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Research Article

Optimizing nitrogen and potassium for aerobic rice (*Oryza sativa* L.) in elevated -temperature environments

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Abstract
Increasing atmospheric temperature is the consequence of global warming, which is anticipated to impact crop growth and development and decrease the productivity of crops in tropical regions. The field experiments were conducted during the summer season of 2020 and 2021 at College farm, Kerala Agricultural University, Thrissur, to study the response of different rice varieties to elevated temperatures (2-3°C above ambient condition) during the flowering stage with different N and K levels under aerobic conditions. The experiments were laid out in Randomized Block Design consisting of eight treatments viz. V_1F_0 – Vaishak + 60 kg N and 30 kg K_2O (Control – ambient temperature); V_1F_1- Vaishak+60 kg N and 30 kg K_2O; V_1F_2- Vaishak+90 kg N and 45 kg K_2O; V_1F_3- Vaishak+120 kg N and 60 kg K_2O (under stress); V_2F_0- Aiswarya+60 kg N and 30 kg K_2O (Control – No stress);V_2F_1- Aiswarya+60 kg N and 30 kg K_2O; V_2F_2- Aiswarya+90 kg N and 45 kg K_2O; V_2F_3- Aiswarya+120 kg N and 60 kg K_2O (under stress). The tallest plant, higher number of tillers per hill, leaf area index, grain protein, grain and straw yield were observed with higher N and K levels (120: 60 kg/ha). The study revealed that the application of 90 kg N and 45 kg K_2O produced comparable grain yields of Vaishak (2365 kg/ha in 2020 and 2186 kg/ha in 2021) and Aiswarya (2395 kg/ha in 2020 and 2104 kg/ha in 2021) to that of 120 kg N and 60 kg K_2O/ha in both Vaishak and Aiswarya. Under elevated temperatures, the variety Aiswarya and Vaishak gave better yields to the farmers when supplied with 90 kg N and 45 kg K_2O.

Keywords: Aerobic rice, Elevated temperature, Nitrogen, Potassium, Yield

INTRODUCTION

Rice (*Oryza sativa* L.) is a staple for more than half of the world's population, with a production area of 167 million hectares and a yield of more than 782 million tons in 2018. Southeast Asia, where rice accounts for

76% of caloric intake, has worrying estimates of being the fastest-warming region on record. Despite its importance, rice cultivation has numerous challenges worldwide, including biotic and abiotic stresses (Radha *et al*., 2023). Forecasts suggest that by 2030, roughly 16% of the worldwide rice farming area will experience a minimum of 5 reproductive days over crucial temperature thresholds, with this proportion anticipated to climb to 27% by 2050 (Xu *et al*., 2020).

It is projected that by the end of the 21st century, in India the mean annual temperature will rise by 3-5°C and rice yields have been estimated to be reduced by 41 per cent due to temperature stress (Krishnan *et al*., 2020). The most sensitive stage to high-temperature stress was found to be that from flowering to maturity. The mean maximum temperature over Kerala has risen by 0.8°C, the minimum by 0.2ºC and the average by 0.5ºC, indicating that the temperature trend in Kerala followed the west coast trend (Mohan, 2018).

Adopting proper nutrient management practices could be an important step towards realising high and stable yield under high-temperature conditions expected due to global warming. Nitrogen plays a very crucial role in temperature stress tolerance as the photosynthetic capacity of plants is closely associated with leaf nitrogen content. Nitrogen fertilization is reported to mitigate the adverse effects of abiotic stresses, and studies have revealed that N-adequate plants can tolerate excess light by maintaining photosynthesis at high rates and developing protective mechanisms. Application of sufficient nitrogen during the reproductive stage is important to reduce the occurrence of heat damage (Padhan *et al*., 2023).

Potassium also plays a crucial role in the survival of crop plants under environmental stress, apart from its role in growth and yield. It is essential for many physiological processes, such as photosynthesis, turgidity, nutrient uptake, assimilate transport and enzyme activation for protein synthesis under abiotic stress conditions (Rani *et al*., 2021). It also regulates cellular turgor pressure to avoid wilt, controls the regulation of stomatal opening and closing, and greatly enhances plant drought and heat tolerance. However, very little research has been conducted on alleviating high-temperature stress through fertilizer application. The present study aimed to examine the effect of nitrogen and potassium nutrition on growth, yield attributes, yield, protein content and NPK uptake of Vaishak and Aiswarya aerobic rice varieties under high-temperature stress.

MATERIALS AND METHODS

The field experiments were conducted during the summer (January to April) of 2020 and 2021 at Kerala Agricultural University, Vellanikkara, Thrissur, to study the response of different rice varieties to elevated temperatures (2-3°C) during the flowering stage with different NK levels under aerobic conditions. For imposing temperature stress, portable transparent polythene chambers were kept in each plot from the flowering stage to the maturity stage. The experiments were laid out in a Randomized Block Design consisting of eight treatments. The Treatments were V_1F_0 – Vaishak applied with 60 kg N and 30 kg K_2O (Control – No stress), V_1F_1- Vaishak applied with 60 kg N and 30 kg K_2O under stress, V_1F_2- Vaishak applied with 90 kg N and 45 kg K_2O under stress, V_1F_3- Vaishak applied with 120 kg N and 60 kg K_2O under stress, V_2F_0 – Aiswarya applied with 60 kg N and 30 kg K_2O (Control – No stress), V_1F_1- Aiswarya applied with 60 kg N and 30 kg K_2O under stress, V_1F_2- Aiswarya applied with 90 kg N and 45 kg K_2O under stress, V_1F_3- Aiswarya applied with 120 kg N and 60 kg K_2O under stress. Vaishak was purchased from the Regional Agricultural Research Station, Pattambi, Kerala and the Aiswarya (MAS 946-1) from UAS, Bangalore. These two varieties were selected based on their better performance from previous pot culture experiments under elevated temperatures. The temperature inside the chambers was monitored and was observed to be 2-3°C above ambient conditions (28 to 33°C) (Fig 1.). 60: 30: 30 Kg N: P_2O_5: K_2O per ha is the recommended dose for upland rice as per Package of Practices (KAU, 2016).

For imposing temperature stress, portable transparent polythene chambers with the dimensions of 2 m x 2 m x 1.5 m were fabricated. The top of the chamber was covered with UV UV-stabilised polythene sheet and the sides were covered using transparent polythene sheet, leaving a gap of 15 cm from the ground level at the base for free air passage (Singh *et al*., 2010). The plot size was 5 m x 4 m, and the growth chambers were kept in the field during the flowering to maturity phase of rice. Observations were taken from sample plants inside the chamber.

The field was ploughed twice, levelled and laid out as

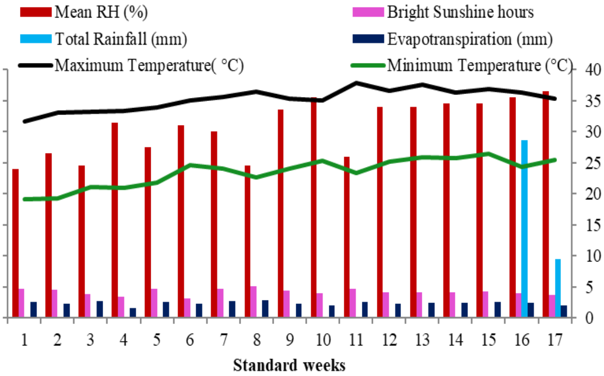

Fig. 1. *Average weather parameters during the summer season of the year 2020 and 2021*

per the experimental design. Seeds were dibbled at 20 x 15 cm spacing in each plot. Sowing was done on 1st January 2020 and 2021. Farmyard manure @ 5 t/ha was applied uniformly to all plots and mixed well with the soil. Nitrogen and potassium were applied equally in three split doses first as basal, second at active tillering and third at the panicle initiation stage. The total dose of phosphorus (30 kg/ha) was applied during land preparation. Pre-emergence application of oxyfluorfen1.5 ml/l of water was done two days after sowing (DAS). Two hand weedings were carried out, first at 30 DAS and second at 60 DAS. The crop was irrigated daily and irrigation was withheld one week before harvest. The crop was harvested at maturity. The plants outside the chamber were harvested first, and plants inside the chamber from each plot were harvested separately. The grain and straw were separately dried and weighed and yields were recorded.

Growth parameters

Plant height (cm)

In the field experiment, the height of five plants, selected randomly from each replication, was observed at 30 DAS, 60 DAS; and 110 DAS and expressed in cm. Plant height was measured from the tiller's base to the topmost leaf's tip. At harvest, the plant height was measured from the stem's base to the panicle's tip.

Number of tillers per hill

The tiller number per hill from five randomly selected plants was recorded from each replication at 30 DAS, 60 DAS; and 110 DAS and mean values were computed.

Leaf area index

The maximum length and breadth of the 3rd leaf from the top of the three tagged plants were measured at 60 DAS and the mean value was multiplied by the total number of leaves. The LAI was worked out using the formula given by Yoshida *et al*. (1976).

$$\text{Leaf area Index} = \frac{L \times B \times 0.75 \times \text{Total number of leaves}}{\text{Ground area}} \quad \text{Eq.1}$$

Where, L - Maximum length of the 3rd leaf blade from the top (cm); B - Maximum width of the leaf blade (cm)

Grain yield

The grains from an area of 2 x 2 m^2 inside the chamber were harvested separately and weighed after drying. In control plots, all the plants from each replication were harvested separately and weighed after drying. The grain yield was converted to per hectare area and expressed in kg/ha.

Straw yield

In the field experiment, the straw from an area of 2x2 m^2 inside the chamber was harvested separately and weighed after drying. The straw yield was converted to per hectare area and expressed in kg/ha.

Harvest Index

The harvest index was calculated as the ratio of economic yield to biological yield.

HI = Economic yield / Biological yield Eq.2

Protein content of grain

The crude protein content of grain was calculated by multiplying the nitrogen content with the factor 6.25 (Simpson *et al*., 1965). N content was estimated in plant samples by Kjeldahl method (Kjeldahl, 1883).

Crude protein content=6.25x Ncontent in the plant. Eq.3

Statistical analysis

The analysis of variance was carried out, and a comparison was made using Duncan's multiple range test (DMRT). The mean difference is significant at the P-values < 0.05. Statistical analysis was performed using the SPSS 16.0 software (SPSS Inc., Chicago, USA).

RESULTS AND DISCUSSION

The rice variety Vaishakh was taller than Aiswarya at all stages of growth and the plant height at 110 DAS was 114.60 cm in 2020 and 112.60 cm in 2021 for Vaishakh where, as it was only 90.20 cm in 2020 and 88.50 cm in 2020 for Aiswarya (Table 1). Though these two varieties differed significantly at various growth stages, the effect of nutrient levels on a particular variety was insignificant. At 110 DAS, the tallest plant of the variety Vaishakh was observed at 120 kg N and 60 kg K_2O/ha, which was comparable with 90 kg N and 45 kg K_2O/ha in 2020 while during 2021 the variety Vaisakh was comparable at all three N and K levels. At 110 DAS, the shortest plants were observed in the variety Aiswarya under control (116.2 cm in 2020 and 115.8 cm in 2021) which was on par with the same variety under stress in both the years. In variety Aiswarya, during 2020 and 2021 at 110 DAS, the tallest plants were recorded at the highest NK levels, significantly superior to others.

A significant difference in tiller number per hill was observed with different NK levels (Fig. 2 and 3). At 30 DAS, the higher number of tillers per hill was produced by Vaishakh as well as Aiswarya applied with 120 kg N and 60 kg K_2O, which were on par during 2020 and 2021. The lowest tiller numbers were observed with the application of 60 kg N and 30 kg K_2O both in Vaishakh (9.82 and 8.60) and Aiswarya (10.50 and 9) during 2020 and 2021. At later stages (60 DAS and 110 DAS), higher and comparable tiller numbers per hill were registered by application of 120 kg N and 60 kg K_2O and 90 kg N and 45 kg K_2O. The lowest number of tillers per hill was recorded from V_1F_1 and V_2F_1, which was on

Table 1. Effect of N and K nutrition on plant height (cm) under elevated temperature

Treat-ments	Plant height (cm)					
	30 DAS		60 DAS		110 DAS	
	2020	2021	2020	2021	2020	2021
V_1F_0	26.25 ± 0.63^{bc}	25.94 ± 0.58^{c}	83.10 ± 1.95^{a}	82.17 ± 2.13^{a}	116.2 ± 2.76^{ab}	115.8 ± 2.84^{a}
V_1F_1	26.38 ± 0.67^{bc}	26.00 ± 0.64^{bc}	83.60 ± 2.05^{a}	81.90 ± 2.01^{a}	114.60 ± 2.81^{bc}	112.60 ± 2.76^{a}
V_1F_2	27.66 ± 0.53^{b}	27.10 ± 0.51^{ab}	85.30 ± 1.60^{a}	82.60 ± 1.55^{a}	118.70 ± 2.22^{ab}	115.60 ± 2.16^{a}
V_1F_3	30.44 ± 0.87^{a}	28.30 ± 0.83^{a}	87.20 ± 2.57^{a}	84.20 ± 2.48^{a}	123.60 ± 3.64^{a}	120.70 ± 3.55^{a}
V_2F_0	24.32 ± 0.73^{c}	22.21 ± 0.68^{e}	64.4 ± 1.95^{b}	62.3 ± 1.84^{c}	91.3 ± 2.69^{de}	92.45 ± 2.70^{c}
V_2F_1	24.26 ± 0.78^{c}	22.27 ± 0.69^{e}	64.20 ± 1.98^{b}	61.20 ± 1.89^{c}	90.20 ± 2.78^{de}	88.50 ± 2.73^{c}
V_2F_2	27.10 ± 0.82^{b}	23.40 ± 0.72^{de}	67.50 ± 2.08^{b}	65.20 ± 2.01^{bc}	99.00 ± 3.05^{de}	96.30 ± 2.97^{bc}
V_2F_3	28.01 ± 0.52^{b}	24.80 ± 0.46^{cde}	69.00 ± 1.29^{b}	67.30 ± 1.26^{b}	107.10 ± 2.00^{c}	103.60 ± 1.94^{b}

Data presented are means from four replicates with standard errors. Within each treatment, different letters at each column indicate significant differences by Duncan's multiple range test at P < 0.05. Note: V_1F_0 – Vaishak + 60 kg N and 30 kg K_2O (Control – No stress), V_1F_1- Vaishak + 60 kg N and 30 kg K_2O (under stress), V_1F_2- Vaishak + 90 kg N and 45 kg K_2O (under stress), V_1F_3- Vaishak + 120 kg N and 60 kg K_2O (under stress), V_2F_0 – Aiswarya + 60 kg N and 30 kg K_2O (Control – No stress), V_2F_1- Aiswarya + 60 kg N and 30 kg K_2O (under stress), V_2F_2- Aiswarya + 90 kg N and 45 kg K_2O (under stress), V_2F_3- Aiswarya + 120 kg N and 60 kg K_2O (under stress)

par with V_1F_0 (11.65 and 10.80 in 2021) and V_2F_0 (13.23 in 2020 and 11.74 in 2021). A reduction in tiller number was observed in both varieties by harvest stage at all nutrient levels. Tiller numbers in all treatments except Aiswarya applied with 120: 60 N: K_2O kg/ha were statically comparable.

A significant difference in leaf area index was observed (Table 2). Application of 120 kg N and 60 kg K_2O in Vaishakh resulted in the highest LAI value of 5.70 (2020) and 5.40 (2021), which was comparable to Aiswarya supplied with the same NK dose (5.60 in 2020 and 5.29 in 2021) and Vaishakh applied with 90 kg N and 45 kg K_2O (5.12 in 2020), and they were superior to other treatments. The lowest value was observed for Aiswarya (4.55 and 4.23) and Vaishakh (4.77 and 4.72) applied with 60 kg N and 30 kg K_2O under control.Significant increase in grain yield was obtained with different N and K levels under high-temperature stress and a linear trend could be observed with an increase in N and K levels (Table 3). The highest grain yield of 2906 kg/ha in 2020 and 2546 kg/ha in 2021 was obtained by the application of 120 kg N and 60 kg K_2O to Vaishakh, which was on par with variety Aiswarya at the same NK level (2783 and 2358 kg/ha) and were superior to all treatments. The next highest yield was registered by the application of 90 kg N and 45 kg K_2O in Vaishakh (2365 and 2186 kg/ha) and Aiswarya (2395 and 2104 kg/ha). Under stress, the lowest grain yield was recorded with 60 kg N and 30 kg K_2O in Aiswarya (2001 and 1788 kg/ha). The grain yield of Vaishakh (2486 and 1937 kg/ha) and Aiswarya (2214 and 2098 kg/ha) under control is on par with V_1F_1 and V_2F_1 in 2020 and 2021, respectively.

Almost the same trend as grain yield was observed under high temperatures. The highest straw yield of 3602 and 3256 kg/ha was registered for Vaishakh applied with 120 kg N and 60 kg K_2O, which was superior to all treatments (Table 3). The lowest straw yield was recorded for the Aiswarya variety (2836 and 2454 kg/ha) and Vaishakh variety (2946 and 2701 kg/ha) applied with 60 kg N and 30 kg K_2O under stress, followed by Aiswarya (2214 and 2098 kg/ha) and Vaishak (2486 and 2369 kg/ha) under control in 2020 and 2021 respectively.

The Harvest index was not altered by N and K application under high-temperature stress or at ambient temperature (Table 3). Values were statistically comparable and ranged from 0.46 to 0.41 under stress. Under stress, a higher harvest index was recorded for Aiswarya applied with 120 kg N and 60 kg K_2O (0.46 in 2020), whereas the application of 60 kg N and 30 kg K_2O in Vaishakh and Aiswarya registered a lower harvest index (0.41 in 2020 and 0.42 in 2021). Under control, Vaishak and Aiswarya registered a harvest index of 0.43 and 0.44 in both years.

The grain protein content of Aiswarya applied with 120 kg N and 60 kg K_2O (5.83 and 5.32 % in 2020 and 2021) was significantly superior to other treatments (Fig. 4). Application of 60 kg N and 30 kg K_2O in Vaishakh (Control) registered lower protein content in grain (4.96 and 4.52% in 2020 and 2021).

The variety Vaishakh was taller than Aiswarya. In both varieties, height increased with an increase in levels of N and K in two years. Taller plants were observed with the application of 120: 60 kg N:K_2O/ha followed by 90: 45 kg NK/ha. At harvest, application of 120 kg N and 60 kg K_2O/ha in rice the plant height increased by 17 % (2020) and 12 % (2021) in Aiswarya and 6 % (2020) and 4% (2021) in Vaishakh compared to control (V_1F_0 and V_2F_0) in each variety. The increase in plant height with increased N application, irrespective of variety, is primarily due to enhanced vegetative growth with more nitrogen and potassium supply. This might have favourably influenced various physiological processes, includ-

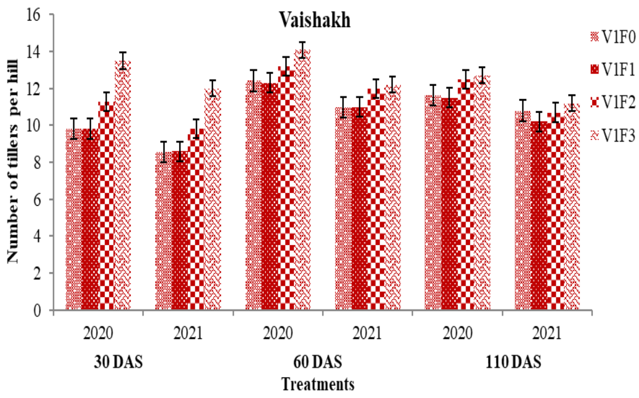

Fig. 2. *Effect of N and K nutrition on number of tillers per hill of variety Vaishakh under elevated temperature. The analysis of variance was carried out and comparison was done by Duncan's multiple range test (DMRT) at 5% level of significance [V_1F_0 – Vaishak + 60 kg N and 30 kg K_2O (Control – No stress), V_1F_1- Vaishak + 60 kg N and 30 kg K_2O (under stress), V_1F_2- Vaishak + 90 kg N and 45 kg K_2O (under stress), V_1F_3- Vaishak + 120 kg N and 60 kg K_2O (under stress)]*

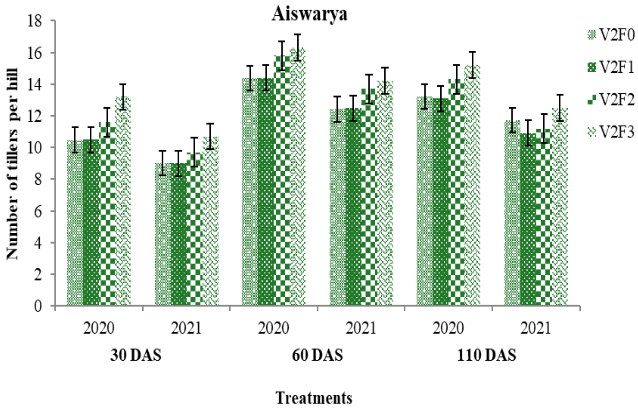

Fig. 3. *Effect of N and K nutrition on number of tillers per hill of variety Aiswarya under elevated temperature. The analysis of variance was carried out and comparison was done by Duncan's multiple range test (DMRT) at 5% level of significance [V_2F_0 – Aiswarya + 60 kg N and 30 kg K_2O (Control – No stress), V_2F_1- Aiswarya + 60 kg N and 30 kg K_2O (under stress), V_2F_2- Aiswarya + 90 kg N and 45 kg K_2O (under stress), V_2F_3- Aiswarya + 120 kg N and 60 kg K_2O (under stress)]*

Table 2. Effect of N and K nutrition on Leaf Area Index under elevated temperature

Treatments	LAI at 60 DAS	
	2020	2021
V_1F_0	4.77 ± 0.11^{bc}	4.72 ± 0.12^{bc}
V_1F_1	4.80 ± 0.12^{bc}	4.30 ± 0.11^{d}
V_1F_2	5.56 ± 0.10^{a}	4.90 ± 0.09^{bc}
V_1F_3	5.70 ± 0.17^{a}	5.40 ± 0.16^{a}
V_2F_0	4.55 ± 0.13^{c}	4.23 ± 0.14^{d}
V_2F_1	4.56 ± 0.14^{c}	4.20 ± 0.13^{d}
V_2F_2	5.12 ± 0.16^{b}	4.70 ± 0.14^{c}
V_2F_3	5.60 ± 0.10^{a}	5.29 ± 0.10^{ab}

Data presented are means from four replicates with standard errors. Within each treatment, different letters at each column indicate significant differences by Duncan's multiple range test at $P < 0.05$. Note: V_1F_0 – Vaishak + 60 kg N and 30 kg K_2O (Control – No stress), V_1F_1- Vaishak + 60 kg N and 30 kg K_2O (under stress), V_1F_2- Vaishak + 90 kg N and 45 kg K_2O (under stress), V_1F_3- Vaishak + 120 kg N and 60 kg K_2O (under stress), V_2F_0 – Aiswarya + 60 kg N and 30 kg K_2O (Control – No stress), V_2F_1- Aiswarya + 60 kg N and 30 kg K_2O (under stress), V_2F_2- Aiswarya + 90 kg N and 45 kg K_2O (under stress), V_2F_3- Aiswarya + 120 kg N and 60 kg K_2O (under stress)

ing cell division, cell elongation, intermodal elongation, photosynthesis metabolism and assimilate production under elevated temperature. Similarly, the application of 220 kg N/ha recorded the tallest plants in Egyptian rice genotypes (Gewaily *et al*., 2018). Ye *et al*. (2019) found that the plant height of rice was increased by 2.5 % compared to the control (Without nitrogen). Also, plant height increased significantly with increasing K application rate, which was 12.4-24.5 % compared to control (96.7 cm).

The tiller number also increased with N and K levels at all growth stages. At 60 DAS and harvest, the highest tiller number per hill was registered by application of 120 kg N and 60 kg K_2O in Aiswarya (15.13 and 13.50), significantly higher than N and K applied at lower levels. V_1F_1 registered the lowest number of tillers per hill followed by V_1F_0 (11.50 in 2020 and 10.20 in 2021). A reduction in tiller number was observed in both varieties by harvest stage at all nutrient levels. Also, Chandrika *et al*. (2017) stated that the aerobic rice variety Anagha registered a higher number of tillers applied with 150 kg N/ha and 50 kg K/ha. Wang *et al*. (2017) found an increase in the length of flag leaves and the number of tillers with increasing N and K amounts to the influence of N on leaf development, tiller production and increasing leaf photosynthetic activity in 'Liangyou-287' rice variety. The combined application of nitrogen and potassium produced the highest number of total tillers (Ye *et al*., 2019).

Application of 120 kg N and 60 kg K_2O in Vaishakh resulted in the highest LAI value of 5.68, comparable with Aiswarya with the same NK dose (5.44) and Vaishakh applied with 90 kg N and 45 kg K_2O. This might be due to an increased number of tillers, which resulted in more leaves with high N and K levels.V_2F_1 registered the lowest LAI followed by V_2F_0 (4.55 in 2020 and 4.23

in 2021). Similar findings were reported by Chandrika *et al*. (2017), who found that application of 150 kg N/ha and 50 kg K_2O/ha recorded the highest LAI in the aerobic rice variety Anagha. Several experiments showed that nitrogen affects the gibberellin hormone indirectly through cytokinin and increases the growth of young leaves and terminal branches in super hybrid rice 'YLT900' (Liu *et al*., 2019). At higher nitrogen levels, LAI decline was slower, which can be attributed to the positive effect of nitrogen on vegetative growth and the increase in leaf photosynthetic activity in wheat variety Xindong 20 (Zhang *et al*., 2021). In the present study, the increase in LAI was higher in the application of 120 kg N and 60 kg K_2O/ha by 25 per cent in Vaishakh and Aiswarya followed by N and K applied at 90 and 45 kg/ha (12.5 and 14 % in Vaishakh and Aiswarya).

Application of 120 kg N and 60 kg K_2O/ha increased grain yield by 36 and 38 per cent in Aiswarya and Vaishakh compared with 60:30 kg N: K_2O/ha under control. However, the yield of Vaisakh was higher compared to Aiswarya at all levels of N and K. It can be seen that application of 90:45 kg N: K_2O/ha increased grain yield by 19 and 14 per cent in Vaishakh and Aiswarya than control (2486 and 2369 kg/ha in Vaishakh and 2214 and 2098 kg/ha in Aiswarya). The increase in growth parameters such as plant height and number of tillers per hill under elevated temperature might have contributed to higher dry matter production. This increased dry matter production might have resulted in higher yield when elevated temperature is given during vegetative stages. Also, heat stress reduces plant photosynthetic capacity through metabolic limitations and oxidative damage to chloroplasts with concomitant reductions in dry matter accumulation and yield (Kaur *et al*., 2017). They also reported differences in varietal sensitivity in wheat and found that the number of tillers and panicles was inversely related to temperature. Similarly, grain yield increased relatively with an increment of nitrogen fertilizer, but a further increase in nitrogen level produced higher straw yield that ultimately gave the lower harvest index in the Anagha rice variety under aerobic conditions (Chandrika *et al*., 2017). Liu *et al*. (2019) concluded that higher N levels increased the total number of tillers and spikelets per panicle in super hybrid rice 'YLT900', alleviating rice yield loss during the flowering stage. The high temperature was detrimental to several yield components, which were alleviated by the high rate of NO_3^- fertiliser in two hybrid rice varieties 'Liangyoupeijiu' and 'Ilyou602'(Yang *et al*., 2022).

Higher doses of N and K in aerobic soil conditions also resulted in higher straw yield. The highest straw yield of 3602 and 3256 kg/ha was registered for Vaishakh ap-

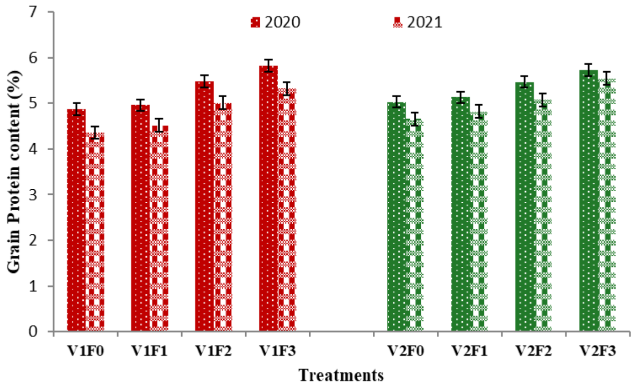

Fig. 4. *Effect of N and K nutrition on grain protein content under elevated temperature. The analysis of variance was carried out and comparison was done by Duncan's multiple range test (DMRT) at 5% level of significance. [V_1F_0 – Vaishak + 60 kg N and 30 kg K_2O (Control – No stress), V_1F_1- Vaishak + 60 kg N and 30 kg K_2O (under stress), V_1F_2- Vaishak + 90 kg N and 45 kg K_2O (under stress), V_1F_3- Vaishak + 120 kg N and 60 kg K_2O (under stress), V_2F_0 – Aiswarya + 60 kg N and 30 kg K_2O (Control – No stress), V_2F_1- Aiswarya + 60 kg N and 30 kg K_2O (under stress), V_2F_2- Aiswarya + 90 kg N and 45 kg K_2O (under stress), V_2F_3- Aiswarya + 120 kg N and 60 kg K_2O (under stress)]*

Table 3. Effect of N and K nutrition on grain yield, straw yield and harvest index under elevated temperature

Treatments	Grain yield (kg/ha)		Straw yield (kg/ha)		Harvest index	
	2020	2021	2020	2021	2020	2021
V_1F_0	2486 ± 64.21^{b}	2369 ±38.47^{bc}	2956 ± 76.82^{bc}	2964 ± 68.87^{b}	0.43 ± 0.01	0.43 ± 0.01
V_1F_1	2103 ± 51.51^{c}	1937 ± 47.45^{de}	2946 ± 72.16^{cd}	2701 ± 66.16^{b}	0.42 ± 0.01	0.42 ± 0.01
V_1F_2	2365 ± 44.25^{b}	2186 ± 40.90^{bc}	3108 ± 58.15^{bc}	2854 ± 53.39^{b}	0.43 ± 0.01	0.43 ± 0.01
V_1F_3	2906 ± 85.55^{a}	2546 ± 74.95^{a}	3602 ± 106.04^{a}	3256 ± 95.85^{a}	0.45 ± 0.01	0.44 ± 0.01
V_2F_0	2214 ±65.23^{c}	2098 ± 63.74^{cd}	2730 ± 85.62^{bc}	2543 ± 79.24^{bc}	0.44 ± 0.01	0.44 ± 0.01
V_2F_1	2001 ± 61.67^{c}	1788 ± 55.11^{e}	2836 ± 87.41^{d}	2454 ± 75.64^{c}	0.41 ± 0.01	0.42 ± 0.01
V_2F_2	2395 ± 73.82^{b}	2104 ± 64.85^{cd}	3010 ± 92.77^{bcd}	2684 ± 82.73^{bc}	0.44 ± 0.01	0.44 ± 0.01
V_2F_3	2783 ± 52.07^{a}	2358 ± 44.11^{b}	3208 ± 60.02^{b}	2874 ± 53.77^{b}	0.46 ± 0.01	0.45 ± 0.01

Data presented are means from four replicates with standard errors. Within each treatment, different letters at each column indicate significant differences by Duncan's multiple range test at $P < 0.05$. Note: V_1F_0 – Vaishak + 60 kg N and 30 kg K_2O (Control – No stress), V_1F_1- Vaishak + 60 kg N and 30 kg K_2O (under stress), V_1F_2- Vaishak + 90 kg N and 45 kg K_2O (under stress), V_1F_3- Vaishak + 120 kg N and 60 kg K_2O (under stress), V_2F_0 – Aiswarya + 60 kg N and 30 kg K_2O (Control – No stress), V_2F_1- Aiswarya + 60 kg N and 30 kg K_2O (under stress), V_2F_2- Aiswarya + 90 kg N and 45 kg K_2O (under stress), V_2F_3- Aiswarya + 120 kg N and 60 kg K_2O (under stress) plied with 120 kg N and 60 kg K_2O, which was superior to all treatments in 2020 and 2021. The average increase in straw yield was 21 per cent in Vaishakh and 14 per cent in Aiswarya compared to control (2956 and 2964 kg/ha in Vaishakh and 2730 and 2543 kg/ha in Aiswarya) in both years. It is established that nitrogen application can enhance straw yield by increasing tiller number and plant height. In super hybrid rice 'YLT900', the higher straw yield was obtained with the highest dose of NK level (140 kg N/ha and 50 kg/ha) (Liu *et al*. 2019). The straw yield increased with an increase in nitrogen levels and the highest straw yield of 11.29t/ha was obtained at 160 kg nitrogen per hectare and 60 kg potassium per ha in hybrid rice 'Arize 6444 gold'(Pal *et al*. 2021).

A significant increase in grain protein content in rice and N and K nutrition were observed, and values ranged from 4.74 to 5.63%. Grain protein content increased with an increase in N and K levels. The lowest grain protein content was observed in V_1F_0 and V_2F_0 (Control) in both years. This might be due to increased nitrogen assimilation (protein synthesis) in plants because nitrogen is a major component. The highest value of grain protein content has appeared in the wheat cultivar 'Seds 12' applied with 80 kg N/ha and 48 kg K/ha (Mohamed, 2017). Potassium is also involved in forming proteins through the polymerisation of amino acids. An increase in grain protein content in the wheat variety Siran-2010 at higher doses of K (80 kg/ha) was reported by Ali *et al*. (2019).

Conclusion

The present study showed that N and K nutrition can help mitigate the elevated temperature (31-35°C) stress in aerobic rice cultivation. Also, the response of both the varieties to higher N and K levels indicates the need to apply more N and K fertilizers in summer (28 to 33°C) under irrigated conditions. The application of 90 kg N and 45 kg K_2O produced a grain yield comparable to that of 120 kg N and 60 kg K_2O/ha in both Vaishak and Aiswarya. The increase in grain yield over the recommended dose of 60:30 kg N: K_2O/ha was about 20 per cent with the application of 90 kg N and 45 kg K_2O. The variety Aiswarya and Vaishak gave better yields to the farmers when supplied with 90 kg N and 45 kg K_2O under elevated temperatures.

Conflict of Interest

The authors declare that they have no conflict of interest.

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