TRENDS IN GREENHOUSE FARMING TECHNOLOGY: A REVIEW

Abstract

The quest for food security and sustainability has generated a new trends towards the purpose and use of the greenhouse farming technology. For the developed world, there is an increase rate of research and development of new trends involving greenhouse technology. The scenario is a well far cry from what is obtainable in the developing world, Africa and Nigeria in particular. The various advantages presented by greenhouse farming technology is grossly underutilized by developing world. This study focused on reviewing the various types of greenhouse (GH) in existence, present research trends in GH technology, adaptable irrigation type for GH farming, design criteria for GH, trends in smart GH farming. The study has brought to fore what has been done regarding GH farming and open up wide range of areas where research gaps abound while exposing the deficits in the developing world. Harnessing the huge advantages presented by willingly and vigorously engaging in GH farming technology will help to mitigate hunger and adverse food security thereby meeting, at least, one of the sustainable development goals of United Nations. In addition, the inclusion of Information Technology (IT) and Internet of Thing, robotic agriculture and adaptation of GIS and farm site mapping, etc has proven from literature that that is the way to go in other to make food sufficiently available, reduce risk, waste as well as drudgery encountered in traditional GH farming.

Keywords: Greenhouse, Microclimate, Irrigation, Smart Agriculture, Intelligent Greenhouse.

1.0 Introduction:

Greenhouse (also called glasshouse, hothouse, screen house, shade house and crop top structure) is a system for modification and management of environmental factors that allows plants to be grown in suitable climates that may not be well suited for their growth and development. In brief, a greenhouse farming optimizes growing conditions and protects the crops from extreme weather events, protect crops from pests and diseases, enables effective crop managements. In the 17^{th} – mid 19^{th} century, greenhouses were commonly made of brick or timber with normal proportion of window space and some means of heating, Samapika *et al.*, 2020, Tiwari, 2003. Greenhouses are important in agriculture, horticulture and botanical science, Samapika *et al.*, 2020, Rajender *et al.*, 2017. The modern greenhouse is usually a glass or plastic enclosed frame structure, used for the production of fruits, vegetables, flowers and any other plants that require controlled environment for it survival. Components such as cover materials, climate-control systems, and irrigation and fertilization equipment are regularly evaluated by growers, designers and researchers, to improve their efficiency, lower inputs, and reduce undesired environmental effects, Samapika *et al.*, 2020, Rajender *et al.*, 2017; Tiwari, 2003. There are different type of greenhouses, however, polyethylene or polyvinyl, fiberglass, plastic films, transparent and translucent are commonly used as cover materials while the frame structure could be made of aluminum, galvanized steel or such woods as redwood, cedar or cypress. A greenhouse can become too hot or cold, some type of ventilating system is usually needed to provide optimum environment for growth and production of given plant. The plants cultivated in greenhouses fall into several broad categories based on their temperature requirements during nighttime hours. In a cool greenhouse, the nighttime temperature fall to about 7 – 10 ^{o}C. Among the plants that thrive in cool greenhouse are azaleas, cinerarias, cyclamens, carnations, fuchsias, geraniums, sweet peas, snapdragons and various types of bulbous plants like daffodils, irises, tulips, hyacinths and narcissi. A warm greenhouse has nighttime temperatures of 10 – 13 ^{o}C. Begonias, gloxinias, African violets, orchids, roses and many kinds of ferns, cacti and other succulents are adaptable to such temperatures. In the tropics, greenhouse has nighttime temperature of 16 – 21 ^{o}C, variety of palms and orchids can be grown, Rajender *et al.* (2017). Greenhouse farming is a broad term that involves various types of sheltered structures. Important elements that are associated with this type of farming include shape of the structure, lifespan, cover material, size of the farm and level of farm management technology. Each greenhouse structure is inclusive of aspects that react differently then and to other management aspects. These include: the amount of sunlight, the amount of natural ventilation, the size of the farm, heating requirements, condensation run-off, efficiency of materials and costs, Samapika *et al.*, 2020, Tiwari, 2003.

In this review, the effects of greenhouse gas emission, its effects on the environment as well as the drying mechanism of greenhouses (GH) are out of the scope of this study. Objectively, emphasis is strictly on greenhouse for farming purposes; their developmental evolution over the years and current trends in the utilization of greenhouse for food security and sustainability.

2.0 The Review:

Published articles (Literature) ranging between year 1989 – 2020, over three decades, were downloaded and used for review. The downloaded literature were sorted out and categorised into those that reported on the origin of greenhouse (GH); type of existing GH; general research trends in GH development; adaptable irrigation type for GH farming; design criteria for GH and trends in smart GH.

2.1 Types of Greenhouse (GH)

Classification and types of GH is done based on different parameters such as: Cost investment, Shape of GH, Roof of GH, Utility of GH, GH construction materials, GH Covering materials, GH cladding materials, GH climate control mechanism, etc, Bartok, 2000; Connellan, 2002; Tiwari, 2003; Cox *et al.,* 2010; FAO, 2011; Arora, 2012; Castilla and Baeza, 2013. Findings suggested that the type and size of GH is a function of location, use, climate, purpose, topography, soil characteristic, water quantity and quality, labour availability affects the choice of GH, etc, Montero *et al.,* 2013; Brian *et al.,* 2015; Kumar *et al.,* 2016; Waller and Yitayewa, 2016; Rajender *et al.,* 2017; Agricdemy, 2020; Samapika *et al.,* 2020.

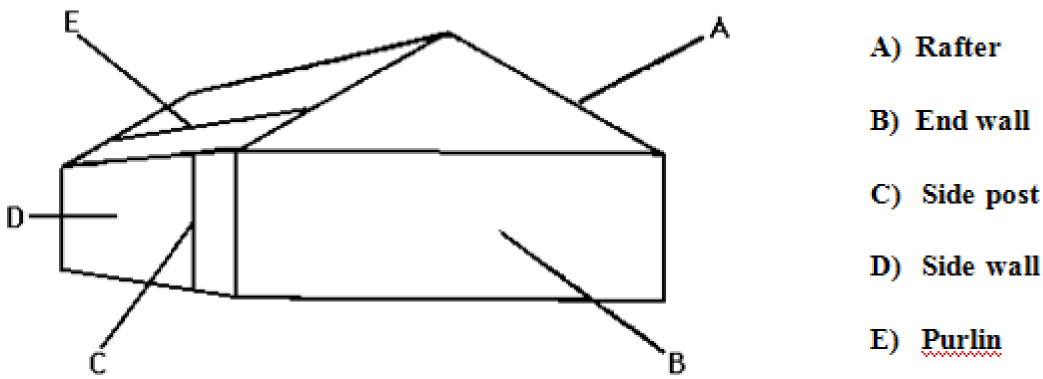

Figure 1: Primary components of a typical greenhouse

Source: Samapika, *et al.,* 2020.

In Nigeria, the use of greenhouses is still obscured and probably restricted to farms in research institutions like International Institute for Tropical Agriculture (IITA), Obasanjo farms, etc. or in the Universities/ research institutions. Crops planted for study are protected from extreme weather conditions that affect their growth while crops' environments are better managed to reduce the harmful effect of pest and diseases, therefore, these plants can be grown and made available throughout the year. Greenhouses are classified as either domestics, plastics or commercials, in Nigeria (agricdemy, 2020).

The use of irrigation technology in farming in Nigeria, especially in the southern region is very limited compared to the northern region. Irrigation technology still remains the available option to supplement natural rain-fed agriculture. However, the choice of a particular irrigation system is affected by factors like climate, topography, soil characteristics, water quality and quantity (Arora, 2012; Waller and Yitayew, 2016).

2.2 GH Development and Utilisation

In Nigeria and elsewhere, Greenhouse farming is the business of working on and managing the growing of crops and plants inside a greenhouse. Akpenuun and Mijinyawa (2020) worked on split-gable greenhouse developed for tropical conditions and equipped with humidifiers and circulating fan for climate control. The work was carried out at Ilorin town in Ilorin-South local government of Kwara State, Nigeria. Five varieties of Irish potato were cultivated in- and outside the greenhouse in two rainy and dry seasons. Three seedlings of each variety were planted with 10 replicates using Completely Randomised Design (CRD). They concluded that climate data and yield in and outside the greenhouse differed significantly. In trying to establishing the potential of a greenhouse (GH) for the production of crops like Irish potato in the tropics, Akpenuum and Mijinyawa (2018) showed that the yield and growth data in and outside the greenhouse were significantly different at 0.01. Mijinyawa and Osiade (2011) again conducted a survey in Oyo State aimed at establishing the present status of the use of greenhouse in the region. Infrequent research activities, prohibitive cost of construction and maintenance were among reasons given for the abandonment of most of the greenhouse studied in the region. The introduction of greenhouses in crop production was concluded to be one of the ways of combating the effects of climate change on crop production. Ale *et al.* (2019) designed and constructed a greenhouse for the evaluation of the performance of Okra in the Sahel region of Ondo State, Nigeria. The evaluation process was carried out in the dry season to determine the effects of greenhouse and liquid organic fertilizer on the performance of Okra. Results revealed that greenhouse has potential to improve the growth performance Okra while inorganic fertilizer has no significant influence of the yield of okra fruit.

Omobowale and Sijuwade (2019) opined that greenhouse cultivation is highly influenced by the microclimate, which affects plant growth and development. Shading is an option for ensuring a relatively cool environment within tropical greenhouses which tends to heat up due to intense solar radiations. Omobowale and Sijuwade (2019) study was aimed at comparing the microclimate between a partially shaded greenhouse and unshaded one with respect to its effect on the crops. Cucumber (*Cucumis sativus*) and Okra (*Abelmoschus esculentus*) were grown in two greenhouses during the dry season of early 2018. One greenhouse was shaded with white coloured high-density polythelene film at the roof level while the other greenhouse was left unshaded. Both greenhouses were naturally ventilated. Results showed that shading had a positive effect on the growth compared to the okra parameter observed in the unshaded greenhouse as there was significant difference in the leaf length, leaf breadth, stem girth, plant height and yield ($3.71 \pm 0.58 and 2.56 \pm 1.21$ t/ha for shaded and unshaded respectively) at P< 0.05. There was significant difference in stem height of cucumber, as well as the incoming solar radiation at P < 0.05. Partial shading had minimal but positive effect on the crops.

Omobowale, (2020) reported that sustainable agriculture is critical towards paving a way for year-round production and supply of food. He observed that cultivation of fruits and vegetables are vital due to high demand and nutritional values it provides to consumers. The rising global population especially in developing countries require other alternatives for sustainable crop production. To this, cultivation in controlled environments using functional and durable greenhouse structures presents an option. In Omobowale, (2020) study, a low-cost greenhouse was designed and constructed in Ibadan, Nigeria using locally available materials and evaluated. Afrormosia wood was used in constructing the frame while polyethylene of 2.5 mm thickness was used as sheathing material for the walls. The floor which covered an area of 24 m^2 was made of porous concrete of batching mixture 1:4 (cement to gravel) while the wall was 4 m high. Ventilation was passive with a vent area equal to 25% of total surface area; made up of 20% at the wall area and 5% as the roof vent. The roof was pitched at a 18° slope to allow easy drainage of rain water. Sweet pepper (*Capsicum annuum, Cabernet*) seeds procured from Burpee Seeds USA were cultivated with the aid of planting pots within the greenhouse in comparison with those planted in the open field for a duration of eight weeks. He based their evaluation on crop growth and yield parameters correlated with solar radiation, temperature and relative humidity in the greenhouse and ambient environments, respectively using randomized complete block design. Data were subjected to descriptive and correlation analysis. Peak temperature and RH were 31.1℃ and 91.1% respectively within the greenhouse in comparison with 29.7℃ and 89.7% respectively outside. Peak solar radiation was 413.4W/m^2 in the greenhouse compared to 690.3 W/m^2 in the ambient. Growth parameters showed that the crops in the greenhouse performed optimally when compared with plants in the open field with a yield of 18.1 t/ha in the greenhouse compared with no-yield recorded in the open field. Omobowale, (2020) concluded that utilization of greenhouses in crop cultivation can help to mitigate the problem of food shortage

The scope of greenhouse in Agricultural Engineering (cultivation, drying and space heating) was studied by Kumar *et al.*, 2006. They agreed that greenhouse provides control environment for high value crops like flowers, medicinal plants, etc. They also agreed that crops grown inside greenhouse are healthy and give better experimental results. They pointed out that latitude and crop requirements are two factors that the design of greenhouse depends on. Different heating and cooling arrangements could be done inside a greenhouse depending on crop requirements. They further emphasized that drying of crops, fruits, medicinal plants inside a greenhouse helps in reducing postharvest losses. Brian *et al.* (2015) opined that low cost design greenhouse and its innovation have the potential to contribute to increased food security, particularly in areas where global climate change is creating additional variability in local weather patterns. They described the preliminary design of a greenhouse that uses open source control Systems. This takes advantage of the decreasing cost and size of sensors to automate systems that have the potential to increase the efficiency and yield of greenhouses.

Sabin *et al.* (2020) verified the greenhouse roof-covering-material selection using the finite element method (FEM). Heating, Ventilation, and Air Conditioning (HVAC) were used to control the situations. They observed that the covering materials of several conventional greenhouses are manufactured using polyethylene, which exhibits a limitation with respect to temperature control for ensuring optimal plant growth. Conducting the experiment using three different covering material configurations, obtained results were verified using FEM. Castilla and Baeza (2013) held that site selection is a key factor for profitable and sustainable greenhouse production. They emphasized that the main factors determining location and site selection of a greenhouse production area are: cost of production, quality of produced yield, and transportation cost to markets. They observed further that during the warm season, especially in the Mediterranean and tropical areas, where there is high solar radiation and the temperature exceeds the recommended maximum threshold level, the greenhouse effect has an adverse impact on the microclimate and crop performance. Solar radiation is the main climate parameter needed to evaluate the climate suitability of a region for protected cultivation. Other climate parameters, such as soil temperature, wind, rainfall and air composition (humidity and CO_2), influence to a lesser degree the evaluation of climate suitability (Castilla and Baeza, 2013). They opined further that the following varieties of factors must be considered in locating a greenhouse: Topography, Microclimate, and Protection from cold wind; Irrigation water, Soil characteristics, flooded areas, Air pollution, Expansion, Labour availability, Communications network and Orientation

Two greenhouse models were identified by Montero *et al.* (2013) which were the active climate control (characterized by High yields**,** Good quality almost all year round**,** regular production and High costs) and passive climate control (characterized by Limited yields, Good quality in limited periods**,** Irregular production and Low costs).

There are numerous options available to greenhouse operators to minimize or eliminate risks related to locating greenhouse in temperate, subtropical and tropical climate zones, environmental modification techniques. The techniques are broadly categorized into: greenhouse design (shape, dimensions and roof configuration), reducing solar load through shading and venting, forced air circulation and evaporative cooling (Connellan, 2002).

FAO (2011) listed the factors to be considered in selecting the location of a greenhouse to include: Topography, Soils, Windbreaks, Water supply and quality, Electricity, Roadways and labour force.

Two basic design of greenhouse exists, namely the *Quonset* and the *A-frame*. The Quonset is based on an arched roof that permits stresses on the structure to be efficiently transferred to the ground. Quonset greenhouses are normally available in two basic designs (FAO, 2011). FAO (2011) also listed greenhouse design parameters to include light, design load, foundation, Orientation, Size, and heights. The structural materials can be grouped into floors, frames and coverings. Floors may be constructed of porous concrete, Portland cement, gravel or compacted clay covered with a strong polypropylene fabric.

2.3 General research trends in GH technology

Literature showed that they are different relevant lines of research related to different aspects of greenhouse farming. This include: Use of water for irrigation in GH, design of optimum GH structures, conserving GH soil in the best growing condition, energy consumption of the system (GH) as a whole, climate control within the GH facilities, pest control within the GH facilities, etc, USBG, 2013; Pack and Mehta, 2012; Teitel *et al.*, 2012; Hua *et al.*, 2019; Asgharipour *et al.*, 2020; Cossua *et al.*, 2020; Jose *et al.*, 2020; Kimura *et al.*, 2020. Findings showed that research trends tend towards the followings - the use of photovoltaic greenhouse (PVG) to increase crop production and adaptability, benefits of microclimates for optimizing GH environmental control, sitting of GH as a function of orientation, light direction and ventilation, good site selection, hydroponic and traditional, dynamic integration of a greenhouse management system and an environment information acquisition system can supply sufficient information for good control strategies and for decision-support, reliable model development to predict and control the microclimate of greenhouse, the use of energy to evaluate the sustainability of greenhouse systems, USBG, 2013; Pack and Mehta, 2012; Teitel *et al.*, 2012; Hua *et al.*, 2019; Asgharipour *et al.*, 2020; Cossua *et al.*, 2020; Jose *et al.*, 2020; Kimura *et al.*, 2020.

Asgharipour, *et al.*, 2020, observed that the use of energy to evaluate the sustainability of greenhouse systems leads to management recommendations to increase the sustainability of production in these systems. Four greenhouse systems one each for cucumber, tomato, bell pepper, and eggplant production, located in Jiroft city, Iran, were evaluated using energy sustainability indices. To accomplish this study, 56, 31, 19, and 12 greenhouses were selected for cucumber, tomato, bell pepper, and eggplant production, respectively. Analysis of twelve energy indices and a study of the social characteristics of the producers using Analytic Hierarchy Analysis (AHA) showed that the sustainability of the cucumber production system was greater than that of the other three systems. They reported the calculated unit energy values for economic yield (UEVE) generally indicated that greenhouse systems were at least 100 times more sustainable than open farm systems for the production of different products, primarily because of drastically reduced soil erosion. The highest (5.10E+04 sej J^{-1} [4.96E+04, 5.25E+04]) and lowest (7.27E+03 sej J^{-1} [7.09E+03, 7.45E+03]) UEVE values were calculated for the bell pepper and cucumber systems, respectively. Therefore, selection of a plant with more potential to use free local environmental energy, higher yield, and more efficient use of labor will lead to greater sustainability of greenhouse vegetable production systems. Sustainability can also be increased by paying attention to the sociotechnical characteristics of the producers, the use of technologies to reduce non-renewable inputs to the greenhouse building, and by reducing the proportion of non-renewable inputs used overall, Asgharipour, *et al.*, 2020.

Yilmaz, *et al.*, 2005 examined the current status of the Turkish greenhouse industry and highlights issues important for its competitiveness. The greenhouse industry was reported to be the fastestgrowing segment of agriculture in Turkey, mainly because of favourable climatic conditions. They however observed that, in recent years the greenhouse industry has been forced to adopt an increasingly competitive place in the market. The competitive market environment for greenhouse produce does not necessarily provide growers with any assurances about sales volume, a sufficient price, or favourable financial outcome. Currently, greenhouse operators in Turkey are faced with problems such as declining crop prices, price fluctuations based on over-supply, poor market systems and sales uncertainty, and lack of grower cooperatives. These problems have resulted in income uncertainty and market risks for greenhouse operators. In addition, strong dependency on imported inputs and excessive use of chemicals are other weaknesses of the Turkish greenhouse industry, Yilmaz, *et al.*, 2005.

Yongguang, *et al.*, (2007) opined that a real-time environment information acquisition system is essential if models and vegetable-crop information are to be integrated with a greenhouse management expert system for good decision making. Their designed greenhouse management expert system has four functional modules: (1) cultivation techniques, (2) pest and disease diagnosis and prevention, (3) nutrient deficiency diagnosis and fertilisation, and (4) environment control. The hardware and software of the environment information acquisition system were incorporated into the expert system, which also offers a multi-interface for sensors and is easily extended and maintained. Implementation was accomplished with the whole system to ensure its reliability and applicability for expert system, on-line decision making. The results showed that a dynamic integration of a greenhouse management system and an environment information acquisition system can supply sufficient information for good control strategies and for decision-support.

2.4 Adaptable Irrigation type for GH farming

For an effective irrigation delivery, the design must consider parameters such as available moisture, root zone depth, allowable moisture depletion, net peak water requirements, irrigation frequency and cycle, and irrigation efficiencies in order to calculate the design flow (FAO, 1989; 2008). The maximum amount of water to be supplied has to be determined using factors such as soil type, root depth and the irrigation method. Three simple methods in determining irrigation schedules are plant observation method (including determination of soil moisture content using gypsum blocks, tensiometers and neutron probes), estimation method and simple calculation method. Determination of irrigation schedule for a given crop could be based on the total growing period, based on the months of peak irrigation, or based on a combination of the two schedules above.

Localized irrigation is usually comprised of drip, micro-jet (jet Spray) and micro-sprinkler irrigation while the advantages of localized irrigation system over others include: reduction in the evaporative component of evapotranspiration, reduction in weed growth due to limited wetted areas, penetration of water into problematic soil is improved by the slow rate of water application, and localized irrigation is considered as a water-saving technology. The probable disadvantages of the system include it's being prone to clogging because of very small aperture of the water emitting devices, movement of salts to the fringe of wetted area of the soil which may cause salinity problems through the leaching of salts by rain to the main root volume, the lateral lines can be damaged by rodents, dogs and other animals in search of water, not economical for the crops with very high population density due to large numbers of laterals and emitters required (FAO – SAFR, 2002; Grag, 2007; Arora, 2012).

From literature, it has been established that greenhouse crops are irrigated by means of applying water to the media surface through drip tubes or tapes, by hand using a hose, overhead sprinklers and booms or by applying water through the bottom of the container through sub-irrigation, or by using a combination of these delivery systems. Babatunde and Mofoke, 2006, Douglas *et al.*, 2010, Teitel *et al.*, 2012, Hochmuth and Hochmuth, 2018. Some of the results from irrigating greenhouse crops include: that maximum yield of roselle grown under irrigation could be attained with a weekly irrigation interval and a gross application depth of 188 mm; Micro irrigation system is the best way for watering plants in a polyhouse as per the daily needs and the stage of the crop; Rockwool or perlite media receive water from individual emitters placed at the base of each plant enabling that each plant is irrigated from a short; Sensors and Controllers are used for controlling climatic parameters automatically inside hi-tech greenhouses, Babatunde and Mofoke, 2006, Douglas *et al.*, 2010, Teitel, *et al.*, 2012, Hochmuth and Hochmuth, 2018.

2.5 Design criteria for GH

Different researcher uses different design parameters as a yardstick (baseline) for the design of GH. Such baseline factors could be cost of construction, local climate and bioclimate requirements of the site, construction materials availability, purpose of research, type of GH desired to be constructed, etc. Rajender, *et al.*, 2017; Hochmuth and Hochmuth 2018; Bucklin, 2020; Sutar, 2020. Findings revealed that the cultivar growing technology under the low cost greenhouse is assuming an important role in Indian Agriculture (and many parts of world) in the future years. Some presented suggestions and options for designing and operating a greenhouse for vegetable production in perlite or rockwool. The local climate and the bioclimatic requirements of the species to be cultivated, once the proper site has been selected, is a necessary influencing factor to choose the cladding material, the type of structure and the architectural shape of the greenhouse Rajender *et al.*, 2017; Hochmuth and Hochmuth 2018; Bucklin, 2020; Sutar, 2020

2.6 Trends in smart GH/farming

Globally, farming generally and GH farming in particular has evolve from the traditional farming system to exploring the application of Internet of Thing (IoT) in the agricultural sectors - Smart agriculture. Various sensors which aid IoT and agriculture, their applications, challenges, advantages and disadvantages are now being researched into for agricultural sustainability, food security and resource optimisation. Development of smart greenhouse models, which helps the farmers to carry out the work in a farm automatically without the use of much manual inspection. The use of Artificial Intelligence (AI) in GH, called intelligence greenhouse for food production. Thus, the current trends of research in smart farming/GH includes the use of drones, robotic agriculture/farming, application of GIS and farm/GH site mapping for sustainable food production. Kodali *et al.* 2016; Wang and Yu, 2019; Chen *et al.* 2020; Fedotova et *al.,* 2020; Katzin *et al.*, 2020; Ratnaparkhi *et al.,* 2020; Tripathy *et al.* 2020. Findings from literature revealed that the application of IoT, robots, AI, GIS and site mapping to GH agriculture/farming and hydroponics (soilless farming) is the new trends in GH farming with a robust chances of improving and increasing crops yields and eliminating human interference and drudgery for sustainable food production and security. Kodali *et al.* 2016; Wang and Yu, 2019; Chen *et al.* 2020; Fedotova et *al.,* 2020; Katzin *et al.,* 2020; Ratnaparkhi *et al.,* 2020; Tripathy *et al.* 2020.

3.0 CONCLUSION

Greenhouse technology in agriculture for research and commercial production purposes has been in existence and continues to be useful in the production and study of choice plants; prevented from the influence of the environment and effects of diseases and pests. Literature support the employment of greenhouses coupled with the appropriate irrigation systems in the study and production of any selected crop(s). Definition of greenhouse and the required optimum operational environments were discussed in line with greenhouse development and utilization in Nigeria and globally. Types of existing greenhouses, classifications, component parts, materials used for it construction, etc were reviewed. GH development and utilization globally and within Nigeria in particular was also reviewed. General research trends in greenhouse technology, adaptable irrigation as source of water supply for greenhouse farming, design criteria for greenhouses and trends in smart greenhouse technology were all reviewed. The results so obtained from the study could be a source of information to assisting stakeholders like farmers and the government who may be interested in commercializing the production and processing of any staple crop within their locality, into desired end products in the agricultural value chain. The review also opened vista of researchable areas in GH farming technology to include, but not limited to robotic farming, application of Artificial Intelligence (AI) in GH farming, use of drone in GH farming, application of GIS and farm/GH site mapping, all aimed towards sustainable food production and security.

REFERENCES

Agricdemy, (2020). https://agricdemy.com/post/greenhouse-farming-nigeria. Greenhouse Farming. Assessed online 14 November 2020.

Akpenuun, T. D. and Mijinyawa, Y. (2020). Impact of a split-gable greenhouse microclimate on the yield of Irish potato (*Solanum Tuberosum L.*) under tropical conditions. Journal of Agricultural Engineering and Technology (JAET), Volume 25 No.1. www.niae.net,: 54 – 78.

Akpenuun, T. D. and Mijinyawa, Y. (2018). Evaluation of a Greenhouse under tropical conditions using potato (*Solanum Tuberosum*) as the test crop. Acta Technologica Agriculturae 2, Nitra, Slovaca Universitas Agriculturae Nitriae,: 56 – 62.

Ale, M. O., Akinyoola, J. A., Fawohunre, A. J. and Aderibigbe, A. T. B. (2019). Design and construction of a Greenhouse for evaluation of the performance of Okra in the Sahel region of Ondo State, Nigeria. International Journal of Advanced Research (IJAR) 7 (9): 24 – 31. www.journalijar.com

Arora, K. R. (2012). Irrigation, Water Power and Water Resources Engineering. Standard Publishers Distributors, Delhi: 1010 -1051.

Asgharipoura, M. R., Amiria, Z. and Daniel E. Campbellb, D. E. (2020). Evaluation of the sustainability of four greenhouse vegetable production ecosystems based on an analysis of emergy and social characteristics. Ecological Modelling 424 (2020) 109021, journal homepage: www.elsevier.com/locate/ecolmodel.: 1 – 17.

Babatunde, F. E. and Mofoke, A. L. E. (2006). Performance of Roselle (Hibiscus Sabdariffa L) as influenced by irrigation schedules. Pakistan journal of Nutition 5 (4): 363 – 367.

Bartok, J. W. (2000). Greenhouses for homeowners and gardeners. Natural Resources, Agriculture, and Engineering Services (NRAES), Ithaca, New York: 9 – 13.

Brian G., Nile K., Kent K., Rowen P., Jonathan R., Kody S., Albert S., Austin S., and Justin H. (2015). Preliminary Design of a Low-Cost Greenhouse with Open Source Control Systems. Humanitarian Technology: Science, Systems and Global Impact 2015. Procedia Engineering 107 (2015): 470 – 479. Available online at www.sciencedirect.com. Retrieved on 13 November 2020

Bucklin, R. A. (2020). Physical Greenhouse Design Considerations—Florida Greenhouse Vegetable Production Handbook, Vol 2. Bulletin HS776, IFAS Extension, University of Florida, publications : 1 – 5. http://nfrec.ifas.ufl.edu/index.

Castilla and Baeza (2013). Greenhouse site selection, In: Good Agricultural Practices for greenhouse vegetable crops (Principles for Mediterranean climate areas). FAO plant production and protection, Paper 217 : 21 – 34.

Chen, M., Zhou, J. and Li, P. (2020). Data communication mechanism for greenhouse environment monitoring and control: An agent-based IoT system. Information Processing in Agriculture 7 (2020): 444 – 456. Journal homepage: www.elsevier.com.locate/inpa. Available at www.sciencedirect.com

Connellan, G. J. (2002). Selection of Greenhouse Design and Technology Options for High Temperature Regions. Proc. IS on Trop. Subtrop. Greenhouses: 113 – 117.

Cossua, M., Yanob, A., Solinasa, S., Deligiosa, P. A., Tilocaa, M. T., Cossuc, A. and Luigi, L. (2020). Agricultural sustainability estimation of the European photovoltaic Greenhouses. European Journal of Agronomy 118 (2020) 126074: 1 – 12.

Cox, D., Clifton, N., Bartok, J. W., LaScola, T. (2010). Massachusetts greenhouse Industry best management Practices guide. UMass extension. Massachusetts Department of Agricultural Resources: 1 – 2.

Douglas, C., Natalia, C., John, W. B. and Taryn, L. (2010). The Greenhouse BMP Manual: Massachusetts greenhouse Industry best management Practices guide. The Scotts Company and by Brad Mitchell, Massachusetts Farm Bureau Federation and Michael Botelho, Massachusetts Department of Agricultural Resources: 1 – 39.

FAO (1989). Irrigation water management: irrigation scheduling. Training manual No. 4. Prepared by Brouwer, C., Prins, K. and Heibloem, M. Accessed online 14 November 2020.

FAO (2008). Process of using and calculating irrigation design parameters. FAO papers, module 7. Accessed online 14 November 2020.

FAO – SAFR (2002). Localized Irrigation System planning, design operation and maintenance.

Irrigation Manual, Volume IV, Module 9, Prepared by Savva, P. A. and Frenken, K.: 1 – 82.

FAO (2011). Rural structures in the tropics. Design and development. Prepared by Mrema, G. C., Gumbe, L.O., Chepete, H. J. and Agullo, J. O., *Rome*: 343 – 350.

Fedotova, G. V., Ivan F. Gorlov, I. F., Glushchenko, A. V., Slozhenkina, M. I. and Natyrov, A. K. (2020). Trends of Scientific and Technical Development of Agriculture in Russia In: Digital economy: Complexity and Variety versus Rationality. Lecture notes in Networks and Systems 87. E. G. Popkova and B. S. Sergi (Eds.): Springer Nature Switzerland AG 2020 : 193–200.

Grag, S. K. (2007). Irrigation Engineering and Hydraulic Structures. Khanna Publishers, Delhi.: 1 – 56.

Hua Y., Qi-Fang, L. and Huai-Qing, Y. (2019). Deterministic and stochastic modelling of greenhouse microclimate. Systems Science & Control Engineering, 7, 3 : 65 – 72.

Hochmuth, G. and Hochmuth, R. (2018). Design Suggestions and Greenhouse Management for Vegetable Production in Perlite and Rockwool Media in Florida. Bulletin 327. UF/IFAS EDIS Publications: 1 – 24. http://nfrec.ifas.ufl.edu/index.

José A. A., Juan, F. V., Belén, L .and Isabel, M. R. (2020). An Analysis of Global Research

Trends on Greenhouse Technology: Towards a Sustainable Agriculture. International Journal of Environmental Research and public Health: 17, 664: 1 – 22. www.mdpi.com/journal/ijerph

Katzin, D., Van Mourik, S., Kempkes, F., and Van Henten, E. J. (2020). GreenLight - An open source model for greenhouses with supplemental lighting: Evaluation of heat requirements under LED and HPS lamps. Biosystems Engineering 194 (2020): 61 – 81. Journal homepage:www.elsevier.com/locate/issn/15375110. Available online at www.sciencedirect.com

Kimura, K., Yasutake. D., Kaikawa, K. and Kitaro, M. (2020). Spatiotemporal variability of leaf photosynthesis and its linkage with microclimates across an environment-controlled greenhouse. Biosystems Engineering, 195 (2020): 97 – 115. Journal homepage: www.elsevier.com/locate/issn/15375110. Available online at www.sciencedirect.com.

Kodali, R. K., Jain, K. and Karagwal, S. (2016). IoT based smart greenhouse. Researchgate. https://www.researchgate.net/publication/316448621: 1 – 7.

Kumar, A., Tiwari, G.N., Kumar, S. and Pandey M. (2006). Role of Greenhouse Technology in Agricultural Engineering. International Journal of Agricultural Research 1 (4): 364 – 372.

Mijinyawa, Y. and Osiade, G. I. (2011). The status of Greenhouses utilization in Oyo State, Nigeria. Journal of Emerging Trends in Engineering and Applied Sciences (JETEAS) 2 (4): 561 – 566. Scholarlink Research Institute Journal. jeteas.scholarlinkresearch.org

Montero, J. I., Teitel, M., Baeza, E., Lopez, J. C. and Kacira, M. (2013). Greenhouse design and covering materials, In: Good Agricultural Practices for greenhouse vegetable crops (Principles for Mediterranean climate areas). FAO plant production and protection, Paper 217: 35 – 64.

Omobowale, M. O. (2020). Evaluation of a low-cost Greenhouse for controlled environment cultivation of sweet pepper. Arid Zone Journal of Engineering, Technology & Environment, AZOJETE March 2020, Vol. 16 (1): 28 – 36.

Omobowale, M. O. and Sijuwade, T. O. (2019). Comparative analysis of partial external shading on the performance of greenhouse grown Cucumber (*cucumis Sativus*) and Okra (*Abelmoschus Esculentus*). In: Innovations and Technologies for sustainable Agricultural mechanization and livestock transformation for economic growth, Proceedings of 40th annual conference and 20th International Conference- Omu-Aran 2019 of the Nigerian Institution of Agricultural Engineers, Proc, NIAE: volume 40 : 952 – 959.

Pack and Mehta (2012). Design of Affordable Greenhouses for East Africa. IEEE Global Humanitarian Technology Conference. DOI 10.1109/GHTC: 104 – 110.

Rajender, G., Sushanth, K., Mithun, K. Devender, B., Raju, D. and Anoosha, K. (2017). Design and development of low cost greenhouse to raise different cultivars". International journal of agricultural science and research (ijasr) issn (p): 2250-0057; issn (e): 2321-0087 vol. 7, issue 3: 29 - 36

Ratnaparkhi, S., Khan, S., Arya, C., Khapre, S., Singh, P., Diwakar, M. and Shankar, A. (2020). Smart agriculture sensors in IOT: A review, Materials Today: Proceedings, https://doi.org/10.1016/j.matpr.2020.11.138.

Samapika, D., Barsha, T., Smaranika, M., Basabadatta, S. and Jnana, B. P. (2020). Green-houses: Types and Structural Components. *In:* Protected Cultivation and Smart Agriculture edited by Sagar Maitra, Dinkar J Gaikwad and Tanmoy Shankar. New Delhi Publishers, New Delhi: 09 - 17.

Sabin, M.C., Ram Karthikeyan, R., Periasamy, C., and Sozharajan, B. (2020). Verification of the greenhouse roof-covering-material selection using the finite element method. Materials Today: Proceedings 21 (2020): 357–366.

Sutar, R. F. (2020). Design and Maintenance of Green House, Pages 31 – 35. www.AgriMoon.Com, info@agrimoon.com.

Teitel, M., Montero, J. I. and Beaza, E. J. (2012). Greenhouse design: Concepts and trends. Proceeding of Acta Horticulturae: 605 – 620.

Tiwari G. N. (2003). A Text book of "Greenhouse Technology for controlled Environment" Alpha Science Publisher.

Tripathy, P. K., Tripathy, A. K., Agarwal, A. and Mohanty, S. P. (2020). MyGreen: An IoT-Enabled Smart Greenhouse for Sustainable Agriculture. IEEE Consumer Electronics Magazine · February 2021: 1 – 7.

United State Botanic Garden - USBG, (2013). Greenhouse manual, an introductory guide for educators. National Center for Appropriate technology: 12 – 25.

Waller, P. and Yitayew, M. (2016).Irrigation and Drainage Engineering. Springer International Publishing AG Switzerland is part of Springer Science Business Media (www.springer.com): 289 – 304.

Wang, X. and Yu, H. (2019). Research on Control System of Intelligent Greenhouse of IoT Based on Zigbee. *J. Phys.: Conf. Ser.* 1345 042036.

Yilmaz, I., Sayin, C., and Ozkan, B. (2005). Turkish greenhouse industry: past, present and future. New Zealand Journal of crop and horticultural science, Vol. 33: 233 – 240.

Yongguang, H., Pingping, L., Xiliang, Z., Jizhang, W., Lanfang, C. and Weihong, L. (2007). Integration of an environment information acquisition system with a greenhouse management expert system, New Zealand Journal of Agricultural Research, 50 (5): 855 – 860.