Nitrogen, Phosphorus and Potassium Concentrations in the Grains of Selected Rice Varieties in Sri Lanka

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ABSTRACT (HEADING 1)

Rice (*Oryza sativa* L.) is the staple food for Sri Lankans, and it serves as a key source of essential mineral elements. The variation of grain nutrient concentrations as affected by genetic factors (variety, grain color and age group) are not known, and those were tested in the current study. Total of 200 rice grain samples were collected using a stratified random sampling approach, representing all agro-climatic zones in Sri Lanka. Grain nitrogen (N), phosphorus (P) and potassium (K) concentrations were measured using Kjeldahl, Colorimetric, and General methods, respectively. Grain N P and K concentrations were significantly different among rice varieties (P<0.1). Grain N concentration varied between 4-19 mg g^{-1}. The highest grain N concentration was recorded in Bg 307 (14 mg g^{-1}) while the lowest (*i.e.,* < 10 mg g^{-1}) in Bg 367, Bg 374, Bg 358, Bg 310 and Bg 379-2. Grain P concentration varied in the range 0.6-1.7 mg g^{-1}. Grain P concentration in At 406 was the highest (1.6 mg g^{-1}), followed by Bg 307, Bg 94-1, Bg 367 *i.e.,* >1.3 mg g^{-1} and the lowest in Bg 403, Ld 365 and Bg 310 *i.e.*, < 1 mg g^{-1}. Bg 357, Ld 365, Bg 406, Ld 368 and Bg 310 rice varieties showed significantly lower P concentration than other varieties (P<0.1) Grain N, P and K concentrations were similar among different age classes of rice varieties (P>0.05). Moreover, grain N and P concentrations between the red and white grain varieties were similar (P>0.05). However, varieties with white color grains had higher K concentration than in red rice varieties. There was a significant correlation between grain P and K concentrations (r =0.496, P<0.001). This information would be useful when selecting rice varieties with high and low nutritional qualities and implementing sustainable nutrient management practices in rice-based cropping systems in Sri Lanka.

KEYWORDS: *Age class, Nitrogen, Phosphorus, Potassium, Rice*

1 INTRODUCTION

It is expected that authors will submit carefully written and proofread material. Careful checking for Rice (*Oryza sativa* L.) is one of the principal food crops belongs to the family Poaceae and has an edible starchy cereal grain (Abeysekara *et al*., 2017). It is widely cultivated throughout the world including Sri Lanka. Therefore, rice records as the most important cereal crop for Sri Lankans (Hettiarachchi *et al*., 2016). According to the Department of Agriculture in Sri Lanka, more than 1.8 million farm families rely on rice cultivation for their livelihood. As one of the most important tropical cereal, rice provides almost 21 percent of the total caloric intake of the human population and contains higher amount of nutrients such as protein, lipids, minerals, vitamins and especially dietary carbohydrates which provides most of the daily energy for the mankind mainly in developing countries. In addition to the traditional rice varieties, Department of Agriculture in Sri Lanka has developed high yielding, improved rice varieties which are currently being cultivated island wide (Samaranayake *et al*., 2017). It is also known that physiochemical and nutritional properties of rice vary significantly among varieties (Abeysekara *et al*., 2017).

Demand for rice increases with the rapid population increment. Hence, nutrient application plays a vital role in increasing productivity in order to achieve this demand (Gunaratne *et al.,* 2011). Application of fertilizers has been identified as a key factor affecting the yield and quality of rice grain

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(Gunaratne *et al.,* 2011). At present, nitrogen (N), phosphorus (P) and potassium (K) have become the major nutrients recommended to increase the productivity of rice and the quality of rice grain (Moe *et al*., 2019). Rice is the major source of energy, protein, minerals and vitamins for Sri Lankans (Abeysekera *et al*., 2017; Kumari *et al*., 2017). Hence, both physiochemical properties and nutritional properties of rice grains are important to the rice consumers (Samaranayake *et al*., 2017). However, these properties show a significant difference among rice varieties (Abeysekera *et al*., 2017).

According to Ning *et al*. (2010) N effects on AA composition, protein accumulation and their distribution in rice grains. Subsequently, it enhances the eating and cooking qualities of rice grains (Ning *et al*., 2010). Murthy *et al*. (2015) also elaborated that the grain quality increases with the increment of N and P nutrition. Because, N and P are the main components of protein synthesis and protein content and this directly affects the grain quality in terms of grain strength and head rice recovery (Murthy *et al*., 2015). Both soluble and storage proteins of rice grains and their distribution vary with N content of grains (Leesawatwong *et al*., 2005). Nitrogen also contributes to yield by facilitating many physiological processes including photosynthesis. However, N is the most crucial and limiting nutrient that affects grain yield (Wang *et al*., 2017).

Potassium plays a vital role in unloading sugars from chloroplasts to grain storage cells through phloem cells. Therefore, K deficiency would result in low grain yield of rice (Ranamukhaarachchi *et al*., 2006). In addition, K is important in regulating stomatal movements, photosynthesis and N metabolism (Hou *et al*., 2019). About 60 – 85% soil P is stored in grains and therefore, considerable amount of P is removed at harvest through grains (Wang *et al*., 2016; Yamaji *et al*., 2017). Moreover, most of the grain P is non-accessible to humans as the major fraction of grain P is present in the chemical form called phytate which cannot be easily digested. Therefore, understanding P concentration in rice grains is important to manage P removal from agricultural lands and avoid eutrophication (Yamaji *et al*., 2017).

As an agricultural country, Sri Lanka possesses large number of traditional rice varieties with high medicinal and nutritional properties. However, as a result of population growth and technology development improved rice varieties were introduced (Hafeel *et al*., 2020). At present, improved rice varieties are widely cultivated in the country due to their high yield, disease resistance and drought tolerance (Diyabalanage *et al*., 2016). It has been reported that out of the total paddy cultivating lands, 98.8% is acquired by improved rice varieties (Liyanaarachchi *et al*., 2020). Bg360, Bg352, Bg367, Bg366, Bg358, At306, At405 are commonly used improved rice varieties by Sri Lankan farmers (Hettiarachchi *et al*., 2016). Accumulation of N, P and K in rice grain may vary with rice varieties, grain color and their age group. However, this variability has not been explored before. Hence this study was designed to provide necessary information on the accumulation of N, P and K in rice grains. Using these data; N: P: K ratios of different rice varieties can be generated and subsequently it can be used to balance the fertilizer application plans. Information from this study can be used to reduce nutrient losses through harvesting and minimize environmental pollution through fertilizer application.

2 MATERIALS AND METHODS

2.1 Grain sample collection

Total of 200 grain samples were collected representing 25 administrative districts, different irrigation methods and agro-climatic zones (ACZ). Twenty-five panicles were collected from a selected paddy track (*Yaya*) representing the mainly cultivated rice variety of that *Yaya*. Grain samples collection was done using a stratified random sampling approach as described in Kadupitiya *et al*. (2021).

2.2 Grain potassium and phosphorus measurements

One gram of de-husked rice grain sample was taken to the crucible. It was kept inside the muffle furnace for two hours until getting the ash. Temperature was set as 200 °C in the 1st hr and 450 °C in the 2nd hr. After cooling the sample, five mL of 6 M nitric acid was added in to the crucible by using 5 mL pipette. Then grain ash was mixed with nitric acid properly by using a glass rod. It was put in to the 100 mL beaker and crucible and glass rod were washed out with 1% nitric acid in to the beaker. Then beaker was boiled about 15 minutes and 5 mL of 3 M nitric acid was added during boiling. Then solutions were kept outside for cooling. Beaker solution was filtered into the 50 mL volumetric flask.

Beaker was washed and filtered in to the volumetric flask. Then it was volume up until 50 mL by using distilled water.

For P concentration measurements, 2 mL of solution were pipetted out from the volumetric flask and added in to the test tube by using 2 mL pipette. Then 6 mL of distilled water was added in to the test tube. 2 mL of nitro-vando molybdate was added in to the test tube. After that, the test tube was shaken properly. Then P concentration was measured by using spectrophotometer.

Potassium concentration in 50 mL volumetric flask was measured by using the flame photometer. When determining both P and K concentrations in rice grain samples, laboratory standards and blanks were used for quality control (Givens *et al*., 2004).

2.3 Grain nitrogen measurements

De-husked rice grain samples were ground by using mortar and pestle. Then one gram of grain sample was measured by using electronic balance and added it in to the Kjeldahl tube. Then 7 mL of sulfosalicylic acid was added in to the tube and it was kept for 30 minutes in fume hood. Then 0.5 g of sodium thiosulfate was added in to the tube and again it was kept for 15 minutes. Then 0.2 g of catalyst mixture was added in to the tube. Then 3 mL of conc. sulfuric acid and 3 mL of hydrogen peroxide were added in to the tube. Then Kjeldahl tube was kept about one and fifteen hours in digestion unit under 380 °C temperature. After the digestion, it was kept about 30 minutes for cooling. Then 30 mL of distilled water was added in to the tube. Then it was distilled by using distillation unit. Twenty mL of methyl bromide solution was placed in to the conical flask, and it was kept inside the distillation unit. After the conical flask was filled to 100 mL and the solvent turns green, it was titrated until the solvent color was getting light pink color by using 0.1 M of HCL. When determining N concentration in rice grain samples, laboratory standards and blanks were used for quality control.

2.4 Statistical analysis

The mean, minimum and maximum of N, P and K concentrations were determined using descriptive statistics. Strengths of the relationships between elements (paired comparisons) were determined using Pearson's linear correlation coefficient (r). Concentration of elements among rice varieties was compared using analysis of variance (ANOVA), and mean separation was done through Duncan's Multiple Range Test (DMRT). All the interpretations are made at α=0.05.

3 RESULTS

3.1 Grain N, P and K concentration of selected rice grains in Sri Lanka

Nitrogen concentration in rice grains was relatively higher than P and K concentrations (Fig. 1). Nitrogen concentration of rice grains varied between 3.95 mg g^{-1} to 19.36 mg g^{-1} with a mean value of 10.80 mg g^{-1}. Mean grain P concentration was 1.17 mg g^{-1} and it ranged between 0.10 mg g^{-1} to 1.76 mg g^{-1} (Fig. 1). Grain K concentration was in the range of 1.61 mg g^{-1} to 4.65 mg g^{-1} with a mean value of 2.81 mg g^{-1} (Fig. 1).

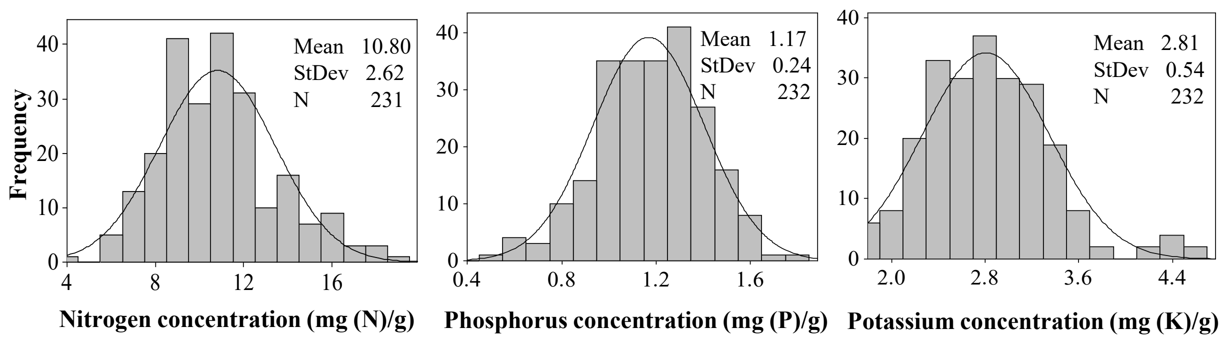

Figure 1. Distribution of N, P and K concentrations of selected paddy grains in Sri Lanka

3.2 N, P and K concentration of selected rice varieties

Grain N, P and K concentrations were significantly differed among selected rice varieties ($P<0.1$). The highest grain N concentration was recorded in Bg 307 (14 mg g^{-1}) while the lowest in Bg 367, Bg 374, Bg 358, Bg 310, Bg 379-2 *i.e.,* < 10 mg g^{-1} (Fig. 2). Traditional rice varieties recorded 11.42 mg N g^{-1} concentration.

At 406 and Bg 307 rice varieties showed the highest grain P concentration *i.e.,* > 1.50 mg g^{-1} while Bg 403, Ld 365 and Bg 310 varieties recorded lowest P concentration i.e., less than 1 mg g^{-1} (Fig. 2). Bg 357, Ld 365, Bg 406, Ld 368 and Bg 310 rice varieties showed significantly lower P concentration than other varieties ($P<0.1$). 68% of the farmers have cultivated rice varieties bred at Batalagoda followed by Ambalantota (19%), bombuwala (7%), Labuduwa (2.6%) and traditional rice (2.6%) varieties.

Grain N, P and K concentrations were similar among the age categories of selected rice varieties *i.e.,* 3, 3.5, 4, 4.5 age categories. Most of the cultivated rice varieties belonged to 3.5 months age category (85%) while the second highest was in the age group less than three months (11%). Moreover, grain N and P concentrations between the red and white grain varieties were similar ($P>0.05$). However, varieties with white color grains had higher K concentration than in red rice varieties. At 406, Bg 307 rice varieties recorded relatively higher N, P and K concentrations.

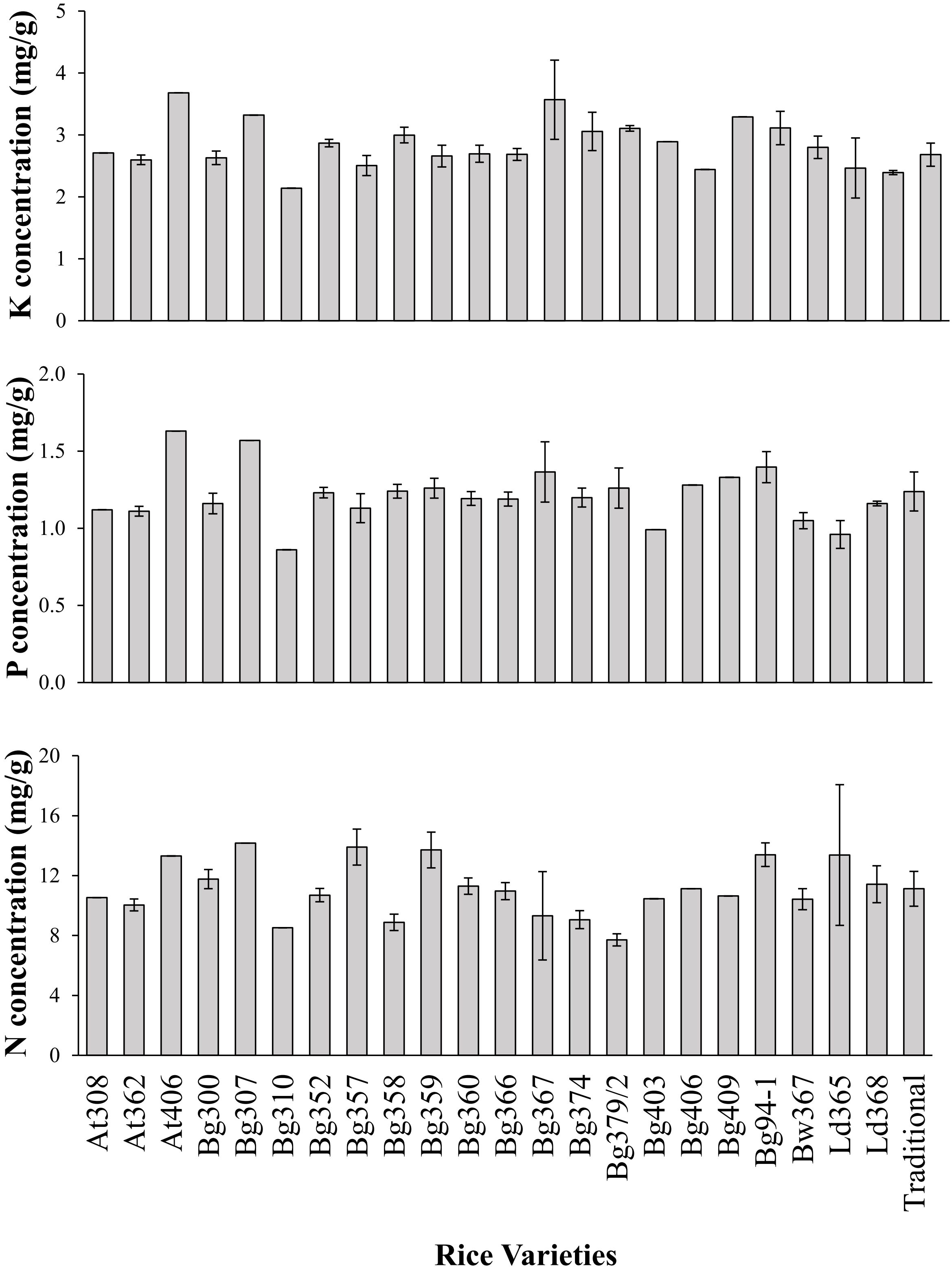

Figure 2. Nitrogen, phosphorus and potassium concentrations of selected rice varieties

3.3 Relationships between N, P and K concentrations of rice grains

There was a significant correlation between grain P and K concentrations (*r* =0.496, P<0.001) (Fig. 3). However, correlation between N and P concentrations, and N and K concentrations were not significant (P>0.05) (Fig. 3).

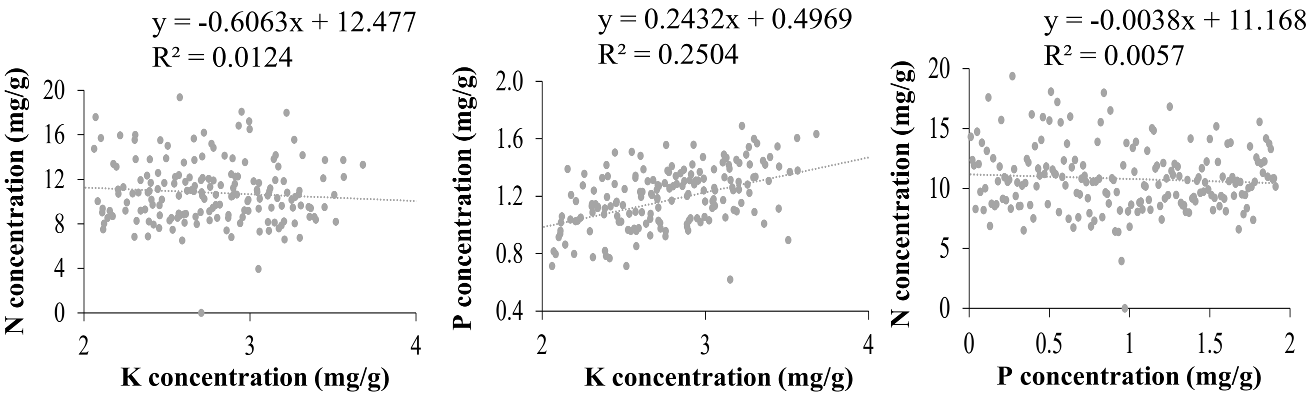

Figure 3. Linear relationships between grain N, P and K concentrations

4 DISCUSSION

Nitrogen, P and K are the essential nutrients which are responsible for high productivity (Lan *et al*., 2012). According to Li *et al*. (2014) there was a difference in N, P and K accumulation among varieties in China. In our study grain N, P and K concentrations exhibited a significant difference among varieties (Fig. 3.2). When comparing three graphs of N, P and K concentrations (Fig. 3.2), N concentration was considerably high in all selected rice varieties. Urea is the main source of N used in paddy cultivation. Almost all farmers (100% farmers of the study) applied urea as the main source of N fertilizer (data not shown). Murthy *et al*. (2015) reported that N uptake and accumulation in rice plant and grain significantly increased when increase the N fertilizer dose. High N concentration creates favorable conditions for foliage growth to enhance the accumulation of photosynthates and eventually it increases the growth and the yield (Murthy *et al*., 2015). In this study all rice varieties recorded high N concentration indicating high uptake due to the high availability of N in soil. According to Fig. 3.2, K and P concentrations in grains were relatively low. However, the concentrations of P and K do not reflect deficiency for rice. All farmers except few have applied TSP (98%) and MOP (99%) as P and K sources in to the soil. Overall results reveal that the observed grain N, P and K concentrations were reached due to the application of N, P and K through supplementary fertilizers and it would be needed to maintain the same practice to ensure similar grain N, P and K concentrations.

In Sri Lanka, all the rice varieties belong to genotype of *Indica*. Yulong *et al*. (2021) reported that *Indica* rice has higher nitrate absorption activity than *Japonica*. However, in their study the average grain N concentration reported was 11.8 mg g^{-1} (Yulong *et al*. 2021). In this study, the average grain N concentration reported was 10.8 mg g^{-1} which is similar as Yulong *et al*. (2021). Hafeel *et al*. (2020) analyzed the crude protein (CP) content of improved and traditional rice varieties of Sri Lanka and reported that N concentration of improved rice varieties varied from 8.3 to 15.25 mg g^{-1} in cooked rice (Hafeel *et al*., 2020). When considering the findings of Abeysekara *et al*. (2017) the maximum N accumulation by rice grains could not be occurred under Sri Lankan condition. Other than the varietal effect, N, P, and K concentrations may vary with soil type, environmental factors and the rates of fertilizer application especially, urea and muriate of potash (Lie *et al*., 2014; Pinson *et al*., 2014). Recent study revealed that grain N concentration also affect by the climatic change (Yulong *et al*., 2021). Yulong *et al*. (2021) elaborated that climate warming could increase N concentration in crop while lowering the Nitrogen use efficiency (NUE). Therefore, proper N application and management would result maximum utilization and accumulation of N in rice grains (Li *et al*., 2014). Pinson *et al*. (2014) reported grain K concentration in between 1.5 – 4.3 mg g^{-1} and P concentration in between 2.19 – 4.78

mg g^{-1} (Pinson *et al*., 2014). Potassium concentrations reported in the present study (1.6 – 4.7 mg g^{-1}) are in agreement with Pinson *et al*. (2014). However, P concentration reported in this study is less than that reported by Pinson *et al*. (2014). Cassman *et al*. (2002) defined that 10 – 12 mg g^{-1} is the ideal N concentration for grain which is given optimal cooking and eating quality. Interestingly, our findings are agree with that by given N concentration in 10 mg g^{-1}. Moreover, Huang *et al*. (2020) reported that the daily requirement of P and K concentration of human 800-1000mg and 2000-2500mg respectively.

Many studies reported that N accumulation is positively related to K accumulation (Lie *et al*., 2014; Hou *et al*., 2019). According to Lie *et al*. (2014), a positive correlation between N, P and K accumulation was present in high yielding rice varieties. Recent study showed that both grain N and K are critical elements to enhance yield. Nitrogen directly affects grain yield and yield components. Moreover, N accumulation of rice grains is influenced by K application. Maximum N utilization and accumulation by rice grains could be achieved by proper management of both N and K (Hou *et al*., 2019). However, present study did not show a correlation between N and K concentrations of rice grains. In comparison to N concentration, K and P concentrations reported were at low levels. Stone and Homberger (2016) described that, farmers especially in the Asian countries apply more N fertilizer (urea) exceeding the recommended level, as it is cheap without considering its effective utilization. According to Hou *et al*. (2019) adding more N without considering K application is wastage. High N concentration in grains reflects that more N is available in soil to be taken up by rice grains. However, it does not reach to the maximum level. Because, effective N accumulation was prevented by low K concentration. However, there was a correlation between K and P concentrations (Fig. 3.3). According to Pinson *et al*. (2014) the strongest and most consistent correlations are occurred among P, K and Mg. This P and K correlation is not considered in terms of chemical analogs or uptake mechanism. However, P and K correlations are highly associated with grain accumulation which means that P is available in the grain as a mixed form of K-Mg salt in phytic acid. Therefore, a high correlation could be seen among P, K and Mg (Pinson *et al*., 2014).

According to the present study, N and P concentrations were similar among both red and white rice varieties. But, varieties with white color grains had higher K concentration than in red rice varieties. However, Priya *et al*. (2019) reported that red rice varieties contain more N and P than white rice varieties due to the presence of rice bran (Priya *et al*., 2019). Nitrogen concentration in Sri Lankan red rice was reported as 15.41 mg g^{-1} whereas Priya *et al*. (2019) reported it as 10.56 mg g^{-1}. The study conducted by the Jiang *et al*. (2008) found that K concentration of milled rice from white brown rice were higher than those from red and b lack brown rice. Moreover, the variation in nutrient composition in different rice varieties also differ with the environmental condition, nature of soil and fertilizer application (Jiang *et al.,* 2008). Soil variation and fertilizer application by farmers which were not analyzed in this study may be the reason for this nutrient concentration variation among red rice varieties.

5 CONCLUSION

Present study revealed that the varietal effect of rice grains has a significant impact to the grain nutrient concentrations. Grain N concentration was considerably higher than P and K concentration in all selected rice varieties. Grain nutrient concentrations were similar among the age categories of selected varieties. A positive correlation could be observed between grain P and K concentrations. This information would be crucial when selecting rice varieties with high and low nutritional qualities, and implementing sustainable nutrient management practices in rice-based cropping systems in Sri Lanka.

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