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REVIEW PAPER

Botanical gardens as valuable resources in plant sciences

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Abstract
Botanical gardens are collections of plants cultivated in a closed space to be utilized for scientific inquiry, recreation, conservation, botanical and horticultural education and also for public landscape aesthetics. Due to their richness in plant diversity and also their facilities, botanical gardens can have remarkable roles in agricultural studies and plant sciences. In addition, botanical gardens are very important regarding to their roles in creating green space in urban spaces, tourist attractions, economical objects and well-being aspects of peoples. Accordingly, in this study, the roles of botanical gardens were reviewed regarding to biodiversity and genetic studies, seed science, plant protection, soil and water researches, ecological evaluation, climate change, research and educations. These topics were also discussed regarding to their usage in agriculture and plant science studies. Furthermore, some scientific potentials of botanical gardens for future studies have been also taken into account.

Keywords Diversity · Climate change · Evaluation · Seed · Education · Research botanic designing · Aesthetic

Introduction

During the history, the human has been interested in gathering plants and using them where there are requirements. Accordingly, plants and human being have an inevitable interaction in their life. One of the human manipulations on the plant life is garden establishment, in which human has made a closed space for plants for growing and also completing their life cycle. There is evidence showing that the first gardens were founded in Egypt, Syria, China and Mexico which their uses were only limited to economic and aesthetic objects (Greene

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1910). Although the gardens were firstly funded for obtaining the plant products, depending on various requirements human has lately tried to create gardens for several purposes. One of the main purposes of gardens foundation was related to plant botany, research and education which were generally named botanic garden. Based on the definition given by the union for the conservation of nature (IUCN), a botanic garden is a garden containing scientifically ordered and maintained collections of labelled plants, and open to the public for the purposes of recreation, education and research (Griffiths and Huxley 1992). Moreover, a botanic garden has another definition by scientists and organizations which is close to IUCN's definition. For example, it is believed that a botanical garden is a collection of living plants that nowadays have four major functions: scientific inquiry, recreation, botanical and horticultural education and public landscape aesthetics (Sim 2001). A botanical plant collection is a documented group of living plants intentionally organized according to specific criteria or taxonomy, phytogeography, habitat, and utility that are the most common themes encountered (DeMarie III 1996; Dosmann 2006; Lighty 1984). As noted in the mentioned definitions, a botanical garden is comprehensive when it is built based on a scientific view. In other words, scientific purposes are the fundamental formation of botanical gardens while the aesthetic aspects are concealed within its appearance. Although the botanical garden has been accepted as a scientific garden, it seems that it has not been well known for agricultural teachers, plant scientists, researchers and scientists. In addition, the botanical garden's potentials regarding to new agricultural studies and plant sciences have been poorly studied. This study was related to importance of botanical gardens in agricultural and plant studies and was focused on some aspects of botanical gardens for agricultural research and plant science. In addition, and according to the above, many literatures outlined from botanical gardens study in agricultural and plant sciences were reviewed.

History of botanical gardens

It is difficult to determine an exact date for the first creation of botanical gardens in the world because there are some places in which we can find a collection of plants being cultivated by people throughout the history and sometimes they cannot be considered as a botanical garden. Plant collection and gardening has a long history as the first examples dating back around 3000 years to ancient Egypt and Mesopotamia (O'Donnell and Sharrock 2018). In a general term, botanical gardens have been probably developed from a small house garden and used to include several medicinal plants collected from nature (Rae 1996), but the scientific proposes were not compatible with what is known today. In fact, botanical garden can be accepted when botany science was developed and also stated within educational and research centers such as schools and universities. From an educational perspective, the first botanical gardens were created in Pisa, Padua, Florence, Bologna, Leyden, Leipzig, Paris, Montpellier and Heidelberg during 1543–1600 (Stearn 1971). The evidence shows that the foundation of the educational botanic gardens was started from Italy and the first botanical gardens were established in Pisa (Orto botanico, 1543, by Luca Ghini) and then in Padua and Florence in 1545 (Britton 2016; Chiarugi 1953; Rakow and Lee 2015). Thereafter, creation of botanical gardens, with pedagogical proposes, was intensified in the Europe and other places around the world. Nowadays, there are 1775 botanic gardens and arboreta in 148 countries around the world (www.bgci.org) which provide a large collection of plants for research and education.

Botanical gardens, potent instruments in biodiversity and genetic diversity research

Biodiversity has been defined by scientists with a few variations in concepts. In a general term, biodiversity or biological diversity is defined as the conservation of the variety of species and the variability of living organisms, their habitats and the biological ecosystems, encompassing the ecological and evolutionary processes of the natural environment (Waldman and Shevah 2000). Biological diversity is the variety of life forms, the ecological roles they perform and the genetic diversity they contain. Since genes are the ultimate source of biological diversity at all levels of biological systems (i.e., molecular, organismic, population, species and ecosystem), genetic diversity and biological diversity are used interchangeably in some contexts (Wilcox 1984). The other definition of the biodiversity has been submitted by the United Nations Earth Summit as "the variability among living organisms from all sources, including, 'inter alia', terrestrial, marine and other aquatic ecosystems (Hawksworth 1995b). By incorporating these definitions, it can be said that biodiversity is variability within and among species of the living organisms. Among the living organisms, plants have a high diversity in the nature. A botanical garden is a collection of plants in which a diversity of plants is created as in a natural ecosystem. Since botanical gardens are so rich in plant diversity, many of the non-plant organisms (such as fungi, bacteria and viruses) can also be attracted to the gardens to prepare a unique place for research and study. In fact, botanical gardens are simulated models of biodiversity in the nature. Many of the plants collected in botanical gardens are potent instruments for research in plant diversity studies and there are a lot of researches that take advantages of botanical gardens.

Up until 1981, it has been estimated that 35,000 vascular plant species representing 15% of the world's flora were cultivated in the botanical gardens (Raven 1981), while it is expected that plant collections have been increased in the recent decades. It means that a large part of the world's biodiversity can be observed in botanical gardens. In a more recent report, it has been noted that the number of species cultivated in botanical gardens may exceed 40,000 (Heywood 1992). It is the "largest assemblage of biodiversity outside the nature" (Hurka 1994). In addition, it has been estimated that approximately 1700 botanical gardens conserve up to 100,000 species (Heywood 1991b) and maintain jointly approximately 3.2 million samples (Hawksworth 1995a) demonstrating the botanical gardens capability to conserve plants and also have the high plant diversity which can affect the world's ecosystem. This quantity of the plant diversity can prepare a unique source for research and study. There is a study showing that plant richness in the botanical gardens can be described in terms of a relatively small number of large-scale patterns (Pautasso and Parmentier 2007). This means that the simulation of the plant diversity in the world and also their responses to the environmental variation can be studied as a small ecosystem model in the botanical gardens.

Although the plant diversity in botanical gardens is so rich, the main plants involving in human life such as agricultural crops (Wheat, Corn, Rice, etc.) are found very fewer than other plants in botanical gardens. In other words, there is no overlap of taxa among the 25 most plant species commonly maintained at botanic gardens and the 25 agricultural crop products that contribute well over 60% of a typical humans daily caloric intake. It means that there is a gap between botanical gardens activity and agricultural production, which may be a serious threat for global food security (Miller et al. 2015).

According to this, the presence of important crops and their genetic resources in botanical gardens is required more than previous.

Although botanical gardens have plant species and also have many other organisms such as fungi, bacteria, viruses and etc., some botanical gardens have a valuable DNA bank of plants which can play a role as valuable plant sources in regards to genetic and biodiversity. In fact, DNA banking may be a useful technique to preserve the plant biodiversity through small safe spaces. Some of the plant DNA banks of the world have been listed by Hodkinson et al. (Hodkinson et al. 2007). Two of the important DNA banks are summarized by Jain et al. (2012): Royal Botanic Garden, Kew, UK (the world's largest DNA bank, consisting over 20,000 DNA specimens representative of all plant families) and US Missouri Botanical Garden.

Since the DNA conservation is easier than other biodiversity conservation ways, the global genome biodiversity network (GGBN) was formed in 2011 in order to store DNA fragments (Droege et al. 2013). The GGBN collected 1,687,371 DNA fragments from all organisms in which plant DNA is a large part of these collections. Similarly, the DNA Bank-Net is an association of institutions that have begun to have DNA accession and DNA-rich materials (Adams 1993). Regarding to genome collection, botanical gardens have been started to collect heritage information and in some conditions, they are interesting to find the genome instead of cultivation of the plants. Many of the plant materials kept in the botanical gardens are potential to give the genome information. The valuable DNA fragments can be achieved from the seed preserved in botanical garden herbariums and museums, in the condition of the viability of seeds (Walters et al. 2006). By development of equipment in manipulation on DNA, a botanical garden will be able to create a huge gene bank with exact information, which may be utilized by future generations. By availability of the unique plant genome information in botanical gardens, plant breeders are usually looking for finding the genes which improve crop performance in yield and stability under abnormal conditions. In institutes that are working on plant breeding, many of the funds are allocated to find the genome sources which use their useful genes in order to introduce desired crops. By having a botanical garden with high plant diversity, the way to reach the desired genotype can be shortened and furtherly the costs usually economized. In fact, a botanical garden can economically reduce the research costs.

Botanical gardens: safe places for plant conservation

The plant population in the world has a dynamic trend throughout the history. Although, sometimes plant species have been increased in their life, there is evidence showing that many of the valuable plant species have overthrown in the entire world. Plant conservation is urgently needed because many species are going to become extinct and many others are threatened and endangered (Prance 2000). Regarding to extinction of plants, botanical gardens have played a role as potent guards and also have had vital roles in the preservation of the plant species. In fact, botanical gardens have been a safe place for plants to be alive. Botanical gardens are considered to be "a vital link" within plant conservation programs (Hurka 1994). The Botanic Gardens Conservation International (BGCI) database showed more than 700 botanic gardens in the world, indicating more than 150,000 taxa, among which are more than 12,000 threatened species (sensu IUCN). Based on a report, At least 30% of all known plant species are found in botanic garden collections, including 41% of threatened species (O'Donnell and Sharrock 2018), showing the important role of botanical gardens in rescue of plants. The efforts on collecting, cultivating and also conservation of the plants are increased in the world, especially through botanical gardens' activities. Botanical gardens, apart from their role of keeping and displaying rare and exotic plants over the centuries, and playing an important role in the distribution of important crop species, have only begun to recognize plant genetic resources (PGR) as a major concern and have started to develop concepts about how to maintain these resources (Rauer and Deutschland 2000).

Frankel et al. (1995) believed that plant conservation would not be possible without the world's botanic gardens. There are many scientific programs and efforts from botanical gardens in the world to preserve the endangered plants. For example, nine species, categorized as 'extinct in the wild', have been preserved in the living collections of European botanical gardens (Maunder et al. 2001). Based on the reports, in 2000, 13 of the species held at the Royal Botanic Gardens, Kew, are known to be extinct in the wildlife and there are at least 20 extinct taxa in cultivation in British botanical gardens (Prance 2000). Some of the African leafy vegetables were conserved and produced at Maseno University botanic garden, Kenya (Onyango and Onyango 2005). Due to the potentials of botanical gardens in conservation of plants, many of the botanical gardens prepared some scientific programs in order to save plants. For example, the international conifer conservation program of royal botanic garden Edinburgh was the extended program that focused on plant conservation (Thomas and Tripp 1998). Approximately, 15,000 species of the cultivated plants in botanical gardens are threatened in the wild (WRI 1992), that shows the importance of putting emphasis on the botanical gardens capability in saving the plants. The potential of botanical garden in conservation of medicinal plants has been fully reviewed (Heywood 1991a).

The conservation of plants in botanical garden can be conducted through two ways: ex situ and in situ conservations. ex situ conservation involves the sampling, transfer and storage of target taxa from the collecting area, whereas in situ conservation involves the designation, management and monitoring of target taxa where they are encountered (Maxted et al. 2000). It can be said that ex situ is more static while in situ is more dynamic. The ex situ strategy can have some techniques including seed storage, in vitro storage, DNA storage, pollen storage, field gene bank and botanical garden conservation while protected area, on-farm and home garden conservation are in situ methods (Engelmann and Engels 2002). Both of the *ex* and in situ conservations of plants are applicable to a botanic garden.

The botanical gardens naturally have done the conservation for plants even if their foundation goals have not been only defined for plant saving. Nevertheless, by the botanical garden potential in plant conservation, most of the botanical gardens have defined some conservative projects for plants in their long-term programs. For instance, the botanic garden of Modena started various in situ/ex situ integrated conservation projects for the endangered plants (Del Prete et al. 2006). By having some similar projects in other botanical gardens, it can be possible to rescue a huge number of threatened plants in the world. Regarding to this and based on the global strategy for plant conservation (GSPC, 2011–2020), the preservation of at least 75% of the threatened plant species in garden collections (ex situ) have been decided by plants 2020 program (target 8), which showed the importance of the botanical gardens in rescuing plants. In regard to the capability of botanical gardens in plant conservation, the status and strategy for ex situ conservation of rare and endangered plants in Chinese botanical gardens have been reported (Yang et al. 2005). The plant conservation necessarily imposed much cost on institutes while a botanical garden potentially can decrease the cost and energy for plants rescue.

Botanical garden as a unique instrument in plant taxonomy and systematic

One of the major roles of botanical gardens is their valuable materials in plant taxonomy and systematics, because they have a large number of plant species and also there are dried plant parts. It has been estimated that combined collections of the botanic gardens in all of the world potentially include up to one-third of all known plant species (Sharrock 2011; Smith 2016). Based on a report from Canada, it has been estimated that approximately 45,000 taxa of vascular plants are in cultivation among botanical gardens and arboreta across Canada, including something more than 1700 indigenous species (Galbraith and Rapley 2005). In addition, it has been reported that over 80% of botanical institutions in Canada, including botanical gardens, have active programs for documenting their plant collections, which can be a large document for taxonomy studying and etc. The preserved collections of botanical gardens present unique opportunities in taxonomy, systematics and other related fields (Galbraith and Rapley 2005).

Since botanical gardens often include the local species, it can state that botanical gardens can be considered as a suitable foundation for taxonomy and systematic research. Based on a report of FAO (FAO), 410 botanical gardens have conserved ornamental or wild native endangered species, 169 medicinal or forest species, and 119 germplasm of cultivated species. This report obviously showed the importance of botanical gardens as a valuable source in order to taxonomy and systematics. Some of the useful applications of botanical gardens in the taxonomy have been previously reviewed (Dosmann 2006; Pautasso and Parmentier 2007; Stevens 2007).

In addition to morphological aspects of plant specimens obtained from botanical gardens, the plant taxonomy and its relation to physiological traits could also be studied in plants inside on a botanical garden, as some methods for studying the photosynthetic taxonomy of the angiosperms obtained from several botanical gardens have been documented (Tregunna et al. 1970).

Botanical gardens usually have herbaria and libraries which are valuable sources in systematics and taxonomy studies. Moreover, botanical gardens may have museums that are very useful in plant taxonomy and systematics. Generally, a herbarium, a collection of pressed plants mounted on paper, is usually been found in most of the botanical gardens (Nesbitt 2014). It has been estimated that the world's major herbaria contain over 387 million specimens (Thiers 2018) which provide a large materials for research. In addition to plant materials of herbarium, fungi and alga can also be observed along with plant materials in herbarium specimens. These organisms interestingly can provide a valuable source in research and education.

One of the useful applications of a herbarium material is the ability to help in introducing new plant species by botanists. Producing such varieties relies on the deployment of genes often found in the wild plants conserved in botanic garden collection (Sharrock 2013). For example, new taxa of *solenostoma* and *plectocolea* were introduced based on the study of collections in the New York botanical garden herbarium (Bakalin 2013).

The herbarium specimens also can be used in order to find the phytochemical analysis among plants. For example, the herbarium specimens of Stevia (*Stevia rebaudiana*) were evaluated among 110 species of Stevia to find the sweetness property (Gyllenhaal et al. 1990) and Pinus resin has been obtained in Royal botanic gardens and thereafter evaluated (Stacey et al. 2006). Since herbarium specimens are dry, they are useful for phytochemistry analysis regarding the plant chemical substances derived from dry tissues. This object could be interesting when some of the plants are distinguished from each other by their phytochemical properties.

Herbarium materials can provide an excellent source of information for molecular phylogenetic studies in plants (Zuntini et al. 2013). The botanical garden herbariums may have other valuable parts of plant such as seeds, DNA and pollen, giving remarkable data from plants used in research and education. Totally, a herbarium has potential to help in presenting classification as well as the introduction of new plant species.

Regarding taxonomy and classification, one of the main outputs of botanical gardens is finding the geographic distributions of species (Pyke and Ehrlich 2010) which allows researchers to find the plant's origin and biography. In addition, the track temporal changes can be facilitated by using herbarium data. In fact, herbarium data showed the ecosystem properties of the collected plant samples. Since some of the properties such as date of sampling, sampling time and sampling location are usually written in herbarium specimens, the herbarium specimens can be used in ecological and phonological studies in regarding to plant's life.

In addition to herbarium, xylarium, a collection of well-curated authenticated wood specimens can provide valuable sample relating to plant studies. Generally, xylarium collections can be used for developing libraries of wood density and biomass data for use in reducing emissions from deforestation and degradation (REDD) and carbon sequestration programs (Smith 2019).

Seed research in a botanical garden

Seed is the most important factor in plant distributions around the world and plays a vital role in the complementation of the plant life cycle. Therefore, any change in the seed distribution can affect the plant life cycle. It is inevitable that seeds can get or lose some valuable traits during the dispersal process which may change the next plant generation. Botanical gardens have a huge source of the plant's seeds which have a large potential in the agriculture and plant studies. It has been recommended that botanical gardens should establish seed banks for protection and conservation of our natural plant genetic resources (Hurka et al. 2003). Regarding to seed collections, it has been estimated that 350 botanic gardens together maintain seed collections of 57,000 taxa (O'Donnell and Sharrock 2018). The world's botanic gardens already conserve and manage around a third of all known plant species in their living collections as well as seed banks as an insurance policy against extinction (Smith 2019). The advantages of a seed bank are in its economy of space and larger sample sizes (Ashton 1988). In addition, the seeds of some species can survive hundreds of years in conditions of low humidity and low temperature (Li and Pritchard 2009) while most of the plants are not able to live for a long time. The seed bank creation has been recognized as being the most efficient way of storing large numbers of living plants in one place (Linington and Pritchard 2001). It has been reported that at least 350 botanic gardens involved in seed banking in 74 countries which their combined collections include endemic species from at least 166 countries and approximately representing nearly 7000 genera (O'Donnell and Sharrock 2018). By finding the importance of seed bank, many of the botanical gardens are trying to create a seed bank of plants because the seed storage is easier in comparison with other parts of plants. In this regard, BGCI launched the Global Seed Conservation Challenge (GSCC) in 2014 to support seed banking in botanic gardens and to increase the number of threatened species in seed banks (O'Donnell and Sharrock

2017). Regarding the seed bank creation, the most noteworthy seed gene bank project of botanic gardens is the Millenium seed bank project at the royal botanic gardens Kew which was programmed to gain 10% of the world's plant diversity. In addition, the center for plant conservation at the Missouri botanical garden in St. Louis is another successful example in the seed bank foundation (Hurka et al. 2003).

Seeds obtained from botanical garden are valuable sources for demographic studies and also find the historical change in plant growth and traits, as in a study in botanical garden of Charles University in Prague, 951 species of the central European flora were examined in order to find their demography (Herben et al. 2012).

Seeds are the main foods for birds and the birds can intensify the seed dispersal in the world. The dependency of birds to seed and their roles in seed dispersal also create an opportunity to study the plant-birds interaction in an ecosystem, as seed dispersal by birds in Nanjing botanical garden has been studied by Li and Yin (2004). Similar studies have also been done by other researchers (Li et al. 2001; Tang et al. 2008). Due to the high diversity of the plants in botanical gardens and in regarding to their seed bank, they can provide a seed exchange network in order to have plant diversity improvement and also plant conservation in the world. In other words, botanical gardens that maintain active seed banks can increase efforts to display plant species as members of natural assemblages of species (Schoen and Brown 2001), which have facilitated the plant rescue and research.

Many valuable studies have been conducted by using the seed obtained from botanical gardens (Aviezer and Lev-Yadun 2015; Gasperi-Campani et al. 1977; Kranz and Huss 1996; Shi et al. 2011; Ul'chenko et al. 1998; Von Reis and Lipp 1982; Zheng 1991), showing the importance of botanical garden potential in research, especially in seed research.

Some of the seeds available in the botanical garden herbarium may be able to keep their germinations (Godefroid et al. 2011) which are valuable materials to understand the previous plant behaviors. In fact, the seed obtained from botanical gardens are carriers of some valuable information relating to previous generations of plants.

Soil, water and ecological evaluation through botanical gardens database

A botanical garden can prepare a small ecosystem in which some natural phenomena are researchable. Since botanical gardens usually have specific water, soil and most of the organisms, their relationship can be studied as ecological evolution and research. In a botanical garden, the ecological study is not only referred to plant but also can include living of other organisms such as herbivores and microorganisms in water and soil. For example, the physico-chemical properties of soil and cast of *Metaphire posthuma* collected from botanical garden were evaluated in a study in India and it was found that earthworm of botanical garden was more efficient in cast production as compared to earthworm of agricultural field (Singh et al. 2016). Many of the green flagellate, *Euglena gracilis*, behaviors have been studied by using a vertical column immersed in a pond in a botanical garden in Marburg (Häder and Griebenow 1988).

Microclimate and CO_2 exchange of some lichens were recorded in botanical garden Würzburg, northern Bavaria (Lange et al. 1997). Similarly, ecology of soil oribatid mites in three contrasting sites at botanical garden at West Bengal has been evaluated (Sanyal and Sarkar 1993).

In a study and in regard to water consumption, the plant water-use efficiency was evaluated among trees at the Los Angeles county arboretum and botanic garden in Arcadi and it has been suggested that the water use efficiency was a useful measure of the balance between some critical costs and benefits of irrigated urban trees and may be helpful in determining which trees should be planted to maximize growth while conserving water (McCarthy et al. 2011). In order to simulate the long-term water requirements of the Padova botanical garden, its evapotranspiration has been estimated (Morari and Giardini 2001) which would be useful to be used in similar regions. In a research, the algal flora of the Missouri botanical garden have been studied (Hayden 1910) and the richness of the organism has been noted and discussed. Similarly, zooplanktonic organisms in water bodies in the botanical garden of the Jagiellonian University in Krakow (Komala and Przybos 2000) and Lichens in the new botanical garden of the University of Zürich, Switzerland (Aptroot and Honegger 2006) have been studied.

The gas exchange of Carex species from eutrophic wetlands and its dependence on microclimatic and soil wetness conditions were studied in a botanical garden of the university dttsseldorf (Busch and Lösch 1999). In a similar study, growth pattern and photosynthetic activity of different bamboo species were studied in botanical garden of Rome (Gratani et al. 2008), in which their net photosynthesis during autumn, winter and spring were measured. In addition, the response of these bamboo species to temperature and also their CO_2 carbon sequestration were assessed. The results have obviously shown that botanical gardens have the ability to show the long time influence of climatic factors on the micro-organism's life. In this regard, the effects of precipitation increase on soil respiration were examined in the south china botanical garden (Deng et al. 2012).

Regarding ecological studies, in an ecological evolution, the germination ecology of coastal plants in relation to salt environment was studied by using the seeds collected from Tsukuba botanical garden of national science museum, Japan (Mariko et al. 1992). It is showing that botanical gardens are potent instruments for ecological research, due to their long time data collection and also high frequency of organism interactions. In this way, the ecophysiological behavior of some species of woody perennials recovered on the botanical garden of Caracas were studied and it was found that drought resistance species were associated with their high sensitivity to leaf-air vapor pressure deficit and lower leaf conductance (Olivares and Medina 1992). Similarly, the leaf biomass and leaf carbon sequestration of *Pistacia atlantica* in national botanical garden of Iran were estimated (Panahi et al. 2011). In addition, acorn production of oaks and their qualitative characteristics were investigated in Zagros section of national botanical garden of Iran (Panahi et al. 2009). All the data are showing that a botanical garden is able to provide a micro-ecosystem which facilitates the studies relating to plant ecology and also other organisms relations to plants. Actually, the long-term data obtained from botanical gardens act as powerful instruments for ecologist in order to find the living organism's response to their environment which simplifies the ecological interactions understanding relating to plants.

Plant protection can be studied easier in a botanical garden

Botanical gardens are so interesting for plant protection researchers, due to their high diversity and also their various responses to pest and microorganisms. In fact, long living of plants inside botanical gardens is very interesting for those who look for tolerant and resistant plants to pest and diseases. In a botanical garden, the relationship between host and pathogen can be monitored for a long time and their reciprocal interaction can be seen or diurnally recorded. All of the pathogens are detectable inside a botanical garden, providing a stable source for studying their lives. Many remarkable findings of plant protection studies have been obtained via using botanical gardens. In addition, there is an ability to study the long-term effect of some herbicides in a botanical garden or study herbicide's effects on different genotypes of plants. for example, two plants from botanical garden of teaching and research farm LAUTECH, Ogbomoso, were tested to find insecticides properties against major field insect pests of cowpea (*Vigna unguiculata*) in Nigeria (Olaitan and Abiodun 2011).

Scale insects on ornamental plants in confined spaces have been described by using the insect collected from containers and soils of Warsaw and greenhouses of the botanical garden of Maria Curie-Sklodowska University in Lublin (botanical garden of UMCS) (Goszczyński and Golan 2011). Moreover, a Branch-beating was also performed in a study in the botanical garden of the Corvinus University of Budapest, which was led to the first data on occurrence of the mosaic leafhopper, *Orientus ishidae* (Matsumura) (Hemiptera: Cicadellidae), in Hungary (Koczor et al. 2013).

In addition to herbivory studies, the positive aspects of plant–insect can be studied in the botanical gardens. For example, the pollination system and reproductive strategy of two orchids in the botanical garden of the national orchid conservation Center (Shenzhen, southeastern China) were assessed (Koczor et al. 2013). In a study in Thailand, *Chilades pandava* Horsfield herbivory among 85 Cycadaceae species was determined in a botanical garden to identify patterns that may improve horticultural and conservation management practices (Marler et al. 2012).

In a research, the common diseases of medicinal plants in south China's botanical garden were distinguished which can help to control them (Dongming et al. 2003). The ability of epiphytic bacteria to alter leaf surface permeability was evaluated and reported in botanical garden of the university of Wurzburg (Schreiber et al. 2005).

The biocontrol potential of endophytic fungi was examined in medicinal plants from wuhan botanical garden in China (Xiang et al. 2016). Moreover, the diversity and antimicrobial activity of endophytic fungi isolated from *Nyctanthes arbor-tristis* grown in botanical garden of Banaras Hindu University (India) have been reported (Gond et al. 2012). The fungal root endophyte among medicinal plants of the Institute of natural fibers and medicinal plants, Plewiska, near Poznań were studied (Zubek et al. 2012).

The first report of a disease of peony caused by alfalfa mosaic virus was reported from plant cultivated in the botanical garden of the University of Parma (Bellardi et al. 2003). Some weed species obtained from botanical garden of the university of Copenhagen were introduced as carrying potato mop-top virus (Andersen et al. 2002). The mentioned findings are showing a unique place for studying the plant pest and diseases and can be an experimental station for agricultural research and educations.

The botanical gardens can also be places for the study of organisms living in the soils such as nematodes. In this regard, the first report of northern root-knot nematode of Zagros oaks was carried out in the national botanical garden of Iran (Sohrabi et al. 2015). The same results enable researchers to study plant's pathogens and consequently find the best solution strategy.

In addition to pests, it is possible to study the weeds behavior inside a botanical garden, which helps to find the efficient control of them. For example, diversity and ecological characteristics of some weeds of wheat fields was evaluated in botanical garden at Azakhel, Pakistan (Hussain and Shah 2009). In another study, researchers have tried to study the greenhouse weeds in the botanical garden of PAS in Warsaw-Powsin (Galera and Ratyńska

1999). Inside a botanical garden, it is also possible to evaluate the weed's relationships with other organisms, as the relationships of invasive plants with soil micro-organisms (fungi and bacteria) that have been studied in Xishuangbanna tropical botanical garden, China (Xiao et al. 2014).

According to plenty of documents and results obtained via using botanical gardens, it can be argued that botanical gardens are desirable places for conducting research involving plant protection and finding new aspects of plant pest and diseases behaviors. A large part of the protection management of plant's life against pathogen can be derived through practical research in botanical gardens.

Climate change study via using botanical gardens

Climate change is accepted as a global challenge for future life and certainly will also impact our relationship with plants (Schaal 2019). Accordingly, we need some conditions that help us to study the climate change, especially related to effects on plant's life. Botanical gardens are places with some plants that experience long-time life under different conditions. So, the long-time effects of various conditions can be easily observed in the plants grown in a botanical garden. In other words, botanical gardens and their components can act as valuable materials for climate change studies in regard to this object. Some of the botanical garden's roles related to climatic changes have been almost noted (Primack and Miller-Rushing 2009) and it has been noted that botanical gardens are valuable institutions in climate change research as they offer a great range of resources such as a diverse flora including invasive species, herbarium specimens, phenological gardens as well as consistent environmental conditions through extensive care (Primack and Miller-Rushing 2009). A botanical garden has been described as an artificial ecosystem, especially in urban areas (Schwartz et al. 2006; Wania et al. 2006); thereby, it will be possible to study the ecosystem dynamics relating to climatic factors. In fact, botanical gardens give small models of ecosystems to researcher to study the hid part of the climate change process. Botanical gardens may serve as a 'window to the world,' allowing to get an understanding of the global relationships of climate change related phenomena (Sellmann and Bogner 2013a).

It has been reported that botanical gardens can provide direct evidence for the consequences of climate change through the accumulation of data about long-term flowering patterns for a diversity of plants (Schwartz 2003) providing an irreplaceable contribution to climate-change research (Primack and Miller-Rushing 2009). Some scientists believed that botanical gardens facilitate comparative evolutionary, ecological, and phylogenetic studies due to their rich diversity and taxonomic representations (De Carvalho et al. 2004; Karlson et al. 2004; Miller-Rushing et al. 2007). Researchers at botanical gardens can address questions of how individual, long-lived plants respond to climate change over their lifetimes in terms of phenology, physiology, growth, and anatomy (Primack and Miller-Rushing 2009). By interpretation of the data obtained through botanical gardens, it will be easy to find the plant responses to climate change and consequently improve the sustainable food security for human. The climate change findings can be fundamental bases for future agriculture which can be ascertained by long-term observations in botanical gardens.

Regarding climate change studies, scientists are interested to use local data in order to survey the climate change effects on local agricultural products, which may guarantee the food security. The botanical gardens often provide some useful data for climate change studying and interpretation. By survey the 88 responses received from botanic gardens in

40 countries, it has been shown that 80% of these botanical gardens were working with local communities to enhance food production (Sharrock 2013), which may provide valuable data for studying the climate change.

Many of the botanical gardens have long-time recorded data about plant's life which can act as a historical identity of plants. These valuable records are able to simulate the climatic change. In fact, the effects of the climatic factors on plants are usually recorded in the most of the botanical gardens which can help to better evolution of climate change.

At some times with climate change studying in botanical gardens, the effect of environmental stress on plants can also be addressed. For instance, the effect of cold stress was evaluated on a large number of woody plant species located in the national botanical garden of Iran, which revealed some valuable notes about the woody plants behavior during their life (Jalili et al. 2010). Similarly, in a study in Munich botanical garden and by using the data from its herbarium, researchers argued that photoperiod- and chilling-sensitive woody species cannot rapidly track climate warming (Zohner and Renner 2014). In a study in Ecological Botanical Garden of the University of Bayreuth, it was demonstrated that cold tolerance of tree species was related to the climate of their native ranges (Kreyling et al. 2015). Moreover, it has been emphasized that herbarium data are so useful in order to understand plant phonological responses to changes in temperature and climate (Davis et al. 2015). Botanical gardens can provide direct evidence for the consequences of climate change through the accumulation of data about long-term living for a diversity of plants.

There is evidence showing that climate change effects on plants can be obtained by herbarium specimens (Bolmgren and Lönnberg 2005; Bowers 2007; Lavoie and Lachance 2006). However, time and place of the sampling of herbarium sample should be carefully considered. The phylogeny and historical biogeography of Geraniaceae in relation to climate changes and pollination ecology were studied by using the seeds obtained from a botanical garden in Madrid (Fiz et al. 2008). By studying 21 plant species in Xishuangbanna tropical botanical garden, it was suggested that phenology of tropical plants was changed significantly in response to the regional climate change (Zhao et al. 2013).

In a botanical garden, it is possible to study the relationship of plant with other organisms, especially during a long time, as in a botanical garden in China, it was found that warming will not only affect plant invasions directly, but also will derive either enemy release or increase that will result in contrasting effects on invasive plants (Lu et al. 2013). Some of these results can help to manage the agriculture responding to climate change. In fact, the yield losses of crops by climate change could be alleviated by prediction of climate change effects on agricultural products. This objective can be achieved by botanical gardens.

The botanical garden are also able to provide some results from climate change even if related to other objects, as the effects of global warming on seasonal tourism for the last 20 years in Beijing was studied by using Peach flower Stanza located on Beijing Botanical Garden (Ma and Fang 2006).

Botanical gardens can educate people on environmental phenomena

Educational purposes have been considered as major parts of the botanical gardens foundation, because there are a lot of equipment and spaces inside the botanical gardens which simplify the education in regard to plant science. Botanical garden purposes often have been principally defined for research and education (Dosmann 2006; Watson et al. 1993).

The education in the botanical gardens can be useful for both academic programs and visitors. Education on the environmental objects to visitors may accelerate the reach to sustainability. It has been noted that botanical gardens can be visited by over 300 million visitors a year globally, which is potential for a great improve of the visitor's knowledge (Williams et al. 2015).

Towards globalization of plant science education, a botanical garden can be an education center for elementary schools up to the expert researchers. Botanical gardens have huge potential to promote the environmental science in public. Some examples of effective collaborations through botanical gardens has been described aim to increase public engagement with food and agriculture, which were included exhibits, demonstration farms, experiential education, community outreach and collaborative biocultural conservation (Krishnan et al. 2019). Education in botanic gardens can come in a variety of forms: children's summer camp, family programs, school programs such as field trips, teacher training and development, adult education and certification programs as well and student internships (Krishnan and Novy 2016). It's believed that education programs in botanical gardens could influence cognitive, affective and motivational attitudes positively (Wiegand et al. 2013). Based on Wyse and Sutherland (Wyse and Sutherland 2000), public education, ex situ conservation, and scientific research are the major roles of a botanical garden. The role of a botanical garden in education is so important that in Germany they are called ' 'green schools'' or ' 'green classrooms''(Wiegand et al. 2013). In a botanical garden, there are several ways such as guided tours, talks, exhibitions, workshops, and free-choice learning, artistic approaches, plant labels, posters, and nature trails and many others that may facilitate the education process for learners (Falk 2005; Kneebone and Willison 2007). In fact, education could be so easy by having a lot of valuable collection of plants and their dependences. Botanical gardens can act as eco-attractions having some scientifically benefits for visitors. It has been tested that paying a visit to a botanical garden enhances the degree of satisfaction of visitors (He and Chen 2012).

One of the main purposes of the education in botanical gardens is education on sustainable development (Willison 2006) and accordingly, environmental education programs may have an influence on participants' environmental attitudes (Sellmann and Bogner 2013b) as in Germany, it has been reported that botanical gardens can act as appropriate learning sites for education on sustainable development (Sellmann 2014). The effect of the environmental education classes at Missouri botanical garden on attitude and knowledge change of elementary school children was assessed and it was found that these classes increased the knowledge base of participating children (Kahtz 1995). In a study in Royal botanical gardens, Kew, it was observed that children talk spontaneously about the easily observed features of plants such as color, shape and smell, and offer past experiences with garden plants, when they were in the garden (Tunnicliffe 2001). Moreover, it has been reported that the knowledge base of participating children was increased after the visit of Missouri botanical garden (Kahtz 1995) showing effectiveness of gardens for children learning. In a study, it was found that visitors of botanical garden get more awareness about climate impact after the visit of plants in botanical garden (Brownlee et al. 2013). Some similar results relating to education program were found in a study in botanical garden of university of Bayreuth (Sellmann and Bogner 2013a). There are possibilities in botanical gardens that provide effective education regarding to sustainability in agriculture. By evaluation the Sustainable Communities Field School (FS) program in Vancouver, Canada, it has been reported that FS participants were more knowledgeable about sustainability issues, more connected to nature, and more willing to engage in sustainability actions, compared to regular garden visitors who did not receive the FS tour (Zelenika et al. 2018). Based on the mentioned research it has been suggested that community-based research and education collaborations, such as the FS program, can provide important opportunities for botanical gardens and nature-based organizations to have a direct contribution to sustainability education.

In regard to the role of botanical gardens in agricultural education, it can be said that a botanical garden can act as a large classroom with high amount of education facilities that simplify teaching for teacher and also learning for learners. One of the examples is the state botanical garden of Georgia that showed a great potential to support interdisciplinary learning experiences in the fields including botany, horticulture, environmental design, ecology, anthropology, geography, instructional technology, science education, entomology and forestry (Lewis and Affolter 1999). The literatures are showing that every place of a botanical garden can be considered as a classroom for teacher and students; therefore, the education efficiency can be increased.

Plant science educated people cause developed community by their greater participation and outreach, innovative education, as citizen science has been emphasized as one of the seven priorities for strategic action in the plant sciences, announcing in Schenzhen Declaration (Crane et al. 2019).

The role of botanical gardens in economic issues

Botanical gardens were the importance of trade and commerce as well as competition between colonial powers in the eighteenth and nineteenth centuries (Heywood 1987) and it seems that this role has amplified more by understanding the new usage in plants. It has also been accepted that most of the older tropical botanical gardens were established during the colonial era, as a consequence of trade and commerce (Heywood 1987) and many of the new botanical gardens were established in accordance with economic development (Chen et al. 2009). Some botanical gardens have played a pivotal role regarding to economical objects which led to a high value marketing cases. The Arogyapacha (*Trichopus zeylanicus)* is one of these cases that commercialized through a contract between the tropical botanical garden research institute of Trivandrum and a pharmaceutical company which its market value was estimated $1 billion (Varshney 2004). The effort of some botanical gardens was obviously seen towards economic issues as noted that Kew botanical garden searched for economically useful plants, most often in South America... improved them, and transferred them to Asia (Foster 1999). The *Hevea brasiliensis*, as rubber tree from the Amazon jungle was firstly transferred to the Kew royal botanical garden, in 1875 and thereafter propagated which affects the economic situation of the people due to its valuable application in electricity, transport and war machine (Cornish et al. 2017; Schultes 1977). The economic botany at Kew has been reviewed (Cornish et al. 2017), as a case study in a botanic garden and revealed some economic aspects of botanical gardens. The literatures are showing a high potential of botanical gardens in trade and commercializing, as many of the botanical gardens are doing now.

Future prospective of botanical gardens in regard to research and education in plant sciences

Since agriculture and also plant life are responsible for food security in the world, anything related to these sciences will play a remarkable role in the human future life. In this regard, botanical gardens, due to their valuable resources for agriculture and richness in plant species, can have vital roles in agriculture development and security. Actually, botanical gardens are source banks for agriculture and some of the botanical gardens are working to improve the food security of the world. For example, Royal Botanic Gardens, has a project dealing with identify, collect and preserve seeds from the wild relatives of 29 crops important for global food security (Miller et al. 2015). The role of botanical gardens in crop wild relative (CWR) has been reviewed and it has been concluded that the botanical gardens should be high on the list of potential collaborators for CWR outreach programs (Moreau and Novy 2018).

Creation of botanical gardens especially in regions with rich flora has been suggested by the International Union for Conservation of Nature and Natural Resources (IUCN) and also World Wide Fund for Nature (Pinheiro et al. 2006) in order to maintain essential ecological processes and life-supporting systems and to preserve genetic diversity (Tilman 2000). Allocating more funds to botanical gardens in species-rich regions have also been recommended (Pautasso and Parmentier 2007). There are a lot of research works which have emphasized to protect and develop the botanical gardens, due to their important roles in the world ecosystems. Approximately, it has been accepted that plants facilitate the ecosystem services in the planets and a reliable connection between ecosystem services and biodiversity has been shown (Knapp 2019). The relationships of the botanical gardens and environmental studies have been fully sensed by researchers as in China as it was said that the future of the botanical gardens is intimately linked to the future of the ecological environment of the region (Qiu 2009).

Protection of old botanical gardens is vital for their managers, because most of the buildings and landscapes are constructed by old materials. In addition, the plants grown in old botanical gardens need more protection, due to their high value and probably weakness to conditions.

Most of the botanical gardens have been developed during a long time and some of them are potential to be developed more nowadays. In order to develop botanical gardens, some of the scientific aspects should be considered, especially in those that are located in the urban spaces. New technologies can be employed in order to develop botanical gardens. In addition, plants can be cultivated based on scientific aspects.

By finding the high value of the botanical gardens in the human life, many of the countries have been trying to establish botanical gardens. Regarding establishment of a botanical garden, there are some notes that may improve its designing and yielding. The design and architecture of a botanical garden are more complicated than a general garden because of the environmental requirements for plants, user's requests and also the standards of the open and closed spaces. The number, type and area of botanical garden spaces are dependent on the climate conditions, garden area and location of the site. Generally, four zones can be considered for botanical gardens which include: (1) research and education, (2) offices and management, (3) exhibition and entertainment and (4) welfare and services. These zones may have been overlapped in many spaces. The research and educational zones can have several spaces such as greenhouses, objective gardens, gene bank, herbarium, labs, library, halls and classes while offices and management zones can have spaces such as management office, conference room, reception and information desk. In the exhibition and entertainment zones, some spaces such as museums, galleries, gardens, walkways, greenhouses, children parks and plant shopping can be designed. Welfare and services zones can have restaurants, coffee shop, amphitheater, parking and toilets. However, the scientific purposes may affect on botanical garden architecture designing and it can help to create an attractive space in order to develop human well-being, based on user's requirements. A botanical garden should have a flexible design and also should have the ability of being changed in performance during the time. The spaces of a botanic garden should be designed as they have the best connections. The easy accessibility should be considered in the space designing of a botanic garden, especially for the disabled people. A conscious climate architecture may increase the performance of a botanic garden. In this regard, the elongation and direction of the buildings, type and color of materials, form and size of windows, externals walls insulation, use of the solar energy and definition of some spaces before the entrance can be noted. Furthermore, the landscape designing and the related parameters such as slope, plant row direction, shading factors, wind barrier designing, plant light requirements and plant colors should be considered. Generally, aesthetic aspects are the inseparable elements in a botanical garden architecture in order to create memorable memories in the visitor's minds and; accordingly, many aspects may be useful which include: creation of beautiful visuals and landscapes, rational use of the colors and textures, effective and continuous connection with the nature and environment, diversity in the walkways, distinction of the domains, framing of the nature by architectural elements, use of the green porch, corridor, bridge, balcony and roofs, definition of the spaces territory by plants, separation of walking ways and car roads and finally respect to the nature.

Botanic Gardens Conservation International (BGCI) prepared some guidelines in order to develop botanical garden activities. Most of the goals defined by BGCI have been reviewed by Maunder (1994). However, there are some suggestions that may improve a botanical garden establishment. We believe that gardening and technical staff and also expert staff are the main gate to the entrance of a botanical garden, because they can adjust the situations for botanical garden establishment and also determine the needs. In addition, the technical staff can see the problem easier and solve them as soon as possible.

New technology can assure the botanical gardens for long living and better output. There are some new technologies that minimize the costs and energy for botanical gardens. New technologies can be used in all places of a botanical garden. In addition, new places and spaces such as greenhouse, aquaria, arboreta, gene bank and labs can be established by modern equipment. Data recording is usual in botanical gardens and this object can be digitized and consequently the variation be modeled by computers. Digitization of herbarium records, gen banks and genome information could be a major option in the new botanical gardens. The availability of large rooms or stores with controlling the temperature, light and humidity is useful to keep plant materials for long periods. Education spaces such as classroom, lab and conference hall are necessary for botanical gardens. Some amenities should be prepared near the botanical gardens for visitors and researchers.

In the new botanical gardens, it is better to allocate the suitable location for plants. In fact, the plants may be located based on their growth habitats. Today, the collection of plants is easier than the past and it is expected to have more plants cultivated in botanical gardens. However, collection and translocation of the plants and seeds and other plant materials should be done according to scientific aspects and international rules. The botanical gardens may have network sharing project in order to provide their needs. In this regard, there is an International Plant Exchange Network (IPEN) for conditions and members (von den Driesch et al. 2005) that are able to provide plant materials. However, it should be noted that any translocation of plants flora should be done under Convention on Biological Diversity (CBD) guidelines (Davis 2008) and access and benefit sharing (ABS) rules (Martinez and Biber-Klemm 2010). In addition to plant collection, as noted previously and Like GGBN, botanical gardens can be tried to collect the genome information of the plants.

The smart equipment, modern irrigation, suitable soil tillage, appropriate cropping technology could be considered in new botanical gardens. By having a scientific botanical garden, it will be possible to introduce new plants, use model plants, study and do research, attract tourists and increase the economical incomes. In addition, it can provide a human well-being.

Conclusion

The literatures showed that botanical gardens have had some benefits for agriculture and plant sciences and showed more potential that may have not seen by researcher. However, many of the scientific findings related to plant science have been obtained through botanical gardens. Moreover, botanical gardens have shown a potential to help the plant researchers to have a better understanding of the issue. The findings and potentials were related to biodiversity, genetic, seed, soil science, water research, plant protection, plant breeding, biotechnology, ecology and evolution, taxonomy, systematic, physiology, ecophysiology, phenology, climate change and education. Based on the review, it can be concluded that botanical gardens were pioneer in the plant science research and education and have the ability to support the research in order to reach sustainable development in agriculture. Finally and after reviewing the beneficial effects of botanical gardens and evidence on interests of these places, some of the notes were suggested that may be useful in the botanical garden protection and establishment.

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