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REMOTE SENSING THE SEASONAL LEAF CHLOROPHYLL VARIATIONS OF LITCHI PLANTS IN SOUTHERN CHINA

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ABSTRACT

Ratio-index-based model is proven to be an effective method of estimating leaf chlorophyll content of tree canopy. In this study, a ratio-index retrieval model was developed with the Landsat TM8 TM3-band reflectance, and the seasonal variations of canopy leaf chlorophyll contents before and after cold disasters were assessed. In a single day, leaf chlorophyll contents of Litchi plants indicate significantly and linearly correlation with 1/TM3 values, whereas on the whole, they present positive logarithmic relationship with the values of root mean square error (RMSE) = 7.35 mg/g; R^2 = 0.7714). Results of this study showed that due to cold disaster, canopy leaf chlorophyll contents generally declined from autumn (12th October 2013) to winter (31th December 2013 and 16th January 2014). In particular, the canopy leaf chlorophyll contents slightly varied (< 10 mg/g) for regions with higher chlorophyll contents, whereas they varied more greatly for regions with lower contents (> 15 mg/g).

Keywords: leaf chlorophyll content, retrieval model, cold disaster.

AIMS AND BACKGROUND

Litchi is a specific fruit tree mainly dispersed in tropical and warm subtropical countries such as Southern China, Thailand, India, South Africa, Madagascar, Mauritius,

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and Australia. In these regions, litchi production is steadily growing[1]. In 2008, China has a total of 580 700 ha of Litchi orchards; hence, it accounts for 50% of world litchi production. Litchi plants are successfully cultivated in the regions of China particularly situated between 19 and 24°N, covering Guangdong, Guangxi, Fujian, Hainan, and Yunnan provinces[2]. Among these areas, Guangdong is the largest litchi-producing province, contributing to nearly 61.21% of Chinese total litchi output[3]. In fact, litchi is currently the largest fruit industry in Guangdong province, accounting for 32% of the total area under fruit cultivation[4].

Litchi is extremely sensitive to environment and requires specific climate conditions. In particular, this fruit tree grows best in places with short, dry, and cool weather conditions, but frost-free winters (daily maximum temperature condition below 20 to 22°C) and long and hot summers (daily maximum temperature of above 25°C) with high rainfall (1200 mm) and high humidity[5]. However, drought and cold meteorological disasters of tropical vegetations (i.e. litchi plants) frequently occur in Guangdong because of the uneven distribution of annual rainfall, strong evaporation and transpiration, and unexpected low air temperatures in the province. Since 1990, six strong cold disasters have occurred in Guangdong and have caused serious economic losses (about 50 billion Yuan)[6]. In 2004, 2007, and 2009, three disastrous droughts yet again occurred in Guangdong, inducing severe economic losses (about 30 billion Yuan)[7]. Therefore, the potential affected areas of litchi cultivation must necessarily be detected for pre-disaster prevention and post-disaster assessment.

The most visible features of litchi tree that have endured drought and cold disasters are the drying-up and withering of its canopy leaves. Hence, chlorophyll content of canopy leaf is a convincible factor that indicates disaster degree. Remote sensing of leaf chlorophyll content has been conducted for years and applied for crops[8], grasses[9], and forest[10]. Index-based methods[11] such as the normalised difference vegetation index[12,13], simple ratio index[14.15], chlorophyll absorption ratio index[16–18], red-edge vegetation index[19], normalised area over reflectance curve[20], and integrated vegetation index[21], are the most commonly used retrieval model of estimating leaf chlorophyll content of forest canopy.

From the abovementioned techniques, the ratio-index-based model has been proven to be an effective method of estimating the leaf chlorophyll content of tree canopy. Accordingly, this study first develops a ratio-index retrieval model using the Landsat TM8 TM3-band reflectance and subsequently assesses the seasonal variations of canopy leaf chlorophyll contents before and after cold disasters.

EXPERIMENTAL

Study area. Zhongluotan, a town located in Guangzhou City of Guangdong Province, Southern China, was selected as the study area (Fig. 1). The climate in this town belongs to the typical subtropical monsoon maritime climate of Southern Asia, with an average annual sunshine of about 1688.9 h, and annual mean air temperature of nearly

22.8°C. Meanwhile, the absolute annual maximum and minimum air temperatures of Guangzhou are roughly 38.7 and 2.0°C, respectively. In this locality, litchi orchards are mainly planted along the Liuxi River, a tributary of Pearl River. Abnormal low temperature conditions always result in unexpected cold disasters that adversely affect litchi trees.

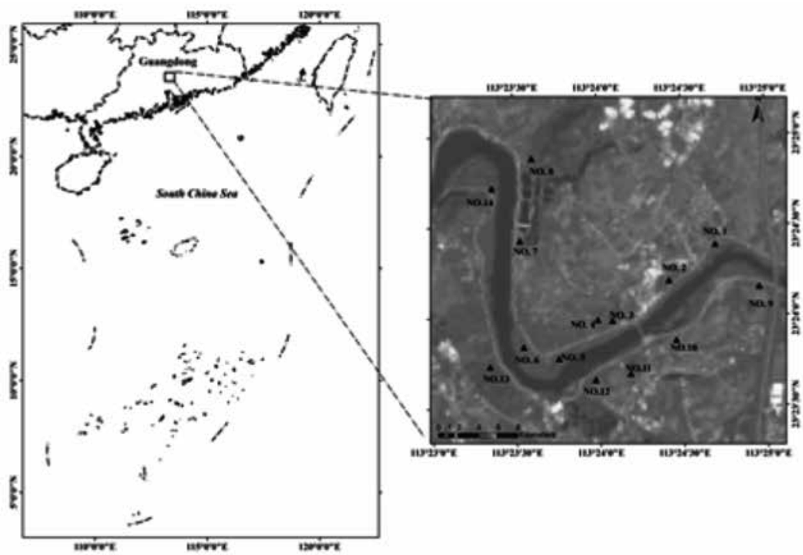

Fig. 1. Zhongluotan Town and sampling sites

Material. This study measured leaf chlorophyll content using the SPAD-502 Chlorophyll Meter Model. In particular, the canopy chlorophyll contents of Litchi trees were determined by collecting nine leave samples from each tree canopy (Fig. 2). The average value of sampled night leaf chlorophyll contents was assumed to be the canopy chlorophyll content of the selected litchi trees. Meanwhile, the average value of the canopy chlorophyll content of neighbouring four litchi trees was assumed to be the chlorophyll content of the corresponding pixel in the satellite imagery. Subsequently, the average canopy chlorophyll content was used to match with the pixel-based reflectance of satellite imagery at the same spatial position.

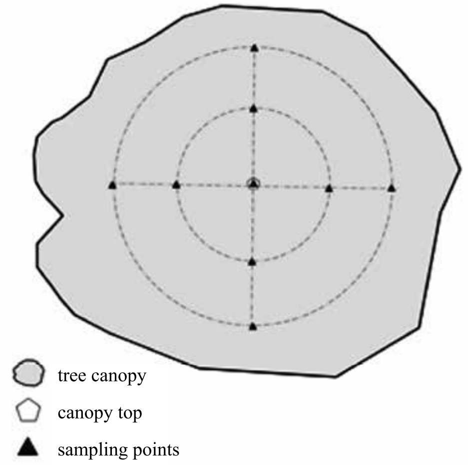

Fig. 2. Canopy chlorophyll content sampling method

Landsat TM-series data are one of the most frequently used kinds of remote-sensing data for environmental studies[22]. Landsat TM8 data are composed of night bands (Table 1). TM1 (0.433 to 0.453 μm) and TM2 (with a central wavelength of 0.49 μm) are used for coastal water studies and vegetation classifications; TM3 (0.56 μm) is used for crop identification, vegetation stage studies, and water reflectance measurements; TM4 and TM5 (0.66 and 0.83 μm, respectively) are used to calculate vegetation indices, draw biomass measurements, and identify water borderline; TM6 and TM7 (1.65 and 2.22 μm, respectively) are used for cloud, ice, and snow discriminations. Meanwhile, TM9 (1.360 to 1.390 μm) is the short-infrared band used to detect water vapour and clouds. Accordingly, TM3, TM4, and TM5 are potential means of estimating the chlorophyll content of canopy leaves.

Table 1. Band characteristics of Landsat TM8 image

Bands	Frequency (μm)	Spatial resolution (m)
Band1 Coastal	0.433–0.453	30
Band 2 Blue	0.450–0.515	30
Band 3 Green	0.525–0.600	30
Band 4 Red	0.630–0.680	30
Band 5 NIR	0.845–0.885	30
Band 6 SWIR 1	1.560–1.660	30
Band 7 SWIR 2	2.100–2.300	30
Band 8 Pan	0.500–0.680	15
Band 9 Cirrus	1.360–1.390	30

Three cloud-free scenes of Landsat TM8 imageries derived on 12th October 2013 (autumn), 31st December 2013 (winter), and 16th January 2014 (winter) were selected in the Landsat TM archive of the Global Land Cover Facility at the University of Maryland. The Satellite passing times of these scenes were at about 10:54, 10:53 and 10:53 a.m. (Beijing time), separately. The path and row numbers of TM imageries were 122 and 44, respectively. In these three days, the weather was normal. As demonstrated by the three images, the study area was fairly covered by clouds.

RESULTS AND DISCUSSION

Development of chlorophyll content retrieval model. The results of the study showed that, for each day, the leaf chlorophyll contents of litchi plants were significantly and linearly correlated with 1/TM3 values (Fig. 3). Determination coefficients on 12th October 2013, 31st December 2013, and 16th January 2014 were 0.6295, 0.7193, and 0.7738, respectively. A positive logarithmic relationship was identified between chlorophyll contents and 1/TM3 values (Fig. 4) based on the relations of these two elements that were discovered using the data on the specified dates. Fitting formula was Chl = 19.496 × ln(1/TM3) + 158.35 (RMSE = 7.35 mg/g; R^2 = 0.7714). In this study, the integrated logarithmic chlorophyll retrieval model was adopted to monitor the seasonal variations of canopy leaf chlorophyll contents of litchi plants in Zhongruotan.

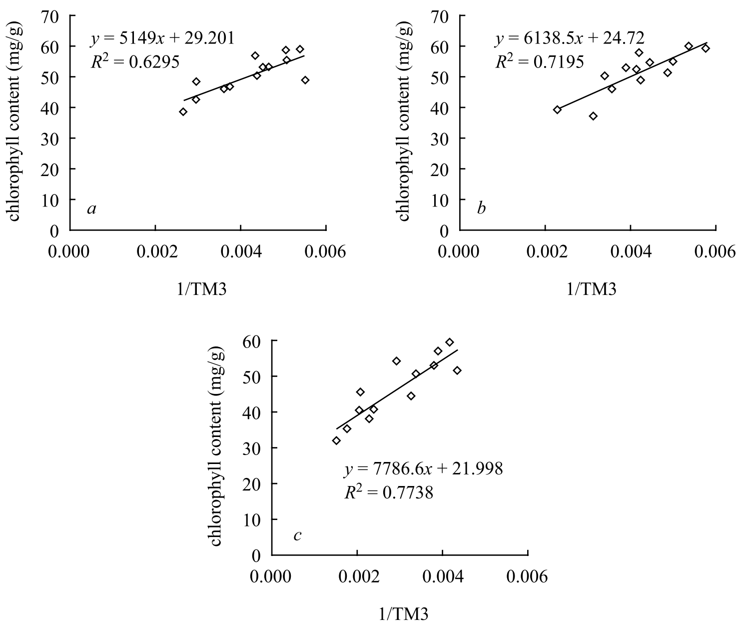

Fig. 3. Chlorophyll content retrieval model for: 12th October 2013 (*a*), 31st December 2013 (*b*), and 16th January 2014 (*c*)

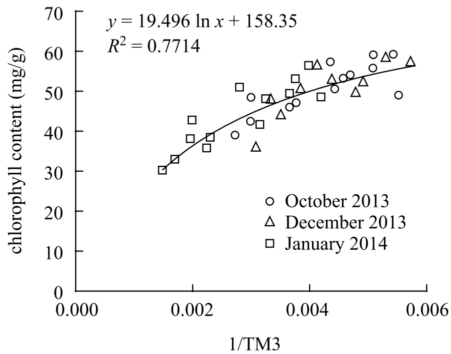

Fig. 4. Integrated chlorophyll content retrieval model

Seasonal variations of canopy leaf chlorophyll contents. The canopy leaf chlorophyll contents of litchi plants in the litchi orchards of Zhongruotan on 12th October 2013, 31st December 2013, and 16th January 2014 are mapped and shown in Fig. 5. The results of the analysis indicate that the canopy leaf chlorophyll contents were generally declining from autumn (12th October 2013) to winter (31st December 2013 and 16th January 2014). This particular instance is mainly due to the fact that the leaf chlorophyll contents of litchi trees can easily be influenced by cold air temperature, and their leaves could quickly turn yellow.

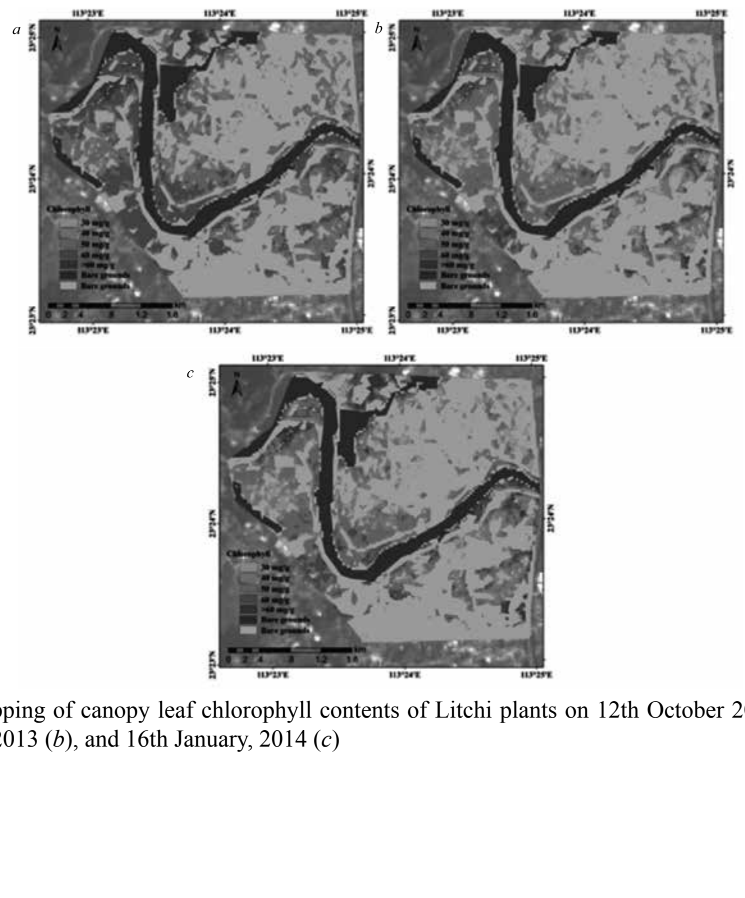

Fig. 5. Mapping of canopy leaf chlorophyll contents of Litchi plants on 12th October 2013 (*a*), 31st December 2013 (*b*), and 16th January, 2014 (*c*)

The degree of the seasonal variations of canopy leaf chlorophyll contents of litchi plants in Zhongruotan was further assessed, and the results are shown in Fig. 6. The figure particularly demonstrates that the canopy leaf chlorophyll contents slightly varied (<10 mg/g) for regions with higher chlorophyll contents, whereas they varied more greatly (>15 mg/g) for regions with lower contents. This occurrence was induced by the condition that old litchi trees always have more chlorophyll contents in their leaves and could have higher tolerance to cold weather. By contrary, young litchi trees always have smaller chlorophyll contents in canopy leaves with lower cold tolerance.

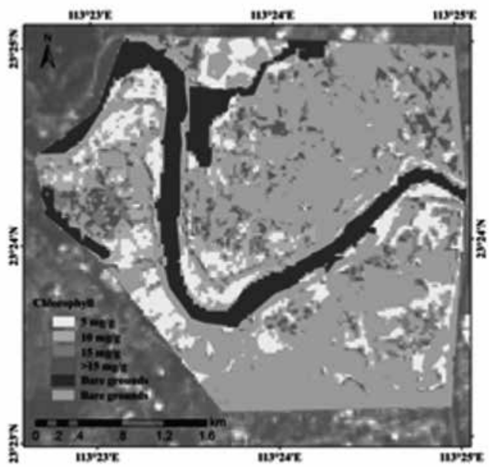

Fig. 6. Variations of canopy leaf chlorophyll contents of litchi plants

CONCLUSIONS

This study determined a positive logarithmic relationship between chlorophyll contents and 1/TM3 values (Chl = 19.496 × ln(1/TM3) + 158.35; RMSE = 7.35 mg/g; R^2 = 0.7714). In particular, the seasonal variations of canopy leaf chlorophyll contents of litchi plants in Zhongruotan were monitored with a chlorophyll retrieval model. Affected by cold disaster, the canopy leaf chlorophyll contents generally declined from 12th October 2013 to 31st December 2013 until 16th January 2014. Old litchi trees with higher leaf chlorophyll contents were more seriously affected by the calamity, whereas young litchi trees with lower leaf chlorophyll contents were less affected.

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REFERENCES

1. S. K. MITRA: Overview of Lychee Production in the Asia-Pacific Region. In: Lychee Production in the Asia-Pacific Region (Eds M. K. Papademetriou, F. J. Dent). Food and Agricul. Organization of UN, Regional Office for Asia and the Pacific, Bangkok, Thailand, 2002, 5–13.
2. H. B. CHEN, H.B., HUANG: China Litchi Industry: Development, Achievements and Problems. Acta Hortic (ISHS), **558**, 31 (2004).
3. D. S. LI, C. LIAO, B. X. ZHANG, Z. W. SONG: Biological Control of Insect Pests in Litchi Orchards in China. Biol Control, **68**, 23 (2014).
4. X. M. HUANG: Lychee Production in China. In: Lychee Production in the Asia-Pacific Region (Eds M. K. Papademetriou, F. J. Dent). Food and Agric. Organization of the UN, Regional Office for Asia and the Pacific, Bangkok, Thailand, 2001, 41–54.
5. R. B. SINGH: Welcome Address. In: Lychee Production in the Asia-Pacific Region (Eds M. K. Papademetriou, F. J. Dent). Food and Agric. Organization of the UN, Regional Office for Asia and the Pacific, Bangkok, Thailand, 2002, 2–4.
6. X. Z. CHEN, S. S. CHEN, R. F. ZHONG, Y. X. SU, J. S. LIAO, D. LI, L. S. HAN, Y. LI, X. LI: A Semi-empirical Inversion Model for Assessing Surface Soil Moisture Using AMSR-E Brightness Temperatures. Hydrol, **456**, 1 (2012).
7. X. Z. CHEN, Y. X. SU, D. LI, G. Q. HUANG, W. Q. CHEN, S. S. CHEN: Study on the Cooling Effects of Urban Parks on Surrounding Environments Using Landsat TM Data: A Case Study in Guangzhou, Southern China. Remote Sens, **33** (18), 5889 (2012).
8. Y. PENG, A. A. GITELSON: Application of Chlorophyll-related Vegetation Indices for Remote Estimation of Maize Productivity. Agr For Meteorol, **151** (9), 1267 (2011).
9. R. DARVISHZADEH, A. K. SKIDMORE, M. SCHLERF, C. ATZBERGER: Inversion of a Radiative Transfer Model for Estimating Vegetation LAI and Chlorophyll in Heterogeneous Grassland. Remote Sens. Environ, **112**, 2592 (2008).
10. H. CROFT, J. M. CHEN, Y. ZHANG, A. SIMIC: Modelling Leaf Chlorophyll Content in Broadleaf and Needle Leaf Canopies from Ground, CASI, Landsat TM 5 and MERIS Reflectance Data. Remote Sens Environ, **133**, 128 (2013).
11. N. H. BROGE, E. LEBLANCB: Comparing Prediction Power and Stability of Broadband and Hyperspectral Vegetation Indices for Estimation of Green Leaf Area Index and Canopy Chlorophyll Density. Remote Sens Environ, **76**, 156 (2000).
12. J. W. ROUSE, R. H. HAAS, J. A. SCHELL, D. W. DEERING, J. C. HARLAN: Monitoring the Vernal Advancements and Retrogradation of Natural Vegetation. In NASA/GSFC, Final Report, Greenbelt, MD, USA, 1974, 1–137.
13. A. TILLACK, A. CLASEN, B. KLEINSCHMIT, M. FÖRSTER: Estimation of the Seasonal Leaf Area Index in an Alluvial Forest Using High-resolution Satellite-based Vegetation Indices. Remote Sens Environ, **141**, 52 (2014).
14. P. N. SLATER, R. D. JACKSON: Atmospheric Effects on Radiation Reflected from Soil and Vegetation as Measured by Orbit Sensors Using Various Scanning Directions. Appl Optics, **21**, 3923 (1982).
15. R. M. NAVARRO-CERRILLO, J. TRUJILLO, M. S. de LA ORDEN, R. HERNÁNDEZ-CLEMENTE: Hyperspectral and Multispectral Satellite Sensors for Mapping Chlorophyll Content in a Mediterranean *Pinus sylvestris* L. Plantation. Int J Appl Earth Obs Geoinf, **26**, 88 (2014).
16. M. S. KIM, C. S. T. DAUGHTRY, E. W. CHAPPELLE: The Use of High Spectral Resolution Bands for Estimating Absorbed Photosynthetically Active Radiation (Apar). In: Proc. of the Sixth Symposium on Physical Measurements and Signatures in Remote Sensing, Val D'Isere, France, 1994, 299–306.

17. D. HABOUDANE, R. JOHN, J. R. MILLERA, N. TREMBLAY, P. J. ZARCO-TEJADA, L. DEXTRAZE: Integrated Narrow-band Vegetation Indices for Prediction of Crop Chlorophyll Content for Application to Precision Agriculture. Remote Sens Environ, **81**, 416 (2002).
18. C. S. T. DAUGHTRY, C. L. WALTHALL, M. S. KIM, E. BROWN de COLSTOUN, J. E. McMurtrey III: Estimating Corn Leaf Chlorophyll Concentration from Leaf and Canopy Reflectance. Remote Sens Environ, **74**, 229 (2000).
19. R. MAIN, M. A. CHO, R. MATHIEU, M. M. O'KENNEDY, A. RAMOELO, S. KOCH: An Investigation into Robust Spectral Indices for Leaf Chlorophyll Estimation. ISPRS J Photogramm, **66** (6), 751 (2011).
20. J. DELEGIDO, S. van WITTENBERGHE, J. VERRELST, V. ORTIZ, F. VEROUSTRAETE, R. VALCKE, R. SAMSON, J. P. RIVERA, C. TENJO, J. MORENO: Chlorophyll Content Mapping of Urban Vegetation in the City of Valencia based on the Hyperspectral NAOC Index. Ecol Indic, **40**, 34 (2014).
21. C. Y. WU, Z. NIU, Q. TANG, W. J. HUANG: Estimating Chlorophyll Content from Hyperspectral Vegetation Indices: Modeling and Validation. Agr Meteorol, **148**, 1230 (2008).
22. S. S. CHEN, X. Z. CHEN, W. Q. CHEN, Y. X. SU, D. LI: A Simple Retrieval Method of Land Surface Temperature from AMSR-E Passive Microwave Data. A Case Study over Southern China during the Strong Snow Disaster of 2008. Appl Earth Obs Geoinf, **13** (1), 140 (2011).
23. J. VERRELST, M. E. SCHAEPMAN, Z. MALENOVSKÝ, J. G. CLEVERS: Effects of Woody Elements on Simulated Canopy Reflectance: Implications for Forest Chlorophyll Content Retrieval. Remote Sens Environ, **114** (3), 647 (2010).
24. I. UGULU, M. C. UNVER, Y. DOGAN: Determination and Comparison of Heavy Metal Accumulation Level of *Ficus carica* Bark and Leaf Samples in Artvin, Turkey. Oxid Commun, **39** (1-II), 765 (2016).
25. A. McCIONI, G. AGATI, P. MAZZINGHI: New Vegetation Indices for Remote Measurement of Chlorophylls Based on Leaf Directional Reflectance Spectra. J Photochem Photobiol, **61** (1), 52 (2011).
26. S. V. IVANOV, M. STEFCHEVA, P. E. MITEVA, E. K. SHOPOVA, V. S. ALEXIEVA: Salicylic Acid Alleviates Leaf Rust-inducible Oxidative Processes in Wheat Plants. Oxid Commun, **31** (4), 895 (2008).

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