



UDC 633; DOI 10.18551/rjoas.2023-05.15

## STOMATAL CONDUCTANCE OF DUKU (*LANSIUM DOMESTICUM* CORR.) IN RESPONSE TO INUNDATION

Mapegau Mapegau, Hayati Islah, Nusifera Sosiawan, Ichwan Budiayati\*, Irianto Irianto  
Department of Agroecotechnology, Faculty of Agriculture, University of Jambi, Indonesia

Nasamsir Nasamsir

Department of Agrotechnology, Faculty of Agriculture, Batanghari University, Indonesia

\*E-mail: [budiayati\\_ichwan@unja.ac.id](mailto:budiayati_ichwan@unja.ac.id)

### ABSTRACT

The study aimed at evaluating the stomatal conductance reaction in several duku accessions to inundation conditions. This study was conducted in the Experiment Station of the Faculty of Agriculture, Jambi University, Mendalo Indah Village, Muaro Jambi Regency. The research was carried out simultaneously or in series in two groups. Group I had no inundation of planting media or 100% field capacity (FC) and Group II had inundation (150% FC) of planting media using a Completely Randomized Design (CRD) with 3 replications. One variety and tree accessions of Jambi duku tested for their response to inundation in this study were: Duku Variety Kumpeh (DVK-01), Duku Selat Accession (DSA-1), duku Danau Lamo Accession (DLA-2, and Duku Senaning accession (DSA-3). The observed variables include Relative Water Content (RWC), Stomatal Conductance (SC), and Photosynthetic Rate (PR). The results showed that inundation at the level of 150% field capacity (FC) affected all observed variables. There was a decrease in RWC, SC, and PR values in DSA-1, DLA-2, and DSA-3 compared with no inundation (100% FC). DVK-01 (duku variety Kumpeh) showed relatively no decrease in RWC, SC, and PR values. At the inundation level of 150% FC, RWC, SC, and PR values were comparatively the same in all tested accessions. The adaptation mechanism of the three accessions tested in response to inundation was seemingly through a decrease in stomatal conductance, while the Kumpeh variety (DVK-01) by maintaining root permeability. The information obtained from this study can be used for further evaluation of the physiological traits of duku in the future.

### KEY WORDS

Duku, inundation, stomatal conductance.

The increasing CO<sub>2</sub> in the atmosphere that has exceeded 400 ppm has triggered an increase in Earth's temperature in the last 10 years (NOAA/National Oceanic and Atmospheric Administration, 2017). This climate change has led to severe and uneven rainfall distribution (Intergovernmental Panel for Climate Change, 2001). This phenomenon can worsen poor land drainage conditions, causing inundation in agricultural areas, including in the duku main planting area in Jambi Province. Inundation is a condition where the soil can no longer store more water or exceeds the field capacity so that water inundates the roots of plants (Striker, 2012). Such inundation conditions can disrupt the plant root respiration system because of the decreased oxygen content in the soil (Blom and Voesenek, 1996; Serres and Voesenek, 2008). This in turn affects plant metabolism and productivity (Serres and Voesenek, 2008; Colmer and Vosenek, 2009).

Repeated inundation that occurred in several duku planting centers in Jambi has caused serious problems, such as drying leaves and sudden death of the plants, locally known as *mati meranggas* (deciduous death). To date, it is estimated that more than 50% of Jambi's duku plants have died (FGD, 2019). This condition has caused a decline in Jambi duku production. In 2017, duku production experienced the highest decline among other fruit production, which was around 32.82%, recorded production in the fourth quarter only reached 20814 quintals (Hayati, 2020).



An effort to reduce the negative effects of waterlogging includes the development of duku varieties that are tolerant to waterlogging. Hopefully, these plants will be able to adapt to poorly drained areas of repeated flooding. One of the physiological traits affecting the degree of plant resistance to inundation stress (abiotic) is the stomatal open-close response/stomatal conductance. Stomata act as a tool or pathway for gas traffic ( $\text{CO}_2$  and  $\text{H}_2\text{O}$ ) from outside to inside the plant, in other words, the metabolic process is in line with the level of stomatal opening and closing. This study was aimed at evaluating the nature of stomatal conductance of several accessions and one variety of duku plants grown in inundation for further use in evaluating the physiological traits of duku in the future.

## METHODS OF RESEARCH

The research was conducted at the Experiment Station of the Faculty of Agriculture, Jambi University, Muaro Jambi Regency. This study was conducted in parallel or in series in two groups. Group I has no flooding or 100% field capacity (FC) and Group II was Flooding (150% FC) of the growing media. This experiment used a completely randomized design (CRD) with 3 replications. This study tested the response of 1 variety and 4 accessions of Jambi duku against inundation: Duku Variety Kumpeh (DVK-01), Duku Selat Accession (DSA-1), Danau Lamo Accession (DLA-2), and Duku Senaning Accession (DSA-3).

The soil used was an alluvial type taken from the village of Kota Baru, Selat, one of the growing centers of duku in Jambi. The soil was then left air-dried in a screen house for 10 days, with the roof covered with plastic to avoid the rain. This planting medium was mashed evenly. The crushed soil was mixed evenly with cow manure at a ratio of 2: 1, before being put into experimental pots (buckets) of 8 kg each.

Field capacity (FC) was obtained by watering the soil media slowly until saturated in 3 sample pots that had been filled with 8 kg of soil. The amount of water poured was 3 liters, then allowed to stand for 24 hours. The water that comes out of the pot is recorded as 1 liter. Thus, the water retained in the pot at 100% field capacity was 2 liters, making the weight of the pot at 100% field capacity 10 kg. To reach 150% field capacity, another 1 liter of water is added so that the weight of the pot becomes 11 kg. The weight of the pots at 100% field capacity and 150% field capacity was maintained until the end of the study. All experimental pots were watered to ensure FC conditions, 1 day before planting, inundation at 150% FC was done one week after planting.

Observation of Relative Water Content (RWC), calculated by the formula (Kramer, 1969):

$$\text{RWC} = (\text{FW} - \text{ODW}) / (\text{TW} - \text{ODW}) \times 100\%$$

Where: RWC = relative water content, FW = fresh weight of sample leaves, DWO = oven dry weight, and TW = turgor weight. Leaf sampling for RWC measurement was conducted at noon (12:30 pm) 4 weeks after inundation (WAI).

Stomatal conductance was observed using a leaf porometer (Decagon Inc. US), at the age of 4 WAI. Photosynthetic Rate (PR) was observed using a multi-spec porometer, at the age of 4 WAI.

## RESULTS AND DISCUSSION

The result indicated that the relative water content (RWC) of DVK-01, DSA-1, DLA-2, and DSA-3 were relatively similar in the non-flooded condition (100% FC). However, the highest RWC value was observed in DVK-01 which measured 92.6% and the lowest was found in ADS-03 which measured 89.3%. Under flooded conditions (150% FC) there was a significant decrease in RWC in DSA-1, DLA-2, and DSA-3, but there was no significant decrease in RWC in DVK-01. At 150% FC, the highest RWC value was recorded in DVK-01, which was 83.25%, while the lowest was in DSA-3, which reached 59.8%, but it was relatively similar to the RWC in DSA-1 (62.3%) and DLA-2 (60.5%) (Figure 1).

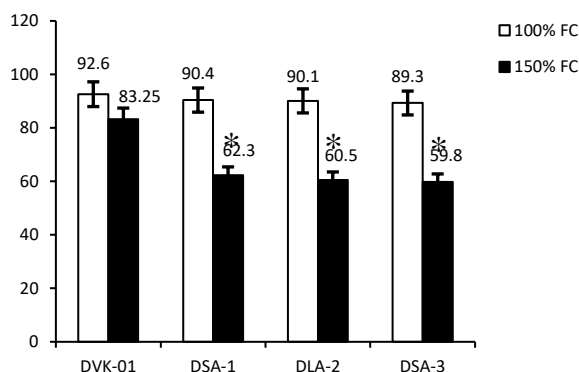


Figure 1 – Relative water content at 100% FC as well as 150% FC state. (\*) denotes a significant difference according to the T-test at a 5% confidence level

The research revealed that waterlogging affected the conductance of stomata. The observational results of the SC response at the age of 4 weeks after inundation (WAI) showed that the SC value in the condition of no inundation (100% FC) was relatively the same among DVK-01, DSA-1, DLA-2, and DSA-3, but the highest SC value was recorded in DVK-01 ( $540.7 \text{ mmol H}_2\text{O} \cdot \text{m}^{-2} \cdot \text{min}^{-1}$ ) and the lowest in DLA-2 ( $530.2 \text{ mmol H}_2\text{O} \cdot \text{m}^{-2} \cdot \text{min}^{-1}$ ). Under 150% FC conditions, a significant decrease in SC values was observed in all accessions, except for DVK-01 which showed no significant decline in SC values. In these conditions, the highest SC value was obtained in DVK-01 ( $507.8 \text{ mmol H}_2\text{O} \cdot \text{m}^{-2} \cdot \text{min}^{-1}$ ) and the lowest in DLA-2 at  $350.4 \text{ mmol H}_2\text{O} \cdot \text{m}^{-2} \cdot \text{min}^{-1}$  (Figure 2).

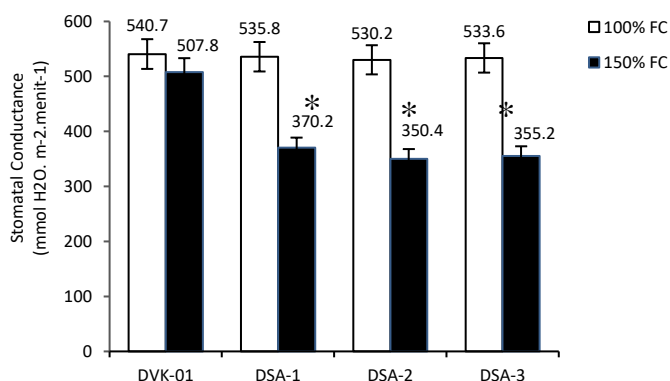


Figure 2 – Stomatal conductance under 100% FC and 150% FC environment. (\*) indicates a significant difference according to the T-test at a 5% confidence level

Inundation affected the photosynthetic rate. The observation of PR at 4 weeks after inundation (WAI) revealed that the PR value in the no-inundation state (100% FC) was relatively similar among DVK-01, DSA-1, DLA-2, and DSA-3 at  $0.68 \text{ g} \cdot \text{cm}^{-2} \cdot \text{min}^{-1}$ ,  $0.62 \text{ g} \cdot \text{cm}^{-2} \cdot \text{min}^{-1}$ ,  $0.64 \text{ g} \cdot \text{cm}^{-2} \cdot \text{min}^{-1}$ , and  $0.62 \text{ g} \cdot \text{cm}^{-2} \cdot \text{min}^{-1}$ , respectively. The highest value of the PR, however, was observed in DVK-01 at  $0.68 \text{ g} \cdot \text{cm}^{-2} \cdot \text{min}^{-1}$  and the lowest in DSA-1 and DSA-3 at  $0.62 \text{ g} \cdot \text{cm}^{-2} \cdot \text{min}^{-1}$ , respectively (Figure 3). Under the 150% FC waterlogging condition, all accessions showed a significant decrease in PR value, except for DVK-01 which showed no significant decrease in PR value. In this inundation period, the highest PR value was obtained in DVK-01 ( $0.57 \text{ g} \cdot \text{cm}^{-2} \cdot \text{min}^{-1}$ ) and the lowest in DSA-3, which was  $0.28 \text{ g} \cdot \text{cm}^{-2} \cdot \text{min}^{-1}$ .

Relative water content is a parameter to measure the weathering or absorption of water by the roots of plants. The significant reduction in RWC in accessions DSA-1, DLA-2, and DSA-3 under 150% FC inundation at the age of 4 WAI, indicated that roots were unable to absorb water optimally and thus the need for water for the canopy was not fulfilled. One initial physiological response of plants to inundation is a decreased stomatal conductance (Gomes and Kozlowski 1980; Pezeshki and Chambers 1985; Folzer et al. 2006). Inundation



not only enhances stomatal resistance but also limits water uptake, leading to an internal water deficit (Jackson and Hall, 1987, Ismail and Noorm, 1996, Pezeshki et al., 1996; Pezeshki, 2001, Nicolas et al., 2005; Folzer et al., 2006; Parent et al., 2008).

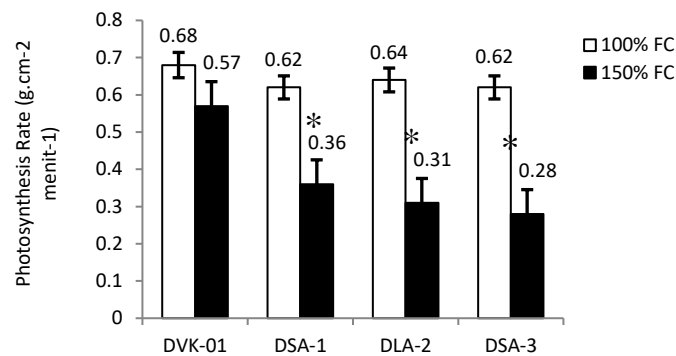


Figure 3 – Photosynthetic rate under 100% FC and 150% FC environment.  
(\*) indicates significant differences according to T-test at a 5% confidence level

The lack of O<sub>2</sub> under inundation conditions could reduce the root hydraulic conductivity (L<sub>p</sub>), leading to a reduction in root permeability (Clarkson et al., 2000; Else et al., 2001). The decreased L<sub>p</sub> maybe associated with aquaporin molecules by cytosolic pH (Tournaire-Roux et al., 2003). Shreds of evidence suggest that the regulation of the intrinsic plasma membrane proteins (PIPs) by their pH is particularly relevant under anoxic conditions (Postaire et al., 2007). Up-regulation of aquaporin genes commonly associated with a decrease in root L<sub>p</sub> as aquaporins regulate radial water movement in roots (Vandeleur et al., 2005). Accordingly, it appears that the low L<sub>p</sub> in the whole plant under water logged conditions is most likely related to the impediment of water transport by aquaporins, although in-depth studies on the influence of aquaporins on the whole plant water regulation during water logging are still lacking. In addition, the low radial water transport could be partly explained by the presence of oxygen gradients within the root tissue. There is clear evidence that in water logged soil, an O<sub>2</sub> gradient exists between the stele which maybe in anoxic conditions, and the cortex cell which may only be in hypoxic conditions (Thomson and Greenway, 1991; Colmer, 2003). These differences in the micro-environment may thus a PRO lead to inter-sectional differences in cell energy level and hence low root L<sub>p</sub>. This was not the case with DVK-01 although there was a decrease in RWC values under 150% FC conditions, it was not as significant as compared to the RWC under 100% FC conditions. This indicated that accession DVK-01 was more resistant or more tolerant to inundation. It can further be explained that in the 150% FC condition for 4 weeks of water logging, there has been no significant reduction in L<sub>p</sub> of the roots in accession DVK-01, therefore no reduction in root permeability. This means that there was no impediment in water transport by aquaporins that control radial water movement in the roots.

The immediate effect of waterlogging, according to Blom and Voesenek (1996), is a hypoxic phase, followed by a steep decline in the O<sub>2</sub> availability resulting in anoxic conditions. The limited O<sub>2</sub> effect on cellular metabolism depends on its concentration and the possible gradual decrease in O<sub>2</sub> availability in the roots and it affects plant metabolism. Anoxia, i.e. where ATP is only generated through fermentative glycolysis because there is no O<sub>2</sub> availability any longer. Accordingly, as the anaerobic conditions are developed in water logged soil, there is an increased amount of by-products of fermentative metabolism accumulates in the root environment, and levels of CO<sub>2</sub>, methane, and volatile fatty acids are elevated (Pezeshki, 2001). A reduction in energy availability has consequences on cellular processes, leading to water and nutrient imbalances and/or deficiencies (Dat et al., 2006). Furthermore, these environmental changes may also predispose plants to other stresses, in particular to pathogenic infections (Munkvold and Yang, 1995, Yanar et al., 1997; Balerdi et al., 2003).



The mechanism by which plants tolerate water stress (inundation) is the response of stomata open-close or stomatal conductance. The metabolism process in the plant body proceeds along with the level of stomatal opening and closing. If the metabolism is obstructed, the stomatal conductance will decrease or may even stop completely. In inundated conditions, the stomatal conductance of plants often drops due to the reduction in the conductance value of the roots (Davies and Flore, 1986). This situation applied to Selat duku accession (DSA-1), Danau Lamo duku accession (DLA-2), and Senaning duku accession (DSA-3) as a mechanism of survival of these accessions in responding to inundation situation. As a consequence, the photosynthesis rate decreases (Dias-Filho, 2002, Bertolde et al., 2012). It was different with the duku variety Kumpeh (DVK-01) where the stomatal conductance relatively did not show a significant decrease (more open stomata). It appeared that the adaptation mechanism of this variety in responding to inundation was to maintain root permeability to ensure that water absorption was not disturbed. High water content which can be absorbed by plant roots ensures the full fillment of plant requirements to maintain the turgidity of its tissues. Once water is sufficient, plant cell becomes more turgid, including the stomatal cover cell. This will cause the stoma to open. The increasing turgor is due to the water inflow from neighboring cell to the ccover cell. On the contrary, when the turgor of the closing cell decreases, stoma will close.

Stomatal conductivity of duku accessions DSA-1, DLA-2, and DSA-3 which were inundated at the level of 150% FC decreased. This may result from the suppression of metabolic rate as an adaptation strategy of these accessions to inundation, leading to low water content that can be absorbed by the roots (RWC 62.3%, 60.5%, and 59.8%, respectively). In flooded conditions, photosynthesis in the cover cell is inhibited. Therefore, less CO<sub>2</sub> is released and fewer H<sup>+</sup> ions are also released from the cover cell, so the cellular pH remains low. When the cover cell is in an acidic condition (low pH), phosphorylase is not activated to convert amyllum into glucose. Consequently, the osmosis pressure of the cover cell remains unchanged. Because of that, the stomatal opening rate does not increase (low stomatal conductance). Furthermore, according to Davies and Flore (1986), if the metabolism is inhibited, the SC will decrease or even stop completely. In inundated conditions, plant SC often decreases due to a reduction in the conductance value of the roots. Consequently, the photosynthesis rate will decline (Dias-Filho, 2002, Bertolde et al., 2012).

In contrast, the water absorption ability of the duku variety Kumpeh (DVK-01) was still higher (RWC = 83.25%) so that it could maintain the photosynthetic rate. CO<sub>2</sub> gas in the leaves is converted to CH<sub>2</sub>O, as a result of which H<sup>+</sup> ions are decreased in the cover cell so that the cellular pH increases. This pH increase activates the phosphorylase enzyme which will convert amyllum into glucose. Thus, water from neighboring cell flows into the cover cell. The osmotic pressure of the cover cell rises, encouraging water to osmosis towards the cover cell. Consequently, the stomata will open more widely, resulting in higher stomatal conductance. This means that the stomatal conductance of duku variety Kumpeh (DVK-01) toward CO<sub>2</sub> into the leaves is higher so the rate of photosynthesis is also higher. Fitter and Hay (1994) stated that usually, the opening of stomata along with conditions stimulate photosynthesis. Stomatal conductance is a response that is closely related to the photosynthesis process (Soleh et al., 2017; Soleh et al., 2020).

## CONCLUSION

The duku Selat accession (DSA-1), duku Danau Lamo accession (DLA-2), and duku Senaning accession (DSA-3) were more sensitive to inundation, while the duku variety Kumpeh (DVK-01) was more tolerant. The adaptation mechanism of accessions DSA-1, DLA-2, and DSA-3 in response to inundation conditions differed from the duku variety Kumpeh (DVK-01). The three accessions were adapted to inundation through a reduction in stomatal conductance, while the duku variety Kumpeh (DVK-01) was adapted by preserving root permeability.





## ACKNOWLEDGMENTS

We acknowledge Husnaldi, S.Pd. the field manager/officer of the Experiment Station of the Faculty of Agriculture, Universitas Jambi as a field technician who has helped supervise and maintain the plants during this research.

## REFERENCES

1. Balerdi C.F., Crane J.H., & Schaffer B. (2003). Managing your tropical fruit grove under changing water table levels. Fact Sheet HS 957, 1-5.
2. Blom C.W., & Voeselek L.A. (1996). Flooding: The survival strategies of plants. *Tree Physiology* 11, 290-295.
3. Boivin, P., Favre, F., Hammecker, C., Maeght, J.L., Delarivière, J., Poussin, J.C., & Wopereis, M.C.S. (2002). Processes driving soil solution chemistry in a flooded rice-cropped vertisol: Analysis of long-time monitoring data. *Geoderma* 110,87-107.
4. Buckner, B., Johal, G.S., & Janick-Buckner, D. (2000). Cell death in maize. *Physiologia Plantarum* 108, 231-239 Cao FL, Conner WH (1999) Selection of flood-tolerant *Populus deltoides* clones for reforestation projects in China. *Forest Ecology and Management* 117, 211-220.
5. Blom C.W., & Voeselek L.A. (1996). Flooding: The survival strategies of plants. *Tree Physiology* 11, 290-295.
6. Cao F.L., & Conner W.H. (1999). Selection of flood-tolerant *Populus deltoides* clones for reforestation projects in China. *Forest Ecology and Management* 117, 211-220.
7. Chen H., Qual P.R.R., & Blank, R. (2005). Effect of soil flooding on photosynthesis, carbohydrate partitioning, and nutrient uptake in the invasive exotic *Lepidium latifolium* *Aquatic Botany* 82, 250-268.
8. Chang W.P., Huang L., Shen M., WeFWter C., Burlingame A.L., & Roberts J.K. (2000). Patterns of protein synthesis and tolerance of anoxia in root tips of maize seedlings acclimated to a low-oxygen environment, and identification of proteins by mass spectrometry. *Plant Physiology* 122, 295-318.
9. Clarkson D.T., Carvajal M., Henzler T., Waterhouse R.N., Smyth A.J., Cooke D.T., & Steudle E. (2000). Root hydraulic conductance: Diurnal aquaporin expression and the effects of nutrient stress. *Journal of Experimental Botany* 51,61-70.
10. Colmer, T.D. (2003). Long-distance transport of gases in plants: A perspective on internal aeration and radial oxygen loss from roots. *Plant, Cell, and Environment* 26, 17-36
11. Dat, J., Capelli, N., Folzer, H., Bourgeade, P., & Badot P-M. (2004). Sensing and signaling during plant flooding. *Plant Physiology and Biochemistry* 42, 273-282.
12. Dat J, Folzer H, Parent C, Badot, P-M, & Capelli, N. (2006). Hypoxia stress: Current Understanding and Perspectives. In: Teixeira da Silva JA (Ed) *Floriculture, Ornamental, and Plant Biotechnology: Advances and Topical Issues (Vol 3)*, Global Science BooSC, Isleworth, United Kingdom. pp 664-674.
13. Jambi Provincial Agriculture Office. (2009). Data on food crop agriculture and horticulture in 2008. Department of Food Crop Agriculture. Jambi Provincial Government.
14. Drew, M.C. (1997). Oxygen deficiency and root metabolism: Injury and acclimation under hypoxia and anoxia. *Annual Review Plant Physiology and Plant Molecular Biology* 48, 223-250.
15. Drew, M.C, Cobb, B.G., Johnson, J.R., Andrews, D., Morgan, P.W., Jordan, W., & Jiu H.C. (1994). Metabolic acclimation of root tips to oxygen deficiency. *AnnaPR of Botany* 74, 281-286.
16. Else, Coupland, D., Dutton, L, & Jackson M.B. (2001). Decreased root hydraulic conductivity reduces leaf water potential, initiates stomatal closure, and slows leaf expansion in flooded plants of castor oil (*Ricinus communis*) despite diminished delivery of ABA from the roots to shoots in xylem sap. *Physiologia Plantarum* 111, 46-54.
17. Felle, H.H. (2005). pH regulation in anoxic plants. *AnnaPR of Botany* 96, 519-532.



18. Folzer, H., Dat, J., Capelli, N., Rieffel, D., & Badot P.M. (2006). Response to flooding of sessile oak: An integrative study. *Tree Physiology* 26, 759-766.
19. Fukao, T., & Bailey-Serres, J. (2004). Plant responses to hypoxia- is survival a balancing act? *Trends in Plant Science* 9, 449-456.
20. Gibbs, J., & Greenway, H. (2003). Mechanism of anoxia tolerance in plants. I. Growth, survival, and anaerobic catabolism. *Functional Plant Biology* 30, 1-47.
21. Hayati I. (2020). The role of environmental and plant factors in the development of duku stem canker disease caused by *Phytophthora palmivora*. Doctor dissertation, Graduate School, Bogor Agriculture University, Bogor, Indonesia.
22. Igamberdiev, A., & Hill, R. (2004). Nitrate, NO, and hemoglobin in plant adaptation to hypoxia: an alternative to classic fermentation pathways. *Journal of Experimental Botany* 55, 2473-2482.
23. Ismail, M.R., & Noor K.M. (1996). Growth and physiological processes of young starfruit (*Averrhoa carambola* L.) plants under soil flooding. *Scientia Horticulturae* 65, 229-238.
24. Ito, O., Ella, E., & Kawano, N. (1999). Physiological basis of submergence tolerance in rainfed lowland rice ecosystem. *Field Crops Research* 64, 75-90.
25. Jackson, M.B., & Hall, K.C. (1987). Early stomatal closure in waterlogged pea plants is mediated by abscisic acid in the absence of foliar water deficits. *Plant, Cell, and Environment* 10, 121-130.
26. Kaldenhoff, R., & Fischer, M. (2006). Functional aquaporin diversity in plants. *Biochimica and Biophysica Acta – Biomembranes* 1758, 1134-1141.
27. Kato-Noguchi, H. (2000). Evaluation of the importance of lactate for the activation of ethanolic fermentation lettuce roots in anoxia. *Physiologia Plantarum* 109, 28-33.
28. Kingston-Smith, A.H., & Theodorou M.K. (2000). Post-ingestion metabolism of fresh forage. *New Phytologist* 148, 37-55.
29. Kirk, G.J.D., Solivas, J.L., & Alberto, M.C. (2003). Effects of flooding and redox conditions on solute diffusion in soil. *European Journal of Soil Science* 54, 617-624.
30. Lu, Y., Watanabe, A., & Kimura, M. (2004). Contribution of plant photosynthates to dissolved organic carbon in a flooded rice soil. *Biogeochemistry* 71, 1-15.
31. Malik, A.I., Colmer, T.D., Lambers, H., & Schortemeyer, M. (2001). Changes in physiological and morphological traits of roots and shoots of wheat in response to different depths of waterlogging. *Australian Journal of Plant Physiology* 28, 1121-1131.
32. Munkvold, G.P., & Yang, X.B. (1995). Crop damage and epidemics associated with 1993 floods in Iowa. *Plant Disease* 79, 95-101.
33. Nakazono, M., Tsuji, H., Li, Y., Saisho, D., Arimura, S-I, Tsutsumi, N., & Hirai, A. (2000). Expression of a gene encoding mitochondrial aldehyde dehydrogenase increases under submerged conditions. *Plant Physiology* 124, 587-598.
34. Nicolas, E., Torrecillas, A., Dell'Ami, J., Alarcon, J.J. (2005). The effect of short-term flooding on the sap flow, gas exchange, and hydraulic conductivity of young apricot trees. *Trees – Structure and Function* 19, 51-57.
35. Parent, C., Berger, A., Folzer, H., Dat, J., Crivencoeur, M., Badot, P-M, & Capelli, N. (2008). Novel non-symbiotic hemoglobin from oak: Cellular and tissue specificity of gene expression. *New Phytologist* 177, 142-154.
36. Peng, H-P., Chan, C-S., Shih, M-C., & Yang S.F. (2001). Signaling events in the hypoxic induction of alcohol dehydrogenase gene in *Arabidopsis*. *Plant Physiology* 126, 742-749.
37. Pezeshki, S.R., & Chambers, J.L. (1985). Stomatal and photosynthetic response of sweet gum (*Liquidambar styraciflua*) to flooding. *Canadian Journal of Forest Research* 15, 371-375.
38. Pezeshki, S.R., Pardue, J.H., & Delaune R.D. (1996). Leaf gas exchange and growth of flood-tolerant and flood-sensitive tree species under low soil redox conditions. *Tree Physiology* 16, 453-458.
39. Pezeshki, S.R. (2001). Wetland plant responses to soil flooding. *Environmental and Experimental Botany* 46, 299-312.
40. Postaire, O., Verdoucq, L., & Maurel, C. (2007). Aquaporins in plants: From molecular structure to integrated functions. *Advances in Botanical Research* 46, 75-136.



41. Probert, M.E., & Keating, B.A. (2000). What soil constraints should be included in crop and forest mode? *Agriculture, Ecosystems, and Environment* 82, 273-281.
42. Ram, P.C., Singh, B.B., Singh, A.K., Ram, P., Singh, P.N., Singh, H.P., Boamfa, I., Harren, F., Santosa, E., Jackson, M.B., Setter, T.L, Reuss, J., Wade, L.J., Pal Singh V., & Singh, R.K. (2002). Submergence tolerance in rainfed lowland rice: Physiological basis and prospects for cultivar improvement through marker-aided breeding. *Field Crops Research* 76, 131-152.
43. Sachs, M., & Vartapetian, B. (2007). Plant anaerobic stress I. Metabolic adaptation to oxygen deficiency. *Plant Stress* 1, 123-135.
44. Secchi, F., Lovisolo, C., Uehlein, N., Kaldenhoff, R., & Schubert, A. (2007). Isolation and functional characterization of three aquaporins from olive (*Olea europaea* L.). *Planta* 225, 381-392.
45. Gomes, A.R.S., & Kozlowski, T.T. (1980). Growth responses and adaptations of *Fraxinus pennsylvanica* seedlings to flooding. *Plant Physiology* 66, 267-271.
46. Soleh, M.A., Manggala, R., Maxiselly, Y., Ariyanti, M., & Anjarsari, I.R.D. (2017). Stomatal conductance response of sugarcanes under abiotic stress. *Jurnal Kultivasi* Vol. 16 (3), 490-493.
47. Soleh, M.A., Anjarsari, I.R.D., & Rosniawaty, S. (2020). The waterlogging condition has reduced stomatal conductance, radiation-using efficiency, and growth components of some sugarcane genotypes. *Jurnal Kultivasi* Vol. 19 (2), 1114-1118.
48. Summers, J., Ratcliffe, R., & Jackson, M. (2000). Anoxia tolerance in the aquatic monocot *Potamogeton pectinatus*: Absence of oxygen stimulates elongation in association with an unusually large Pasteur effect. *Journal of Experimental Botany* 51, 1413-1422.
49. Thomson, C.J., & Greenway, H. (1991). Metabolic evidence for stellar anoxia in maize roots exposed to low O<sub>2</sub> concentrations. *Plant Physiology* 96, 1294-1301.
50. Tournaire-Roux, C., Sutka, M., Javot, H., Gout, E., Gerbeau, P., Luu D-T, Bligny, R., & Maurel, C. (2003). Cytosolic pH regulates root water transport during anoxic stress through the gating of aquaporins. *Nature* 425, 393-397.
51. Niemietz, R. C., Tilbrook, J., & Tyerman, S.D. (2005). Roles of aquaporins in root response to irrigation. *Plant and Soil* 274, 141-161.
52. Vartapetian, B.B., Andreeva, I.N., Generozova, I.P., Polyakova, L.I., Maslova, I.P., Dolgikh, Y.I., & Stepanova, A.Y. (2003). Functional electron microscopy in studies of plant response and adaptation to anaerobic stress. *Annals of Botany* 91, 155-172.
53. Vartapetian, B.B. (2006). Plant anaerobic stress as a novel trend in ecological physiology, biochemistry, and molecular biology: 2. Further development of the problem. *Russian Journal of Plant Physiology* 53, 711-738.
54. Vartapetian, B.B., & Polyakova, L.I. (1998). Protective effect of exogenous nitrate on the mitochondrial ultrastructure of *Oryza sativa* coleoptiles under strict anoxia. *Protoplasma* 206, 163-167.
55. Yanar, Y., Lipps, P.E., & Deep I.W. (1997). Effect of soil saturation duration and soil water content on root rot of maize caused by *Pythium arrhenomanes* *Plant. Disease* 81, 475-480.
56. Yordanova, R., Christov, K., & Popova, L. (2004). Antioxidative enzymes in barley plants subjected to soil flooding. *Environmental and Experimental Botany* 51, 93-101.
57. Zarate-Valde, J.L., Zdsoski, R.J., & Lauchli, A.E. (2006). Short-term effect of moisture on soil solution pH and soil Eh. on of the exodermis of two wetland species, *Phragmites australis* and *Glyceria maxima* *New Phytologist* 173, 264-278.