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To Study the Effects of Diseases on Plants Using Hyperspectral Data

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Abstract: **Many diseases cause severe economic loss to farmers through increased cost of pesticides and reduced yields. Visual inspection of disease is carried out when the photosynthetic tissues are already damaged. Hyper spectral reflectance is an effective and useful technique to assess the disease infection. The aim of this study is to examine the potential of hyper spectral reflectance in detecting the incidence of disease on various plants. It analyzes the plant health through measurement of reflectance at several wavelengths which allows the disease to be detected earlier and properly controlled. This paper summarises the disease detection research work done by different authors and importance of remote sensing, spectroradiometry to determine infection in plants, crops before symptoms become visually perceptible.**

Keywords: - **Agriculture, Plant Disease, Spectral Reflectance, Symptoms.**

I. INTRODUCTION

Disease management is important because it can cause serious damage to sugarcane crops that often lead to reduced crop yield and quality. To solve this problem it is necessary to take various curative measures, like disease detection and mapping. For instance, to apply chemicals for disease control, the location and spatial extent of affected crops must be first determined. However, a lot of work has been done, successfully demonstrating the use of narrow-band spectral indices for general assessment of crop condition. Therefore, it is necessary to examine the potential of satellite hyperspectral imagery to find the incidence of sugarcane 'orange rust' disease [1], [2]. Accurate appraisals of disease severity, disease occurrence and the negative impacts of diseases on the quality and quantity of agricultural produce are essential for field crop and horticulture. Timely assessment of plant disease incidence is basis for planning targeted plant protection activities in field as well as greenhouse production. It is necessary to forecast temporal and spatial disease spread in specific growing regions. General method for the detection and diagnosis of plant diseases include visual plant disease estimation by human [3], [4]. However, the high spectral and spatial resolution of hyperspectral technology increases the possibility to recognize peculiarities in the normal plant growth process at an early stage i.e. before the damage can occur. This possibility is helpful for most researches in the field of disease detection and vegetation stress [5], [6].

The viral, bacterial and fungal infections by insects result in plant diseases. Upon infection, a crop shows symptoms that appear on various parts of the crops causing a notable agronomic impact. It is important to determine the disease of the crops so that the effective control measures are to be taken for the infected crops. Sometimes disease identification is mainly done by visual inspections but with the advancement of technology in an agriculture field, the remote sensing techniques have been used to determine diseases in agricultural crops [7], [8]. Many studies focus on broad spectral bands such as the near-infrared (NIR) and visible (VIS) spectral ranges (350 nm to 1300 nm), which are widely used for vegetation analysis. Hyperspectral remote sensing technology is useful for detailed environmental and plant studies [9], [10]. Nowadays, electromagnetic wavelengths used are ranging from the ultraviolet to microwave portions of the spectrum (i.e. 350 nm to 2500 nm). The data obtained are in many hundreds of contiguous spectral bands which allow analysis of crop disease, crop and biochemical or biophysical characteristics associated with crop status [11], [12]. Hyperspectral remote sensing helps in disease detection in plants through spectral properties of it. The spectral measurements are taken at shortwave infrared, visible and near infrared regions ranging from 350 – 2500 nm. To minimize the economic loss caused by diseases and reduce environment pollution, it is important to properly assess the disease in the plants so that exact control measures can be applied timely to the infested plants [13], [14].

II. RELATED WORK

TSWV (Tomato Spotted Wilt Virus) is one of the most harmful virus infecting vegetable crops. The tospoviruses similar to TSWV are infecting more than 1000 monocot and dicot species throughout the world [15]. Plant resistance and strategies which reduce viral transmission from plant to plant are the good methods for controlling tospoviruses. TSWV causes symptoms like stem death, wilting, yellowing, stunting, sunken spots, poor flowering and ring spots on plant leaves.

These spots become brown and then followed by browning of leaves that die. Due to this infection, green fruit show concentric rings of brown or yellow alternating with the background green color and brown rings appear on red-ripe fruit [16]. Yellow rust on winter wheat crop has resulted in huge reductions in the wheat grain quality. It is essential to detect and assess this disease. Lin-Sheng Huang et al. used yellow rust in wheat to determine the capability of estimating the infection index in various leaf layers of the crop using hyperspectral measurements on the individual wheat diseased leaves. In addition, yellow rust spectral index (YRSI) was constructed to find the disease using sensitive bands in the visible (704 nm), SWIR (1926 nm) and NIR (1423 nm) regions. The hyperspectral reflectance data of wheat sample leaves were measured using field-portable ASD FieldSpec Pro FR 2500 spectrometer with the ASD′s Leaf Clip in the short-wave infrared (SWIR) ranges (350–2500 nm), visible and near infrared (VNIR) [17].

Qi Liu et al. investigated the potential usefulness of an ASD spectroradiometer to determine wheat stripe rust in the latent period. The results show that wheat stripe rust can be found based on the canopy spectral detection. Thus, the method can be efficiently used for identification of infections of wheat stripe rust [18]. The optical properties of healthy vegetation, green leaves or canopies are characterized by high absorption in the blue band (400 - 500 nm) and the red band (600 - 700 nm), but high reflectance in the green band (500 - 600 nm), and very high reflectance and transmitance in the near infrared band (NIR: 700 - 1500 nm) [19], [20].

It is found that infected wheat crop has less root and shoot biomass than the uninfected crop. Thus, it results in strong decrease in water-use efficiency [21], [22]. Post-cultivation losses due to diseases and sub-standard quality are estimated to be 30%–40%. Overall, the economic losses due to infections are estimated at 40 billion dollars annually in the United States alone [23]. Vigier et al. found that the reflectance in the red wavelengths for e.g. 675–685 nm resulted in the identification of sclerotinia stem rot infection in soybean crop [24].

The reflection of healthy vegetation is high in the near-infrared (NIR) portion i.e. at 700 nm – 1300 nm. Due to disease infection or pests that harm the leaves, the reflectance in the NIR portion is expected to be lower. In the study of maize dwarf mosaic virus, Ausmus and Hilty concluded that in the reflectance studies of crop diseases the NIR wavelengths were very much useful [25]. Zhang, et al. conducted a study on stress in tomatoes induced by late blight disease and determined that the NIR region was much valuable than the visible region to detect disease [26].

III. METHODOLOGY

Greenhouse experiment was conducted by D. Krezhova et al. with young tobacco plants infected with TSWV. Remote sensing technique and spectral reflectance was used for detecting and assessing the development of the viral infection. At growth stage 4-6 expanded leaf, few plants were infected with TSWV having critical symptoms of yellow spotting. Hyperspectral reflectance data of both healthy (i.e. control) and infected leaves was collected by a portable fibre-optics spectrometer in the near-infrared and visible spectral ranges. Spectral reflectance analysis was conducted in NIR, red, red edge and green regions. The differences between the reflectance spectra of control and infected leaves were assessed by means of the Student’s t-criterion at ten selected wavelengths and first derivative analysis. The viral infection in the leaves was found by the serological method DAS-ELISA. On the 14th day the differences of averaged reflectance spectra against the control were statistically significant at four of the investigated wavelengths and the presence of TSWV was established, i.e. the latent infection has been occurred. On the 20th day the statistical analysis results in the shift of the red edge position, i.e. the infection is deepening i.e. in agreement with serological analyses [27].

Modifications in spectral reflection and differences between spectral signatures can be distinguished by calculating difference spectra, ratios or derivations. This methodology is a useful tool to compare spectra of healthy and diseased plants [28], [29]. Mahlein et al. determined several significant regions of difference spectra from plants diseased with sugar beet rust, Cercospora leaf spot and powdery mildew as well as from healthy plants [30].

Depending on the reflectance characteristics, spectral algorithms using wavelengths of spectral signatures are developed in remote sensing of vegetation. They are correlated to various biophysical and biochemical plant parameters indicating plant health. Spectral vegetation indices (SVIs) are mainly used for mapping, analyzing and monitoring temporal and spatial variation in vegetation [31], [32].

The yellowish appearance of leaves is the visual indication of plant stress that reduces chlorophyll concentrations in plant leaves. M. L. Adams et al. introduced yellowness index (YI) for measuring chlorosis of leaves in stressed plants. Quantitatively, YI is three-point approximation of the second derivative of the spectra. YI is an approximation of a spectral second derivative so it is less sensitive to atmospheric effects than other vegetation indices [33].

Swati B. Magare et. al. concluded that glyphosate application for weed control can drift onto an off target area, causing unwanted damage to crops. Chlorophyll content is a good indicator of plant health. Early detection of crop injury from

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off-target drift of glyphosate is essential in crop production [34].

IV. RESULT AND DISCUSSION

A. Apan et al. found that there is a significant difference in spectral reflectance signatures of sample areas with the sugarcane orange rust disease and can be distinguished from non-diseased areas. The diagnostic symptoms of orange rust disease may be related to changes in moisture content, leaf pigments and internal leaf structure. Therefore, SVIs (Spectral Vegetation Indices) focusing on these changes were selected and the ability of each index was found depending on the accuracy of classification. Results showed that hyperion imagery can be used to determine orange rust disease in sugarcane crops. The various indices that are used i.e. visible near-infrared (VNIR) bands (e.g. SIPI and R800/R680) provide separability and the combination of VNIR bands with the moisture-sensitive band (1660 nm) increased the separability of rust-affected areas. The recently developed 'Disease–Water Stress Indices' (DWSI-1 = R800/R1660; DSWI-2 = R1660/R550; DWSI-5 = (R800+R550) / (R1660+R680)) provided the largest correlations which showed their good ability to differentiate sugarcane areas affected by orange rust disease [35].

Normalized difference vegetation index (NDVI) is used to analyze plant health condition as well as studies related to nutrient requirements for plant. It is a measure of the normalized difference in reflectance of red and near infrared wavelength bands [36], [37]. Zhang J et al. reported the correlation between NDVI data obtained from hyperspectral imaging of plants and various factors like plant stress, plant diseases, biomass etc. [38].

Leaf chlorophyll content index (CCI) has been used as a trait to monitor genotypes under different conditions like leaf nitrogen concentration, nutrition availability etc. Since, stripe rust affects plant's photosynthesis activity due to breakdown of chlorophyll pigments it can be used as an index for detection of rust at early stages [39], [40]. Jing et al. found the relation between wheat stripe rust and chlorophyll content of the plant [41].

Apoorva Arora et al. conducted an experiment on wheat in which Plant Canopy temperature (CT), Normalized difference vegetation index (NDVI) and Chlorophyll content index (CCI) were recorded twice, 7 days apart, when disease severity approached maximum values on the susceptible controls. The results show that the temporal ground-based NDVI is most effective in analyzing quantitative rust reaction followed by chlorophyll content index and canopy temperature [42].

Swati B. Magare et. al. found that 2,4-D Amine Herbicide reduced the chlorophyll content in wheat and corn. ASD FieldSpec4 Spectroradiometer was used for measuring spectral reflectance of detached wheat and corn leaves. For both the crops, leaves sprayed with different 2, 4-D rates shows separability of chlorophyll content. DVI (Difference Vegetation Index), NDVI (Normalized Difference Vegetation Index), MCARI (Modified Chlorophyll Absorption Ratio Index), SR (simple Ratio), CI Red Edge (Chlorophyll Index Red Edge) and Vog1 (Vogelmann red edge index 1) indices were used to estimate chlorophyll content. Based on the values obtained through spectral indices, it is concluded that the chlorophyll content in both the crops decreased with the use of 2, 4-D Amine [43].

Based on the regression coefficient plots as well as the results of Martens' Uncertainty Test, A. Apan et al. found that the most significant spectral bands for identification of tomato disease corresponded to the reflectance red-edge (i.e. 690 nm-720 nm), as well as the visible region (i.e. 400nm-700nm) and part of near-infrared wavelengths (i.e. 735 nm-1142 nm). The mean reflectance values of diseased tomato samples were different from the healthy ones [44]. P. Chavez et al. concluded that the spectral vegetation indices i.e. SAVI, NDVI and IPVI help in early detection of viral infection in potato fields before manifestation of chlorosis can be identified by visual inspection [45].

V. CONCLUSION

Accurate disease detection and diagnosis is important for controlling plant diseases and mitigating the economic losses that incur. The most widely used method for detecting disease is visual inspection which is time consuming and can be used when damage has already occurred to plants. As compared to this traditional method that relies on visual observation, remote sensing is a cost effective and efficient technique for disease detection that has facilitated the monitoring of plant disease at various spectral resolutions.

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REFERENCES

[1] Thenkabail, P., Smith, R., and Depauw, E., "Evaluation of narrowband and broadband vegetation indices for determining optimal hyperspectral wavebands for agricultural crop characterization", Photogrammetric Engineering and Remote Sensing, Vol. 68, pp. 607–621, 2002.

[2] Kanemasu, E. T., Niblett, C. L., Manges, H., Lenhert, D., and Newman, M. A., "Wheat: its growth and disease severity as deduced from ERTS-1", Remote Sensing of Environment, Vol. 3, pp. 255–260, 1974.

[3] Bock, C. H., Poole, G. H., Parker, P. E., and Gottwald, T. R,"Plant disease severity estimated visually, by digital photography and image analysis, and by hyperspectral imaging", Crit. Rev. Plant Sci., Vol. 29, pp. 59-107, 2010.

[4] Panda, S. S., H. Gerrit and O. P. Joel, "Remote sensing and geospatial technological applications for site-specific management of fruit and nut crops: a review", Remote Sensing, Vol. 2, pp. 1973–1997, 2010.

[5] Delalieux, S., J. A. N. Van Aardt, W. Keulemans, E. Schrevens and P. Coppin, "Detection of biotic stress (Venturia inaequalis) in apple trees using hyperspectral data: nonparametric statistical approaches and physiological implications", European Journal of Agronomy, Vol. 27, pp. 130-143, 2007.

[6] Krezhova, D. D., T. K. Yanev, V. S. Alexieva and S. V. Ivanov, "Early detection of changes in leaf reflectance of pea plants (Pisum sativum L.) under herbicide action", In: S. Kurnaz (Editor), Recent Advances in Space Technologies. (Proceedings of 2nd International conference of Recent Advances in Space Technologies, Istanbul, Turkey, 9-11 June, 2005), pp. 636-641, 2005.

[7] Sankarana, S., A. Mishraa, R. Ehsania and C. Davis, "A review of advanced techniques for detecting plant diseases", Computers and Electronics in Agriculture, Vol. 72, pp. 1–13, 2010.

[8] Yang, Z., M. N. Rao, N. C. Elliott, S. D. Kindler and T. W. Popham, "Differentiating stress induced by greenbugs and Russian wheat aphids in wheat using remote sensing", Computers and Electronics in Agriculture, Vol. 67, pp. 64–70, 2009.

[9] Bravo, C., D. Moshou, J. West, A. Mc Cartney and H. Ramon, "Early disease detection in wheat fields using spectral reflectance", Biosystems Engineering, Vol. 84, Issue 2, pp. 137–145, 2003.

[10] Lee, W. S., V. Alchanatis, C. Yang, M. Hirafuji, D. Moshou and C. Li, "Sensing technologies for precision specialty crop production",Computers and Electronics in Agriculture, Vol. 74, pp. 2–33, 2010.

[11] Muhammed, H. H., "Hyperspectral crop reflectance data for characterizing and estimating fungal disease severity in wheat", Biosystems Engineering, Vol. 91, Issue 1, pp. 9–20, 2005.

[12] Naidu, R. A., E. M. Perryb, F. J. Pierceb and T. Mekuria, "The potential of spectral reflectance technique for the detection of grapevine leafroll-associated virus-3 in two red-berried wine grape cultivars", Computers and Electronics in Agriculture, Vol. 66, Issue 1, pp. 38–45, 2009.

[13] West, J.S., Bravo, C., Oberit, R., Lemaire, D., Moshou, D., and Mc Cartney, H.A.,"The potential of optical canopy measurement for targeted control of field crop diseases", Annual Review of Phytopathology, Vol. 41, pp. 593–614, 2008.

[14] Moshou, D., Bravo, C., West, J., Wahlen, S., McCartney, A., and Ramon, H., "Automatic detection of 'yellow rust' in wheat using reflectance measurements and neural networks", Computers and Electronics in Agriculture, Vol. 44, Issue 3, pp. 173–188, 2004.

[15] Peters, D., "An updated list of plant species susceptible to tospoviruses. In: D. Peters and R.W. Goldbach (Editors)", Recent Progress in Tospovirus and Thrips Research, Wageningen Agricultural University, Wageningen, the Netherlands, pp. 107-110, 1998.

[16] Momol, M. T., S. M. Olson, J. E. Funderburk, J. Stavisky and J. J. Marois, "Integrated management of tomato spotted wilt on field-grown tomatoes", Plant Disease, Vol. 88, pp. 882-890, 2004.

[17] Lin-Sheng Huang, Shu-Cun Ju, Jin-Ling Zhao, Dong-Yan Zhang, Qi-Hong, Ling Teng, Fan Yang1and Yan-Zuo, "Hyperspectral Measurements for Estimating Vertical Infection of Yellow Rust on Winter Wheat Plant", International Journal Of Agriculture & Biology, Vol. 17, pp. 1237–1242

[18] Qi Liu, Yilin Gu, ShuheWang, Cuicui Wang, and Zhanhong Ma, "Canopy Spectral Characterization of Wheat

Stripe Rust in Latent Period", Journal of Spectroscopy, pp. 1-11, 2015.

[19] W. Huang, X. Song, D. W. Lamb, Z. Wang, Z. Niu, L. Liu and J. Wang, "Estimation of Winter Wheat Grain Crude Protein Content from in Situ Reflectance and Ad- vanced Spaceborne Thermal Emission and Reflection Radiometer Image", Journal of Applied Remote Sensing, Vol. 2, Issue 1.

[20] S. V. Ollinger, "Sources of Variability in Canopy Reflec-tance and the Convergent Properties of Plants", New Phytologist, Vol. 189, Issue. 2, pp. 375-394, 2011.

[21] J. A. Price, F. Workneh, S. R. Evett, D. C. Jones, J. Ar-thur and C. M. Rush, 'Effects of Wheat Streak Mosaic Virus on Root Development and Water-Use Efficiency of Hard Red Winter Wheat', Plant Disease, Vol. 94, Issue. 6, pp. 766-770, 2010.

[22] F. Workneh, J. A. Price, D. C. Jones and C. M. Rush, "Wheat Streak Mosaic: A Classic Case of Plant Disease Impact on Soil Water Content and Crop Water-Use Efficiency", Plant Disease, Vol. 94, Issue. 6, pp. 771-774, 2010.

[23] Pimentel, D, Zuniga, R,Morrison, D, "Update on the environmental and economic costs associated with alien-invasive species in the United States", Ecol. Econ., Vol. 52, pp. 273–288, 2005.

[24] Vigier, B.J., Pattey, E. and Strachan, "Narrowband Vegetation Indexes and Detection of Disease Damage in Soybeans", IEEE Geoscience and Remote Sensing Letters, Vol. 1, Issue 4, pp. 255-259, 2004.

[25] Ausmus, B.S. and Hilty, J.W., "Reflectance studies of healthy, maize dwarf mosaic virus-infected, and Helminthosporium maydis-infected corn leaves", Remote Sensing of Environment, Vol. 2, pp. 77-81, 1972.

[26] Zhang, M., Qin, Z., Liu, X. and Ustin, S., "Detection of stress in tomatoes indiced by late blight disease in California, USA, using hyperspectral remote sensing", International Journal of Applied Earth Observation and Geoinformation, Vol. 4, Issue 4, pp. 295-310, 2003.

[27] D. Krezhova, B. Dikova and S. Maneva, "Ground based hyperspectral remote sensing for disease detection of tobacco plants", Bulgarian Journal of Agricultural Science, Vol. 20, Issue 5, pp. 1142-1150, 2014.

[28] Carter, G. A., & Knapp, A. K., "Leaf optical properties in higher plants: linking spectral characteristics to stress and chlorophyll concentration", American Journal of Botany, Vol. 88, pp. 677–684, 2001.

[29] Pietrzykowski, E., Stone, C., Pinkard, E., & Mohammed, C. "Effects of Mycosphaerella leaf disease on the spectral reflectance properties of juvenile Eucalyptus globules foliage", Forrest Pathology, Vol. 36, pp. 334–348, 2006.

[30] Mahlein, A.-K., Steiner, U., Dehne, H.-W., & Oerke, E.-C, " Spectral signatures of sugar beet leaves for the detection and differentiation of diseases", Precision Agriculture, Vol. 11, pp. 413–431, 2010.

[31] Thenkabail, P. S., Smith, R. B., & De Pauw, E., "Hyperspectral vegetation indices and their relationship with agricultural crop characteristics", Remote Sensing of Environment, Vol. 71, pp. 158–182, 2000.

[32] Blackburn, G. A., "Hyperspectral remote sensing of plant pigments", Journal of Experimental Botany, Vol. 58, pp. 844–867, 2007.

[33] M. L. Adams , W. D. Philpot & W. A. Norvell, "Yellowness index: An application of spectral second derivatives to estimate chlorosis of leaves in stressed vegetation", International Journal of Remote Sensing, Vol. 20, Issue 18, pp. 3663- 3675, 1999.

[34] Swati B. Magare, Dr. Ratnadeep R. Deshmukh, "To Study the Impact of Glyphosate on Chlorophyll Content of Crops", International Journal of Innovative Research in Science, Engineering and Technology, Vol. 5, Issue 3, pp. 3036-3040, 2016.

[35] A. Apan , A. Held , S. Phinn and J. Markley, "Detecting sugarcane 'orange rust' disease using EO-1 Hyperion hyperspectral imagery", International Journal of Remote Sensing, Vol. 25, Issue 2, pp. 489–498, 2004.

[36] Devadas R, DW Lamb, S Simpfendorfer and D Backhouse, " Evaluating ten spectral vegetation indices for identifying rust infection in individual wheat leaves", Precision Agriculture, Vol. 10, pp. 459-470, 2009.

[37] Huang W, DW Lamb, Z Niu, Y Zhang, L Liu and J Wang., "Identification of yellow rust in wheat using in-situ spectral reflectance measurements and airborne hyperspectral imaging", Precision Agriculture, Vol. 8, pp. 187–197, 2007.

[38] Zhang J, W Huang, J Li, G Yang, J Luo, X Gu and J Wang.," Development, evaluation and application of a spectral knowledge base to detect yellow rust in winter wheat", Precision Agriculture, Vol. 12, pp. 716–731, 2011.

[39] Wang W, X Yao, Y Tian, X Liu, J Ni, W Cao and Y Zhu, "Estimating leaf nitrogen concentration with three-band vegetation indices in rice and wheat", Field Crops Res., Vol. 129, pp. 90–98, 2012.

[40] Bojovic B and J Stojanovic, "Chlorophyll and carotenoid content in wheat cultivars ss a function of mineral nutrition", Archieves of Biological Sciences, Vol. 57, pp. 283-290, 2005.

[41] Jing L, J Jinbao, C Yunhao, W Yuanyuan, S Wei and H Wenjiang, "Using hyperspectral indices to estimate foliar chlorophyll a concentrations of winter wheat under yellow rust stress", New Zealand Journal of Agricultural Research, Vol. 50, pp. 1031-1036, 2013.

[42] Apoorva Arora, Karnam Venkatesh, Ramesh Kumar Sharma, Mahender Singh Saharan, Neeraj Dilbaghi, Indu Sharma and Ratan Tiwari, "Evaluating vegetation indices for precision phenotyping of quantitative stripe rust reaction in wheat", Journal of Wheat Research, Vol. 6, Issue 1, pp. 74-80.

[43] Swati B. Magare, Dr. Ratnadeep R. Deshmukh, "Analysis of Effects of 2, 4-D Amine on Chlorophyll Content in Crops", International Journal of Engineering Science and Computing, Vol. 6 (6), pp. 7974-7978, 2016.

[44] A. Apan, B. Datt, and R. Kelly, "Detection Of Pests And Diseases In Vegetable Crops Using Hyperspectral Sensing: A Comparison Of Reflectance Data For Different Sets Of Symptoms", Proceedings of SSC 2005 Spatial Intelligence, Innovation and Praxis: The national biennial Conference of the Spatial Sciences Institute, Melbourne: Spatial Sciences Institute, pp. 10-18, 2005.

[45] P. Chaveza, P. Zorogastu, C. Chuquillanqui, L.F. Salazar, V. Mares and R. Quiroz, "Assessing Potato Yellow Vein Virus (PYVV) infection using remotely sensed data", International Journal of Pest Management, Vol. 55, Issue 3, pp. 251–256, 2009.

