博士論文要約（Summary）

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タイトル	Development of Seed Priming Technology for Direct Sowing in Rainfed Rice Cultivation (イネの天水直播栽培における種子プライミング技術体系の確立)

キーワード（Africa）　（Upland rice）　（Hydropriming）

Introduction

Demand of rice is increasing rapidly in Sub-Saharan Africa (SSA) and rice production doubled from 2000 to 2018 caused by increasing rice cultivation area (FAOSTAT, 2020). However, rice yield did not increase much. Therefore, innovative technologies are needed for increasing rice yield in SSA. In SSA, large part of rice cultivation environment is occupied by rainfed field (Balasubramanian, 2007) which depends the water resource on rainfall.

Uganda, that has 44.2 million of people (World Bank Group, 2020), is located in the eastern part of SSA. Population in Uganda is increasing rapidly and it will reach 72.7 million in 2040 (UBOS, 2020). Nowadays, rice becomes popular staple food in Uganda. Rice cultivation area was 2000 ha in1960s and increased to over 7000 ha in 1990s (Imanywoha 2001). It is estimated that rice production and harvested area are 25100 t and 110000 ha in 2008, respectively (MAAIF, 2009). The government of Uganda considers that rice is an important food as the factors for food security at the household level, increasing income of farmer, and improving the outflow of currency (Imanywoha 2001, JICA 2018). Regarding rice cultivation environment in Uganda, rainfed-upland is estimated to be 40000 ha against the 110000 ha of total rice cultivation area (MAAIF, 2009), indicating the upland rice cultivation occupies large part of rice cultivation area in Uganda. The rainfall averages 400–700 mm during rice cultivation season in central Uganda (Miyamoto et al., 2012), and the 311–400 mm of rainfall is needed as minimum water requirement for rice varieties used in East Africa (Matsumoto et al., 2014). Rainfall distribution can be poor because of unpredictable drought in areas for upland rice cultivation (Balasubramanian et al., 2007). Therefore, rice yield in rainfed-upland is 1.8-2.2 t in Uganda (MAAIF, 2009).

The direct seeding is a standard method of rice sowing especially in rainfed upland rice cultivation. It is well known that plant emergence and establishment is important factors for subsequent growth and yield. In upland rice cultivation, plant emergence and establishment seem to be poor because of unstable rainfall amount.

Seed priming is pre-sowing treatment which improves initial, middle and late plant growth under unstable environmental conditions. Priming effects can account for molecular regulation and physiological improvement (Lee and Kim 2000, Farooq et al., 2006, Chen and Arora, 2013, Wojtyla et al., 2016). Further, several priming methods have been developed, such as hydropriming, osmo-priming, nutrient priming, hormonal priming, redox priming, and chemical priming (Jisha et al., 2013).

Especially in hydropriming is known as low-cost and effective techniques (Haris et al., 2001, A. Soltani and E. Soltani, 2015) applicable to SSA.

General objectives and structure of the dissertation

In the last twenty years, basic knowledge of the seed priming technology on rice has been revealed. However, the seed priming technology is not fully utilized in the SSA. Through the trials with farmers, seed priming was effective on farm (Harris et al., 2001). Seed hydropriming is mentioned as practical method comparing with other priming methods (A. Soltani and E. Soltani, 2015), and it is expected that priming can be spread from farmer to farmer (Harris et al., 2001). However, Parera and Cantliffe (1994) pointed out the possible damage of embryo in brown rice during hydropriming treatment, and the problems occurred commonly (Harris et al., 2001). For utilizing the seed priming to famers in SSA, further development of this methodology and usage of seed priming is needed.

In addition, mechanisms of seed priming effects begin to be revealed by previous researches molecular biologically and plant physiologically, while agronomical efficacy of seed priming is not stabilized under the varying environment. The higher yield of rice plants from primed seeds are caused by early plant emergence and establishment, and improved subsequent growth (Harris 2002, Farooq et al., 2006). However, seed priming efficacy on initial growth depends on soil moisture (Lee et al., 1998, Matsushima and Sakagami, 2013), and seed genotypes (Ella et al., 2011, Illangakoon et al., 2016). Further, priming effect is not always appeared in the field trials (Harris et al., 2001) Then, the mechanism of seed priming causing high yield seems more diverse depending the environmental factors. Therefore, it is needed clarify the agronomical efficacy of seed hydropriming comprehensively.

In this dissertation, research aiming at development of seed hydropriming technology was conducted for improving the rainfed upland rice production. Methodology of hydropriming and usage of primed seed were described in chapter 2 and 3. In chapter 2, characters of farmer’s seeds are assessed to determine the appropriated method for hydropriming treatment. In chapter 3, adverse effects of applying seed hydropriming on upland rice cultivation was assessed. Further, mechanisms of differential seed hydropriming efficacy under wide range of soil moisture and agronomical benefits of seed hydropriming were discussed in chapter 4, 5 and 6. In chapter 4, differential priming efficacy on different rice genotypes was assessed under wide range of soil moisture condition. In chapter 5 and 6, seed hydropriming effects on initial, middle, and late plant growth were evaluated under wade range of soil moisture conditions. Through this dissertation, benefits of upland rice cropping system which is combination with the seed hydropriming technology was discussed.

Results and discussion

Application of seed hydropriming technology for upland rice cultivation

Hydropriming is known as the low cost and practical method (Soltani and Soltani, 2015), but the priming technology is not fully utilized in SSA. Regarding hydropriming treatment, seed are soaked in the water for activation of seed metabolism. Then, seeds are dried to the original weight. Panera and Cantliffe (1994) suggested that if radicle appeared during soaking period, seed embryo is damaged by following drying treatment. We found that NERICA 4 seeds from Ugandan farmers should be soaked for 24h on 25°C, which is average temperature in Uganda, regardless the differences of seed quality (Chapter 2). The method can prevent damage by germination during seed soaking period, and activate seed metabolism. Further, adverse effects of hydropriming on rice seed was assessed, when the seeds were buried for long duration in dry soil. The adverse effects of seed priming seemed not to be considered, even if the enzymes were activated before sowing and extremely drought was prolonged after sowing (Chapter 3).

Seed hydropriming effect on upland rice growth

Seed priming efficacy on initial growth depends on the soil moisture (Lee et al., 1998, Matsushima and Sakagami, 2013) and genotypes (Ella et al., 2011, Illangakoon et al., 2016). Therefore, we hypothesized that mechanisms of seed priming causing high yield is more diverse and it is dependent with the environmental factors. Then, we firstly evaluated the seed priming efficacy on various rice genotypes under the varying soil moisture conditions (Chapter 4). Further, we evaluated that priming effects and plant growth behaver of initial, middle, and late growth stages under varying soil moisture conditions (Chapter 5, 6). Priming efficacy on plant emergence and initial growth were maximized under the moderate dry conditions, regardless of genotypes. High efficacy of priming on emergence under moderate dry condition was consistent with the result in the previous reports (Lee et al., 1998, Matsushima and Sakagami, 2013). On the other hand, priming efficacy was decreased with increasing the soil moisture conditions. Further, in the high soil moisture conditions, responses of primed plant was more diverse depending on genotypes (Chapter 4) as partly suggested by previous researches (Ella et al., 2011, Illangakoon et al., 2016). Among genotypes used in this study, two genotypes with both AG and *Sub1* genes, which determine faster seed germination in anaerobic condition (EL-Hendawy et al., 2011), showed the better response to seed priming even in the high soil moisture conditions. Importance of early growth of primed seed was reported by previous research (Soltani and Soltani, 2015). Our results partly confirmed the previous results, and it was indicated that early emergence of primed seed is especially important under low soil moisture stress conditions (Chapter 5). On the other hand, hydropriming seems to be not effective on emergence under severe dry conditions (Chapter 4, 5). However, the seedlings germinated from primed seeds developed roots more vigorously than the control ones, even if shoot growth was not improved (Chapter 3, 5). Developed root growth correlated with plant survival ratio, plant death ratio (Chapter 3), shoot length, and shoot dry weight (Chapter 5) under the severe drought. It is well known that the developed root is important to extract limited soil water and keep water potential of plant (Fukai and Cooper, 1995, Eagles et al., 1997, Bernier et al., 2008). Further, effect of priming seems to be emphasized in the drought (Chapter 5) and it may be caused by the implemented drought tolerance such as activation of ROS scavenging enzymes, accumulation of protein related the stress tolerance (Chen and Arora, 2013 Wojtyla et al., 2016 Zheng et al., 2016). Consequently, hydropriming is effective on initial growth under the varying soil moisture conditions, and the priming effects differs depending the difference in plant behavior with the change of water status (Chapter 3, 4, 5). However, the priming effects was the most obvious in the dry conditions during the middle and late growth stage (Chapter 6). Rice plants grow well regardless the primed or non-primed in the low soil moisture stress conditions. On the other hand, plant from primed seed recovered better than control at the middle and late plant growth stage in the dry condition (Chapter 6) and, they can prevent form delayed growth. Then, we concluded that the priming effects in the drought (Chapter 5, 6) must be the great advantage of fast recovering of priming during middle and late plant growth. One of the agronomical mechanisms against the drought is drought escaping by short growth period (Bernier et al., 2008). In the previous report, early growth and early maturity of plants from primed seeds are reported (Farooq et al., 2006, Binang et al., 2012), as the agronomical advantage of priming. Our result of field trial confirmed an advantage of priming in drought escape. Further, we concluded that the drought escape was not caused by early growth but the prevention from delayed growth of plants from primed seeds, presumed by the comparison under the several soil water statuses. Therefore, seed priming is the most effective when the rainfall was not enough at the beginning and end of rice cultivation season. Further, priming treatment did not contribute the increasing the yield, but prevented the decreasing yield. In case of using hydropriming in the upland cultivation in SSA, it would be a beneficial way to avoid rice yield reduction, because this method was proven to have a great potential for reducing plant injury and also yield loss caused by low rainfall.