718	0.725
Tukey HSD (5%)	18.02	9.51	30.58

HSD, Honestly Significant Difference. Note: The subplot measures 2 m².

4.3.2 Plant Height and Basal Internodes

The plant height varied ($P=0.027$) across sowing dates with the lowest height observed in April sown crops (154.0 cm) compared with later sowing months (~163.9 cm) (Table 4.19). However, there was no significant difference ($P>0.05$) between landraces (Table 4.19) which indicates that both Bario Sederhana and Biris had an average height of ~161.4 cm.

Table 4.19: The plant height at flowering of Bario Sederhana and Biris rice sown on four dates in field at PPT, Universiti Malaysia Sarawak.

Sowing Date (SD)	Plant height (cm)		
	Bario Sederhana	Biris	Mean (SD)
15/04/2019	149.8	158.1	154.0 ^b
27/06/2019	162.1	163.4	162.8 ^a
27/08/2019	161.6	162.5	162.1 ^a
27/10/2020	165.5	168.0	166.8 ^a
Mean (Landrace)	159.7	163.0	
	SD	Landrace	SD*Landrace
P-value	0.027	0.257	0.768
Tukey HSD (5%)	11.01	5.81	18.68

Within each column, means with the same letters (superscript) are not significantly different ($P>0.05$) according to Tukey HSD (5%) test. HSD, Honestly Significant Difference.

In both landraces, the length of basal internodes varied ($P<0.05$) among the position of internodes with the longest length observed on the third internode and the shortest length on the first internode (Table 4.20). Differences between the two sowing dates were significant ($P<0.05$) as well with length of internodes for crops sown in April and October.

Table 4.20: Basal internode length of Bario Sederhana and Biris rice sown on two dates in field at PPT, Universiti Malaysia Sarawak.

Landrace	Sowing Date	Basal internode length (cm)			Mean (SD)
	(SD)	1 st	2 nd	3 rd	
Bario Sederhana	15/04/2019	8.1	8.1	9.4	8.5 ^a
	27/10/2020	7.0	8.1	9.1	8.1 ^b
	Mean (Internode)	7.6 ^b	8.1 ^b	9.3 ^a	
		SD	Internode	SD*Internode	
	P-value	0.032	<0.001	0.107	
Biris	Tukey HSD (5%)	0.40	0.59	1.02	
	15/04/2019	8.3	9.4	9.4	9.0 ^a
	27/10/2020	7.5	8.8	9.1	8.5 ^b
	Mean (Internode)	7.9 ^b	9.1 ^a	9.3 ^a	
		SD	Internode	SD*Internode	
	P-value	0.002	<0.001	0.506	
	Tukey HSD (5%)	0.35	0.5	0.89	

Within each column and row, means with the same letters (superscript) are not significantly different ($P>0.05$) according to Tukey HSD (5%) test. HSD, Honestly Significant Difference.

4.3.3 Flag Leaf

Mean time to flag leaf production quantified using calendar days varied across sowing dates ($P=0.012$) (Table 4.21) with the longer days taken for crops sown on April (149.1 days) compared with crops sown on June and October (128.4 days).

Table 4.21: Time to flag leaf of Bario Sederhana and Biris rice sown on four dates in field at PPT, Universiti Malaysia Sarawak.

Sowing Date (SD)	Time to flag leaf (Days)		
	Bario Sederhana	Biris	Mean (SD)
15/04/2019	149.0	149.3	149.1 ^a
27/06/2019	126.9	131.4	129.2 ^b
27/08/2019	141.8	123.4	132.6 ^{ab}
27/10/2020	129.4	125.7	127.6 ^b
Mean (Landrace)	136.8	132.4	
	SD	Landrace	SD*Landrace
P-value	0.012	0.362	0.355
Tukey HSD (5%)	18.24	9.63	30.95

Within each column and row, means with the same letters (superscript) are not significantly different ($P>0.05$) according to Tukey HSD (5%) test. HSD, Honestly Significant Difference.

4.3.4 Time to Flowering

Mean calendar days to flowering differed with sowing dates ($P < 0.001$) (Table 4.22) with 165.1 days required for crops sown on April compared with 145 -150 days for later sown crops.

Table 4.22: Time to flowering of Bario Sederhana and Biris rice sown on four dates in field at PPT, Universiti Malaysia Sarawak.

Sowing Date (SD)	Time to flowering (Days)		
	Bario Sederhana	Biris	Mean (SD)
15/04/2019	165.6	164.6	165.1 ^a
27/06/2019	145.6	147.2	146.4 ^c
27/08/2019	150.2	149.5	149.9 ^b
27/10/2020	145.7	144.3	145.0 ^c
Mean (Landrace)	151.8	151.4	
	SD	Landrace	SD*Landrace
P-value	<0.0001	0.703	0.629
Tukey HSD (5%)	3.42	1.81	5.81

HSD, Honestly Significant Difference. Time to flowering was calculated from seedling emergence.

4.3.5 Panicles per Subplot

The mean number of panicles per subplot was higher ($P = 0.04$) for crops sown in October (32 panicles) compared with the other three sowing months (~23 panicles) regardless of the landraces (Table 4.23).

Table 4.23: The number of panicles per subplot of Bario Sederhana and Biris rice sown on four dates in field at PPT, Universiti Malaysia Sarawak.

Sowing Date (SD)	Number of panicles/subplot (n)		
	Bario Sederhana	Biris	Mean (SD)
15/04/2019	23.3	22.5	22.9 ^b
27/06/2019	22.5	21.0	21.8 ^b
27/08/2019	24.8	24.8	24.8 ^b
27/10/2020	34.0	29.5	31.8 ^a
Mean (Landrace)	26.1	24.4	
	SD	Landrace	SD*Landrace
P-value	0.04	0.506	0.925
Tukey HSD (5%)	9.76	5.15	16.56

Within each column, means with the same letters (superscript) are not significant ($P>0.05$) according to Tukey HSD (5%) test. HSD, Honestly Significant Difference. Note = The subplot measures 2 m².

4.3.6 Panicle Length

The length of rice panicles showed variation with sowing dates ($P<0.001$) (Table 4.24). Specifically, the longest mean panicle was produced by crops sown in October (29.0 cm) followed by April (25.9 cm) and lastly by June and August (~21.4 cm). There was no significant difference between the landraces.

Table 4.24: The panicle length of Bario Sederhana and Biris rice sown on four dates in field at PPT, Universiti Malaysia Sarawak.

Sowing Date (SD)	Panicle length (cm)		
	Bario Sederhana	Biris	Mean (SD)
15/04/2019	26.8	25.1	25.9 ^b
27/06/2019	21.2	21.2	21.2 ^c
27/08/2019	22.4	20.6	21.5 ^c
27/10/2020	29.1	29.0	29.0 ^a
Mean (Landrace)	24.8	24.0	
	SD	Landrace	SD*Landrace
P-value	<0.0001	0.3	0.771
Tukey HSD (5%)	3.22	1.70	5.47

Within each column, means with the same letters (superscript) are not significant ($P>0.05$) according to Tukey HSD (5%) test. HSD, Honestly Significant Difference.

4.3.7 Percentage of Filled Spikelets

The percentage of filled spikelets was not affected by sowing dates and landraces ($P>0.05$) (Table 4.25). Irrespective of the landrace and sowing date, Bario Sederhana and Biris produced similar mean percentage of filled spikelets which was about 60%.

Table 4.25: The percentage of filled spikelets of Bario Sederhana and Biris rice sown on four dates in field at PPT, Universiti Malaysia Sarawak.

Sowing Date (SD)	Filled spikelets (%)		
	Bario Sederhana	Biris	Mean (SD)
15/04/2019	70.8	56.6	63.7
27/06/2019	52.3	51.7	52.0
27/08/2019	44.8	61.6	53.2
27/10/2020	68.7	73.3	71.0
Mean (Landrace)	59.13	60.77	
	SD	Landrace	SD*Landrace
P-value	0.072	0.77	0.284
Tukey HSD (5%)	21.65	11.43	36.74

HSD, Honestly Significant Difference.

4.3.8 Total Spikelets per Panicle

The total number of spikelets per panicle were affected by the sowing date and landrace interaction ($P=0.007$) (Table 4.26). In particular, Bario Sederhana produced the least total amount of spikelets for crops sown in June (99 spikelets/panicle) whereas Biris yielded the maximum of 234 spikelets/panicle when crops were sown in October. There was no significant difference for the rice planted in April, June and August.

Table 4.26: The total spikelets per panicle of Bario Sederhana and Biris rice sown on four dates in field at PPT, Universiti Malaysia Sarawak.

Sowing Date (SD)	Total spikelets/panicle (n)		
	Bario Sederhana	Biris	Mean (SD)
15/04/2019	126.6	117.0	121.8 ^b
27/06/2019	99.2	109.7	104.5 ^b
27/08/2019	152.5	104.8	128.7 ^b
27/10/2020	171.8	233.8	202.8 ^a
Mean (Landrace)	137.54	141.32	
	SD	Landrace	SD*Landrace
P-value	<0.0001	0.712	0.007
Tukey HSD (5%)	39.56	20.89	67.14

Within each column, means with the same letters (superscript) are not significant ($P>0.05$) according to Tukey HSD (5%) test. HSD, Honestly Significant Difference.

4.3.9 Filled Grain Weight per Subplot

Irrespective of rice landraces, the filled grain weight per subplot varied across sowing dates ($P=0.013$) (Table 4.27) with significantly higher grain weight of 74.0 g/2m² in crops sown on October in comparison to an average of 29.5 g/2m² obtained from earlier sowing months.

Table 4.27: The filled grain weight per subplot of Bario Sederhana and Biris rice sown on four dates in field at PPT, Universiti Malaysia Sarawak.

Sowing Date (SD)	Filled grain weight (g/subplot)		
	Bario Sederhana	Biris	Mean (SD)
15/04/2019	40.1	29.9	35.0 ^b
27/06/2019	18.5	23.5	21.0 ^b
27/08/2019	30.6	34.2	32.4 ^b
27/10/2020	54.5	93.5	74.0 ^a
Mean (Landrace)	35.9	45.3	
	SD	Landrace	SD*Landrace
P-value	0.013	0.443	0.454
Tukey HSD (5%)	39.49	20.86	67.02

Within each column, means with the same letters (superscript) are not significant ($P>0.05$) according to Tukey HSD (5%) test. HSD, Honestly Significant Difference. Note: The subplot measures 2 m².

CHAPTER 5

DISCUSSION

5.1 Germination

A two piece 'broken-stick' regression model was used to describe germination response towards temperature (Figure 4.4). The germination rate increased linearly with increasing temperature until it reached an optimum. Subsequently, the germination rate decline as temperature shifted further from the species-specific optimum with minimal differences between the landraces. Regression analyses estimated T_b of 9.5-11.6 °C, T_{opt} of 32-33 °C and T_{max} of 43.5 °C for Bario Sederhana and Biris rice landraces (Table 4.1). These values were consistent with those reported for other rice cultivars (Ali et al., 2003; Tilebeni et al., 2012). The T_t requirements for germination of Bario Sederhana and Biris were 54-61 °Cd at sub-optimal and 27-29 °Cd at supra-optimal temperatures. In both landraces, germination rate at 40 °C diverged from the linear range and therefore excluded from analysis. Such an extreme temperature was beyond their thermal optima which approached toward the upper end of the critical temperature. This means that seeds either germinated quickly or died, thus resulting in an overestimation of germination rate from a small population of survived seeds. For example, Bario Sederhana took three days to germinate at 40 °C (Figure 4.3) but the seed population that successfully germinated was below 35% (Figure 4.2). An exception was observed in Biris which had 95% of its seed populations that germinated within two days at 40 °C. The capability of Biris landrace to germinate at high temperature may be related to its cultivar origin from lowland of Simunjan, Sarawak where air temperatures often exceeded 36 °C, raising temperatures on the soil surface. Similarly, 13-27 % of Bario Sederhana seed populations was able to germinate at lower temperatures

between 12.5 and 15 °C (Figure 4.2) despite longer time requirement (Figure 4.1a) because of the cultivar's origin from the Kelabit Highlands of Ba'Kelalan, Sarawak where average air temperature is around 19-22 °C. At 30 °C, Bario Sederhana had 93% seed germinated meanwhile at 27.5 °C, Biris had 100% seed germinated. The results of this study showed that temperature had a significant impact on rice establishment and served as the primary driver of development. In an incubator set at 22.5 °C, the final germination percentage of Bario Sederhana rice was 93% (Figure 4.2). This is also the typical soil temperature in Ba'Kelalan, Sarawak's Kelabit Highlands during the month of September when rice is planted. Therefore, to optimise plant population for the best yield, sowing rate might be increased by 7%. The thermal range of common weed species in Malaysian rice fields, such as *Echinochloa crus-galli* (Guillemin et al., 2013), *Echinochloa colona* (Elahifard & Mijani, 2014), *Leptochloa chinensis* (Benvenuti et al., 2004), and *Fimbristylis miliacea* (Begum et al., 2008), was discovered to overlap with the cardinal temperatures for germination of Bario Sederhana and Biris. Due to their similar thermal responses, these will most likely cause weed infestation-related issues, which justifies the requirement for pre-emergence weed control in rice fields.

The thermal time approach provides a uniform measurement of plant development because it summarises each temperature response within the linear range into a single coefficient that can be applied over a wide range of climatic conditions. For example, thermal time estimated for germination of Biris landrace was 54 °Cd for temperatures within the sub-optimal range (Table 4.1), hence at soil temperature of 27 °C, the seeds could be expected to germinate in two days ($54\text{ °Cd} \div 27\text{ °C} = 2\text{ d}$) compared with 3 days at 18 °C ($54\text{ °Cd} \div 18\text{ °C} = 3\text{ d}$). The linear model gave a satisfactory cardinal estimate based on extrapolation of the regression line between germination rate and temperature. It gave a simple calculation

of development rate as a function of temperature. However, particular attention needs to be addressed when using linear method in estimating T_b because a regression line can only fit to a limited set of temperature data. Commonly, the response of development rate towards temperature is practically exponential with a slow curve at temperatures near the T_b (Bonhomme, 2000). When linear extrapolation was made to intercept the x-axis, it excluded thermal responses at the exponential slow curve thus, resulted in a higher estimation of T_b (Nori et al., 2014). It is therefore important to understand that the estimated T_b based on regression analysis is merely a statistical value. In reality, the actual (physiological) T_b for which no development occur is much lower than the calculated value. For Bario Sederhana, the T_b from linear extrapolation was 11.6 °C but at 12.5 °C there was still about 13% of seeds germinated which suggests that there could likely be some germination occurring at the estimated T_b . Because of this limitation, the 95% confidence interval was used to determine whether the estimated T_b was different from 10 °C. The justification of using 10 °C as an indicator for the minimum T_b was based on numerous works reported on tropical crops which includes rice (Angus et al., 1981; Yoshida, 1981; Schultink et al., 1987; Bonhomme et al., 1994; Weikay & Hunt, 1999). It is plausible to accept that at temperatures below 10 °C, there is no development occur in tropical crops. As expected, the 95% confidence interval for T_b of Bario Sederhana and Biris included 10 °C (Table 4.1) thus allowing re-analysis of thermal time using a T_b of 10 °C for comparison with rice cultivars and other tropical crop species.

5.2 Seedling Emergence and Third Leaf Appearance

Seedling emergence is important in determining a successful establishment of plant populations. Both temperature and moisture have a strong impact on the emergence rate in rice. Bario Sederhana seeds sown in pots on 28th December 2020 took the shortest time (2.5 days, 39 °Cd) for seedlings emergence (Table 4.2). This was due to the high average amount of rainfall (474.0 mm) in the month of December through to January (578.2 mm) (Table 3.1). Therefore, there was no limitation in moisture and the temperature was favorable during the emergence period. For sowings during drier months in June and August, seedlings took a longer time to emerge (7.6 – 9.3 days/ 184 – 199 °Cd) due to low amount of rainfall (198 – 235.4 mm). However, sowing on 28th February 2021 using a different seed lot took the longest time (10.1 days, 228 °Cd) for seedlings to emerge despite high total of rainfall (447.0 mm). This was most likely due to poor viability of seeds given the total population of seedlings were below 20% (Figure 4.5) hence those that barely managed to emerge would require a longer time. Therefore, the discrepancy in results was believed to be caused by the conditions of seeds and not environmental factors at the time of sowing. The main reason for using a different seed lot was due to limited quantity of seeds collected from different sources and consequently compromising the results of this study. Therefore, it is emphasised that future study must use seeds from only one seed lot to minimise inconsistency of the results. For Biris, there was no significant difference in calendar days to reach 50% emergence among the sowing dates. Nevertheless, thermal time requirement for emergence of Biris seedlings varied with two distinct results (Table 4.2). Irrespective of the year, sowings in February and April took a longer time for seedling to emerge (153 -164 °Cd). In contrast, seedlings emerged earlier for seeds sown in June, October and December. Meanwhile, sowing in August showed no statistical difference compared to the other five

sowing months. In this study, soil temperature (10 mm depth) was used to quantify thermal time requirement for seedling emergence. The reason for using soil temperature instead of air temperature was because following seed germination, the meristem apex where shoot is to be initiated was located below the soil surface and therefore would respond to soil temperature for subsequent development and growth (McMaster et al., 2003).

In rice plant, third leaf appearance is important to identify timing of the first application of basal fertiliser to ensure enough nutrients for optimum growth. This is because soon after the production of third leaf, rice plant will enter into a tillering phase and the production of the first few tillers highly depend on the fertiliser supplied at the third leaf appearance (Petr et al., 1988; Abdul Razak et al., 2012). The cumulative third leaf appearance exhibited a similar development pattern with cumulative of seedlings emergence (Figure 4.6). In both landraces, total plant populations with three leaves were slightly lower than total population of seedlings that emerged for crops sown in April and June. Total populations of seedlings emerged from the ground were between 10-14% for April sowing date (Figure 4.5) but this declined to 5-7% when the crops reached their third leaf production. Similarly, total seedlings emergence for June sowing date were 75-77% and then decreased to 52-56% at third leaf appearance. Irrespective of the year of sowing, thermal time to third leaf formed a systematic variation with calendar months (Figure 4.7). In both landraces, thermal time to third leaf increased with each successive sowing month from February to June but then decreased thereafter until December. These systematic variations in thermal time to third leaf with sowing months suggest that time to third leaf appearance was not only affected by temperature and moisture. In this pots experiment, temperature and moisture were not a constraint because mean soil temperature ranged 25.5 – 28.1 °C which was optimum for rice plant (De Los Reyes et al., 2003) and the water level was maintained at 5

cm above the soil level throughout the duration of rice growth. However, a study of rice plants in a controlled environment chamber found that photoperiod sensitivity commenced at the appearance of fourth leaf for Bario Sederhana and third leaf for Biris landrace (Hossen & Nori, 2023). Although the state of Sarawak experiences a consistent 12 hours photoperiod throughout the year with minimal differences in minutes, such a small difference in photoperiod may affect rice development. Therefore, the differences in thermal time to third leaf appearance in this study may be attributed to the variation of photoperiod at the location of planting.

5.3 Leaf Production

Phyllochron is defined as the interval of leaf emergence (Veeramani et al., 2012). In its simplest interpretation, longer phyllochron means slower rate of leaf production while shorter phyllochron refers to faster rate of leaf production. In the pot experiment, the number of leaves on the main stem was recorded until the plant has produced the flag (final) leaf. The production of leaves on the main stem increased linearly with thermal time accumulation (Figure 4.8). The inverse of the slope of the relationship was used to determine the phyllochron. Regardless of landraces, the longest phyllochron (28.7 days/leaf, 639 °Cd/leaf) was observed for crops sown on 1st April 2019 (Table 4.4, Table 4.5). The phyllochron was affected by the sowing date and landrace interaction (Table 4.4). For Bario Sederhana, the phyllochron declined (become faster) quadratically as sowing months shifted from April to October (Figure 4.9a). In contrast, the response of phyllochron toward sowing months in Biris can be described by a bi-linear relationship (Figure 4.9b). The phyllochron of Biris was found to decrease (become faster) from April to June but this increased (become slower) when crops were sown later in consecutive months. Both landraces had a similar final

number of leaves on the main stem (8.5 leaves) to complete its vegetative development (Table 4.6). Nevertheless, the amount of time in calendar days and heat units the crops took to produce the similar final number of leaves (flag leaf) were different with sowing months (Table 4.7 & Table 4.8). These differences occurred due to the differences in phyllochron at sowing. The phyllochron of Bario Sederhana was 646 °Cd/leaf for crops sown on April compared with 467 °Cd/leaf for crops sown on October (Table 4.5). The longer phyllochron in April sown crops resulted in a longer time of 3787 °Cd to flag leaf after the production of 8.5 leaves on the main stem. In contrast, October sown crops only required 2282 °Cd to flag leaf with the same number of leaves. In general, temperature is the main factor that affects the rate of leaf appearance (Ellis et al., 1993). As temperature fluctuates over the months in a year, crops may require a different number of days to produce leaves. Therefore, thermal time approach is used to provide a uniform measurement for crop development (Bonhomme, 2000). Despite that, the findings of this study reported a systematic variation of thermal time for phyllochron across the sowing months. Given that the fluctuation of temperatures over the months are minimal between 26.0 -27.5°C (Table 3.1), this systematic variation suggests that the phyllochron of rice was not solely driven by temperature but it was also influenced by a secondary factor, i.e., photoperiod. According to Dore (1959) found that a 14-minute variation in photoperiod between January and September in Melaka resulted in a significant difference in time to flowering of rice crops. Sarawak traditional rice has been claimed to be photoperiodic sensitive due to its long growing duration (Amri et al., 2017). In addition, the daylength throughout one year in Kota Samarahan, Sarawak varies up to 12 minutes (Table 3.1) thus, sowing crops at different time should take into consideration a possible effect of photoperiod at the location of planting.

5.4 Flowering

For pots and field experiments, crops sown in April took the longest calendar days to flower compared with later sowing months (Table 4.11 & Table 4.22). When time to flowering for crops in pots was quantified in thermal time, flowering in both landraces become quicker as sowing months delayed from April to October (Figure 4.11). In rice crops, flowering begins after the appearance of the flag leaf which marks the completion of vegetative development. This means that whether the crops flower quicker or later would be determined by the time taken to flag leaf appearance on the main stem. Indeed, thermal time to flowering across sowing months in both landraces followed a similar pattern with time to flag leaf appearance (Figure 4.10). The longest time to flag leaf in April sowing month caused the longest time for the crops to enter flowering stage. Likewise, crops sown in October that took the shortest time to flag leaf flowered the quickest. In the previous discussion (Section 5.3), the variation in time to flag leaf was influenced by differences in phyllochron which was believed to be modified by photoperiod. Rice plants are responsive to photoperiod for only during the inductive phase, which is after a juvenile phase and before flowering (Vergara & Chang, 1985). Photoperiod affects plant development by altering the leaf production rate (Wu et al., 2004) and consequently time to flowering (Andrade et al., 2022). When plants begin to perceive photoperiod, it will send stimulus to the meristems where primordia are to be initiated. At this point of time, the plants have decided which primordium will turn into a reproductive bud. Therefore, when photoperiod extends the duration of vegetative development, this will cause the plants to flower later and vice versa. The implication of having a longer vegetative development is that it will cause the crops to mature later and therefore requires additional farm input in relation to fertiliser and pesticide

application. In this study, the effect of photoperiod was not investigated but rather an assumption of a secondary factor that may contribute to the changes in crop development.

5.5 Grain Development

Grain development was quantified in calendar days and thermal time from the pot experiment. Following rice anthesis, the florets developed further into individual grain throughout the process of grain filling and ripening. These processes were mainly driven by temperature. Overall, grain development took between 22.8-32.6 days/520-818 °Cd for Bario Sederhana and 22.5-30.2 days/472-784 °Cd for Biris to become ripened from the time of flowering (Table 4.12 & Table 4.13). The results of this study showed that crops which flowered earlier (shortest time to flowering) had a longer duration of grain development compared with those that flowered later (longest time to flowering). For example, Bario Sederhana sown in October flowered within the shortest time, i.e. 124.4 days/2980 °Cd (Table 4.11). Following flowering, the grain development took the longest time of 32.6 days/818 °Cd to become ripen compared with earlier sowing months (22.8 days/521 °Cd) (Table 4.12 & Table 4.13). The advantage of rice plants that flowered earlier is that they can have a longer duration of photosynthesis for as long as the environmental conditions (temperature and moisture) are favorable (Yoshida, 1981). The longer the time plant took for photosynthesis, the higher amount of sugars are to be produced and pumped into the grains. Therefore, a longer duration of photosynthesis process means longer duration of grain filling (from milky stage to hard grain). This eventually led to a higher grain weight.

5.6 Plant Height and Length of Basal Internodes

For the pots experiment, the plant height was measured when the crops had produced the flag leaf. Both Bario Sederhana and Biris had an average height of ~162 cm with no significant difference between the landraces (Table 4.9). However, there was a significant difference among the plant height in relation to sowing dates. In the present study, seeds sown on 27th October 2020 produced plants with higher height (166.4 cm) compared with other sowing dates (159.1 – 162.8 cm) (Table 4.9). These differences can be explained by environmental variation. Crops grown at different sowing dates experienced different environmental impacts. In this study, total amount of rainfall experienced by crops growing on 27th October 2020 sowing date was ~2483.0 mm over a duration of five months from sowing to flag leaf stage compared with those that were sown on 1st April 2019 which only experienced a total average rainfall of ~1420.7 mm (Table 3.1). Therefore, when moisture is plentiful it enhances plant growth through cell elongation, division, and differentiation. The increment of plant height with higher moisture regime was also reported previously (Rafiq et al., 1999). The average maximum temperature experienced by both seeds sown on 27th October 2020 and 1st April 2020 was not significantly different. For the field experiment, the final height of both landraces, Bario Sederhana and Biris was measured later when the rice plant has reached the heading stage. Nevertheless, the plant height in the field condition followed the same pattern with those in the pots with the lowest height recorded from crops sown on 1st April 2019 (154.0 cm) (Table 4.19). The effect of different sowing dates on plant height was also reported by Akbar et al. (2010). The advantage of having crops with a shorter height is that they can avoid the incidence of lodging during panicle formation (Kumari & Bains, 2018).

In addition, basal internodes are important structures in determining the plant lodging resistance. Results from the pots experiment showed significant differences in the length of internodes between two sowing dates in Bario Sederhana (Table 4.10). On an average basis, crops sown in October had longer internode length (10.2 cm) compared to crops sown in April (6.7 cm). In both landraces, the third internode was the longest (11.4-12.1 cm) followed with the second (7.9-8.3 cm) and then the first internode (4.5-5.7 cm). The length of basal internodes from crops grown in field at Pusat Peyelidikan Tumbuhan (PPT) conformed with those in the pots experiment (Table 4.20). Similar finding was also reported by Zhang et al. (2016). Lodging resistance is primarily influenced by the three basal internodes, with the second internode (when counted from the soil surface upwards) being particularly important. Crops with shorter basal internodes have stronger lodging resistance. Apart from internode length, lodging resistance is significantly influenced by other stem characteristics such as stem diameter, culm wall thickness and internode plumpness (Islam et al., 2007).

The elongation of internodes is dependent on the culm growth. As the culm growth increases, both the number of elongated internodes and the length of the internodes increase as well. The availability of light is the greatest factor that affect the elongation of internodes (Vergara et al., 1965). In this study, there was no limitation to light access given that both experiments were conducted in open area outside the Plant Growth Laboratory and in field at Pusat Penyelidikan Tumbuhan UNIMAS. Nevertheless, the average amount of rainfall received by the sowing dates varied, with crops sown in October receiving more total rainfall than crops sown in April which may contribute to the cause of variation in culm growth. Unfortunately, due to covid-19 movement restrictions, the data collection of internodes for crops sown in June and August for both pots and field experiments were unable to be obtained.

5.7 Yield and Yield Components

The length of rice panicle is an important yield-related trait which strongly affects grain number, grain density and rice quality (Sun et al., 2016; Wang et al., 2019). Essentially, longer panicle will lead to a higher number of grains. The results from pots and field experiments showed that crops that had a greater plant height were found to have a longer panicle length. The present study clarified, crops from October sowing months that produced tall plants also had longer panicles (Table 5.1). Longer panicles in October sown crops were believed to be associated with high amount of moisture received during vegetative and reproductive phases which favors the elongation process of both stem and panicles.

Table 5.1: Mean plant height, panicle length, number of spikelets/panicle, percentage of filled spikelets and filled grain weight of Bario Sederhana and Biris rice sown in pots and field in Universiti Malaysia Sarawak.

Experiment	Sowing Date (SD)	Plant height (cm)	Panicle length (cm)	Spikelets/panicle (n)	Filled spikelets (%)	Filled grain weight* (g/unit area)
Pot	1/04/2019	159.1 ^c	24.6 ^{ab}	108.5 ^b	58.1 ^a	28.8 ^{ac}
	27/06/2019	159.9 ^c	23.8 ^b	122.0 ^b	69.4 ^a	24.3 ^{ac}
	27/08/2019	162.8 ^b	20.8 ^c	98.7 ^b	37.1 ^b	17.8 ^{bc}
	27/10/2020	166.4 ^a	27.2 ^a	204.5 ^a	69.5 ^a	35.0 ^a
Field	1/04/2019	154.0 ^b	25.9 ^b	121.8 ^b	63.7	35.0 ^b
	27/06/2019	162.8 ^a	21.2 ^c	104.5 ^b	52.0	21.0 ^b
	27/08/2019	162.1 ^a	21.5 ^c	128.7 ^b	53.2	32.4 ^b
	27/10/2020	166.8 ^a	29.0 ^a	202.8 ^a	71.0	74.0 ^a

Within each column, means with the same letters (superscript) are not significant ($P>0.05$) according to Tukey HSD (5%) test. * Unit area for pot experiment was 0.056 m² and field experiment was 2m². Note: Data were extracted from Table 4.9, Table 4.14-17, Table 4.19, Table 4.24-27.

In addition, crops with the longest panicle length (October sown) eventually produced the most number of spikelets per panicle in both pots and field experiments. In contrast, earlier sown crops which produced shorter panicle had a lower number of spikelets per panicle. However, during the grain development period, earlier sown crops experienced a significant loss of grains due to infestation by birds, which was the main reason for lower number of spikelets per panicle despite precaution measurement was taken by protecting the panicles with plastic bags (Figure 5.1).



Figure 5.1: Destroyed panicles due to bird infestation at Plant Growth Laboratory, UNIMAS.

It was only until September 2020 when net houses were established to protect the plants in on-going experiments. The variation in filled spikelets percentage with sowing dates was believed to be associated with air temperatures experienced by the spikelets during

heading. Specifically, crops sown on 27th August 2019 reached heading between the end of January and middle of February 2020 when the maximum daily air temperatures ranged from 27.2 – 47.1 °C. According to Yoshida (1981), exposure to a temperature of 38 °C for just two hours during heading was found to cause a decrease in spikelet fertility from 90 to 20%, while exposure to a temperature of 41°C for only one hour resulted in a complete loss of fertility. In addition, a study conducted by Kim et al. (1996) observed the production and viability of rice pollen decreased when the daytime maximum temperature exceeded 33 °C, and it was found to reach zero when the temperature rose to 40 °C. Therefore, extreme high temperatures were the main reason for the lowest percentage of filled spikelets in August sown crops in pots experiments (37.1%) (Table 5.1). Coupled with low number of spikelets per panicle, these have led to the lowest filled grain weight of 17.8 g/pot for August sown crops. Similarly, Lack et al. (2012) reported excessive heat during pollination and grain filling was the main cause of disorder in rice grain formation and consequently reduced the grain weight. In contrast, October sown crops had the heaviest filled grain weight of 35.0 g/pot because of high number of spikelets per panicle (n=204) plus high percentage of filled spikelets (69.5%).

For the field experiment, the planting dates affected the yield component as both landraces sown in October had the highest number of panicles per subplot (n=32) (Table 4.23). Crops grown during this month experienced favorable soil temperatures of 25.2 -30.6 °C during early establishment and 24.6 -27.2 °C during active tillering. Furthermore, these crops received the most amount of rainfall during their vegetative phase from November to January (Table 3.1) when active tillering process was crucial to determine the production of panicles. On account of this and along with high number of spikelets per panicle (n=203) and filled spikelets percentage of 71.0% (Table 5.1), October rice crops produced a

remarkably the highest grain weight of 74.0 g/subplot. Therefore, planting during this month of the year is suitable for optimum growth of rice to obtain desirable yield components. In fact, the rice planting season in Sarawak typically begins in October or early November to coincide with the start of the northeast monsoon season which brings more rainfall to cater optimum growing conditions for dryland rice. Given that traditional rice varieties take around five months to develop, therefore the grains can be harvested in March when rainfall has started to considerably decline and the average air temperature is around 31 °C. This could inhibit crop flowering during May's warm weather (~33 °C) and hence hinder empty grain.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

The cardinal temperatures for Bario Sederhana and Biris landraces had a base temperature, T_b of 10 °C, optimal temperature, T_{opt} between 32 – 33 °C, and maximum temperature, T_{max} of 43 °C. The T_t requirements for germination at sub-optimal range were 62 °Cd for Bario Sederhana and 53 °Cd for Biris while at supra-optimal range, both landraces required 27 – 29 °Cd for seed germination. Thermal time requirement for seedlings emergence varied with sowing dates by landraces but with no particular order of sowing month. Seedlings took between 39 and 228 °Cd to emerge from the ground. Time to third leaf appearance exhibited a systematic variation with an increased T_t requirement from February to June and then declined with subsequent months until the end of December. The phyllochron of Bario Sederhana declined following each successive sowing date with the shortest phyllochron of 467 °Cd when seeds were sown on the month of October. Meanwhile, the phyllochron of Biris showed a trend where it started to decline from April towards June before increasing from June towards August until October. The phyllochron of Biris was the shortest (495 °Cd) for June sown crops. Both landraces produced a maximum of 8.5 leaves on the main stem before the crops turned reproductive. In pot experiments, the flag leaf appearance was the quickest for crops sown in October and the latest for those sown in April. In the field conditions, planting in April gave the shortest plant height but resulted in longer basal internodes. For both landraces, sowing later in October resulted in the quickest time to flower while sowing as early as April took the longest time to flower. Consequently, crops that flowered the quickest had an extended time for seed development because the phenophase coincided with favourable temperatures and moisture at the time of the year. Essentially, these optimum environmental conditions for October

sown crops gave a longer panicle growth, resulting in more production of spikelets per panicle, higher number of tillers which resulted in higher number of panicles and optimizing fertilisation process which gave a higher percentage of filled spikelets. These components altogether gave the heaviest grain weight to October sown crops.

Understanding how temperature affects rice phenology and yield can help decision-makers select the ideal time to plant seeds based on local meteorological information. It is therefore advised to sow traditional rice in Sarawak's wet-and-dry climate between late September and early October for the best seedling emergence and subsequent crop establishment during the rainy season. For farmers, the thermal time requirements that were determined in this study are helpful guidelines. Estimation of crop phenology using thermal time approach is uniform because thermal time show that a plant needs the same number of heat units at every stage of development. Thermal time requirement for each stage can be converted to days. Farmers can use the precise number of days to each stage to correctly anticipate the time of each development stage.

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