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Rice Response to Spermine Foliar Application and Its Association with Aerial Imagery Monitoring Under Water Stress Conditions

(Tindak Balas Padi terhadap Pengaplikasian Foliar Spermin Daun dan Kaitannya dengan Pemantauan Imej Udara dalam Keadaan Tekanan Air)

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ABSTRACT

Rice is the most consumed food in the world, mainly in Asia and Africa. Malaysia is the second-largest rice importer in Southeast Asia after Indonesia. However, rice yield is limited by water stress. One alternative for a quicker strategy to mitigate water stress is through a combination of foliar spermine application and efficient rice management practices via image monitoring techniques using drone technology. The present study was aimed at evaluating the effects of spermine on rice physiological response and its association with aerial imagery and yield during reproductive stage under water stress. The experiment was carried out under greenhouse conditions using a two-factorial randomized complete block design (RCBD), with foliar spermine treatment as the first factor and water stress as the second factor. Physiological parameters showed significantly higher tiller number per pot and photosynthesis rate by 29% and 31%, respectively. Correspondingly, the Normalised Difference Vegetation Index (NDVI) using aerial imagery monitoring showed an increased value in spermine treatments by 2% compared to control. Furthermore, NDVI readings and photosynthetic rate were positively correlated linearly with R^2= 0.51. Interestingly, spermine treatments alleviated water stress effects by 40%, 17% and 12% in grain weight per pot, grain number per panicle and percentage filled grain. Biomass partitioning in roots improved by 44% in spermine treatments, even under water stress, due to an efficient translocation of assimilates. In conclusion, spermine foliar application significantly improved growth, grain filling and rice yield production, which was also supported by NDVI values using aerial imagery monitoring.

Keywords: Normalised Difference Vegetation Index (NDVI); rice; spermine; Unmanned Aerial Vehicle (UAV); water stress

ABSTRAK

Nasi adalah makanan utama di seluruh dunia, terutamanya di Asia dan Afrika. Malaysia merupakan pengimport beras kedua terbesar di Asia Tenggara selepas Indonesia. Walau bagaimanapun, penghasilan padi dihadkan oleh tekanan air. Antara alternatif untuk strategi yang lebih cepat bagi mengurangkan tekanan air adalah melalui gabungan semburan foliar spermina dan amalan pengurusan padi yang cekap dengan kaedah teknik pemantauan imej menggunakan teknologi dron. Penyelidikan ini bertujuan untuk menilai kesan spermina terhadap gerak balas fisiologi padi dan perkaitannya dengan imej udara dan hasil di bawah tekanan air pada peringkat pembiakan. Uji kaji ini telah dijalankan di rumah hijau dengan menggunakan dua faktor dalam Reka Bentuk Blok Lengkap Secara Rawak (RCBD) dengan rawatan foliar spermina sebagai faktor pertama dan tekanan air sebagai faktor kedua. Parameter fisiologi menunjukkan bilangan tiler di setiap pasu dan kadar fotosintesis yang lebih tinggi masing-masing sebanyak 29% dan 31%. Sejajar dengan itu, Indeks Kenormalan Perbezaan Tumbuhan (NDVI) menggunakan pemantauan imej udara menunjukkan peningkatan nilai dalam rawatan spermina sebanyak 2% berbanding kawalan. Tambahan pula, bacaan NDVI dan kadar fotosintesis berkolerasi positif secara linear dengan R^2=0.51. Menariknya, rawatan foliar spermina mengurangkan tekanan air sebanyak 40%, 17% dan 12% dalam berat biji setiap pasu, bilangan biji setiap tangkai dan peratusan biji yang berisi. Pemetakan biojisim dalam akar bertambah sebanyak 44% dalam rawatan foliar spermina disebabkan oleh translokasi asimilasi yang cekap walaupun di bawah tekanan air. Kesimpulannya, semburan foliar spermina telah meningkatkan pertumbuhan, pengisian biji dan pengeluaran hasil padi yang ketara seperti yang disokong oleh nilai NDVI yang menggunakan pemantauan imej dari udara.

Kata kunci: Indeks Kenormalan Perbezaan Tumbuhan (NDVI); padi; spermina; Kenderaan Udara Tanpa Pemandu (UAV)

Introduction

Most Asian nations consume rice as their main staple meal, and the region consumes more than 80% of the world's rice. The demand for rice is expected to rise due to the current high level of consumption as the population continues to expand. In Malaysia, rice is a staple and an integral part of the culture. However, Malaysia (2.2%) is the second largest net importer of rice recorded by the Southeast Asia (SEA) region after Indonesia (3.4%) and before the Philippines (1.2%) (Zulkafli et al. 2021). At the same time, Malaysia has the lowest self-sufficiency level (SSL) at 70% compared to the Philippines and Indonesia, with 93% and 97%, respectively (Zulkafli et al. 2021).

Rice is a heavy water feeder, but water is becoming scarce because of climate change (Chowdhury et al. 2014). It occurs mostly due to the variation in quantity and distribution of rainfall during the rainy season, and it may impact rice plants according to its timing, duration and intensity. In general, water stress is a term used to describe when the demand for water is greater than the amount of water available at a certain period of time. Water stress is one of the most severe abiotic stresses limiting rice yield worldwide, and it poses a serious threat to rice sustainability in rainfed agriculture (Wu & Cheng 2014). At the vegetative stage of rice, drought can affect development rate, plant height, leaf area and tillering, while at the reproductive stage, it mainly affects panicle branching, spikelet formation and pollen viability. After flowering, it can affect grain setting and filling and their resulting grain number and mass (Lima et al. 2021). Under extreme circumstances, it may abruptly stop several metabolic activities, reducing photosynthesis and cell division, and even causing cell death (Farooq, Wahid & Lee 2009). Plants respond to water stress as a result of a series of biochemical and physiological reactions that help maintain water balance, photosynthesis, and ion homeostasis (Razi & Muneer 2021). The rate of photosynthesis is largely dependent on stomatal movements, especially under severe water deficit conditions where stomatal conductance is substantially reduced (Dai et al. 2020). Plants close their stomata to cope with drought stress and prevent excessive transpiration, although this reduces carbon dioxide uptake and impedes the usual rate of photosynthesis in the plant. Interestingly, flag leaf (photosynthesis) contributes 20-60% to the ultimate yield (Asli & Houshmandfar 2011). The response of rice to water is more sensitive during the reproductive stage, as it is more detrimental to plant processes than other growth stages (He et al. 2020; Zain & Ismail 2016).

Spermine (SPM), one of the polyamine compounds found in plant cells, is an essential abundant substance because it protects and controls a variety of cellular roles and activities against biotic and abiotic stimuli. Various physiological processes in plants, including embryogenesis, organogenesis, leaf senescence, flowery-induction and blooming, fruit production and maturing, and abiotic and biotic plant stress responses, have been linked to spermine in plants (Berahim et al. 2021; Hussain et al. 2011). Additionally, SPM improved water-stressed plants by boosting net photosynthesis and dry matter output, which are linked to maintaining leaf water status and improving rice crop production and water usage efficiency (Hussain et al. 2011). Therefore, the introduction of exogenous spermine significantly reduced the negative effects of drought stress in certain crops (Berahim et al. 2021; Farooq, Wahid & Lee 2009). Spermine is involved in various biological functions, including cell division, growth stimulation, and the suppression of ethylene synthesis and senescence (Jonas, Salas & Baltazar 2012). On the contrary, spermine foliar can be applied quickly at controlled rates.

In recent years, data from remote sensing has become a novel and practical technique for researching vegetation's temporal and geographical dynamics (Cristiano et al. 2014). Passive sensors offer data on the amount of solar energy reflected at various wavelengths of the electromagnetic spectrum by different land coverings. In the case of vegetation, spectral indices are typically used to examine features linked to the function and structure of ecological systems. One of the most widely used spectral indicators is the normalized vegetation index (NDVI), which is highly correlated with the quantity of photosynthetic activity intercepted by vegetation and the quantity of chlorophyll content and green biomass in leaves (Cristiano et al. 2014; da Silva et al. 2020; Ya et al. 2019). Therefore, the temporal dynamics of photosynthesis rate and crop growth's productivity may be well-understood using this spectral measure. For that reason, this study was conducted to examine the spermine's effect on physiological characteristics and rice yield, as well as its association with aerial imagery under water stress conditions at the late vegetative stage.

Materials and Methods

STUDY AREA AND COMPOSITION OF THE SOIL

The experiment was conducted in the glasshouse facilities at Field 16, Faculty of Agriculture, Universiti Putra Malaysia. The properties of soil collected from the upper 20 cm were analyzed for physical (sand, silt, clay, and texture classes) (Gee & Bauder 1986) and chemical analysis (organic matter, total nitrogen, available phosphorus (Bray & Kurtz 1945) and available potassium (Metson 1956)). The soil was acquired from the Kemubu Agricultural Development Authority (KADA) rice-growing area in Kelantan, Malaysia. KADA is the second-largest granary area in Peninsular Malaysia, and it is the driest place for rice planting in Malaysia during the off-season. The soil used as a cultivation medium consists of clay loam textures (29% sand, 21% silt and 50% clay) with pH 6.1 and 1.9% organic carbon. The soil comprised 0.81% total nitrogen, 24 mg kg^{-1} existing phosphorus and 15 mg kg^{-1} existing potassium.

PLANT MATERIALS AND GROWTH CONDITIONS

The MR219 rice variety was used in this experiment. The seeds were placed in a pot with a size of 390 widths × 390 diameters × 350 mm height, containing approximately 18 kg of soil. Compound fertilizer with an equal ratio of N:P:K was applied at 140 kg ha^{-1} at 15 days after sowing (DAS), while 80 kg ha^{-1} urea was added at 35 DAS. Additionally, N:P:K blue (12:12:17:2 trace elements) was used at 100 kg ha^{-1} at 50 and 70 DAS (Berahim et al. 2021). Required plant protection measures were followed to prevent production loss from weeds, pests and diseases. In this trial, weeding was done manually with frequent visual observation. The glasshouse wire mesh keep out rodents and birds.

EXPERIMENTAL DESIGN AND TREATMENTS

In this study, two sources of water regimes (well-watered and cyclic water stress for 10-day intervals) and two foliar sprays (control and spermine (modified from Farooq, Wahid & Lee 2009)) were conducted using Randomized Complete Block Design (RCBD) with four replications. A stock solution of spermine (SPM) (Sigma-Aldrich, Malaysia) was prepared by dissolving 1 g of SPM in 100 mL of water. It was then diluted with distilled water to reach a final concentration of 100 µM. Prior to application, these solutions were kept at 5 °C. One percent of dimethyl sulfoxide (Sigma Aldrich) was prepared as a spreader-sticker in both treatments. Large plastic sheets were used to protect nearby plants from the spray solution. A Stihl-type hand sprayer (USA) was used to constantly spray the plants up to the point of runoff; on average, about 100 mL of spermine solution was applied per pot. Foliar applications were applied two times at 40 and 50 DAS in the early morning between 9 and 10 a.m. with constancy sprays. The foliar spray was applied 20 and 10 days before the reproductive stage (starting at 61-90 DAS, for 30 days). On the 30^{th} DAS, the water stress treatment for seven cycles was initiated (which lasted 10 days, with re-watering done on the first day of each cycle) (Zain & Ismail 2016). Throughout the rice cultivation, irrigation kept the water level at 5 cm.

SOIL MOISTURE, PLANT HEIGHT AND TILLER NUMBER

The soil water content was measured during the late reproductive stage (50-60 DAS) using the HH2 Moisture

Meter (Delta-T, UK). The height of the plant was then measured using the techniques outlined by Zain et al. (2014), starting at the plant's base and ending at the topmost leaf blade. Finally, a fully expanded tiller was counted as a tiller number per pot at 60 DAS with four replications.

CHLOROPHYLL CONTENT, PHOTOSYNTHETIC RATE AND STOMATAL CONDUCTANCE MEASUREMENTS

The chlorophyll content and photosynthetic rate were measured on the second leaf from the uppermost (fully developed leaf) using a portable Minolta SPAD 502 Plus chlorophyll meter (Delta T, UK) and a portable photosynthesis machine (Li-6400XT, LI-COR, Lincoln, Nebraska, USA), respectively. The CO_2 reference rate and photosynthetic photon flux density were standardized at 400 µmol $m^{-2}s^{-1}$ and 1000 mmol $m^{-2}s^{-1}$, respectively. The stomatal conductance was derived from similar equipment used by photosynthetic measurement. Four replicates for each parameter were recorded at 60 DAS.

RICE CROP IMAGING USING A MULTIROTOR UNMANNED AERIAL VEHICLE (UAV)

All plants in the glasshouse (arrangement by randomized complete block design) were taken out and arranged according to the water regime in the open space for better evaluation of the image captured. A multirotor UAV DJI Phantom 4 Pro V2.0 was used for RGB imaging with a gimbal-stabilized 4K60 and 20-megapixel RGB digital camera attached. Meanwhile, the UAV DJI Inspire 2 with a MicaSense RedEdge-M multispectral sensor was used for multispectral imaging, consisting of red, green, blue, red edge and near-infrared bands. Both UAVs were flown at 20 m from the surface with Ground Sample Distance (GSD), 1 cm and 1.37 cm per pixel, RGB and a multispectral sensor simultaneously. Before data collection, the flight plan was created on a tablet with DroneDeploy software. Then, the flight plan was designed using DJI Pilot apps on a smartphone.

All the images captured by the UAVs were imported into Agisoft Metashape Professional software to perform photogrammetric processing of digital images. The software aligned the images, ran image mosaicking and generated orthophoto and 3D spatial data for GIS applications. Then, the image data were imported into ArcGIS 10.2 software for visualization and analysis. Finally, the calculation of NDVI was carried out in the ArcGIS 10.2 software using the formula: NDVI = (NIR – RED)/(NIR + RED), where NIR: near-infrared and RED: red. The methodology and equipment used in this study are shown in Figure 1.

YIELD ATTRIBUTES

All plants were harvested at 120 DAS and dried for 72 h at 60 °C in the oven. The yield attributes measured were grain per pot, number of panicles per hill, number of grains per panicle, percentage of filled grains per panicle and thousand grains weight. The percentage of filled grains per panicle was manually counted, whereas the thousand grain weight and grain per pot were measured using a weighing scale (QC 35EDE-S Sartorius, Germany). For each treatment, ten panicles were taken as samples. Full grains were manually differentiated from empty grains before the grains were weighed. Finally, the following formula (Berahim et al. 2021) was used to get the overall proportion of filled grains:

Percentage of filled grain per panicle =

$$\frac{\text{Number of filled grains}}{\text{filled grains}} \times 100\%$$

BIOMASS PARTITIONING

At 120 DAS, four plants from each treatment were harvested. After drying the plant parts for three days at 72 °C in the oven until their dry weights were uniform, they were separated and weighed into roots, culms, and leaves. The total biomass was derived from the dry weights of the leaf, culm, root, and overall yield. The harvest index measures how dry matter is divided between grains and vegetative components. The ratio of the dry weight of the grain to the total weight was used to compute the harvest index. Harvest index is equal to grain dry weight divided by the overall dry weight of the plant (Berahim et al. 2021).

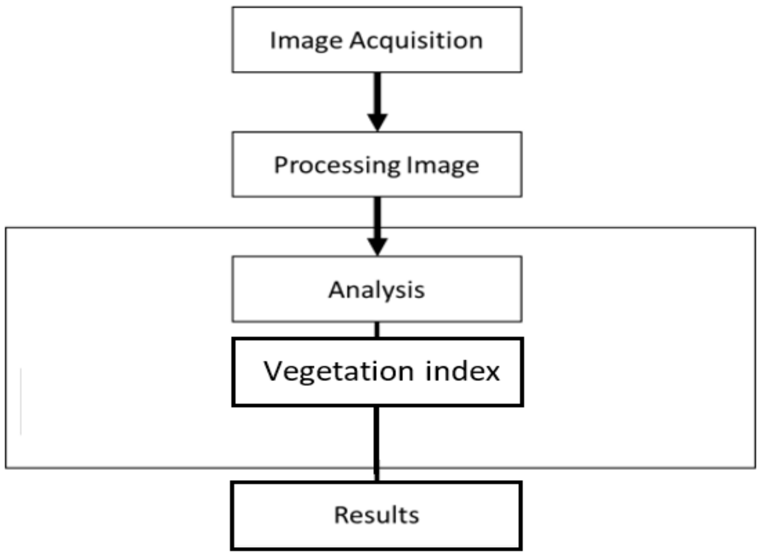
STATISTICAL ANALYSIS

All data were analyzed using Analysis of Variance (ANOVA) at $p \leq 0.05$ followed by Least Significant Different (LSD) for mean comparison analysis using the Statistical Analysis System (SAS 9.2).

RESULTS AND DISCUSSION

Generally, at the reproductive stage, the maximum water requirement is critical for grain development.

However, throughout the 10 days of water stress induction, the soil moisture content steadily declined from 80% to 32%. This range of soil moisture is categorized under severe water stress conditions, as described by Pacheco et al. (2021). The signs of plant stress were displayed on day 5, when the soil water content was 57% and the leaf started rolling (Figure 2). The signs of plant stress were similar to those of Fen et al. (2015).



(a)

(b) (c) (d)

FIGURE 1. (a) The methodology used for rice crop monitoring in this study, (b) DJI Phantom 4 Pro UAV (c) DJI Inspire 2 UAV and (d) MicaSense multispectral camera

Tiller number, plant height, photosynthetic rate, chlorophyll content and stomatal conductance of rice plants during the late vegetative stage under different foliar sprays and water regimes are shown in Table 1. There were no significant differences between the interaction of foliar sprays and water regimes in all the parameters described earlier. In foliar spray, tiller number per pot was increased in the spermine treatment with 27 tillers compared to the control (21 tillers). Similarly, spermine treatment improved chlorophyll content, photosynthesis rate and stomatal conductance by 8%, 31% and 55%, respectively. Under different water regimes, water stress treatment (13.9 µmol m^{-2} s^{-1}) increased the photosynthesis rate compared to well-watered conditions (10.5 µmol m^{-2} s^{-1}). Interestingly, spermine treatments also increased the tiller number per pot by 29% compared to control. Both spermine and water stress treatments improved the photosynthetic rate by 31% and 32% compared to the control, respectively. The highest stomatal conductance supported this parameter in spermine treatments with 374 mmol m^{-2} s^{-1}.

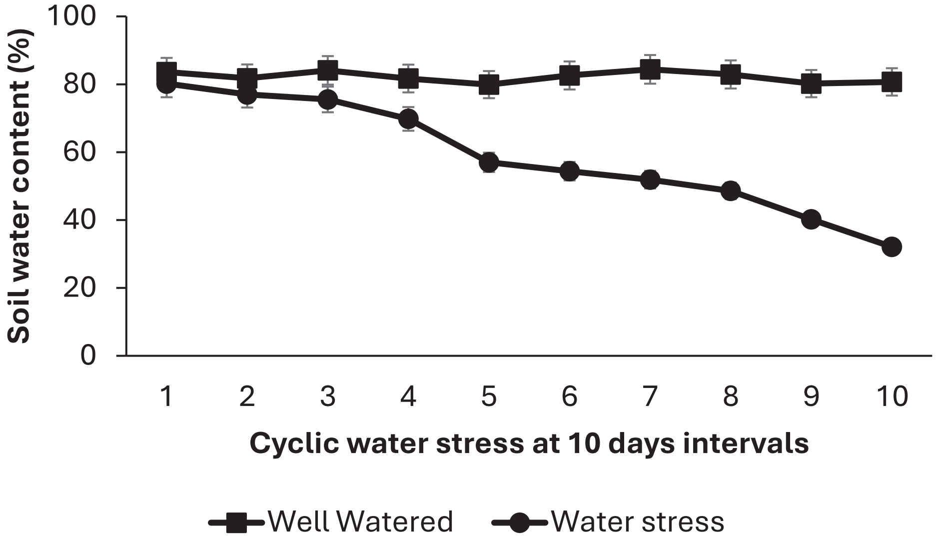


FIGURE 2. Changes in soil water content in well-watered and water stress treatment during reproductive stage (71-80 DAS) at 10 days intervals

TABLE 1. Plant height, tiller number, chlorophyll content, photosynthetic rate and stomatal conductance of rice plants during reproductive stage in different foliar spray and water regime

Treatments	Plant height (cm)	Tiller number (per pot)	Chlorophyll content (SPAD values)	Photosynthetic rate (µmol m^{-2} s^{-1})	Stomatal conductance (mmol m^{-2} s^{-1})
Foliar spray	82.6 ± 1.37^a	21±1.06^b	41.5±1.78^b	10.9±0.78^b	241±0.02^b
Control Spermine	82.8±1.14^a	27±1.60^a	44.8±0.24^a	14.3±0.78^a	374±0.02^a
Water regime					
Well-watered	83.0±1.50^a	25±0.58^a	42.6±1.13^a	10.5±0.90^b	311±0.04^a
Water stress	82.3±1.54^a	22±1.53^a	43.7±1.70^a	13.9±0.04^a	305±0.06^a
Source			F (Pr>F)		
Foliar spray, S	NS	**	**	**	**
Water regime, W	NS	NS	NS	*	NS
S x W	NS	NS	NS	NS	NS
CV (%)	2.26	11.93	6.86	9.05	11.20

Mean values followed by the same letters within a column for each factor was not significantly different at P≤0.05 by the LSD test. *P≤0.05, **P≤0.01, NS: Non-significant. Data were presented as lease square means ± standard errors. CV: Coefficient of variation

In the present study, stomatal conductance was considerably increased by spermine treatments. It was used to evaluate changes in growth in terms of tiller number, photosynthetic rate and growth rate. These results suggest spermine's capacity to act as an endogenous plant growth regulator that mediates various physiological processes in plants and endogenous spermine metabolism manipulation may impact a crop's ability to withstand drought stress (Capell, Bassie & Christou 2004; Paparella et al. 2015). Furthermore, these findings indicated that water stress and spermine treatments could increase the assimilation for recovery processes as part of the plant adaptation strategy (Hubbart et al. 2013). Short-term water stress could promote the photosynthetic potential, which is basically consistent with the results of previous studies under water regimes. This is because, at this stage, proper water stress can promote the photosynthetic activity of rice compared to the control (Zhang et al. 2023).

Foliar spermine application is one of the short-term strategies to mitigate water stress. This strategy was economical, easy to apply, and quicker to alleviate water stress in rice plants (Berahim et al. 2021). Interestingly, spermine foliar treatments improved tremendously in photosynthetic rate. It also enhanced the maximum photosynthetic rate for yield production, even during water stress. These results are similar to those of Berahim et al. (2019) and Farooq, Wahid and Lee (2009). Furthermore, they discovered that exogenous spermine treatment enhanced rice tolerance to drought, as shown by photosynthetic capacity under water scarcity (Farooq, Wahid & Lee 2009; Zhang et al. 2008), which also supported the findings of the current study.

Table 2 and Figure 3 show the RGB and multispectral images from the Unmanned Aerial Vehicle (UAV) at the reproductive stage with NDVI values. There was a significant difference between the interaction of foliar sprays and water regimes. Interestingly, with UAV monitoring using a multispectral sensor, there are higher NDVI values between treatments, mainly with foliar spermine applications. Spermine foliar treatments enhanced the value of NDVI under water stress (0.8614) compared to the control (0.8465). Remarkably, NDVI values were increased under spermine foliar applications in both water regimes. These results indicated that multispectral and RGB cameras are appropriate tools for growth and yield monitoring or prediction (Elshikha et al. 2022; Zhang et al. 2021).

TABLE 2. Average normalized difference vegetation index (NDVI) values in different treatments during the reproductive stage in different foliar spray and water regime

Treatments	NDVI (NDVI values)	
Water regime	Well-watered	Water stress
Foliar spray		
Control	0.8388±0.01[a]	0.8465±0.01[b]
Spermine	0.7958±0.01[b]	0.8614±0.01[a]
Source	F (Pr>F)	
Foliar spray, S	**	
Water regime, W	**	
S x W	**	
CV (%)	4.33	

Mean values followed by the same letters within a column not significantly different at P≤0.05 by the LSD test, *P≤0.05, **P≤0.01, NS: Non-significant. Data were presented as lease square means ± standard errors. CV: Coefficient of variation

Spermine foliar applications enhanced photosynthetic rate with NDVI values. Figure 4 shows a positive linear correlation between NDVI values and photosynthetic rate. The significant coefficient of 0.51 in the relationship showed that the highest NDVI values were obtained with 0.7958 NDVI values and 14.3 µmol m^{-2} s^{-1} in spermine treatments. Based on regression (y = 0.0171x + 0.5715, R^2 = 0.51), the relationship demonstrated that the increase in photosynthetic rate increased NDVI values. Similar findings by Muraoka et al. (2013) and Zhang et al. (2020) found that the canopy photosynthetic capacity correlated significantly with vegetation indices, including the NDVI values.

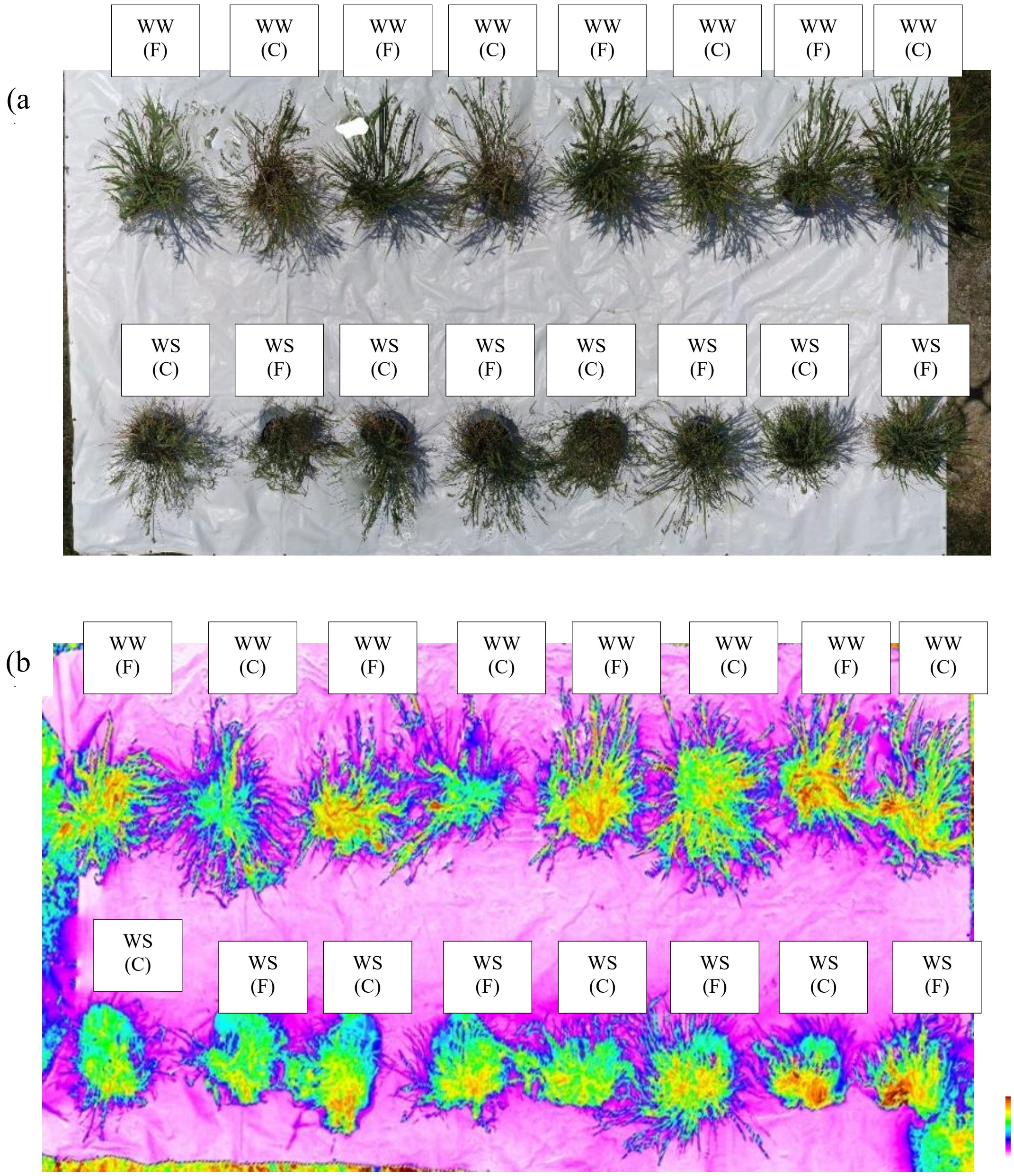


FIGURE 3. (a) RGB and (b) NDVI images were generated from the RGB and multispectral sensors during reproductive stage. WW: well-watered, WS: water stress, C: control treatments and F: Spermine foliar treatments

As shown in Figure 5 and Table 3, when compared to well-watered treatments, yield components are considerably impacted by water stress. There were significant differences between the interaction of foliar sprays and water regimes in grain filling percentage and thousand grain weight, but not for other parameters. A reduction of 34% of grain filling and grain weight losses under water stress treatments was obtained compared to well-watered. Interestingly, spermine treatments alleviated water stress effects by 40% and 14% of grain weight and well-watered treatments compared to control, respectively. The treatment with spermine also resulted in statistically significant increases in grain number per panicle (17%) and filled grain percentage (12%). In comparison to the control, which weighed only 19.2 g, the spermine treatments increased the 1,000-grain weight by 10%. Under water stress treatment, the harvest index reading decreased, showing a 28% decrease in yield production.

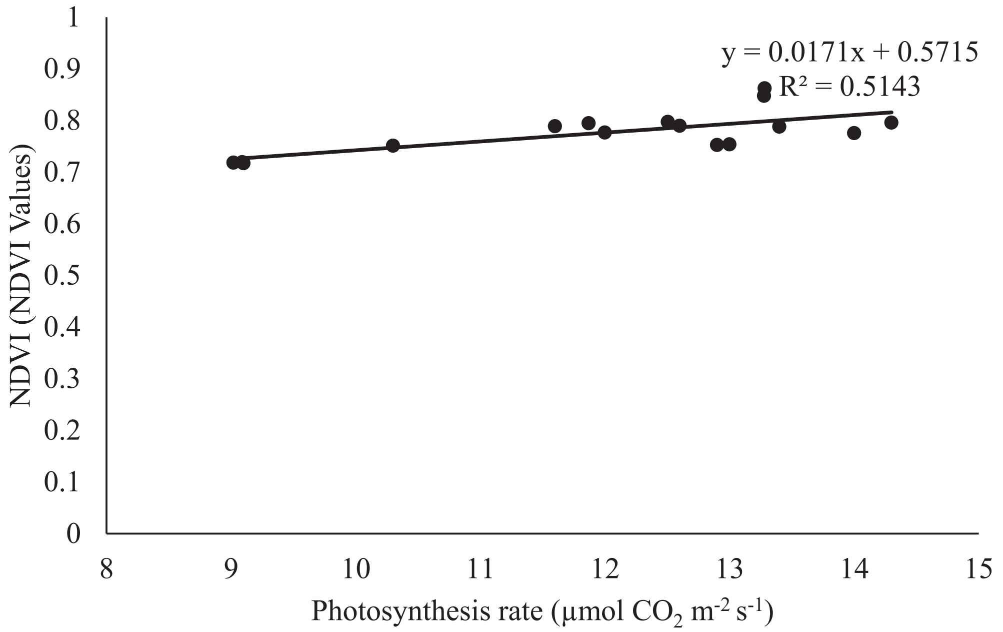


FIGURE 4. Relationship between normalized difference vegetation index (NDVI) with photosynthetic rate of rice plants

FIGURE 5. Rice grain per pot (21-27 panicles) at 120 DAS in well-watered with control treatment (WW+C), well-watered with spermine treatment (WW+SPM), water stress with control treatment (WS+C) and water stress with spermine treatment (WS+SPM)

Grain weight and grain filling were the most affected during water stress. The usage of spermine sprays on rice plants led to enhanced yield components, as similarly reported by Lemoine et al. (2013) and Sekhar et al. (2015). Previous studies have suggested that spermine may promote effective sink activity by enhancing the metabolic processes of assimilating intake and alteration and, concurrently, improving the partitioning of dry matter to generative storage organs (Hussain et al. 2011).

Figure 6 shows rice biomass partitioning at 120 DAS in different foliar sprays and water regimes. Both factors were not significantly different, but there was a significant difference between the interaction of foliar sprays and water regimes in culm biomass only. However, spermine foliar treatments improved root biomass by 41% at 120 DAS compared to control. Water stress treatments also enhanced root weight by 9% in the same DAS compared to well-watered conditions. Remarkably, adding foliar spermine and water stressed treatments altered the assimilate partitioning pattern. The dry matter was separated away from shoot organs and reallocated into the roots by 44% and 43.6% in spermine and under water stress treatments, respectively. For whole plant dry matter, there was a 10% and 10.2% reduction of assimilate partitioning in spermine and water stress treatments, respectively. These findings indicated that under water stress and spermine treatments, the plant adaptation strategy was to search for water availability in the soil by elongation or expansion of the roots, known as hydrotropism. This method of coping with water stress by shifting the direction of root growth when there is a lack of water is an efficient survival technique (Chang et al. 2019).

TABLE 3. Yield attributes of rice plants at 120 DAS in different foliar spray and water regime

Treatment	Panicle length (cm)	Number of grains (per panicle)	Filled grains (%)	1,000-grain weight (g)	Grain weight (g/pot)	Harvest Index
Foliar spray	23.6±1.10[a]	119±3.90[b]	70.9±3.64[b]	19.2±3.03[b]	50.4±1.52[b]	0.28±3.04[a]
Control Spermine	24.1±1.75[a]	139±4.31[a]	83.1±4.10[a]	21.2±2.38[a]	70.9± 0.98[a]	0.27±1.97[a]
Water regime						
Well-watered	25.4±0.90[a]	155±3.43[a]	80.9±1.19[a]	23.1±0.60[a]	80.9 ±1.44[a]	0.32±2.87[a]
Water stress	22.2±0.29[b]	100±2.36[b]	60.6±7.31[b]	21.9±0.67[a]	60.6 ±1.94[b]	0.23±3.88[b]
Source				F (Pr>F)		
Foliar spray, S	NS	**	**	*	**	NS
Water regime, W	**	*	**	NS	*	*
S x W	NS	NS	NS	NS	NS	NS
CV (%)	14.46	4.99	9.18	4.09	6.01	11.24

Mean values followed by the same letters within a column each factor was not significantly different at P≤0.05 by the LSD test, *P≤0.05, **P≤0.01, NS: Non-significant. Data were presented as lease square means ± standard errors. CV: Coefficient of variation. DAS: Days after sowing

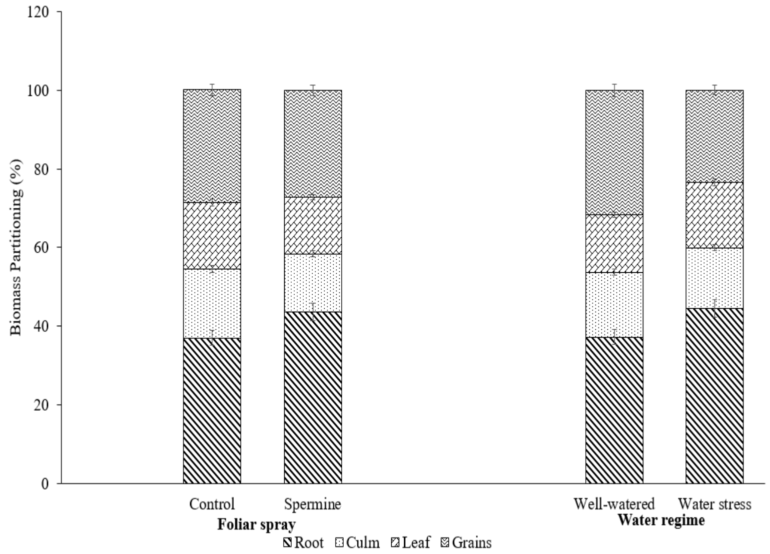


FIGURE 6. Biomass partitioning (%) of rice plants at reproductive stages in different foliar spray and water regime

CONCLUSION

In conclusion, spermine foliar application mitigated the water stress effect during late vegetative stage through the improvement of physiological characteristics, including rice yield performance, which is also supported by aerial imagery values.

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