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Rice (*Oryza sativa* L.) yield and potassium use efficiency as affected by potassium fertilizer sources

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Abstract
Enhancing potassium use efficiency (KUE) is vital for sustainable rice production. In a pot experiment, T_1 (Canada origin) significantly outperformed T_2 (Morocco origin) in grain yield for BRRI dhan 61 (7205 kg ha^{-1}), BRRI dhan 68 (6050 kg ha^{-1}), and BRRI dhan 28 (4227.3 kg ha^{-1}). BRRI 61 exhibited superior filled grain and 1000 grain weight under T_1. In T_1-treated soil, BRRI 61 recorded the highest grain K uptake (63.56 kg ha^{-1}), surpassing BRRI 68 and BRRI 28. With T_1, BRRI 61 demonstrated 1.24 and 2.70 times greater agronomic efficiency than BRRI 68 and BRRI 28, respectively, along with a crop recovery efficiency of 0.42. T_1 treatment improved agronomic traits across varieties. Recommending T_1 fertilizer for BRRI 61 is suggested to optimize yield, K uptake, and use efficiency, emphasizing its potential for sustainable rice cultivation.

Keywords: Potassium, source, use efficiency, rice, uptake, yield

1. Introduction

Rice (*Oryza sativa* L.) is the primary food source for more than one-third of the world's population, highlighting its significance as a main grain all over the world, including Bangladesh. Bangladesh faces the challenge of providing sustenance for a population of approximately 163.65 million people despite having only 8.75 million hectares of agricultural land (Brolley, 2015) [1]. According to a study conducted by Islam and Muttaleb (2016) [7], rice security is frequently associated with food security in numerous nations, including Bangladesh. Researchers around the globe are making a concerted effort to increase the yield potential of rice varieties. According to a study conducted by Islam *et al*., 2016 [8], the adoption of improved rice varieties, coupled with advances in soil and fertilizer management technologies, has resulted in a significant increase in crop yields in Bangladesh and other rice-growing nations. Potassium, an essential mineral micronutrient, serves a crucial role in the intricate processes of plant growth and yield. It is commonly utilized in the domain of fertilization management systems to increase crop yield (Hafsi *et al*., 2014) [5]. Potassium fertilizers have diverse compositions and release rates. The chemical composition and solubility of these fertilizers exhibit variations. The alternation between these sources has the potential to impact the availability of potassium to the rice plants (Islam *et al*., 2018) [9]. Diverse varieties of rice have distinct nutritional demands and capacities for potassium uptake. Certain cultivars of rice may possess a greater natural capacity to effectively utilize potassium derived from either the soil or fertilizers. The selection of a rice variety that demonstrates enhanced efficiency in the utilization of available potassium has the potential to yield favourable effects on potassium usage efficiency. This, in turn, would necessitate a reduced amount of potassium input for achieving optimal growth (Miah *et al*., 2006) [11]. Zhang *et al*., 2010 [16] state that the administration of potassium (K) fertilizer is a common agricultural practice used to maintain the productivity of rice crops in a rice-rice cropping system. To ensure the correct application of potassium (K) fertilizer to meet the needs of rice cultivation and to derive a justifiable approach for K fertilizer usage that maximizes financial benefits, it is essential to investigate the efficiency of K utilization, crop recovery efficiency, and agronomic efficiency (Nge, L, 2016) [13]. The optimization of potassium management in rice production encompasses a variety of strategies, such as conducting extensive soil testing to evaluate potassium levels, employing balanced fertilization techniques, selecting potassium-efficient cultivars, and implementing agricultural practices that promote enhanced potassium uptake and utilization. The purpose of these techniques is to ensure that the rice plant has access to a sufficient and balanced quantity of potassium throughout all phases of its development.

This is done to maximize the plant's growth, yield, and overall productivity. Improving potassium utilization efficiency in rice cultivation not only facilitates increased crop productivity but also promotes sustainable agricultural practices by reducing the ecological effects associated with excessive fertilizer application and optimizing the use of existing potassium reserves. This study aims to investigate the potassium use efficiency of three selected rice varieties from different potassium fertilizer sources.

2. Materials and Methods

2.1 Soil collection and analysis: A pot experiment was carried out in the field lab of Soil, Water and Environment discipline, Khulna University during January to May 2023. Surface (0-15cm) soil sample was collected, air dried, sieved with a 2 mm sieve and mixed homogeneously. Soil samples were collected for chemical and physical characterization as follows: pH-7.10, EC-1.15 dSm^{-1}, organic matter-1.73%, total K-0.89%, available K-620 mg kg^{-1} and texture-silty clay loam.

2.2 Treatments: Two sources of K fertilizers were used as treatment such as T_1=Canada and T_2=Morocco origin. The total K content in the Canada and Morocco origin was 25.82% and 23.40% respectively. Pots receive no K fertilizer termed as control.

2.3 Test plants: Commonly cultivated and easily available three rice varieties BRRI *dhan*61 (BRRI 61), BRRI *dhan*68 (BRRI 68), and BRRI *dhan*28 (BRRI 28) were utilized as test plants.

2.4 Pot experiment: Forty days old seedlings of each rice variety were transplanted into the earthen pots (26 cm in diameter and 22 cm in height) containing 5kg soil. Pots were arranged in CRD way with four replications. Each pot received the recommended dose of fertilizer for rice growth (BRAC, 2018).

2.5 Estimation of use efficiency parameters

2.5.1 Agronomic Efficiency (AE) (kg kg^{-1}): AE is used as a short-term indicator of the impact of applied nutrients on productivity and is calculated by the following equation:

$$AE = \frac{Yk - Yo}{K}$$

Y_o=Yield in control pot, Y_k=Yield in K applied pot

2.5.2 Crop Recovery Efficiency (CRE) (kg kg^{-1}): CRE is an indicator of the potential nutrient loss from the cropping system obtained from the following:

$$CRE = \frac{Uk - Uo}{K}$$

U_o= Uptake of K in the control pot, U_k=Uptake in the K-treated pot

2.6 Statistical Analysis: Minitab (version 19.0) statistical software was used to conduct a two-way analysis of variance (ANOVA) at the 95% significant level. Means and standard deviation were estimated and graphs were prepared using Microsoft Excel (2021).

3. Result and Discussion

3.1 Agronomic use efficiency (AE) and Crop recovery efficiency (CRE)

AE of three rice varieties showed significant variation with K fertilizer application (Fig 1). The AE was found higher in T_1 treatment irrespective of the rice genotypes. Among rice genotypes, BRRI 61 (24.39) produced the highest AE followed by BRRI 68 (19.70) and BRRI 28 (9.02) due to T_1. However, the increased AE between BRRI 61 and BRRI 68 did not vary significantly with T_1.

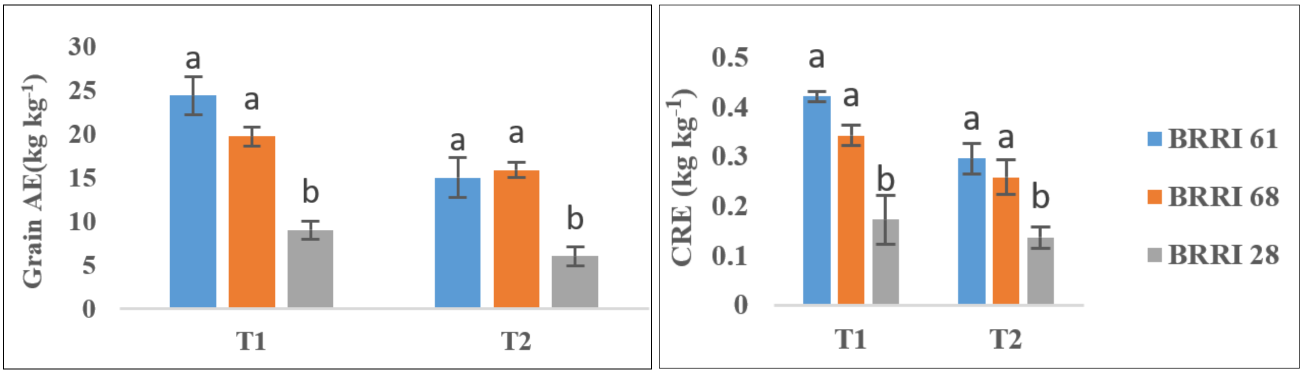

Fig 1: Effects of potassium fertilizer sources on agronomic efficiency and crop recovery efficiency of different rice varieties. Columns annotated with the same letter are not significantly different at $p \leq 0.05$.

CRE of three rice varieties was significantly influenced by the application of fertilizer sources (Fig 1). BRRI 61 showed the highest CRE (0.42) followed by BRRI 68 (0.34) and BRRI 28 (0.17) with T_1 treatment. BRRI 61 showed the highest (0.29) and BRRI 28 showed the lowest (0.13) with the application of T_2. However, the increase of CRE of BRRI 61 and BRRI 68 did not vary significantly with the application of T_1. The difference in AE and CRE may be due to the genetic differences of the rice varieties. The unique genetic characteristics of each rice variety play a crucial role in determining its capacity for absorbing and utilizing essential soil nutrients efficiently. Alterations in K use efficiencies were recorded by Silva *et al*., (2014) [15] and Sabir *et al*. (2003) [14]. This result was in accordance with the findings of Murthy *et al*., (2015) [12].

3.2 Grain and Shoot Yield

Figure 2 indicated that there was a significant ($p \leq 0.05$) variation in grain yield among different rice varieties depending on the sources of potassium fertilizer used. In control treatment, there was a variation in the grain yield and it varied from 2871 to 4400 kg ha^{-1}. The amount of yield in T_1 applied rice varieties showed a significant increase and it varied from 4227.3 to 7205 kg ha^{-1}. In T_2 applied rice varieties, it also showed a variation from 3880.8 to 6127 kg ha^{-1}.

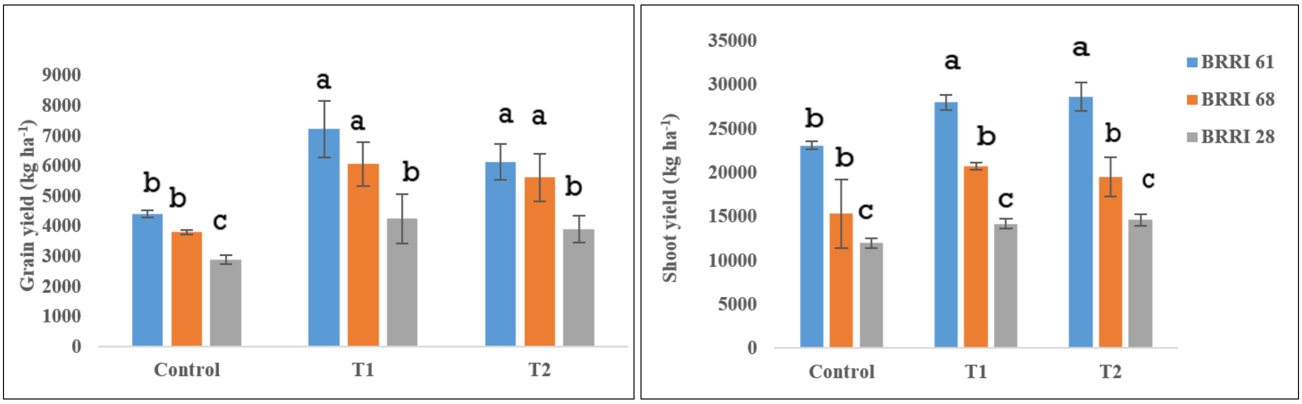

Fig 2: Effects of potassium fertilizer sources on grain and shoot yield of different rice varieties. Columns annotated with the same letter are not significantly different at $p \leq 0.05$.

The shoot yield of three rice varieties was significantly influenced by the application of fertilizer sources (Fig 2). In control treatment, there was a variation in the shoot yield and it varied from 11958.91 to 23059.19 kg ha^{-1}. The amount of shoot yield in T_1 applied rice varieties showed a significant increase and it varied from 14127.86 to 27938.49 kg ha^{-1}. In T_2 applied rice varieties, it also showed a variation from 14591.93 to 28583.66 kg ha^{-1}. The result showed that BRRI 61 and BRRI 68 had shown a significant increase in grain and shoot yield compared to BRRI 28. This was probably due to the different amounts of K uptake abilities of different rice genotypes. The result also showed that BRRI 61 and BRRI 68 had a higher K uptake ability than BRRI 28. A previous experiment conducted by Gweyi-Onyango *et al*., (2021) [4] and Ju *et al*., (2015) [10] also showed similar kinds of results.

3.3 Filled and Unfilled Grain Per Panicle

This study found a statistically significant difference in filled grain per panicle ($p \leq 0.05$) (Fig 3). Using T_1 treatment, BRRI 61 (163.75) had the highest filled grain per panicle followed by BRRI 68 (137.5) and BRRI 28 (106.75). However, the increased filled grain per panicle between BRRI 61 and BRRI 68 did not vary significantly due to T_1. With the application of T_2, BRRI 61 showed the highest and BRRI 28 showed the lowest result.

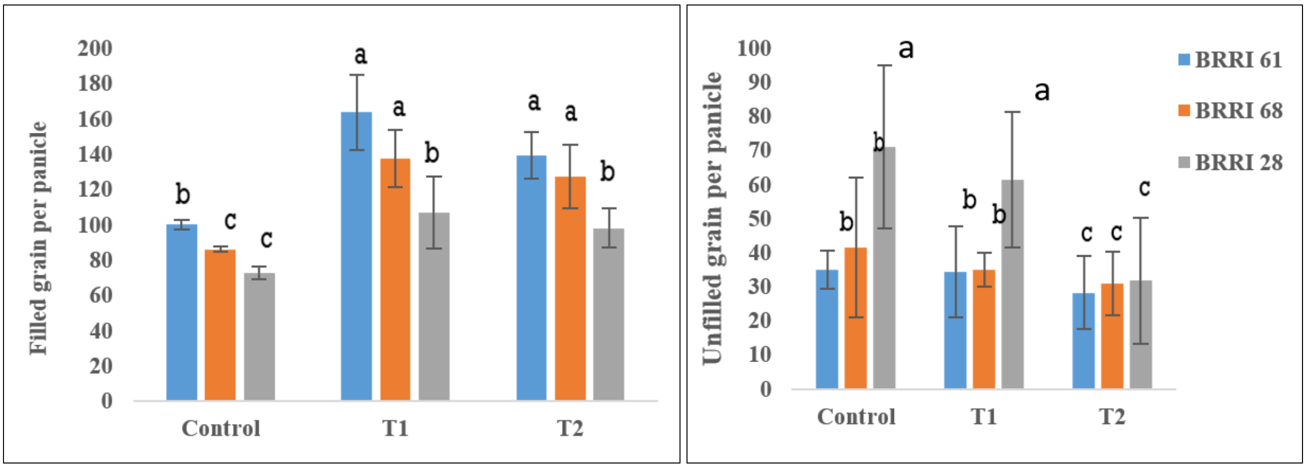

Fig 3: Effects of potassium fertilizer sources on filled and unfilled grain per panicle of different rice varieties. (Columns annotated with the same letter are not significantly different at $p \leq 0.05$)

In the control treatment in unfilled grain per panicle (Fig 3), there was a variation in the unfilled grain per panicle in rice varieties and it varied from 35 to 71. With the application of T_1, BRRI 28 showed a higher (61.5) unfilled grain per panicle followed by BRRI 68 (35) and BRRI 61 (34.25). There is no significant difference in BRRI 61(28.25) and BRRI 68 (31) with T_1 treatment. T_2 treatment showed the same result as T_1 in all rice genotypes.

A decrease in the number of unfilled grain panicles was seen across multiple treatments and rice genotypes. The most probable cause behind the variation in result is the physiological characteristics of different rice varieties on grain development and filling capacity, which may influence the production of panicles. In their previous investigation, Zubaer *et al*. (2007) [17] found similar kinds of outcomes.

3.4 Weight of 1000 Grains: The findings shown in Figure 4 indicate that there was a statistically significant increase observed in the 1000-grain weight considering the various sources of fertilizers and rice varieties. Upon the application of T_1 and T_2 fertilizers, it was observed that BRRI 61 and BRRI 68

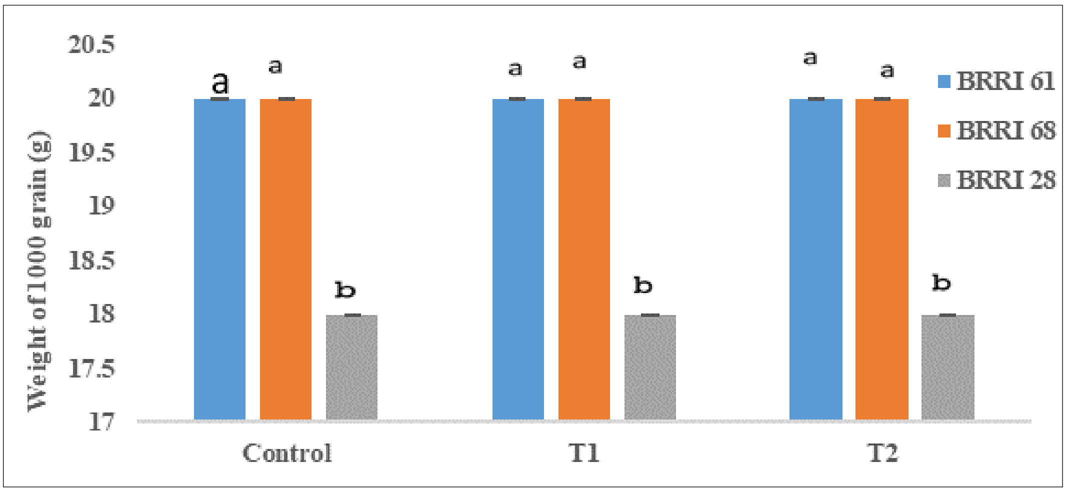

Fig 4: Effects of potassium fertilizer sources on the weight of 1000 grains of different rice varieties. (Columns annotated with the same letter are not significantly different at $p \leq 0.05$)

exhibited an equivalent 1000-grain weight of 20g but BRRI 28 had shown a significantly reduced result. The difference in the result might have occurred because of inherent physiological differences across rice genotypes. It could cause a significant variation in both growth and development of rice. Hartati *et al.*, (2018) [6] also found similar kinds of results in their research about the effectiveness of potassium fertilizer application in the quality of rice.

3.5 Nutrient Harvest Index: The Nutrient Harvest Index (NHI) was highest when both treatments were applied to BRRI 68, as shown in Figure 5 a significant difference in rice, NHI was found ($p \leq 0.05$). In control treatment, NHI varied from 6.86 to 10.82%. The amount of NHI in T_1 applied rice varieties showed a significant increase in NHI over control and it varied from 11.16 to 16.34%. In T_2 applied rice varieties, it also showed a variation from 8.50 to 17.09%.

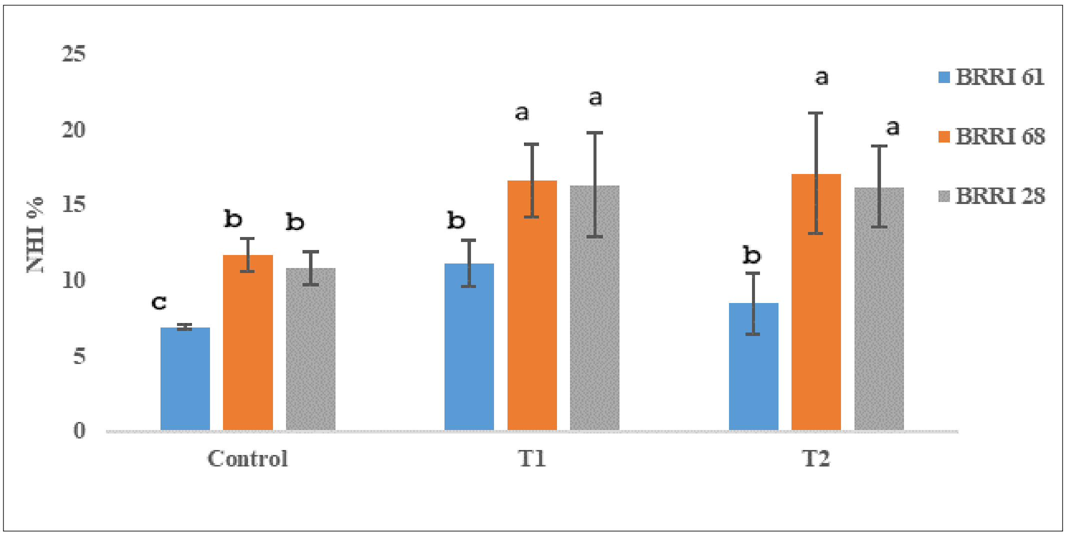

Fig 5: Effects of potassium fertilizer sources on NHI of different rice varieties. (Columns annotated with the same letter are not significantly different at $p \leq 0.05$)

Different rice varieties use different sources of fertilizer more or less effectively depending on how well they can absorb the nutrients and how they react to availability and timing. To determine nutrient proportions that affect the uptake of nutrients by various plant varieties, it is essential to manage fertilizer sources effectively. Different plant species may require different conditions to reach a balanced nutrient profile, which can affect their growth and nutrient harvest index. Deng *et al.*, (2023) [2] also found similar kinds of results.

3.6 K Uptake and Content by Rice Grain

Rice potassium (K) uptake differed significantly, with a $p \leq 0.05$ (Fig 6). In the control treatment, there was no variation in the uptake of K in rice varieties and uptake varied from 6.17 to 13.62 kg ha^{-1}. The amount of K uptake in T_1 applied rice varieties showed a significant increase in K uptake over control and it varied from 25.94 to 63.56 kg ha^{-1}. In T_2 applied rice varieties, it also showed K uptake varied from 21.87 to 49.07 kg ha^{-1}.

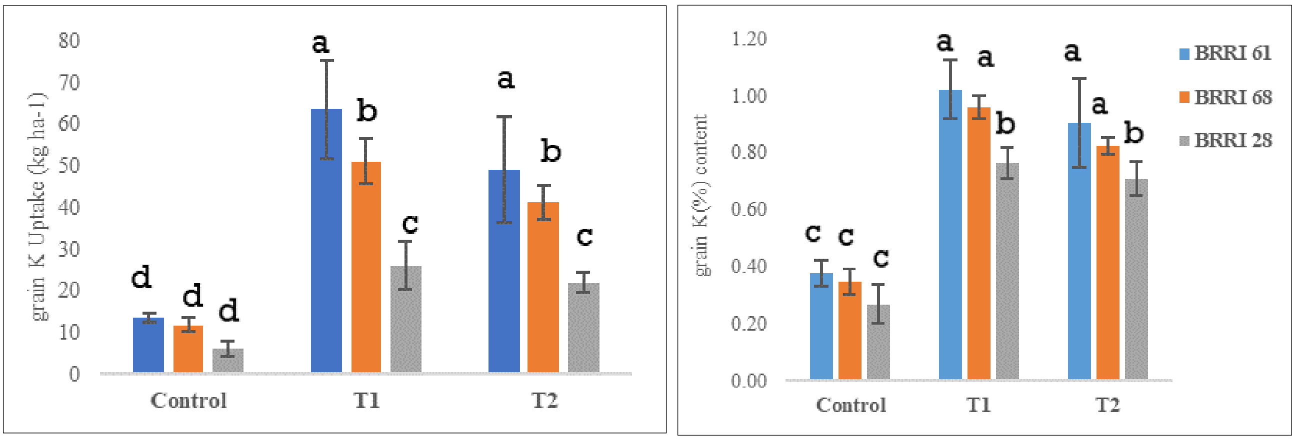

Fig 6: Effects of potassium fertilizer sources on K uptake and content by rice grain of different rice. (Columns annotated with the same letter are not significantly different at $p\leq 0.05$)

This study found significant differences in rice plant potassium (K) content (Fig 6). A statistically significant difference ($p\leq0.05$) supports the findings. All rice genotypes showed that T_1 had more potassium (K) than T_2. In the control treatment, there was no variation in the K content in the shoot of rice varieties and it varied from 0.27 to 0.38%. BRRI 61 had higher K content (1.02%) followed by BRRI 68 (.096%) and BRRI 28 (0.76%) with the application of T_1. Due to T_2, BRRI 61 showed the highest (0.9%) and BRRI 28 showed the lowest (0.71%) result. The difference seen in the result probably happened due to the variation of K content and uptake in different treatments. It can also happen because of differences in k content in different treatments. Islam and Muttaleb (2016) [7] also found similar kinds of results.

3.7 K Uptake and Content by Shoot

There was significant variation in rice potassium (K) uptake, with a $p\leq0.05$ (Fig 7). The amount of K absorbed by rice varieties' shoots varied in the control treatment, ranging from 57.72 to 205 kg ha^{-1}. The T_1 applied rice variety shoots' K uptake varied from 132.84 to 505.69 kg ha^{-1}, indicating a significant increase over the control. Additionally, it was shown that K uptake in T_2-applied rice varieties varied from 120.92 to 526.75 kg ha^{-1}.

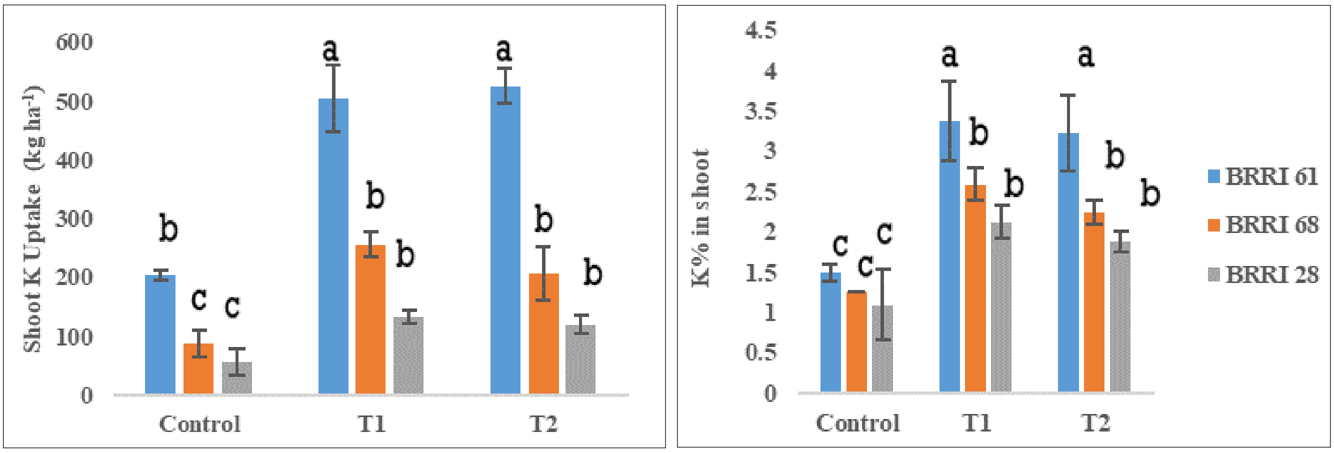

Fig 7: Effects of potassium fertilizer sources on K uptake and content by rice shoot of different rice. (Columns annotated with the same letter are not significantly different at $p\leq0.05$)

The potassium (K) content of rice plants varied significantly, according to this study (Fig 7). The results are supported by a statistically significant difference ($p\leq0.05$). T_1 had higher potassium (K) than T_2, as demonstrated by all rice genotypes. The K content in the rice varieties' shoots varied from 1.10 to 1.49% in the control treatment, with no variation observed. With the application of T_1, BRRI 61 had a higher K content (3.38%), followed by BRRI 68 (2.59%) and BRRI 28 (2.12%). T_2 resulted in BRRI 61 to show the highest result (3.22%) and BRRI 28 to show the lowest result (1.88%). The difference in K uptake and content by shoot in different rice genotypes matches the difference seen in K uptake and content by rice grain. The difference in the result was probably due to the variation of available K in the soil. The genetic variations between the rice genotypes may be the cause of it. The ability of each rice variety to effectively absorb and use essential soil nutrients is largely determined by its distinct genetic characteristics. Filho *et al*., (2017) [3] discover similar kinds of outcomes.

4. Conclusion

Potassium use efficiency of three distinct rice varieties (BRRI 61, BRRI 68, and BRRI 28) in conjunction with two potassium fertilizer sources T_1 (Canada) and T_2 (Morocco) was tested by conducting a pot experiment. T_1 significantly improved the morphological and yield characteristics of BRRI 61 compared to the other rice genotypes. Agronomic efficiency (24.39 kg kg^{-1} and 15.01 kg kg^{-1} for T_1 and T_2 respectively) and crop recovery efficiency (0.42 kg kg^{-1} and 0.30 kg $k^{-1}g$ for T_1 and T_2 respectively) were found higher in

BRRI 61 rice. Grain K content and uptake were favoured with the applied T_1 source in BRRI 61 which varied with changing the fertilizer source and rice genotypes. However, the application of potassium fertilizer from the T_2 source had deleterious impacts on yield and use efficiency parameters irrespective of the rice genotypes studied. Therefore, it can be concluded that potassium fertilizer from Canada origin can be used for better growth performance and higher yield of BRRI 61 rice.

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