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Identifying Black Rice Cultivated Area Using Sentinel2

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***Abstract*—Kalabati(Oriza Sativia L.) is a black or forbidden rice variety with rich medicinal and nutrient values. Traditionally, several studies acknowledged the unlimited potential of black rice and intensive research conducted in the laboratory environment to determine its benefits. The presence of anthocyanin(anth) content in Kalbati rice plants turns leaves into black or purple. Several studies identified rice canopy using remote sensing technologies, but none attempted to distinguish black rice areas. Understanding the existence and yield of black rice helps governments or policyholders to take appropriate decisions to promote its benefits in society for broader consumption. This study aims to evaluate the feasibility of using satellite imagery to identify the anth content of Kalabati plant leaves using leaf optical properties. Sentinel2 based indices help to identify Anth content in the leaves using its multi-spectral(MSI) instrument. A combination of Modified Anthocyanin Index(mARI), Chlorophyll Vegetation Index(CVI) and Green Leaf Index(GLI) is used to determine the complex rice canopy of the black rice that exists at a negligible percentage among other crops. The correlation of mARI with CVI has an RMSE value of 0.11314, and the same RMSE value of mARI with GLI is at 0.66441. Finally, the study concluded anth content in Kalabati rice could be interpreted using multi-spectral data from Sentinel-2.**

***Index Terms*—Black Rice, Kalabati, Remote Sensing, Sentinel-2.**

I. INTRODUCTION

Rice is the primary cereal food for nearly 50% of the population across the world. In 2020, Asia alone contributed for 91% of 514 million metric tonnes of rice produced worldwide. Several governments in Asian countries supply rice at a subsidy rate for the millions of people living in poverty, and therefore it influences critical food security conditions in the society. Nevertheless, rice loses its nutrient benefits during the milling process from bran and hulls, which are a source of B vitamin, iron and zinc minerals. Consequently, people who depend on polished rice suffer from vitamin deficiencies(1; 2).

Rice fortification(3) is one of the underutilized opportunities to overcome vitamin and mineral deficiencies(1; 4). Several studies demonstrated significant benefits to leverage hot and cold extrusion technologies during the fortification process(5; 6). It is challenging to get acceptance from producers and consumers in both extrusion processes due to alterations in the natural process. Alternative to rice fortification is following the bio-fortification technique(7) to increase the nutritious value when plants grow. The bio-fortification process goes through cross-breeding or genetic modification phases to yield high nutritious output. Each of these fortification processes requires focused efforts to get the required output. On the other hand, black rice is a naturally available nutrient-rich breed cultivated in a few landraces due to less demand.

Black rice(8) is one of the rice cultivars from the species of Oryza sativia L which has 118K genes under three genomes in the genomics database(9; 10; 11) as of today. The black rice is also famous as ”forbidden rice” due to restricted access for ordinary people during kings time in China. Despite these facts, it’s widely accepted that black rice is rich in medicinal values(12; 13; 14; 15; 16; 17; 18; 19; 20) and brings several health benefits if it’s consumed regularly. It is also served as a particular food or beverage item in festivals and celebrations as part of socio-cultural practices(21). Anthocyanin(Anth) presence in the rice makes it a black or purple. Anth content is also responsible for the different colouration of the plant leaves like red, purple, blue(22). There are various past and ongoing studies to use Anth as a potential replacement for synthetic dyes(23; 24; 25; 26) and functional colorants(27; 28; 22; 29). The black rice has many Anths which exists in different parts of the rice plant like leaves, grains, stigma and stem at different development stages(30).

Despite its benefits, society is less aware of black rice existence and hardly any demand for cultivation in the agricultural community. Governments’ strategic decisions play a critical role in bringing awareness and promoting health benefits to increase the demand for black rice as a primary staple food. Policymakers need to identify and assess the current state of the cultivated area to establish the desired goals of bringing it as a regular commodity for the citizens. Manual surveys and assessments of crop identification and classification require a lot of time and cost. Remote sensing technology offers plenty

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of benefits to identify various crops at a spatial scale with better accuracy and quality with minimal resources. Hence, this study aims to evaluate the feasibility of using satellite imagery to identify the cultivated area of Kalabati rice(a black rice variety). The presence of anthocyanin(anth) content in Kalbati rice plants turns leaves into black or purple. Sentinel2 based indices help to identify Anth content in the leaves using its multi-spectral(MSI) instrument. A combination of Modified Anthocyanin Index(mARI), Chlorophyll Vegetation Index(CVI) and Green Leaf Index(GLI) is used to determine the complex rice canopy of the black rice that exists at a negligible percentage among other crops. mARI and CVI indexes are proportional to each other, indicating the rice plant's healthy vegetation with anthocyanin content. At the same time, the GLI had shown negative values in the study area of the black rice that tells which is a non-green canopy.

a) Study Area: The study was conducted in the Bhongir region of Warangal District of Telangana, located at the coordinates of 752’44.8”N and 7853’53.4”E. The area accounts for a tiny portion of the Black Rice variety, i.e. Kalbati. Figure 1 shows the geographical location and in-situ picture captured in August 2021 from the study area. The Kalabati rice canopy appears in black, whilst the white rice area is in green.

[b]1

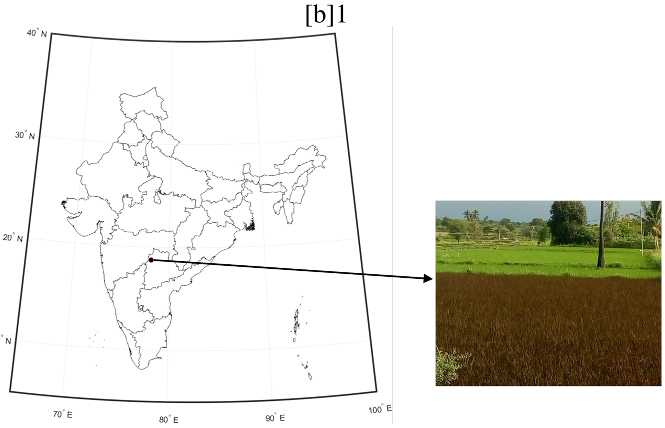

Fig. 1. A black rice variety - Kalbati cultivated location with in-situ picture

In the remaining part of the document, section 2 describes estimation techniques used to calculate anth content in plant leaves using traditional and advanced technologies. Section 3 elaborates materials and methods employed to identify the black rice canopy in the study area. Section 4 discusses results; finally, section 5 concludes the benefits of study and opportunities at a spatial scale.

II. ESTIMATION TECHNIQUES

Traditionally, estimating Anthocyanin(Anth) in plant leaves, fruits and grains are laborious and time-consuming. High Performance Liquid Chromatography(HPLC), Ultra-Performance Liquid Chromatography/Time-of-Flight Mass Spectrometry (UPLC/Q-TOF-MS), pH differential methods are used (31; 32; 33; 34; 12; 35; 36; 37; 38; 39) in a controlled laboratory environment.

Spectroscopy is an alternative to wet chemical methods to determine anth content in leaves(40; 41). In the past, various non-invasive studies happened in vivo to estimate and determine leave properties using spectral indexes(42; 43; 44; 45; 46). Chlorophyll, which participates in the plants photosynthesis activity, directly affects primary production(47) as it contains nitrogen essential for nutrient status. The chlorophyll decreases during the senescence at different stages of plant growth(48). Floods and plant stress adversely influences the chlorophyll absorption rate. It is crucial to determine whether plant colouration changes are natural or not to understand healthy vegetation. The leaves observed at the wavelength of 550nm spectral bands strongly correlate with Chlorophyll and Anth content(49). Non-destructive study of Anth in leaves suggested using green and red edge spectral bands and near-infrared(43). The current study leveraged experimental analysis of the handheld spectroscopy and applied those approaches at the spatial scale for the black rice canopy.

The existence of MSI satellites helps to determine spectral indices of anths at specific spatial and temporal resolutions. In this study, an attempt is made to determine the modified Anthocyanin Reflectence Index(mARI)(50; 51) its relationship with Chlorophyll Vegetation Index(CVI)(52; 53) and Green Leaf Index(GLI)(54; 52) at spatial scales using Sentinel-2. mARI helped to recognize anthocyanin whilst CVI determined the chlorophyll content of the leaves, and GLI assessed the leaf's greenness across the canopy. mARI and CVI indexes are proportional to indicated healthy plant vegetation with anthocyanin content, responsible for colouration. At the same time, GLI had shown negative values which means non-green colour. The correlation of mARI with CVI has an RMSE value of 0.11314, which means anth is approximately calculated with 89% accuracy. Similarly, GLI is around 65%, indicates a non-green region.

III. MATERIALS AND METHODS

Global Monitoring for Environment and Security(GMES)(55) is a joint initiative of the European Space Commission(EC), and the European Space Agency(ESA) manages the Sentinel-2 program. Sentinel-2 has a constellation of two satellites, Sentinel-2A and Sentinel-2B, which systematically acquires optical imagery with a frequent revisit in five days at the equator. It has a 290km field of view(fov) and MSI with 13 different spectral bands at different wavelengths. Sentinel bands in the visible(RGB) and near-infrared(NIR) range helps to monitor agricultural lands with 10m, 20m and 60m spatial resolutions with 5 and 10 days of temporal resolution.

The SNAP(Sentinel Application Platform) tool is used to analyze Sentinel-2A and Sentinel-2B tiles. Copernicus Open Access Hub, managed by ESA, offered high-resolution tiles in all bands from 2020 to study the leaf optical properties of black rice(Kalbati) from vegetative reproductive stages to the ripening stage. The image data is acquired in Aug'2020, Oct'2020, Dec'2020 and Mar'2021. These months fall under Kharif, which is a local name for the rainy season of June to November, and Rabi is a dry season for the period from December to March(56).

Single Look Complex(SLC) images are ortho-rectified to Sentinel level-2A Bottom of Atmosphere(BOA) images. The pixel values of black rice and non-black rice cultivated land is retrieved to correlate and contrast observations mARI(50; 51), CVI(52; 53) and GLI(54; 52) values. Several models are built using B2 to B9 bands of Sentinel -2 and then compared their relationships with mARI(50; 51); values fluctuate based on the scanner's incident angle at different stages of the plant growth. Consequently, it is not possible to use mARI alone to identify the rice at a spatial scale. So, used CVI(52; 53) to determine whether it's rice grown area with the appropriate value. CVI helped standardize the vegetation state of the rice canopy. Then, to rule out the study in green-leaf rice canopy, GLI(52; 53) values are considered. Finally, mARI and CVI values helped to identify the black rice canopy.

[b].6

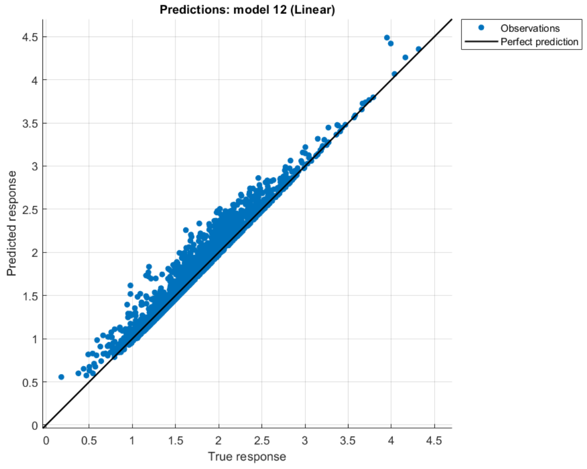

Fig. 2. Correlation of mARI and CVI

[b].6

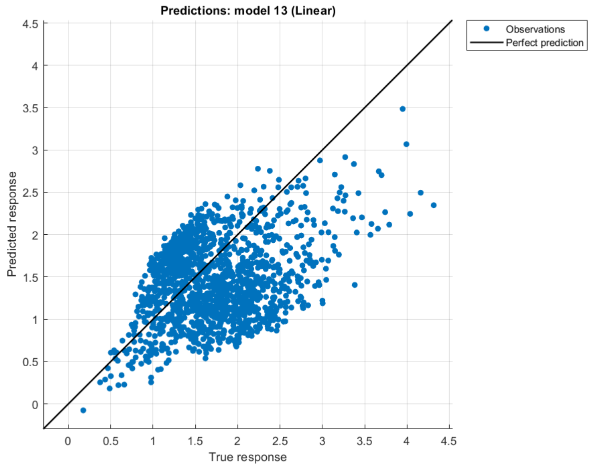

Fig. 3. Correlation of mARI and GLI

Fig. 4. mARI Correlation with CVI and GLI using Trained and Test Data

IV. RESULTS AND DISCUSSION

The current study examined leaf optical properties at the spatial scale using satellite imagery to determine Anth(mARI) containing black rice leaves and its correlation with Chlorophyll(CVI) and green leaves(GLI).

TABLE I
RMSE VALUES OF FIG:2

mARI vs CVI	mARI vs GLI
0.11314	0.66441

These indices help determine black rice in the study area, which is challenging to identify alone with one specific index due to the complex nature of the black rice canopy that exists along with the brown rice canopy. mARI helped to recognize anthocyanin whilst CVI determines chlorophyll content of the leave and GLI can assess the greenness of the leaf. mARI and CVI indexes are proportional to each other to indicate healthy vegetation of the plant with anthocyanin content. At the same time, GLI is inversely proportional to mARI, which means non-green colour. The correlation of mARI with CVI has an RMSE value of 0.11314, and the same RMSE value of mARI with GLI is at 0.66441. The study closely examined the existence of anth content in black rice canopy with 89% accuracy.

V. CONCLUSION

As per the studies mentioned above, black rice has numerous medicinal values to prevent chronic diseases but is less cultivated globally. According to historical literature, autocrats played a crucial role in deciding eligibility for cultivation in the designated areas. Consequently, the socio-economic status of people played a pivotal role in the limited adaptability to the cultivation. However, society is moving towards a health-first mindset, demanding better organic and traditional grains to reduce unnecessary medical expenses. The past studies believe that black rice is best among the contemporary grain of the staple foods with certitude. So far, farmers have adopted the cultivation of black rice to a limited extent as there is hardly any demand as very few people are aware of its existence. So many studies have been conducted in the black rice area, but mostly limited to the hand-held spectroscopy or in the laboratory environment as described earlier.

The current study considered the outcome of laboratory observations from the hand-held spectroscopic instruments, scaled them to spatial level using remote sensing images to study complex characteristics of the black rice. The study also acknowledges the difficulty of determining black rice colour, transforming it into various shades from vegetative to ripening. Consequently, more than one spectral indices used to distinguish healthy vegetation of the Kalbati black rice. The study also highlighted the nutrient and medicinal benefits to create awareness among people to overcome malnutrition and food security. Governments and policymakers can use remote sensing technology to identify black rice cultivated lands to estimate and assess the need for society to promote health benefits among people and increase farming practice in the agriculture community.

REFERENCES

[1] P. B. Dexter, “Omni/usaid,” 1998.

[2] H. Chen, T. Siebenmorgen, and K. Griffin, “Quality characteristics of long-grain rice milled in two commercial systems,” *Cereal chemistry*, vol. 75, no. 4, pp. 560–565, 1998.

[3] S. Muthayya, J. Hall, J. Bagriansky, J. Sugimoto, D. Gundry, D. Matthias, S. Prigge, P. Hindle, R. Moench-Pfanner, and G. Maberly, “Rice fortification: an emerging opportunity to contribute to the elimination of vitamin and mineral deficiency worldwide,” *Food and nutrition bulletin*, vol. 33, no. 4, pp. 296–307, 2012.

[4] S. Alavi, B. Bugusu, G. Cramer, O. Dary, T.-C. Lee, L. Martin, J. McEntire, and E. Wailes, “Rice fortification in developing countries: a critical review of the technical and economic feasibility. a2z project, academy for educational development. washington, dc, 2008.”

[5] K. Bett-Garber, E. Champagne, D. Ingram, and C. Grimm, “Impact of iron source and concentration on rice flavor using a simulated rice kernel micronutrient delivery system,” *Cereal chemistry*, vol. 81, no. 3, pp. 384–388, 2004.

[6] Y. Li, L. L. Diosady, and S. Jankowski, “Effect of iron compounds on the storage stability of multiple-fortified ultra rice®,” *International journal of food science & technology*, vol. 43, no. 3, pp. 423–429, 2008.

[7] P. Nestel, H. E. Bouis, J. V. Meenakshi, and W. Pfeiffer, “Biofortification of staple food crops,” *The Journal of nutrition*, vol. 136, no. 4, pp. 1064–1067, 2006.

[8] U. K. Kushwaha, “Black rice: Research, history and development,” *Black Rice: Research, History and Development*, pp. 1–192, 2016.

[9] M. K. Tello-Ruiz, S. Naithani, P. Gupta, A. Olson, S. Wei, J. Preece, Y. Jiao, B. Wang, K. Chougule, P. Garg, *et al.*, “Gramene 2021: harnessing the power of comparative genomics and pathways for plant research,” *Nucleic Acids Research*, vol. 49, no. D1, pp. D1452–D1463, 2021.

[10] M. Zhang, B. Guo, and Z. Peng, “Genetic effects on fe, zn, mn and p contents in indica black pericarp rice and their genetic correlations with grain characteristics,” *Euphytica*, vol. 135, no. 3, pp. 315–323, 2004.

[11] C. Kim, S. Kikuchi, Y. Kim, S. Park, U. Yoon, G. Lee, J. Choi, Y. Kim, and S. Park, “Computational identification of seed-specific transcription factors involved in anthocyanin production in black rice,” *BioChip Journal*, vol. 4, no. 3, pp. 247–255, 2010.

[12] H. Ichikawa, T. Ichiyanagi, B. Xu, Y. Yoshii, M. Nakajima, and T. Konishi, “Antioxidant activity of anthocyanin extract from purple black rice,” *Journal of medicinal food*, vol. 4, no. 4, pp. 211–218, 2001.

[13] I. Kaneda, F. Kubo, and H. Sakurai, “Antioxidative compounds in the extracts of black rice brans,” *Journal of health science*, vol. 52, no. 5, pp. 495–511, 2006.

[14] S. de Pascual-Teresa, “Molecular mechanisms involved in the cardiovascular and neuroprotective effects of anthocyanins,” *Archives of biochemistry and biophysics*, vol. 559, pp. 68–74, 2014.

[15] H. Kamei, T. Kojima, M. Hasegawa, T. Koide, T. Umeda, T. Yukawa, and K. Terabe, “Suppression of tumor cell growth by anthocyanins in vitro,” *Cancer Investigation*, vol. 13, no. 6, pp. 590–594, 1995.

[16] P.-N. Chen, W.-H. Kuo, C.-L. Chiang, H.-L. Chiou, Y.-S. Hsieh, and S.-C. Chu, “Black rice anthocyanins inhibit cancer cells invasion via repressions of mmps and u-pa expression,” *Chemico-biological interactions*, vol. 163, no. 3, pp. 218–229, 2006.

[17] S. Thomasset, N. Teller, H. Cai, D. Marko, D. P. Berry, W. P. Steward, and A. J. Gescher, “Do anthocyanins and anthocyanidins, cancer chemopreventive pigments in the diet, merit development as potential drugs?,” *Cancer chemotherapy and pharmacology*, vol. 64, no. 1, pp. 201–211, 2009.

[18] C. S. Bowen-Forbes, Y. Zhang, and M. G. Nair, “Anthocyanin content, antioxidant, anti-inflammatory and anticancer properties of blackberry and raspberry fruits,” *Journal of food composition and analysis*, vol. 23, no. 6, pp. 554–560, 2010.

[19] S. Qi, J. He, H. Han, H. Zheng, H. Jiang, C. Y. Hu, Z. Zhang, and X. Li, “Anthocyanin-rich extract from black rice (: Oryza sativa L. Japonica) ameliorates diabetic osteoporosis in rats,” *Food and Function*, vol. 10, no. 9, pp. 5350–5360, 2019.

[20] Y. Knox, K. Hayashi, T. Suzutani, M. Ogasawara, I. Yoshida, R. Shiina, A. Tsukui, N. Terahara, and M. Azuma, “Activity of anthocyanins from fruit extract of ribes nigrum l. against influenza a and b viruses.,” *Acta virologica*, vol. 45, no. 4, pp. 209–215, 2001.

[21] S. Shijagurumayum, G. Devi, C. Singh, *et al.*, “Chakhao: Scented traditional rice of manipur (india).,” *Journal of Advanced Scientific Research*, vol. 12, 2021.

[22] E.-S. M. Abdel-Aal, J. C. Young, and I. Rabalski, “Anthocyanin composition in black, blue, pink, purple, and red cereal grains,” *Journal of agricultural and food chemistry*, vol. 54, no. 13, pp. 4696–4704, 2006.

[23] R. B. Kanarek, “Artificial food dyes and attention deficit hyperactivity disorder,” *Nutrition reviews*, vol. 69, no. 7, pp. 385–391, 2011.

[24] M. M. Giusti and R. E. Wrolstad, “Acylated anthocyanins from edible sources and their applications in food systems,” *Biochemical engineering journal*, vol. 14, no. 3, pp. 217–225, 2003.

[25] A. B^{1}kowska-Barczak, “Acylated anthocyanins as stable, natural food colorantsa review,” *Polish journal of food and nutrition sciences*, vol. 14, p. 55, 2005.

[26] M. H. Buraidah, L. P. Teo, S. N. Yusuf, M. M. Noor, M. Z. Kufian, M. A. Careem, S. R. Majid, R. M. Taha, and A. K. Arof, “TiO 2/chitosan-NH 4I(+I 2)-BMII-based dye-sensitized solar cells with anthocyanin dyes extracted from black rice and red cabbage,” *International Journal of Photoenergy*, vol. 2011, 2011.

[27] P. Loypimai, A. Moongngarm, P. Chottanom, and T. Moontree, “Ohmic heating-assisted extraction of anthocyanins from black rice bran to prepare a natural food colourant,” *Innovative Food Science and Emerging*

Technologies, vol. 27, 2015.

[28] K. Kikuchi, A. Chiba, K. Miyake, T. Nakai, and M. Tokuda, "Anthocyanin food coloring agent from purple corn," *Japan. Kokai*, vol. 77, no. 130, p. 824, 1977.

[29] T. Laokuldilok and N. Kanha, "Microencapsulation of Black Glutinous Rice Anthocyanins Using Maltodextrins Produced from Broken Rice Fraction as Wall Material by Spray Drying and Freeze Drying," *Journal of Food Processing and Preservation*, vol. 41, no. 1, 2017.

[30] E. Mackon, Y. Ma, G. C. Jeazet Dongho Epse Mackon, Q. Li, Q. Zhou, and P. Liu, "Subcellular Localization and Vesicular Structures of Anthocyanin Pigmentation by Fluorescence Imaging of Black Rice (Oryza sativa L.) Stigma Protoplast," *Plants*, vol. 10, no. 4, 2021.

[31] H. Ichikawa, T. Ichiyanagi, B. Xu, Y. Yoshii, M. Nakajima, and T. Konishi, "Antioxidant activity of anthocyanin extract from purple black rice," *Journal of Medicinal Food*, vol. 4, no. 4, 2001.

[32] S. N. Ryu, S. Z. Park, and C. T. Ho, "High Performance Liquid Chromatographic Determination of Anthocyanin Pigments in Some Varieties of Black Rice," *Journal of Food and Drug Analysis*, vol. 6, no. 4, 1998.

[33] W. Dedio, R. Hill, and L. Evans, "Anthocyanins in the pericarp and coleoptiles of purple-seeded rye," *Canadian Journal of Plant Science*, vol. 52, no. 6, pp. 981–983, 1972.

[34] T. Oki, Y. Sawai, M. Sato-Furukawa, and I. Suda, "Validation of ph differential method for the determination of total anthocyanin content in black rice and black soybean with interlaboratory comparison," *Bunseki Kagaku*, vol. 60, no. 10, pp. 819–824, 2011.

[35] O. López-Fernández, R. Domínguez, M. Pateiro, P. E. Munekata, G. Rocchetti, and J. M. Lorenzo, "Determination of polyphenols using liquid chromatography–tandem mass spectrometry technique (lc–ms/ms): A review," *Antioxidants*, vol. 9, no. 6, p. 479, 2020.

[36] J.-M. Kong, L.-S. Chia, N.-K. Goh, T.-F. Chia, and R. Brouillard, "Analysis and biological activities of anthocyanins," *Phytochemistry*, vol. 64, no. 5, pp. 923–933, 2003.

[37] I. Konczak and W. Zhang, "Anthocyaninsmore than nature's colours," *Journal of Biomedicine and Biotechnology*, vol. 2004, no. 5, p. 239, 2004.

[38] J. Hao, H. Zhu, Z. Zhang, S. Yang, and H. Li, "Identification of anthocyanins in black rice (Oryza sativa L.) by UPLC/Q-TOF-MS and their in vitro and in vivo antioxidant activities," *Journal of Cereal Science*, vol. 64, 2015.

[39] G. A. Blackburn, "Hyperspectral remote sensing of plant pigments," *Journal of experimental botany*, vol. 58, no. 4, pp. 855–867, 2007.

[40] D. W. Lee and R. Graham, "Leaf optical properties of rainforest sun and extreme shade plants.," *American Journal of Botany*, vol. 73, no. 8, 1986.

[41] A. A. Gitelson, M. N. Merzlyak, and O. B. Chivkunova, "Optical Properties and Nondestructive Estimation of Anthocyanin Content in Plant Leaves¶," *Photochemistry and Photobiology*, vol. 74, no. 1, 2001.

[42] Z. Xiaobo, S. Jiyong, H. Limin, Z. Jiewen, M. Hanpin, C. Zhenwei, L. Yanxiao, and M. Holmes, "In vivo noninvasive detection of chlorophyll distribution in cucumber (cucumis sativus) leaves by indices based on hyperspectral imaging," *Analytica Chimica Acta*, vol. 706, no. 1, pp. 105–112, 2011.

[43] A. A. Gitelson, O. B. Chivkunova, and M. N. Merzlyak, "Nondestructive estimation of anthocyanins and chlorophylls in anthocyanic leaves," *American Journal of Botany*, vol. 96, no. 10, 2009.

[44] S. Y. Dillen, M. O. de Beeck, K. Hufkens, M. Buonanduci, and N. G. Phillips, "Seasonal patterns of foliar reflectance in relation to photosynthetic capacity and color index in two co-occurring tree species, quercus rubra and betula papyrifera," *Agricultural and Forest Meteorology*, vol. 160, pp. 60–68, 2012.

[45] N. Huang, Z. Niu, Y. Zhan, S. Xu, M. C. Tappert, C. Wu, W. Huang, S. Gao, X. Hou, and D. Cai, "Relationships between soil respiration and photosynthesis-related spectral vegetation indices in two cropland ecosystems," *Agricultural and Forest Meteorology*, vol. 160, pp. 80–89, 2012.

[46] A. A. Gitelson, Y. Gritz, and M. N. Merzlyak, "Relationships between leaf chlorophyll content and spectral reflectance and algorithms for non-destructive chlorophyll assessment in higher plant leaves," *Journal of plant physiology*, vol. 160, no. 3, pp. 271–282, 2003.

[47] I. Filella, L. Serrano, J. Serra, and J. Penuelas, "Evaluating wheat nitrogen status with canopy reflectance indices and discriminant analysis," *Crop Science*, vol. 35, no. 5, pp. 1400–1405, 1995.

[48] M. N. Merzlyak and A. Gitelson, "Why and what for the leaves are yellow in autumn? on the interpretation of optical spectra of senescing leaves (acerplatanoides l.)," *Journal of Plant Physiology*, vol. 145, no. 3, pp. 315–320, 1995.

[49] W.-D. Huang, K.-H. Lin, M.-H. Hsu, M.-Y. Huang, Z.-W. Yang, P.-Y. Chao, and C.-M. Yang, "Eliminating interference by anthocyanin in chlorophyll estimation of sweet potato (ipomoea batatas l.) leaves," *Botanical studies*, vol. 55, no. 1, pp. 1–10, 2014.

[50] A. A. Gitelson, G. P. Keydan, and M. N. Merzlyak, "Three-band model for noninvasive estimation of chlorophyll, carotenoids, and anthocyanin contents in higher plant leaves," *Geophysical research letters*, vol. 33, no. 11, 2006.

[51] R. Main, M. A. Cho, R. Mathieu, M. M. OKennedy, A. Ramoelo, and S. Koch, "An investigation into robust spectral indices for leaf chlorophyll estimation," *ISPRS Journal of Photogrammetry and Remote Sensing*, vol. 66, no. 6, pp. 751–761, 2011.

[52] E. R. Hunt, C. Daughtry, J. U. Eitel, and D. S. Long, "Remote sensing leaf chlorophyll content using a visible band index," 2011.

[53] M. Vincini, E. Frazzi, and P. DAlessio, "A broad-band leaf chlorophyll vegetation index at the canopy scale," *Precision Agriculture*, vol. 9, no. 5, pp. 303–319, 2008.

[54] N. Gobron, B. Pinty, M. M. Verstraete, and J.-L. Wid-

lowski, “Advanced vegetation indices optimized for upcoming sensors: Design, performance, and applications,” *IEEE Transactions on Geoscience and Remote Sensing*, vol. 38, no. 6, pp. 2489–2505, 2000.

[55] M. Drusch, U. Del Bello, S. Carlier, O. Colin, V. Fernandez, F. Gascon, B. Hoersch, C. Isola, P. Laberinti, P. Martimort, A. Meygret, F. Spoto, O. Sy, F. Marchese, and P. Bargellini, “Sentinel-2: Esa’s optical high-resolution mission for gmes operational services,” *Remote Sensing of Environment*, vol. 120, pp. 25–36, 2012. The Sentinel Missions - New Opportunities for Science.

[56] S. Ferrant, A. Selles, M. Le Page, P.-A. Herrault, C. Pelletier, A. Al-Bitar, S. Mermoz, S. Gascoin, A. Bouvet, M. Saqalli, B. Dewandel, Y. Caballero, S. Ahmed, J.-C. Marchal, and Y. Kerr, “Detection of irrigated crops from sentinel-1 and sentinel-2 data to estimate seasonal groundwater use in south india,” *Remote Sensing*, vol. 9, no. 11, 2017.