International Journal of Built Environment & Sustainability

IGCESH 2018 SPECIAL ISSUE

THE SPATIAL EPIDEMIOLOGY OF JACKFRUIT PEST AND DISEASES: A REVIEW

Norraisha Md Sabtu[a], Mohamad Hafis Izran Ishak[b], Nurul Hawani Idris[a*]

[a]Department of Geoinformation, Faculty of Built Environment and Surveying Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Johor, Malaysia
[b]Department of Control and Mechatronics, School of Electrical Engineering, Faculty of Engineering, Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Johor, Malaysia

Article history
Received
15 May 2018
Received in revised form
19 December 2018
Accepted
25 December 2018
Published 01 April 2019
*Corresponding author
hawani@utm.my
DOI: 10.11113/ijbes.v6.n1-2.395

ABSTRACT

Jackfruit is identified as targeted produced for premium fruit and vegetable (EPP 7). Meanwhile in Johor, jackfruit is the third biggest fruit produced in 2016. Jackfruit contains a lot of benefits which certainly good for living things and have been used in various sector such as medicine, food, anti-bacterial and anti-oxidant, antifungal effect, immunomodulatory effect and else. However, the existence of pests and diseases have threatened the productivity of jackfruit plant particularly in tropical countries including Malaysia. There are many factors that can affect the occurrence of pests and plant diseases of jackfruit such as shoot borers, bark borers, mealy bug and scale insects, blossoms and fruit rots and bacterial die-back. Several studies have been devoted to model the plant pests and diseases epidemiology, though the contexts that focus in tropical environment and jackfruit plant are limited. Therefore, this paper aims to discuss abiotic factors and spatial methods that have been used to define dispersal pattern and relationship between abiotic factors including major climatic variables with plant pests and diseases occurrence data, particularly in tropical climate. This paper could be used as a basis to understand the epidemiological models in combating pest and plant disease and to support towards the effective management of jackfruit pests and diseases in tropical countries, particularly Malaysia.

Keywords: Jackfruit, Pest & Plant Disease, Abiotic Factor, Spatial Modelling

1. Introduction

Artocarpus Heterophyllus is the scientific name of jackfruit which the fruit belong to the family of Moracea and usually confused with the closely related species Artocarpus integer (Harb, et al., 2015). Jackfruit is planted in India, Bangladesh, Philippines, Sri Lanka, Malaysia, Thailand, and several areas in Brazil and Queensland, Australia. In Malaysia, Johor is the third biggest producer of jackfruit in Malaysia after Pahang and Negeri Sembilan (DOA, 2016). Due to its globally high demand, the fruit is grown as an alternative crop. Furthermore, Biworo, et al. (2015), reported that jackfruit is targeted as the premium fruit and vegetables exported to the Middle East and Europe.

There are so many benefits from the fruit, tree, branches of jackfruit. The fruit is enriched with a diverse of nutrients and edible where the fruit can be consumed when its ripe and when its green as vegetable. The tree as well can provide many other uses in environmental protection. As an example, Indonesia folk consume the plants in medicine and used as anti-bacterial, anti-diabetic, antioxidant, anti-inflammatory and anti-helmintics (Jose and John, 2017). Approximately, 2Megajoule energy per kg/wet weight of ripe perianth Besides, the fruit can supply at (Swami, et al., 2012). Phytonutrients contain in jackfruit such as lignans, flavones and saponins have the properties of anticancer, antiulcer, antihypertensive and antiaging (Gapasin, et al., 2014).

Research by Salahuddin, et al., (2015a) stated that insect pest infestation is one of the cause behind declining production of jackfruit. Some of the major pests and diseases in India include shoot borers, bark borers, mealy bug and scale insects, blossoms and fruit rots and bacterial die-back. In Malaysia, Chowdhury and Hossain, (2012), reported that "Karat Buah" or known as Uredo Artocarpi is the reason behind the poor productivity of jackfruit whereby, 30 percent of production yield decreased each year.

A study by Bouwmeester, et al., (2016) stated that weather may affect the growth of jackfruit. Excessive rain, humidity and temperature can affect the plant to get diseases such as leaf spot due to Colletortrichum gloeosportoides. Furthermore, Luvisi, et al., (2016) reported from observation the trees may show more symptoms when it's in 'stressed' because of nutrition imbalances, soil types, terrain conditions or injury after or during rainy season, where humidity is relatively high.

Abreast with the vast of technology development, mapping and modelling loss of crop due to pest and disease would be easier. Nowadays, the advancement of geospatial make a lot of things easier. Geospatial are widely used in various sectors whether to collect data, manage information and store data, for mapping, prediction or to model. For example, Ahmed, et al., (2014) have used GIS spatial statistic method to study the pattern of pest spreading and its relationship with landscape characteristics such as drainage and type of soils. Meanwhile, Pandey, et al., (2017) used geostatistical method in mapping crop disease incidence. Therefore, this paper discusses relevant studies that have been devoted in identifying the abiotic factors that affect pest and plant disease using spatial methods.

2. Abiotic Factors

Abiotic is a non-living physical and chemical element in the ecosystem. Normally, abiotic resource is acquired from lithosphere, atmosphere, and hydrosphere. Water, air, soil, sunlight, and minerals are the example of abiotic factor (Ahmed et al., 2014; Luvisi et al., 2016). Meanwhile, biotic is the living organisms of the environment that consist of macro and micro-organisms. Manifestation of the genetic factor on phenotypic expression may affected due to these organisms (Ramanan, Kim, Cho, Oh, & Kim, 2016).

Pandey et al., (2017) stated that an uncompromising effect on plant growth and yield due to abiotic and biotic stress combinations since the phenomena of global warming, and any potential state abnormalities related with the phenomena. (Bouwmeester et al., 2016). Abiotic factor might affect the mortality of forest pests in variety life stages and in many ways. Based on Ahmed et al., (2014) and Kumar, et al., (2017) season can give significant impact on disease infected on plant. Paterson, et al., (2013) stated that, the alteration in forecast climatic conditions leading environment in the fields to be more complex resulting a new challenge in making crops with multiple stress-tolerant. The occurrence and spread of pathogens, insects, and weed influenced by the abiotic stress conditions such as drought, high and low temperature and salinity (Kadiyala et al., 2015; Suzuki, et al., 2014).

Factor on plant stresses can be divided into three criteria based on the number of interacting factors. Which are single, multiple individual, and combined. Where a single stress shows only one stress factor affecting plant growth and development; whereas the impact of two or more stresses occurring at different time periods without any overlap (multiple individual) indicates on multiple stress or occurring concurrently

with at least some degree of overlap between them (combined). The co-occurrence of drought and heat stresses during summer is an example of a combined abiotic stress, whereas a bacterial and fungal pathogen attacking a plant at the same time represents a case of combined biotic stress (Salahuddin, et al., 2015b).

Abiotic factor can give a significant impact on jackfruit growth. Based on Abdullah (2015), treatment on soil can give excellent improvement on germination jackfruit seed and successfully emergence of seedlings. Rhizopus rot is a disease that occur on jackfruit flowers and young fruit due to fungus stored in soil plant debris. Besides that, the disease favour in a warm and rainy days (Baggio,et al., 2017; Dalavi,et al., 2016). The seasonal changes effect on the nutrient concentration of nutrient in the leaf. The optimal is on April-May which on spring season (Sun et al., 2015). As stated by Arora and Parle, (2016), temperature play a vital role in jackfruit growth where a tree cannot survive in too cold, and drought conditions. Thus, abiotic factor can give a significant impact on jackfruit growth.

3. Pests and Plant Diseases

Issues on insect pests and plant disease have turned into plight as it can cause significant reduction in both quantity and quality of yields. According to Baiti, et al., (2017) and Friel and Ford, (2015) crop losses persistently up to 20% of the world harvest due to plant disease. Globally, there is a significant impact on the range of ecosystem services, changes in natural landscapes and recreational or cultural value, decreasing wildlife habitats and biodiversity and also affecting the forest ability to sequester carbon, combat desertification (or protect water shade) due to the damage cause by invasive forest pests and diseases (Macpherson, et al., 2017; *The Value of Forests*, n.d.). According to Bebber and Gurr, (2015), fungal and oomycete pathogen lead the global invasion of yield. However, plant disease issues are not a new problem. Based on history, plant epidemics caused by fungi and the fungal-like oomycetes had happened since 19th century (Fisher et al., 2012).

A healthy plant is a plant that can undergo physiological activity at the best of its genetic potential. However, the routine can be disrupted and divergence from the usual when there is a presence of insect pest or pathogen (Ghiasi, et al., 2017). Every plant has their own specific pest and disease infested on the crops (Cerda et al., 2017). Fruit rot is one of the diseases that attack most crops such as peach, papaya, tomato, jackfruit and much more (Baiti et al., 2017; Ghosh, et al., 2015). Example of fungi that causes fruit disease such as peaches is phylum Ascomycota whereas fruit rot is cause by anamorphic pathogen and a few others pathogens (Baiti et al., 2017). Meanwhile, fruit rot pathogen attack on jackfruit is from genera Rhizopus and Mucor, where Rhizopus artocarpi is example of fungi that attack on jackfruit (Nelson, 2005).

Shoot and fruit borer are also attack jackfruit, eggplant, tomato, brinjal and many other crops (Biotica, et al., 2015 ; Lakshmidevi, et al., 2017; Roy, et al., 2017). For jackfruit, the pest that attack the fruit is Diaphania caesalis (walker) where the growth is influence by the temperature, relative humidity, wind speed and rainfall (Kallekkattil and Krishnamoorthy, 2017).

On the other hand, fruit bronzing disease is also affecting on many crops such as jackfruit, pepper, tomato, strawberry (Cluever et al., 2015; Gapasin et al., 2014; Lakshmidevi et al., 2017; Mergaert, et al., 2015). Nevertheless, a disease is also happened due to a biotic agent. Based on Mergaert et al., (2015) biotic agent that caused fruit bronzing on jackfruit is caused by Pantoea stewartia (Smith) Mergaert et al. (2015), Pantoea stewartia is a bacterium that also infected on corn. Next section will discuss the spatial methods that have been applied to assess and monitor the plant pests and diseases.

4. Spatial Methods

An environmental factors or abiotic environment is a community of living organisms that interact to each other and their environment which creating an ecosystem (Tsatsakis et al., 2017). Many abiotic factors play significant roles in the interactions that happen on plant. However, the understanding of an ecosystem can be quite hard cause by the potential complexity of multiple and multifactorial ecological

interactions. Therefore, environmental factors that effect on the growth of pest and diseases may vary to each other. Thus, there are plenty of research have been conducted in finding suitable methods to understand the environmental factors influencing the incident of pests and diseases. the

Along with vast in technology development, several ways in overcoming loss in crop yield have arisen. Today, the geoinformation technology including Geospatial Information System (GIS) and remote sensing are widely use in collecting an accurate crop information and analyzing collected data. Spatial analysis has been widely used by researches, student, in business and many more. Spatial analysis is a toolkit in GIS software that allowed to investigate geographic pattern in spatial data and the relationship between feature and can also be used for prediction (Nelson and Greenough, n.d.).

There are many techniques that have been applied in identify abiotic factors that influence on pest and plant disease including statistical analysis. For example, Nayak, et al., (2018) has used multivariate statistical methods in interpretation of rice plant to describe variability in the data, discrimination analysis to classify observations-based variables and canonical correlation to describe the relationship between variables at a given geographical location of differences environmental conditions. For example, Bosman, (2016), use spatial analysis to prove the impact of environment on the incidence of panama disease on banana. The study used principal component analysis (PCA) to understand the variability of the landscape in the study area and produced stratification map. To find the environmental variables that influence on panama disease, statistical models (i.e. t-test, linear regression, quadratic regression and stepwise regression) have been used. A study by McCreadie and Adler, (2012) have used mantel tests and null model to test the potential influence of stream conditions, species interactions and dispersal patterns of larval black flies within ecoregions and across ecoregions on summer and springs. Whereas, Al-Kindi, et al., (2017) used interpolation method (i.e. Inverse Distance Weighting) in creating distribution map of Dubas Bug infestation on date palms in Oman using statistical analysis (i.e. Ordinary Least Square) to develop a model to identify the environmental factors that affect Dubas Bug growth.

Another study is by Donatelli et al., (2017) that model the impactof pest and disease on agricultural systems using input from air temperature, precipitation, relative humidity and leaf wetness. On the other hand, Tonnang et al., (2017) compare a few models in identifying the area and the impact of insect pest populations. The study investigates how the abiotic factor such as climate change effected the pest growth.

Duku, et al., (2016) used spatial modelling to quantify the loss of rice yield due to disease under a climate change and predicting losses on leaf blast due to leaf blast declining. The finding shows the effects of climate changes are varied across geographies. A study by Hwang et al., (2017) used phenology model in predict the impact of temperature change on the distribution and abundance of maize stem borers in different altitudes and topography. A study by Kaizer, et al., (2015) develop a predictive model using negative binomial model to describe the number of active, off-host larvae from 2007 to 2011 and to determine the environmental variables associated with the pattern. The study was determined the effect of off-host larvae and plant in forest in United States. The variables are day length, degree days, total precipitation prior to sampling, wind speed, saturation deficit, number of adults, number of adults prior to sampling.

Nevertheless, in combating the jackfruit pest and disease, there are a few studies have been conducted though limited in applying spatial analysis technique. For example, a study by Ahmed et al, (2013) has been conducted to determine time of infestations, damaging activity of larva and amount of damage per infested fruit to control the effect of Diaphania Caesalis. Whereas, Kallekkattil and Krishnamoorthy, (2017) developed a forewarning model to forecast the incidence of jackfruit shoot and fruit borer (i.e. Diaphania caesalis walker). The model was used to investigate the influence of abiotic factors (i.e. maximum and minimum temperatures, maximum and minimum relative humidity, wind speed and rainfall) on the incidence of jackfruit shoot and fruit borer. A study by Soumya and Krishnamoorthy (2015) have

applied morphological and biochemical analysis to understand a host plant resistance in jackfruit germplasm.

Therefore, there is a need for future studies to exploit the capabilities of spatial methods for further understanding the pattern and the relationship of factors that affecting the occurrence of pest and disease, particularly in Jackfruit plant so that a comprehensive pest and disease management that considers the abiotic factors including the spatial landscape can be designed by stakeholders in combating jackfruit pest and disease.

5. Conclusion

Jackfruit is a potential crop to be marketed worldwide due to its rich nutrition. However, the existence of pests and plant diseases threatened the crops production. Therefore, there is a need to understand behaviour and abiotic factors that can affect jackfruit plant pests and diseases. Geospatial approach including spatial analysis methods have been widely used to understand the pest and disease pattern and predict the incidents in agriculture. It is a powerful tool in identify relationship between abiotic factor and the occurrence on pest and plant disease. Spatial analysis and advanced spatio-temporal models could support in managing the occurrence and monitoring the epidemical of pests and disease and improve the production yield of the jackfruit industry.

Acknowledgement

The authors would like to thank the Ayer Itam Plant Biosecurity Unit, Department of Agriculture (DOA) for providing the data. This study is supported by the Ministry of Education Malaysia and Universiti Teknologi Malaysia through the GUP Tier-1 grant (17H13) awarded to the corresponding author.

References

Abdullah, R. (2015). Study on Diseases of Jackfruit in the Nursery and it's management, (May).

Ahmed, A.M.M., Ramírez Y Avilés, L., Sánchez, F.J.S., Al-Zyoud, F.A. & Barros-Rodriguez, M. (2014). An overview on some biotic and abiotic factors affecting the population dynamics of leucaena psyllid, *Heteropsylla cubana* Crawford (Homoptera: Psyllidae): Contributory factors for pest management. *Tropical and Subtropical Agroecosystems*. 17(3): 437–446.

Al-Kindi, K.M., Kwan, P., Andrew, N. & Welch, M. (2017). Impact of environmental variables on Dubas bug infestation rate: A case study from the Sultanate of Oman. *PLoS ONE*. 12(5): 1–17.

Arora, T. & Parle, A. (2016). Jackfruit: a Health Boon. *International Journal of Research in Ayurveda & Pharmacy*. 7(3): 59–64.

Baggio, J.S., Hau, B. & Amorim, L. (2017). Spatiotemporal analyses of rhizopus rot progress in peach fruit inoculated with *Rhizopus stolonifer*. *Plant Pathology*. 66(9): 1452–1462.

Baiti, N., Murad, A.B.D., Izzati, A. & Zainudin, M. (2017). Review of Fruit Rot Diseases of Important Tropical and Some Temperate Fruit Crops. 3: 138–156.

Bebber, D.P. & Gurr, S.J. (2015). Crop-destroying fungal and oomycete pathogens challenge food security. 74: 62–64.

Biotica, C., Soumya, K. & Venkatesha, M.G. (2015). Occurrence of Jack shoot and fruit borer, *Diaphania caesalis* (Walker) (Pyralidae: Lepidoptera) in Kerala , India. 9(3): 295–299.

Bosman, M. (2016). Role of the environment on the incidence of Panama disease in bananas.

Bouwmeester, H., Heuvelink, G.B.M. & Stoorvogel, J.J. (2016). Mapping crop diseases using survey data: The case of bacterial wilt in bananas in the East African highlands. *European Journal of Agronomy*. 74: 173–184.

Cerda, R., Avelino, J., Gary, C., Tixier, P., Lechevallier, E. & Allinne, C. (2017). Primary and secondary yield losses caused by pests and diseases: Assessment and modeling in coffee. *PLoS ONE*. 12(1): 1–17.

Chowdhury, M.S.M. & Hossain, I. (2012). Effects Of Temperature, Rainfall And Relative Humidity On Leaf Spot Of Jackfruit Seedling And Its Eco-Friendly Management. *The Agriculturists*. 9(1–2): 126–136.

Chowdhury, M.S.M., Mazed, H.E.M.K. & Irin, I.J. (2015a). Study on seedling diseases of jackfruit (*Artocarpus heterophyllus* L.) in Bangladesh. *Indian Journal of Applied Research*. 1: 24–29.

Chowdhury, M. S. M., Mazed, H. E. M. K. & Irin, I. J. (2015b). Study on seedling diseases of jackfruit (*Artocarpus heterophyllus* L.) in Bangladesh. *Indian Journal of Applied Research*. 1(April 2015): 24–29.

Clark, D. and Hirsch F. *(2014). The Value of Forests. (n.d.).* United Nations publication.

Cluever, J.D., Smith, H.A., Funderburk, J.E., Frantz, G., Florida, F. & Thrips, F. (2015). Thrips in Florida Strawberry Crops. *The University of Florida's Institute of Food and Agricultural Sciences*. 1: 1–9.

Dalavi, R.B., Kamble, S.S. & Kawale, T.R. (2016). Efficacy of Ridomil in Combating Fruit Rot of Jackfruit in Sindhudurg and Kolhapur Districts of Maharashtra. *Trends in Biosciences Journal*. (5): 1094–1096.

DOA, D. of A. (2016). Fruit Crops Statistic 2016. *Department of Agriculture, Malaysia*. 1–180.

Donatelli, M., Magarey, R.D., Bregaglio, S., Willocquet, L., Whish, J.P.M. & Savary, S. (2017). Modelling The Impacts Of Pests And Diseases On Agricultural Systems. *Agricultural Systems*. 155: 213–224.

Duku, C., Sparks, A. H. & Zwart, S. J. (2016). Spatial Modelling Of Rice Yield Losses In Tanzania Due To Bacterial Leaf Blight And Leaf Blast In A Changing Climate. *Climatic Change*. 569–583.

Fisher, M.C., Henk, D.A., Briggs, C.J., Brownstein, J.S., Madoff, L.C., Mccraw, S.L. & Gurr, S.J. (2012). Emerging Fungal Threats To Animal, Plant And Ecosystem Health. *Nature*. 484(7393): 186–194.

Fortin, M.-J. & Dale, M.R.T. (2005). Spatial Analysis: A Guide for Ecologists, Cambridge University Press. 12.

Friel, S. & Ford, L. (2015). Systems, Food Security And Human Health. *Food Security*. 7(2): 437–451.

Fruit, E. & Borer, S. (2012). Fact Sheet, 7–8.

Gapasin, R.M., Garcia, R.P., Christine, T., Cruz, C.S.De. & Borines, L.M. (2014). Fruit Bronzing: a New Disease Affecting Jackfruit Caused by *Pantoea stewartii* (Smith) Mergaert Pantoea stewartii et al. *Annals of Tropical Research*. 36(1): 17-31.

Ghiasi, R., Allahyari, M.S., Damalas, C.A., Azizi, J. & Abedi, M. (2017). Crop Protection Services By Plant Clinics In Iran: An Evaluation Through Rice Farmers' Satisfaction. *Crop Protection*. 98: 191–197.

Ghosh, R., Barman, S., Mukhopadhyay, A. & Mandal, N.C. (2015). Biological Control Of Fruit-Rot Of Jackfruit By Rhizobacteria And Food Grade Lactic Acid Bacteria. *Biological Control*, 83: 29–36.

Harb, E.M., Reda, M., Alhady, A.A. & Elsalam, N.A.A. (2015). In vitro Rapid Propagation of Jackfruit (*Artcarpus heterophyllus* Lam.). *American-Eurasian Journal of Agricultural & Environmental Sciences*. 15(2): 147–153.

Hwang, C., Correll, M.J., Gezan, S.A., Zhang, L., Bhakta, M.S., Vallejos, C.E., Boote, K.J., Clavijo-Michelangeli, J.A. & Jones, J.W. (2017). Next Generation Crop Models: A Modular Approach To Model Early Vegetative And Reproductive Development Of The Common Bean (*Phaseolus vulgaris* L.). *Agricultural Systems*. 155: 225–239.

Jackfruit, T. (2018). Jackfruit, 1–9.

Vazhacharickal, P.J, Sajeshkumar, N.K. & John Mathew, J. (2017). Morphological Diversity, Nutritional Quality And Value Addition Of Jackfruit (*Artocarpus heterophyllus*) in Kerala. *International Journal of Innovative Research and Review*, (May). Retrieved from https://www.researchgate.net/profile/Prem_Vazhacharickal/publication/317035659_Morphological_diversity_nutritional_quality_and_value_addition_of_jackfruit_Artocarpus_heterophyllus_in_Kerala/links/592093400f7e9b99793fca3f/Morphological-diversity-nutritiona

K.Soumya, A.Krishnamoorthy, P.P. & M.G.Venkatesha (2015). Evaluation Of Jackfruit Germplasm Against Jack Shoot And Fruit Borers; *Diaphania caesalis* (Wlk) (Lepidoptera: Pyralidae). *Pest Management in Horticultural Ecosystems*. 21(1): 8–10.

Ahmed, K.U., Rahman, M.M., Alam, M.Z., Hossain, M.M. & Miah, M.G. (2013). Evaluation of Some Control Methods Against the Jackfruit Trunk Borer, *Batocera Rufomaculata* De Geer (Cerambycidae: Coleoptera). *Bangladesh Journal of Zoology*. 41(2): 181–187.

Kadiyala, M.D.M., Nedumaran, S., Singh, P.S.C., Irshad, M.A. & Bantilan, M.C.S. (2015). An Integrated Crop Model And GIS Decision Support System For Assisting Agronomic Decision Making Under Climate Change. *Science of the Total Environment*. 521–522: 123–134.

Kaizer, A.M., Foré, S.A., Kim, H.J. & York, E.C. (2015). Modeling the Biotic And Abiotic Factors That Describe The Number Of Active Off-Host *Amblyomma americanum* larvae. *Journal of Vector Ecology*. 40(1): 1–10.

Kallekkattil, S. & Krishnamoorthy, A. (2017). Forecasting the Incidence Of Jackfruit Shoot And Fruit Borer *Diaphania caesalis* Walker (Pyralidae: Lepidoptera) in Jackfruit (*Artocarpus heterophyllus* Lam.) ecosystems. *Journal of Entomology and Zoology Studies*. 5(1): 483–487.

Kumar, G.S., Raju, S.V.S. & Kattula, S.Y. (2017). Role of Different Abiotic Factors Influencing Fluctuations of Fruit and Shoot Infestation Caused by *Earias vittella* on Okra (*Abelmoschus esculentus* L.). *International Journal of Current Microbiology and Applied Sciences*. 6(6): 2514–2521.

Lakshmidevi, P., Parthasarathy, S. & Gopalakrishnan, C. (2017). Expression of Defense Responses in Tomato against Vascular Wilt and Fruit Borer through Consortia of Fluorescent Pseudomonads and Entomopathogenic Fungi. *International Journal of Current Microbiology and Applied Sciences*. 6(11): 3300–3313.

Luvisi, A., Ampatzidis, Y.G. & De Bellis, L. (2016). Plant Pathology And Information Technology: Opportunity For

Management Of Disease Outbreak And Applications In Regulation Frameworks. *Sustainability (Switzerland)*. *8*(8).

Machalaba, C., Romanelli, C., Stoett, P., Baum, S. E., Bouley, T. A., Daszak, P. & Karesh, W. B. (2015). Climate change and health: Transcending silos to find solutions. *Annals of Global Health*. *81*(3): 445–458.

Macpherson, M.F., Kleczkowski, A., Healey, J.R. & Hanley, N. (2017). Payment for Multiple Forest Benefits Alters The Effect Of Tree Disease On Optimal Forest Rotation Length. *Ecological Economics*. *134*: 82–94.

McCreadie, J.W. & Adler, P.H. (2012). The Roles Of Abiotic Factors, Dispersal, And Species Interactions In Structuring Stream Assemblages Of Black Flies (Diptera: Simuliidae). *Aquatic Biosystems*. *8*(1): 1.

Mergaert, S., Gapasin, R.M., Garcia, R.P. & Christine, T. (2015). Fruit Bronzing: A New Disease Affecting Jackfruit Caused by Fruit Bronzing: a New Disease Affecting Jackfruit Caused by *Pantoea stewartii* (Smith) Mergaert et al., (May). *Annals of Tropical Research*, 36(1), 17-31.

Nayak, P., Mukherjee, A.K., Pandit, E. & Pradhan, S.K. (2018). Application of Statistical Tools for Data Analysis and Interpretation in Rice Plant Pathology. *Rice Science*. *25*(1): 1–18.

Nelson, E.L. & Greenough, P.G. (n.d.). Geographic Information Systems in Crises, 312.

Nelson, S. (2005). Rhizopus Rot of Jackfruit, (Plant Disease), PD-29.

Pandey, P., Irulappan, V., Bagavathiannan, M.V. & Senthil-Kumar, M. (2017). Impact of Combined Abiotic and Biotic Stresses on Plant Growth and Avenues for Crop Improvement by Exploiting Physio-morphological Traits. *Frontiers in Plant Science*. *8*(April): 1–15.

Paterson, R.R.M., Sariah, M. & Lima, N. (2013). How will climate change affect oil palm fungal Diseases? *Crop Protection*. *46*: 113–120.

Roy, K., Rathod, A. & Devi, M.S. (2017). Bio - Efficacy Of Bifenthrin 8 SC Against Shoot And Fruit Borer And Red Spider Mite Of Okra, Abelmoschus esculentus (L.) Moench, *9411*(Table 1). *Journal of Applied and Natural Science*. 9(1): 344-350.

Saunders, M.E., Peisley, R.K., Rader, R. & Luck, G.W. (2016). Pollinators, Pests, And Predators: Recognizing Ecological Trade-Offs In Agroecosystems. *Ambio*. 45(1): 4–14.

Sun, Y., Yang, J., Wang, H., Zu, C., Tan, L. & Wu, G. (2015). Standardization of Leaf Sampling Technique in Jackfruit Nutrient Status Diagnosis. *Agricultural Science*. 6(1): 232–237.

Suzuki, N., Rivero, R.M., Shulaev, V., Blumwald, E. & Mittler, R. (2014). Abiotic and Biotic Stress Combinations. *New Phytologist*. 203(1): 32–43.

Swami, S.B., Thakor, N.J., Haldankar, P.M. & Kalse, S.B. (2012). Jackfruit and Its Many Functional Components as Related to Human Health: A Review. *Comprehensive Reviews in Food Science and Food Safety*. 11(6): 565–576.

Tonnang, H.E.Z., Hervé, B.D.B., Biber-freudenberger, L., Salifu, D., Subramanian, S., Ngowi, V.B., Guimapi, R.Y., Anani, B., Kakmeni, F.M., Affognon, H. & Niassy S. (2017). Advances in crop insect modelling methods — Towards a Whole System Approach. *Ecological Modelling*. 354: 88–103.