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Stabilizing Grain Yield and Nutrition Quality in Purple Rice Varieties by Management of Planting Elevation and Storage Conditions

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Abstract: Purple rice has become an interesting source of nutritional value among healthy cereal grains. The appropriate cultivation together with post-harvest management would directly benefit farmers and consumers. This study aimed (i) to determine the yield, grain nutritional quality, and antioxidant capacity of purple rice varieties grown at lowland and highland elevations, and (ii) to evaluate the effects of storage conditions on the stability of the rice nutritional value during six months of storage. The high anthocyanin PES variety grown in the lowlands had a higher grain yield than the plants grown in the highlands, but grain anthocyanin concentration had the opposite pattern. In the high antioxidant capacity KAK variety, grain yield and DPPH activity were not significantly different between plants grown at the two elevations. The storage of brown rice and vacuum-sealed packages were both found to preserve greater anthocyanin concentrations in PES, but there was no effect on the DPPH activity of KAK. The grain properties were not significantly different between storage at 4 °C and room temperature. This study suggests that the optimal cultivation practices and storage conditions would result in the higher yield and grain quality of purple rice varieties.

Keywords: anthocyanin; pigmented rice; lowland rice; highland rice; rice antioxidant; rice yield

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1. Introduction

Antioxidant properties are a typical characteristic of colored or pigmented rice grains. Purple rice in particular is well known as a source of anthocyanins as well as other phenolic compounds with high antioxidative capacity [1]. Purple rice varieties are normally grown in both highland and lowland elevations, although many more varieties are cultivated in the high elevation areas [2]. However, properties such as the level of anthocyanin vary depending on the variety and practical management, as well as post-harvesting conditions. Each of these factors is the subject of ongoing research aimed at improving the nutritional properties while increasing production. A breeding program has been successfully established for high-grain quality rice varieties such as gamma oryzanol [3], and for improving other characteristics, e.g., iron, anthocyanin, and phenol [2]. Two glutinous purple rice varieties were used in this study: Pieisu (PES), a representative line with high anthocyanin concentration, and Kum Aka (KAK), a high-antioxidant capacity variety that was selected from the high elevation area [2]. However, a previous report demonstrated that the grain anthocyanin accumulation and antioxidant capacity among nine purple rice varieties grown in the aerobic condition varied according to the altitude and the responsiveness of each variety, whereby some varieties produce more intense grain pigmentation and higher concentrations of anthocyanin in the highland, while some varieties did so in the lowland. No altitude effects were seen in the others and the concentration was in positive correlation with the antioxidant capacity (Trolox equivalent) of the rice grains [4]. On the other hand, a recent study has reported that growing purple rice varieties at lowland altitudes in waterlogged conditions resulted in more intense pigmentation than plants grown in the aerobic condition, but this varied according to rice varieties and cropping years [5]. A previous report has shown that the transcription of genes involved in the anthocyanin biosynthesis pathway was suppressed under high temperatures, resulting in impaired grain anthocyanin synthesis in pigmented rice [6]. In the other plants, the decline in anthocyanin compounds was also found under water stress [7]. Thus, there can be many factors in rice cultivation practice affecting the anthocyanin and antioxidant properties in purple rice varieties, such as growing elevation, climate, soil condition and water management. The appropriate growing conditions of the selected lines with high anthocyanin concentration and antioxidant capacity would improve the stability of the yield and the associated grain nutritional quality, for the benefit of farmers as well as consumers. However, limited information has been reported on grain nutrition quality, especially for bioactive compounds such as anthocyanin and antioxidant capacity as affected by growing altitudes.

In addition, post-harvest operations, such as the storage conditions, are important to maintain and ensure nutrient stability for health benefits. After harvesting from the field, paddy rice (rough rice) usually has its moisture content reduced before being stored and processed into brown rice (unpolished) or white rice (polished rice). Interestingly, storage in paddy form has been shown to be a better method for retaining anthocyanin and antioxidant capacity in the local purple rice varieties compared with brown rice, although this still needs to be confirmed [8]. Anthocyanin compounds in purple rice are known to be very unstable under thermal processing [9]. The storage temperature was found to have an impact on their stability; for example, storage at ambient temperature (30 °C) led to higher anthocyanin reduction in the non-glutinous purple rice than storage at 22 °C [10]. In contrast, storage at −25 °C, or room temperature (~30 °C), did not affect the anthocyanin concentration or antioxidant capacity of the glutinous purple rice [8]. Thus, the effects of storage temperature on the grain nutritional values of rice appears to be complex, involving many factors that require further investigation.

On the other hand, vacuum-sealed packaging has been suggested as an option to increase the shelf life of food products in both wet and dry conditions, as an effective technique for reducing the chemical reactions and loss of chemical composition during storage [11]. Moreover, storage conditions without oxygen have been reported to have a positive effect on the stability of anthocyanin and antioxidant capacity in red rice [12]. This suggests the additional benefit of using vacuum-sealed packages to retain anthocyanin content and antioxidant capacity. The technique of vacuum-sealing for retaining anthocyanin in pigmented rice has been applied in several studies [10,11], while a recent report showed that the anthocyanin concentration was not significantly different between the grains stored under conventional and vacuum-atmosphere conditions [13]. The literature indicates variation in the effects of storage temperature and packaging on the stability of anthocyanin content and antioxidant capacity among purple rice varieties. Therefore, minimizing losses of the grain nutritional quality during storage based on simple methods has become a focal point in this area of research. Therefore, the aims of the present study were (i) to evaluate the impact of different cultivation altitudes on the stability of grain yield and nutritional quality in the relevant purple rice varieties, and (ii) to investigate the stability of grain nutritional quality in rice stored under different conditions. The appropriate pre- and post-harvest operations are necessary to achieve a highly consistent and desirable quality of purple rice grains, as purple rice has many potential commercial applications.

2. Materials and Methods

2.1. Effects of Planting Elevation on Yield and Its Grain Nutritional Quality

Seeds of the two purple rice varieties ((i) Pieisu (PES), a glutinous endosperm and photosensitive type with a high anthocyanin concentration (designated as a high-anthocyanin PES variety) and (ii) Kum Aka (KAK), a glutinous endosperm and photosensitive type having a high antioxidant capacity (designated as a high-antioxidant capacity KAK variety) derived from the Agronomy Division at Chiang Mai University) were used in this study [2]. Plants were grown in the wet season during July to November of 2018 to evaluate the effects of planting elevation on yield and grain nutritional quality. The experiment was carried out at two elevations. Chiang Mai University was designated as the lowland elevation (18°47′ N, 98°57′ E, 314 msl, 20–34 °C average temperature, 50–91% relative humidity and 972 mm annual rainfall), and Tung Luang village, Mae Win subdistrict, Mae Wang district was designated as the highland elevation (18.61°N, 98.77°E, 864 msl, 18–27 °C average temperature, 69–100% relative humidity and 1100 mm annual rainfall). The experiment was set as a randomized complete block design with three independent replications. The seedlings of 30-day-old plants were manually transplanted into the field with a plot size of 3 × 5 m with three plants per hill at 25 × 25 cm^2 spacing. The N:P:K (15:15:15) fertilizer comprising nitrogen, phosphorus and potassium was applied at the same rate of 10 kg ha^{-1}, half at maximum tillering and half at flowering. Rice plants were grown as wetland rice (flooded soil conditions) under the same field management for both sites. Grain yield and agronomical characteristics were evaluated at maturity within a one square meter sampling area in each replication. The grain was manually threshed, and yield was recorded at 14% moisture content. The agronomical characteristics comprised number of tillers plant^{-1}, number of panicles plant^{-1}, filled grains, thousand grain weight, number of spikelets plant^{-1}, culm length, panicle length, harvest index, and days to flowering. The paddy rice was mechanically de-husked (Model P-1 from Ngek Huat Co., Ltd., Bangkok, Thailand) to produce brown rice (the grain retains the pericarp layer) for anthocyanin analysis in a high-anthocyanin PES variety, while brown rice of the high-antioxidant capacity KAK variety was ground in a hammer mill for antioxidant capacity analysis. All grain samples were measured for grain moisture content before chemical analysis and the concentrations were calculated on a dry weight basis.

2.2. Effects of Storage Condition on Anthocyanin Concentration and Antioxidant Capacity

The study was conducted from December 2018 to May 2019. Paddy rice samples of the two purple rice varieties previously harvested from both sites were mixed and used to evaluate the effects of storage conditions on the stability of anthocyanins and on antioxidant capacity. Experiments were conducted to (i) evaluate the effects of storage grain form on the anthocyanin concentration in the PES variety and the antioxidant capacity in the KAK variety stored for six months, and (ii) evaluate the grain nutritional quality under different packaging methods and storage temperatures. The first experiment was designed as a factorial arrangement based on a completely randomized design with four independent replications and two factors. The factors were storage grain form and time. Samples (100 g) of paddy rice (unhusked grain) and brown rice (de-husked grain) at ~12% moisture content were packed in closed plastic bags (polyethylene) and stored for six months at room temperature conditions (30 °C). The second experiment was conducted with the same design, comprising the three factors of vacuum packaging, storage temperature, and time. Approximately 100 g samples of brown rice (de-husked grain) were packed in closed plastic bags of two types (non-vacuum and vacuum packages) and stored under two storage temperatures (room temperature and 4 °C in a refrigerator) for six months. The individual samples were collected at 0, 1, 3, and 6 months after the storage for both experiments; the grain moisture content was measured in a way similar to in the above experiment before chemical analysis, and the concentrations were calculated on a dry weight basis.

2.3. Anthocyanin Concentration Analysis

Anthocyanin concentration was determined by using the modified pH differential method [14]. About 2.5 g of whole brown rice PES variety was extracted with 25 mL (70% methanol and 30% 1.5 mol L^{-1} HCl, v/v) and shaken for 1 h. The extract solution was filtered through Whatman No. 1 filter paper. The filtrate (2 mL) was added to two buffer solutions (0.025 mol L^{-1} potassium chloride buffer, pH 1.0 and 0.4 mol L^{-1} sodium acetate buffer, pH 4.5) and then filled to a 25 mL final volume. The absorbance of anthocyanin was measured at 520 and 700 nm using a spectrophotometer (Biochrom Libra S22, Cambridge, UK). The absorbance of the anthocyanin pigment was expressed as cyanidin-3-glucoside, the main anthocyanin in purple rice, and was calculated as follows:

$$\text{Anthocyanin} = (\text{A} \times \text{MW} \times \text{DF} \times 1000)/(\epsilon \times \text{L})$$

where A = (A520 nm–A700 nm) pH 1.0–(A520 nm–A700 nm) pH 4.5, MW is the molecular weight of cyanidin-3-glucoside (449.2 g mol^{-1}), DF is the dilution factor, ϵ is the molar absorbance (26,900 L mol^{-1} cm^{-1}), and L is the cell path length (1 cm). The anthocyanin concentration was reported as mg kg^{-1} dry weight.

2.4. Antioxidant Capacity Analysis

The antioxidant capacity was determined by the free radical-scavenging activity of 2,2-diphenyl-1-picrylhydrazyl (DPPH activity) [15]. About 1.0 g of rice flour was extracted with 10 mL of the methanol solvent. The extract was shaken on an orbital shaker (IKA KS 250 B) for 30 min and then separated by centrifugation (MSE Super Minor, East Sussex, UK) at 4000 rpm for 10 min and filtered through a 0.22 µm Nylon syringe filter. The reaction mixture contained 0.3 mL sample extract, 1.6 mL methanol and 0.5 mL of 0.1 mmol L^{-1} DPPH solution. Blank tubes were prepared using 0.3 mL supernatant and 2.1 mL of methanol. The mixtures were shaken, incubated in the dark at room temperature for 20 min, and the absorbance was measured with a spectrophotometer at 517 nm. The DPPH radical-scavenging activity (%) of the samples and standard (Trolox) were calculated as follows:

$$\text{DPPH-scavenging capacity (\%)} = [(\text{AC} - \text{AS})/\text{AC}] \times 100$$

where AC is the absorbance of the control and AS is the absorbance of the sample. The DPPH radical-scavenging activity was calculated using a calibration curve with Trolox concentrations ranging from 10 to 62 µg mL^{-1} (R^2 = 0.99). The DPPH activity was reported as mg kg^{-1} dry weight.

2.5. Statistical Analysis

Statistix version 9.0 statistical software was used to calculate the means of all variates and to perform analysis of variance (ANOVA) among the factors. The least significant difference test (LSD) at the 95% confidence level ($p < 0.05$) was used to identify significant differences in the responses.

3. Results

3.1. Effects of Planting Elevation on Yield and Grain Nutritional Quality

The responses of the high-anthocyanin PES and high-antioxidant capacity KAK varieties to growing elevation in terms of grain yield and agronomical characteristics are shown in Table 1. The elevation strongly affected the grain yield of the high-anthocyanin PES variety, with a 1.8-fold higher grain yield in rice plants grown at the lowland elevation compared with the highland location. Similarly, slightly higher filled grain and culm length were found in plants grown at the lowland elevation compared to the highland location, whereas plants grown at the highland elevation flowered earlier than the lowland plants. The altitude had no significant impact on the other agronomical characteristics. The anthocyanin concentration was significantly different in the two elevations (Figure 1A). A 38% higher grain anthocyanin concentration was found in plants grown at the highland elevation compared with the lowland plants.

Table 1. Grain yield and agronomic characteristics of two glutinous purple rice varieties (high-anthocyanin PES and high-antioxidant capacity KAK) grown in two elevations.

Area	Grain Yield (ton ha^{-1})	Number of Tillers Plant^{-1}	Number of Panicles Plant^{-1}	Filled Grain (%)	1000 Grain Weight	Number of Spiklets Plant^{-1}	Panicle Length	Culm Length	Harvest Index	Days to Flowering
High-grain anthocyanin PES variety										
Lowland	5.14 ± 0.46 a	7.9 ± 0.2	7.6 ± 0.0	93.8 ± 0.2 a	33.0 ± 0.57	114 ± 13	28.3 ± 0.3	83.4 ± 1.8 a	0.37 ± 0.01	86 ± 1 b
Highland	2.85 ± 0.36 b	6.8 ± 0.1	6.7 ± 0.1	91.9 ± 0.1 b	33.0 ± 0.21	135 ± 4	27.5 ± 0.4	76.4 ± 1.2 b	0.37 ± 0.03	100 ± 1 a
F-test	*	ns	ns	**	ns	ns	ns	*	ns	***
High-DPPH activity KAK variety										
Lowland	2.95 ± 0.10	7.5 ± 1.0	7.0 ± 0.8	84.8 ± 3.4	37.8 ± 1.1	86 ± 3.0	25.9 ± 1.5	66.5 ± 4.7	0.41 ± 0.03	87 ± 0 b
Highland	2.99 ± 0.09	6.9 ± 0.6	6.8 ± 0.6	89.3 ± 5.5	37.9 ± 1.1	89 ± 0.6	24.9 ± 0.5	63.7 ± 1.3	0.37 ± 0.01	100 ± 1 a
F-test	ns	ns	ns	ns	ns	ns	ns	ns	ns	***

Data were analyzed by F-tests (* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$, ns: non-significant $p > 0.05$). Different letters indicate least significant differences within the column in each variety ($p < 0.05$). The values of grain yield and yield components are expressed as mean ± SD ($n = 3$).

In the case of the high-antioxidant capacity KAK variety, the growing altitude was not significant for grain yield or the yield component. Plants grown at the lowland altitude flowered earlier than the high-altitude plants. Similar to the yield, the antioxidant capacity related to the DPPH activity was not affected by the planting elevation (Figure 1B).

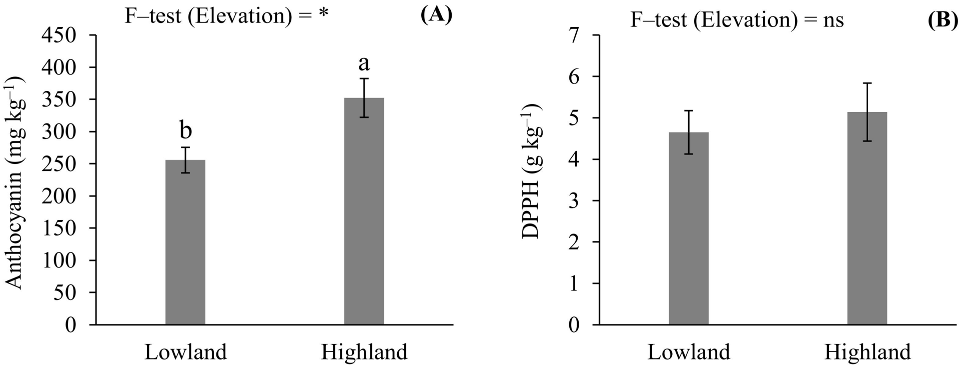

Figure 1. Anthocyanin concentration of the high-anthocyanin PES variety (**A**) and the DPPH activity of the high-antioxidant capacity KAK variety (**B**) grown at lowland and highland elevations. Data were analyzed by F-tests (* $p < 0.05$, ns: non−significant $p < 0.05$). Different letters indicate least significant differences ($p < 0.05$). The values of anthocyanin concentration and DPPH activity are expressed as mean ± SD ($n = 4$).

3.2. Effects of Storage Conditions on Anthocyanin Concentration and Antioxidant Capacity

The anthocyanin concentration of the high-anthocyanin PES variety was significantly affected by the storage grain form and time (Figure 2A). A reduction in anthocyanin concentration was found in all stored grains compared with the initial grains. The anthocyanin concentration declined differently between paddy rice and brown rice, whereby a reduction of 30% was found in brown rice in the first month, while this declined by 64% in paddy rice during the same period. In contrast, the concentration in rice stored in the same way as brown rice but for longer periods of storage (three and six months) increased by 34–66% compared with the 1-month-stored grains. The DPPH activity of the high-antioxidant KAK variety increased with storage time (Figure 2B). The stored grains had about 9–21% higher DPPH activity than the initial grains, and the highest DPPH activity was observed in the grains stored for three months. However, the type of storage had no effect on DPPH activity.

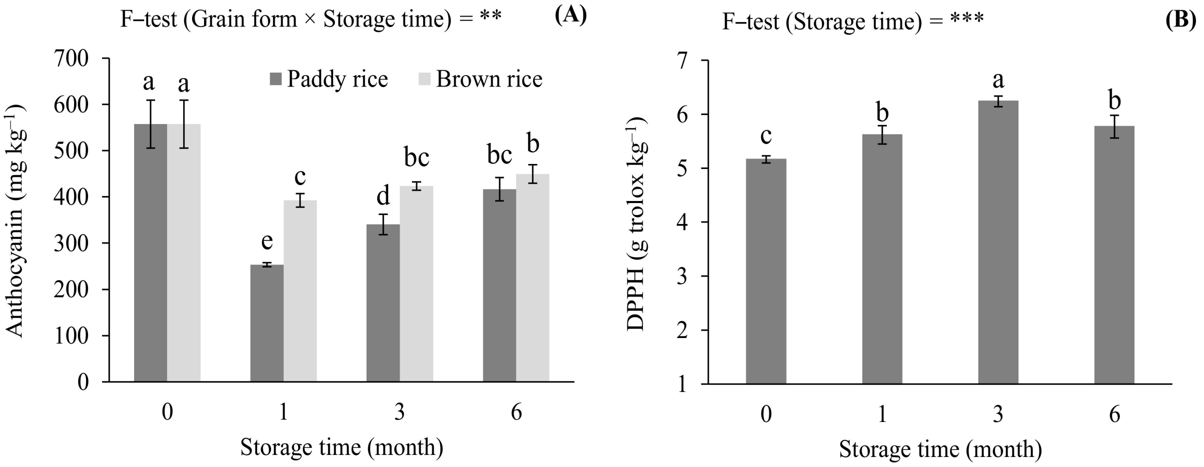

Figure 2. Anthocyanin concentration of the high-anthocyanin PES variety stored in paddy rice and brown rice forms for six months (**A**) and the DPPH activity of the high-antioxidant capacity KAK variety stored for six months (**B**). Data were analyzed by F-tests (** $p < 0.01$, *** $p < 0.001$). Different letters indicate least significant differences ($p < 0.05$). The values of anthocyanin concentration and DPPH activity are expressed as mean ± SD ($n = 4$).

In addition, the packaging slightly affected anthocyanin concentration in the high-anthocyanin PES variety (Figure 3A). Rice stored in the vacuum-sealed packages had 10% higher anthocyanin content compared with the non-vacuum-packaged rice throughout the storage time. Anthocyanin concentration was significantly affected by the storage time (Figure 3B).

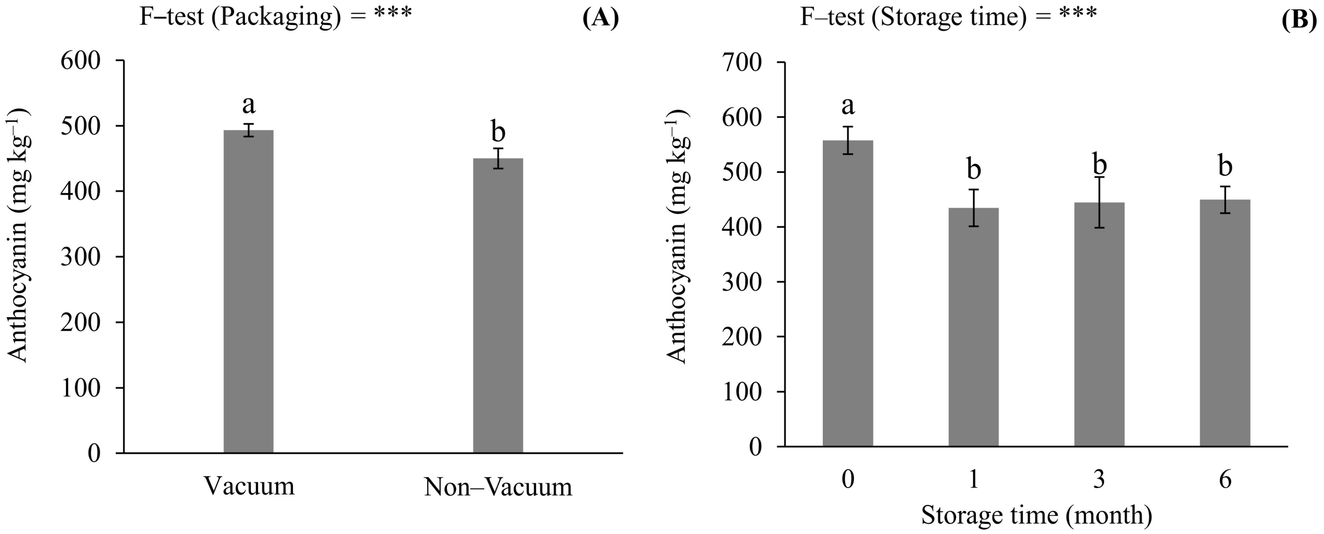

Figure 3. Anthocyanin concentration of the high-anthocyanin PES variety stored in vacuum and non-vacuum packaging (**A**) and after storage for six months (**B**). Data were analyzed by F-tests (*** $p < 0.001$). Different letters indicate least significant differences ($p < 0.05$). The values of anthocyanin concentration are expressed as mean ± SD ($n = 4$).

A decline in anthocyanin concentration was found in the 1-month-stored grains, with a reduction of 22% compared with non-storage grains, although this reduction was constant until the end of the storage period. In contrast, the DPPH activity of the high-antioxidant capacity KAK variety was increased by 9—18% in all stored grains compared with the initial grains, with the highest values in grains stored for three and six months (Figure 4). Nonetheless, the grains stored at room temperature and 4 °C conditions were not significantly different in terms of the anthocyanin concentration in the high-anthocyanin PES variety or the DPPH activity in the high-antioxidant KAK variety.

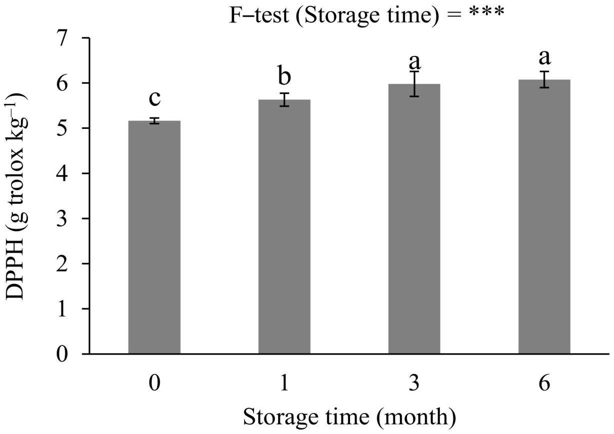

Figure 4. DPPH activity of the high-antioxidant capacity KAK variety stored in vacuum- and non-vacuum-sealed packages. Data were analyzed by F-tests (*** $p < 0.001$). Different letters indicate least significant differences ($p < 0.05$). The values of DPPH activity are expressed as mean ± SD ($n = 4$).

4. Discussion

The genotype × planting altitude interaction influenced the grain yield and nutrition qualities of the selected lines in this study. The higher grain yield when planted in the lowland altitude of the high-anthocyanin rice PES variety compared with the highland altitude resulted from the higher percentage of filled grains, but no effect of growing altitude on grain yield was found in the high-antioxidant capacity KAK variety. The low grain yield of the high-anthocyanin PES grown in the highland may have been due to the colder temperature and higher humidity compared with the conditions for plants grown in the lowland altitude, as the temperature and humidity may have reduced the formation of grains, resulting in unfilled grains. A previous study found that spikelet fertility and pollen germination on the stigma during anthesis were reduced at 17 °C [16], and a low temperature (16 °C) during the tillering stage was also found to reduce plant photosynthetic rate and growth performance in rice crops [17]. Likewise, a previous report showed that the difference in light intensity between the lowland and highland elevations could be one of the main factors affecting grain yield in rice crops [18]. There is a large gap in the flowering date between the lowland and highland plants, as higher temperatures at the lowland site may accelerate the rate of photosynthesis and the metabolism in rice, promoting an early flowering time [4,18]. Thus, a cultivation practice of growing each rice variety in the optimal condition of temperature, light intensity, humidity and rainfall would help to promote plant growth performance, productivity and grain quality. However, it is necessary to confirm the current results by increasing the number of rice varieties with variations in grain nutritional characteristics, as well as extending growing locations and altitudes.

Besides the yield, the grain anthocyanin concentration varied between the two elevations. The higher grain anthocyanin concentration in plants grown at the highland site may have been caused by the lower temperatures during plant growth and development compared with the lowland altitude. Rice plants grown at 16 °C air temperature for 28 days did not show an increase in grain anthocyanin concentration compared to plants grown at 32 °C [19], but variation may occur between cultivation and maturity, as observed in the current study. Thus, the response of grain anthocyanin synthesis to a low temperature may depend on the critical temperature at each growth stage, especially during grain formation after fertilization. This is in agreement with a previous study reporting that pigmented rice grown under high temperatures at the grain filling stage showed a decreased synthesis of grain anthocyanin caused by the suppression of gene transcription [6]. A low temperature has been reported to induce anthocyanin biosynthesis in some fruits and edible leaves [19,20], whereas the regulation of anthocyanin synthesis in purple rice under low temperature is poorly understood. Anthocyanin synthesis is influenced by light intensity, whereby low light conditions negatively affect anthocyanin synthesis in many plants [21,22]. Even though this study did not measure light parameters, light intensity can usually be estimated by humidity and rainfall. In the case of rice grown at the highland elevation, the high humidity and rainfall are supposed to indicate less light intensity; however, this did not result in lower anthocyanin concentration compared to the plants grown at the lowland site with higher light intensity. Thus, the synthesis of anthocyanin in purple rice grains in this study suggests that temperature was the factor that most strongly influenced anthocyanin synthesis in purple rice. Although the grain anthocyanin content in the PES rice variety was unstable in this study, agronomic management practices, including nitrogen fertilizer and continuous flooding culture, may help to stabilize the synthesis of anthocyanin pigments, especially when rice plants are grown in the lowland conditions [5,23]. It would be interesting to investigate the interaction effects between light and temperature in terms of grain anthocyanin synthesis among rice varieties for the health benefit of rice consumers. Interestingly, the KAK variety had a stable antioxidant capacity under the shifts in elevation, which capacity probably depends on many bioactive compounds. The presence of anthocyanins, flavonoids and phenolic acids has been documented as major anti-oxidative compounds in pigmented rice [24,25]. Future study is needed to examine in an individual compound whether it is stable when grown between the different altitudes and other management practices. However, post-harvest management by storing rice in the different conditions is one of the factors controlling the stabilization of nutritional values in rice grain after harvesting.

Most studies on the storage of rice grain have been focused on controlling stored grain pests and disease infestation [26], while limited information is available on how the storage of rice grains effects their nutritional quality, which is important information for approaching high-nutrient rice. This study has presented valuable information for storage management to stabilize grain qualities of purple rice varieties. The storage in brown rice form has the potential to retain the grain anthocyanin concentration at higher levels compared to the paddy form, in accordance with a previous study [8]. Anthocyanin degradation is caused by enzymatic activities, which may involve polyphenol oxidases, peroxidases and β-glucosidases [27], and the enzymatic degradation of anthocyanin has been detected in waste materials from rice and corn husks [28,29]. It is possible that the enzymatic activities in rice husks may interact with anthocyanin compounds and accelerate the deterioration of anthocyanin in the bran; however, the relevant chemical reactions have not been characterized. In addition, the present study has shown that sealed packaging retained more grain anthocyanin than open packaging. Likewise, dried fruits stored under evacuated O_2 and CO_2 packaging presented higher anthocyanin stability [30], possibly due to the conditions without oxidative reactions. Although sealed vacuum packaging did not lead to a significantly greater retention of anthocyanin in the 6-month-stored grains, this would be beneficial for longer periods of storage. The results indicate that storage temperature did not affect the anthocyanin or antioxidant capacity in purple rice throughout the first six months. This was also found in sorghum grains, where storage for six months did not affect anthocyanin content or antioxidant capacity under various temperatures of 4, 25 and 40 °C [31]. The storage of rice as flour at low temperatures (4 °C) during four months showed the lowest reduction in anthocyanin concentration compared to storage at higher temperatures of 25, 35 and 45 °C [32]. Thus, the stability of the grain nutritional quality as affected by storage temperature and time can be varied by the nature of the product. Similar experiments with higher numbers of purple rice varieties and a wide range of grain nutritional qualities would help to further confirm the effects of storage conditions on the stabilization of grain nutritional qualities.

5. Conclusions

This study concludes that the yield and nutritional quality of the selected purple rice varieties were influenced by the interaction between genotypes and planting elevation due to the variation in many factors present in each environment. The grain yield and anthocyanin concentration of the high-anthocyanin variety PES were varied between the lowland and highland elevations, mainly due to the variation in temperature and humidity controlling plant growth and anthocyanin synthesis. However, additional factors, including fertilizer and water management, may help to stabilize yield and grain anthocyanin content among the purple rice varieties when planting elevation cannot be controlled. Grain yield and antioxidant capacity in the high-antioxidant capacity variety KAK were stable when the variety was grown at both the lowland and highland elevations. The information obtained from this study should be valuable to farmers for the proper management of rice varieties and growing conditions to ensure the level of yield and grain quality. This study has also indicated that the special grain qualities of the selected purple rice varieties can be preserved by packaging them as brown rice in vacuum-sealed containers and keeping them at room temperature during storage. These factors can be applied as an alternative management strategy to secure grain quality for consumers, without negative impacts on grain yield for rice growers.

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(Sansanee Jamjod); Draft preparation, S.Y.; Review and editing, C.P.-u-T. All authors have read and agreed to the published version of the manuscript.

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